Canadian Tissue Residue Guidelines for the Protection of Wildlife Consumers of Aquatic Biota

PROTOCOL

Protocol for the Derivation of Canadian Tissue Residue Guidelines for the Protection of Wildlife that Consume Aquatic Biota

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Contents

Abstract

Wildlife in aquatic ecosystems are dependent on aquatic biota such as fish, shellfish, invertebrates, and plants as their primary source of food. These aquatic food sources provide the main exposure route for aquatic-based wildlife species to persistent substances that accumulate in food webs. In order to assess and manage persistent, bioaccumulative, toxic substances, tissue residue guidelines for wildlife are being developed under the auspices of the Canadian Council of Ministers of the Environment. This document provides the protocol for deriving nationally consistent, scientifically defensible tissue residue guidelines to protect, restore, and sustain wildlife that consume aquatic biota in freshwater, estuarine, and marine ecosystems. Tissue residue guidelines developed using this protocol will provide measures to assess the significance of substances in aquatic biota and help manage the competing uses of the aquatic environment.

Résumé

Les espèces fauniques que l'on trouve dans les écosystèmes aquatiques dépendent du biote tel que le poisson, les mollusques et les crustacés, les invertébrés et les plantes comme source principale de nourriture. Celle-ci constitue la voie d'exposition principale de ces espèces aux substances qui persistent et s'accumulent dans les chaînes trophiques. Sous les auspices du Conseil canadien des ministres de l'environnement sont présentement élaborées les recommandations pour les résidus dans les tissus d'espèces fauniques dans le but d'évaluer et de gérer les substances toxiques tant persistantes que biocumulatives. Ce rapport fournit le protocole qui permettra de mettre au point des recommandations nationales uniformes et scientifiquement justifiables pour les résidus dans les tissus en vue de protéger, de rétablir et de maintenir les espèces fauniques qui consomment le biote des écosystèmes d'eau douce et des écosystèmes estuariens et marins. Les recommandations pour les résidus dans les tissus élaborées suivant ce protocole fourniront les moyens d'évaluer l'importance des substances dans le biote aquatique et aideront à gérer les utilisations concurrentielles de l'environnement aquatique.

Preface

In response to growing public concern that chemical substances entering the environment were a major factor placing ecosystems and human health at risk, the Canadian Council of Ministers of the Environment (CCME) undertook to develop nationally consistent, scientifically defensible guidelines for environmental quality in Canada (CCREM 1987). These environmental quality guidelines for water, sediment, soil, and biota tissue are recommended to maintain, protect and restore aquatic and terrestrial ecosystems in Canada and their various uses (CCREM 1987; CCME 1991a, 1991b, 1993, 1995b, 1996b; Environment Canada 1991). These guidelines provide measures of environmental quality that are easily understood, communicated, and implemented as the basis for management decisions.

For substances that are persistent and bioaccumulative, the main route of exposure for wildlife in aquatic ecosystems is the consumption of contaminated aquatic prey species such as fish. In order to address this route of exposure, tissue residue guidelines, which are levels of chemical substances in aquatic biota, are being developed to protect, restore, and sustain wildlife that consume aquatic biota. in freshwater, estuarine, and marine ecosystems. This document outlines the procedures for deriving nationally consistent, scientifically defensible tissue residue guidelines for the protection of wildlife species. This is intended as a working document so that the methodology can be applied and tested. Some refinements or changes may become necessary. Tissue residue guidelines will subsequently be developed using this

protocol and will be published in separate reports.

The use and interpretation of the terms criteria, *guidelines, objectives,* and *standards* vary among different agencies and countries. For the purposes of this document, these terms are defined as follows:

Criteria - The scientific data that are evaluated to derive tissue residue guidelines.

Guidelines - Numerical limits or narrative statements recommended to support and maintain designated uses of the aquatic environment.

Objectives - Numerical limits or narrative statements that have been established to protect and maintain designated uses of the aquatic environment at a particular site.

Standards - Objectives that are recognized in enforceable environmental control laws of one or more levels of government.

These definitions are consistent with those used in the discussion of Canadian water quality guidelines (CCREM 1987).

Glossary

Acute — A brief exposure to a stressor or the effects associated with such an exposure. It can refer to an instantaneous exposure (i.e., oral gavage) or continuous exposures of minutes to a few days (Suter et al. 1994).

ASTM — American Society for Testing and Materials.

bioaccumulation — General term describing a process by which chemical substances are accumulated by aquatic organisms from water directly or through consumption of food containing the chemicals (CCREM 1987).

Bioconcentration — A process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination (CCREM 1987).

biomagnification — Result of the processes of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels. The term implies an efficient transfer of chemicals from food to consumer so that residue concentrations increase systematically from one trophic level to the next (CCREM 1987).

chronic — An extended exposure to a stressor (conventionally taken to include at least a tenth of the life span of a species) or the effects resulting from such an exposure (Suter et al. 1994).

K_{ow} — Octanol/water partition coefficient. The ratio of a chemical's solubility in *n*-octanol and water at equilibrium. The logarithm of K_{ow} is used as an indication of a chemical's propensity for bioconcentration by aquatic organisms (CCREM 1987).

OECD — Organisation for Economic Co-operation and Development.

tissue residue — Chemical substance(s) in aquatic biota tissue, such as fish, shellfish, invertebrates, and aquatic plants on a whole body, wet weight basis.

tissue residue guideline (TRG) — Narrative statement or maximum numerical concentration of a substance in aquatic biota tissue recommended to protect wildlife that consume aquatic biota.

tissue residue objective (TRO) — Narrative statement or maximum numerical concentration of a substance in aquatic biota tissue that have been established at specific sites to protect the designated uses of aquatic biota.

wildlife — For the purposes of tissue residue guidelines, this term may include mammalian, avian, reptilian, or amphibian species that consume aquatic biota.

INTRODUCTION

A number of wildlife species, such as bald eagles, osprey, many colonial nesting birds, aquatic mammals, and turtles, are dependent on aquatic species, such as fish, as their primary source of food. These aquatic prey species on which wildlife depend for food can accumulate certain metals, organometals, and hydrophobic organic substances from water, suspended solids, sediment, and food (Connell 1990). These substances persist in aquatic biota because of the slow rates at which they are metabolized and excreted. Consequently, the consumption of contaminated aquatic food provides the main route of exposure to bioaccumulative, persistent toxic substances for aquatic-based wildlife species.

