



Evaluation of PFAS in Recreational Waterbodies in Massachusetts

Technical Support Document

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1. BACKGROUND AND OVERVIEW

Since 2015 PFAS have been detected in groundwater, surface water, and residential drinking water wells, associated with contaminated sites in Massachusetts. Recent surveillance of surface water by the Massachusetts Department of Environmental Protection (MassDEP) and the US Geological Survey indicates that PFAS may be present in Massachusetts waterbody locations at concentrations as high as 109 nanograms per liter (ng/L), or parts per trillion (ppt) (MassDEP, 2021). As this PFAS may not always be associated with any known point-source or site-related contamination, the Massachusetts Department of Public Health (DPH) may be asked to determine if these locations are safe for recreational activities such as swimming and fishing.

This document has been prepared to support emerging contaminant surveillance at recreational waterbodies conducted by the DPH. The purpose of this memorandum is to provide an overview of the methodology that DPH will use to evaluate the human health risk of exposure to poly- and perfluorinated substances (PFAS) in surface water and fish. This includes both development of candidate Action Levels (cALs) for surface water and fish, and follow-up actions when cALs are exceeded.

MDPH has developed the following cALs for surface water (cSWAL) and fish (cFAL):

Table 1.1. Candidate Action Levels

Media	Value
Surface Water (cSWAL)	23 ng/L
Fish (cFAL)	0.22 µg/kg

The cALs listed in Table 1.1 are calculated using toxicity criterion and exposure assumptions discussed in Section 2. The cALs will be used to screen waterbodies, to determine whether further evaluation or risk reduction measures are required. If the cSWAL is exceeded, DPH will conduct a waterbody-specific risk assessment to determine which recreational activities (e.g., swimming, boating, wading) are safe, as outlined in Section 3. If the cFAL is exceeded, DPH will issue fish consumption advisories, as outlined in Section 4. The cALs will be updated as new toxicity criteria and/or exposure assumptions are available.

2. SCREENING AND EVALUATION RECCOMENDATION

Screening values, including the cALs described here, are risk-based concentrations that account for both toxicity and potential exposure, and represent a concentration that is expected to be safe for all individuals, including potentially sensitive or vulnerable individuals. The toxicity (or potency) is characterized by established criteria, which represent a dose, in milligrams of contaminant per kg of body weight, that individuals can be exposed to every day without experiencing adverse health effects. The potential exposure is estimated by characterizing the magnitude, frequency, and duration of contact with the environmental media (e.g., such as surface water when swimming, or the consumption of locally caught fish).

Toxicity criteria for PFAS have been developed by the Agency for Toxic Substances and Disease Registry (ATSDR), MassDEP and the US Environmental Protection Agency (US EPA). ATSDR non-cancer toxicity criteria are referred to as a Minimal Risk Level (MRL); non-cancer toxicity criteria developed by MassDEP and US EPA are referred to as a Reference Dose (RfD). Functionally, MRLs are equivalent to RfDs. Candidate Action Levels for both surface water and fish are based on

ATSDR's MRL of 2.0×10^{-6} mg/kg-day for PFOS, which ATSDR has determined is the most potent of the PFAS compounds for which there are suitable data for deriving toxicity criteria (ATSDR, 2021).

The cAL represents a concentration that all individuals, including those who may be exposed to greater amounts of PFAS (i.e., vulnerable individuals), can be exposed to without experiencing adverse health effects. To be protective of all individuals under all reasonably foreseen exposure scenarios, they are derived assuming maximum potential exposure. As such, values for characterizing the magnitude, frequency and duration of contact will likely overestimate actual contact for most, if not all individuals.

If a surface water or fish action level is exceeded, DPH will conduct a waterbody-specific evaluation. For surface water, DPH will conduct a waterbody-specific risk assessment, using exposure parameters tailored to expected use of the waterbody in question. For fish, DPH will issue waterbody-specific fish consumption advisories, based on the concentration of PFAS detected in fish. Exceedance of action levels will also trigger a consideration of non-recreational activities (e.g. subsistence fishing), that could result in potentially greater PFAS exposure than would occur under a recreational exposure scenario.

2.1 Surface Water Action Level

DPH recommends a **candidate Surface Water Action Level (cSWAL) of 23 ng of PFAS per liter of water (ng/L)** for surface waterbodies that are intended for swimming (e.g., permitted bathing beaches). Consistent with ATSDR recommendations for evaluating PFAS compounds individually, this value should be applied to individual measurements of all PFAS for which there are established toxicity criteria. Currently, there are established toxicity criteria for five PFAS, including: perfluorobutane sulfonic acid (PFBS), perfluorohexane sulfonic acid (PFHxS), perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), and perfluorononanoic acid (PFNA). If the concentration of all five PFAS are less than 23 ng/L, the waterbody would be safe for swimming, for all age groups. If *any* of these compounds (individually) exceed a cSWAL of 23 ng/L, a waterbody-specific risk assessment would be required.

The development of the cSWAL is based on the following assumptions:

1. A single screening value that can be applied to all PFAS is needed to determine when a waterbody is assumed to be safe for unlimited engagement in any recreational activity, under all reasonably anticipated circumstances.
2. The primary route of exposure to PFAS in surface water is incidental, or non-intentional ingestion of water. The absorption of PFAS through the skin is a negligible source of potential exposure. Among all potential recreational activities (e.g., swimming, paddle boarding, kayaking, etc.), incidental/non-intentional ingestion is greatest during swimming.
3. The most vulnerable receptor, based on surface water ingestion relative to body weight, is a young child, aged 2 to < 6 years, with a body weight of 17.4 kg (ATSDR, 2016).

