Evaluation of PFAS in Recreational Waterbodies in Massachusetts

Technical Support Document

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1. BACKGROUND AND OVERVIEW

Since 2015, emerging contaminants known as per- and poly-fluorinated alkyl substances (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 U.S. 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). If there is potential for people to be exposed to PFAS in a waterbody, 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 Technical Support Document has been prepared to support emerging contaminant surveillance conducted by DPH at recreational waterbodies. The document provides an overview of the methodology that DPH will use to evaluate the human health risk of exposure to PFAS in surface water and fish. It includes both development of Action Levels (ALs) for surface water, public bathing beaches[1], and fish and describes follow-up actions when ALs are exceeded.

MDPH has developed the following ALs for surface water (SWAL), public beaches (PBAL) and fish (FAL):

Table 1.1. Action Levels

Media	Value
Surface Water (SWAL)	20 ng/L
Public Beach (PBAL)	90 ng/L
Fish (FAL)	0.22 µg/kg

The ALs listed in Table 1.1 are calculated using toxicity criterion and exposure assumptions discussed in Section 2. The ALs will be used to screen waterbodies, to determine whether notification, further evaluation, or risk reduction measures are required:

For Surface Water
- If PFAS concentrations at a waterbody with a public bathing beach exceed the SWAL, but are less than or equal to the PBAL, signage will be posted notifying that PFAS has been detected in the waterbody, but that it is safe to swim.
- If PFAS concentrations exceed the PBAL, DPH will conduct a waterbody-specific evaluation to determine whether recreational activities should be limited, as outlined in Section 3.

For Fish
- If PFAS concentrations exceed the FAL, DPH will issue a fish consumption advisory, as outlined in Section 4.

The ALs will be updated as new toxicity criteria and/or exposure assumptions are available.

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[1] These action levels were developed to evaluated data collected by DPH at recreational waterbodies in 2022. As new information becomes available regarding PFAS toxicity, these action levels will be updated accordingly.

2. ACTION LEVELS AND EVALUATION

Screening values, including the ALs 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 individuals.[2] 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 individual PFAS have been developed by the federal Agency for Toxic Substances and Disease Registry (ATSDR) and the US Environmental Protection Agency (US EPA). MassDEP has developed a single toxicity criterion for the sum of 6 PFAS.[3] ATSDR non-cancer toxicity criteria are referred to as Minimal Risk Levels (MRLs); non-cancer toxicity criteria developed by US EPA and MassDEP are referred to as Reference Doses (RfDs). Functionally, MRLs are equivalent to RfDs. Action Levels for both surface water and fish are based on ATSDR's MRL of 2.0×10^{-6} mg/kg-day for perfluorooctane sulfonic acid (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 AL represents a concentration that all individuals, including those who may be exposed to greater amounts of PFAS relative to their body weight and individuals who are more likely to experience adverse health effects from exposure to PFAS (i.e., sensitive individuals), can be exposed to without experiencing adverse health effects. To be protective of all individuals under all reasonably foreseen exposure scenarios, ALs 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 PFAS concentrations at a waterbody with a public bathing beach exceed the SWAL, but are less than or equal to the PBAL, signs will be posted notifying that PFAS has been detected in the waterbody, but that it is safe to swim. If the PBAL is exceeded, DPH will conduct a waterbody-specific evaluation, to determine whether swimming should be either limited or prohibited. If the FAL is exceeded, DPH will issue a waterbody-specific fish consumption advisory, based on the concentration of PFAS detected in fish. Exceedance of the FAL will also trigger consideration of fishing scenarios that could result in potentially greater PFAS exposure than would occur under a typical recreational fishing scenario (e.g., subsistence fishing, or consumption of the whole fish rather than just the filet portion). DPH will evaluate information regarding populations that fish in the waterbody to assess whether subsistence fishing may be a concern at the waterbody, and whether fish consumption patterns differ from that of a typical recreational fisher.

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[2] Sensitive individuals include individuals who may have greater exposure to a contaminant, and who may be more susceptible to experiencing health effects from exposure to the contaminant.

[3] Includes perfluorohexane sulfonic acid (PFHxS), perfluoroheptanoic acid (PFHpA), perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorononanoic acid (PFNA), and perfluorodecanoic acid (PFDA)

2.1 Exposure Point Concentration

An exposure point concentration (EPC) represents a concentration of a contaminant of concern in media (such as surface water or fish) to which an individual may be exposed. If the EPC exceeds the Action Level for the corresponding media, further action and/or analyses are required to notify the public that PFAS are present in the media, and limit exposure, if needed.

2.1.1 Surface Water Exposure Point Concentration

For surface water at public beaches, the maximum concentration in surface water across all PFAS compounds with toxicity criteria at the public beach is used as the EPC. If an individual PFAS compound is not detected in any of the samples collected at a beach, the concentration for that PFAS is assumed to be zero. This is consistent with how MassDEP handles non-detects in drinking water sources (MassDEP, 2021).

2.1.2 Fish Tissue Exposure Point Concentration

The EPC for fish is the average PFAS concentration for at least three fish per species in a given waterbody. If an individual PFAS compound is not detected in any of the fish for a given species, the PFAS concentration is assumed to be zero (MassDEP, 2021).

