Environment and Climate Change Canada / Environnement et Changement climatique Canada

Canadian Environmental Protection Act, 1999

Federal Environmental Quality Guidelines

Bisphenol A

Environment and Climate Change Canada

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Introduction

Federal Environmental Quality Guidelines (FEQGs) provide benchmarks for the quality of the ambient environment. They are based solely on the toxicological effects or hazards of specific substances or groups of substances. FEQGs serve three functions: first, they can be an aid to prevent pollution by providing targets for acceptable environmental quality; second, they can assist in evaluating the significance of concentrations of chemical substances currently found in the environment (monitoring of water, sediment and biological tissue); and third, they can serve as performance measures of the success of risk management activities. The use of FEQGs is voluntary unless prescribed in permits or other regulatory tools. Thus FEQGs, which apply to the ambient environment, are not effluent limits or "never-to-be-exceeded" values, but may be used to derive effluent limits. The development of FEQGs is the responsibility of the Federal Minister of Environment and Climate Change Canada under the *Canadian Environmental Protection Act, 1999* (CEPA) (Government of Canada (GC) 1999). The intent is to develop FEQGs as an adjunct to the risk assessment/risk management of priority chemicals identified in the Chemicals Management Plan (CMP) or other federal initiatives. This factsheet describes the FEQGs for water, sediment and biological tissue to protect aquatic life and mammalian consumers of aquatic life from adverse effects of bisphenol A (BPA) (Table 1). This BPA factsheet was based largely on the data found in the Screening Assessment Report (SAR) published under Canada's Chemicals Management Plan (Environment Canada, Health Canada (EC, HC) 2008) and was revised following public comment.

FEQGs are similar to Canadian Council of Ministers of the Environment (CCME) guidelines in that they are benchmarks for the quality of the ambient environment and are based solely on toxicological effects data. Where data permit, FEQGs are derived following CCME methods. FEQGs are developed where there is a federal need for a guideline (e.g. to support federal risk management or monitoring activities) but where the CCME guidelines for the substance have not yet been developed or are not reasonably expected to be updated in the near future.

Table 1. Federal Environmental Quality Guidelines for Bisphenol A (BPA).

Water (µg/L)	Sediment* (µg/kg dw)	Wildlife Diet (µg/kg food ww)	
		Mammalian	Avian
3.5	25	660	110

*Normalized to 1% organic carbon
dw = dry weight; ww = wet weight

Substance Identity

BPA or phenol, 4,4' -(1-methylethylidene)bis- (CAS No. 80-05-7) is a synthetic organic compound with phenol functional groups used in the production of epoxy resins and polycarbonate plastics. BPA is considered by the European Chemicals Bureau to be a Category 3 reproductive toxicant, that is, a substance which causes concern for human fertility based on evidence of reproductive toxicity in experimental animals (EC, HC 2008). Environment Canada and Health Canada have assessed the potential human health and ecological effects of BPA, taking into account its persistence and bioaccumulative potential (EC, HC 2008). Based on this assessment, it was concluded that BPA is entering or may enter the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity and that constitute or may constitute a danger in Canada to human life or health (EC, HC 2008). BPA meets the ecological categorization criteria for persistence in sediment (though not for air, water or soil) but does not meet the criteria for bioaccumulation potential (EC, HC 2008), as set out in the *Persistence and Bioaccumulation Regulations* (GC 2000). There are a number of sources of BPA, including production, use or disposal of many polymers. As well, under anaerobic conditions, a related compound, tetrabromobisphenol A (TBBPA) can be debrominated in the environment to form bisphenol A (BPA). Thus BPA in the environment may arise from direct releases but there is also the strong possibility that it arises from debromination of TBBPA. FEQGs for TBBPA have also been developed (EC 2016).