4. The cSWAL incorporates reasonable maximum expected values for exposure related to incidental ingestion of water while swimming, based on the National Human Activity Pattern Survey (US EPA, 1996). Specifically, the young child would:
 - a. Swim five days/week;
 - b. Spend three hours swimming per day; and
 - c. Ingest approximately two cups of water while swimming.
5. Exposure to surface water while swimming is averaged over the period between Memorial Day and Labor Day, when swimming is most likely to occur.
6. The cSWAL incorporates a relative source contribution of 20%, which accounts for exposure to PFAS from sources other than surface water, including dietary sources, as well as water and indoor dust. This value is informed by an analysis of dietary intake of PFAS conducted by the European Food Safety Authority (EFSA, 2020); and a study by Egeghy and Lorber (2011) that evaluated exposure from food, water and indoor dust.

Table 2.1 outlines the values and basis for the parameters used to calculate the cSWAL.

Table 2.1. Input Parameters - Candidate Surface Water Action Level (cSWAL) for PFAS

Parameter	Value	Basis
Minimal Risk Level, MRL (mg/kg-day)	2×10^{-6}	ATSDR Minimal Risk Level for PFOS (ATSDR, 2021)
Body Weight, BW (kg)	17.4	Mean body weight for 2 - < 6 year old (ATSDR, 2016, US EPA, 2011)
Exposure Frequency, EF (days/month)	20	90 th percentile for exposure frequency (US EPA, 1996)
Exposure Time, ET (hours/day)	3	90 th percentile for time spent swimming (US EPA, 1996)
Ingestion Rate, IR (L/hour)	0.152	90 th percentile for incidental ingestion of surface water while swimming (US EPA, 2019)
Exposure Duration, ED (months)	3.3	Professional judgement that swimming would occur between Memorial Day and Labor Day
Averaging Time, AT (days)	102	Dictated by exposure duration
Relative Source Contribution, RSC (%)	20	Professional judgement, considering exposure to PFOS from sources other than surface water

Using the parameters in Table 2.1, the cSWAL (ng/L) is calculated as follows:

$$cSWAL = MRL \times \left(\frac{1 \times 10^6 \text{ ng}}{\text{mg}} \right) \times \left(\frac{BW \times AT}{IR \times ET \times EF \times ED} \right) \times RSC$$

Additional discussion of the basis for the exposure parameters, as well as exposure parameters for other age groups, are included in Appendix A. Appendix A also includes a discussion of a SWAL based on MassDEP exposure criteria and exposure assumptions.

Section 3 outlines the approach for conducting a waterbody-specific risk assessment, when the cSWAL is exceeded.

2.2 Fish Tissue Action Level

DPH recommends a **candidate Fish Action Level (cFAL) of 0.22 µg of PFAS per kilogram of fish (µg/kg)** (equivalent to 0.22 ng PFAS per g of fish). Consistent with ATSDR recommendations for evaluating PFAS compounds individually, this value should be applied to individual measurements

of PFBS, PFHxS, PFOA, PFOS, and PFNA. If *any* of these compounds (individually) exceed a candidate Action Level (cFAL) of 0.22 µg/kg, a waterbody-specific analysis to evaluate how frequently an individual should consume fish from the specific waterbody would be required. A concentration below 0.22 µg/kg for any of these PFAS compounds would be protective for unlimited consumption of fish for both the general population and sensitive populations.

The development of this cFAL is based on the following assumptions:

1. The cFAL would allow for a sensitive individual (e.g., a young child, woman of child-bearing age) to eat one fish meal every day, and still not be exposed to a PFOS dose that exceeds the MRL.
2. The most vulnerable individual, in terms of ingestion rate relative to body weight, is a toddler, aged 1 to <3 years, with a body weight of 12.6 kg (US EPA, 2011).
3. A health protective and reasonable maximum estimate of freshwater fish consumption for a toddler is 113.4 grams per day (g/day).
 - a. This estimate is equivalent to a child eating a 4-ounce serving of fish every day, and represents an unrestricted consumption of fish from a waterbody, for recreational fish consumption.
 - b. A 4-ounce serving size for a child is equal to half of the recommended serving size of fish for an adult (8 oz, or 227 grams). The approach of basing a child's ingestion rate on half of the adult ingestion rate is consistent with US Food and Drug Administration (US FDA) and MassDEP guidance (US FDA, 2019; MassDEP, 2008) as well as US EPA analyses (US EPA, 2002; US EPA Region 1, 2005).
 - c. An intake of 113.4 g/day is consistent with upper percentile daily fish consumption estimates for young children of freshwater and estuarine finfish and shellfish (US EPA, 2002).

Table 2.2 outlines the values and basis for the parameters used to calculate the cFAL.

Table 2.2. Input Parameters - Candidate Fish Action Level (cFAL) for PFAS

Parameter	Value	Basis
Minimal Risk Level, MRL (mg/kg-day)	2×10^{-6}	ATSDR Minimal Risk Level for PFOS (ATSDR, 2021)
Body Weight, BW (kg)	12.6	Mean body weight for 1 - < 3 year old (US EPA, 2011)
Ingestion Rate, IR (g/day)	113.4	Equivalent to ingestion of 4 ounces/day

Using the parameters in Table 2.2, the cFAL (µg/kg) is calculated as follows:

$$cFAL = MRL \times \left(\frac{1 \times 10^3 \mu g}{mg} \right) \times \left(\frac{BW}{IR} \right) \times \left(\frac{1 \times 10^3 g}{kg} \right)$$

Section 4 outlines development of fish consumption advisories for waterbodies where the cFAL is exceeded.