2.2 Action Levels

2.2.1 Surface Water Action Level

DPH recommends a **Surface Water Action Level (SWAL) of 20 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, the SWAL is applied to individual measurements of all PFAS for which there are established toxicity criteria. This includes: hexafluoropropylene oxide dimer acid (GenX), perfluorobutanoic acid (PFBA), perfluorobutane sulfonic acid (PFBS), perfluorohexane sulfonic acid (PFHxS), perfluorooctanoic acid (PFOA), PFOS, and perfluorononanoic acid (PFNA). If the concentration of each individual PFAS is less than 20 ng/L, the waterbody would be safe for swimming, for all age groups, and no posting is required. If *any* of these compounds (individually) exceed a SWAL of 20 ng/L but are less than or equal to the PBAL (of 90 ng/L), signs will be posted at public beaches indicating that PFAS has been detected in the waterbody, but that it is safe to swim.

The development of the SWAL is based on the following assumptions:
1. An action level that can be applied to all PFAS is needed to determine when to notify the public that PFAS has been detected in surface water at a public beach where individuals might swim.
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 sensitive individual, based on surface water ingestion relative to body weight, and time spent swimming, is a young child, aged 2 to < 6 years, with a body weight of 17.4 kg (ATSDR, 2016).

4. The SWAL 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). The exposure values used to calculate the SWAL are high-end estimates and represent a hypothetical scenario that would overestimate exposure for most, if not all, individuals. Specifically, the young child would:
   a. Swim seven 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 SWAL is based on the toxicity of PFOS, which is the most potent PFAS, using toxicity values developed by the Agency for Toxic Substances and Disease Registry. Because the critical toxic effects for PFOS are very similar to those for PFNA (see Table 3.1), the SWAL considers that toxic effects of PFOS are additive to those of PFNA. This provides an additional margin of safety when calculating the SWAL.

7. The SWAL incorporates a relative source contribution of 50%, which accounts for exposure to PFAS from sources other than surface water, including dietary sources as well as water and indoor dust.

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

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

Parameter	Value	Basis
Minimal Risk Level - PFOS, MRL_{PFOS} (mg/kg-day)	2×10^{-6}	ATSDR Minimal Risk Level for PFOS (ATSDR, 2021)
Minimal Risk Level - PFNA, MRL_{PFNA} (mg/kg-day)	3×10^{-6}	ATSDR Minimal Risk Level for PFNA (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)	30	98th percentile for exposure frequency (US EPA, 1996)
Exposure Time, ET (hours/day)	3	90th percentile for time spent swimming (US EPA, 1996)
Ingestion Rate, IR (L/hour)	0.152	90th 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 (%)	50	NHANES Report on Biomonitoring (CDC, 2022a)

Using the parameters in Table 2.1, the SWAL (ng/L) is calculated as follows[4]:

$$SWAL = MRL_{PFOS} \times \left(\frac{1 \times 10^6 \ ng}{mg}\right) \times \left(\frac{BW \times AT}{IR \times ET \times EF \times ED}\right) \times RSC \times \left(1 - \frac{MRL_{PFOS}}{MRL_{PFOS} + MRL_{PFNA}}\right)$$

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[4] Calculated value of 23 ng/L adjusted down to 20 ng/L, to harmonize with Massachusetts Maximum Contaminant Level for PFAS in drinking water of 20 ng/L. The last term in the equation accounts for additivity of PFOS and PFNA.

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

2.2.2   Public Beach Action Level

DPH recommends a Public Beach Action Level (PBAL) of 90 ng of PFAS per liter of water (ng/L) for surface waterbodies that are intended for swimming (i.e., permitted bathing beaches). As with the SWAL, and consistent with ATSDR recommendations for evaluating PFAS compounds individually, this value should be applied to the detected concentration of each individual PFAS compound for which there is an established toxicity criterion (GenX, PFBA, PFBS, PFHxS, PFOA, PFOS, and PFNA). If the concentration of each of the individual PFAS compounds is less than 90 ng/L, the waterbody would be safe for swimming, for all age groups. If *any* of these compounds (individually) exceed a PBAL of 90 ng/L, a waterbody-specific risk assessment would be required to determine whether any restrictions should be placed on swimming at the beach.

DPH developed the PBAL to be protective of young children who might swim at the same public beach on a regular basis. Although very little PFAS are absorbed through the skin, individuals may accidentally ingest water while swimming. Information regarding how often children swim, how much time per day they spend swimming, and how much water they accidentally ingest while swimming was derived from analyses by the U.S. Environmental Protection Agency, including the National Human Activity Patterns Survey (US EPA, 1996), and the Exposure Factors Handbook (US EPA, 2011).

The PBAL 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 swimming for a high-frequency, sensitive user.
2. Children (ages 2 - < 11 years) would swim seven days/week, for two hours/day.
3. While in the water, infants, toddlers, and children would accidentally ingest approximately 3.5 tablespoons of water per hour, or slightly less than half a cup per day.
4. Exposure to surface water while swimming is averaged over the period between Memorial Day and Labor Day when swimming is most likely to occur.
5. The PBAL is based on the toxicity of PFOS, which is the most potent PFAS, using toxicity values developed by the Agency for Toxic Substances and Disease Registry. At a waterbody with a public bathing beach, the PBAL considers that toxic effects of PFOS are additive with those of PFNA.
6. The PBAL incorporates a relative source contribution (RSC) of 50%, which accounts for exposure to PFAS from sources other than surface water, including dietary sources as well as drinking water and indoor dust.