Uses

No BPA was manufactured in Canada at the reporting threshold of $\geq$100 kg in 2006, however, 100 000 to 1 million kg was used, and approximately half a million kg was imported either alone, in a product, in a mixture or in a manufactured item (EC, HC 2008). The major uses of BPA in Canada were reported in resins, curing agents, hardeners, monomers, paperboard packaging, metal cans and industrial coatings, plasticizers, adhesives, chain oil, brake fluid, heat transfer fluid and lubricant formulations (EC, HC 2008). The widespread use of BPA in polycarbonate is in the manufacturing of compact discs, food and beverage contact containers (e.g., bottles, pitchers, water carboys, tableware and storage containers), water pipes, medical devices, glazing applications, film and in the electric, electronics and automotive industry (EFSA 2006; NTP 2007). The Government of Canada has undertaken a number of risk management actions to reduce releases to the environment including a Pollution Prevention Planning Notice for industrial and commercial users of BPA and an Environmental Performance Agreement with paper recycling mills. In both cases, the effluent release target concentration for industrial effluents and paper recycling mill effluents was set at 1.75 µg/L based on the Predicted No Effect Concentration (PNEC) from the 2008 SAR (GC 2012a, 2013). All of these measures are anticipated to reduce point source inputs to wastewater treatment plants and surface water. To address human health concerns, the Government of Canada has prohibited the importation and sale of polycarbonate baby bottles that contain bisphenol A (GC 2012b) and efforts to minimize exposure via food containers are on-going to ensure that Canadian exposure to BPA is kept as low as reasonably achievable, particularly for newborns and infants (HC 2012).

Fate, Behaviour and Partitioning in the Environment

BPA is characterized as having low vapour pressure (5.3×10^{-6} Pa) and moderate water solubility (120-257 mg/L) (EC, HC 2008). The log organic carbon-water partition coefficient (log K_{oc}) of 2.85 (ECB 2003; Loffredo and Senesi 2006) indicates a moderate affinity to sediment. When released into the atmosphere, BPA is predicted to exist almost entirely in the particulate phase and would be removed through dry deposition or photolysis (Eisenreich et al. 1981). The small fraction present as vapour would react with photochemically generated hydroxyl radicals (half-life ~0.13 days; AOPWIN 2000) or undergo photolysis. It is predicted that when BPA is released into water, the majority (96.9%) of it will remain in water due to its moderate solubility (EQC 2003). Similarly, because of its moderately low organic carbon partitioning tendency, most BPA (78.7% to 99.3%) will partition to the soil compartment when the primary receptor following the release is the soil. Biodegradation is expected to be the dominant loss process for BPA in most aquatic and terrestrial environments with biodegradation half-lives of less than four days in natural waters (Dorn et al. 1987). This suggests that the medium into which it is released may be particularly important in predicting the partitioning behaviour and fate of BPA in the environment. There are many studies showing that bisphenol A does not degrade or degrades only slowly under conditions of low or no oxygen (Ronen and Abeliovich 2000, Voordeckers et al. 2002, Ying and Kookana 2003, Ying et al. 2003) and the measured presence in sediment, a medium to which there is no direct release, is further evidence of this slow degradation.

The high pK_a range of 9.59 to 11.30 indicates that BPA is a very weak acid (EC, HC 2008). Shareef et al. (2006) reported no significant variation in solubility of BPA over the pH range of 4 to 10, and no change with ionic strength (up to 0.1 moles/L potassium nitrate). Soil adsorption of BPA is generally reversible, with desorption occurring quickly and completely, thus it is expected to leach down the soil profile and possibly contaminate groundwater where there are acidic sandy soils (Loffredo and Senesi 2006). Potential contamination of groundwater from soil-based BPA contamination is site-specific and difficult to predict across the Canadian landscape (EC, HC 2008) but may include contamination via subsurface leakage from landfills, municipal wastewater treatment infrastructure and septic systems (Rudel et al.1998).

The log octanol-water partition coefficient (log K_{ow}) (3.32) suggests that BPA may have some potential to accumulate in organisms. However, the substance demonstrates low bioaccumulation potential based on bioconcentration factor (BCF) for fish and other aquatic species. Measured BCF values range from 3.5 to

68 in fish (NITE 1977; Lindholst et al. 2001; Lee et al. 2004), but are higher in freshwater clams (107 to 144; Heinonen et al. 2002) and frogs (131 to 147; Koponen et al. 2007). Takahashi et al. (2003) calculated bioaccumulation factors (BAF) of 18 to 650 for periphyton and from 8 to 170 for benthos, and suggested that food may be an important uptake route for organisms in the aquatic environment.

