Comparison of Published Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) Fish Consumption Advisories in Australia and USA

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ABSTRACT: Fish consumption advisories limit the number of suggested fish meals consumed per waterway and species based on the concentration of specific chemicals. Advisories are non-enforceable health advice, provided to help consumers make health protective decisions. Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) have been detected in recreationally consumed fish in the USA and Australia (among many other countries), in some cases prompting PFAS fish consumption advisories. During initial investigations, conservative screening levels are typically used as a first step to identify whether concentrations require further investigation based on potential risk to consumers. Investigation levels for PFAS are typically based on consumption rates equivalent to meal frequencies of three meals per week or more, whereas existing fish consumption advisories for compounds such as mercury are typically based on a meal frequency of three meals per week or less. Historically, published bioconcentration factors, which convert surface water concentrations into fish tissue concentrations were used as an initial step to investigate the potential for fish to bioaccumulate PFAS. Bioconcentration factors are no longer typically used, in favor of direct measurements.

This study compares the calculation methodology and outcomes of PFAS fish consumption advisories across regulatory bodies in the USA and Australia. Bioconcentration factors are discussed along with implications for modelling vs direct measurement of fish concentrations. Perfluorooctane sulfonate (PFOS) fish consumption advisories and consumption rates are compared to fish consumption advisories for mercury to determine if PFAS expands the number of at risk fisheries.

Four states in the USA and several Australian states have calculated fish consumption advisories. The wide range of PFOS fish consumption advisory values in the USA illustrates the differences in both science-based and policy-based decisions. The comparison to existing fish consumption advisories for mercury shows minimal overlap, with PFOS advisories typically set at 1 meal per week or fewer. Fish advisories are typically set at the safe consumption level, whereas investigation levels may be set at 10% of the safe level, which is why existing advisories need to be taken into account when considering investigation levels and communicating exceedances to stakeholders. The range of surface water concentrations calculated using published bioconcentration factors varied over three orders of magnitude, illustrating the level of uncertainty and further supporting the use of direct measured fish tissue concentrations.

INTRODUCTION

Fish consumption advisories are not enforceable regulations, but recommendations to limit or avoid eating certain fish, which are intended to help consumers make health protective decisions about eating contaminated fish caught in local waters (USEPA, 2013). This paper focuses on the numerical basis for Perfluorooctane sulfonate (PFOS) fish consumption advisories. PFOS is an eight-carbon chain sulfonate within the class of chemicals called Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS), which are collectively considered contaminants of emerging concern (USEPA, 2017). This class of manmade fluorinated compounds are highly persistent in the environment, and are extensively found in multiple media due to widespread manufacturing and use on surfaces to repel oil and water (ATSDR, 2018). Although this paper focuses on fish and surface water in the USA and Australia, it is noted that PFOS has been detected in fish tissue and other animal tissues in countries around the globe (Giesy & Kannan, 2001).

PFOS within the food supply enters the human foodchain as it is readily absorbed by oral exposure, does not biodegrade and is not metabolized (ATSDR, 2018). PFOS may also transfer to plants (Lechner & Knapp, 2011), providing another avenue for entering the food chain. Although PFOS has been associated with a wide range of potential health effects and there have been significant numbers of toxicity evaluations in humans and laboratory animals, setting appropriate dose-response relationships has been an evolving process. The dose-response process has been complicated by the wide difference in elimination half-lives between species, difficulty obtaining adequate mechanistic data and species difference mechanisms, and the common problem that measurement of exposure levels vary significantly between epidemiology and experimental studies (ATSDR, 2018).

PFOS is a concern in recreationally consumed fish because PFOS is frequently detected in fish tissue when collocated surface water is impacted, it bioaccumulates in animal tissue, and may correspond to an increased risk of harm to human health (HEPA, 2018; USEPA, 2011). Some studies have suggested that PFOS bioaccumulates but may not biomagnify in animals without lungs (including fish), showing highly variable concentrations that do not necessarily correlate to the size, age, or trophic level of the fish (HEPA, 2018), this has resulted in guidance typically suggesting the completion of an exposure evaluation and suggestion of direct sampling edible tissues (HEPA, 2018).