3. WATERBODY-SPECIFIC RISK ASSESSMENT

If the surface water concentration for any of the PFAS for which there are toxicity criteria exceeds the cSWAL of 23 ng/L, a waterbody-specific risk assessment should be conducted, relating exposure to toxicity. In contrast to the cSWAL, which is based on reasonable maximum values for

exposure parameters such as exposure time, exposure frequency and ingestion rate, the waterbody-specific risk assessment incorporates values for exposure parameters that reflect expected patterns of use for the waterbody in question. For example, exposure frequency for a young child may be less than five days per week for a waterbody with limited availability of parking. The basic approach for conducting a waterbody-specific risk assessment is outlined below.

3.1 Exposure Estimate

Using waterbody-specific exposure parameters, an exposure dose is calculated as follows:

$$Exposure\ Dose = EPC \times \left(\frac{IR \times ET \times EF \times ED}{BW \times AT} \right) \times \frac{0.001\ mg}{\mu g}$$

Where:

EPC = Exposure Point Concentration ($\mu g/L$);

IR = Ingestion Rate (L/hour);

ET = Exposure Time (hours/day)

EF = Exposure Frequency (days/month)

ED = Exposure Duration (months)

AT = Averaging Time (days); and

For waterbodies with multiple sampling locations, and samples with duplicate analyses, the EPC is the maximum measured concentration.

Exposure doses are calculated for swimming, wading, and boating.

3.2 Toxicity Criteria

Toxicity criteria for individual PFAS have been established for five individual PFAS, including PFBS, PFHxS, PFOA, PFOS and PFNA. MassDEP has also developed a toxicity criterion applicable to the sum of six PFAS, including PFHxS, PFOA, PFOS, PFNA, perfluoroheptanoic acid, and perfluorodecanoic acid. Toxicity criteria used in the waterbody-specific risk assessment are listed in Table 3.1.

Table 3.1. PFAS Toxicity Criteria for Waterbody-Specific Risk Assessments

Contaminant	Value (mg/kg-day)	Critical Effect	Type	Source
PFBS	9×10^{-4}	Thyroid hormone perturbation	Subchronic RfD	US EPA, 2021
PFHxS	2×10^{-5}	Thyroid follicular cell damage	Intermediate MRL	ATSDR, 2021
PFOA	3×10^{-6}	↑Pup activity Skeletal alterations		
PFOS	2×10^{-6}	↓Pup body weight Delayed eye opening		
PFNA	3×10^{-6}	↓Pup body weight Developmental delays	RfD	MassDEP, 2019
Sum 6 PFAS ^a	5×10^{-6}	Developmental, Liver toxicity, Immunotoxicity		

MRL – Minimal Risk Level; PFBS – perfluorobutane sulfonic acid (PFBS); PFHxS – perfluorohexane sulfonic acid; PFOA – perfluorooctanoic acid; PFOS – perfluorooctane sulfonic acid; PFNA – perfluorononanoic acid; RfD – Reference Dose
[a] Includes PFHxS, perfluoroheptanoic acid (PFHpA), PFOA, PFOS, PFNA and perfluorodecanoic acid (PFDA)

3.3 Risk Evaluation

Risks for individual exposure pathways and for individual contaminants are expressed as a hazard quotient (HQ), calculated as follows:

$$HQ = \frac{\text{Exposure Dose} \left(\frac{\text{mg}}{\text{kg} \cdot \text{day}} \right)}{\text{MRL or RfD} \left(\frac{\text{mg}}{\text{kg} \cdot \text{day}} \right) \times RSC}$$

Where:

MRL = ATSDR Minimal Risk Level (mg/kg-day);

RfD = MassDEP (mg/kg-day); and

RSC = Relative Source contribution (unitless)

The relative source contribution accounts for PFAS exposure from sources other than surface water, such as drinking water, food, or consumer products.

The Hazard Index (HI) sums individual HQs across contaminants with similar critical effects. If the HQ or HI is greater than one, then exposure exceeds a level at which adverse health effects may occur. If the HQ or HI is less one, exposure to PFAS are not likely to cause adverse health effects.

4. FISH CONSUMPTION ADVISORIES

Fish consumption advisories (FCAs) are typically risk-based recommendations of an estimated frequency of fish consumption (e.g., servings per day, week, month, or year) associated with negligible risk of adverse health effects. Fish consumption advisories are informed by the measured concentration of contaminants in a sample of fish representative of a specific waterbody. The underlying basis for the recommendation is often an established potency (or toxicity) criterion, such as an MRL or RfD. Generally speaking, there is an inverse relationship between contaminant concentration in fish tissue and recommended consumption level (i.e., as contamination concentration in fish increases, the recommended frequency for consuming fish decreases).

When a waterbody-specific assessment is required following an exceedance of the DPH PFAS cFAL (0.22 µg/kg), threshold values that account for different populations (i.e., general population vs. sensitive individuals) and consumption patterns will be used to develop more refined waterbody-specific recommendations. This location-specific assessment will also trigger local public health notification, and allow consideration of non-recreational activities (e.g. subsistence fishing) at a specific waterbody that may result in greater potential PFAS exposure (e.g., > 1 meal/day) than evaluated in typical recreational use exposure scenarios.