Measured Concentrations

EC, HC (2008) reported ambient concentrations of BPA in Canada with the highest values of 12 µg/L and 0.061 µg/kg dw for surface water and sediment, respectively. Most surface water concentrations were much lower than the maximum reported value with levels more in the range of 0.01 to 0.1 µg/L. Most recently, the CMP monitoring program reported concentrations of BPA in Canada in various media (ECCC 2016a,b,c,d). The highest reported values from these studies were: 9.7 ng/L in surface water from the west basin of Lake Erie (2012); 8025.6 ng/L in non- Great Lakes surface water at Lower Beaverdams (ON) (February 2012); 51 ng/g in surface sediment sampled from the Pacific region (2014); 70 ng/g in sediment cores sampled in Ontario (2013); 97 ng/g in suspended sediment sampled from Quebec (2013); and 36.33 pg/g ww in carp *(Cyprinus carpio)* from Hamilton Bay (ON) (2004) (ECCC 2016a,b,c,d). Specifically, for surface water, concentrations of BPA in the Great Lakes (2012) ranged from 5 to 9.7 ng/L (mean 5.3 ng/L; 80% of samples below detection limit of 5 ng/L) (ECCC 2016a). Surface water concentrations of BPA in rivers, creeks, and lakes excluding the Great Lakes (2008 to 2012) ranged from 5 to 8025.6 ng/L (mean 79.42 ng/L; 46% of samples below detection limit of 5 ng/L) (ECCC 2016b). Surface sediment concentrations ranged from 2 to 51 ng/g (mean 6.0 ng/L; 67% of samples below detection limit of 2 ng/g) (ECCC 2016c). Sediment core concentrations ranged from 2 to 70 ng/g (mean 9 ng/g; 52% of samples below detection limit of 2 ng/g) (ECCC 2016c). Suspended sediment concentrations ranged from 2 to 97 ng/g (mean 21 ng/g; 3% of samples below detection limit of 2 ng/g) (ECCC 2016c). Fish tissue concentrations ranged from 5 to 36.33 pg/g ww (mean 6.55 pg/g ww; 78% of samples below detection limit of 5 pg/g ww) (ECCC 2016d).

In earlier studies, Chu et al. (2005) reported the highest sediment concentrations of BPA (up to 0.061 µg/kg dw) in the western basin of Lake Erie, likely reflecting the substantial loading and input from numerous wastewater treatment plants in the region. High levels have been measured in some Canadian industrial wastewaters, most notably those associated with paper and allied products (maximum 149 µg/L; median 8.72 µg/L), chemicals and chemical products (maximum 91.27 µg/L; median 1.5 µg/L) and commercial laundries (maximum 43.45 µg/L; median 6.56 µg/L) (Lee and Peart 2002). BPA has also been detected in influent, effluent, and sludge collected from municipal wastewater treatment plants across Canada with effluent levels generally lower than those found in influents, indicating some removal during wastewater treatment, although treatment efficiency varies widely from less than 1% to 99% removal depending on treatment technology, pH and temperature (EC, HC 2008). Rudel et al. (1998) reported BPA concentrations of up to 1.41 µg/L in groundwater samples collected in the vicinity of municipal landfills and wastewater treatment plants where effluent is discharged to infiltration beds.

Mode of Action

BPA can alter hormonal, developmental or reproductive function in rats and mice (ECB 2003, Li et al. 2008). BPA produces estrogenic effects via interactions with estrogen receptors (ER) (Gould et al. 1998; Kuiper et al. 1998; Pennie et al. 1998). The estrogen receptor family includes the classic ERα, ERβ, and their splice-variants, extranuclear estrogen receptors associated with cell membranes and neuronal synapses (Woolley 2007). BPA is found to have limited binding affinity with ERα, but has nearly a tenfold higher affinity for ERβ. It is possible that BPA preferentially affects ERβ-containing tissues, including the ovary, cardiovascular system and brain (Harris 2007) and those with cell membrane receptors (Quesada et al. 2002). Additionally, BPA has been shown to have transgenerational effects (significantly reduced fertilization rate and embryo survival) as well as impacts on regulation of CYP11A and CYP11B gene expression (involved in drug metabolism and synthesis of cholesterol, steroid, and lipids) in Japanese medaka (Sun et al. 2014).

