Non-Human Biota Dose Assessment Equations and Data

NWMO TR-2014-02 R001 February 2015

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R001	February 2015	-Addition of data for Sm and Pd -Correction of units for C-14 Concentration Ratios -Modification of tissue concentration equation for the Concentration Ratio Method -Use of Canadian data for Sedge Species Concentration Ratios -Update of Mink Occupancy Factor -Miscellaneous editorials

ABSTRACT

Title: **Non-Human Biota Dose Assessment Equations and Data**
Report No.: **NWMO TR-2014-02 R001**
Author(s): Chantal Medri[1] and Glen Bird[2]
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Abstract
This report describes the equations and data that could be used to model the potential post-closure radiological impacts of a deep geological repository on non-human biota. Previously, these impacts were evaluated using No-Effect Concentrations (NECs) (Garisto et al. 2008), where the criteria were expressed as a screening/threshold concentration. Once modelled, the methodology presented here would generate various dose rates to non-human biota, which can be compared to screening/threshold dose rates.

The partitioning behaviour of radionuclides between the media and the organisms are described with two different approaches (Concentration Ratios and Transfer Factors), such that results can be generated by either approach. This affects the results for mammals and birds.

This report describes a method for calculating dose rates to non-human biota and provides all required equations and input parameters. The equations are based on those shown in the CSA N288.6 (CSA 2012). Data are provided for three Canadian ecosystems: the southern Canadian deciduous forest (SCDF), boreal forest (BF) and inland tundra (IT).

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1. INTRODUCTION

The objective of this report is to describe the equations and data that could be used for assessing the potential post-closure radiological impact of a deep geological repository on non-human biota.

Previously, these impacts were analysed using No-Effect Concentrations (NECs) (Garisto et al. 2008). NECs represented a media concentration threshold for which there was confidence that there would be no significant ecological effect on non-human biota if the NECs were not exceeded. These concentrations were derived based on simple pathways and dose rate criteria.

In Europe, the calculation of dose consequences to non-human biota is largely performed using the ERICA approach (for example, Torudd 2010). This also uses simple pathways, but it takes the media concentrations as input and explicitly calculates dose rates which are compared to screening/threshold criteria. The ERICA approach is available as software, the ERICA Tool.

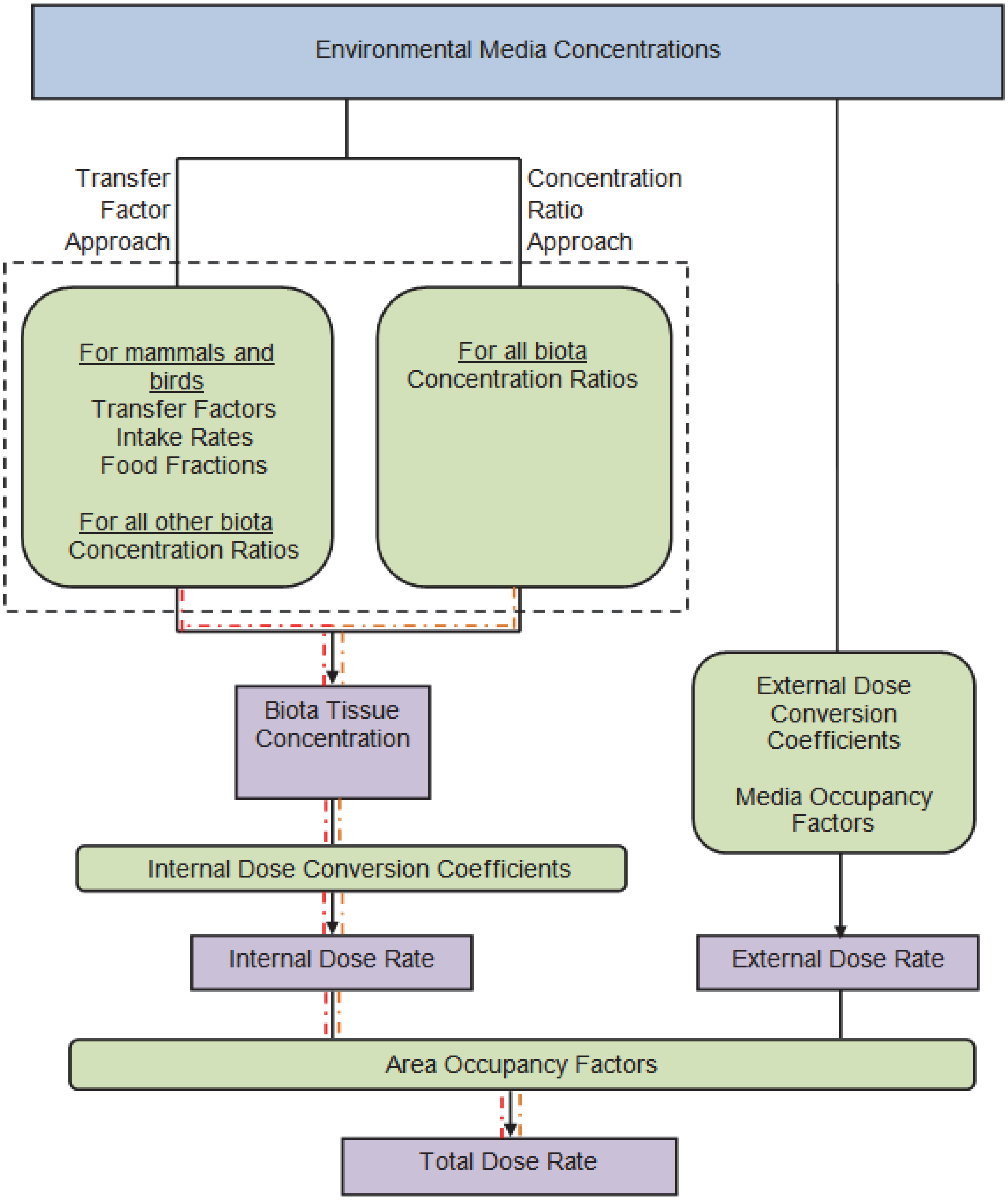
One of the significant differences between ERICA and the NECs is the approach used to model the partitioning behaviour of a radionuclide between the media and the organism. Concentration ratios (CRs) estimate the concentration in all organisms based on the concentration of an appropriate substrate media (soil, water, sediment and air). Transfer factors (TFs) estimate the concentration in mammals and birds based on the intake rate of food, soil, water or sediment. ERICA uses the CR approach, whereas the NECs were derived including both the CR and the TF approaches.

The equations and data presented here can be used to generate results for both radionuclide partitioning approaches. As with ERICA, the output may be compared to threshold/screening dose rate criteria. The equations are based on those shown in CSA (2012).

This report describes the theory of the assessment method, provides all equations for the calculations, discusses the rationale for the selection of biota used to represent each ecosystem and provides other key parameter values.

2. THEORY AND EQUATIONS

The purpose of the dose assessment is to calculate external and internal dose rates to non-human biota given exposure to a contaminated environment. The calculation method accounts for contamination by various radionuclides and pathways to different organisms and includes both approaches of calculating biota tissue concentrations (CRs and TFs). Figure 2-1 depicts the dose calculation flow chart, given a set of input media concentrations.



Note: Purple boxes represent calculated quantities, green boxes represent model parameters and the blue box represents inputs.

Figure 2-1: Non-Human Biota Dose Assessment Flow Chart

2.1 ENVIRONMENTAL MEDIA CONCENTRATION

The dose assessment method is designed to calculate doses that result from exposure to four potentially contaminated media: soil, water, sediment and air (for C-14 only). The method assumes that the water and sediment concentrations are in equilibrium, unless both media concentrations are specified by the user. The equilibrium is modeled using the following equations:

$$C_{sed}^{i} = C_{w}^{i} \cdot Kd_{sed}^{i} \quad (2.1)$$

Where;
C_{sed}^{i} is the sediment concentration of each radionuclide i (Bq/kg_{dw})
C_{w}^{i} is the water concentration of each radionuclide i (Bq/L)
Kd_{sed}^{i} is the sediment-water distribution coefficient of each radionuclide i (L/kg_{dw})

Media concentrations are converted from units of mol/kg or mol/m^3 to Bq/kg or Bq/m^3 using the radionuclide half-lives in the ENDF/B-VII.1 library (Chadwick et al. 2011).

2.2 BIOTA TISSUE CONCENTRATIONS

2.2.1 Concentration Ratio Approach

The following equation is for calculating the biota tissue concentration for all radionuclides except C-14 when using CRs:

$$C_{t}^{i} = C_{w}^{i} CR_{w}^{i} (OF_{w} + OF_{seds}) + C_{s}^{i} CR_{s}^{i} (OF_{os} + OF_{is}) \quad (2.2)$$

Where
C_{t}^{i} is the biota tissue concentration radionuclide i (Bq/kg_{fw});
C_{s}^{i} is the concentration for each radionuclide i in soil(Bq/kg_{dw});
C_{w}^{i} is the concentration for each radionuclide i in water (Bq/L);
CR_{s}^{i} is the concentration ratio for each radionuclide i for soil (kg_{dw}/kg_{fw});
CR_{w}^{i} is the aquatic concentration ratio for each radionuclide i for water (L/kg_{fw});
OF_{w} is the water occupancy factor[-];
OF_{seds} is the sediment-surface occupancy factor[-];
OF_{os} is the occupancy factor on soil[-]; and
OF_{is} is the occupancy factor in soil[-].

The CSA (2012) recommends a simplified version of Equation (2.2) for plants, invertebrates and fish (where aquatic and terrestrial exposures are considered separately), except that the CR is termed "bioaccumulation factor". For mammals and birds, the CSA (2012) recommends the TF approach. However, for the CR approach, Equation (2.2) is adopted for all biota.

For fish, benthic invertebrates, amphibians and aquatic plants, the CR is the ratio between the fresh weight (fw) biota tissue concentration and the water concentration. For plants, earthworms and reptiles, the CR is the ratio between fresh weight biota tissue concentration and the dry weight (dw) soil concentration. For mammals and birds, the CR is the ratio between the fresh weight biota tissue concentration and the dry weight soil concentration in the terrestrial environment and biota tissue and water in the aquatic environment. This ratio is termed an aggregated CR because it simplifies the food chain to a single ratio between the concentration in biota tissue and media and differs from the conventional CR of biota tissue/feed for mammals and birds.

The tissue concentration for C-14 is expressed as follows (adapted from ICRP 2009):

$$C_t^{C-14} = C_w^{C-14} CR_w^{C-14}(OF_w + OF_{seds}) + C_a^{C-14} CR_a^{C-14}(OF_{os} + OF_{is}) \qquad (2.3)$$

Where
C_a^{C-14} is the concentration of C-14 in air (Bq/m^3); and
CR_a^{C-14} is the concentration ration for C-14 in air (m^3/kg_{fw}).

CSA (2012) recommends the use of specific activity models for C-14. While the equations describing the transfer of C-14 in the CR approach are no different from any other radionuclides, the CRs for C-14 have been derived using specific activity models (Hosseini et al. 2008, ICRP 2009, IAEA 2010). The underlying assumption is that the C-14 has reached isotopic equilibrium with stable C-12, a very reasonable assumption in the context of long-term contamination. However, this approach adds uncertainty to the model since a given CR value may not describe the specific site and may produce a very different result from that of the specific activity model.

2.2.2 Transfer Factor Approach

In the TF approach, tissue concentrations of mammals and birds are calculated using TFs. For all other biota, tissue concentrations are calculated using CRs (using Equation (2.2) shown above).

CSA (2012) recommends the following equation for calculating the tissue concentration of mammals and birds due to the concentration in the soil, water and sediment:

$$C_{t,sws}^i = \sum_m C_m^i \cdot I_m \cdot TF^i \qquad (2.4)$$

Where;
$C_{t,sws}^i$ is the biota tissue concentration of radionuclide i from soil, water and sediment (Bq/kg_{fw})
C_m^i is the media concentration for each radionuclide i (Bq/L or Bq/kg_{dw});
I_m is the ingestion rate of medium m (soil, water or sediment)(L/y or kg_{dw}/y); and
TF^i is the TF of each radionuclide i (y/kg_{fw}).

The TF is the fractional transfer per day, classically computed as the concentration in the animal divided by the daily intake of the specified radionuclide. In the current model, it has been converted to the fractional transfer per year.

CSA (2012) recommends the Equation (2.4) for biota ingestion of food, with summation over food types, and using fresh weight units for both concentration and ingestion rates. Therefore, for the ingestion of food (i.e. other non-human biota), Equation (2.4) is modified to take into account fresh weight units for food, and to express the intakes of different food items as a fraction of total food intake. The biota tissue concentration due to the ingestion of food is expressed by Equation (2.5).

$$C_{t,f}^{i} = I_f \cdot TF^{i} \sum_{j} (C_{tt}^{j,i} \cdot F_f^{j}) \tag{2.5}$$

Where:

$C_{t,f}^{i}$	is the tissue concentration of radionuclide i due to contaminated intake [Bq/kg_{fw}]
I_f	is the intake of food [kg_{fw}/y];
TF^{i}	is the TF for radionuclide i [y/kg_{fw}];
F_f^{j}	is the food fraction of biota j in diet [-];and
$C_{tt}^{j,i}$	is the tissue concentration of biota j and radionuclide i [Bq/kg_{fw}].

The total tissue concentration of mammals and birds is the sum of contributions from soil, water and sediment and from food, as shown in Equation (2.6).

$$C_t^{i} = C_{t,sws}^{i} + C_{t,f}^{i} \tag{2.6}$$

The TF approach as applied here does not use a specific activity model to describe the transfer of ^{14}C.

2.3 OCCUPANCY FACTORS

Occupancy factors describe the relative amount of time spent in a medium or area. In this assessment, two different types of occupancy factors are used.

Media Occupancy Factor (MOF): Describes the relative time spent in soil, on soil, in water, in sediment, at sediment surface and at water surface for all organisms. These are equivalent to the occupancy factors used in ERICA. The MOF should sum to one for each organism. The MOF is used to weight the relative contributions from exposures from each medium.

Area Occupancy Factor (AOF): Describes the relative time spent in the assessment area. The AOF may be less than one for migratory species and species that occupy large territories. The AOF is used to weight the total dose (internal and external) to reflect the time spent in contaminated areas. This factor is not explicitly considered in ERICA, although it can easily be added to the assessment by modifying the MOFs.

The MOFs and the AOFs used in this model are shown in Section 3.8.

2.4 DOSE CONVERSION COEFFICIENTS (DCC)

The DCC is the dose rate absorbed per activity concentration in the organism (internal dose) or the medium (external dose). As recommended by CSA (2012), the DCCs used in this model are those that are generated by the ERICA Tool. As shown in Equation (2.7), the DCCs for each radionuclide (*i*) and each exposure geometry (*j*) are calculated by multiplying the alpha, beta or gamma (*k*) components of the DCC by an appropriate radiation weighting factor (RBE) (see further in Section 3.6):

$$DCC_j^i = \sum_k DCC_j^{k,i} \cdot RBE^k \quad (2.7)$$

Where:
DCC_j^i is the DCC for radionuclide *i* and geometry *j* [(μGy/h)/(Bq/kg_{fw})];
$DCC_j^{k,i}$ is the DCC for radionuclide *i,* geometry *j* and radiation type *k* [(μGy/h)/(Bq/kg_{fw})]; and
RBE^k is the RBE for radiation type *k* [-].

2.5 DOSE RATES

Organisms receive an internal dose from the radionuclides in their tissues and an external dose from exposure to the radionuclides in the surrounding environment. The equations for calculating both are shown below.

2.5.1 Internal Dose

The following equation provides the calculation of the internal dose rate (μGy/h):

$$D_{int}^i = DCC_{int}^i C_t^i \quad (2.8)$$

Where:
D_{int}^i is the internal dose due to radionuclide *i* [μGy/h];
DCC_{int}^i is the internal DCC of radionuclide *i* [(μGy/h)/(Bq/kg_{fw})]; and
C_t^i is the tissue concentration or radionuclide *i* [Bq/kg_{fw}].

2.5.2 External Dose Rate

Similar to CSA (2012), the aquatic and terrestrial external dose rates (μGy/h) are calculated as follows:

$$D_{ext}^i(aquatic) = DCC_{ext,w}^i\left[(OF_w + 0.5 \cdot OF_{seds})C_w + (0.5 \cdot OF_{seds})f_{sed}C_{sed}^i\right] \quad (2.9)$$

$$D_{ext}^i(terrestrial) = f_{soil}C_s^i[DCC_{ext,os}^i OF_{os} + DCC_{ext,is}^i OF_{is}] \quad (2.10)$$

Where:

$DCC^{i}_{ext,w}$ is the aquatic external dose coefficient for each radionuclide (water or sediment) i [(μGy/h)/(Bq/L)or (μGy/h)/(Bq/kg_{fw})];
$DCC^{i}_{ext,os}$ is the external dose coefficient on soil for each radionuclide i [(μGy/h)/(Bq/kg_{fw})];
$DCC^{i}_{ext,is}$ is the external dose coefficient in soil for each radionuclide i [(μGy/h)/(Bq/kg_{fw})];
OF_{w} is the water occupancy factor[-];
OF_{seds} is the sediment-surface occupancy factor[-];
OF_{os} is the occupancy factor on soil[-];
OF_{is} is the occupancy factor in soil[-];
f_{sed} is the sediment dry to wet weight conversion factor [kg_{dw}/kg_{fw}];
f_{soil} is the soil dry to wet weight conversion factor [kg_{dw}/kg_{fw}];
C^{i}_{w} is the water concentration of each radionuclide i [Bq/L];
C^{i}_{sed} is the sediment concentration of each radionuclide i [Bq/kg_{dw}]; and
C^{i}_{s} is the soil concentration of each radionuclide i [Bq/kg_{dw}].

Contrary to CSA (2012), Equation (2.9) does not account for time spent at the water surface or in the sediment because biota species in this model are not assumed to spend time in these locations. The fractions of 0.5 refer to the half-spheres of influence at the sediment surface.

All MOFs sum to one. Note that f_{sed} and f_{soil} are not included in the equation shown in the CSA (2012), but the conversion is implied. This is because biota and water activity concentrations are estimated via CRs and sediment-water distribution coefficient (Kd^{i}_{sed}) that require soil and sediment activity concentrations expressed on a dry weight basis, and the because estimation of external dose rates are estimated via DCCs that require soil and sediment activity concentrations expressed on a wet weight basis.

Contrary to CSA (2012), but consistent with ERICA, this model does not consider the exposure to radionuclides on the surface of the soil (given in Bq/m^2), but rather, assumes that radionuclides on the soil surface are mixed into the soil volume. ERICA does not generate soil surface DCCs.

The external dose rate is summed for all exposure media to give the total external dose rate.

$$D^{i}_{ext} = D^{i}_{ext}(aquatic) + D^{i}_{ext}(terrestrial) \tag{2.11}$$

Where

D^{i}_{ext} is the total external dose rate for radionuclide i [μGy/h].

2.5.3 Total Dose Rate

The total dose rate reported in the assessment is the sum of the external and internal dose rates, weighted by the AOF, to represent the fact that some species may not spend all their time in the contaminated area. Therefore, the equation for the total dose rate (μGy/h) to each organism is:

$$D^{i}_{tot} = (D^{i}_{ext} + D^{i}_{int})AOF \tag{2.12}$$

Where:

D_{tot}^{i} is the total dose rate for radionuclide i [μGy/h]; and
AOF is the area occupancy factor.

3. PARAMETER DATA

3.1 WATER-SEDIMENT PARTITIONING COEFFICIENTS

As per Equation (2.1), the water-sediment partitioning coefficient is required to calculate the sediment concentration based on the water concentration (or vice-versa). The water-sediment partitioning coefficients are listed in Table 3.1. Data are preferentially taken from CSA (2008), followed by Sheppard et al. (2012) and the default values in the ERICA Tool.

Table 3.1: Water-Sediment Distribution Coefficients

Element	Water-Sediment Distribution Coefficient (L/kg $_{fw}$)	Reference
Ac	450	Default Value, ERICA Tool
Am	20000	CSA (2008)
Bi	1500*	Davis et al. (1993)
C	50	CSA (2008)
Ca	620	Sheppard et al. (2012)
Cl	17	CSA (2008)
Cs	2700	CSA (2008)
I	76	CSA (2008)
Mo	100	CSA (2008)
Nb	1600	CSA (2008)
Ni	4000	CSA (2008)
Np	25	CSA (2008)
Pa	5400	CSA (2008)
Pb	19000	Sheppard et al. (2012)
Pd	670*	Davis et al. (1993)
Po	7300*	Davis et al. (1993)
Pu	5400	CSA (2008)
Ra	4900	CSA (2008)
Rn	0	Default Value, ERICA Tool
Sb	450	CSA (2008)
Se	1500	CSA (2008)
Sm	51000	Sheppard et al. (2012)
Sn	1300	CSA (2008)
Tc	1.4	CSA (2008)
Th	30000	CSA (2008)
U	330	CSA (2008)
Zr	6000	CSA (2008)

* No data is given in CSA (2008), Sheppard et al. (2012) or the ERICA Tool. Therefore, the value for organic soil from Davis et al. (1993) is adopted here.

3.2 REPRESENTATIVE BIOTA

The assessment method considers the effects to a large range of biota as shown in Table 3.2 and Table 3.3. The biota species are representative of the main taxonomic groups found in ecosystems that represent a range of Canadian conditions: southern Canadian deciduous forest (SCDF), boreal forest (BF) and inland tundra (IT) (a potential far-future climate condition during glaciations). Currently the list assumes an inland site; therefore a marine ecosystem is not included.