To derive specific levels of fish consumption that would be safe to consume every day, toxicity criteria for individual PFAS (either ATSDR MRLs, or US EPA RfDs) are used to derive the threshold amount of PFAS that may be present in fish that an individual could consume, at specified frequencies, and still not exceed the toxicity criteria. These threshold amounts are derived for both sensitive individuals and the general public. Threshold Levels for issuing FCAs are based on the following assumptions:

1. Threshold levels should specifically consider sensitive life stages (e.g., children younger than 12 years of age, pregnant women, women of childbearing age who may become pregnant and nursing mothers).
 - a. **To consider the most sensitive life stage**, threshold levels are derived for a typical toddler, aged 1 to <3 years, that weighs 12.6 kg (US EPA, 2011).
 - b. A health protective and reasonable maximum estimate of freshwater fish consumption for a child is 113.4 grams per day (g/day).
 - i. This estimate is equivalent to a child eating a 4-ounce serving of fish every day, and represents an unrestricted use of fish from a waterbody, for recreational fish consumption.
 - ii. A 4-ounce serving size for a child is equal to half of the recommended serving size of fish for an adult (8 oz, or 227 grams). The approach of basing the ingestion rate for a child on half the adult ingestion rate is consistent with US EPA and MassDEP guidance (US FDA, 2019; MassDEP, 2008), as well as US EPA analyses (US EPA, 2002; US EPA Region 1, 2005).
 - iii. An intake of 113.4 g/day is consistent with upper percentile daily fish consumption estimates for young children of freshwater and estuarine finfish and shellfish (US EPA, 2002).
2. **When considering the general population**, threshold levels are derived for an 11-16 year old, with a body weight of 56.8 kg (US EPA, 2011), and a reasonable maximum estimate of freshwater fish consumption of 227 grams per day (g/day).
 - a. Deriving threshold levels based on an 11-16 year old is consistent with DPH fish consumption advisories for the general population, which apply to individuals 12 years of age or older. Use of an adult intake rate for this age group is also consistent with US FDA guidance on eating fish, which assumes fish meal sizes for this age group are the same as adult meal sizes (US FDA, 2019).
 - b. An intake rate of 227 g/day is consistent with an individual eating an 8 ounce (i.e., half a pound) serving of fish every day and represents unrestricted consumption of fish from a waterbody.
 - c. An intake rate of 227 g/day for adults is used by US EPA as an upper percentile estimate of fish consumed per meal, as well as by other states, for the purpose establishing fish advisories (e.g., CT DPH, 2018; Great Lakes Consortium, 2018; MDHHS, 2016).

Table 4.1 outlines the values and basis used to calculate the advisory thresholds, according to frequency of consumption.

Table 4.1. Parameters – Advisory Threshold

Parameter	Value	Basis
<i>Toxicity Criteria</i>		
PFBS	9×10^{-4}	Sub-chronic RfD (US EPA, 2021)
PFHxS	2×10^{-5}	MRL (ATSDR, 2021)
PFOA	3×10^{-6}	MRL (ATSDR, 2021)
PFOS	2×10^{-6}	MRL (ATSDR, 2021)
PFNA	3×10^{-6}	MRL (ATSDR, 2021)
<i>Sensitive Populations</i>		
Body Weight, BW (kg)	12.6	Mean body weight for 1 - < 3 year old (US EPA, 2011)
Ingestion Rate, IR (g/day)	113.4	Equivalent to ingestion of 4 ounces/day
<i>General Population</i>		
Body Weight, BW (kg)	56.8	Mean body weight for adults (US EPA, 2011)
Ingestion Rate, IR (g/day)	227	Equivalent to ingestion of 8 ounces/day
<i>All Populations</i>		
Averaging Time (days/year)	365	Dictated by advisory denominator
Consumption Frequency, CF (meals/year)	Varies	Dictated by advisory

MRL – Minimal Risk Level; PFBS – perfluorobutane sulfonic acid (PFBS); PFHxS – perfluorohexane sulfonic acid; PFOA – perfluorooctanoic acid; PFOS – perfluorooctane sulfonic acid; PFNA – perfluorononanoic acid; RfD – Reference Dose

Using the parameters in Table 4.1, advisory threshold concentrations, by consumption frequency, are calculated as follows:

$$\text{Advisory Threshold} = (\text{MRL or RfD}) \times \left(\frac{BW \times AT}{CF \times IR} \right)$$

Table 4.2 lists the advisory thresholds for issuing fish consumption advisories, for both the general population and sensitive populations, including children and women of child-bearing age.

Appendix B includes fish consumption advisories based on MassDEP's toxicity criterion and exposure assumptions, as well as fish consumption advisories developed by other jurisdictions.

Table 4.2. DPH PFAS Guidelines for Issuing Recreational Fish Consumption Advisories