The presence of toxic substances in contaminated areas of Canada has resulted in a number of adverse effects on wildlife species, sometimes endangering wildlife populations. For example, in the Great Lakes, field studies have reported declines in populations of a number of important wildlife species such as the peregrine falcon, the double-crested cormorant, the black-crowned night heron, the bald eagle, mink, and otter (Government of Canada 1991). Effects on wildlife species have been linked to organochlorines in the Great Lakes and include effects on reproduction, eggshell thinning, congenital malformations (i.e., gross birth defects), behavioural changes, mortality, and alterations in recruitment (Government of Canada 1991). Similarly, in the Fraser River, declines in populations of great blue herons, cormorants, bald eagles, and ospreys have been linked to the presence of metals and organic substances such as pesticides, PCBs, dioxins, and furans (Environment Canada 1995).

The protocol outlines the procedures for deriving tissue residue guidelines (TRGs) for wildlife in aquatic ecosystems. It is intended as a flexible procedural guide and is not intended to replace best scientific judgment when developing guidelines. TRGs are concentrations in the tissues of aquatic organisms (e.g., fish) recommended to protect wildlife that consume aquatic biota in freshwater, estuarine, or marine ecosystems. In order to protect a wildlife species of concern, the guidelines must be applied to the diet at the trophic level at which a particular species feeds. To protect all wildlife, and particularly for environmental contaminants with a strong potential to biomagnify, the guidelines should be applied at the highest known aquatic trophic level.

BACKGROUND

Canadian environmental quality guidelines are developed by the Canadian Council of Ministers of the Environment (CCME) using formal protocols (CCME 1991a, 1991b, 1993, 1995b, 1996b; Environment Canada 1991) to provide a consistent, scientifically defensible approach for assessing and managing toxic substances in the environment. These guidelines are numerical concentrations or narrative statements in various media (i.e., water, sediment, and soil) recommended to protect, enhance, and restore designated uses of the environment.

Protection of wildlife in aquatic ecosystems (e.g., mammals and birds) is not currently addressed in the protocols for the development of water and sediment quality guidelines for the protection of aquatic life (CCME 1991a, 1995b). Indirect effects on wildlife were considered in the development of water quality guidelines for aquatic life on an ad hoc basis for substances such as PCBs and DDT in CCREM (1987). Since the publication of CCREM (1987), concerns have been raised that effects on wildlife needed explicit consideration in guideline development using a consistent protocol, particularly for bioaccumulative, persistent substances.

Biota tissue was selected as an appropriate medium for the development of guidelines to protect wildlife in aquatic ecosystems for two main reasons. First, food consumption is the main exposure route for wildlife to bioaccumulative, persistent toxic substances. Second, water quality guidelines are not appropriate for these substances since they are difficult to measure in water with current analytical techniques. These substances are more likely to be detected in the tissues of aquatic organisms or sediments than in water (Gaskin et al. 1973; Mehrle et al. 1988; USEPA 1989; Barron 1990; Fordham and Reagan 1991; Moore and Walker 1991).

Dietary TRGs are designed mainly for bioaccumulative, persistent toxic substances that are targeted for virtual elimination from the environment under various agency policies (e.g., Government of Canada/Environment Canada 1995; OMOEE 1993; International Joint Commission 1987). TRGs and other environmental quality guidelines provide benchmarks to help interpret biological monitoring data and serve as the scientific basis for determining interim management objectives and performance indicators to measure progress in virtual elimination strategies.

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Approaches used by various jurisdictions to evaluate the significance of substances in aquatic biota to consumers of those biota were critically evaluated in the preparation of this protocol (Huston 1988; USEPA 1989; Keenan et al. 1990; Pollock et al. 1990; Newell et al. 1987; USEPA 1995; Thomann and Parkerton 1991). The approach developed by Newell et al. (1987) (Appendix A) was used as the basis for the guideline derivation procedure.

For noncarcinogenic substances, it is generally believed that there is some toxic threshold level of exposure below which effects will not occur. For carcinogenic substances, the current regulatory model assumes that any nonzero level of exposure to the carcinogen will pose some risk of effects to an organism. Although Newell et al. (1987) proposed a hazard and risk assessment approach for deriving fish flesh criteria for noncarcinogens and carcinogens, respectively, a single approach was selected for Canadian TRGs for dietary species for consumption by wildlife in aquatic ecosystems. This was considered appropriate for the following reasons: (a) the criteria derived using the negligible risk level for carcinogens selected by Newell et al. (1987) of one additional risk of cancer in 100 individuals were generally within the same order of magnitude as the criteria derived using the hazard assessment approach for the same substances; (b) although carcinogenicity may affect individuals in a population, it is generally a postreproductive phenomenon unlikely to affect wildlife population levels; and (c) few TRGs for the protection of human health (HWC 1990b) are currently available upon which to base a carcinogenic risk level for protecting wildlife.

A number of research needs were identified in the preparation of this protocol, including (a) quantification of uncertainty in extrapolation from laboratory animals to wildlife species; (b) quantification in the variability of the sensitivities of wildlife species to various substances; and (c) the influence of assimilation efficiency and the extrapolation of this variable among species. Because of these knowledge gaps, three main assumptions were made in the development of the protocol: (1) that dosage rates from toxicity studies on mammalian and avian species can be extrapolated to wildlife species using biological data on body weight and food ingestion; (2) that by considering ecologically significant endpoints in guideline derivation, such as reproduction, growth, development, and survival of young and adult individuals resulting from toxicity tests, populations of wildlife species will also be protected; and (3) that for wildlife, 100% of exposure to a substance is from aquatic food sources (adjustment for other exposure

routes may be considered on a site-specific basis [Appendix B]). The guidelines are substance-specific, except when information is available on the toxicity of mixtures (e.g., dioxins, furans, and co-planar PCBs), and may not provide protection of wildlife from multiple chemicals.

Guiding Principles

The following guiding principles for the development of dietary TRGs for the protection of wildlife were modified from CCME (1991a).

- In deriving dietary TRGs for the protection of wildlife, all avian and mammalian species that consume aquatic life may be considered, if data are available. Interim guidelines are derived when data are available but limited. Guidelines derived from data on mammalian and avian species are considered to be protective of only mammals and birds.

- Data on amphibians and reptiles are not required for the development of TRGs, but may be considered when data are available. Guidelines derived from data on mammalian, avian, amphibian, and/or reptilian species are considered to be protective of all classes of species or which data are considered.

- Fish and other aquatic life, excluding amphibians and reptiles, are assumed to be protected by water quality guidelines (CCME 1991a) and sediment quality guidelines (CCME 1995b).