The list of selected representative biota for this study is based on the taxonomic categories of FASSET (Pröhl et al. 2003), ICRP (2008) and the ERICA Tool (Brown et al. 2008). Representative biota species were selected for each ecosystem. FASSET, ICRP and ERICA taxonomic categories that are not included are discussed below.

3.2.1 Aquatic Biota

The **northern leopard frog** has been selected as the representative amphibian, as it is common and has a wide distribution in the SCDF and BF (Dewey 1999). Amphibians are absent from the arctic tundra due to the cold conditions (Moore 2008).

The **Canada goose** is a good representative of the taxonomic grouping 'aquatic bird' and is especially relevant in Canada because it is common and well represented in the SCDF, the BF and IT. Although an aquatic bird, the Canada goose feeds both on land and on water.

The **mallard** has also been included in the assessment to represent aquatic birds as it is a common valued ecosystem component in Canadian environmental assessments and, like the Canada goose, is found in all three ecosystems (Rogers 2001). Although both Canada geese and mallards feed in water and on land, the mallard has a larger aquatic component, feeding heavily on benthic invertebrates and aquatic plants, whereas the Canada goose tends to feed primarily on riparian or upland vegetation. With geological disposal, future releases are most likely to travel with groundwater flow to a topographical low area such as a lake or wetland. Therefore, including the mallard as a representative species captures different and potentially more important food chain pathways.

The loon has been selected to represent a pisivorous aquatic bird. The **common loon** is found in the SCDF and the BF and to some extent the tundra (Evers 2010), and the **red-throated loon** is found in the IT (Ivory 1999), where it is assumed to occupy a tundra pond as opposed to marine habitat.

The **beaver**, the **mink** and the **muskrat** have been selected to represent aquatic mammals. The beaver and mink are especially relevant in Canada because they are common in the SCDF and the BF (EPA 2012). The beaver is a herbivore that feeds primarily on riparian vegetation, whereas the mink is a carnivore that feeds on fish, aquatic invertebrates (e.g., crayfish) and small mammals such as mice and muskrats. The muskrat has also been included as it is one of the most widely distributed mammals in North America occupying both the SCDF and the BF (CWS 1987). Both the mink and the muskrat are common valued ecosystem components in Canadian environmental assessments (e.g., EC/HC 2003). The muskrat has a small home range, is active throughout the year, and feeds primarily on aquatic vegetation, including the roots or tubers of aquatic plants during the winter months (muskrats do not make food caches like beavers to survive the winter). In comparison, beavers feed primarily on riparian vegetation, particularly the bark of trees which tends to have higher radionuclide concentrations than in other parts of the plant. All three mammals are considered to occupy both the terrestrial and aquatic environments, but the mink is conservatively assumed to be primarily aquatic feeding on fish and the muskrat.

Aquatic plants are represented by **pondweeds** in the SCDF and the BF and by the **water sedge** in the IT. However, pondweeds and water sedge are found in all three ecosystems (Aikens *et al.* 2007). Pondweed is representative of submerged species (which has an implicit epiphyte component), whereas water sedge is representative of emergent species, and riparian and wetland plants. Neither are fully representative of free-floating aquatic plants, but in general submerged aquatic macrophytes derive much of their elemental content from the water column as do the free-floating species.

Benthic invertebrates are assumed to represent a few of the taxonomic groupings given by ERICA; namely, aquatic insects, gastropod, bivalve mollusk, and crustaceans. These taxonomic categories have been represented by **chironomid larvae** that live in the sediment. In the assessment of the long term radiation dose to biota from a deep geological repository in Sweden, Torudd (2010) predicted radiation dose rates in the order insect larvae (0.19×10^{-3} µGy/h) > bivalve mollusks (3.7×10^{-4} µGy/h > gastropods (2.8×10^{-4} µGy/h). On the basis of Torudd (2010), chironomid larvae can be used as the primary representative species since protection of chironomid larvae protects the other benthic invertebrates.

The **lake whitefish** has been selected as a representative benthic fish. It feeds heavily on benthic invertebrates and detritus and is present in all three ecosystems (Scott and Crossman 1998). Also, data are more readily available for the lake whitefish than for other similar species (for example, the white sucker).

The **lake trout** has been selected as the representative species for pelagic fish, since it is well represented in deep lakes in the south and shallower lakes in the north that do not freeze to the bottom. The lake trout is present in all three ecosystems (Scott and Crossman 1998).

Table 3.2 summarises the aquatic biota species that were selected to represent each ecosystem and each taxonomic category defined for this assessment. Additionally, the table shows the classification of other common biota that are assumed to have the same dose consequences and references safety assessments that have used each representative biota.

Table 3.2: Summary of Representative Aquatic Biota

Category	Sub-Category	Selected Representative Biota	Other Common Biota	SCDF[c]	BF[c]	IT[c]	Ref
Amphibian[a]		Northern Leopard Frog		X	X		1,2
Aquatic Bird	Omnivorous	Canada Goose[b]		X	X	X	1
		Mallard		X	X	X	2
	Pisivorous	Red-throated Loon	Common merganser and red-breasted merganser, scaup			X	3
		Common Loon		X	X		4
Aquatic Mammal[a]		Mink[b]		X	X		3,4
		Beaver[b]		X	X		1
		Muskrat[b]		X	X		2,5
Aquatic Plants		Pondweeds		X	X	X	1, 3
		Water Sedge		X	X	X	6
Benthic Invertebrate		Chironomid Larvae	Aquatic Snail, Bivalve Clam, Crayfish, Chironomid Larvae	X	X	X	1,2,5
Fish	Benthic	Lake Whitefish	White Sucker	X	X	X	8
	Pelagic	Lake Trout	Northern Pike Smallmouth Bass Walleye	X	X	X	8

1. Garisto *et al*. (2008), 2. EcoMetrix Inc and C. Wren & Associates (2005), 3.Cameco (2011), 4. Areva (2011), 5. EC/HC (2003), 6. Sheppard (2002), 7. AECL(2001), 8.Beak (1994), 9 OPG (2009), 10. OPG (2011)

Notes:

a Because of the low temperatures, the IT has less biodiversity. Amphibians and aquatic mammals are not represented.

b. In this model, the Beaver, the Muskrat, the Mink and the Canada Goose are considered to be both aquatic and terrestrial organisms.

c. SCDF = Southern Canadian Deciduous Forest, BF = Boreal Forest, and IT = Inland Tundra

3.2.2 Terrestrial Biota

The **common garter snake** has been selected as representative of the reptile category as it is the most common snake species present in the SCDF and the BF (Zimmerman 2002) and has one of the furthest north distributions of the reptiles. However, snakes, like amphibians, being poikilotherms, are not present in the tundra because of the cold conditions (Moore 2008).

The **great horned owl** has been selected as representative of the category terrestrial carnivorous bird and is especially relevant in Canada because of its wide distribution, being found in all three ecosystems (CWS 1991a). The great horned owl is found in the subarctic tundra, but is absent from the high arctic tundra. The diet of the great horned owl in the IT is modeled differently from its diet in the other two ecosystems.

The **ruffed grouse** and the **willow ptarmigan** have been selected as representatives of terrestrial herbivorous birds. They are especially relevant in Canada because the ruffed grouse is a common game bird in the SCDF and the BF (Dunn and Alderfer 2006) and the willow ptarmigan is distributed throughout the Arctic tundra area (Hannon *et al*. 1998).

Earthworms have been selected as representative terrestrial invertebrates and are especially relevant in Canada because earthworms are found in all three ecosystems (Petersen *et al*. 2008) and are an excellent surrogate for other soil invertebrates. The Canadian earthworm fauna is largely represented by exotic species introduced from Europe, the native species with the exception of enchytraeids largely being wiped out by glaciation events (refugia exist in western Canada). Introduced species of worms are now found in many areas of the SCDF and the boreal forest. Earthworms are important in terrestrial food chains and play an important role in soil processing.

The terrestrial mammal category is divided into two groups based on size: small and large. This is reasonable for carnivorous mammals as large predators are still relatively common in Canada. In the case of herbivorous mammals, the two size groups reflect differences in exposure (occupancy factors and TFs) and sensitivity to radiation. The different sizes of herbivorous mammals are accounted for by ICRP and ERICA in their choice of reference organisms.

The **red fox** and **arctic fox** have been selected as representative carnivorous terrestrial mammals. They are especially relevant in Canada because the red fox is common in the SCDF and the BF and inhabits the IT ecosystem, whereas the arctic fox is common in the IT ecosystem (Fox 2007, CWS 1993a, CWS 1990a). The fox is a common VEC in Canadian environmental assessments (EC/HC 2003).

The **eastern cottontail rabbit**, the **snowshoe hare** and the **arctic hare** have been selected as representative biota for small herbivorous mammals in the SCDF, BF and IT, respectively. These biota species can be considered representative in the food chain of their respective ecosystems.

Rodents are representative biota that are also small terrestrial mammals and are especially relevant to Canada because rodents are found in all three ecosystems and are important organisms in the food chain. The **meadow vole** and the **brown lemming** have been selected as representative rodent small terrestrial mammals. The meadow vole is widely distributed in the SCDF and the BF ecosystems (Neuburger 1999) whereas the brown lemming is common in the IT ecosystem (Barker 2003).

The **groundhog** and **arctic ground squirrel** have been selected to represent burrowing mammals. The groundhog is widely distributed in the SCDF and the BF (CWS 1991b) whereas the arctic ground squirrel is common in the IT (Lutz 2000). As burrowing mammals, they are potentially exposed to high doses of radiation from inhalation of radon (and its progeny) in their burrows (Macdonald and Laverock 1998), in addition to the conventional pathways of ingestion through their diet and external exposure to groundshine. Burrow ventilation rates will influence progeny buildup and associated doses, and these rates are unknown for most burrowing species. Large uncertainties are associated with the calculated doses and their interpretation for burrowing mammals.

ERICA does not specifically include a large carnivorous mammal in its reference organism list, possibly because there is a more limited population of large predators in Western

Europe. However, this taxonomic category is especially relevant to Canada because large carnivorous mammals (such as the wolf), are common in all three ecosystems. The wolf has been selected as a good representative of a large terrestrial carnivorous mammal and is especially relevant to Canada because it is common in all three ecosystems of interest.

The **brush wolf** is prevalent in the SCDF ecosystem and although it is found throughout the BF (CWS 1990c), the **grey wolf** dominates in the BF ecosystem (Dewey and Smith 2002). The **Arctic wolf**, a subspecies of the grey wolf, occupies the IT ecosystem (Wilson and Ruff 1999). The brush wolf preys on deer and smaller animals, whereas the grey wolf is a predator of large herbivorous mammals such as deer and moose, and the Arctic wolf preys on caribou.

White-tailed deer, **moose** and **barren-ground caribou** are selected as representative of large herbivorous mammals and are especially relevant to Canada because they are common in their respective biomes. White-tailed deer are found in the SCDF and BF (CWS 1990b), moose are found in BF and are expanding into the IT and are present in the northern portion of SCDF (CWS 1997) and barren-ground caribou are found in the IT (CWS 2005c).

The **white cedar** and the **dwarf arctic willow** have been selected to represent trees. The white cedar is found in moist soil particularly riparian areas in both the SCDF and the BF ecosystems (Farrar 2005), and is a preferred food for deer (and probably moose). Radiation sensitivity is in the order coniferous trees > deciduous trees > shrubs > herbaceous species (grasses/herbs and forbs) > lichen and fungi (EC/HC 2003) so a conifer representative of wet conditions is an ideal representative biota. The dwarf arctic willow is common to the IT (Garisto et al. 2008).

No specific species has been selected to represent **berries**; they are simply referred to as berries and are modeled as having a diameter of 1 cm.

Sedge species are selected as species to represent grasses and herbs and are especially relevant in Canada because sedges are found in all three ecosystems (FNAEC 2002). Sedges are associated with wetlands and moist soils, and hence are likely to be exposed to radiation from a deep groundwater discharge. They are also a source of food for herbivores.

No specific **lichen** species has been selected to represent lichen. Lichens are found in all three ecosystems (Brodo 2012). Lichens are not likely to be exposed to radionuclides from a deep geological repository since they prefer drier conditions, e.g., rocks and trees, and hence would not be exposed to radionuclides from a deep groundwater discharge. Lichens are also very tolerant to radiation, and would not be affected at radiation dose rates that would kill most plants and mammals. Nevertheless, lichen is retained as a representative biota because of its importance as a source of food for caribou during the winter. Table 3.3 shows the terrestrial biota species that were selected to represent each ecosystem and each taxonomic category defined for this assessment. Additionally, the table shows the classification of other common biota that are assumed to have the same dose consequences and references safety assessments that have used each representative biota.

Table 3.3: Summary of Representative Terrestrial Biota

Category	Sub-Category	Selected Representative Biota	Other Common Biota	SCDF[c]	BF[c]	IT[c]	Ref
Reptile[a]		Common Garter Snake		X	X		-
Terrestrial Bird	Carnivorous	Great Horned Owl	Red-tailed hawk	X	X	X	6
	Herbivorous	Willow Ptarmigan				X	1
		Ruffed Grouse		X	X		1
Terrestrial Invertebrate		Earthworm		X	X	X	1
Terrestrial Mammal	Small Carnivorous	Red Fox		X	X		1
		Arctic Fox				X	5
	Small Herbivorous	Arctic Hare				X	1,9
		Eastern Cottontail Rabbit		X			9
		Snowshoe Hare			X		1
	Rodents	Meadow Vole		X	X		10
Terrestrial Mammal	Rodents	Brown Lemming				X	-
	Small Burrowing	Groundhog		X	X		1,2
		Arctic Ground Squirrel				X	-
	Large Carnivorous	Brush Wolf		X			1,2
		Gray Wolf			X		-
		Arctic Wolf				X	-
	Large Herbivorous	White-Tailed Deer		X	X		1,2,6
		Moose[b]			X		1,6
		Barren-Ground Caribou				X	-
Terrestrial Plants	Tree	White cedar		X	X		2
		Dwarf (Arctic) Willow				X	1
	Berries	Berries		X	X	X	1
	Grasses and Herbs	Sedge Species	Heal All (9)	X	X	X	6
	Lichen	Lichen		X	X	X	1

1. Garisto *et al*. (2008), 2. EcoMetrix Inc and C. Wren & Associates (2005), 3.Cameco (2011), 4. Areva (2011), 5. EC/HC (2003), 6. Sheppard (2002), 7. AECL (2001), 8.Beak (1994), 9 OPG (2009), 10. OPG (2011).

Notes:

a Because of the low temperatures, the IT has less biodiversity. Reptiles are not represented.

b. In this model, the Moose is considered to be both an aquatic and terrestrial organism.

c. SCDF = Southern Canadian Deciduous Forest, BF = Boreal Forest, and IT = Inland Tundra

3.2.3 Taxonomic Categories Not Represented

The list of selected representative biota for this study is meant to cover the taxonomic categories of FASSET (Pröhl et al. 2003), ICRP (2008) and the ERICA Tool (Brown et al. 2008). However, some categories were not represented, and the rationale is explained below.

In general, short-lived organisms that reproduce early in life and which produce numerous offspring are more tolerant to radiation. In comparison, long-lived, late to reproduce and slow reproducing (low number of progeny) species are more sensitive to radiation (Turner 1975). In this respect, rapidly reproducing species such as bacteria, fungi, algae (phytoplankton), and zooplankton are categories of taxa that are highly tolerant of radiation and as such are not included as taxonomic categories. Both phytoplankton and zooplankton can be important to aquatic food chains, but are less exposed than benthic invertebrates to sediment-associated contaminants. The plankton are omitted and covered under benthic invertebrates, since these are more likely to be exposed and are more radiosensitive.

The categories of flying insect in ERICA and the terrestrial insect in ICRP have not been included in the study because adult insects are much more radioresistant than their juvenile life stages. In the case of aquatic insects, juvenile stages frequently inhabit sediment and other bottom substrates (benthic invertebrates) where they are most likely exposed to higher levels of radiation than adults, Likewise, many terrestrial insects have their early life stages in soil where they are more likely to receive greater exposure to radiation than adults. Furthermore, flying insects (like bees) receive low external exposure while in the air and have a low radiological impact because of their reproductive strategies (i.e., short life cycles, large egg production).

FASSET includes a large bird egg and a small bird egg in its list of reference organisms (Pröhl 2003). Radioactive strontium (in particular) may accumulate in the shell and comparatively high transfer of some radionuclides may occur to egg contents. Thus, the bird egg can potentially be exposed to high levels of radiation. The egg is also likely to be a more radiosensitive life-stage. ICRP (2008) also included the duck egg and adult in their reference animal list. Although radioactive strontium has the potential to deposit in the shell, radioactive strontium is not a contaminant of concern in for deep geological disposal of used fuel and, therefore, is not a consideration in this evaluation. Further, there is little difference in the transfer of contaminants to the flesh in adult birds and to the egg (Sheppard et al. 2010b). Therefore, accounting for radionuclide transfer to the egg provides no further level of protection to birds than afforded by protection of the adult.

The terrestrial gastropod from ERICA has not been included since the gastropod will receive a smaller external dose from soil-associated radionuclides than the earthworm, since it resides on soil rather than in soil. Moreover, CRs and radiological effects data are more available for the earthworm. For both reasons, the earthworm is more suitable as a representative terrestrial invertebrate. In the assessment of long term radiation effects of a deep geological repository, Torudd (2010) reported that Tier 3 dose rates were slightly lower to the terrestrial gastropod than a soil invertebrate (ICRP's earthworm), e.g., 6.0×10^{-5} verses 6.3×10^{-5} μGy/h. Thus, protection of the earthworm protects the terrestrial gastropod.

3.3 RADIONUCLIDE PARTITIONING BEHAVIOR

The migration of radionuclides in the environment is complex, and in order to predict the movement of radionuclides in the environment and the resulting concentrations in various environmental compartments, simplified pathway models have been widely adopted. These models use CR and TF. Their values are derived from site data, taken from the literature or in the case of animal TFs some are derived from kinetic metabolic models. An assumption of these models is that transfers of radionuclides are linearly dependent on exposure concentration. The deviation from linearity is considered a component of the variation in CR or TF. A significant assumption in the use of literature CRs is that the CR and TF data are transferable from one ecosystem/location to another.

Further complications are that the substrate for some organism is not simple, and biological data are lacking. For both amphibians and reptiles, ingestion rates and TFs are poorly known. However, most amphibians are sufficiently aquatic that they can be modelled as fish. Their contaminant uptake is through both food ingestion and absorption through the skin. Reptiles can be modelled as mammals and birds, although the uncertainties of doing this are not well known.

3.3.1 Concentration Ratios (CRs)

For the terrestrial environment and plants in particular, the CR is often derived by using soil concentrations for a specified depth of soil, usually the depth of cultivation. The assumption is made that root uptake from deeper layers is not significant (excluding the case where only the subsoil is contaminated) and what does occur is linearly related to uptake from the surface soil. Although plants can absorb radionuclides through their foliage, it is assumed that the radionuclides found in plant shoots are from root uptake and from adhesion of local soil dust, and in the case of ^{210}Pb from radon emitted from the local soil. For CR values for animals, the assumption also is that the exposure pathways (consumption of plants and direct ingestion of soil) involve the contamination in the top soil layer only.

The CR parameter has specific statistical attributes. It has a lognormal distribution, which is usually characterized by the geometric mean (GM) as a measure of central tendency, and the geometric standard deviation (GSD) as a measure of variability. For a well defined parameter that has been adequately measured, the GSD for most radionuclides will be about 3. For more poorly defined or rarely measured parameters, the GSD is higher and may be above 6. However, this assessment model does not take into account explicitly the statistical variability of transfer parameters, but this variability must be considered when interpreting results and evaluating model uncertainty.

CR values vary markedly among different environments and plant and animal types. Plant and soil concentrations used in the ratios are often expressed on a dry weight basis, because their moisture content is variable. However biota doses are calculated from fresh weight tissue concentrations. Therefore, CR values are converted to fresh weight for plants and animals.

For higher vertebrates (i.e. mammals and birds), the CR between the biota fresh weight tissue concentration to water or to dry weight soil concentration is referred to as an aggregated CR (CRag), and are for the whole organism. The CRag approach simplifies the food chain transfer of contaminants to the transfer of contaminant from water or soil directly to the mammal or bird tissue, and does not account explicitly for food chain transfer or diet. The CRag is measured the same as that for plants, amphibians, fish, etc. In comparison, conventional CRs for mammals and birds are tissue/food ratios. However, for simplicity in this report the term CR will refer to the concentration between biota tissue and water, soil or air (for C-14 only), irrespective of biota type. Where presented, CR between tissue and food will be clearly specified as such.

The international CR databases (Hosseini et al. 2008, ICRP 2009, IAEA 2010) contain a considerable number of default values from various sources, including different taxa and different environments (e.g. marine). In the current model, the approach taken was to use as much empirical data that are relevant to the Canadian environment as possible.