Target Population	Consumption Frequency	Serving Size (g/day)	Advisory Threshold (µg/kg)				
			PFOS	PFBS	PFHxS	PFOA	PFNA
Sensitive Population	1 meal/day	113.4	≤ 0.22 ^a	≤ 100	≤ 2.22	≤ 0.33	≤ 0.33
	2 meals/week	32.3	≤ 0.78	≤ 351	≤ 7.80	≤ 1.17	≤ 1.17
	1 meal/week	16.2	≤ 1.56	≤ 702	≤ 15.6	≤ 2.34	≤ 2.34
	2 meals/month	7.5	≤ 3.38	≤ 1,520	≤ 33.8	≤ 5.07	≤ 5.07
	1 meal/month	3.7	≤ 6.76	≤ 3,040	≤ 67.6	≤ 10.1	≤ 10.1
	1 meal/2 months	1.9	≤ 13.5	≤ 6,080	≤ 135	≤ 20.3	≤ 20.3
	1 meal/6 months	0.62	≤ 40.6	≤ 18,200	≤ 406	≤ 60.8	≤ 60.8
	1 meal/year	0.31	≤ 81.1	≤ 36,500	≤ 811	≤ 122	≤ 122
	Do Not Consume	--	> 81.1	> 36,500	> 811	> 122	> 122
General Population^b	1 meal/day	226.8	≤ 0.50	≤ 225	≤ 5.01	≤ 0.75	≤ 0.75
	2 meals/week	64.6	≤ 1.76	≤ 791	≤ 17.6	≤ 2.64	≤ 2.64
	1 meal/week	32.3	≤ 3.52	≤ 1,580	≤ 35.2	≤ 5.27	≤ 5.27
	2 meals/month	14.9	≤ 7.62	≤ 3,420	≤ 76.2	≤ 11.4	≤ 11.4
	1 meal/month	7.5	≤ 15.2	≤ 6,850	≤ 152	≤ 22.8	≤ 22.8
	1 meal/2 months	3.7	≤ 30.5	≤ 13,700	≤ 305	≤ 45.7	≤ 45.7
	1 meal/6 months	1.2	≤ 91.4	≤ 41,100	≤ 914	≤ 137	≤ 137
	1 meal/year	0.6	≤ 183	≤ 82,200	≤ 1820	≤ 274	≤ 274
	Do Not Consume	--	> 183	> 82,200	> 1820	> 274	> 274

[a] This value also serves as the DPH Fish Action level (FAL). Exceeding this level would trigger a waterbody specific advisory and a FCA recommendation.

[b] Applies to individuals older than 12 years of age

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APPENDICES

Appendix A – Calculation of Surface Water Action Levels

Surface Water Action Levels (SWALs) are developed for incidental ingestion while swimming, for intermediate exposure, and for non-cancer endpoints. Equations and exposure assumptions are based on guidance from the Agency for Toxic Substances and Disease Registry (ATSDR) and the U.S. Environmental Protection Agency (US EPA) (e.g., ATSDR, 2016a, b; US EPA, 1989), as well as professional judgement. SWALs are calculated for perfluorooctane sulfonic acid (PFOS), as the most potent of the PFAS for which there are toxicity criteria, for age groups ranging from birth to adult. The cSWAL is selected as the minimum SWAL among age groups.

For each age group, the SWAL is calculated according to the following equation:

$$SWAL = THI \times \left(\frac{MRL}{IF} \right) \times RSC$$

Where:

THI	=	Target Hazard Index (unitless);
MRL	=	PFOS Minimal Risk Level (mg/kg-day);
IF	=	Intake Factor (L/kg-day); and
RSC	=	Relative Source Contribution (unitless)

As noted by ATSDR (2021), exposure to PFOS via dermal absorption is expected to be of minimal concern. Moreover, information required to evaluate dermal exposure to PFOS, such as dermal permeability or octanol-water partition coefficient, are not available for PFOS. As such, dermal exposure to PFOS is not evaluated.

For comparison purposes, and to provide perspective on the cSWAL, a Surface Water Action Level (SWAL) based on Massachusetts Contingency Plan (MCP) guidance is also presented. The MCP-based SWAL is calculated using the Massachusetts Department of Environmental Protection (MassDEP) Reference Dose (RfD) for the six PFAS regulated by MassDEP (Sum 6 PFAS), which include perfluorohexane sulfonic acid (PFHxS), perfluoroheptanoic acid (PFHpA), perfluorooctanoic acid (PFOA), PFOS, perfluorononanoic acid (PFNA) and perfluorodecanoic acid (PFDA); along with MCP exposure assumptions, where available.

A.1 Toxicity

Toxicity Criteria

Toxicity is evaluated using the following toxicity criteria:

Table A.1. Toxicity Criteria for calculating SWALs

Contaminant	Value (mg/kg-day)	Critical Effect	Type	Source
PFOS	2×10^{-6}	↓Pup body weight Delayed eye opening	Intermediate MRL	ATSDR, 2021
Sum 6 PFAS	5×10^{-6}	Developmental toxicity Liver toxicity Immunotoxicity	RfD	MassDEP, 2019

MRL – Minimal Risk Level; PFAS – per- and polyfluoroalkyl substances; PFOS - perfluorooctane sulfonic acid; RfD – Reference Dose

Target Hazard Index

SWALs are calculated for a target hazard index of 1.

A.2 Exposure Calculation

Exposure to surface water is characterized by an Intake Factor (IF), which quantifies the volume of surface water an individual is exposed to normalized to body weight, in units of liters per kg per day (L/kg-day). The IF is calculated as follows:

$$IF = \frac{(IR \times t_{event} \times EV \times EF \times ED)}{(BW \times AT)}$$

Where:

IR	=	Surface water incidental ingestion rate (L/hr)
t_{event}	=	Duration of recreational event (hr/event)
EV	=	Events per day (day) ⁻¹
EF	=	Exposure frequency (days/month)
ED	=	Exposure duration (months)
BW	=	Body weight (kg)
AT	=	Averaging time (days)

A.3 Exposure Assumptions

Surface Water Action Levels are calculated for different age groups, based on expected differences in the magnitude and/or frequency of exposure. Age ranges for children (up to 20 years of age) are based on ATSDR's Exposure Dose Guidance (ATSDR, 2016b). Adult exposures are calculated for women of child-bearing age (WOCBA), which ATSDR defines as 15 – 45 years of age (ATSDR, 2016b). Consistent with US EPA guidance (US EPA, 1989) SWALs are calculated reasonable maximum exposure assumptions (e.g., 95th or 90th percentile, or approximation thereof) for

parameters related to magnitude of exposure (e.g., ingestion rate, exposure frequency, exposure duration). Central tendency assumptions are used for parameters related to body size (e.g., weight, surface area).