- Dietary TRGs are set to protect the most sensitive life stage of the most sensitive wildlife species exposed to a substance through the consumption of aquatic organisms. One goal in setting a guideline is to protect all life stages of all species during a lifetime exposure to a substance in aquatic food sources.

- Dietary TRGs are single maximum concentrations of a substance in aquatic biota that would not be expected to result in adverse effects on wildlife.

- Unless otherwise specified, a guideline refers to the total concentration of a substance in an aquatic organism on a wet weight basis since wildlife tend to consume whole organisms. Lipid concentrations should be converted to whole body concentrations.

- TRGs can apply to tissue residues in dietary species including fish, shellfish, invertebrates, or aquatic plants that are consumed by wildlife (e.g., piscivores,

insectivores, and herbivores). The types of food sources selected for TRG application will depend upon site-specific factors such as the wildlife species requiring protection, the food preferences of those wildlife species, and the trophic level of the food source.

Overview

The following is a brief overview of the guideline derivation protocol.

Selection of Substances

Priority substances of national concern are identified for TRG development in consultation with federal, territorial, and provincial agencies. TRGs are mainly targeted for substances that have a tendency to accumulate and persist in aquatic biota and present a hazard to wildlife that consume these species. Appropriate substances for TRGs would tend to have a bioconcentration factor (BCF) or bioaccumulation factor (BAF) of ≥ 5000; a log K_{ow} of ≥ 5; and be persistent (e.g., half-lives in water and sediment of ≥ 182 and ≥ 365 d, respectively) (Environment Canada 1995). Monitoring data on levels in aquatic species can also be used to determine if development of a TRG is necessary.

Literature Search

Comprehensive data on the toxicology of a substance are necessary for the development of TRGs. Supplementary information on the substance is also reviewed to assist with the development and use of the TRG. Literature searches should gather the following information:

- production and uses;
- physical and chemical properties;
- sources to aquatic environments;
- environmental concentrations;
- methods of quantification and current detection limits;
- environmental fate and behaviour;
- bioaccumulation ;
- toxicokinetics;
- mode of action;
- acute, subchronic, and chronic toxicity to mammalian, avian, reptilian, and amphibian species;
- genotoxicity, teratogenicity, and mutagenicity;
- key routes of exposure; and
- existing guidelines, objectives, and standards.

Evaluation of Toxicological Data

Not all the information reported in the toxicological literature is appropriate for deriving TRGs for wildlife. Each toxicological study obtained must be evaluated to ensure that good field and laboratory practices were used in the design and execution of the experiment and classified as acceptable or unacceptable. Only acceptable studies may be used to fulfill the minimum data requirements and derive the guideline.

Data Set Requirements

In order to proceed with the guideline derivation process, certain minimum toxicological data set requirements must be met.

Guideline Derivation

TRGs should be derived from the results of appropriate chronic toxicity studies that consider the most sensitive life stages and endpoints tested. The tolerable daily intake (TDI) is calculated by dividing the geometric mean of the lowest-observed-adverse-effect level (LOAEL) and the no-observed-adverse-effect level (NOAEL) by an appropriate uncertainty factor. The TDI is used, in conjunction with daily food ingestion rates (FI) and body weights (W) for wildlife species, to derive the final TRG.

Evaluation of Toxicological Data

Because of the variability that exists in the quality of published toxicity studies, each study must be evaluated and classified as acceptable or unacceptable using the following criteria.

Acceptable Toxicological Data

Toxicological studies should be designated as acceptable if they meet the following criteria.

- Toxicity studies should follow generally accepted, good laboratory practices of exposure and environmental controls. Those tests that followed published protocols by standard-setting associations (e.g., ASTM, OECD) are acceptable. Novel approaches or experimental protocols   may   be   used   if   an

evaluation of the methods indicates they are adequate. Responses and survival of controls must be within acceptable limits for the life stage and species used in the test.

- A clear dose-response relationship should be demonstrated in the study. Studies with limited treatment levels may be considered if other toxicological studies support the effect level.

- Dosage rates (in milligrams per kilogram per day), exposure duration, formulation, and administration method used in the study should be reported. Dosage rates that have been estimated are acceptable, but measured dosage rates are preferred.

- The substance should be administered in the test via the oral route (i.e., in food, in water, or by gavage). Dietary exposure studies are preferred. Tests using other administration methods (i.e., dermal, respiratory, intravenous, intramuscular, subcutaneous, or intra-peritoneal) should not be used unless sufficient suppor-tive information on the pharmacokinetics (absorption, distribution, metabolism, and excretion) of the substance was available and the dosage was measured.

- The study should be designed to consider sensitive endpoints, such as embryonic development, early survival, growth, reproduction, adult survival, and other ecologically relevant responses. Endpoints that are of uncertain ecological relevance may not be used in the guideline derivation process.

- For controlled field studies (e.g., mesocosms), a clear dose-response relationship should be experimentally established and effects reasonably apportioned to the substance.

- Statistical procedures used to analyze the data must be reported and be of an acceptable scientific standard.

Unacceptable Toxicological Data

Toxicological data are considered unacceptable for use in the derivation of TRGs if they do not meet the above criteria. Data are also considered unacceptable if insufficient information was reported to assess the adequacy of the test design, procedures, or results. Unacceptable data may be upgraded to acceptable data if ancillary information is available from related studies or obtained directly from the author(s).

Data Requirements for Guideline Derivation

Since TRGs for wildlife are designed to protect the most sensitive species and life stages of wildlife that consume aquatic biota in Canada, they require both avian and mammalian toxicity data. The following minimum data requirements have been established to reduce uncertainty in extrapolations from laboratory to wildlife species, to reduce uncertainty in extrapolations from short-term to long-term exposures, and to account for variability in sensitivities that exist among species.

Minimum Toxicological Data Set Requirements: Full Guideline

The following information is required to recommend a full TRG.

Mammals
- At least three toxicity studies are required on three mammalian species. Studies on traditional laboratory or domestic species (e.g., rats or mice) may be used, however, studies on wildlife species that feed on aquatic organisms are preferred.

- At least two of these studies must be subchronic or chronic tests considering sensitive endpoints (e.g., reproduction, development, growth, or survival of young).

Birds
- At least two toxicity studies are required on two avian species. Studies on traditional avian laboratory or domestic species (e.g., chicken) may be used, however, studies on wildlife species that feed on aquatic organisms are preferred.

- At least one of these studies must be a subchronic or chronic test considering sensitive endpoints (e.g., reproduction, development, growth, or survival of young).