CRs that are derived using empirical data relevant to the Canadian environment are shown in Appendix A (Table A.13). This is followed by data given in IAEA (2010) (second tier), which are consistent with the ERICA database (Hosseini et al. 2008) and additional information. The IAEA (2010) database was the latest international database published, and therefore built on the information in both Hosseini et al. (2008) and ICRP (2009), hence the first choice of the international databases. ICRP (2009) is the third tier database drawn on to provide CRs, followed lastly by the ERICA-Tool database. Default values where no empirical data were available follow the same order in selection of their values. For Ac, Bi, and Sn where no data or few data were available, surrogate values are based on similarity in behavior expected from elements occupying adjacent locations in the periodic table. In this respect, Th serves as a surrogate for Ac, Sb for Bi, and Pb for Sn. Rn values are zero because of its short half-life.

Further assumptions for surrogate values are listed below Table 3.4 and Table 3.5, which contain the terrestrial and aquatic CRs.

CSA (2012) recommends the use of specific activity models for C-14. The equations describing the transfer of C-14 in the CR approach use the concentration of C-14 in air rather than in soil. The air CRs for C-14 have been derived using specific activity models (Hosseini et al. 2008, ICRP 2009, IAEA 2010). The use of specific activity models ensures that the predicted concentrations are consistent with the specific activity concept. However, because CRs that are derived based on the specific activity model in one environment may not be applicable to another environment, this approach is not entirely consistent. Despite this uncertainty, the current model assumes that the use of specific activity concepts for C-14 is implicit in the use of CRs derived using specific activity models.

Table 3.4: Terrestrial Concentration Ratios

Biota	Foxes & Wolves[o]		Rodents and Burrowing Mammals[p]		Rabbit and Hares[q]		Barren-Ground Caribou		Berries		Canada Goose		Common Garter Snake		Dwarf (Arctic) Willow	
Default	**Mammal**		**Rat**		**Rat**		**Deer**		**Fruit**		**Duck/Bird**		**Frog/ Reptile**		**Shrub**	
Element	**(m^3/kg_{fw} for C in air or kg_{dw}/kg_{fw} for all other elements in soil)**															
Ac	1.2E-04	f	6.3E-05	f	6.3E-05	f	1.0E-04	f	2.3E-03	f	7.1E-03	f	7.6E-02	f	5.9E-04	f
Am	4.1E-02	a	3.6E-04	b	3.6E-04	b	2.1E-03	b	6.6E-05	c,s	2.8E-02	b	1.0E-01	b	5.0E-03	a
Bi	2.2E-06	g	6.0E-02	g	6.0E-02	g	9.8E-03	g	1.5E-03	d	6.0E-02	g	6.0E-02	g	1.1E-02	g
C	1.3E+03	a	1.3E+03	b	1.3E+03	b	1.3E+03	b	1.3E+03	i	1.3E+03	b	1.3E+03	b	8.9E+02	a
Ca	2.0E+00	b	7.1E-03	d	7.1E-03	d	2.0E-02	d	6.8E-02	d	5.7E-02	d	2.0E+00	b	6.7E-01	d
Cl	7.0E+00	a	7.0E+00	b	7.0E+00	b	1.8E+00	d	1.1E+00	i	7.0E+00	b	7.0E+00	b	1.0E+00	a
Cs	2.9E+00	a	5.4E-03	d	5.4E-03	d	1.1E+00	d	5.5E-03	d	8.1E-02	d	2.8E-02	b	4.9E-03	d
I	4.0E-01	a	4.0E-01	b	4.0E-01	b	4.0E-01	b	7.0E-04	d	4.0E-01	b	4.0E-01	b	5.3E-02	i
Mo	1.7E-02	k	1.1E-02	d	1.1E-02	d	8.6E-04	d	2.0E-02	d	1.0E-01	d	1.0E-01	k	6.2E-02	d
Nb	1.9E-01	a	1.9E-01	b	1.9E-01	b	4.4E-04	d	5.7E-04	d	1.2E-02	d	1.9E-01	b	2.7E-04	d
Ni	7.2E-02	a	7.2E-02	b	7.2E-02	b	1.3E-03	d	6.9E-03	d	4.9E-02	d	3.0E-01	b	2.1E-02	d
Np	1.9E-02	b	1.9E-02	b	1.9E-02	b	8.9E-04	b	4.3E-02	m	2.8E-02	b	1.0E-01	b	3.1E-01	a
Pa	1.9E-02	b	1.9E-02	b	1.9E-02	b	8.9E-04	b	4.3E-02	m	2.8E-02	b	1.0E-01	b	4.3E-02	m
Pb	3.9E-02	a	2.1E-04	d	2.1E-04	d	2.2E-03	k	1.9E-04	d	4.7E-03	d	2.6E-03	b	5.0E-03	d
Pd	-	t	-	t	-	t	-	t	4.3E-02	e	-	t	-	t	3.0E-02	n
Po	2.8E-03	a	7.5E-04	b	7.5E-04	b	2.4E-03	b	4.0E-02	m	9.6E-03	b	3.3E-02	b	9.9E-02	a
Pu	2.3E-02	a	1.9E-02	b	1.9E-02	b	8.9E-04	b	1.2E-05	c,s	1.0E-02	b	9.3E-03	b	3.2E-02	a
Ra	2.7E-02	a	7.2E-03	d	7.2E-03	d	3.8E-03	d	1.7E-02	d	5.5E-02	b	1.7E-02	b	2.2E-01	d
Rn	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u
Sb	2.2E-06	a	6.0E-02	b	6.0E-02	b	9.8E-03	d	3.3E-03	d	6.0E-02	b	6.0E-02	b	1.1E-02	d
Se	6.3E-02	a	2.0E-02	d	2.0E-02	d	7.0E-01	d	7.1E-02	m	1.0E-02	b	1.0E-02	b	8.0E-02	d
Sm	1.9E-04	k	6.0E-06	d	6.0E-06	d	1.1E-05	d	8.5E-05	d	2.1E-03	d	1.9E-04	k	4.6E-04	d
Sn	3.9E-02	h	2.1E-04	h	2.1E-04	h	2.2E-03	h	2.7E-02	d	4.7E-03	h	2.6E-03	h	5.0E-03	h
Tc	3.7E-01	a	1.2E-04	d	1.2E-04	d	2.4E-03	d	8.1E-02	d	2.7E-01	d	3.5E-01	b	4.2E-02	d
Th	1.2E-04	a	6.3E-05	b	6.3E-05	b	1.0E-04	b	2.3E-03	m	7.1E-03	d	7.6E-02	b	5.9E-04	d
U	1.1E-04	a	2.3E-04	d	2.3E-04	d	2.5E-04	d	2.3E-04	d	9.1E-04	d	6.7E-01	b	6.3E-04	d
Zr	1.2E-05	a	1.1E-02	d	1.1E-02	d	7.2E-04	d	1.4E-02	d	1.2E-01	d	1.2E-05	b	9.4E-05	a

a. ERICA Tool Database (Hosseini et al. 2008), b. ICRP (2009), c. IAEA(2010), d. Table A.13, e. Norden et al. (2010), f. same as Th, g. same as Sb, h. same as Pb, i. same as white cedar. j. same as Canada goose, k. same as white-tailed deer, l. Same as dwarf arctic willow, m. same as white cedar, n. same as sedge species, o. includes arctic fox, red fox, arctic wolf, brush wolf & gray wolf, p. includes arctic ground squirrel, beaver, brown lemming, groundhog, meadow vole, mink & muskrat, q. includes arctic hare, eastern cottontail rabbit & snowshoe hare , r. includes great horned owl, ruffed grouse & willow ptarmigan, s. assumes berries are 81.6% water, t. no data available and u. Value is 0 because of short half-life.

Table 3.4: Terrestrial Concentration Ratios (Cont)

Biota	Earthworm		Birds[r], not Canada Goose		Lichen		Moose		Sedge Species		White Cedar		White-Tailed Deer	
Default	**Soil Inverterbrate**		**Duck/Bird**		**Lichen/ Byrophytes**		**Deer**		**Grasses**		**Pine Tree**		**Deer**	
	(m^3/kg_{fw} for C in air or kg_{dw}/kg_{fw} for all other elements in soil)													
Ac	8.8E-03	e	3.8E-04	e	3.0E-02	e	1.0E-04	e	9.2E-03	e	2.3E-03	e	1.0E-04	f
Am	1.1E+00	b	2.8E-02	b	1.0E-01	a	2.1E-03	b	7.3E-03	c,s	1.7E-02	b	2.1E-03	b
Bi	6.0E-03	g	6.0E-02	g	6.3E-02	d	1.7E-02	g	8.8E-02	d	1.5E-02	g	4.2E-02	g
C	4.3E+02	b	1.3E+03	b	1.3E-03	i	1.3E+03	b	8.9E+02	b	1.3E+03	b	1.3E+03	b
Ca	1.0E+01	b	2.0E+00	b	1.7E+00	d	3.7E-02	d	2.8E-01	d	1.8E-01	d	2.2E-02	d
Cl	1.7E-01	b	7.0E+00	b	9.6E-01	a	7.0E+00	b	4.9E+01	b	1.1E+00	b	7.0E+00	b
Cs	4.8E-02	b	2.2E-01	b	3.8E-01	d	1.6E-02	d	1.0E-02	d	6.6E-03	d	9.6E-02	d
I	1.4E-01	b	4.0E-01	b	3.6E-01	a	4.0E-01	b	5.3E-02	b	5.3E-02	b	4.0E-01	b
Mo	1.0E-01	j	1.0E-01	j	7.6E-01	d	2.5E-02	d	1.2E+00	d	2.7E-02	d	1.7E-02	d
Nb	5.1E-04	b	1.9E-01	b	1.3E-02	d	2.7E-03	d	1.2E-03	d	8.6E-04	d	1.6E-02	d
Ni	2.3E-02	b	3.1E-01	b	1.6E-01	d	1.8E-02	d	4.6E-02	d	1.8E-02	d	1.3E-02	d
Np	1.1E+00	b	2.8E-02	b	4.3E-02	m	8.9E-04	b	6.8E-03	c,s	4.3E-02	b	8.9E-04	b
Pa	1.1E+00	b	2.8E-02	b	4.3E-02	m	8.9E-04	b	3.3E-02	b	4.3E-02	b	8.9E-04	b
Pb	5.7E-01	b	2.1E-02	b	1.8E-01	d	1.1E-01	d	2.2E-03	d	3.0E-03	d	2.2E-03	d
Pd	-	t	-	t	3.0E-02	n	-	t	3.0E-02	e	3.0E-02	n	-	t
Po	9.6E-02	b	9.6E-03	b	1.0E+01	d	2.4E-03	b	1.8E-01	d	4.0E-02	b	2.4E-03	b
Pu	2.1E-02	b	1.0E-02	b	4.3E-02	m	8.9E-04	b	3.5E-05	c,s	4.3E-02	b	8.9E-04	b
Ra	2.2E+00	b	5.5E-02	b	2.1E-01	a	2.6E-03	d	2.4E-02	d	1.1E-02	d	2.5E-03	d
Rn	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u	0.0E+00	u
Sb	6.0E-03	b	6.0E-02	b	3.2E-01	a	1.7E-02	d	3.1E-02	d	1.5E-02	d	4.2E-02	d
Se	1.5E+00	b	1.0E-02	b	7.1E-02	m	3.7E-01	d	1.3E+00	b	7.1E-02	d	2.8E-01	d
Sm	2.1E-03	j	2.1E-03	d	6.9E-02	d	1.1E-04	d	8.8E-04	d	2.0E-03	d	1.9E-04	d
Sn	5.7E-01	h	2.1E-02	h	1.8E-01	h	1.1E-01	h	6.8E-02	h	3.0E-03	h	9.8E-04	h
Tc	3.5E-01	b	1.7E-01	b	2.0E+01	a	1.6E-03	d	3.6E-02	d	1.6E-02	d	4.4E-02	d
Th	8.8E-03	b	3.8E-04	b	3.0E-02	d	1.0E-04	b	9.2E-04	d	2.3E-03	d	1.0E-04	b
U	8.8E-03	b	4.9E-04	b	5.8E-02	d	4.5E-04	d	1.5E-03	d	4.2E-03	d	4.5E-04	d
Zr	5.1E-04	b	1.2E-05	b	3.9E-01	d	1.2E-05	b	2.5E-03	b	5.3E-03	d	1.2E-05	b

a. ERICA Tool Database (Hosseini et al. 2008), b. ICRP (2009), c. IAEA(2010), d. Table A.13, e. Norden et al. (2010), f. same as Th, g. same as Sb, h. same as Pb, i. same as white cedar. j. same as Canada goose, k. same as white-tailed deer, l. Same as dwarf arctic willow, m. same as white cedar, n. same as sedge species, o. includes arctic fox, red fox, arctic wolf, brush wolf & gray wolf, p. includes arctic ground squirrel, beaver, brown lemming, groundhog, meadow vole, mink & muskrat, q. includes arctic hare, eastern cottontail rabbit & snowshoe hare , r. includes great horned owl, ruffed grouse & willow ptarmigan, s. assumes berries are 81.6% water, t. no data available and u. Value is 0 because of short half-life.

Table 3.5: Aquatic Concentration Ratios

Biota	Mammals[m]		Canada Goose		Chironomid Larvae		Fish[k]		Birds[l], excluding Canada Goose		Northern Leopard Frog		Aquatic Plants[m]	
Default	**Fish**		**Fish**		**Insect larvae**		**Fish**		**Fish**		**Fish**		***Potomogeton* or Aquatic Plant**	
							(L/kg$_{fw}$)							
Ac	4.4E+02	g	7.6E+02	g	2.9E+03	g	4.4E+02	g	7.6E+02	g	4.4E+02	g	1.0E+03	g
Am	2.4E+02	f	2.4E+02	f	2.4E+03	c	2.4E+02	c	2.4E+02	f	2.4E+02	f	3.7E+03	c
Bi	5.5E+01	h	2.7E+01	h	2.1E+02	h	5.5E+01	h	2.7E+01	h	5.5E+01	h	2.2E+01	h
C	4.0E+05	f	4.0E+05	f	6.5E+04	c	4.0E+05	c	4.0E+05	f	4.0E+05	f	1.6E+04	c
Ca	8.3E+02	f	1.6E+00	d	3.4E+01	c	8.3E+02	d	1.6E+00	d	8.5E+02	b	3.0E+02	d
Cl	1.3E+03	f	1.3E+03	f	1.6E+02	c	1.3E+03	d	1.3E+03	f	1.3E+03	f	3.6E+02	a
Cs	1.4E+04	f	1.8E+04	d	2.3E+01	c	1.4E+04	d	1.8E+04	d	2.1E+02	c	2.1E+03	d
I	3.7E+01	f	3.9E+01	d	1.7E+01	c	3.7E+01	d	3.9E+01	d	1.3E+02	a	3.6E+01	d
Mo	1.1E+02	f	8.6E+01	d	4.5E-01	c	1.1E+02	d	8.6E+01	d	1.1E+02	f	1.3E+02	d
Nb	5.0E+01	f	3.1E+02	d	5.0E+01	f	5.0E+01	d	3.1E+02	d	5.0E+01	f	2.0E+03	d
Ni	3.2E+02	f	3.5E+02	d	3.2E+02	f	3.2E+02	d	3.5E+02	d	2.0E+04	c	5.7E+02	d
Np	2.0E+01	f	2.0E+01	f	9.5E+03	c	2.0E+01	b	2.0E+01	f	2.0E+01	f	7.2E+03	c
Pa	2.0E+01	f	2.0E+01	f	2.0E+01	f	2.0E+01	b	2.0E+01	f	2.0E+01	f	2.0E+01	f
Pb	1.1E+02	f	2.4E+02	d	2.2E+01	c	1.1E+02	d	2.4E+02	d	1.7E+01	c	4.4E+02	d
Pd	-	n	-	n	1.4E+00	e	1.2E-01	e	-	n	1.2E-01	f	1.1E+00	e
Po	3.6E+01	f	3.6E+01	f	3.6E+01	f	3.6E+01	c	3.6E+01	f	3.6E+01	f	2.5E+03	a
Pu	2.1E+04	f	2.1E+04	f	7.4E+03	c	2.1E+04	c	2.1E+04	f	2.1E+04	f	2.6E+04	c
Ra	3.0E+02	f	3.0E+02	f	1.0E+02	c	3.0E+02	d	3.0E+02	f	3.0E+02	f	2.6E+02	f
Rn	0.0E+00	o	0.0E+00	o	0.0E+00	o	0.0E+00	o	0.0E+00	o	0.0E+00	o	0.0E+00	o
Sb	5.5E+01	f	2.7E+01	d	2.1E+02	c	5.5E+01	d	2.7E+01	d	5.5E+01	f	2.2E+01	d
Se	2.1E+01	f	6.9E+00	d	5.7E+02	c	2.1E+01	d	6.9E+00	d	2.1E+01	f	1.0E+03	a
Sm	7.2E+01	f	7.2E+01	d	1.6E+03	c	1.1E+02	d	7.2E+01	d	7.2E+01	f	5.1E+02	d
Sn	1.1E+02	i	3.8E+01	d	2.2E+01	i	1.1E+02	i	3.8E+01	d	1.7E+01	i	2.9E+01	d
Tc	1.1E+01	f	2.6E+02	d	2.6E+01	c	1.1E+01	d	2.6E+02	d	1.1E+01	f	5.6E+00	d
Th	4.4E+02	f	7.6E+02	d	2.9E+03	c	4.4E+02	d	7.6E+02	d	4.4E+02	f	1.0E+03	d
U	5.4E+01	f	1.1E+01	d	1.7E+02	c	5.4E+01	d	1.1E+01	d	5.4E+01	f	2.1E+02	d
Zr	3.0E+02	f	2.7E+01	d	7.5E+01	a	3.0E+02	d	2.7E+01	d	3.0E+02	f	7.2E+01	d

a. ERICA Tool Database (Hosseini et al. 2008), b. ICRP (2009), c. IAEA (2010), d. Table A.13, e. Norden et al. (2010), f. same as fish, g. same as Th, h. same as Sb, i. Same as Pb, j. includes beaver, mink, moose and muskrat, k. includes lake trout and lake whitefish, l. includes mallard and red-throated loon, m. includes pondweeds and water sedge, n. no data available and o. Value is 0 because of short half-life.

3.3.2 Transfer Factors (TFs)

TFs were developed to describe the transfer of radionuclides to vertebrate animals (mammals and birds). Although a tissue/food CR model can be used for these animals, a key variable is the amount of contaminated food the animal consumes. To account for this, the TF is defined as the fraction of the daily intake of contaminant that is transferred to the tissue of concern. The units are time per mass (or volume) of tissue, usually d/kg. When multiplied by the contaminant intake per day as Bq/d, the result is contaminant per mass of tissue. The TF is also lognormally distributed, and shares the statistical characteristics described for the CR.

TFs used in this model for mammals and birds were calculated by dividing the tissue/food CRs for each representative biota by its ingestion rate, preferentially using data that are relevant to the Canadian environment. Tissue/food CRs that are derived using empirical data that are relevant to the Canadian environment are shown in Table A.14 and Table A.15. Tissue/food CRs tend to be relatively consistent among species (Sheppard *et al*. 2010a). Therefore, an assumption was made that the average of the CRs for mammals (rabbit, caribou, moose and white-tailed deer) could be used to represent the tissue/food CR values for those mammals where no CR values were available, i.e., the average CR was divided by the representative-biota-specific ingestion rates to give biota specific TFs until better data are available. Likewise, the tissue/food CRs for the Canada goose were assumed to be consistent with those of other representative birds (i.e., these CRs were divided by the representative-bird-species ingestion rates to give bird specific TFs).

TFs that were unavailable from empirical Canadian data were supplemented preferentially using CSA (2008) and then NCRP (1996) and Staven et al. (2003). The TFs in CSA (2008) are available for beef, poultry, rabbit and deer (among others), whereas NCRP (1996) contains TFs for beef and Staven et al. (2003) contains TFs for poultry, both for a large number of radionuclides. These were converted to TFs specific to the representative biota species in this report using the methodology shown below.

Using the ingestion rates published in CSA (2008) for all TFs originating from CSA (2008) and Staven et al. (2003) and the ingestion rate published in NCRP (1996) for all beef TFs originating from NCRP (1996), the TFs were converted to tissue/feed CRs ($CR^{i}_{feed/tissue}$, $kg^{feed}{}_{dw}/kg^{tissue}{}_{fw}$) using the following equation:

$$CR^{i}_{feed/tissue} = TF^{i}_{b,\ ref} \cdot I_{b,ref} \tag{3.1}$$

Where:

$TF^{i}_{b,\ ref}$ is the TF for each biota reported in CSA (2008), NCRP (1996) or Staven et al. (2003) (d/kg_{fw}); and

$I_{b,ref}$ is the ingestion rate of feed for each biota (kg_{dw}/d) reported in CSA (2008) or NRCP (1996).

These tissue/feed CRs are then converted back to a TF for representative biota (TF^{i}_{b}, y/kg_{fw}) by division with the ingestion rate (kg_{fw}/y) for each representative biota shown in Table 3.10, using the following equation:

$$TF_b^i = \frac{CR_{feed/tissue}^i}{f_{dw/fw} \cdot I_b} \tag{3.2}$$

$f_{dw/fw}$ is the dry/fresh weight ratio of food (kg_{dw}/kg_{fw}) reported in CSA (2008) or NRCP (1996); and

I_b is the ingestion rate shown in Table 3.10 (kgfw/y).

CSA (2008) beef values were used to describe wolf and foxes, poultry values were used to describe birds, rabbit values were used to describe all small mammals (burrowing, rodents, hares and rabbits) and deer values were used to described all ungulates. NCRP (1996) beef values were used to describe all mammals and Staven et al. (2003) poultry values were used to describe all birds.