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

Table 2.2. Input Parameters - Public Beach Action Level (PBAL) for PFAS

Parameter	Value	Basis
Minimal Risk Level - PFOS, MRL_{PFOS} (mg/kg-day)	2×10^{-6}	ATSDR Minimal Risk Level for PFOS (ATSDR, 2021)
Minimal Risk Level - PFNA, MRL_{PFNA} (mg/kg-day)	3×10^{-6}	ATSDR Minimal Risk Level for PFNA (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)	30	98th percentile for exposure frequency (US EPA, 1996)
Exposure Time, ET (hours/day)	2	75th percentile for time spent swimming (US EPA, 1996)
Ingestion Rate, IR (L/hour)	0.053	75th 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 (%)	50	Professional judgement, considering exposure to PFOS from sources other than surface water

Using the parameters in Table 2.2, the PBAL (ng/L) is calculated as follows[5]:

$$PBAL = MRL_{PFOS} \times \left(\frac{1 \times 10^6\ ng}{mg} \right) \times \left(\frac{BW \times AT}{IR \times ET \times EF \times ED} \right) \times RSC \times \left(1 - \frac{MRL_{PFOS}}{MRL_{PFOS} + MRL_{PFNA}} \right)$$

Additional discussion of the basis for the exposure parameters, as well as exposure parameters for other age groups, are included in Appendix A.

Section 3 outlines the approach for conducting a waterbody-specific risk assessment when the PBAL is exceeded (i.e., when the EPC for the public beach is greater than the PBAL).

2.2.3   Fish Tissue Action Level

DPH recommends a **Fish Action Level (FAL) 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 PFBA, PFBS, PFHxS, PFOA, PFOS, PFNA, and GenX. If *any* of these compounds (individually) exceed the FAL 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 all of these PFAS compounds would be protective for unlimited consumption of fish for both the general population and sensitive populations.

The development of this FAL is based on the following assumptions:
1. The FAL is based on the toxicity of PFOS, which is the most potent PFAS, using toxicity values developed by the Agency for Toxic Substances and Disease Registry.

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[5] Calculated value of 101 ng/L adjusted down to 90 ng/L, to harmonize with Massachusetts Imminent Hazard Level for PFAS in drinking water of 90 ng/L.

2. The FAL would allow for sensitive individuals (e.g., children younger than 13 years of age or people who are nursing, pregnant, or may become pregnant) to eat one fish meal every day and still not be exposed to a PFOS dose that exceeds the MRL.

3. The most sensitive 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).

4. 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 MassDEP guidance (MassDEP, 2008) as well as US EPA analyses (US EPA Region 1, 2005).

Table 2.3 outlines the values and basis for the parameters used to calculate the FAL.

Table 2.3. Input Parameters - Fish Action Level (FAL) 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 FAL (µg/kg) is calculated as follows:

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

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

3. WATERBODY-SPECIFIC RISK ASSESSMENT FOR SURFACE WATER

If the surface water concentration for any one of the individual PFAS compounds for which there are toxicity criteria exceeds the PBAL of 90 ng/L, a waterbody-specific risk assessment should be conducted, to evaluate whether swimming should be restricted. The first step of a waterbody-specific risk assessment is to conduct a screening evaluation, as outlined below.

3.1 Screening Evaluation

Depending on the specific PFAS that exceeds the PBAL, and the EPC, swimming may be safe even if one or more PFAS exceeds the PBAL. Therefore, the first step in the risk assessment is to evaluate whether the EPC for any of the seven PFAS with toxicity criteria exceed their specific action levels. Action levels for individual PFAS compounds are calculated using input parameters listed in Table 2.2, and toxicity criteria listed in Table 3.1. Action levels are listed in Table 3.2.

As shown in Table 3.1, the critical toxicological effects for deriving PFAS toxicity criteria are not unique to individual PFAS compounds. For example, the critical effect for both GenX and PFBA

involves liver toxicity. Because PFAS compounds may co-occur in the environment, DPH developed action levels applicable to groups of PFAS with similar critical effects. For these, the action level corresponds to the action level for the most potent PFAS in the group, and the EPC for each PFAS in the group is adjusted to an equipotent EPC for the most potent PFAS in the group, to calculate a total PFAS EPC for the group. For example, considering PFHxS, PFBA, and PFBS, for which the critical effect involves the thyroid, the EPCs for PFBA and PFBS are adjusted to represent an equivalent PFHxS EPC, to calculate a total equivalent PFHxS EPC.