Minimum Toxicological Data Set Requirements: Interim Guideline

In cases where the minimum data requirements for the derivation of TRGs are not met, interim guidelines may be developed provided the following reduced minimum data requirements are met.

At least one of the mammal and bird studies below must be a subchronic or chronic toxicity test. Acute studies may be used to support chronic toxicity data, however, the use of only acute toxicity data to derive a guideline should be avoided.

Mammals
- At least three acute, subchronic, and/or chronic toxicity studies are required on three mammalian species. Studies on traditional laboratory or domestic species (e.g., rats or mice) may be used, however, studies on mammalian wildlife species that feed on aquatic organisms are preferred.

Birds
- At least one acute, subchronic, or chronic toxicity study is required on one avian species. Studies on traditional avian laboratory or domestic species (e.g., chicken) may be used, however, studies on avian wildlife species that feed on aquatic organisms are preferred.

Additional Data

Toxicity data on amphibian and reptilian species may be considered, if available, but are not required for the derivation of TRGs. These data may be used to derive a TDI and reference concentration (RC) for amphibian or reptilian species. These data may not be used to fulfill the mammalian or avian minimum data requirements. However, if amphibians and reptiles are the most sensitive species, the lower RC may be adopted as the recommended TRG.

Rationale for Minimum Toxicological Data Set

Mammalian and avian wildlife species exhibit a wide range of sensitivities to environmental contaminants. Variability in the toxicological data set can arise due to several factors, including the exposure route employed, genetic variability within a single species (e.g., between strains or stocks, genders, or life stages tested), and differences in sensitivity between species. For example, Olson and McGarrigle (1992) found the acute toxic potency of tetrachlorodibenzo-*p*-dioxin (TCDD) exhibited up to a 5000-fold difference in sensitivity among three mammalian species. Gaines and Linder (1986) found that there were up to five-fold differences in intraspecies sensitivities to 57 pesticides in Sherman rats. For most substances, the toxicological database is dominated by information on rodent responses to contaminant exposure, which has been generated in support of human health assessments. These studies can provide insight into intraspecies variability in toxic responses such as genetic differences, life stages tested, endpoints measured, and test duration. Data on avian species are also necessary for the derivation of TRGs because these species are known to be particularly sensitive to many substances (Hill and Camardese 1986).

The number and types of studies required for deriving TRGs were selected by examining several typical databases on the effects of pesticides on mammalian and avian species. This preliminary analysis suggests that estimates of the LOAEL using randomly selected data sets were generally within one order of magnitude of the actual LOAEL, provided three mammalian and two avian toxicity studies were included in the data set (CCME 1993). No evidence was found to indicate that variability in toxicity data would differ for industrial organic substances or metals.

Availability of Minimum Toxicological Data Set

A preliminary literature search found that the required number of acceptable toxicological studies was available for most typical organic (Eisler 1986b; CCME 1995a) and inorganic (CCME 1996a; Eisler 1985a, 1985b, 1986a, 1989a, 1989b, 1989c) substances that would be targeted for TRG development. Toxicity studies on mammalian species were more prevalent in the literature than studies on avian species. Therefore, it was necessary to include less stringent requirements for avian species than mammalian species in the minimum data set for full TRGs and interim TRGs. Toxicity data on amphibian and reptilian species are not well represented in the literature and therefore could not be required in the minimum data set at this time.

Guideline Derivation Procedure

Calculation of Tolerable Daily Intake

The first step in the guideline derivation procedure is the calculation of tolerable daily intakes (TDIs) in milligrams per kilogram of body weight per day ($mg \cdot kg^{-1} \ bw \cdot d^{-1}$) for both mammalian and avian species from the most sensitive endpoint tested in the toxicological literature. Two TDIs are calculated (i.e., for mammals and birds) for use in the RC calculations because of the uncertainty associated with interclass extrapolations. The TDI is operationally defined as an estimate in milligrams per kilogram of body weight per day of a substance that is not anticipated to result in any adverse health effects following chronic exposure to

a population of wildlife species including sensitive subgroups. Adverse effects are considered as functional impairments or pathological lesions that may affect the performance of the organism or reduce its ability to respond to additional stressors (HWC 1990a).

The TDIs for mammals and birds are calculated from the results of chronic toxicity tests in which the substance was orally administered and sensitive endpoints were measured. The TDI is calculated by taking the geometric mean of the LOAEL and NOAEL from an acceptable toxicological study and dividing by an appropriate uncertainty factor (UF):

$$TDI = (LOAEL \cdot NOAEL)^{0.5} \div UF$$

where

TDI	= tolerable daily intake
LOAEL	= lowest-observed-adverse-effect level
NOAEL	= no-observed-adverse-effect level
UF	= uncertainty factor

When the NOAEL is indeterminate in a toxicological study, it may be estimated. The NOAEL is preferably estimated from the dose-response curve taking into consideration the magnitude of the response and the slope of the dose-response curve for the measured effect (Abt Associates Inc. 1995). If it is not possible to estimate the NOAEL from the dose-response curve, the NOAEL may be estimated following the procedure specified in CCME (1993):

$$NOAEL = LOAEL \div 5.6$$

The dosage (in units of milligrams per kilogram of food) of the LOAEL and NOAEL may be adjusted to a daily intake rate (in units of milligrams per kilogram of body weight per day) by taking into consideration the body weight (bw) (in kilograms) and daily food ingestion (which may be in units of kilograms per day or grams per day) of the test species. For example,

$$[(mg\ chemical \div kg\ food) \cdot (g\ food \div d) \cdot (1\ kg \div 1000\ g)] \div kg\ bw = mg\ chemical \cdot kg^{-1}\ bw \cdot d^{-1}$$

Body weights and daily food ingestion, on a wet weight basis, should be used from the toxicity study from which the LOAEL and NOAEL are derived. If these values are not available from the study, they may be obtained from the literature (e.g., Banfield 1974; Dunning 1993; NIOSH 1993) or estimated using allometric equations (Appendix C).

Selection of Uncertainty Factor

An uncertainty factor is used to account for various sources of potential uncertainty in the estimate of the doses of the substance that is expected to not have an adverse effect. Sources of potential uncertainty include differences in toxicity of a substance due to gender, life stage, species of organism tested, duration of exposure (i.e., to extrapolate to life-time exposures), nature and severity of the effect measured, exposure route, laboratory versus field conditions, and other factors. The total uncertainty factor applied for the derivation of a TDI may not be less than 10 in order to extrapolate to a long-term exposure concentration without an effect. The uncertainty factor selected may be higher than 10 depending on the substance, type, amount, and quality of data available.