The resulting TFs are shown inTable 3.6, where the Am, C, Cl, Np, Pa, Pu, Ra, Se, Sn, Tc and Th values were converted from CSA (2008) and Ac, Pd and Pu are from NCRP (1996) and Staven et al. (2003).

Table 3.6: Transfer Factors

	Arctic Fox	Arctic Ground Squirrel	Arctic Hare	Arctic Wolf	Barren-ground Caribou	Beaver	Brown Lemming	Brush Wolf	Canada Goose	Common Loon	Eastern Cottontail Rabbit	Gray Wolf	Great Horned Owl
						(y/kg$_{fw}$)							
Ac	2.3E-06	1.2E-05	3.1E-06	4.1E-07	1.9E-07	7.0E-07	7.6E-05	7.8E-07	9.5E-05	1.1E-05	1.5E-05	4.1E-07	2.2E-05
Am	1.1E-06	3.8E-05	1.0E-05	2.0E-07	3.1E-07	2.3E-06	2.5E-04	3.8E-07	1.9E-05	2.1E-06	4.8E-05	2.0E-07	4.3E-06
Bi	4.7E-03	2.4E-02	6.4E-03	8.5E-04	3.9E-04	1.5E-03	1.6E-01	1.6E-03	8.4E-04	9.4E-05	3.0E-02	8.5E-04	1.9E-04
C	6.0E-03	1.0E-01	2.7E-02	1.1E-03	8.4E-04	6.3E-03	6.8E-01	2.1E-03	1.4E-01	1.5E-02	1.3E-01	1.1E-03	3.1E-02
Ca	6.2E-05	3.1E-04	6.8E-05	1.1E-05	8.5E-06	1.9E-05	2.1E-03	2.1E-05	1.1E-03	1.2E-04	3.2E-04	1.1E-05	2.4E-04
Cl	7.6E-04	3.8E-03	1.0E-03	1.4E-04	6.2E-05	2.3E-04	2.5E-02	2.6E-04	2.8E-02	3.1E-03	4.9E-03	1.4E-04	6.3E-03
Cs	1.2E-02	6.1E-02	3.0E-03	2.2E-03	2.5E-03	3.8E-03	4.1E-01	4.2E-03	2.4E-03	2.7E-04	1.4E-02	2.2E-03	5.5E-04
I	3.5E-04	1.7E-03	1.4E-04	5.2E-05	8.1E-06	9.0E-05	9.8E-03	1.0E-04	2.3E-02	2.6E-03	6.9E-04	5.2E-05	5.3E-03
Mo	1.1E-04	5.7E-04	6.2E-05	2.0E-05	1.3E-05	3.5E-05	3.8E-03	3.9E-05	4.4E-04	4.9E-05	3.0E-04	2.0E-05	9.9E-05
Nb	2.9E-04	1.5E-03	4.0E-04	5.3E-05	9.5E-07	9.1E-05	9.8E-03	1.0E-04	1.9E-04	2.1E-05	1.9E-03	5.3E-05	4.3E-05
Ni	7.9E-04	4.0E-03	1.1E-03	1.4E-04	6.5E-05	2.4E-04	2.7E-02	2.7E-04	1.3E-04	1.4E-05	5.1E-03	1.4E-04	2.9E-05
Np	2.6E-05	1.0E-04	2.7E-05	4.7E-06	8.4E-07	6.3E-06	6.8E-04	8.9E-06	4.9E-05	5.5E-06	1.3E-04	4.7E-06	1.1E-05
Pa	7.5E-07	1.6E-05	4.3E-06	1.4E-07	1.3E-07	9.8E-07	1.1E-04	2.6E-07	3.2E-05	3.5E-06	2.0E-05	1.4E-07	7.2E-06
Pb	4.3E-02	2.2E-01	9.6E-05	7.8E-03	3.6E-03	1.3E-02	1.5E+00	1.5E-02	3.9E-04	4.4E-05	4.6E-04	7.8E-03	8.9E-05
Pd	2.3E-05	1.2E-04	3.1E-05	4.0E-06	1.9E-06	7.1E-06	7.4E-04	8.0E-06	4.8E-06	5.2E-07	1.5E-04	4.0E-06	1.1E-06
Po	5.7E-04	2.9E-03	7.7E-04	1.0E-04	4.7E-05	1.8E-04	1.9E-02	2.0E-04	3.7E-02	4.1E-03	3.7E-03	1.0E-04	8.3E-03
Pu	1.4E-06	4.0E-05	1.1E-05	2.6E-07	3.4E-07	2.5E-06	2.7E-04	4.9E-07	1.5E-05	1.6E-06	5.1E-05	2.6E-07	3.3E-06
Ra	6.5E-05	7.6E-04	2.0E-04	1.2E-05	6.2E-06	4.6E-05	5.0E-03	2.2E-05	4.8E-04	5.3E-05	9.6E-04	1.2E-05	1.1E-04
Rn	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sb	1.3E-03	6.7E-03	1.8E-03	2.4E-04	8.7E-06	4.1E-04	4.5E-02	4.6E-04	1.5E-03	1.7E-04	8.5E-03	2.4E-04	3.4E-04
Se	6.7E-03	3.4E-02	9.2E-03	1.2E-03	8.2E-04	2.1E-03	2.2E-01	2.3E-03	1.4E-01	1.6E-02	4.4E-02	1.2E-03	3.3E-02
Sm	8.8E-05	4.6E-04	1.1E-05	1.5E-05	7.4E-08	2.8E-05	2.9E-03	3.1E-05	2.2E-04	2.5E-05	5.0E-05	1.5E-05	5.1E-05
Sn	7.5E-04	3.2E-03	8.6E-04	1.4E-04	2.7E-05	2.0E-04	2.1E-02	2.6E-04	2.7E-03	3.0E-04	4.1E-03	1.4E-04	6.1E-04
Tc	6.5E-05	5.6E-04	1.5E-04	1.2E-05	4.6E-06	3.4E-05	3.7E-03	2.3E-05	6.5E-03	7.3E-04	7.2E-04	1.2E-05	1.5E-03
Th	8.2E-06	3.2E-04	8.6E-05	1.5E-06	2.7E-06	2.0E-05	2.1E-03	2.8E-06	2.1E-04	2.3E-05	4.1E-04	1.5E-06	4.7E-05
U	8.5E-05	4.3E-04	4.7E-06	1.5E-05	1.6E-06	2.6E-05	2.9E-03	2.9E-05	1.1E-04	1.2E-05	2.2E-05	1.5E-05	2.4E-05
Zr	7.5E-05	3.8E-04	1.9E-04	1.3E-05	4.8E-07	2.3E-05	2.5E-03	2.6E-05	1.2E-04	1.4E-05	9.2E-04	1.3E-05	2.8E-05

Based Canadian Empirical data in Appendix A.3	Based on CSA (2008)	Based on NCRP (1996)	Based on Staven et al. (2003)

Table 3.6: Transfer Factors (Cont)

	Ground-hog	Mallard	Meadow vole	Mink	Moose	Muskrat	Red Fox	Red-throated Loon	Ruffed Grouse	Snowshoe Hare	White Tailed Deer	Willow Ptarmigan
	(y/kg$_{fw}$)											
Ac	3.9E-06	2.5E-05	2.4E-04	1.1E-05	1.7E-07	1.1E-05	5.1E-06	1.1E-05	4.4E-05	7.3E-06	2.0E-06	3.8E-05
Am	1.3E-05	4.9E-06	8.0E-04	3.5E-05	2.8E-07	3.7E-05	2.4E-06	2.1E-06	8.9E-06	2.4E-05	3.3E-06	7.7E-06
Bi	8.1E-03	2.2E-04	5.0E-01	2.2E-02	3.5E-04	2.4E-02	1.1E-02	9.4E-05	3.9E-04	1.5E-02	4.2E-03	3.4E-04
C	3.5E-02	3.5E-02	2.2E+00	9.3E-02	7.6E-04	1.0E-01	1.3E-02	1.5E-02	6.3E-02	6.5E-02	8.9E-03	5.4E-02
Ca	1.1E-04	2.7E-04	6.6E-03	2.8E-04	4.8E-06	3.1E-04	1.4E-04	1.2E-04	5.0E-04	1.6E-04	2.5E-05	4.3E-04
Cl	1.3E-03	7.2E-03	8.1E-02	3.5E-03	5.7E-05	3.8E-03	1.7E-03	3.1E-03	1.3E-02	2.4E-03	6.6E-04	1.1E-02
Cs	2.1E-02	6.2E-04	1.3E+00	5.6E-02	8.8E-04	6.1E-02	2.7E-02	2.7E-04	1.1E-03	7.0E-03	4.4E-03	9.7E-04
I	5.0E-04	6.0E-03	3.1E-02	1.3E-03	6.2E-05	1.5E-03	6.5E-04	2.6E-03	1.1E-02	3.4E-04	1.1E-04	9.3E-03
Mo	1.9E-04	1.1E-04	1.2E-02	5.2E-04	1.4E-05	5.6E-04	2.5E-04	4.9E-05	2.0E-04	1.5E-04	5.6E-05	1.8E-04
Nb	5.0E-04	4.9E-05	3.1E-02	1.4E-03	5.1E-05	1.5E-03	6.5E-04	2.1E-05	8.9E-05	9.4E-04	1.6E-04	7.7E-05
Ni	1.4E-03	3.3E-05	8.4E-02	3.6E-03	7.2E-05	3.9E-03	1.8E-03	1.4E-05	6.0E-05	2.5E-03	5.4E-04	5.2E-05
Np	3.5E-05	1.3E-05	2.2E-03	9.3E-05	7.6E-07	1.0E-04	5.8E-05	5.5E-06	2.3E-05	6.5E-05	8.9E-06	2.0E-05
Pa	5.4E-06	8.2E-06	3.4E-04	1.5E-05	1.2E-07	1.6E-05	1.7E-06	3.5E-06	1.5E-05	1.0E-05	1.4E-06	1.3E-05
Pb	7.4E-02	1.0E-04	4.6E+00	2.0E-01	9.6E-03	2.2E-01	9.6E-02	4.4E-05	1.8E-04	2.3E-04	5.7E-04	1.6E-04
Pd	3.8E-05	1.2E-06	2.4E-03	1.0E-04	1.7E-06	1.1E-04	5.2E-05	5.2E-07	2.2E-06	7.4E-05	2.0E-05	1.9E-06
Po	9.7E-04	9.4E-03	6.1E-02	2.6E-03	4.3E-05	2.8E-03	1.3E-03	4.1E-03	1.7E-02	1.8E-03	5.0E-04	1.5E-02
Pu	1.4E-05	3.8E-06	8.5E-04	3.7E-05	3.1E-07	4.0E-05	3.2E-06	1.6E-06	6.8E-06	2.5E-05	3.6E-06	5.9E-06
Ra	2.6E-04	1.2E-04	1.6E-02	6.9E-04	5.7E-06	7.5E-04	1.4E-04	5.3E-05	2.2E-04	4.8E-04	6.6E-05	1.9E-04
Rn	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sb	2.3E-03	3.9E-04	1.4E-01	6.1E-03	1.8E-04	6.6E-03	3.0E-03	1.7E-04	7.0E-04	4.3E-03	1.3E-03	6.0E-04
Se	1.1E-02	3.7E-02	7.1E-01	3.1E-02	4.6E-04	3.3E-02	1.5E-02	1.6E-02	6.7E-02	2.2E-02	3.3E-03	5.8E-02
Sm	1.5E-04	5.6E-05	9.3E-03	4.0E-04	1.5E-05	4.2E-04	2.0E-04	2.5E-05	1.0E-04	2.6E-05	1.2E-04	9.0E-05
Sn	1.1E-03	6.9E-04	6.8E-02	2.9E-03	2.5E-05	3.7E-03	1.7E-03	3.0E-04	1.3E-03	2.0E-03	2.9E-04	1.1E-03
Tc	1.9E-04	1.7E-03	1.2E-02	5.1E-04	4.2E-06	5.5E-04	1.5E-04	7.3E-04	3.0E-03	3.6E-04	4.9E-05	2.6E-03
Th	1.1E-04	5.3E-05	6.8E-03	2.9E-04	2.5E-06	3.2E-04	1.8E-05	2.3E-05	9.5E-05	2.0E-04	2.9E-05	8.2E-05
U	1.5E-04	2.7E-05	9.0E-03	3.9E-04	6.3E-06	4.2E-04	1.9E-04	1.2E-05	4.9E-05	1.1E-05	2.0E-04	4.3E-05
Zr	1.3E-04	3.1E-05	8.0E-03	3.5E-04	5.6E-06	3.7E-04	1.7E-04	1.4E-05	5.7E-05	4.6E-04	6.6E-05	4.9E-05

Based Canadian Empirical data in Appendix A.3	Based on CSA (2008)	Based on NCRP (1996)	Based on Staven et al. (2003)

3.4 FOOD FRACTIONS

Food fractions are used with TFs to estimate radionuclide transfer to mammals and birds as a result of various components of their diets. Given that there is no exact set of specific food fractions, the food fractions used in this model are based mainly on expert opinion and data on diet compositions of various organism from accounts in Burt and Grossenheider (1976), Banfield (1974), US EPA (1993), Sample and Suter (1994), etc.

Table 3.7 gives the assumed food fractions.

Table 3.7: Food Fractions

Consuming↓ / Consumed→	Arctic Ground Squirrel	Arctic Hare	Barren-ground Caribou	Berries	Brown Lemming	Canada Goose	Canada Goose (Tundra)	Chironomid Larvae	Dwarf Arctic Willow	Earthworm	Eastern Cottontail Rabbit	Lake Trout	Lake Whitefish	Lichen	Mallard	Meadow Vole	Moose	Muskrat	Northern Leopard Frog	Pondweeds	Ruffed Grouse	Sedge Species	Water Sedge	White Cedar	White Tailed Deer	Willow Ptarmigan	Reference
Arctic Fox		0.4			0.4		0.1																			0.1	CWS (1990a)
Arctic Ground Squirrel				0.1	0.1				0.4													0.4					ADW(Lutz, 2000)
Arctic Hare				0.1					0.45													0.45					ADW (Betzler, B. 2011)
Arctic Wolf			1																								Wilson and Ruff (1999)
Barren-Ground Caribou									0.3					0.4								0.3					CWS (2005b)
Beaver																				0.15		0.35	0.15	0.35			CWS (2005a)
Brown Lemming									0.5													0.5					ADW (Barker, 2003)
Brush Wolf											0.3					0.2					0.1				0.4		CWS (1990c)
Canada Goose																				0.1		0.4	0.1	0.4			US EPA (1993)
Canada Goose (Tundra)									0.4											0.1		0.4	0.1				US EPA (1993)
Common Loon								0.2				0.4	0.4														CWS (1994a)
Eastern Cottontail Rabbit																						0.5		0.5			US EPA (1993)
Gray Wolf											0.1						0.4				0.1				0.4		CWS (1993b)
Great Horned Owl						0.2					0.2					0.2					0.4						CWS (1991a)
Great Horned Owl (Tundra)	0.25	0.3			0.25																					0.2	CWS (1991a)
Groundhog																						0.5		0.5			CWS(1991b)
Mallard								0.4												0.3			0.3				CWS (1996)
Meadow Vole																						0.5		0.5			ADW (Neuburger, 1999)
Mink								0.2				0.15	0.15		0.1			0.3	0.1								US EPA (2012)
Moose																				0.1		0.4	0.1	0.4			CWS (1997)
Muskrat																				0.35		0.15	0.35	0.15			CWS (1987)
Red Fox											0.4					0.3					0.2	0.05		0.05			US EPA (1993)
Red-throated Loon								0.2				0.4	0.4														CWS (1994a)
Ruffed Grouse				0.1																		0.45		0.45			CWS (1986)
Snowshoe Hare																						0.5		0.5			CWS (2005c)
White-tailed Deer				0.1																		0.45		0.45			CWS (1990b)
Willow Ptarmigan				0.1					0.4	0.1												0.4					CWS (1994b)

3.5 INGESTION RATE

Ingestion rates are only required in the TF approach and only for mammals and birds. Food and water ingestion rates are allometrically scaled from the mass of the organisms using the equation proposed by the US EPA (1993), unless otherwise specified. The equations that were used are as follows:

$$FI_{bird} = 0.648 \cdot (M_b)^{0.651} \tag{3.3}$$

$$FI_{mammal} = 0.235 \cdot (M_b)^{0.822} \tag{3.4}$$

$$WI_{bird} = 0.059 \cdot (M_b)^{0.67} \tag{3.5}$$

$$WI_{mammal} = 0.099 \cdot (M_b)^{0.90} \tag{3.6}$$

Where:

FI_{bird} is the food ingestion rate for birds (g_{dw}/d);
FI_{mammal} is the food ingestion rate for mammals (g_{dw}/d);
WI_{bird} is the water ingestion rate for birds (L/d);
WI_{mammal} is the water ingestion rate for mammals (L/d); and
M_b is the mass of the biota (g).

These food ingestion rates are expressed on a dry weight basis, but must be converted to a fresh weight basis for compatibility with calculated tissue concentration of food items, which are expressed on a fresh weight basis. These are converted using dry/fresh weight ratios for consumed foods for each biota. The dry/fresh weight ratios used in this analysis were calculated using a weighted average of the dry/fresh weight ratios of meat (0.30), poultry (0.30), fish (0.25), berries (0.16), terrestrial plants (0.19) and aquatic plants (0.10) from CSA (2008). Weighting corresponds to the food fractions shown in
Table 3.7. Calculated dry/fresh ratios are shown in Table 3.8.

Table 3.8: Dry/fresh Weight Ratio for the Foods Consumed by Representative Biota

Representative Biota	Ratio (kg_{dw}/kg_{fw})	Representative Biota	Ratio (kg_{dw}/kg_{fw})
Arctic Fox	0.30	Great Horned Owl (Tundra)	0.29
Arctic Ground Squirrel	0.20	Groundhog	0.19
Arctic Hare	0.19	Mallard	0.18
Arctic Wolf	0.30	Meadow Vole	0.19
Barren-Ground Caribou	0.19	Mink	0.29
Beaver	0.16	Moose	0.17
Brown Lemming	0.19	Muskrat	0.13
Brush Wolf	0.30	Red Fox	0.29
Canada Goose	0.17	Red-Throated Loon	0.26
Common Loon	0.26	Ruffed Grouse	0.19
Eastern Cottontail Rabbit	0.19	Snowshoe Hare	0.19
Gray Wolf	0.30	White-Tailed Deer	0.19
Great Horned Owl	0.30	Willow Ptarmigan	0.20

Soil and sediment ingestion rates are based on the fractional composition of soil/sediment in the diet given by Beyer et al. (1994). In the absence of data for a particular organism, data from the most similar organism from Beyer et al. (1994) was used.

The fraction of soil/sediment in the diet as well as the species from Beyer et al. (1994) selected to represent each species is shown in Table 3.9.

Table 3.9: Fractional Composition of Soil and Sediment in Diet on a Dry Weight Basis

Representative Biota	Fraction of Soil/Sediment in diet[a]	Biota from Beyer et al. (1994)
Arctic Fox	0.028	Red Fox
Arctic Ground Squirrel	0.054	Average for prairie dogs
Arctic Hare	0.063	Eastern Cottontail Rabbit
Arctic Wolf	0.028	Red Fox
Barren-Ground Caribou	0.05	Average for all mammals
Beaver	0.05	Average for all mammals
Brown Lemming	0.024	Meadow Vole
Brush Wolf	0.028	Red Fox
Canada Goose	0.082	Canada Goose
Common Loon	0.02	Ring-Necked Blue Bird
Eastern Cottontail Rabbit[b]	0.063	Eastern Cottontail Rabbit
Gray Wolf	0.028	Red Fox
Great Horned Owl	0.05	Non soil/sediment dwelling birds
Groundhog	0.02	Woodchuck
Mallard	0.033	Mallard
Meadow Vole	0.024	Meadow Vole
Mink	0.05	Average for mammals
Moose	0.02	Moose
Muskrat	0.05	Average for mammals
Red Fox	0.028	Red Fox
Red-Throated Loon	0.02	Ring-Necked Blue Bird
Ruffed Grouse	0.099	Average of Woodcock and Turkey
Snowshoe Hare	0.063	Eastern Cottontail Rabbit
White-Tailed Deer	0.02	White-Tailed Deer
Willow Ptarmigan	0.099	Average of Woodcock And Turkey

[a] Only the beaver, mallard, merganser, mink, moose, muskrat and red-throated loon are assumed to consume sediment. All other species consume soil.
[b] from Sample and Suter (1994). Note that values in Sample and Suter (1994) are expressed as dry weight soil/sediment as a fraction of fresh weight food. However, these, original reference (Arthur and Gates, 1988) uses units and values consistent with what is presented above.

Because the fractional composition of the diet is given on a dry weight basis in Beyer et al. (1994), the daily soil/ingestion is calculated by multiplying the fractional diet composition by the daily intake of dry weight food, the latter computed from moisture content data in Table 3.8.