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

Contaminant	Value (mg/kg-day)	Critical Effect	Type	Source
GenX	3×10^{-6}	Liver toxicity		US EPA, 2021a
PFBA	1×10^{-3}	↓ Thyroxine ↑ Liver hypertrophy	Chronic RfD	US EPA, 2022
PFBS	3×10^{-4}	Thyroid hormone perturbation		US EPA, 2021b
PFHxS	2×10^{-5}	Thyroid follicular cell damage		
PFOA	3×10^{-6}	↑Pup activity Skeletal alterations		
PFOS	2×10^{-6}	↓Pup body weight Delayed eye opening	Intermediate MRL	ATSDR, 2021
PFNA	3×10^{-6}	↓Pup body weight Developmental delays		
Sum 6 PFAS[a]	5×10^{-6}	Developmental, Liver toxicity, Immunotoxicity	RfD	MassDEP, 2019

GenX - hexafluoropropylene oxide dimer acid; MRL – Minimal Risk Level; PFBA – perfluorobutanoic acid; PFBS – perfluorobutane sulfonic acid; 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)

Table 3.2. Action Levels for Individual PFAS

PFAS	Critical Effect	Applicability	Action Level (ng/L)
GenX	Liver toxicity	If PFBA not detected	252
PFBA	↓ Thyroxine ↑ Liver hypertrophy	If PFBS, PFHxS, GenX not detected	83,900
PFBS	Thyroid hormone perturbation	If PFBA, PFHxS not detected	25,200
PFHxS	Thyroid follicular cell damage	If PFBA, PFBS not detected	1,680
PFOA	↑Pup activity Skeletal alterations	Always applicable	252
PFOS	↓Pup body weight Delayed eye opening	If PFNA not detected	168
PFNA	↓Pup body weight Developmental delays	If PFOS not detected	252
GenX + (3/1000) x PFBA[1]	Liver toxicity	If GenX and PFBA detected	252
PFHxS + [(2/100) x PFBA] + [(2/30) x PFBS][2]	Thyroid Effects	If PFHxS, PFBA and/or PFBS detected	1,680
PFOS + (2/3) x PFNA[3]	↓Pup body weight Developmental delays	If PFOS and PFNA detected	168

[1] Assumes toxicity of GenX and PFBA are additive; action level based on toxicity of Genx; PFBA concentration adjusted based on MRL for GenX relative to PFBA

[2] Assumes toxicity of PFHxS, PFBA, and PFBS are additive; action level based on toxicity of PFHxS; PFBA and PFBS concentrations adjusted based on MRL for PFHxS relative to PFBA, PFBS, respectively.

[3] Assumes toxicity of PFOS and PFNA are additive; action level based on toxicity of PFOS; PFNA concentration adjusted based on MRL for PFOS relative to PFNA.

The scenarios below illustrate application of the action levels shown in Table 3-2, for when an individual PFAS exceeds the PBAL. For example, in Scenario A, although the PFOS EPC exceeds the PBAL of 90 ng/L, the total equivalent PFOS EPC of PFOS and PFNA is less than 168 ng/L. In contrast, for Scenario B, the total equivalent PFOS EPC is greater than 168 ng/L.

Scenario A: PFOS EPC > 90 ng/L

PFAS	EPC	
GenX	ND	
PFBA	ND	
PFBS	ND	• PFOS + (MRL_{PFOS}/MRL_{PFNA})*PFNA < 168 ng/L
PFHxS	78	► Swimming is **safe** at Public Beach A
PFOA	29	
PFOS	134	
PFNA	48	

Scenario B: PFOS EPC > 90 ng/L

PFAS	EPC	
GenX	ND	
PFBA	9.4	
PFBS	ND	• PFOS + (MRL_{PFOS}/MRL_{PFNA})*PFNA > 168 ng/L
PFHxS	83	► Unlimited swimming is **not safe** at Public Beach B
PFOA	33	► Conduct risk assessment to identify restrictions
PFOS	154	
PFNA	28	

Scenario C: PFHxS EPC > 90 ng/L

PFAS	EPC	
GenX	ND	
PFBA	ND	
PFBS	ND	• PFHxS < 1680 ng/L
PFHxS	153	► Swimming is **safe** at Public Beach C
PFOA	13	
PFOS	70	
PFNA	11	

3.2 Evaluation of Swimming Restrictions

If the EPC for an individual PFAS, or combined concentration of PFAS with the same or similar critical effects (i.e., a total equivalent EPC), exceeds the corresponding action level in Table 3.2, the next step is to evaluate whether it is safe for individuals to swim in the waterbody on a limited basis. If none of the EPCs (for individual PFAS compounds) or total equivalent EPCs (for groups of PFAS with similar critical effects) exceed the corresponding action level, then the waterbody is considered safe for unlimited use.