Table A.2 lists exposure assumptions for the DPH SWALs; Table A.3 lists exposure assumptions for the MassDEP SWAL. Discussion of the basis for the exposure assumptions follows the tables.

Table A.2. Exposure Assumptions for Recreational Exposure to Surface Water – DPH SWAL

EXPOSURE PARAMETERS	AGE (YEARS)							BASIS
	birth to<1	1 to <2	2 to <6	6 to <11	11 to <16	16 to <21	WOCBA ^a	
Event Duration, t_{event} (hrs/event)	1	1	1	1	1	1	1	Professional judgement
Event Frequency, EV (events/day)	1	1	3	3	3	3	3	<i>Birth</i> - <2: Professional judgement 2 - <i>WOCBA</i> : US EPA (1996) Table QBNp-17h;
Exposure Frequency, EF (days/month)	20	20	20	30	30	30	20	US EPA (1996) Table QBS-17g
Exposure Duration, ED (months)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	Professional judgement that swimming occurs between Memorial Day and Labor Day
Averaging Time, AT (days)	102	102	102	102	102	102	102	Dictated by exposure duration
Body Weight, BW (kg)	7.8	11.4	17.4	31.8	56.8	71.6	68	<i>Birth</i> - < 21: Mean for 1999-2006 NHANES (US EPA, 2011) <i>WOCBA</i> : Exposure Dose Guidance (ATSDR, 2016)
SW Ingestion Rate, IR (L/hr)	0.152	0.152	0.152	0.152	0.152	0.105	0.152	US EPA (2019) Table 3-93

[a] Women of Child-Bearing Age; 15-45 years is used for this calculation per ATSDR (2016b).

Table A.3. Exposure Assumptions for Recreational Exposure to Surface Water – MCP/MassDEP-Based SWAL

EXPOSURE PARAMETERS	AGE (YEARS)			BASIS
	1 to <2	2 to <6	6 to <11	
Event Duration, t_{event} (hrs/event)	1	1	1	Professional judgement
Event Frequency, EV (events/day)	3	3	3	US EPA (1996) Table QBNp-17h;
Exposure Frequency, EF (days/month)	30	30	30	US EPA (1996) Table QBS-17g
Exposure Duration, ED (months)	3.3	3.3	3.3	Professional judgement that swimming occurs between Memorial Day and Labor Day
Averaging Time, AT (days)	102	102	102	Dictated by exposure duration
Body Weight, BW (kg)	17	39.9	58.7	MCP Guidance (MassDEP, 2015)
SW Ingestion Rate, IR (L/hr)	0.152	0.152	0.152	US EPA (2019) Table 3-93

Notes on Tables A.1 and A.2, Exposure Assumptions for Recreational Exposure to Surface Water:**Event Duration, t_{event} (hours/event)**

- Based on professional judgement, the event duration is assumed to be one hour for all age groups, for both the DPH SWAL and the MCP-based SWAL.

Event Frequency - EV (events/day)DPH SWAL:

- Birth - <2 years:* The EV is assumed to be one, based on professional judgement that the number of times per day that an infant or toddler might swim would be limited by the need for close supervision.
- Age 2 years - WOCBA:* Assuming an event duration of one hour, the EV is the number of events resulting in a total swimming exposure time consistent with the 90th percentile for time spent swimming/day, from the National Human Activity Pattern Survey (NHAPS) (US EPA, 1996, Table QBNp-17h). Total time swimming is three hours/day; the EV for individuals 2 years of age or older is thus 3.

MCP-based SWAL:

- In the absence of MCP guidance for time spent swimming, the NHAPS 90th percentile for time spent swimming of three hours/day (US EPA, 1996, Table QBS-17g) is used for all age groups, resulting in an EV of 3.

Exposure Frequency, EF (days/month)DPH SWAL:

- For older children (6 to < 11 years), adolescents (11 to < 16 years), and young adults (ages 16 to < 21 years), the DPH SWALs assume individuals might swim every day, or 30 days/month. An EF of 30 days/month corresponds with the NHAPS 99th percentile value for 5 – 11 year olds, and the 97.6th percentile for 5 – 11 year olds, for frequency of swimming at a public swimming pool (US EPA, 1996, Table QBS-17g).
- The percentiles for the NHAPS data are calculated as shown in Table A.4. Use of these high percentiles for the SWAL is based on professional judgement that individuals would be more likely to swim at a local beach within walking distance, than a public swimming pool that may not be within walking distance.
 - For younger children (birth to < 6 years) and women of child-bearing age, the SWAL is calculated using an EF of 20 days/month, corresponding with approximately the NHAPS 90th percentile value. Use of a lower EF for younger children and women of childbearing age is based on the assumption that younger children would not swim at a waterbody without being accompanied by an adult, who would be less likely to swim every day.

MCP-based SWAL:

- In the absence of MCP guidance for swimming frequency, an EF of 30 days/month is used for all age groups.

Exposure Duration, ED (months)

- The ED represents the duration, in months, that individuals could reasonably be exposed to surface water in a recreational scenario. The ED for recreational waterbodies is 3.3 months, based on the assumption that individuals would engage in recreational water-related activities from Memorial Day to Labor Day.