Aquatic Toxicity

Information regarding BPA chronic toxicity on freshwater organisms was gathered from toxicity papers either identified in the SAR (EC, HC 2008) or found in a 2015 literature search. All studies were further evaluated, and only those meeting CCME (2007) reliability criteria and considered acceptable for developing Federal Water Quality Guideline (FWQG) are presented in Table 2. Of the acceptable studies considered, there were acceptable long-term toxicity data for 16 different species, with values ranging from 3.16 µg/L to 7800 µg/L for various endpoints. Invertebrates and fish were more sensitive to BPA than plants or amphibians, although the sensitivities overlap among taxa. The most sensitive fish species was the three-spined stickleback (*Gasterosteus aculeatus*) and the least sensitive fish species was rainbow trout (*Oncorhynchus mykiss*). The most sensitive invertebrate and plant species were the New Zealand mud snail (*Potamopyrgus antipodarum*) and the green alga *Raphidocelis subcapitata,* respectively. The least sensitive invertebrate and plant species were the rotifer *Brachionus calyciflorus* and duckweed (*Lemna gibba*), respectively. The amphibian *Xenopus laevis* was moderately sensitive when compared to other species.

Federal Environmental Quality Guidelines Derivation

Information regarding BPA toxicity was gathered from toxicity papers either identified in the SAR (EC, HC 2008) or found in a 2015 search of the scientific literature. Studies were further evaluated to determine data acceptability according to the appropriate CCME (1995; 1998; 2007) protocol prior to inclusion in the dataset.

Federal Water Quality Guideline

FWQGs are preferably developed using CCME (2007) protocols. In the case of BPA, there were enough acceptable chronic toxicity data after the 2015 literature search update to meet the CCME data requirements for a Type A guideline[1] using a species sensitivity distribution (SSD). Each species for which appropriate toxicity data were available (Table 2) was ranked according to sensitivity and its position on SSD was determined (Figure 1). Several cumulative distribution functions (normal, logistic, extreme value and Gumbel) were fit to the data using regression methods and the model fit was assessed using statistical

Table 2. Chronic Aquatic Toxicity Endpoints used in Species Sensitivity Distribution for Bisphenol A.

Species	Group	Endpoint	Concentration in Water* (µg/L)	Reference
Three spine stickleback (*Gasterosteus aculeatus*)	■	165-d MATC (Growth-gonad size)	3.16	de Kermoysan et al. (2013)
Goldfish (*Carassius auratus*)	■	10-d NOEC** (Gonad weight)	11	Hatef et al. (2012)
New Zealand mud snail (*Potamopyrgus antipodarum*)	●	28-d MATC (Reproductive success)	20	Sieratowicz et al. (2011)
African clawed frog (*Xenopus laevis*)	◆	21-d LOEC*** (Delayed metamorphosis)	23	Heimeier et al. (2009)
Zebrafish (*Danio rerio*)	■	180-d MATC (F2 Survival)	45	Keiter et al. (2012)

[1] CCME Type A guidelines are based on the species sensitivity distribution approach. This is the most preferred method. For further detail on the minimum data requirements for Type A guidelines see CCME (2007).