To evaluate whether swimming is safe on a limited basis, the equation used to calculate the PBAL is re-arranged to determine the target exposure frequency (EF_T) that would ensure exposure to PFAS while swimming does not exceed an acceptable level, as defined by toxicity criteria and other exposure assumptions (e.g., body weight, incidental ingestion of surface water). The EF_T is calculated as follows, using values for input parameters as defined in Table 2.2:

For exposure to individual PFAS:

$$EF_T = \left(\frac{1}{EPC_{PFAS}}\right) \times (MRL \text{ or } RfD) \times \left(\frac{1 \times 10^6\ ng}{mg}\right) \times \left(\frac{BW \times AT}{IR \times ET \times ED}\right) \times RSC$$

For combined exposure to GenX and PFBA:

$$EF_T = \left(\frac{1}{EPC_{GenX} + \left(\frac{RfD_{GenX}}{MRL_{PFBA}}\right) \times EPC_{PFBA}}\right) \times (RfD_{\ GenX}) \times \left(\frac{1 \times 10^6\ ng}{mg}\right) \times \left(\frac{BW \times AT}{IR \times ET \times ED}\right) \times RSC$$

For combined exposure to PFBA, PFBS and PFHxS:

$$EF_T = \left(\frac{1}{EPC_{PFHxS} + \left(\frac{MRL_{PFHxS}}{MRL_{PFBA}}\right) \times EPC_{PFBA} + \left(\frac{MRL_{PFHxS}}{MRL_{PFBS}}\right) \times EPC_{PFBS}}\right) \times (MRL_{\ PFHxS}) \times \left(\frac{1 \times 10^6\ ng}{mg}\right) \times \left(\frac{BW \times AT}{IR \times ET \times ED}\right) \times RSC$$

For combined exposure to PFOS and PFNA:

$$EF_T = \left(\frac{1}{EPC_{PFOS} + \left(\frac{MRL_{PFOS}}{MRL_{PFNA}}\right) \times EPC_{PFNA}}\right) \times (MRL_{\ PFOS}) \times \left(\frac{1 \times 10^6\ ng}{mg}\right) \times \left(\frac{BW \times AT}{IR \times ET \times ED}\right) \times RSC$$

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 toxicity criterion, such as an MRL or RfD. Generally speaking, as the 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 FAL (0.22 µg/kg), threshold values for specific consumption frequencies will be used to develop more refined waterbody-specific recommendations. Threshold values are the maximum PFAS concentration in fish for a corresponding consumption frequency. This location-specific assessment will also trigger local public health notification and allow consideration of non-recreational activities (e.g. subsistence fishing) at a waterbody that may result in greater potential PFAS exposure (e.g., > 1 meal/day, or consumption of the whole fish rather than just the fillet portion) 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 13 years of age; or people who are nursing, pregnant, or may become pregnant).
    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 MassDEP guidance (MassDEP, 2008), as well as US EPA analyses (US EPA Region 1, 2005).

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 13 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 (2000) as an 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
Toxicity Criteria (ng/kg-day)		
GenX	3	Chronic RfD (US EPA, 2021a)
PFBA	1000	Chronic RfD (US EPA, 2022)
PFBS	300	Chronic RfD (US EPA, 2021b)
PFHxS	20	MRL (ATSDR, 2021)
PFOA	3	MRL (ATSDR, 2021)
PFOS	2	MRL (ATSDR, 2021)
PFNA	3	MRL (ATSDR, 2021)
Sensitive Populations		
Body Weight, BW (kg)	12.6	Mean body weight for 1 - < 3 year old (US EPA, 2011)
Ingestion Rate, IR (g/meal)	113.4	Equivalent to ingestion of 4 ounces/meal
General Population		
Body Weight, BW (kg)	56.8	Mean body weight for 11 - < 16-year-old (US EPA, 2011)
Ingestion Rate, IR (g/meal)	227	Equivalent to ingestion of 8 ounces/meal
All Populations		
Averaging Time (days/year)	365	Dictated by advisory denominator
Consumption Frequency, CF (meals/year)	Varies	Dictated by advisory

GenX - hexafluoropropylene oxide dimer acid; MRL – Minimal Risk Level; PFBA - perfluorobutanoic acid; 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:

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

For example, for sensitive populations, the PFOS advisory threshold for eating two meals/month is calculated as:

$$2\ ng/kg - day \times \left(\frac{12.6\ kg \times 365\ days/year}{24\ meals/year \times 113.4\ ng/year}\right)$$

Table 4.2 lists the advisory thresholds for issuing fish consumption advisories, for both the general population and sensitive populations, including children younger than 13 years of age; or people who are nursing, pregnant, or may become pregnant.