Although direct measurement of concentrations in fish tissue is generally recommended (HEPA, 2018), initial evaluation of the pathway, particularly during site characterization has historically used surface water data combined with bioconcentration factors. Bioaccumulation factors have been published to provide an estimate for the level of PFOS in surface water that would correspond to a concentration of PFOS in fish tissue. The unique properties of PFAS cause them to bind to proteins, primarily accumulating in blood and liver, rather than accumulating in fats as previously studied hydrophobic persistent organic pollutants do, which makes the use of current predictive models and bioconcentration factors highly uncertain (HEPA, 2018; Ng & Hungerbühler 2014). Therefore, we evaluate the range of surface water concentrations calculated using bioconcentration factors from the fish advisory concentrations and compare these to measured surface water concentrations to identify whether there is merit to this approach.

Although developing fish consumption advisories for PFOS is relatively new, all 50 states, and five Native American tribes use some fish consumption advisories to protect public health from fish caught in local waters (USEPA, 2013). Mercury is one of the most common chemicals fish advisories are developed for, therefore the PFAS advisories are also discussed in the context of existing state and federal fish advisories for other compounds including mercury. Existing advisories may be particularly relevant when considering initial investigations into the PFAS transport pathway. The first step of a targeted investigation is to identify whether the contaminant migration pathway is complete from a source area to fish tissue, and whether the potential risk is negligible or requires further investigation. This is accomplished by the comparison of fish tissue concentrations to risk-based screening levels. Fish concentrations in the USA are often initially compared to the calculated United States Environmental Protection Agency (USEPA) Regional Screening Levels (RSLs) for fish consumption (USEPA, 2019). In Australia, Food Standards Australia New Zealand (FSANZ) has developed "trigger levels" (FSANZ, 2017a), which are similar to the RSLs in purpose. These initial screening levels are generally based on consumption rates that may be higher than current relevant fish advisories.

In this paper we research available fish consumption advisories in the USA and Australia and compare the calculation approaches, inputs and outcome of PFAS fish consumption advisories across regulatory bodies. We research bioconcentration factors and surface water concentrations. We discuss some of the key reasons for variability in the fish consumption advisories and we discuss how the choice of direct measurement or modelling can impact the risk management decisions.

MATERIALS AND METHODS

This study was accomplished in three parts: first literature research was undertaken to source information used in the study, second calculations were performed using the researched material, and third the results of the calculations were compiled and the outcomes were compared and conclusions drawn.

Literature Research. The first step of this analysis was to perform on-line research to identify fish consumption advisories based on PFOS, or other PFAS compounds if applicable, and the underlying assumptions and calculation methodologies. Where applicable, the waterbodies and species that fish consumption advisories apply to, accompanying fish tissue concentrations and surface water concentrations where collected. Research was also performed to locate published PFOS bioconcentration factors for fish tissue from surface water, particularly where adopted by regulatory guidance documents. Research was accomplished using search engines including Google and Google Scholar. Follow-up correspondence was undertaken with regulatory bodies including Alabama Department of Public Health and the Minnesota Department of Health to confirm the information obtained was current, and to confirm calculation inputs. Other general state advisories and the federal mercury advisories were also researched.

Calculations. Once fish advisories were located, the calculations were replicated to confirm the inputs. Specific meal frequencies provided in the guidance documentation were not found to be consistent, therefore numbers were calculated to generate a number for the same meal frequencies for each state. This allowed direct comparison of values. Advisory calculations were also replicated using published consumption rates and toxicity values for Australia. Investigation levels also provide a point of comparison, which include the RSLs in the USA and the FSANZ trigger values for fish consumption in Australia.

Bioconcentration factors were applied to each of the calculated fish advisories at the 1 meal per month frequency and the corresponding surface water concentration was calculated. The range of calculated surface water concentrations have been compared to measured surface water concentrations where this information was available.

Compilation and conclusions. Data obtained from the literature research and calculations performed were compiled in tables in order to draw conclusions. Key information is provided in the Results and Discussion section.