Averaging Time, AT (days)

- The averaging time is the same as the exposure duration, but in terms of days rather than months.

Body Weight, BW (kg)DPH SWAL:

- Body weights represent the mean of 1999-2006 data from the National Health and Nutrition Examination Survey (NHANES) as analyzed by US EPA (2011).

MCP-based SWAL:

- Body weights are based on summary data in US EPA's Exposure Factors Handbook (as cited by MassDEP, 2015).

Surface Water Ingestion Rate, IR (L/hour)DPH SWAL:

- The SWAL is calculated using an IR of 0.152 ml/hour for birth to < 16 years, and an IR of 0.105 for ages 16 to < 21 years and women of child-bearing age. An IR of 0.152 corresponds with the 95th percentile IR for children ages 11 to <16 years old, based on underlying data from DuFour (2017) for swimmers > 6 years of age, as summarized in U.S. EPA's Exposure Factors Handbook (US EPA, 2019)¹.
- DPH did not identify data relating to ingestion rates for children < 6 years of age. In the absence of ingestion rate data for children < 6 years of age, and because the 90th percentile value in the EFH for children ages 6 to <11 years is lower than for 11 to <16 years, the value for 11 to <16 year olds is also used for younger children. An IR of 0.105 corresponds with the 95th percentile IR adolescents/young adults, ages 16 to < 21 years.

MCP-based SWAL:

- In the absence of MCP guidance, an IR of 0.152 L/hour is used for all age groups.

¹ Based on recommendations from Table 3-93.

Table A.4 Swim Frequency

# Times Swimming/Month (data from US EPA, 1996: "Descriptive Statistics Tables from a Detailed Analysis of the National Human Activity Pattern Survey (NHAPS) Data" Table QBS-17g)																										
Age	n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	20	23	24	25	26	28	29	30
1-4	63	11	14	7	3	3	4	1	3	1	4		2	1	1	2			2						1	2
5-11	100	16	15	7	9	6	4	2	4		7		5			11	2		3		1	2				5
12-17	84	21	13	7	4	8	4	2	3	1	8		1			2		1	4				1			2
18-64	360	86	48	50	27	22	11	5	14		18	3	15	1	1	10			15	1		7	1	1		15
# Times swimming/month (%) (calculated)																										
Age	n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	20	23	24	25	26	28	29	30
1-4	63	17.5	22.2	11.1	4.8	4.8	6.3	1.6	4.8	1.6	6.3	0.0	3.2	1.6	1.6	3.2	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	1.6	3.2
5-11	100	16.0	15.0	7.0	9.0	6.0	4.0	2.0	4.0	0.0	7.0	0.0	5.0	0.0	0.0	11.0	2.0	0.0	3.0	0.0	1.0	2.0	0.0	0.0	0.0	5.0
12-17	84	25.0	15.5	8.3	4.8	9.5	4.8	2.4	3.6	1.2	9.5	0.0	1.2	0.0	0.0	2.4	0.0	1.2	4.8	0.0	0.0	0.0	1.2	0.0	0.0	2.4
18-64	360	23.9	13.3	13.9	7.5	6.1	3.1	1.4	3.9	0.0	5.0	0.8	4.2	0.3	0.3	2.8	0.0	0.0	4.2	0.3	0.0	1.9	0.3	0.3	0.0	4.2
# Times swimming/month (cumulative %) (calculated)																										
Age	n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	20	23	24	25	26	28	29	30
1-4	63	17.5	39.7	50.8	55.6	60.3	66.7	68.3	73.0	74.6	81.0	81.0	84.1	85.7	87.3	90.5	90.5	90.5	93.7	93.7	93.7	93.7	93.7	93.7	95.2	98.4
5-11	100	16.0	31.0	38.0	47.0	53.0	57.0	59.0	63.0	63.0	70.0	70.0	75.0	75.0	75.0	86.0	88.0	88.0	91.0	91.0	92.0	94.0	94.0	94.0	94.0	99.0
12-17	84	25.0	40.5	48.8	53.6	63.1	67.9	70.2	73.8	75.0	84.5	84.5	85.7	85.7	85.7	88.1	88.1	89.3	94.0	94.0	94.0	94.0	95.2	95.2	95.2	97.6
18-64	360	23.9	37.2	51.1	58.6	64.7	67.8	69.2	73.1	73.1	78.1	78.9	83.1	83.3	83.6	86.4	86.4	86.4	90.6	90.8	90.8	92.8	93.1	93.3	93.3	97.5

A.4 Relative Source Contribution

The relative source contribution (RSC) accounts for exposures to the contaminant of concern from sources other than those accounted for by the SWAL, such as diet or air. Per US EPA guidance (2000) RSCs range from 20 – 80%, with 20% used as a default in the absence of adequate data supporting a higher RSC.

Both the DPH and MCP-based SWALs are calculated using an RSC of 20%, which is consistent with RSCs used by other government agencies for calculating risk-based drinking water levels, and with available exposure data. For example, Massachusetts, New Jersey and US EPA use an RSC of 20% for PFOS drinking water levels (MassDEP, 2019; NJDWQI, 2018; USEPA, 2016). As shown in Table A.5, PFOS estimated intakes, primarily from the diet, range from approximately 0.2 ng/kg-day for adults, to 4 ng/kg-day or greater for infants and toddlers. The estimated intakes for infants and toddlers exceed the PFOS MRL 2 ng/kg-day respectively PFOS.