Appendix B includes 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)	Fish Tissue Concentration (µg/kg)				
			PFOS	PFBA	PFBS	PFHxS	PFOA, PFNA, GenX
Sensitive Population	**1 meal/day**	**113.4**	< 0.22[a]	< 111	< 33	< 2.22	< 0.33
	2 meals/week	32.3	> 0.22 - 0.78	> 111 - 390	> 33 - 117	> 2.22 -7.80	> 0.33 - 1.17
	1 meal/week	16.2	> 0.78 - 1.56	> 390 - 780	> 117 - 234	> 7.80 - 15.6	> 1.17 - 2.34
	2 meals/month	7.5	> 1.56 - 3.38	> 780 - 1,680	> 234 - 506	> 15.6 - 33.8	> 2.34 -5.07
	1 meal/month	3.7	> 3.38 - 6.76	> 1,680 – 3,370	> 506 – 1,010	> 33.8 - 67.6	> 5.07 -10.1
	1 meal/2 months	1.9	> 6.76 - 13.5	> 3,370 - 6,750	> 1,010 – 2,020	> 67.6 - 135	> 10.1 -20.3
	1 meal/6 months	0.62	> 13.5 - 40.6	> 6,750 - 20,500	> 2,020 – 6,080	> 135 - 406	> 20.3 -60.8
	1 meal/year	0.31	> 40.6 - 81.1	> 20,500 - 40,500	> 6,080 - 12,100	> 406 - 811	> 60.8 -122
	Do Not Consume	--	> 81.1	> 40,500	> 12,100	> 811	> 122
General Population[b]	1 meal/day	226.8	< 0.50	< 250	< 75	< 5.01	< 0.75
	2 meals/week	64.6	> 0.50 - 1.76	> 250 - 879	> 75 - 264	> 5.01 - 17.6	> 0.75 - 2.64
	1 meal/week	32.3	> 1.76 - 3.52	> 879 – 1,750	> 264 - 527	> 17.6 - 35.2	> 2.64 - 5.27
	2 meals/month	14.9	> 3.52 - 7.62	> 1,750 - 3,800	> 527 – 1,140	> 35.2 - 76.2	> 5.27 - 11.4
	1 meal/month	7.5	> 7.62 - 15.2	> 3,800- 7,610	> 1,140 – 2,280	> 76.2 - 152	> 11.4 - 22.9
	1 meal/2 months	3.7	> 15.2 - 30.5	> 7,610- 15,200	> 2,280 - 4,570	> 152 - 305	> 22.9 - 45.7
	1 meal/6 months	1.2	> 30.5 - 91.4	> 15,200 - 45,700	> 4,570 - 13,700	> 305 - 914	> 45.7 - 137
	1 meal/year	0.6	> 91.4 - 183	> 45,700- 91,400	> 13,700 - 27,400	> 914 - 1820	> 137 - 274
	Do Not Consume	--	> 183	> 91,400	> 27,400	> 1820	> 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

The Surface Water Action Level (SWAL) and Public Beach Action Level (PBAL) 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. Candidate SWALs (cSWAL) and PBALs (cPBAL) 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 SWAL and PBAL are selected as the minimum cSWAL and cPBAL across age groups.

For each age group, the cSWALs and cPBALs are calculated according to the following equation:

$$cSWAL/cPBAL = THI \times \left(\frac{MRL_{PFOS}}{IF}\right) \times \left(1 - \frac{MRL_{PFOS}}{MRL_{PFOS} + MRL_{PFNA}}\right) \times RSC$$

Where:

THI	=	Target Hazard Index (unitless);
MRL_{PFOS}	=	PFOS Minimal Risk Level (mg/kg-day);
MRL_{PFNA}	=	PFNA 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, is not available for PFOS. As such, dermal exposure to PFOS is not evaluated.

For comparison purposes and to provide perspective on the SWAL and PBAL, action levels based on Massachusetts Contingency Plan (MCP) guidance are also presented. The MCP-based action levels are 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 cSWALs and cPBALs

Contaminant	Value (mg/kg-day)	Critical Effect	Type	Source
PFOS	2×10^{-6}	↓Pup body weight Delayed eye opening	Intermediate MRL	ATSDR, 2021
PFNA	3×10^{-6}	↓Pup body weight Developmental delays		
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

The cSWALs and cPBALs 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

Candidate Surface Water Action Levels (cSWALs) and Public Beach Action Levels (cPBALs) 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 people who are

nursing, pregnant, or may become pregnant, which ATSDR defines as 15 – 45 years of age (ATSDR, 2016b). Consistent with US EPA guidance (US EPA, 1989), cSWALs are calculated using reasonable maximum exposure (RME) assumptions (i.e., $\geq$ 90th percentile) for parameters related to magnitude of exposure (e.g., ingestion rate, exposure frequency, exposure duration). cPBALs are calculated using a combination of RME and upper end values (i.e., 75th percentile) for parameters related to exposure magnitude. Central tendency assumptions are used for parameters related to body size (e.g., weight, surface area) for both cSWALs and cPBALs. The SWAL and PBAL discussed above (in Section 2.2) are selected as the lowest, or most protective cSWAL and cPBAL.

Tables A.2.a and A.2.b list exposure assumptions for the DPH cSWALs and cPBALs; Tables A.3.a and A.3.b list exposure assumptions for the MassDEP action levels. Discussion of the basis for the exposure assumptions follows the tables.

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

EXPOSURE PARAMETERS	AGE (YEARS)							BASIS
	birth to<1	1 to <2	2 to <6	6 to <11	11 to <16	16 to <21	PCBA[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	*Birth - <2:* Professional judgement *2 - PCBA:* US EPA (1996) Table QBNp-17h;
Exposure Frequency, EF (days/month)	20	20	30	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	*Birth - < 21:* Mean for 1999-2006 NHANES (US EPA, 2011) *PCBA:* 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] People of child-bearing age (e.g. who are nursing, pregnant, or may become pregnant)*; 15-45 years is used for this calculation per ATSDR (2016b).*