Table 3.10: Ingestion Rates

Representative Biota	Food (kg $_{fw}$/y)	Ref	Water (L/y)	Ref	Soil (kg$_{dw}$/y)	Sediment (kg$_{dw}$/y)	Ref
Arctic Fox	350	a	170	a	2.9		c
Arctic Ground Squirrel	100	a	30	a	1		c
Arctic Hare	410	a	130	a	4.9		d
Arctic Wolf	2000	a	1100	a	17		c
Barren-Ground Caribou	6800	a	2700	a	65		c
Beaver	2100	a	630	a		17	c
Brown Lemming	17	a	3.7	a	0.08		c
Brush Wolf	1000	a	560	a	9		
Canada Goose	37	b	52	b	0.5		c
Common Loon	220	a	59	a		1.1	c
Eastern Cotton-tail Rabbit	87	d	43	a, b	1		d
Gray Wolf	2000	a	1100	a	17		c
Great Horned Owl	92	a	28	a	1.4		c
Great Horned Owl (Tundra)	95	a	28	a	1.4		c
Groundhog	330	a	97	a	1.2		c
Mallard	140	a	44	a		0.8	c
Meadow Vole	5.2	b	2.8	b	0.02		c
Mink	80	b	36	a, d		1.1	c
Moose	8200	e	8500	a		28	c
Muskrat	170	a	36	a		1.1	c
Red Fox	160	d	140	a, d	1.3		c
Red throated Loon	220	a	59	a		1.1	c
Ruffled Grouse	71	a	14	a	1.3		c
Snowshoe Hare	170	a	49	a	2		d
White-tailed Deer	640	d	1900	a	2.4		c, d
Willow Ptarmigan	78	a	16	a	1.5		c

a. US EPA (1993) using allometric scaling from mass
b. US EPA (1993)
c. Beyer et al. (1994)
d. Sample and Suter (1994)
e. CWS (1997)

3.6 RELATIVE BIOLOGICAL EFFECTIVENESS (RBE)

The extent and type of damage from radiation exposure depends, in part, on the type of radiation. In the human dosimetric model, a radiation weighting factor that compares the effectiveness of different types of radiation (alpha, beta and gamma) to the effectiveness of irradiation with 300 keV photons has been defined as the Relative Biological Effectiveness (RBE). The product of the RBE and the absorbed dose in humans results in the equivalent dose.

However, the concept of equivalent dose has to be modified before it can be applied to non-human biota. The current RBEs applied for humans focus on stochastic effects, while current research on effects to non-human biota are focused on deterministic effects (e.g. morbidity, mortality, mutations etc.). Therefore, although RBEs are well defined for the protection of humans from radiation, there is no similar consensus on the values for the protection of non-human biota.

Despite the lack of well-defined RBEs for non-human biota, Table 3.11 summarises the RBEs that are selected for the model, based the best available knowledge in the references shown.

Table 3.11: Relative Biological Effectiveness

Radiation Type	Value	Reference
Alpha	10	UNSCEAR (2008), ERICA (Brown et al. 2008), CSA (2012)
Beta/gamma	1	UNSCEAR (2008), ERICA (Brown et al. 2008), CSA (2012)
Low Beta	2	CNSC (2010), CSA (2012)*

*RBE for Tritium

3.7 SOIL AND SEDIMENT DRY/WET WEIGHT CONVERSION FACTORS

The dry/wet weight conversion factors for soil and sediment are required for estimating the total dose rate via the dose conversion factors, which are expressed on a wet weight basis. Because soil and sediment activity concentrations are measured on a dry weight basis, a conversion is required.

Dry weight/wet weight conversion factors are given for organic soil and organic sediment, since the scenario is for a deep groundwater discharge to the biosphere, where the soils and sediment will most likely be organic. For the model, the assumed dry/wet weight conversion factors for organic soil is 0.8 kg_{dw}/kg_{fw} (CSA 2008).

Surface profundal sediments of lakes are usually high in water content and generally about 90% water in the top 5 cm of sediment. Sediment moisture contents in littoral sediments from three Canadian Shield lakes were used in the Environment Canada and Health Canada PSL2 assessment (EC/HC 2003) for default values where no data were available. The moisture contents had a mean of 93% by mass for the top 1-cm slice, 90% for the top 2-cm slices, 87% for the top 3-cm, and 83% for the top 5-cm of sediment. These values are reasonable default values for sediment moisture for littoral sediments close to shore where waterfowl and wildlife are more likely to be exposed to lake sediments. However, it must be recognized that the moisture content of sediment is extremely variable with sediment type, ranging from nearly 0% by weight for rock to almost 100% for very flocculent sediment.

In the modelling of a generic Canadian lake, uniform sediment conditions are generally assumed throughout the lake. For such a simulation a dry/wet weight conversion factor for organic sediment of 0.9 kg_{dw}/kg_{fw} has been selected as the default value.

3.8 OCCUPANCY FACTORS

MOF and AOF are found in Table 3.12. Assumptions regarding the occupancy factors are found in Table 3.13.

Table 3.12: Media and Area Occupancy Factors

Representative Biota	MOF				AOF
	In Soil	On Soil	Water	Sediment Surface	
Arctic Fox	0.2	0.8			1
Arctic Ground Squirrel	0.6	0.4			1
Arctic Hare		1			1
Arctic Wolf	0.25	0.75			0.5
Barren-Ground Caribou		1			0.5
Beaver		0.5	0.5		1
Berries		1			1
Brown Lemming	0.6	0.4			1
Brush Wolf	0.25	0.75			0.25
Canada Goose		0.5	0.5		0.5
Chironomid Larvae				1	1
Common Garter Snake	0.5	0.5			1
Common Loon			1		0.5
Dwarf (Arctic) Willow		1			1
Earthworm	1				1
Eastern Cottontail Rabbit		1			1
Gray Wolf	0.25	0.75			0.25
Great Horned Owl		1			1
Groundhog	0.6	0.4			1
Lake Trout			0.9	0.1	1
Lake Whitefish			0.1	0.9	1
Lichens		1			1
Mallard			1		0.5
Meadow Vole		1			1
Mink		0.5	0.5		1
Moose		0.8	0.2		1
Muskrat		0.5	0.5		1
Northern Leopard Frog			0.5	0.5	1
Pondweeds				1	1
Red Fox	0.2	0.8			1
Red-Throated Loon			1		0.5
Ruffed Grouse		1			1
Sedges Species		1			1
Snowshoe Hare		1			1
Water Sedge				1	1
White Cedar		1			1
White-Tailed Deer		1			1
Willow Ptarmigan		1			1

Table 3.13: Assumptions for Occupancy Factors

VEC	MOF Assumptions	AOF Assumptions
Amphibian	Assumed to spend half its time swimming in water and other half of its time at sediment surface [MOF(water)=0.5 and MOF(sediment surface)=0.5]	Not migratory out of the assessment area, for maximum exposure [AOF=1].
Aquatic Bird	Conservatively assumed to be immersed in water at all times [MOF(water)=1] Assume Canada goose spends half its time in the water surface and half its time on land [MOF(water)=0.5 and MOF(on soil)=0.5]	Aquatic Birds are migratory birds and spend half their time away from the assessment area [AOF=0.5].
Aquatic Mammal	Assume beaver, muskrat and mink spend half their time in water and half their time on land [MOF(on soil) =0.5, MOF(water)=0.5].	Not migratory out of the assessment area, for maximum exposure [AOF=1].
Aquatic Plant	Exposed at the sediment/water interface [MOF(sediment surface)=1]	Unable to migrate [AOF=1].
Benthic Invertebrate	Assumes that they live at the sediment surface [MOF(sediment surface)=1]	Small range, no migration [AOF=1].
Fish	To represent a range of exposures, benthic fish are assumed to occupy the bottom waters (sediment surface) 90% of the time and the water column 10% of the time, whereas pelagic fish occupy the water column 90% of the time and the bottom waters 10% of the time. Thus, for benthic fish, MOF[water]=0.1 and MOF[sediment surface]=0.9 and for pelagic fish, MOF[water]=0.9 and MOF[sediment surface]=0.1.	Conservatively assume that the representative fish are not migratory.
Reptile	Common garter snake spends half the year in hibernation [MOF(in soil) =0.5 and MOF(on soil)=0.5]	Small range, no migration out of the assessment area [AOF=1]
Terrestrial Bird	Assumed to live on soil where they would receive maximum exposure. [MOF(soil)=1	Terrestrial birds assumed to not be migratory [AOF=1].
Terrestrial Invertebrate	Live in soil [MOF(in soil)=1].	Small range, no migration [AOF=1].
Terrestrial Mammal	Assume terrestrial mammals live on the soil [MOF(on soil)=1]. With the following exceptions: • Foxes, which rears its young in dens, spend some time in the soil and most of their time on the soil [MOF(in soil)=0.2 and MOF(on soil)=0.8]. • Small burrowing mammals spend slightly more time in their burrows than at the surface [MOF(in soil)=0.6 and MOF(on soil)=0.4]. • Brown lemmings live in colonies and breed below the surface [MOF(in soil)=0.6 and MOF(on soil)=0.4] • Wolves spend some time in soil, because some have dens [MOF(in soil)=0.25 and MOF(0.75)]. • Moose spends 20% of the time in the water and 80% of the time on the land. [MOF(water)=0.2 and MOF(on soil)= 0.8]	Because of huge range, gray wolf and brush wolf are assumed to spend only 25% of time in area [AOF=0.25]. Similar assumptions for barren-ground caribou, who is in the area 50% of time [AOF=0.5]. Arctic Wolf was assumed to spend the same fraction of time in the area as its prey [AOF=0.5] All other mammals spend 100% of time in area [AOF=1].
Terrestrial Plant	Live on soil [MOF(on soil)=1]	Unable to migrate [AOF=1].

3.9 DOSE CONVERSION COEFFICIENTS (DCCS)

The ERICA Tool uses the calculation methods described by Ulanovsky and Pröhl (2006) and Ulanovsky et al. (2008) to calculate DCCs for a suite of reference organisms and default radionuclides. The tool also calculates DCCs for user-defined organisms (within certain mass limits) and for most radionuclides included in ICRP Publication 38 (ICRP 1983). The DCCs used in this assessment are those generated by the ERICA Tool with the masses and dimensions of the representative biota.

The ERICA tool generates separate DCCs for the low beta, beta-gamma and alpha components and for the following exposure geometries:

- Internal; and
- External in soil, on soil, in water and in air.

In this model, it is assumed that no organism receives a dose from immersion in air, thus the external DCCs in air are not used. Further details about the assumed exposure situations are shown in the ERICA Help function (ERICA 2011).

3.10 ORGANISM MASSES AND DIMENSIONS

In order to generate the DCCs, ERICA requires the mass, length, width and height of all organisms. The following assumptions were made in order to determine these parameters:

- All organisms have the density of water (1000 kg/m^3);
- All organisms have the shape of an ellipsoid; and
- The relative dimensions of each organisms are based on the most appropriate reference organisms from ICRP (2008) or FASSET (Pröhl et al. 2003);

The parameter that is more commonly measured for each organism (the mass or length) was obtained from literature. If a range of values was reported in the literature, an average value was used.

Using the relationship between the volume of an ellipsoid, the mass, the density, the relative dimensions of the representative biota and the mass or length obtained from literature, the remaining parameters were calculated.

Some organism dimensions and masses were adopted directly from ICRP (2008) and FASSET (Pröhl et al. 2003). These are:

- Chironomid larvae (FASSET freshwater insect larvae)
- Lichen (ICRP Bryophyte)
- Earthworm (ICRP Earthworm)

The relative dimensions of each organism are given in Table 3.14, and are based on FASSET (Pröhl et al. 2003) and ICRP (2008).

Table 3.14: Body Shape Proportions from FASSET and ICRP

Source and Body Type	Length	Width	Height
FASSET Insect Larvae	1	0.100	0.100
FASSET Snake	1	0.030	0.030
FASSET Vascular Plant	1	0.002	0.002
ICRP Bryophyte	1	0.056	0.056
ICRP Deer	1	0.462	0.462
ICRP Duck	1	0.333	0.267
ICRP Earthworm	1	0.100	0.100
ICRP Frog	1	0.375	0.313
ICRP Grass	1	0.200	0.200
ICRP Pine Tree	1	0.030	0.030
ICRP Rat	1	0.300	0.250
ICRP Trout	1	0.160	0.120

Table 3.15: Organism Masses and Dimensions

Selected Species	Mass (kg)	Length (m)	Width (m)	Height (m)	Relative Dimensions of:	Reference for Mass/Length
Arctic Fox	**5.8**	0.37	0.17	0.17	ICRP Deer	CWS (1990a)
Arctic Ground Squirrel	**0.80**	0.27	0.082	0.068	ICRP Rat	ADW (Lutz 2000)
Arctic Hare	**4.0**	0.47	0.14	0.12	ICRP Rat	ADW (Betzler 2011)
Arctic Wolf	**50***	0.76	0.35	0.35	ICRP Deer	Blix (2005)
Barren-Ground Caribou	**120**	1.0	0.47	0.47	ICRP Deer	NTENR (2013)
Beaver	**24**	0.85	0.25	0.21	ICRP Rat	CWS (2005a)
Berries	5.0×10^{-4}	0.010	0.010	0.010	Spherical, diameter=1cm	-
Brown Lemming	**0.080**	0.13	0.038	0.032	ICRP Rat	ADW (Barker 2003)
Brush Wolf	**21***	0.57	0.26	0.26	ICRP Deer	ADW (Tokar 2001)
Canada Goose	**3.2**	0.41	0.14	0.11	ICRP Duck	US EPA (1993)
Common Loon	**4.5**	0.46	0.15	0.12	ICRP Duck	CWS (1994a)
Chironomid Larvae	4.2×10^{-5}	**0.020**	0.0020	0.0020	FASSET Insect Larvae	Pröhl et al. (2003)
Common Garter Snake	0.37	**0.92**	0.028	0.028	FASSET Snake	ADW (Zimmerman 2002)
Dwarf (Arctic) Willow	4.4	**2.1**	0.063	0.063	ICRP Pine Tree	USDA (2002)
Earthworm	**0.0050**	0.098	0.0098	0.0098	ICRP Earthworm	ICRP (2008)
Eastern Cottontail Rabbit	**1.2**	0.31	0.094	0.078	ICRP Rat	US EPA (1993)
Gray Wolf	**49***	0.76	0.35	0.35	ICRP Deer	NWF (2014)
Great Horned Owl	**1.5**	0.32	0.11	0.085	ICRP Duck	CWS (1991a)
Groundhog	**3.0**	0.42	0.13	0.11	ICRP Rat	CWS (1991b)
Lake Trout	0.80	**0.43**	0.069	0.052	ICRP Trout	Scott and Crossman (1998)
Lake Whitefish	0.55	**0.38**	0.061	0.046	ICRP Trout	Scott and Crossman (1998)
Lichen	$\mathbf{1.1\times10^{-4}}$	0.041	0.0023	0.0023	ICRP Bryophyte	ICRP (2008)
Mallard	**1.2**	0.30	0.098	0.079	ICRP Duck	CWS (1996)
Meadow Vole	**0.04**	0.10	0.030	0.025	ICRP Rat	Sample and Suter (1994)
Mink	**1.0**	0.29	0.088	0.074	ICRP Rat	Sample and Suter (1994)
Moose	**440**	1.6	0.73	0.73	ICRP Deer	Bowers et al. 2004
Muskrat	**1.0**	0.29	0.088	0.074	ICRP Rat	CWS (1987)
Northern Leopard Frog	0.031	**0.080**	0.030	0.025	ICRP Frog	BC MWLAP (2011)
Pondweeds	2.6×10^{-4}	**0.50**	0.0010	0.0010	FASSET Vascular Plant	Newmaster et al. (1997)
Red Fox	**4.5**	0.34	0.16	0.16	ICRP Deer	US EPA (1993)
Red-Throated Loon	**4.5**	0.46	0.15	0.12	ICRP Duck	CWS (1994a)
Ruffed Grouse	**0.50**	0.22	0.073	0.059	ICRP Duck	CWS (1986)
Sedge Species	1.9	**0.45**	0.090	0.090	ICRP Grass	Craighead (1991)
Snowshoe Hare	**1.4**	0.33	0.099	0.082	ICRP Rat	CWS (2005c)
Water Sedge	4.1×10^{-4}	**0.58**	0.0012	0.0012	FASSET Vascular Plant	Tilley et al. (2011)
White Cedar	1600*	**15**	0.45	0.45	ICRP Pine Tree	Farrar (2005)
White Tailed Deer	**80**	0.89	0.41	0.41	ICRP Deer	Bowers et al. 2004
Willow Ptarmigan	**0.63**	0.24	0.079	0.064	ICRP Duck	CWS (1994b)

*The ERICA limits the size of mammals that spend time in soil to 6.6 kg and the size of terrestrial plants to 1000 kg. Therefore, for the derivation of DCCs using the ERICA Tool, the maximum allowable masses were used.

4. SUMMARY

This report provides the reference equations and biota data that could be used to model the potential post-closure radiological impact of a deep geological repository to non-human biota. The output of the assessment method is the dose rate based on initial media concentrations of soil, water, sediment and air (for C-14 only) for a list of selected species in three relevant Canadian ecosystems.

5. LIST OF ACRONYMS

AOF	Area Occupancy Factor
BF	Boreal Forest
CR	Concentration Ratio
CSA	Canadian Standards Association
DCC	Dose Conversion Coefficient
DW	Dry Weight
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management
FASSET	Framework for ASSessment of Environmental ImpacT
FW	Fresh Weight
GM	Geometric Mean
GSD	Geometric Standard Deviation
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IT	Inland Tundra
Kd	Sediment-Water Distribution Coefficient
MOF	Media Occupancy factor
NCRP	National Council on Radiation Protection & Measurement
NEC	No-Effect Concentrations
RBE	Relative Biological Effectiveness
SCDF	Southern Canadian Deciduous Forest
TF	Transfer Factor

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APPENDIX A: CALCULATION OF CONCENTRATION RATIOS

CONTENTS

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A.1 INTRODUCTION

CRs and TFs that are based on empirical data from the Canadian environment have been preferentially used for this application. In many cases, the CRs were taken directly from published references. However, many other values that were used are not specifically traceable to these reports. This is usually because the cited reports averaged elements, sites or species in a different way than required for this model. However, the original data used to produce the values shown in the published references were available to the NWMO. Since the sampling and analysis methods are described in detail in the published reports, the data have been reused to generate the radionuclide and biota specific values that are required.

Detailed computations that were done to derive the values used in the assessment are shown in this appendix.

There were some generalities in the computations:

- All these data were assumed to be lognormal, so GMs and GSDs were used to summarize.
- When the samples collected of the organism and the respective substrate were from the same site, these samples were considered paired samples. The transfer parameters were computed for each paired sample, and were summarized using GM and GSD. The underlying concentration (and moisture content) data are not reported separately.
- When the samples collected of the organism and the respective substrate were from different sites (albeit always from the same region), these samples were not considered paired samples and the transfer parameters were computed as the ratio of the GMs of the concentration data. Because these computations were done specifically for this report, the GMs of the underlying concentration data are given here.

A.2 TISSUE/MEDIA CONCENTRATION RATIOS

Tissue/Media CRs refers to the aquatic CRs between tissue and water or the terrestrial CRs between tissue and soil. The following details the calculations of these values for the representative biota.

A.2.1 Canada Goose

The GM values for water samples from 11 lakes were reported in Tables 3 Sheppard et al. (2012) and for another 20 lakes in Tables 6 of Sheppard et al. (2012). The original concentration data were combined and new GMs were computed to represent 31 water samples. Details of the sampling and analysis methods for the original data are described in detail in Sheppard et al. (2012). The aquatic CRs were computed as the ratio of the GMs of concentrations in muscle and water.

The GM values for 3 of the 7 soil concentrations reported in Sheppard et al. (2004) were used, because these were from east-central southern Manitoba as were the goose samples. Details of the sampling and analysis methods for the original data are described in detail in Sheppard et al. (2004). The terrestrial CRs were computed as the ratio of the GMs of concentrations in muscle and soil.