Most studies of uncertainty factors are based on human health. The only study found that examined the use of uncertainty factors for the development of wildlife criteria was undertaken by Abt Associates Inc. for the USEPA Great Lakes Water Quality Initiative (GLWQI) (USEPA 1995). Based on this study, adjustments to the uncertainty factor can be made depending on the type and quality of the toxicity data as follows.

Subchronic to Chronic Uncertainty Factor

If only subchronic studies are available in the toxicological literature, an uncertainty factor of 10 may be used in the derivation of the TDI. Abt Associates Inc. (1995) analyzed subchronic to chronic ratios, and their results support the concept of a sliding scale of 1 to 10 in the development of wildlife criteria for the USEPA GLWQI (USEPA 1995). Selection of the subchronic to chronic uncertainty factor should include consideration of the amount of time required for the chemical to reach equilibrium in the tissues. Chemicals that require longer time periods to reach steady state will require a larger uncertainty factor compared to chemicals that reach steady state relatively quickly. Other factors that should be considered include the toxicokinetic properties of the substance, the mechanism of toxic action, the lifespan of the organism, indication of possible latent effects, and whether critical life stages of the organism were exposed (Abt Associates Inc. 1995).

Interspecies Uncertainty Factor

An uncertainty factor of 10 or 100 may be selected to account for differences in interspecies sensitivity dependent on the quantity and quality of studies available. For

example, a lower uncertainty factor (i.e., 10) may be selected if wildlife species are represented in the toxicological literature. For the development of wildlife criteria in the GLWQI, the USEPA recommend an uncertainty factor of 1 to 100 to account for interspecies differences (USEPA 1995). The selection of the uncertainty factor is based on the available toxicity data and on the available data concerning the physicochemical, toxicokinetic, and toxicodynamic properties of the substance in question and the amount and quality of the data available. This factor is then applied to each of five representative wildlife species used in the methodology. The factor is intended for extrapolation within a taxonomic class only and not for interclass extrapolation. A higher uncertainty factor is recommended for Canadian TRGs for wildlife than used in the GLWQI wildlife criteria since the goal of the Canadian guidelines is the protection of all life stages of all wildlife species, whereas the goal of the GLWQI is the protection of five representative species. Abt Associates Inc. (1995) analyzed 246 separate interspecies NOAEL ratios for wildlife and found that 91% of the ratios were less than or equal to a factor of 100.

Intraspecies Uncertainty Factor

No uncertainty factor to account for intraspecies variability in sensitivity is recommended at this time. In the development of wildlife criteria by the USEPA, the applicability of an intraspecies uncertainty factor to avian and mammalian wildlife species was considered questionable since this uncertainty factor was largely founded on extrapolations involving humans. Protection of individuals is a concern for humans, whereas for wildlife, the objective is protection of populations. An analysis of intraspecies variability in sensitivity for wildlife indicated further study was required to quantify this source of uncertainty (Abt Associates Inc. 1995).

Calculation of Reference Concentrations for Wildlife Species

Since the lowest TDI will not necessarily result in the lowest acceptable dietary concentration due to differences in food ingestion, body weight ratios, and use of uncertainty factors, a series of test or reference concentrations are calculated. The lowest of these is carried forward as the TRG.

The rationale for interspecies scaling using a biological basis to extrapolate from mammalian species to humans is

reviewed by Davidson et al. (1986). These researchers indicated body weight most often provides the quantitative basis for intraspecies and interspecies correlation. Surface area has also been used for extrapolation among mammalian species because a direct linear proportionality has been demonstrated between metabolic rate and surface area. Mordenti and Chappell (1989) do not recommend the use of body surface area for interspecies scaling from mammals to humans because surface area is too difficult to measure. Instead, these researchers recommend the use of an allometric constant (i.e., $W^{0.7}$ where W represents body weight) as a surrogate for surface area normalization. Newell et al. (1987) indicated most wildlife are in a narrow range of dose-by-weight to dose-by-surface-area ratios, and interspecies comparisons in their study were for animals of similar surface area. Therefore, a surface-area-to-weight conversion factor was not included in their method. Body weight, without an adjustment for surface area, was also used as a basis for interspecies extrapolation in the wildlife criteria procedure developed by USEPA (1995). Similarly, body weight was selected as a basis for interspecies scaling among mammalian and avian species for TRGs.

Reference concentrations are calculated for key indicator wildlife species (e.g., piscivores) using information on body weight (bw) and daily food ingestion (FI) for these wildlife species as well as the TDI derived from toxicity studies. Only the mammalian TDI is used to extrapolate to mammalian wildlife species. Similarly, only the avian TDI is used to extrapolate to avian wildlife species. The body weights and daily food ingestion rates for selected key avian and mammalian species are summarized in Tables 1 and 2, respectively. Reference concentrations may also be calculated for reptilian and amphibian species using the body weights and daily food ingestion rates in Table 3 when toxicity data are available. The procedure for calculating reference concentrations is indicated below (modified from Huston 1988; Newell et al. 1987; and USEPA 1993):

$$RC_n = TDI \div (FI \div bw)$$

where

RC_n = reference concentration ($mg \cdot kg^{-1}$) where n refers to one of several wildlife species for which an RC may be calculated

TDI = tolerable daily intake ($mg \cdot kg^{-1}$ bw per day)

bw = body weight (kg ww)

FI = food ingestion ($kg \cdot d^{-1}$ ww)

The species with the highest FI:W ratio will necessarily result in the lowest RC. Based on our existing data

Table 1. Body weights and daily food ingestion rates of avian species that consume aquatic biota.