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

EXPOSURE PARAMETERS	AGE (YEARS)							BASIS
	birth to<1	1 to <2	2 to <6	6 to <11	11 to <16	16 to <21	PCBA[a]	
Event Duration, t_{event} (hrs/event)	1	1	1	1	1	1	1	Professional judgement
Event Frequency, EV (events/day)	1	1	2	2	2	2	2	*Birth - <2:* Professional judgement *2 - PCBA:* US EPA (1996) Table QBNp-17h;
Exposure Frequency, EF (days/month)	20	20	30	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	*Birth - < 21:* Mean for 1999-2006 NHANES (US EPA, 2011) *PCBA:* Exposure Dose Guidance (ATSDR, 2016)
SW Ingestion Rate, IR (L/hr)	0.053	0.053	0.053	0.053	0.048	0.041	0.048	US EPA (2019) Table 3-93

[a] People of child-bearing age (e.g. who are nursing, pregnant, or may become pregnant); *15-45 years is used for this calculation per ATSDR (2016b).*

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

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

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

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)	2	2	2	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)	0.053	0.053	0.048	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 the cSWALs and cPBALs, for both DPH and the MCP-based action levels.

Event Frequency - EV (events/day)

Method	cSWAL	cPBAL
DPH	• *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 – PCBA:* 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.	• *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 - PCBA:* Assuming an event duration of one hour, the EV is the number of events resulting in a total swimming exposure time consistent with the 75th percentile for time spent swimming/day, from the National Human Activity Pattern Survey (NHAPS) (US EPA, 1996, Table QBNp-17h). Total time swimming is two hours/day; the EV for individuals 2 years of age or older is thus 2.
MCP-Based	• 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.	• In the absence of MCP guidance for time spent swimming, the NHAPS 90th percentile for time spent swimming of two hours/day (US EPA, 1996, Table QBS-17g) is used for all age groups, resulting in an EV of 2.

PCBA – People of Child-Bearing Age; considered to be ages 15 – 45 years of age (ATSDR, 2016b)

Exposure Frequency, EF (days/month)

Method	SWAL[1]	PBAL[1]
DPH	• For children (2 to < 11 years), adolescents (11 to < 16 years), and young adults (ages 16 to < 21 years), the DPH cSWALs assume individuals might swim every day, or 30 days/month. An EF of 30 days/month corresponds with the NHAPS 98.4th percentile value for 1 – 4 year olds, the 99th percentile for 5 – 11 year olds, and the 97.6th percentile for 12 – 17 year olds, for frequency of swimming at a public swimming pool. Percentiles are provided in Table A.4c, based on empirical data from US EPA's National Human Activity Pattern Survey (US EPA, 1996, Table QBS-17g). Use of these high percentiles for the cSWALs 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 people of child-bearing age, the cSWAL is calculated using an EF of 20 days/month, corresponding with the NHAPS 93.7h percentile value. Use of a lower EF for younger children and people 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.	• For children (2 to < 11 years), adolescents (11 to < 16 years), young adults (ages 16 to < 21 years), and PCBA, the DPH cPBALs assume individuals might swim every day, or 30 days/month. An EF of 30 days/month corresponds with the NHAPS 98.4th percentile values for 1 – 4 year olds, 99th percentile value for 5 – 11 year olds, and the 97.6th percentile for 12 – 17 year olds, for frequency of swimming at a public swimming pool. Percentiles are provided in Table A.4c, based on empirical data from US EPA's National Human Activity Pattern Survey (US EPA, 1996, Table QBS-17g). Use of these high percentiles for the cPBALs 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 < 2 years), the cPBAL is calculated using an EF of 20 days/month, corresponding with the NHAPS 93.7th percentile value. Use of a lower EF for younger children is based on the assumption that younger children would not swim at a waterbody without being accompanied by an adult, who may not swim with an infant or toddler every day.
MCP-Based	• In the absence of MCP guidance for swimming frequency, an EF of 30 days/month is used for all age groups.	• In the absence of MCP guidance for swimming frequency, an EF of 30 days/month is used for all age groups.

[1] Percentiles for the NHAPS data are calculated as shown in Table A.4

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)

Method	SWAL	PBAL
DPH	• The cSWALs are calculated using an IR of 0.152 L/hour for birth to < 16 years, and an IR of 0.105 for ages 16 to < 21 years and people 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). An IR of 0.105 L/hr corresponds with the 95th percentile IR for adolescents/young adults, ages 16 to < 21 years, based on the DuFour data summarized by 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 (0.152 L/hour) is also used for younger children.	• The cPBALs are calculated using an IR of 0.0.053 L/hour for birth to < 11 years, an IR of 0.048 for ages 11 to < 16 years and people of child-bearing age, and an IR of 0.041 for ages 16 to < 21 years. An IR of 0.053 corresponds with the 75th percentile IR for children ages 6 to <11 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]. IRs of 0.048 L/hr and 0.041 L/hr correspond with the 75th percentile IR for older children/adolescents, ages 11 to < 16 years, and adolescents/young adults, respectively, based on the DuFour data summarized by US EPA (2019)[1]. • DPH did not identify data relating to ingestion rates for children < 6 years of age. Therefore, the ingestion rate for 6 to <11-year-olds (0.053 L/hr) is used for younger children.
MCP-Based	• In the absence of MCP guidance, an IR of 0.152 L/hour is used for all age groups.	• In the absence of MCP guidance, an IR of 0.053 L/hour is used for 1 to < 15-year-olds, and an IR of 0.048 L/hr is used for 15 to < 31-year-olds.