Species	Group	Endpoint	Concentration in Water* (µg/L)	Reference
Fathead minnow (*Pimephales promelas*)	■	60-d MATC (F2 Hatching success)	51	Staples et al. (2011)
Japanese medaka (*Oryzias latipes*)	■	44-d MATC (Hatching success)	110	Sun et al. (2014)
European physa (*Physa acuta*)	●	21-d MATC (Hatching success)	224	Sanchez-Arugello et al. (2012)
Guppy (*Poecilia reticulata*)	■	21-d LOEC (40% decline) sperm count (Reproduction)	274	Haubruge et al. (2000)
Atlantic salmon (*Salmo salar*)	■	42-d MATC (Yolk sac edema)	316	Honkanen et al. (2004)
Water flea (*Daphnia magna*)	●	21-d LC_{30} F2 survival (Survival)	400	Brennan et al. (2006)
Lawn shrimp (*Hyalella azteca*)	●	42-d MATC (Reproduction)	734	Mihaich et al. (2009)
Green Alga (*Raphidocelis subcapitata*, formerly *Selenastrum capricornutum* and *Pseudokirchneriella subcapitata*)	▲	96-h EC_{10} (Growth, cell count, volume, reproduction)	1360	Alexander et al. (1988)
Rotifer (*Brachionus calyciflorus*)	●	48-h MATC (Reproduction-Increase in offspring)	2546	Mihaich et al.(2009)
Rainbow trout (*Oncorhynchus mykiss*)	■	28-d MATC (Growth)	6328	Bayer (1999)
Duckweed (*Lemna gibba*)	▲	7-d NOEC (Growth)	7800	Mihaich et al. (2009)

Legend: ■ = Fish; ● = Invertebrate; ▲ = Plant ◆ =Amphibian.
* Nominal or measured concentration, as reported in study. **NOEC = no observed effect concentration. ***LOEC = lowest observable effect concentration;

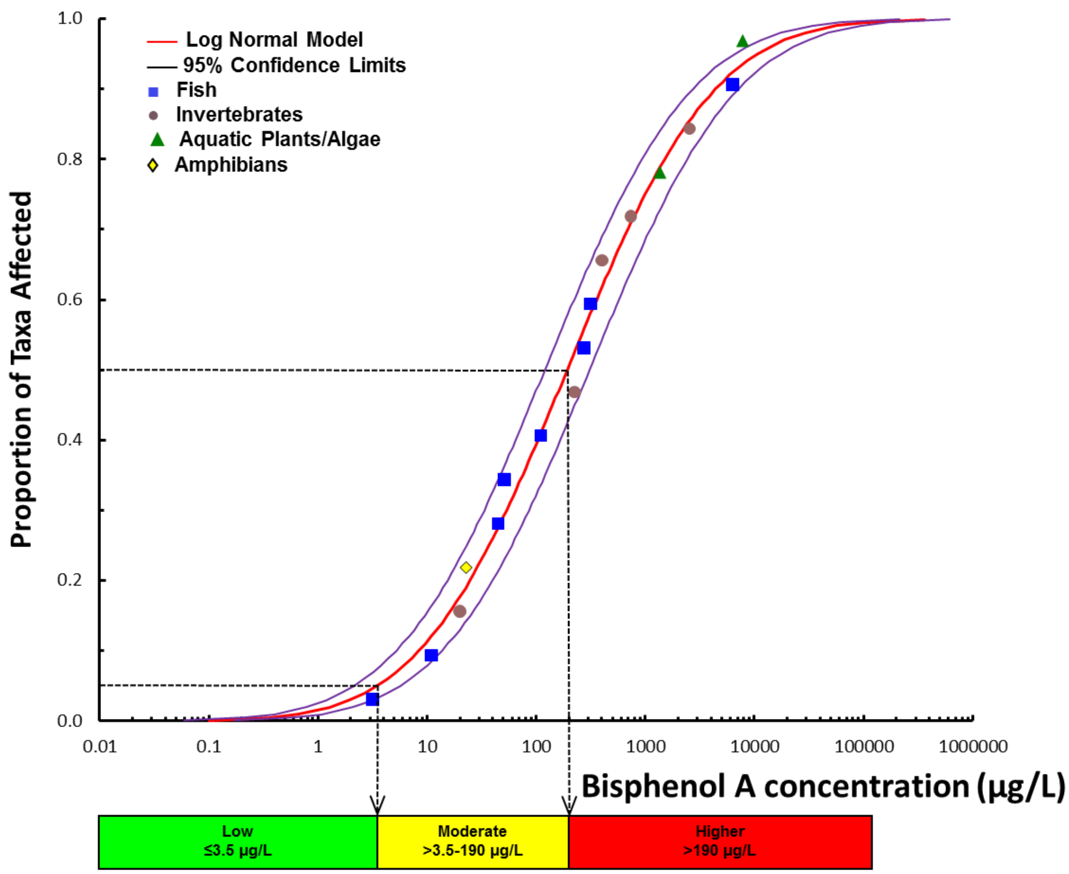

Figure 1. Species sensitivity distribution (SSD) for the chronic toxicity of bisphenol A and relative likelihood of adverse effects of bisphenol A to freshwater aquatic life.