Species	Adult body weight (kg)	Daily food consumption (kg·d⁻¹ ww)	FI:bw ratio
Anseriformes			
Bufflehead *(Bucephala albeola)*			
Male	0.473[*]	0.17[†]	0.36
Female	0.334[*]	0.14[†]	0.42
Common goldeneye *(Bucephala clangula)*			
Male	1.0[*]	0.29[†]	0.29
Female	0.8[*]	0.25[†]	0.31
Mallard *(Anas platyrhynchos)*	1.082[*]	0.25[‡]	0.23
Oldsquaw *(Clangula hyemalis)*			
Male	0.932[*]	0.27[†]	0.29
Female	0.814[*]	0.25[†]	0.31
Wood duck *(Aix sponsa)*			
Male	0.681[*]	0.23[†]	0.34
Female	0.635[*]	0.22[†]	0.35
American wigeon *(Anas americana)*			
Male	0.792[*]	0.25[†]	0.32
Female	0.719[*]	0.23[†]	0.32
Lesser scaup *(Aythya affinis)*			
Male	0.850[*]	0.26[†]	0.31
Female	0.790[*]	0.25[†]	0.32
Common merganser *(Mergus merganser)*			
Male	1.709[*]	0.41[†]	0.27
Female	1.232[*]	0.33[†]	0.27
Red-breasted merganser *(Mergus serrator)*			
Male	1.135[*]	0.235[‡]	0.21
Female	0.908[*]	—	—
Falconiformes			
Bald eagle *(Haliaeetus leucocephalus)*	4.5[§]	0.5[§]	0.11
Osprey *(Pandion haliaetus)*	1.5[‡]	0.3[§]	0.20
Coraciiformes			
Belted kingfisher *(Ceryle alcyon)*	0.15[§]	0.075[§]	0.50
Gaviiformes			
Common loon *(Gavia immer)*	4.134[*]	0.73[†]	0.18
Charadriiformes			
Common tern *(Sterna hirundo)*	0.120[*]	0.073[†]	0.61

Species	Adult body weight (kg)	Daily food consumption (kg·d⁻¹ ww)	FI:bw ratio
Herring gull *(Larus argentatus)*			
Male	1.226[*]	0.34[†]	0.28
Female	1.044[*]	0.3[†]	0.29
Ring-billed gull *(Larus delawarensis)*			
Male	0.566[*]	0.095[‡]	0.17
Female	0.471[*]	—	—
Black-legged kittiwake *(Rissa tridactyla)*			
Male	0.421[*]	0.158[‖]	0.38
Female	0.393[*]	—	—
Razorbill *(Alca torda)*	0.719[*]	0.23[†]	0.32
Common murre *(Uria aalge)*			
Male	1.006[*]	0.29[†]	0.29
Female	0.979[*]	0.29[†]	0.30
Thick-billed murre *(Uria lomvia)*	0.964[*]	0.29[†]	0.30
Black guillemot *(Cepphus grylle)*	0.405[*]	0.16[†]	0.40
Atlantic puffin *(Fratercula arctica)*	0.381[*]	0.15[†]	0.39
Tufted puffin *(Fratercula cirrhata)*	0.779[*]	0.25[†]	0.32
Ciconiiformes			
Great blue heron *(Ardea herodias)*			
Male	2.576[*]	0.54[†]	0.21
Female	2.204[*]	0.49[†]	0.22
Green-backed heron *(Butorides striatus)*	0.212[*]	0.05[‡]	0.24
Procellariiformes			
Wilson's storm-petrel *(Oceanites oceanicus)*	0.032[*]	0.03[†]	0.94
Fork-tailed storm-petrel *(Oceanodroma furcata)*	0.055[*]	0.04[†]	0.73
Northern fulmar *(Fulmarus glacialis)*			
Male	0.609[*]	0.21[†]	0.34
Female	0.479[*]	0.18[†]	0.38

[*] Dunning 1993.
[†] Calculated from the allometric equation derived by Nagy (1987): FI (kg·d⁻¹ ww) = $(0.0582 \cdot W^{0.651}) \cdot 5$, assuming 80% water content for prey species, where FI = food ingestion, W = weight.
[‡] Newell et al. 1987.
[§] USEPA 1993.
[‖] Gabrielsen et al. 1987.

Table 2. Body weights and daily food ingestion rates of mammalian species that consume aquatic biota.

Species	Adult body weight (kg)	Daily food ingestion (kg·d^{-1} ww)	FI:bw ratio
Mustelidae			
Sea otter *(Enhydra lutris)*			
Male	34.4[*]	6.3[†]	0.18
Female	19.7[*]	3.9[†]	0.20
American mink *(Mustela vison)*			
Female	0.6[‡]	0.143[‡]	0.24
River otter *(Lutra canadensis)*	8.0[§]	0.8 (0.7–0.9)[‖]	0.10
Pinnipedia			
Harbour seal *(Phoca vitulina)*			
Male	72.5[*]	11.6[†]	0.16
Female	58[*]	9.7[†]	0.17
Northern fur seal *(Callorhinus ursinus)*			
Male	192[*]	25.9[†]	0.13
Female	42.5[*]	7.5[†]	0.18
Northern elephant seal *(Mirounga angustirostris)*			
Male	3629[*]	289.8[†]	0.08
Female	907[*]	92.7[†]	0.10
Northern sea-lion *(Eumetopias jubata)*			
Male	1000[*]	100.4[†]	0.10
Female	320 (275–365)[*]	39.4[†]	0.12
Walrus *(Odobenus rosmarus)*, eastern Arctic race			
Male	760[*]	80.2[†]	0.11
Female	570[*]	63.3[†]	0.11
Walrus *(Odobenus rosmarus)*, Pacific Ocean race			
Male	1268[*]	122.1[†]	0.10
Female	850[*]	87.9[†]	0.10
Ursidae			
Polar bear *(Ursus maritimus)*			
Male	460 (420–500)[*]	53.1[†]	0.12

[*] Banfield 1974.
[†] Calculated from the allometric equation derived by Nagy (1987): FI (kg·d^{-1} ww) = (0.0687·W$^{0.822}$)·5, assuming 80% water content for prey species, where FI = food ingestion, W = weight.
[‡] CWS 1996.
[§] Newell et al. 1987.
[‖] USEPA 1993.

Table 3. Body weights and daily food ingestion rates of reptilian and amphibian species that consume aquatic biota.

Species	Adult body weight (g)	Daily food ingestion (g·g^{-1} ww)	FI:bw ratio
Snapping turtle *(Chelydra serpentina)*			
Male	10 500[*]	—	—
Female	5 240[*]	0.01–0.016[†]	0.013
Water snake *(Nerodia sipedon)*	207[‡]	0.061[§]	0.063
Bullfrog *(Rana catespeiana)*	249[‖]	0.0169[#]	0.016

[*] Galbraith et al. 1988.
[†] Kiviat 1980.
[‡] Fitch 1982.
[§] Brown 1958.
[‖] McKamie and Heidt 1974.
[#] Estimated from free-living metabolic rate and dietary composition (USEPA 1993).

(Tables 1 and 2), there are avian and mammalian species with ratios as high as 0.94 and 0.24, respectively (although in some cases these are based on allometric equations and not field-derived data). Use of these ratios in developing RCs will result in conservative TRGs protective of all wildlife species. On a site-specific basis, RCs can be calculated for key indicator species provided that accurate information is available regarding FI, bw, and other species-specific and site-specific data (e.g., dietary preferences). The result can be compared to the generic TRG developed to protect all wildlife.