Table A.5. PFOS Intake

Population	Intake (ng/kg-day)	Diet	Water	Dust	Air
Women _{50th%ile} ^b	0.62	98.7%	0.6%	0.5%	0.2%
Women _{75th%ile} ^b	0.89	98.7%	0.6%	0.7%	0.1%
Adolescents _{mean} ^a	1.10	100%	--	--	--
Adult _{median} ^c	1.6	72%	22%	6%	--
Other children _{mean} ^a	2.28	100%	--	--	--
Toddlers _{mean} ^a	2.58	100%	--	--	--
Toddler _{median} ^d	4.0	42%	20%	36%	--
Adolescents _{95th%ile} ^a	4.95	100%	--	--	--
Toddlers _{95th%ile} ^a	6.89	100%	--	--	--
Other children _{95th%ile} ^a	8.51	100%	--	--	--
Infant _{50th%ile} ^e	8.72	99.7%	--	0.2%	0.03%
Infant _{75th%ile} ^e	9.66	99.3%	--	0.6%	0.04%
Women ^f	15.3	✓	--	✓	✓
Toddlers ^f	35.4	✓	--	✓	✓
Infants ^f	54.6	✓	--	✓	✓

✓ - intake includes pathway, but data for evaluating percentage of intake is not available
 [a] EFSA, 2020; lower bound intake¹¹; [b] Haug, 2011; Scenario 1 intake; [c] Egegy, 2011
 [d] Egegy, 2011; age 2 years, assumes BW of 12.6 kg, also assumes 2% of daily dose from dermal absorption; [e] Haug, 2011; Scenario 1 intake, age 6 months, diet is all from breastmilk; [f] Trudel, 2008; intake for intermediate exposure scenario

A.5 Surface Water Action Levels

Surface Water Action Levels across age groups are provided in Table A.6 (for DPH) and Table A.7 (for the MCP-based approach). As shown in Table A.6, the minimum MCP-based SWAL of 38 ng/L is comparable to the cSWAL of 23 ng/L.

Table A.6. Surface Water Action Levels (ng/L), DPH

birth to <1	1 to <2	2 to <6	6 to <11	11 to <16	16 to <21	WOCBA
31	46	23*	29	51	93	132

**Minimum SWAL, used as cSWAL*

Table A.7. Surface Water Action Levels (ng/L), MCP-Based

1 to <8	8 to <15	15 to <31
38	89	132

APPENDIX A - REFERENCES

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Appendix B - Fish Consumption Advisories Supporting Information

Table B.1 Comparison of PFOS Screening Values for Unlimited Consumption of Fish

Agency	SV (µg/kg)	Population	Fish Type	RfD or MRL (ng/kg-day)	Ingestion Rate (g/day)	Ingestion Rate Basis	Meals/month ^a	Body Weight (kg)	Exposure Frequency (days/yr)	Event Frequency (events/day)	RSC	HQ
NJDEP	0.56	Adult ^b	Fish	1.8	227	Assumes daily consumption	Daily	70	365	1	1	1
MDPH	0.22	Child (1 - 3 years)	Fish	2	113.4	Assumes daily consumption ^c	30.4	12.6	365	1	1	1
NHDES	0.78	Child (1 - 6 years)	Fish ^d	3	6.0	95th ^{ile} UFCR Freshwater & estuarine fish, Northeast (US EPA, 2014; Table 20a)	1.6	15	350	1	1	0.1
NHDES	1.08	Adult	Fish ^d	3	23.1	90th ^{ile} UFCR Freshwater & estuarine fish, Northeast (US EPA, 2014; Table 9b)	3.1	80	350	1	1	0.1
US EPA ^e	5.59	Child (1 - 6 years)	Shellfish	20	5.6	90th ^{ile} UFCR, shellfish, Northeast (US EPA, 2014; Table 23b)	1.5	15	350	1	1	0.1
US EPA ^e	6.78	Adult	Shellfish	20	24.6	90th ^{ile} UFCR, shellfish, Northeast (US EPA, 2014; Table 12b)	3.3	80	350	1	1	0.1
US EPA ^e	5.21	Child (1 - 6 years)	Fish ^d	20	6.0	90th ^{ile} UFCR Freshwater & estuarine fish, Northeast (US EPA, 2014; Table 20b)	1.6	15	350	1	1	0.1
US EPA ^e	7.22	Adult	Fish ^d	20	23.1	90th ^{ile} UFCR Freshwater & estuarine fish, Northeast (US EPA, 2014; Table 9b)	3.1	80	350	1	1	0.1
MDHHS	9	Adult	Fish	14	121	Assumes 16 meals/month @ 227 g/meal	16.2	80	365	1	1	1
Great Lakes Consortium ^f	10	Adult	Fish	20	140	Back-calculated from SV GLC uses meal size of 0.5 pounds (227 g)	18.8	70	365	1	1	1
CTDPH ^g	20	Adult	Fish	20	62	Back-calculated from SV CT uses meal size of 0.5 pounds (227 g)	8.3	62	365	1	1	1

UFCR - Usual Fish Consumption Rate
[a] Assumes meal size of 227 g for adults; 113.4 g for children
[b] Applies to both general and high-risk populations
[c] Value falls between 90th and 95th percentile consumption of finfish and shellfish from freshwater/estuarine waters, for 3-5 year old consumers only, based on 2-day average consumption from 1994-1996, 1998 USDA Continuing Survey of Food Intakes by Individuals (CSFII) summarized by US EPA (2002)
[d] Includes finfish & shellfish
[e] Developed for use at Pease Air Force Base
[f] Includes Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin

APPENDIX B - REFERENCES

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