and graphical techniques. The best model was selected based on consideration of goodness of fit. The log normal model provided the best fit; the 5th percentile of the SSD plot is 3.5 µg/L, with lower and upper confidence limits of 2.1 and 5.6 µg/L, respectively. Using the log normal model, the 5th percentile of the SSD, 3.5 µg/L is the Federal Water Quality Guideline for the protection of aquatic life. The FWQG developed herein identifies a benchmark for aquatic ecosystems that is intended to protect all forms of aquatic life for indefinite exposure periods. The FWQG developed for freshwater may be applied to marine waters unless it can be demonstrated that the toxicity differs significantly between these two environments (e.g., due to ionization).

The FWQG represents the concentration below which one would expect either no, or only a low, likelihood of adverse effects on aquatic life. In addition to this guideline, two other concentration ranges are provided for use in risk management. At concentrations above the FWQG up to the 50th percentile of the SSD (i.e., > 3.5 to 190 µg/L), there is a moderate likelihood of adverse effects to aquatic life. Concentrations greater than the 50th percentile (> 190 µg/L) have a higher likelihood of causing adverse effects to aquatic life. Risk managers may find these additional concentration ranges useful in defining short-term or interim risk management objectives for a phased risk management plan. The moderate and higher benchmarks may also be used in setting less protective interim targets for waters that are already highly degraded or where there are socio-economic considerations that preclude the ability to meet the FWQG.

Federal Sediment Quality Guideline

The Federal Sediment Quality Guideline (FSeQG) is intended to protect sediment-dwelling biota (Table 1). The FSeQG applies to indefinite exposure periods to sediments, and specifies the concentration of BPA found in bulk sediment (dry weight (dw)) not expected to result in adverse effects. The guideline may not be appropriate to evaluate the impacts of BPA in aquatic plants growing in sediment as there are no published toxicity data for these species. The FSeQG applies to both freshwater and marine sediments because, due to data limitations, it cannot be demonstrated that the toxicity differs significantly between these two environments (e.g., due to ionization).

Reliable freshwater sediment toxicity data for BPA are few. At the time of the literature search update, the only study measuring chronic toxicity of BPA to benthic organisms via direct sediment exposure was by Staples et al. (2016). This study used standardized Organization for Economic Cooperation and Development and United States Environmental Protection Agency test protocols to examine the effects of BPA on two freshwater invertebrates, the freshwater oligochaete *Lumbriculus variegatus* (mean numbers and biomass), and the freshwater midge *Chironomus riparius* (emergence and development rate). One estuarine amphipod *Leptocheirus plumulosus* (survival, growth and reproduction) was also tested. The NOEC for all three species ranged from 12 to 54 mg/kg-dw. For *Lumbriculus variegatus* the most sensitive endpoint was 28-d biomass reduction with NOEC and LOEC of 22 mg/kg-dw and 57 mg-kg dw, respectively. For midge *C. riparius* the most sensitive endpoint was 28-d emergence reduction NOEC and LOEC of 54 and 110 mg/kg-dw, respectively. For the estuarine amphipod *L. plumulosus*, the most sensitive endpoint was 28-d reduced growth NOEC and LOEC of 12 and 32 mg/kg dw, respectively.