RESULTS AND DISCUSSION

A total of 4 USA states have calculated PFOS fish consumption advisory concentrations: Michigan, Minnesota, New Jersey, and Alabama, which are provided for a range of meal frequencies. At the time of writing this paper, the New Jersey calculations are draft. An additional two states adopted the calculated advisory concentrations from another state to set advisories on specific waterways: New York, which used Michigan and Minnesota, and Wisconsin, which used Minnesota. The states with published fish consumption advisories are shown in Figure 1.

Although the meal frequencies provided differed for each state, all states provided concentrations ranging from an unrestricted, or low restriction (16 meals per month), to a level identified as “Do Not Eat”. The meal frequencies between unrestricted and entirely restricted included 1 meal per week for each USA state. The majority of PFOS fish advisories are developed for the general population and based on adult consumption, however New Jersey also provides consumption advisories for sensitive populations, which include women of childbearing age and children.

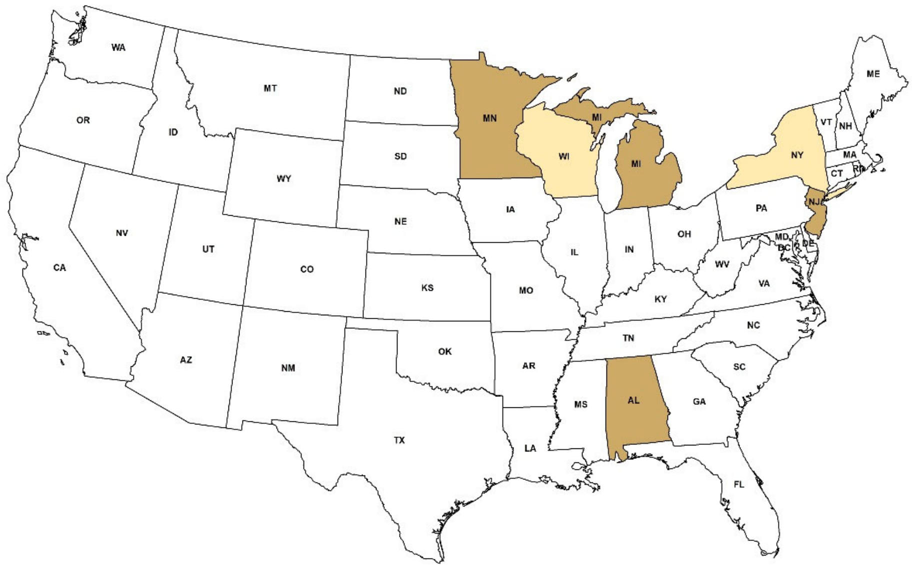

FIGURE 1. Map of USA States with fish consumption advisories. New Jersey advisories are draft. Wisconsin and New York use advisories developed in other states.

The terminology used in Australia differs as does the approach, although fish consumption advisories have been published for waterbodies and species in several states/territories including New South Wales, the Northern Territory, Victoria, and Queensland, the calculated concentrations that correspond to specific meal frequencies are not published as bracketed risk-based levels as they are in the US. In this study, risk-based levels have been calculated for various meal frequencies for comparison to the USA values.

Fish Consumption Advisory Calculation. Fish tissue concentrations (microgram (µg)/kilogram (kg)) that form the numerical basis for fish consumption advisories are calculated by combining assumptions about exposure with toxicity information. Each published calculated series of risk-based values was based on the same two basic equations. The longer equation was used by Michigan (MDHHS, 2018), and is the standard equation used to calculate investigation levels (USEPA, 1989; USEPA, 2019). This basic equation is also used to evaluate risk from ingesting fish in site investigations in the USA and Australia (WSP, 2018) (Equation 1):

$$\text{Fish tissue concentration} = (RfD * RSC * BW * AT) / (IR * EF * ED) \qquad (1)$$

where RfD is the noncancer toxicity value (reference dose) (µg/kg/d); RSC is the relative source contribution (1); BW is the body weight (kg); AT averaging time (for noncarcinogens, AT = ED * 365 days per year); IR is the ingestion rate grams per day (g/day), EF exposure frequency (days/year); and ED exposure duration (years).