Guideline Recommendation and Application

The lowest reference concentration is used to derive a TRG for wildlife. For substances with a high potential to biomagnify within food chains (e.g., DDT), it is important that the TRG be applied to the highest aquatic trophic level (e.g., level 4 fish) in order to protect predators (e.g., raptors) feeding at that level. Application of the TRG at that level will also protect wildlife feeding at lower trophic levels. Where tissue residue data are only available for a lower trophic level organism (e.g., level 2), generic food chain multipliers or other food chain models applied to the higher trophic level may be used to allow estimation of a concentration in the lower trophic level expected to be protective of wildlife feeding at higher trophic levels.

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APPENDIX A
The New York State Department of Environmental Conservation Approach

The New York State Department of Environmental Conservation has developed a procedure for estimating safe levels of contaminants in fish flesh for the protection of piscivorous wildlife species in the Niagara River (Newell et al. 1987). This approach is similar to the approaches for human consumption limits in that it relies on dose-response information from studies on traditional laboratory animals. Data on wildlife species are also considered, when available. This approach uses biological data on the wildlife species that are being considered for protection in an interspecies scaling procedure.

Newell et al. (1987) developed two separate but related procedures for deriving numerical fish flesh criteria. For noncarcinogenic substances, the fish flesh criteria are based on an estimation of the safe daily dose of the toxicant for wildlife species or the wildlife no-observed-adverse-effect level (NOAEL). The wildlife NOAEL may be calculated from the most sensitive acute level or chronic lowest-observed-adverse-effect level (LOAEL) or from the chronic NOAEL reported for laboratory animals in conjunction with appropriate application factors and uncertainty factors. Application and uncertainty factors are selected on the basis of the available information during the toxicological assessment and are defined in the methodology. Only data on mammals are used to extrapolate to mammalian wildlife

species. Similarly, only avian data are used to extrapolate to avian wildlife species. When available, the results of feeding studies on wildlife species are incorporated into the database to provide information on the relative sensitivity of these species.

Fish flesh criteria for noncarcinogenic substances are derived from the wildlife NOAEL by considering the body weights and daily food ingestion of target wildlife species in an interspecies scaling procedure. Using this procedure, fish flesh criteria are derived as follows:

$$\text{Fish flesh criterion} = (\text{NOEL} \div \text{UF}) \cdot (W \div \text{FI})$$
$$(\text{mg} \cdot \text{kg}^{-1} \text{ ww})$$

where

NOAEL = no-observed-adverse-effects level for avian or
          mammalian wildlife species ($\text{mg} \cdot \text{kg}^{-1}$ per day)
UF   = uncertainty factor
W   = body weight (kg)
FI   = food ingestion ($\text{kg} \cdot \text{d}^{-1}$)

Newell et al. (1987) also developed a procedure for deriving fish flesh criteria for carcinogenic substances. This procedure relies on quantitative cancer risk assessments that have been developed for mammalian species. First, a 1 in 100 increased cancer risk dose (CRD_{10^2}) is calculated from the one in one million increased cancer risk dose ($\text{CRD}_{10^{-6}}$) for experimental animals used when calculating human lifetime cancer risk by the New York State Department of Health. This cancer risk dose is then converted to a wildlife dietary guideline by considering the body weights and daily food ingestion of wildlife species, as follows:

$$\text{Fish flesh criterion} = \text{CRD}_{10^{-2}} \cdot W \div \text{FI} \ (\text{mg} \cdot \text{kg}^{-1} \text{ ww})$$

where

$\text{CRD}_{10^{-2}}$ = 1 in 100 cancer risk dose ($\text{mg} \cdot \text{kg}^{-1}$ per day)
          = $\text{CRD}_{10^{-6}}$ 10 000
W   = body weight (kg)
FI   = food ingestion ($\text{kg} \cdot \text{d}^{-1}$)

The fish flesh criteria for the target species may be selected from the results of either of the two derivation procedures (i.e., wildlife NOAEL or the cancer risk dose procedures). A final fish flesh criterion may then be selected from the criteria calculated for the various target species. The guideline for the most sensitive species is then adopted as the final fish flesh criterion.

Newell et al. (1987) recognized the limitations of the toxicological database and structured the procedure to rely on data that are generally available. Thus fish flesh criteria are derived primarily from dose-response data from laboratory studies on non-wildlife mammalian and avian species (e.g., mice, rats, rabbits, or poultry). This may be considered a limitation because of the uncertainty in extrapolating from laboratory species to wildlife species. However, this is also one of the practical strengths of the procedure in that it uses data that are available in the literature. Furthermore, the procedure is flexible enough to consider information on wildlife species when these data are available. Several other limitations of this approach relate primarily to the lack of information on (a) the relative sensitivities and feeding habits of wildlife species, (b) the applicability of data generated on laboratory animals for inferring effects on wildlife species, (c) the dose-response relationships for a number of substances, and (d) the validity of the approach under field conditions (i.e., field validation) (Newell et al. 1987).

APPENDIX B
Consideration of Exposure Routes to Calculate Site-Specific Tissue Residue Objectives

Canadian tissue residue guidelines (TRGs) for the protection of wildlife assume that 100% of wildlife exposure to bioaccumulative substances is from dietary sources. S. Bradbury (1992, U.S. Environmental Protection Agency, Environmental Research Laboratory, Duluth, Minnesota, pers. com.) suggested that for substances with an aquatic bioaccumulation factor (BAF) above 10 000,

food consumption will provide essentially all of the oral xenobiotic exposure for wildlife species. For example, Thomann (1981) indicated that essentially all exposure to PCBs for top food chain organisms is via the consumption of food. However, for substances with an aquatic bioaccumulation factor of less than 10 000, other routes of exposure, such as drinking water or inhalation, may also

result in significant exposure to a substance. Therefore, adoption of the TRG without considering other exposure routes may underestimate wildlife exposure for these substances and result in under-protection of the wildlife species at a site.