Table A.1: Values Used to Derive Concentration Ratios for the Canada Goose

Element	Conc. in muscle [a](mg/kg $_{fw}$) n=5		Conc. in water[b] (µg/L) n=31		Conc. in soil[c] (mg/kg$_{dw}$) n=3		Aquatic CR (L/kg$_{fw}$)	Terrestrial CR (kg$_{dw}$/kg$_{fw}$)
	GM	GSD	GM	GSD	GM	GSD		
Ag	1.3E-03	1.5	3.0E-01	1.6			4.5E+00	
As	4.6E-02	1.3	7.6E+00	2.1	2.0E+00	1.1	6.1E+00	2.3E-02
Au	9.7E-05	2.2	4.0E-03	2.3	1.3E+01	5.1	2.4E+01	7.2E-03
B	1.2E-01	1.8						
Ba	6.6E-01	2.1	2.0E+02	2.0	5.7E+01	3.1	3.3E+00	1.2E-02
Be	7.8E-04	2.9			3.0E-01	4.5		2.6E-03
Bi	2.8E-04				9.6E-02	2.0		2.9E-03
Ca	1.2E+02	1.9	7.8E+03	1.7	2.2E+03	3.9	1.6E+01	5.7E-02
Cd	4.8E-03	1.1	2.0E-02	2.7	4.9E-01	1.8	2.4E+02	9.8E-03
Ce	2.7E-02	2.5	2.1E-01	2.4	1.3E+01	2.9	1.3E+02	2.0E-03
Co	1.3E-02	1.7	5.1E-02	2.5	2.8E+00	4.0	2.6E+02	4.8E-03
Cr	6.3E-01	1.9	3.4E+01	2.0	6.8E+00	3.5	1.9E+01	9.2E-02
Cs	3.5E-02	2.5	2.0E-03	2.1	4.4E-01	2.3	1.8E+04	8.1E-02
Cu	1.8E+00	1.4	1.7E+00	1.8	4.7E+00	3.8	1.1E+03	3.9E-01
Dy	9.2E-04	3.4	1.5E-02	2.2	7.0E-01	3.6	6.1E+01	1.3E-03
Er	4.8E-04	3.3	1.0E-02	2.1	3.3E-01	3.6	4.8E+01	1.5E-03
Eu	5.3E-04	2.9	2.4E-02	2.9	2.4E-01	3.1	2.2E+01	2.2E-03
Fe	5.9E+01	1.4	9.0E+01	2.9	7.9E+03	2.1	6.6E+02	7.5E-03
Ga	1.2E-02	1.7	1.0E-01	1.8	1.3E+00	2.6	1.2E+02	9.2E-03
Gd	1.5E-03	3.3	2.5E-02	2.5	1.1E+00	3.4	6.0E+01	1.3E-03
Ge			9.0E-02	2.1				
Hf	2.6E-03	1.1	3.7E-02	1.7	5.2E-03		7.0E+01	5.0E-01
Ho	1.6E-04	3.3	3.0E-03	2.1	1.3E-01	3.7	5.4E+01	1.2E-03
I	5.1E-02	2.3	1.3E+00	1.6			3.9E+01	
In	9.4E-05	1.2						7.4E-03
K	3.6E+03	1.1	3.0E+02	2.3	7.7E+02	3.9	1.2E+04	4.7E+00
La	1.4E-02	2.4	1.4E-01	2.7	6.6E+00	2.6	9.8E+01	2.1E-03
Li	2.7E-02	4.6	3.0E+00	2.2	2.4E+00	4.7	9.0E+00	1.1E-02
Lu	1.9E-04	1.1	3.0E-03	2.0	1.7E-02		6.2E+01	1.1E-02
Mg	2.5E+02	1.1	2.0E+03	3.5	1.0E+03	4.1	1.3E+02	2.4E-01
Mn	4.4E-01	1.4	3.3E+00	6.1	1.4E+02	5.2	1.3E+02	3.2E-03
Mo	3.4E-02	1.1	4.0E-01	1.6	3.4E-01	5.1	8.6E+01	1.0E-01
Na	9.4E-01	1.1	1.1E+04	1.8	9.4E+01	1.4	8.7E-02	1.0E-02
Nb	2.3E-03	2.9	7.5E-03	1.5	1.9E-01	11.6	3.1E+02	1.2E-02
Nd	1.1E-02	3.0	1.2E-01	2.9	5.1E+00	2.7	9.1E+01	2.2E-03
Ni	3.0E-01	1.9	8.5E-01	2.6	6.1E+00	3.9	3.5E+02	4.9E-02
Pb	4.1E-02	2.0	1.7E-01	1.9	8.6E+00	3.2	2.4E+02	4.7E-03
Pr	3.0E-03	2.8	3.1E-02	3.0	1.8E+00	3.5	9.6E+01	1.6E-03
Rb	4.5E+00	1.5	1.4E-01	2.0	8.1E+00	3.9	3.1E+04	5.6E-01
Re	5.2E-04	7.0	2.0E-03	4.1	1.9E-03	2.0	2.6E+02	2.7E-01
Sb	2.2E-03	3.6	8.0E-02	1.8	4.4E-02	3.5	2.7E+01	4.9E-02
Sc	1.2E-03	3.5	1.0E+00		1.3E+00	2.3	1.2E+00	9.4E-04
Se	1.9E-01	1.6	2.7E+01	2.0	5.3E-01	1.8	6.9E+00	3.5E-01
Sm	2.1E-03	3.3	2.9E-02	2.5	1.0E+00	2.5	7.2E+01	2.1E-03
Sn	1.9E-02	1.4	5.0E-01	2.2	4.4E-01		3.8E+01	4.3E-02
Sr	2.7E-01	2.2	2.2E+01	2.1	1.3E+01	3.4	1.2E+01	2.1E-02
Ta	1.9E-04	3.3	2.0E-03	2.0			9.3E+01	
Tb	2.3E-04	3.2	4.0E-03	2.1	1.4E-01	3.5	5.7E+01	1.6E-03
Te	8.8E-04	1.3			2.9E-02			3.0E-02
Th	8.4E-03	1.0	1.1E-02	2.8	1.2E+00	2.0	7.6E+02	7.1E-03
Ti	4.9E-01	3.6	3.7E+00	1.7			1.3E+02	
Tl	4.7E-03	2.6	3.5E-03	2.0	9.6E-02	2.0	1.3E+03	4.9E-02
Tm	5.7E-05	3.3	2.0E-03	1.8	4.3E-02	3.6	2.8E+01	1.3E-03
U	1.1E-03	2.1	9.7E-02	2.7	1.2E+00	5.3	1.1E+01	9.1E-04
V	2.2E-02	2.4	9.6E+00	2.0	1.1E+01	3.2	2.3E+00	2.0E-03

Element	Conc. in muscle [a](mg/kg $_{fw}$) n=5		Conc. in water[b] (µg/L) n=31		Conc. in soil[c] (mg/kg$_{dw}$) n=3		Aquatic CR (L/kg$_{fw}$)	Terrestrial CR (kg$_{dw}$/kg$_{fw}$)
	GM	GSD	GM	GSD	GM	GSD		
W	3.3E-03	3.1	3.0E-02	2.1			1.1E+02	
Y	4.4E-03	3.2	1.1E-01	2.2	2.3E+00	3.0	4.0E+01	1.9E-03
Yb	3.6E-04	3.4	1.4E-02	2.0	2.0E-01	2.7	2.6E+01	1.8E-03
Zn	3.3E+01	1.2	4.0E+01	2.3	1.9E+01	3.4	8.3E+02	1.7E+00
Zr	4.2E-02	2.5	1.6E+00	2.1	3.6E-01	3.8	2.7E+01	1.2E-01

a. Table 9, Sheppard et al. (2012)
b. Combined data from Tables 3 and 6 ((Sheppard et al. 2012)
c. Table 8 of Sheppard et al. (2004) averaging Black Lake, Pinawa Channel and Milner Ridge soils

A.2.2 Pondweeds

The values reported are taken directly from Table 5 of Sheppard et al. (2012), except for a few data which are taken from the same data set. Details of the sampling and analysis methods for these additional data are described in Sheppard et al. (2012). The aquatic CRs were computed as the ratio of the GMs of concentrations in tissue and water, assuming a 0.13 dw/fw ratio.

Table A.2: Values Used to Derive Concentration Ratios for Pondweeds

Element	Count of Ratio Values	Conc. in Tissue (GM) (mg/kg)	Conc. in Water (GM) (µg/L)	Aquatic CR[c] (L/kg$_{fw}$) n≤7	
				GM	GSD
Ag	0	2.3E-02			
Al	0		3.2E+02[b]		
As	7	3.5E-01	9.8E+00	4.7E+00	1.8
Au	4	2.1E-03	4.4E-03	1.1E+02	1.8
B	0	1.4E+01			
Ba	2	6.9E+01	1.2E+02	4.0E+01	1.0
Be	0	2.2E-02			
Bi	0	7.6E-03			
Br	0		9.5E+01		
Ca	6	2.1E+04	8.5E+03	2.9E+02	1.5
Cd	5	4.7E-01	2.1E-02	2.5E+03	2.6
Ce	7	1.7E+00	3.0E-01	7.3E+02	2.0
Co	7	1.7E+00	7.1E-02	3.1E+03	2.4
Cr	7	2.8E+00	4.5E+01	8.2E+00	2.9
Cs	7	6.2E-02	3.8E-03	2.1E+03	3.2
Cu	7	7.6E+00	1.9E+00	5.2E+02	1.9
Dy	7	7.9E-02	2.0E-02	5.1E+02	2.0
Er	7	4.6E-02	1.3E-02	4.6E+02	2.1
Eu	7	3.8E-02	2.8E-02	1.7E+02	2.2
Fe	7	1.1E+03	1.3E+02	1.1E+03	2.7
Ga	7	1.9E-01	1.4E-01	1.7E+02	3.8
Gd	7	1.3E-01	3.4E-02	4.8E+02	2.3
Ge	1		1.2E-01	1.1E+02	
Hf	7	3.1E-02	4.6E-02	8.7E+01	4.3
Hg	0	1.9E-02			
Ho	6	1.5E-02	5.0E-03	4.8E+02	2.2
I	7	3.9E-01	1.4E+00	3.7E+01	1.7
In	0	1.7E-03			

Element	Count of Ratio Values	Conc. in Tissue (GM) (mg/kg)	Conc. in Water (GM) (μg/L)	Aquatic CR[c] (L/kg_{fw}) n≤7	
				GM	GSD
K	7	1.6E+04	2.6E+02	8.1E+03	2.5
La	7	1.0E+00	1.8E-01	7.2E+02	2.1
Li	7	5.6E-01	4.2E+00	1.7E+01	3.5
Lu	6	6.6E-03	4.8E-03	2.2E+02	2.2
Mg	7	4.1E+03	2.6E+03	2.1E+02	1.3
Mn	7	3.7E+02	3.9E+00	1.2E+04	2.3
Mo	7	4.0E-01	4.0E-01	1.3E+02	1.5
Na	7	2.7E+03	8.9E+03	3.9E+01	2.0
Nb	4	8.7E-02	1.4E-02	2.0E+03	3.0
Nd	7	7.8E-01	1.5E-01	6.8E+02	2.4
Ni	6	4.3E+00	1.3E+00	5.8E+02	2.2
Pb	7	7.4E-01	2.2E-01	4.4E+02	2.6
Pd	0		2.3E-02		
Pr	7	2.0E-01	4.0E-02	6.5E+02	2.3
Rb	7	1.5E+01	1.7E-01	1.2E+04	3.1
Re	2	2.4E-04	2.0E-03	5.6E+00	3.3
Sb	7	1.6E-02	9.2E-02	2.3E+01	1.9
Sc	3	1.7E-01	1.0E+00	3.9E+01	3.7
Se	0		3.6E+01[b]		
Si	0		2.2E+03[b]		
Sm	7	1.3E-01	3.4E-02	5.1E+02	2.1
Sn	5	1.5E-01	5.7E-01	2.9E+01	6.8
Sr	7	4.0E+01	2.0E+01	2.6E+02	1.4
Ta	6	5.5E-03	2.6E-03	3.3E+02	12.0
Tb	6	1.6E-02	5.3E-03	4.8E+02	2.1
Te	0	5.8E-03			
Th	7	1.2E-01	1.6E-02	1.0E+03	3.2
Ti	7	3.4E+01	6.0E+00	7.3E+02	3.0
Tl	4	1.3E-01	2.3E-03	7.8E+03	1.8
Tm	6	5.9E-03	2.6E-03	3.5E+02	2.4
U	7	1.1E-01	6.9E-02	2.1E+02	2.5
V	7	2.0E+00	1.3E+01	2.1E+01	2.9
W	5	2.4E-02	2.8E-02	1.2E+02	2.9
Y	7	4.7E-01	1.4E-01	4.2E+02	2.1
Yb	7	4.2E-02	2.0E-02	2.7E+02	2.2
Zn	7	3.8E+01	4.7E+01	1.0E+02	3.2
Zr	7	1.0E+00	1.9E+00	7.2E+01	4.3

a. Table 5, Sheppard et al. (2012)
b. Same dataset as Sheppard et al. (2012)
c. Computed using paired samples and 0.13 dw/fw.

A.2.3 Grass (Sedges)

The values used to derive the terrestrial CR for sedges are from the same data used to derive the values shown in Tables 13 and 14 of Sheppard et al. (2004). The values in Sheppard et al. (2004) were averaged across species and sites, and here GMs and GSDs were specifically for sedges. Details of the sampling and analysis methods for the original data are defined in Sheppard et al. (2004). A dw/fw ratio of 0.68 is assumed.

Table A.3: Values Used to Derive Concentration Ratios for Grass

Element	Count	Terrestrial CR[a] (kg_{fw}/kg_{dw})	
		GM	GSD
Al	4	6.1E-04	2.1
Ba	4	3.9E-02	2.4
Be	2	2.0E-03	1.4
Bi	1	8.8E-02	
Ca	4	2.8E-01	2.0
Cd	4	2.9E-02	2.6
Ce	4	5.4E-04	2.0
Co	4	2.9E-03	2.2
Cr	3	5.2E-02	3.6
Cs	4	1.0E-02	3.0
Cu	4	1.2E-01	1.9
Dy	4	6.1E-04	1.9
Er	4	6.1E-04	1.7
Eu	4	6.7E-04	1.8
Fe	4	1.6E-03	1.8
Ga	3	2.2E-03	1.7
Gd	4	8.2E-04	1.9
Ho	4	5.7E-04	2.0
In	1	1.0E-02	
La	4	1.2E-03	2.3
Li	3	8.8E-03	3.5
Lu	2	9.5E-04	1.9
Mg	4	2.0E-01	2.1
Mn	4	3.6E-02	2.3
Mo	4	1.2E+00	3.1
Na	4	4.8E-02	1.7
Nb	1	1.2E-03	
Nd	4	6.7E-04	1.9
Ni	4	4.6E-02	3.4
Pb	4	2.2E-03	2.4
Pr	4	8.2E-04	2.0
Rb	4	4.4E-01	4.4
Re	2	8.5E-02	1.3
Sb	2	3.1E-02	4.8
Sc	1	9.5E-03	
Sm	4	8.8E-04	1.9
Sr	4	1.7E-01	1.7
Tb	4	6.8E-04	2.1
Th	4	9.2E-04	2.3
Tl	4	1.1E-02	2.5
Tm	3	6.8E-04	1.7
U	4	1.5E-03	1.7
V	1	1.8E-03	
Y	4	8.2E-04	1.9
Yb	4	5.4E-04	1.7
Zn	4	1.2E-01	1.9
Pb-210	4	1.8E-01	1.7
Po-210	4	1.1E-01	1.7
Ra-226	3	2.4E-02	1.2

a. same dataset as Tables 13 and 14 of Sheppard et al. (2004) here separated by species assuming 0.68 dw/fw.

A.2.4 Fish

The GMs and GSDs shown in Table A.4 are computed using the same original data as used for Table 3 and Table 4 of Sheppard et al. (2012). Because these were for back muscle (fillet) samples, it was desirable to adjust these to whole body values, and the opportunity was provided because there were both muscle and whole body data for Yellow perch. The assumption was that the whole body/muscle CR for perch was relevant to the other species. Where this ratio was not available for certain elements, the median whole body/muscle CR across all other elements of 11.0 was used convert the muscle concentration ratios into whole body concentration ratios. Details of the sampling and analysis methods for the original data are described in Sheppard et al. (2012).

Table A.4: Values Used to Derive Concentration Ratios for Fish

Element	Yellow Perch CR muscle/ water (L/kg$_{fw}$)	Yellow Perch CR whole body/ water (L/kg$_{fw}$)	Conc. ratio whole body/ muscle[b]	Measured Aquatic CR (L/kg$_{fw}$)[a]				Estimated Aquatic CR (L/kg$_{fw}$)				
				Lake whitefish n=2	White Sucker n=4	Lake Trout n=3	Northern Pike n=7	Lake Whitefish n=2	White Sucker n=4	Lake Trout n=3	Northern Pike n=7	Generic Fish n=36
As	5.0E+00	2.1E+01	2.4	8.0E+01	4.4E+01	3.7E+01	8.9E+00	2.0E+02	1.1E+02	9.1E+01	2.2E+01	2.9E+01
Au	3.8E+01	6.0E+01	1.5		8.5E+00	1.6E+02	1.2E+01		1.3E+01	2.4E+02	1.8E+01	3.9E+01
Ba		4.2E+00	4.2				5.8E+00				2.4E+01	7.5E+00
Ca	1.0E+02	1.3E+03	14.2	4.0E+01	2.0E+02	4.7E+01	7.6E+01	5.6E+02	2.8E+03	6.7E+02	1.1E+03	8.3E+02
Cd	2.2E+01	2.6E+03	119.0	1.7E+02	8.9E+02		5.5E+01	2.0E+04	1.1E+05		6.6E+03	1.1E+04
Ce	2.3E+00	1.1E+02	37.3	2.2E+00	4.7E+01	3.2E+00	8.7E-01	8.1E+01	1.7E+03	1.2E+02	3.2E+01	1.0E+02
Cl			11.0	9.5E+01	1.3E+02	1.7E+02	1.2E+02	1.0E+03	1.4E+03	1.8E+03	1.3E+03	1.3E+03
Co	6.3E+01	1.4E+03	25.0	2.6E+02	3.6E+02	9.1E+01	4.0E+01	6.5E+03	9.0E+03	2.3E+03	1.0E+03	1.4E+03
Cr	1.7E-01	4.1E+00	12.7	1.2E-01	1.3E+00	2.4E+00	3.7E-01	1.5E+00	1.7E+01	3.1E+01	4.7E+00	3.3E+00
Cs	9.0E+03	3.6E+03	2.3	4.4E+03	1.6E+03	3.0E+04	9.8E+03	9.9E+03	3.6E+03	6.8E+04	2.2E+04	1.4E+04
Cu	2.6E+02	9.0E+02	2.7	6.4E+01	1.4E+02	9.0E+01	7.0E+01	1.7E+02	3.8E+02	2.4E+02	1.9E+02	2.9E+02
Dy	2.9E+00	8.2E+01	22.2	2.5E+00	1.9E+01	6.5E+00	1.8E+00	5.5E+01	4.2E+02	1.4E+02	4.0E+01	6.7E+01
Er	3.0E+00	6.5E+01	17.7	1.0E+00	1.4E+01		1.6E+00	1.8E+01	2.5E+02		2.8E+01	4.3E+01
Eu	9.7E-01	4.6E+01	28.7		1.0E+01	1.3E+00	2.4E+00		2.9E+02	3.6E+01	6.9E+01	6.0E+01
Fe	9.4E+00	5.3E+02	53.6	6.0E+01	1.5E+02	6.0E+01	1.2E+01	3.2E+03	8.0E+03	3.2E+03	6.4E+02	9.5E+02
Ga		5.6E+01	11.0		1.7E+02		3.4E+01		1.9E+03		3.8E+02	2.1E+02
Gd		8.1E+01	11.0		1.1E+02				1.2E+03			1.3E+02
Ge			11.0									
Hf		2.9E+01	11.0		5.9E+01				6.5E+02			1.0E+02
Hg			11.0									
Ho	2.6E+00	9.0E+01	23.6	1.3E+00	2.0E+01	2.5E+00	1.3E+00	3.1E+01	4.6E+02	6.0E+01	3.1E+01	5.0E+01
I	6.7E+01	7.7E+01	1.1	2.4E+01	3.5E+01	3.2E+01	2.6E+01	2.7E+01	3.8E+01	3.5E+01	2.8E+01	3.7E+01
K	1.1E+04	2.5E+04	1.8	9.0E+03	8.1E+03	2.6E+04	1.8E+04	1.6E+04	1.5E+04	4.7E+04	3.3E+04	2.4E+04
La	2.6E+00	9.1E+01	27.1	2.3E+00	5.4E+01	2.4E+00	1.1E+00	6.1E+01	1.5E+03	6.4E+01	3.1E+01	8.5E+01
Li	4.3E+00	2.2E+01	3.3	4.4E+00	6.7E+00	2.5E+00	2.4E+00	1.5E+01	2.2E+01	8.3E+00	8.0E+00	9.5E+00
Lu		9.4E+01	11.0		8.5E+01		1.9E+01		9.4E+02		2.0E+02	1.4E+02
Mg	1.4E+02	2.2E+02	1.6	6.7E+01	6.7E+01	3.0E+02	2.0E+02	1.1E+02	1.1E+02	4.8E+02	3.2E+02	2.2E+02
Mn	1.3E+01	5.0E+03	276.8	3.1E+02	9.2E+02	8.6E+01	8.9E+01	8.5E+04	2.6E+05	2.4E+04	2.5E+04	2.0E+04
Mo	4.8E+00	1.4E+02	18.8	1.2E+01	1.7E+01	2.5E+00	7.1E+00	2.3E+02	3.1E+02	4.8E+01	1.3E+02	1.1E+02
Na	2.6E+01	2.1E+02	6.1	6.9E+01	9.8E+01	1.0E+02	5.2E+01	4.2E+02	6.0E+02	6.3E+02	3.2E+02	2.9E+02