Equation 1 was further reduced by USEPA to create Equation 2 by removing AT, EF, and ED, as these typically cancel out (USEPA, 2000). Minnesota and New Jersey use this approach (MDH, 2018; NJDEP/NHDOH, 2018). Australia uses the same equation to evaluate measured fish tissue concentrations to develop advisories, by switching the IR and the fish tissue concentrations (FSANZ, 2017b).

$$\text{Fish tissue concentration} = (RfD * BW) / (IR) \quad (2)$$

Toxicity. PFOS is currently evaluated only for non-carcinogenic effects. Therefore, all fish consumption advisory calculations for PFOS consider non-cancer effects and a target hazard quotient (HQ) of 1. The toxicity value is a chronic oral noncancer RfD, which is expressed in units of mg/kg/day. This value is defined as an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations, likely to be without an appreciable risk of deleterious effects during a lifetime (USEPA, 1989).

The published fish advisory calculations are all based on different RfDs. Minnesota selected the toxicity value from the health advisory (USEPA, 2016) (personal communication with Minnesota Department of Public Health, USEPA, 2018). The health advisory RfD is 0.02 µg/kg/d, based on decreased neonatal rat body weight. Alabama selected 0.077 ug/kg/day (Alabama Department of Public Health Perfluoralkyl sulfonate (PFOS) & Fish Consumption Advisory Fact Sheet). Both Michigan (MDHHS, 2018) and New Jersey (NJDEP/NHDOH, 2018) selected state-specific PFOS RfDs. These are shown in Table 1.

Meal Frequency. Fish consumption advisory concentrations are calculated for a variety of meal frequencies to provide advice regarding how often fish can be consumed. The recommended meal frequencies calculated and the determination of “Do Not Eat” is policy decision. Meal frequency is estimated by first assuming the size of the meal eaten, which is used to develop a consumption rate. Published fish advisories in the USA assume a meal = 227 g (8 oz or 1/2 lb) uncooked fish. This value is multiplied by the number of meals eaten over the course of a year, and then divided by the number of days in a year, resulting in an annualized consumption rate in units of g/day. PFOS fish consumption advisories are based on adult body weight and consumption rates, assuming that the ratio for adults and children remains constant (amount eaten by a child reduces relative to body weight) (MDHHS, 2018). New Jersey also provides calculations for sensitive populations, however the only change made was that “Do Not Eat” begins at 12 meals per month. The Greatlakes consumption rates are shown in Table 1 (Great Lakes Consortium, 2007), however Michigan uses slightly different values and the expanded equation. The unpublished value for Michigan uses the Michigan-specific calculation methodology.

For the purpose of comparison, the USEPA RSL based on a target HQ of 0.1 and a consumption rate of 6 g/day, and the Australian trigger level based on a target HQ of 1 and a consumption rate of 73 g/day are both 5.2 ug/kg. These values are both based on a child receptor, rather than an adult.

TABLE 1. **Fish Consumption Advisories (ug/kg)** – Great Lakes consumption rates in g/day are shown for USA values, based on 227 g meal sizes. The Australia consumption rates are based on 150 g meal size, which is used in the Australian mercury advisory. New Jersey values are draft, Australia values are not published, but have been calculated for the purpose of comparison. Calculated values are shown in italics. "Do Not Eat" advisories are shown in shaded cells. Dashes represent cases where unlimited values have not been published. The RfD in the USA is the PFOS/PFOA value, and in Australia it refers to PFOS + PFHxS.