[1] Based on recommendations from Table 3-93.

Table A.4 Swim Frequency

Table A.4a: # 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

Table A.4b: # 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

Table A.4c: # Times swimming/month (cumulative %, or percentile) (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 and PBAL, 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.

As an estimate of background exposure, DPH used serum PFAS levels from the National Health and Nutrition Examination Survey (NHANES), as a measure of exposure across all potential routes and media (CDC, 2022a, b). The RSC was calculated using a serum equivalent for ATSDR's PFOS MRL, as follows:

$$RSC = \frac{MRL_{Serum\ Equivalent}\ -\ NHANES\ Serum\ Concentration}{MRL_{Serum\ Equivalent}}$$

The MRL$_{serum\ equivalent}$ was calculated by dividing the predicted serum value corresponding to the human equivalent dose (HED) that ATSDR used for the PFOS MRL (7.43 µg/L), by the total uncertainty factor applied to the HED (300), resulting in a PFOS MRL$_{serum\ equivalent}$ of 24.8 µg/L.

Table A.6 shows RSCs calculated for different percentiles of PFOS serum levels for the general population. For example, at the 90th percentile serum value, the RSC is calculated as:

$$RSC = \frac{24.8\ \mu g/L - 11.5\ \mu g/L}{24.8\ \mu g/L}$$

DPH selected an RSC of 50%, corresponding to a 90th percentile concentration of PFOS in serum.

Table A.6. PFOS Relative Source Contribution

	50th Percentile	75th Percentile	90th Percentile	95th Percentile
PFOS in serum (µg/L)[1]	4.30	7.50	11.5	14.6
RSC	83%	70%	54%	41%

[1] PFOS levels for linear and branched PFOS isomers for the total population, from the 2017 – 2018 National Health and Nutrition Evaluation Survey (CDC, 2022a)

A.5   Action Levels for Recreational Waterbodies

Candidate Surface Water Action Levels (cSWALs) and Public Beach Action Levels (cPBALs) across age groups are provided in Table A.7 (for DPH) and Table A.8 (for the MCP-based approach). The cSWALs and cPBALs are calculated using the equation on page 21, and the exposure assumptions in Tables A.2 and A.3

Table A.7. Action Levels for Recreational Waterbodies (ng/L), DPH

	birth to<1	1 to <2	2 to <6	6 to <11	11 to <16	16 to <21	PCBA
cSWAL	47	69	23[a]	43	76	139	199
cPBAL	135	198	101[b]	184	363	536	434

[a] Minimum SWAL, lowered to 20 ng/L to correspond with MassDEP MCL for PFAS in drinking water (MassDEP, 2023)
[b] Minimum PBAL, lowered to 90 ng/L to correspond with MassDEP Imminent Hazard Level for PFAS in drinking water (MassDEP, 2022)

Table A.8. Action Levels for Recreational Waterbodies (ng/L), MCP-Based

	1 to <8	8 to <15	15 to <31
cSWAL	38	89	132
cPBAL	410	965	1,415

APPENDIX A - REFERENCES

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Appendix B - Fish Consumption Advisories Supporting Information

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

Agency	SV (µg/kg)[1]	Population	RfD or MRL (ng/kg-day)	Meal Size (g/meal)	Meals/month	Body Weight (kg)	Meal Frequency (days/yr)	RSC
MDPH	**0.22**	**Child (1 - 3 years)**	**2**	**113.4**	**30.4**	**12.6**	**365**	**1**
NHDES[2]	0.36	Child (1 - 6 years)	3	113.4	30.4	16.9	365	0.8
NJDEP	0.56	Adult[3]	1.8	227	30.4	70	365	1
NHDES[2]	0.64	Person of Child-Bearing Age	3	227	30.4	61	365	0.8
NHDES[2]	0.85	Adult	3	227	30.4	80	365	0.8
OHA	2	Adult	4.1	227	23	70	276	1
ME CDC[4]	3.5	Adult[3]	2	227	4.3	80	52.1	0.7
MDHHS	9	Adult	14	227	16	80	192	1
Great Lakes Consortium[5]	10	Adult	20	227	18.8	70	225	1
CTDPH[6]	20	Adult	20	227	8.3	62	99.8	1

CTDPH – Connecticut Department of Public Health; MDHHS – Michigan Department of Health and Human Services; MDPH – Massachusetts Department of Public Health; ME CDC – Maine Center for Disease and Control Prevention; MRL – Minimal Risk Level; NHDES – New Hampshire Department of Environmental Services; NJDEP – New Jersey Department of Environmental Protection; OHA – Oregon Health Authority; RfD – Reference Dose; RSC – Relative Source Contribution; SV – Screening Value

[1] SV = [{RfD or MRL} x BW x 365 (days/year) x RSC]/[Meal Size x Meal Frequency]
[2] SV calculated based on NHDES inputs for RfD, meal size, body weight, and RSC, assuming daily consumption (30.4 meals/month)
[3] Applies to both general and higher-risk populations (e.g., children)
[4] ME CDC assumes consumption rate of 227 g/week
[5] Includes Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin; meals/month back-calculated from SV
[6] Meals/month back-calculated from SV

APPENDIX B - REFERENCES

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