Element	Yellow Perch CR muscle/ water (L/kg$_{fw}$)	Yellow Perch CR whole body/ water (L/kg$_{fw}$)	Conc. ratio whole body/ muscle[b]	Measured Aquatic CR (L/kg$_{fw}$)[a]				Estimated Aquatic CR (L/kg$_{fw}$)				
				Lake whitefish n=2	White Sucker n=4	Lake Trout n=3	Northern Pike n=7	Lake Whitefish n=2	White Sucker n=4	Lake Trout n=3	Northern Pike n=7	Generic Fish n=36
Nb	6.0E+01	1.1E+02	1.9		2.9E+01		1.7E+01		5.5E+01		3.1E+01	5.0E+01
Nd	2.5E+00	1.1E+02	32.5	9.7E+00	2.4E+01	5.1E+00	9.1E-01	3.2E+02	7.9E+02	1.6E+02	2.9E+01	9.5E+01
Ni		1.5E+02	11.01		1.5E+02				1.6E+03			3.2E+02
Pb	3.9E+01	1.3E+02	3.7	1.4E+01	3.6E+01		1.5E+01	5.0E+01	1.3E+02		5.7E+01	1.1E+02
Pr	2.3E+00	1.0E+02	34.6		2.1E+02				7.3E+03			2.4E+02
Rb	5.3E+04	6.4E+04	1.4	2.0E+04	1.2E+04	1.4E+05	6.8E+04	2.8E+04	1.7E+04	2.0E+05	9.7E+04	6.9E+04
Re			1.6			1.3E+01	2.3E+01			2.1E+01	3.8E+01	1.1E+01
Sb	3.8E+00	4.4E+01	8.3	4.2E+01	4.7E+00	1.7E+01	5.4E+00	3.5E+02	3.9E+01	1.4E+02	4.5E+01	5.5E+01
Sc	8.7E-01		1.8									1.0E+00
Se	7.8E+00	2.1E+01	2.2	1.3E+01	5.7E+00	1.7E+02	7.7E+00	2.8E+01	1.2E+01	3.7E+02	1.7E+01	2.1E+01
Sm	2.8E+00	7.9E+01	22.0	1.8E+01	3.5E+01	2.2E+01	2.0E+00	4.0E+02	7.7E+02	4.7E+02	4.4E+01	1.1E+02
Sr	8.7E+00	3.3E+02	41.4	7.4E+00	1.5E+01	7.9E+00	1.2E+01	3.1E+02	6.1E+02	3.3E+02	4.9E+02	3.0E+02
Ta	2.2E+01	8.4E+01	1.6		1.8E+01	1.3E+01			3.0E+01	2.1E+01		2.7E+01
Tb	3.4E+00	9.4E+01	24.9	1.5E+01	4.8E+01	1.9E+01	9.9E+00	3.6E+02	1.2E+03	4.6E+02	2.5E+02	2.6E+02
Th		1.2E+02	11.01		1.7E+02				1.9E+03			4.4E+02
Ti	1.2E+01	2.4E+02	10.7	1.6E+01	3.6E+01	8.8E+01	3.3E+00	1.7E+02	3.9E+02	9.4E+02	3.5E+01	1.1E+02
Tl	2.9E+03	5.4E+03	1.9	1.6E+03	1.3E+03	7.2E+03	3.0E+03	3.0E+03	2.5E+03	1.3E+04	5.6E+03	5.1E+03
Tm	3.8E+00	7.3E+01	12.3		1.5E+02				1.8E+03			1.3E+02
U	8.2E+00	3.7E+01	5.3		1.3E+01				7.0E+01			5.4E+01
V	8.5E-01	1.0E+01	9.1	1.3E+00	4.9E+00		8.4E-01	1.2E+01	4.5E+01		7.6E+00	1.1E+01
W		2.7E+02	11.01		1.1E+02				1.2E+03			3.8E+02
Y	2.5E+00	6.6E+01	20.8	9.2E+00	2.5E+01	6.4E+00	2.0E+00	1.9E+02	5.2E+02	1.3E+02	4.2E+01	7.7E+01
Yb	2.9E+00	4.7E+01	11.4		8.9E+01				1.0E+03			8.0E+01
Zn	3.0E+01	7.6E+02	27.6	4.5E+02	5.6E+02	4.3E+02	1.6E+02	1.2E+04	1.5E+04	1.2E+04	4.4E+03	4.3E+03
Zr		3.0E+01	11.01	1.3E+03	9.5E+01	4.4E+01	8.4E+00	1.5E+04	1.0E+03	4.8E+02	9.2E+01	3.0E+02

a values are not directly from Tables 3 and 4 of Sheppard et al. (2012); these are for specific species from the same dataset.
b using overall median across elements (11.0) where data not available.

A.2.5 Rabbit

The concentration in rabbit muscle shown in Table A.5 originates from the same dataset as used in Sheppard et al. (2012), but is not specifically listed in the report. Details of the sampling and analysis methods for the original data are described in Sheppard et al. (2012). The soil concentrations involved sampling all across southern Ontario, and this represented the most probable source of the commercial alfalfa feed supplied to this rabbit (Sheppard et al., 2012). The soil data were not reported in the Sheppard et al. (2012), but details of the sampling and analysis methods for the original data used for Table A.5 are described.

Table A.5: Values Used to Derive Concentration Ratios for the Rabbit

Element	Conc. in muscle[a] (µg/kg_{fw}) n=1	Conc. in soil[b] (mg/kg) n=57	Terrestrial CR (kg_{dw}/kg_{fw}) n=1
Ag	5.4E-01	2.0E-02	2.6E-02
As	1.1E+01	7.1E+00	1.5E-03
Au		1.9E-03	
B		1.2E+01	
Ba		1.1E+02	
Be		6.5E-01	
Bi		8.1E-02	
Ca	5.3E+04	7.5E+03	7.1E-03
Cd	1.0E+00	2.4E-01	4.3E-03
Ce	5.7E-01	5.0E+01	1.1E-05
Cl	4.0E+05		
Co	8.9E+00	8.6E+00	1.0E-03
Cr	3.0E+01	3.2E+01	9.5E-04
Cs	6.3E+00	1.2E+00	5.4E-03
Cu	6.0E+02	1.8E+01	3.4E-02
Dy	1.6E-02	2.9E+00	5.7E-06
Er		1.4E+00	
Eu	8.1E-02	8.4E-01	9.7E-05
Fe	5.7E+03	2.4E+04	2.4E-04
Ga	2.2E-01	5.7E+00	3.8E-05
Gd		3.7E+00	
Ge		1.3E-01	
Hf		0.0E+00	
Ho	2.7E-03	5.3E-01	5.1E-06
I	7.8E+00		
In		3.2E-02	
K	3.4E+06	2.9E+03	1.1E+00
La	4.3E-01	2.2E+01	1.9E-05
Li		1.7E+01	
Lu		1.5E-01	
Mg	2.8E+05	5.2E+03	5.5E-02
Mn	7.0E+01	5.8E+02	1.2E-04
Mo	8.4E+00	7.3E-01	1.1E-02
Na	4.2E+05	4.4E+02	9.7E-01
Nb		1.0E+00	
Nd		2.3E+01	
Ni		2.1E+01	
Pb	2.7E+00	1.3E+01	2.1E-04

Element	Conc. in muscle[a] (µg/kg$_{fw}$) n=1	Conc. in soil[b] (mg/kg) n=57	Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=1
Pr		6.0E+00	
Rb	4.3E+03	2.5E+01	1.7E-01
Re		1.2E-03	
Sb		1.3E-01	
Sc		4.6E+00	
Se	2.2E+02	1.1E+01	2.0E-02
Sm	2.7E-02	4.5E+00	6.0E-06
Sn		8.7E-01	
Sr	2.0E+02	2.8E+01	7.2E-03
Tb	3.8E-02	4.9E-01	7.6E-05
Te		3.9E-02	
Th		2.2E+00	
Tl	5.7E-01	1.8E-01	3.1E-03
Tm		2.0E-01	
U	2.7E-01	1.2E+00	2.3E-04
V		4.3E+01	
W		0.0E+00	
Y	1.9E-01	1.4E+01	1.3E-05
Yb		1.1E+00	
Zn	1.4E+04	6.5E+01	2.1E-01
Zr	7.3E+00	6.6E-01	1.1E-02
count	18	28	16

a. From same dataset as Sheppard et al. (2012)
b. From same dataset as Sheppard et al. (2009)

A.2.6 Caribou

The concentration in muscle and overburden came from the same dataset as used in Sheppard et al. (2012), but was not reported specifically in the report. Sheppard et al. (2012) describes in detail the sampling and analysis methods for the original data. The overburden concentrations were from samples of unconsolidated surface material (soil-like but not soil).

Table A.6: Values Used to Derive Concentration Ratios for Caribou

Element	Conc. in muscle[a] (ug/kg$_{fw}$) n=1	Conc. in overburden[a] (µg/kg$_{dw}$) n=2	Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=1
Ag	5.2E-01	4.7E+01	1.1E-02
Al		7.4E+06	
As	1.9E+01	5.0E+03	3.8E-03
B	5.2E+01	7.7E+03	6.5E-03
Ba		7.7E+04	
Be		5.3E+02	
Bi		6.9E+01	
Ca	3.5E+04	1.7E+06	2.0E-02
Cd	4.3E+00	2.8E+01	1.4E-01
Ce	4.4E+00	3.0E+04	1.4E-04
Cl	3.7E+05	1.7E+02	1.8E+00
Co	1.9E+01	6.5E+03	2.9E-03

Element	Conc. in muscle[a] (ug/kg$_{fw}$) n=1	Conc. in overburden[a] (µg/kg$_{dw}$) n=2	Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=1
Cr	5.2E+00	1.1E+05	4.7E-05
Cs	1.9E+03	1.4E+03	1.1E+00
Cu	2.5E+03	9.5E+03	2.3E-01
Dy	1.6E-02	8.8E+02	1.7E-05
Er	1.6E-02	3.5E+02	4.5E-05
Eu	2.6E-02	2.8E+02	8.7E-05
Fe	3.8E+04	1.4E+07	2.5E-03
Ga	7.6E-01	3.1E+03	2.1E-04
Gd		1.6E+03	
Ge		1.0E+02	
Hf		1.0E+02	
Hg	5.5E+00		
Ho	2.6E-03	1.4E+02	1.7E-05
I	8.6E+00		
K	3.5E+06	1.7E+06	1.4E+00
La	4.4E+00	1.5E+04	2.8E-04
Li	3.7E+00	2.2E+04	1.5E-04
Mg	2.5E+05	4.1E+06	5.2E-02
Mn	3.5E+02	1.4E+05	2.4E-03
Mo	3.4E+00	3.1E+03	8.6E-04
Na	3.7E+05	3.9E+05	8.2E-01
Nb	2.6E-01	5.7E+02	4.4E-04
Nd	1.0E-01	1.3E+04	7.9E-06
Ni		4.2E+04	
Pb		2.6E+03	
Pr		3.5E+03	
Rb	3.5E+04	1.2E+04	2.1E+00
Re		2.0E+00	
Sb	3.9E-01	4.0E+01	9.8E-03
Sc		1.7E+03	
Se	2.1E+02	2.8E+02	7.0E-01
Sm	2.6E-02	2.3E+03	1.1E-05
Sn		2.8E+02	
Sr	4.2E+01	1.1E+04	3.8E-03
Ta	1.8E-01		
Tb	1.0E-02	1.4E+02	7.0E-05
Te	2.6E-01	4.0E+01	6.5E-03
Th		2.6E+03	
Ti	7.8E+00		
Tl	2.0E+00	9.7E+01	1.7E-02
Tm		1.0E+02	
U	2.6E-01	9.9E+02	2.5E-04
V		2.5E+04	
Y	2.1E-01	3.9E+03	5.2E-05
Yb		2.0E+02	
Zn	6.3E+04	3.1E+04	1.9E+00
Zr	2.6E+00	2.6E+03	7.2E-04

a. Not given in Sheppard et al. (2012), but taken from same dataset.

A.2.7 Moose and Elk

The concentration in muscle came from the same dataset as used in Sheppard et al. (2004) but was not reported. Details of the sampling and analysis methods for the original data are described in Sheppard et al. (2004). The GM values for three of the 7 soils reported in Sheppard et al. (2004) were used, because these were from east-central southern Manitoba as were the moose and elk samples. The terrestrial CRs is taken as the ratio of the concentration in elk or moose muscle to the concentration in the soil.

Table A.7: Values Used to Derive Concentration Ratios for Moose and Elk

Element	Conc. in Soil[b] (mg/kg$_{dw}$) n=3		Conc. in Moose Muscle[a] (µg/kg$_{fw}$) n=1	Conc. in Elk Muscle[a] (ug/kg$_{fw}$), n=1	Moose Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=1	Elk Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=1
	GM	GSD				
As	2.0E+00	1.1	2.0E+02	3.1E+02	1.0E-01	1.6E-01
Au	1.3E+01	5.1				
B			3.9E+02	3.1E+02		
Ba	5.7E+01	3.1				
Be	3.0E-01	4.5		2.7E-02		8.9E-05
Bi	9.6E-02	2.0				
Ca	2.2E+03	3.9	8.2E+04	4.8E+04	3.7E-02	2.2E-02
Cd	4.9E-01	1.8	1.2E+01	8.5E+00	2.5E-02	1.7E-02
Ce	1.3E+01	2.9	5.6E-01	2.2E-01	4.3E-05	1.6E-05
Co	2.8E+00	4.0	5.7E+00	3.1E+00	2.1E-03	1.1E-03
Cr	6.8E+00	3.5	4.8E+01	4.3E+01	7.0E-03	6.3E-03
Cs	4.4E-01	2.3	6.8E+00	5.4E+01	1.6E-02	1.2E-01
Cu	4.7E+00	3.8	1.9E+03	1.1E+03	4.0E-01	2.3E-01
Dy	7.0E-01	3.6	5.0E-02	2.7E-02	7.2E-05	3.9E-05
Er	3.3E-01	3.6	2.2E-02		6.8E-05	
Eu	2.4E-01	3.1	2.8E-02		1.2E-04	
Fe	7.9E+03	2.1	5.0E+04	2.6E+04	6.4E-03	3.3E-03
Ga	1.3E+00	2.6				
Gd	1.1E+00	3.4				
Hf	5.2E-03					
Hg			5.0E+00	3.4E+00		
Ho	1.3E-01	3.7	1.1E-02	4.1E-03	8.5E-05	3.1E-05
I			7.3E+00	1.1E+01		
In			2.2E-01		1.8E-02	
K	7.7E+02	3.9	4.1E+06	3.9E+06	5.4E+00	5.1E+00
La	6.6E+00	2.6	6.4E-01	2.7E-01	9.8E-05	4.1E-05
Li	2.4E+00	4.7	2.6E+02	9.6E+02	1.1E-01	4.0E-01
Lu	1.7E-02					
Mg	1.0E+03	4.1	2.6E+05	2.5E+05	2.6E-01	2.4E-01
Mn	1.4E+02	5.2	2.2E+02	1.3E+02	1.6E-03	9.0E-04
Mo	3.4E-01	5.1	8.4E+00	3.9E+00	2.5E-02	1.1E-02
Na	9.4E+01	1.4	4.9E+05	4.6E+05	5.2E+00	4.9E+00
Nb	1.9E-01	11.6	5.0E-01		2.7E-03	
Nd	5.1E+00	2.7	2.5E-01	8.1E-02	4.9E-05	1.6E-05
Ni	6.1E+00	3.9	1.1E+02		1.8E-02	
Pb	8.6E+00	3.2	9.5E+02		1.1E-01	
Pr	1.8E+00	3.5				
Rb	8.1E+00	3.9	6.3E+03	3.6E+03	7.9E-01	4.4E-01
Re	1.9E-03	2.0		6.8E-02		3.5E-02
Sb	4.4E-02	3.5	7.6E-01	3.2E-01	1.7E-02	7.3E-03
Sc	1.3E+00	2.3				
Se	5.3E-01	1.8	2.0E+02	5.4E+02	3.7E-01	1.0E+00
Sm	1.0E+00	2.5	1.1E-01	8.1E-02	1.1E-04	8.0E-05
Sn	4.4E-01		8.1E+01		1.8E-01	
Sr	1.3E+01	3.4	3.4E+01	2.0E+01	2.6E-03	1.6E-03
Tb	1.4E-01	3.5	3.4E-02	1.4E-02	2.4E-04	9.5E-05
Te	2.9E-02		8.4E-01		2.9E-02	
Th	1.2E+00	2.0				
Ti			3.1E+01			
Tl	9.6E-02	2.0				

Element	Conc. in Soil[b] (mg/kg$_{dw}$) n=3		Conc. in Moose Muscle[a] (µg/kg$_{fw}$) n=1	Conc. in Elk Muscle[a] (ug/kg$_{fw}$), n=1	Moose Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=1	Elk Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=1
	GM	GSD				
Tm	4.3E-02	3.6				
U	1.2E+00	5.3				
V	1.1E+01	3.2				
Y	2.3E+00	3.0	4.8E-01	3.1E-01	2.0E-04	1.3E-04
Yb	2.0E-01	2.7				
Zn	1.9E+01	3.4	5.9E+04	8.4E+04	3.1E+00	4.3E+00
Zr	3.6E-01	3.8				

a. From the same dataset as Sheppard et al. (2012)
b. Table 8 of Sheppard et al. (2004) averaging Black Lake, Pinawa Channel and Milner Ridge soils

A.2.8 White-Tailed Deer

The concentration in muscle was as reported in Table 10 of Sheppard et al. (2012). The GM values for three of the 7 soils reported in Sheppard et al. (2004) were used, because these were from east-central southern Manitoba as were the deer samples.

Table A.8: Values Used to Derive Concentration Ratios for White-Tailed Deer

Element	Conc. in Soil (mg/kg$_{dw}$) n=3		Conc. in Muscle (mg/kg$_{fw}$) n=11		Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=11
	GM	GSD	GM	GSD	
Ag			6.4E-04	2.2	
Al	2.3E+03	6.8			
As	2.0E+00	1.1	5.0E-02	1.3	2.5E-02
Au	1.3E-02	5.1	8.3E-05	3.8	6.2E-03
B	1.0E+00		2.4E-01	1.6	
Ba	5.7E+01	3.1			
Be	3.0E-01	4.5	9.4E-05	1.5	3.1E-04
Bi	9.6E-02	2.0	7.9E-04	5.6	8.3E-03
Ca	2.2E+03	3.9	4.9E+01	1.5	2.2E-02
Cd	4.9E-01	1.8	3.4E-03	1.7	6.9E-03
Ce	1.3E+01	2.9	2.2E-03	2.0	1.7E-04
Co	2.8E+00	4.0	2.3E-03	1.4	8.4E-04
Cr	6.8E+00	3.5	5.3E-02	1.9	7.7E-03
Cs	4.4E-01	2.3	4.2E-02	2.6	9.6E-02
Cu	4.7E+00	3.8	2.0E+00	1.3	4.3E-01
Dy	7.0E-01	3.6	6.5E-05	1.7	9.4E-05
Er	3.3E-01	3.6	3.6E-05	1.7	1.1E-04
Eu	2.4E-01	3.1	5.1E-05	1.6	2.1E-04
Fe	7.9E+03	2.1	3.9E+01	1.6	4.9E-03
Ga	1.3E+00	2.6			
Gd	1.1E+00	3.4	3.0E-04		2.6E-04
Ge	1.0E+00				
Hf	5.2E-03				
Hg					
Ho	1.3E-01	3.7	1.2E-05	1.9	9.1E-05
I			4.9E-03	1.7	
In	1.3E-02	2.5	5.7E-05	2.7	4.5E-03
K	7.7E+02	3.9	4.1E+03	1.1	5.4E+00

Element	Conc. in Soil (mg/kg$_{dw}$) n=3		Conc. in Muscle (mg/kg$_{fw}$) n=11		Terrestrial CR (kg$_{dw}$/kg$_{fw}$) n=11
	GM	GSD	GM	GSD	
La	6.6E+00	2.6	1.1E-03	2.1	1.7E-04
Li	2.4E+00	4.7	8.6E-02	5.5	3.6E-02
Mg	1.0E+03	4.1	2.7E+02	1.1	2.7E-01
Mn	1.4E+02	5.2	1.8E-01	1.3	1.3E-03
Mo	3.4E-01	5.1	5.8E-03	1.7	1.7E-02
Na	9.4E+01	1.4	5.8E-01	1.2	6.2E-03
Nb	1.9E-01	11.6	2.9E-04	1.4	1.6E-03
Nd	5.1E+00	2.7	8.3E-04	2.0	1.6E-04
Ni	6.1E+00	3.9	8.2E-02	1.5	1.3E-02
Pb	8.6E+00	3.2	8.4E-03	2.8	2.2E-03
Pr	1.8E+00	3.5	2.9E-04	1.6	1.6E-04
Rb	8.1E+00	3.9	6.2E+00	1.5	7.8E-01
Re	1.9E-03	2.0	8.4E-05	1.1	4.4E-02
Sb	4.4E-02	3.5	9.9E-04	3.7	4.2E-02
Sc	1.3E+00	2.3	3.0E-04	1.1	2.3E-04
Se	5.3E-01	1.8	1.5E-01	1.6	2.8E-01
Sm	1.0E+00	2.5	1.9E-04	1.7	1.9E-04
Sn	4.4E-01		2.3E-01		5.2E-01
Sr	1.3E+01	3.4	3.2E-02	1.6	2.5E-03
Ta	1.0E+00		3.3E-05	1.4	
Tb	1.4E-01	3.5	2.0E-05	1.6	1.4E-04
Te	2.9E-02		9.1E-04	1.4	3.2E-02
Th	1.2E+00	2.0			
Tl	9.6E-02	2.0	3.4E-04	2.0	3.6E-03
Tm	4.3E-02	3.6			
U	1.2E+00	5.3	5.4E-04		4.5E-04
V	1.1E+01	3.2	6.9E-03	3.8	6.1E-04
W	1.0E+00		2.0E-03		
Y	2.3E+00	3.0	4.7E-04	1.6	2.0E-04
Yb	2.0E-01	2.7			
Zn	1.9E+01	3.4	4.2E+01	1.3	2.2E+00
Zr	3.6E-01	3.8			
count	28	24	23	22.0	21

a. Table 10 Sheppard et al. (2012)
b. Table 8 of Sheppard et al. (2004) averaging Black Lake, Pinawa Channel and Milner Ridge soils

A.2.9 Dwarf Arctic Willow and White Cedar

The CRs for white cedar in the Tables 13 and 14 of Sheppard et al. (2004) were averaged across species and sites. Here, the original dataset was used to calculate GMs and GSDs specifically for the white cedar and dwarf arctic willow. Details of the sampling and analysis methods for the original data are described in Sheppard et al. (2004). A fw/dw ratio of 0.38 was used to express in fresh weight basis.