State	RfD	BW	Unlim.	1 meal per wk	12 meals per yr	6 meals per yr	1 meal per yr
	(mg/kg/d)	(kg)		(32 g/d)	(7.4 g/d)	(3.7 g/d)	(0.62 g/d)
Michigan	1.40E-02	80	-	38	150	300	*1867*
Minnesota	2.00E-02	80	< = 10	50	200	*432*	*2595*
New Jersey	1.80E-03	70	0.56	3.9	17	*34*	204
Alabama	7.70E-02	70	< 40	200	800	*1457*	*8741*
				(21 g/d)	(5 g/d)	(2.5 g/d)	(0.041 g/d)
Australia	2.00E-02	70	-	*66*	*284*	*568*	*3407*

Mercury Fish Consumption Advisories. National fish consumption advisories for mercury recommend 3 or less meals per week for sensitive populations. All PFOS fish consumption advisories have been set at 2 meals per week or fewer, therefore these are all more stringent than the existing mercury advisories.

Bioconcentration Factors. A range of bioconcentration factors were sourced from: RIVM (2010), and ECCC (2017). The RIVM value of 4,500 L/kg for marine species is the geometric mean of bioconcentration values calculated from field data of fish exposed to environmental concentrations as shown in table A1.2 (RIVM, 2010). Reported BCFs for PFOS in Canada were below the RIVM level: 31.6 to 3,614 L/kg for whole body (ECCC, 2017). Previous work by the European Food Safety Authority suggests bioconcentration factors range from 1,000 to 4,000 (EFSA 2008).

Bioconcentration Factors and Fish Tissue Concentrations. Dividing the 1-meal per week fish tissue concentrations by the uptake factors generates surface water concentrations that would be associated with fish tissue concentrations at the 1-meal per week advisory number. Concentrations ranged from 0.00087 ug/L to 0.26 ug/L (equivalent to 0.87 parts per trillion (ppt) to 260 ppt). The lower end of the range of PFOS surface water concentrations corresponding to the 1-meal per week safe fish consumption level is significantly lower than the current drinking water health advisory for PFOS of 70 ppt.

Comparison of Calculated Surface Water to Measured Concentrations. Calculated surface water values were compared to ambient surface water ranges in the United States, compiled by Vedagiri et al. (2018). The results show that the higher end of the range of detected concentrations is generally within the range of calculated freshwater surface water concentrations. Suggesting that the use of bioconcentration factors for an initial investigation could change the outcome based on the bioconcentration factor selected. Without validation by direct measurement of fish species this may be an under or over conservative decision, depending on the bioconcentration factor selected.

CONCLUSIONS

Fish consumption advisory calculations are essentially risk-based screening values, and screening values represent a mixture of science-based and policy-based decisions (Quintin & Fraiser, 2010).The wide range of differences in the "Do Not Eat" determination (from 200 ug/kg in New Jersey and Minnesota to 800 ug/kg in Alabama) shows that the policy decisions behind where to set a value may have a large impact on the final numbers. New Jersey for example sets their “Do Not Eat” advisory at 1 meal per year, whereas the Minnesota “Do Not Eat” advisory is set at 12 meals per year, yet they both equal 200 ug/kg due to the difference in toxicity values.

Fish consumption advisories are based on detected fish tissue concentrations within specific waterways and species. Fish advisories are typically set at the safe consumption level, whereas investigation levels may be set at 10% of the safe level. Existing advisories need to be taken into account when communicating exceedances of risk-based investigation levels to stakeholders because conservative investigation levels are typically based on consumption rates equivalent to meal frequencies of three meals per week or more at the safe level. This may be above existing fish consumption advisories, suggesting that in some cases existing fish consumption advisories are sufficiently protective for PFAS. This also suggests that educating local communities about existing fish consumption advisories may be an important risk communication tool when fish tissue concentrations are detected marginally above investigation levels.

The bioconcentration factors indicated that concentrations below 1 nanogram per liter in surface water may accumulate in freshwater fish at concentrations above a safe 1 meal per week consumption frequency. Therefore, although using bioconcentration factors could provide a conservative initial assessment of potential fish tissue concentrations where direct measured data is not yet available, due to the high variability noted across species (HEPA, 2018), direct measurement is the preferred approach. The evaluation suggests that if fish tissue is a concern, the best approach would be to run low detection analytical methods in surface water, and if detected, sample fish tissue directly.

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