Given the paucity of data, there were an insufficient number of studies to meet the minimum data requirements to develop sediment quality guidelines based on the Spiked-Sediment Toxicity Test Approach in the CCME protocol (CCME 1995). Therefore, the approach used was to calculate a value to protect organisms exposed to sediment pore water based on a value in the water column which should be protective of all aquatic organisms (i.e., the FWQG of 3.5 µg/L) and to convert the pore water value to a concentration in sediment using the equilibrium partitioning method (Di Toro et al. 1991). Using the K_{oc} for BPA of 708 L/kg and normalizing the value to 1% organic carbon in sediment (FSeQG = 0.01 x 708 L/kg x 3.5 µg/L), the resulting FSeQG is 25 µg/kg-dw.

Federal Wildlife Dietary Guideline

The Federal Wildlife Dietary Guideline (FWiDG) is intended to protect non-human mammalian consumers of aquatic biota. This is a benchmark concentration of a substance in aquatic biota (whole body, wet-weight) that may be consumed by terrestrial and semi-aquatic wildlife. The FWiDG for mammals may not be appropriate to extrapolate the impacts of BPA to other terrestrial consumers (e.g., birds or reptiles).

EC, HC (2008) and the US FDA (United States Food and Drug Administration) (2011; 2014) identified 5 mg/kg body weight·day as the no observed adverse effects level (NOAEL) for systemic toxicity of rats exposed to BPA. The studies upon which the NOAEL in these reports is based (Tyl et al. 2002, 2008) reported the lowest observed adverse effects level (LOAEL) causing systemic effects, such as reduced body and organ weights, in adult rats exposed to BPA as 50 mg/kg body weight·day). The tolerable daily intake (TDI) for non-human mammals was calculated as the geometric mean of the LOAEL and NOAEL, with a safety factor of 100 applied to account for interspecies differences. The TDI was then adjusted by the largest food intake:body weight ratio (FI:BW) of mammalian aquatic consumers, that of American mink (0.24 kg prey/kg body weight of predator·day). The resulting FWiDG is 660 µg/kg food wet weight (FWiDG = tolerable daily intake/FI:BW).

For birds, EC, HC (2008) identified 100 mg/kg body weight·day as the lowest concentration causing altered development in domestic chicken (LOAEL) (from Furuya et al. 2006). Furuya et al. (2006) also reported a NOAEL of 1 mg/kg body weight·day. The TDI for non-human mammals was calculated as the geometric mean of the LOAEL and calculated NOAEL, with a safety factor of 100 applied to account for interspecies differences. The guideline was calculated by adjusting the TDI by the largest food intake-body weight ratio (FI:BW) of avian aquatic consumers, that of Wilson's storm petrel (0.94 kg prey/kg body weight of predator·day). Thus the dietary guideline for birds is 110 µg/kg food wet weight.

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List of Acronyms and Abbreviations

BAF— bioaccumulation factor: the ratio of the concentration of a chemical compound in an organism relative to the concentration in the exposure medium, based on uptake from the surrounding medium and food

BCF — bioconcentration factor: the ratio of the concentration of a chemical compound in an organism relative to the concentration of the compound in the exposure medium (e.g. soil or water)

BPA— bisphenol A

CAS — Chemical Abstracts Service

CCME — Canadian Council of Ministers of Environment

CEPA — Canadian Environmental Protection Act

CMP — Chemicals Management Plan
dw— dry weight
EC – Environment Canada
ECCC – Environment and Climate Change Canada
EC_x — effect concentration to x % of test species
ER — estrogen receptor
FEQG — Federal Environmental Quality Guideline
FI:BW — food intake-body weight ratio
FSeQG — Federal Sediment Quality Guideline
FWQG — Federal Water Quality Guideline
FWiDG — Federal Wildlife Dietary Guideline
HC – Health Canada
K_{OC} — organic carbon-water partition coefficient
K_{OW} — octanol-water partition coefficient
LC_x — lethal concentration to x % of test species
LOAEL – lowest observed adverse effects level
LOEC — lowest observable effect concentration
MATC— maximum acceptable toxicant concentration: the geometric mean of the NOEC and LOEC for a species
NOAEL – no observed adverse effects level
NOEC — no observable effect concentration
PNEC — predicted no effect concentration
SAR — screening assessment report
SSD — species sensitivity distribution
TBBPA — tetrabromobisphenol A
TDI — tolerable daily intake
US FDA – United States Food and Drug Administration
ww — wet weight