Wildlife species may be exposed to environmental contaminants from sources other than contaminated foods (e.g., drinking contaminated water and inhalation). The significance of exposure from these other routes will vary depending on the physical and chemical properties of the contaminant as well as the conditions and species present at the site under consideration. Therefore, it is recommended that exposure to a substance from all possible exposure routes, if feasible, be assessed on a site-specific basis for the most sensitive species present at the site. From this multimedia exposure assessment, an apportionment factor (AF) estimating the percent exposure from dietary sources can be calculated. The AF should then be applied to the TRG when deriving a site-specific objective so that the total exposure from all sources is taken into consideration and is calculated as follows:

$$AF = E_D \div E_T$$

where

E_D = daily exposure to contaminant from all dietary sources $(mg \cdot d^{-1})$

E_T = total daily exposure from all sources $(mg \cdot d^{-1})$

The estimated exposure of the most sensitive wildlife species present at the site via inhalation (E_I), water intake (E_W), and dietary ingestion (E_D) may be measured directly in field or laboratory studies. Alternatively, exposure may be estimated indirectly using allometric equations (Appendix C) and environmental concentrations of the substance in air, water, and food at the site of concern (L. Brownlee 1993, National Wildlife Research Centre, Canadian Wildlife Service, Environment Canada, Ottawa, pers. com.; K. Lloyd 1993, National Wildlife Research Centre, Canadian Wildlife Service, Environment Canada, Ottawa, pers. com.). If measured data are not available, the environmental concentrations may be estimated using a model such as fugacity (Mackay 1991). As wildlife tend to be opportunistic feeders, feeding on whatever is available, diet and therefore E_D tend to vary with location and season. To determine a more accurate estimate of E_D, the diet of the most sensitive species can be determined from gut or feces analysis, and the appropriate prey items analyzed for contaminant levels. As well, concentrations in prey can be predicted using a food web model (Gobas 1993). The total

concentration in the diet from all sources is calculated as follows:

$$C_{D,T} = \sum P_i \cdot C_{D,i}$$

where

$C_{D,T}$ = the total concentration of a substance in the diet

P_i = the fraction of the wildlife species diet that consists of component i with concentration of $C_{D,i}$. If, for example, mink consume 70% fish, 10% amphibians, and 20% crustaceans, then P_i are, respectively, 0.7, 0.1, and 0.2 and $C_{D,i}$ is, respectively, the concentrations in the fish (C_f), amphibians (C_a), and crustaceans (C_c).

The following example is given to demonstrate a simple exposure assessment for a mink using fictitious environmental concentration data for compound X. An apportionment factor is then estimated using these data presented in Table B-1.

The apportionment factor is, therefore,

$$AF = 6.87 \div 8.41 = 0.82$$

This apportionment factor would then be applied to the TRG to derive a site-specific objective using the following equation:

$$TRO = TRG \cdot AF$$

where

TRO = tissue residue objective $(mg \cdot kg^{-1})$

TRG = tissue residue guideline $(mg \cdot kg^{-1})$

Table B-1. Example exposure assessment for a mink to compound X.

Media	Environmental concentration	Average bw (kg)	Allometric equation[*]	Estimated daily exposure[†] $(mg \cdot d^{-1})$
Air	$1\ mg \cdot m^{-3}$	1	$0.5458 \cdot W^{0.8}$	$E_I = 0.5458 \cdot 1^{0.8} \cdot 1$ = 0.55
Water	$10\ mg \cdot L^{-1}$	1	$0.099 \cdot W^{0.9}$	$E_W = 0.099 \cdot 1^{0.9} \cdot 10$ = 0.99
Food	$100\ mg \cdot kg^{-1}$	1	$0.0687 \cdot W^{0.822}$	$E_D = 0.0687 \cdot 1^{0.822} \cdot 100$ = 6.87
				$E_T = 8.41$

Note: E_I = daily exposure to contaminant from inhalation; E_W = daily exposure to contaminant from drinking water; E_D = daily exposure to contaminant from diet; E_T = total daily exposure from all sources.

[*]From Appendix C.

[†]Exposure through contact with sediments (dermal contact or ingestion) is assumed to be negligible.

APPENDIX C
Determination of Body Weight, Food Ingestion, Water Ingestion, and Inhalation for Mammalian and Avian Species

In order to conduct an exposure assessment (Appendix B), it is necessary to calculate the food ingestion, water ingestion, and inhalation rates for the wildlife species present at the site. In the absence of measured field or laboratory data, the allometric equations indicated below can be used to estimate these rates.

Also, for some toxicity studies used in the derivation of the tissue residue guideline (TRG), the dosage rate may not be reported in milligrams per kilogram of body weight per day, and thus it may be necessary to calculate this rate from the data provided. In order to perform this calculation, the body weight and food ingestion rate of the tested species are required. The body weight and daily food ingestion should be obtained, when available, from the toxicity test. If this information is not reported, body weights and daily food ingestion reported in the following publications may be used: Banfield 1974; Dunning 1993; or National Institute for Occupational Safety and Health (1993 or latest edition). The food ingestion rate may also be calculated using the allometric equations for food ingestion below.

Allometric Equations

Food Ingestion

Avian species: $FI = (0.0582 \cdot W^{0.651}) \cdot 5^{*}$
(adapted from Nagy 1987; USEPA 1993, Vol. I)

where

FI = food ingestion rate (kg ww·d^{-1})
W = average weight (kg)
Mammalian species: $FI = (0.0687 \cdot W^{0.822}) \cdot 5^{*}$

(adapted from Nagy 1987; USEPA 1993, Vol. I)

where

FI = food ingestion rate (kg ww·d^{-1})
W = average weight of consumer (kg)

Water Ingestion

Avian species: $WI = 0.059 \cdot W^{0.67}$ (from Calder 1981, Skadhauge 1975, and Calder and Braun 1983)

Mammalian species: $WI = 0.099 \cdot W^{0.9}$ (from Calder 1981, Skadhauge 1975, and Calder and Braun 1983)

where

WI = water ingestion (L·d^{-1})

Inhalation

Avian species, excluding passerines: $I = 0.4089 \cdot W^{0.77}$ (from Lasiewski and Calder 1971)

Mammalian species: $I = 0.5458 \cdot W^{0.8}$ (from Stahl 1967)

where

I = inhalation rate (m^3·d^{-1})

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[*]Multiplying the equations by five converts units from a dry weight basis to a wet weight basis where:

dry weight = $0.2 \cdot$ wet weight (A.J. Niimi, pers. com.).

Therefore,

wet weight = dry weight ÷ 0.2
       = dry weight · 5

Reference listing:

Canadian Council of Ministers of the Environment. 1998. Protocol for the derivation of Canadian tissue residue guidelines for the protection of wildlife that consume aquatic biota. Canadian Council of Ministers of the Environment, Winnipeg. [Reprinted in Canadian environmental quality guidelines, Chapter 8, Canadian Council of Ministers of the Environment, 1999, Winnipeg.]