Table A.9: Values Used to Derive Concentration Ratios for White Cedar and Dwarf Arctic Willow

Element	White Cedar Terrestrial CR (kg_{dw}/kg_{fw})			Dwarf Arctic Willow Terrestrial CR (kg_{dw}/kg_{fw})		
	Count	GM	GSD	Count	GM	GSD
Al	11	1.2E-03	1.9	3	4.2E-04	1.3
As	4	3.6E-03	1.8	1	1.7E-02	
Ba	11	4.9E-02	1.5	3	2.6E-02	1.1
Be	11	4.2E-03	2.0	2	4.6E-04	1.5
Bi	4	5.3E-03	3.0			
Ca	11	1.8E-01	2.6	3	6.7E-01	1.5
Cd	11	3.8E-02	2.7	3	3.1E-01	1.1
Ce	11	1.5E-03	1.3	3	3.0E-04	1.2
Co	11	4.2E-03	1.6	3	1.1E-02	2.2
Cr	11	3.7E-03	2.4	2	1.4E-03	1.2
Cs	11	6.6E-03	2.9	3	4.9E-03	1.1
Cu	11	2.8E-02	2.2	3	1.3E-01	1.1
Dy	11	1.7E-03	1.6	3	3.6E-04	1.2
Er	11	1.6E-03	1.6	3	4.2E-04	1.3
Eu	11	1.9E-03	1.6	3	4.2E-04	1.3
Fe	11	1.4E-03	1.5	3	1.3E-03	1.5
Ga	11	1.7E-03	1.8	3	9.9E-04	1.2
Gd	11	2.2E-03	1.6	3	4.6E-04	1.3
Ho	11	1.5E-03	1.7	3	3.3E-04	1.2
In	11	2.9E-03	1.6	3	3.6E-03	1.6
La	11	3.4E-03	1.9	3	4.6E-04	1.2
Li	10	2.2E-03	2.1	2	1.3E-03	1.1
Lu	11	1.4E-03	1.4			
Mg	11	3.6E-02	2.7	3	1.7E-01	2.1
Mn	11	1.6E-02	2.5	3	4.2E-02	1.7
Mo	11	2.7E-02	2.6	3	6.2E-02	2.3
Na	11	3.8E-02	1.9	3	3.3E-02	1.5
Nb	11	8.6E-04	1.8	3	2.7E-04	1.1
Nd	11	1.9E-03	1.7	3	3.4E-04	1.2
Ni	11	1.8E-02	1.7	3	2.1E-02	2.3
Pb	11	3.0E-03	4.3	3	5.0E-03	1.4
Pr	11	2.1E-03	1.6	3	3.6E-04	1.2
Ra	11	1.1E-02	4.6			
Rb	11	5.3E-02	4.7	3	1.6E-01	1.4
Re	3	1.5E-01	4.5	3	1.9E-02	2.3
Sb	10	1.5E-02	4.1	3	1.1E-02	1.2
Sc	4	4.2E-03	1.8			
Se	3	7.1E-02	1.3	3	8.0E-02	1.8
Sm	11	2.0E-03	1.6	3	4.6E-04	1.2
Sr	11	2.2E-01	2.7	3	2.2E-01	1.2
Tb	11	1.9E-03	1.6	3	3.8E-04	1.2
Te	2	2.3E-02	2.0			
Th	11	2.3E-03	2.7	3	5.9E-04	1.4
Tl	11	1.3E-02	4.6	3	8.0E-03	1.6
Tm	11	1.3E-03	1.5	3	3.8E-04	1.2
U	11	4.2E-03	2.2	3	6.3E-04	1.3
V	11	1.4E-03	1.6			
Y	11	2.3E-03	1.9	3	4.6E-04	1.2
Yb	11	1.3E-03	1.5	3	3.5E-04	1.4
Zn	11	5.3E-02	2.0	3	6.5E-01	1.4
Zr	6	5.3E-03	1.4			

Element	White Cedar Terrestrial CR (kg_{dw}/kg_{fw})			Dwarf Arctic Willow Terrestrial CR (kg_{dw}/kg_{fw})		
	Count	GM	GSD	Count	GM	GSD
Ra-226	4	1.1E-02	4.6			

A.2.10 Berries

The dry weight CRs are as reported in Table 24 of Sheppard et al. (2012). The fresh weight CRs were computed from the dry weight CRs assuming the berries were 82% water.

The observed leaf CRs are as reported in the Appendix of Sheppard (1991). An adjustment was used to convert berry CRs to leaf CR for elements where there were no observed leaf CRs. The median leaf/berry CR of 9 (median of 10 elements where both leaf and berry data were available) was used to the adjustment. A dw/fw ratio of 0.59 was used to express concentration ratio in the wet weight basis.

Table A.10: Values Used to Derive Concentration Ratios for Berry Leaf and Fruit

Element	Berry Fruit Terrestrial CR				Berry Leaf Terrestrial CR			
	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD	Count	Observed Dry Weight (kg_{dw}/kg_{dw})	Observed and Estimated Dry Weight (kg_{dw}/kg_{dw})	Fresh Weight (kg_{dw}/kg_{fw})
Ag*	8	1.2E-07	2.1E-08	1.9			1.0E-06	5.9E-07
Al					64	3.0E-03	3.0E-03	1.8E-03
As	7	1.1E-02	1.9E-03	4.7			9.5E-02	5.6E-02
Au	2	3.1E-02	5.6E-03	1.1			2.8E-01	1.7E-01
B	11	1.4E+00	2.5E-01	1.7	64	2.5E-01	2.5E-01	1.5E-01
Ba	11	1.6E-01	2.9E-02	1.5	64	4.9E-02	4.9E-02	2.9E-02
Be	11	1.6E-03	2.8E-04	1.5			1.4E-02	8.3E-03
Bi	3	8.3E-03	1.5E-03	3.9			7.4E-02	4.4E-02
Ca	11	3.8E-01	6.8E-02	1.9	64	9.0E-01	9.0E-01	5.3E-01
Cd	11	4.0E-02	7.2E-03	2.4			3.6E-01	2.1E-01
Ce	11	3.3E-04	6.0E-05	2.0	64	6.6E-02	6.6E-02	3.9E-02
Cl					64	2.3E+00	2.3E+00	1.4E+00
Co	11	4.0E-03	7.3E-04	2.0			3.6E-02	2.1E-02
Cr	11	1.5E-03	2.7E-04	2.1	64	1.0E-02	1.0E-02	5.9E-03
Cs	11	3.1E-02	5.5E-03	2.8			2.7E-01	1.6E-01
Cu	11	1.4E-01	2.6E-02	2.8	64	4.3E-01	4.3E-01	2.5E-01
Dy	11	6.7E-04	1.2E-04	1.9			6.0E-03	3.5E-03
Er	11	9.4E-04	1.7E-04	1.9			8.4E-03	5.0E-03
Eu	11	7.1E-03	1.3E-03	1.7			6.4E-02	3.8E-02
Fe	11	1.6E-03	2.8E-04	2.5	64	4.7E-03	4.7E-03	2.8E-03
Gd	11	1.2E-03	2.1E-04	1.6			1.1E-02	6.5E-03
Ho	11	7.6E-04	1.4E-04	1.9			6.9E-03	4.1E-03
I	2	3.9E-03	7.0E-04	2.0			3.5E-02	2.1E-02
In	7	7.7E-03	1.4E-03	2.5			6.9E-02	4.1E-02
K	11	5.8E+00	1.0E+00	1.5	64	2.3E-01	2.3E-01	1.4E-01
La	11	4.0E-04	7.3E-05	2.0			3.6E-03	2.1E-03
Li	11	1.5E-03	2.6E-04	1.7			1.3E-02	7.7E-03
Mg	11	1.7E-01	3.0E-02	1.9	64	5.0E-01	5.0E-01	3.0E-01
Mn	11	4.5E-01	8.1E-02	2.8	64	3.7E+00	3.7E+00	2.2E+00
Mo	11	1.1E-01	2.0E-02	3.0	16	7.2E-02	7.2E-02	4.2E-02
Na	10	5.4E-02	9.7E-03	2.0	64	3.3E-03	3.3E-03	1.9E-03
Nb	11	3.2E-03	5.7E-04	3.1			2.9E-02	1.7E-02
Nd	11	4.0E-04	7.3E-05	1.9			3.6E-03	2.1E-03

Element	Berry Fruit Terrestrial CR				Berry Leaf Terrestrial CR			
	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD	Count	Observed Dry Weight (kg_{dw}/kg_{dw})	Observed and Estimated Dry Weight (kg_{dw}/kg_{dw})	Fresh Weight (kg_{dw}/kg_{fw})
Ni	11	3.8E-02	6.9E-03	2.3	64	1.4E-01	1.4E-01	8.3E-02
P					64	2.1E+00	2.1E+00	1.2E+00
Pb	10	1.1E-03	1.9E-04	2.4	64	5.2E-02	5.2E-02	3.1E-02
Pr	10	4.0E-04	7.2E-05	1.9			3.6E-03	2.1E-03
Rb	11	1.2E+00	2.1E-01	2.0			1.1E+01	6.5E+00
S					64	3.1E+00	3.1E+00	1.8E+00
Sb	11	1.8E-02	3.3E-03	3.6			1.6E-01	9.6E-02
Sc	10	1.2E-03	2.1E-04	2.1			1.0E-02	5.9E-03
Sm	11	4.7E-04	8.5E-05	1.9			4.2E-03	2.5E-03
Sn	1	1.5E-01	2.7E-02				1.4E+00	8.0E-01
Sr	11	9.7E-02	1.7E-02	1.9	64	1.6E-01	1.6E-01	9.4E-02
Tb	11	8.2E-04	1.5E-04	1.8			7.4E-03	4.4E-03
Ti					64	1.8E-03	1.8E-03	1.1E-03
Tl	3	1.3E-02	2.3E-03	1.4			1.2E-01	7.1E-02
Tm	4	8.4E-04	1.5E-04	1.2			7.5E-03	4.4E-03
U	1	1.3E-03	2.3E-04				1.1E-02	6.6E-03
V	8	4.7E-04	8.4E-05	1.8			4.2E-03	2.5E-03
W	2	6.5E-02	1.2E-02	7.9			5.8E-01	3.4E-01
Y	11	9.1E-04	1.6E-04	1.8			8.2E-03	4.8E-03
Yb	7	2.8E-03	5.0E-04	1.6			2.5E-02	1.5E-02
Zn	11	1.1E-01	1.9E-02	2.1		1.9E-01	1.9E-01	1.1E-01
Zr	2	8.0E-02	1.4E-02	3.0		1.6E-03	1.6E-03	9.4E-04

A.2.11 Forb and Lichen

The CRs for forb and lichen in the Tables 13 and 14 of Sheppard et al. (2004) were averaged across species and sites. Here, the original dataset was used to calculate GMs and GSDs specifically for forb and lichen. Details of the sampling and analysis methods for the original data are described in Sheppard et al. (2004). Dry weight/fresh weight ratios of 0.47 for forb and 0.86 for lichen were used to express concentration ratio in the wet weight basis.

Table A.11: Values Used to Derive Concentration Ratios for Forb and Lichen

Element	Forb Terrestrial CR				Lichen Terrestrial CR		
	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})
Al	17	1.8E-03	8.5E-04	4.1	1	1.8E-01	1.5E-01
Ba	16	1.5E-01	7.1E-02	3.9	1	4.6E-01	4.0E-01
Bi					1	7.4E-02	6.3E-02
Be	11	2.8E-03	1.3E-03	2.8			
Ca	17	1.5E+00	7.1E-01	4.6	1	1.9E+00	1.7E+00
Cd	14	3.3E-02	1.6E-02	2.4			
Ce	17	1.8E-03	8.5E-04	3.7	1	5.9E-02	5.1E-02
Co	17	1.0E-02	4.7E-03	3.0	1	1.0E-01	8.6E-02
Cr	3	2.0E-02	9.4E-03	2.3	1	1.2E-01	1.0E-01
Cs	17	3.2E-02	1.5E-02	4.1	1	4.4E-01	3.8E-01
Cu	17	4.9E-01	2.3E-01	2.5	1	8.9E-01	7.7E-01
Dy	14	1.2E-03	5.6E-04	2.0			
Er	14	1.0E-03	4.7E-04	1.9			
Eu	14	1.8E-03	8.5E-04	2.1			
Fe	17	3.5E-03	1.6E-03	2.2	1	4.2E-02	3.6E-02

Element	Forb Terrestrial CR				Lichen Terrestrial CR		
	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})
Ga	16	4.8E-03	2.3E-03	2.6	1	1.2E-01	1.0E-01
Gd	14	1.7E-03	8.0E-04	2.3			
Ho	14	1.0E-03	4.7E-04	1.9			
In	8	4.0E-03	1.9E-03	1.8			
La	17	5.4E-03	2.5E-03	4.2	1	6.8E-02	5.8E-02
Li	5	8.0E-03	3.8E-03	2.0	1	1.0E-01	8.6E-02
Lu	10	1.1E-03	5.2E-04	1.7			
Mg	17	1.1E+00	5.2E-01	3.0	1	1.3E+00	1.1E+00
Mn	16	7.9E-02	3.7E-02	4.2	1	8.7E-01	7.5E-01
Mo	17	1.1E+00	5.3E-01	2.9	1	8.9E-01	7.6E-01
Na	17	9.2E-02	4.3E-02	1.7	1	3.8E-01	3.3E-01
Nb	7	1.4E-03	6.6E-04	9.5	1	1.5E-02	1.3E-02
Nd	17	2.3E-03	1.1E-03	3.6	1	6.4E-02	5.5E-02
Ni	9	5.1E-02	2.4E-02	2.2	1	1.8E-01	1.6E-01
Pb	17	6.8E-03	3.2E-03	7.5	1	2.1E-01	1.8E-01
Pr	14	1.8E-03	8.5E-04	2.7			
Rb	17	1.3E+00	6.1E-01	4.0	1	1.7E+00	1.5E+00
Re	7	1.0E-01	4.8E-02	2.9	1	6.1E-03	5.2E-03
Sb	14	2.5E-02	1.2E-02	4.4			
Sm	17	2.5E-03	1.2E-03	3.4	1	8.0E-02	6.9E-02
Sr	17	1.1E+00	5.0E-01	3.1	1	9.4E-01	8.1E-01
Tb	14	1.5E-03	7.1E-04	2.0			
Te	4	7.6E-02	3.6E-02	1.8			
Th	17	1.5E-03	7.1E-04	2.2	1	3.5E-02	3.0E-02
Tl	14	2.5E-02	1.2E-02	2.5			
Tm	13	8.9E-04	4.2E-04	1.9			
U	17	2.8E-03	1.3E-03	2.5	1	6.8E-02	5.8E-02
V	1	9.7E-03	4.6E-03		1	8.1E-02	7.0E-02
Y	17	2.5E-03	1.2E-03	4.3	1	1.2E-01	1.0E-01
Yb	16	1.1E-03	5.2E-04	3.6	1	8.1E-02	7.0E-02
Zn	17	2.9E-01	1.4E-01	3.0	1	2.1E+00	1.8E+00
Zr	2	1.3E-01	6.1E-02	1.4	1	4.6E-01	3.9E-01
Pb-210	3	2.6E-01	1.2E-01	4.3	1	1.2E+01	1.0E+01
Po-210	5	2.2E-01	1.0E-01	7.0			
Ra-226	5	1.9E-01	8.9E-02	2.9			

A.2.12 Generic Conifer, Generic Deciduous Shrubs and Generic Deciduous Tree

The CRs for generic conifers, generic deciduous shrubs and generic deciduous trees in Tables 13 and 14 of Sheppard et al. (2004) were averaged across species and sites. Here, the original dataset was used to calculate GMs and GSDs specifically for these species. Details of the sampling and analysis methods for the original data are described in Sheppard et al. (2004). For the generic conifer, only conifer needles and twigs were considered whereas only leaves and twigs were considered for generic deciduous shrubs and trees. Dry weight/fresh weight ratios of 0.50 for generic conifers, 0.59 for generic deciduous shrubs and 0.60 for generic deciduous trees were used to express concentration ratios in the wet weight basis.

Table A.12: Values Used to Derive Concentration Ratios for Generic Trees and Shurbs

Element	Generic Conifer Terrestrial CR				Generic Deciduous Shrub Terrestrial CR				Generic Deciduous Tree CR			
	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD
Al	24	3.5E-03	1.8E-03	14.3	26	2.0E-03	1.2E-03	5.6	15	2.3E-03	1.4E-03	2.7
As	10	5.0E-02	2.5E-02	2.6	2	3.4E-02	2.0E-02	2.1	2	1.1E-01	6.6E-02	1.5
Ba	24	2.0E-01	1.0E-01	4.1	25	2.0E-01	1.2E-01	3.8	15	2.9E-01	1.7E-01	2.4
Be	23	8.2E-03	4.1E-03	3.2	20	3.0E-03	1.8E-03	3.3	15	5.2E-03	3.1E-03	3.9
Bi	5	1.6E-02	7.8E-03	1.8					6	4.8E-02	2.9E-02	2.5
Ca	24	1.7E+00	8.5E-01	6.9	26	2.3E+00	1.4E+00	3.7	15	2.8E+00	1.7E+00	3.8
Cd	17	6.5E-02	3.3E-02	3.0	21	1.1E-01	6.5E-02	3.0	12	4.3E-02	2.6E-02	3.0
Ce	24	2.8E-03	1.4E-03	2.7	26	3.4E-03	2.0E-03	3.3	15	3.9E-03	2.3E-03	2.8
Co	24	1.5E-02	7.5E-03	2.9	26	1.3E-02	7.7E-03	3.3	15	8.5E-03	5.1E-03	2.0
Cr	24	2.1E-02	1.1E-02	3.5	22	9.9E-03	5.8E-03	3.0	14	1.1E-02	6.6E-03	2.1
Cs	24	4.7E-02	2.4E-02	5.9	26	2.4E-02	1.4E-02	4.4	15	2.1E-02	1.3E-02	2.6
Cu	24	2.0E-01	1.0E-01	2.2	26	4.8E-01	2.8E-01	3.3	15	3.0E-01	1.8E-01	1.7
Dy	23	3.5E-03	1.8E-03	2.5	21	2.5E-03	1.5E-03	3.0	15	4.4E-03	2.6E-03	3.6
Er	23	3.7E-03	1.9E-03	2.4	21	2.3E-03	1.4E-03	2.9	15	4.4E-03	2.6E-03	3.7
Eu	20	3.1E-03	1.6E-03	3.3	21	3.2E-03	1.9E-03	3.2	15	6.0E-03	3.6E-03	3.4
Fe	24	4.5E-03	2.3E-03	2.1	26	4.7E-03	2.8E-03	2.0	15	4.7E-03	2.8E-03	1.8
Ga	24	5.9E-03	3.0E-03	2.7	26	5.6E-03	3.3E-03	3.1	15	4.3E-03	2.6E-03	2.1
Gd	23	3.7E-03	1.9E-03	2.5	21	3.8E-03	2.2E-03	3.2	15	5.9E-03	3.5E-03	3.7
Ho	23	3.3E-03	1.7E-03	2.6	21	2.3E-03	1.4E-03	3.0	15	4.2E-03	2.5E-03	3.6
In	17	3.5E-03	1.8E-03	6.4	20	4.1E-03	2.4E-03	3.8	12	1.2E-02	7.2E-03	2.3
La	24	4.4E-03	2.2E-03	2.9	26	1.1E-02	6.5E-03	4.4	15	1.2E-02	7.2E-03	4.4
Li	23	1.2E-02	6.0E-03	3.4	13	1.0E-02	5.9E-03	4.4	9	1.0E-02	6.0E-03	2.3
Lu	14	3.0E-03	1.5E-03	2.8	17	1.8E-03	1.1E-03	2.9	7	1.9E-03	1.1E-03	3.5
Mg	24	3.2E-01	1.6E-01	4.5	26	8.2E-01	4.8E-01	3.5	15	6.1E-01	3.7E-01	2.0
Mn	24	3.7E-01	1.8E-01	9.2	26	2.8E-01	1.6E-01	8.6	15	1.1E-01	6.4E-02	4.8
Mo	24	5.7E-02	2.9E-02	3.0	26	5.6E-01	3.3E-01	3.0	15	1.7E-01	1.0E-01	2.8
Na	24	9.0E-02	4.5E-02	1.8	26	8.3E-02	4.9E-02	1.8	15	8.6E-02	5.2E-02	1.6
Nb	24	3.0E-03	1.5E-03	4.8	22	1.5E-03	8.8E-04	3.7	12	1.4E-03	8.2E-04	2.7
Nd	24	3.2E-03	1.6E-03	2.9	26	5.1E-03	3.0E-03	3.9	15	5.6E-03	3.4E-03	3.8
Ni	24	8.2E-02	4.1E-02	2.6	17	5.9E-02	3.5E-02	2.8	10	7.1E-02	4.2E-02	1.5
Pb	24	1.0E-02	5.0E-03	2.9	26	1.5E-02	8.9E-03	6.1	15	7.7E-03	4.6E-03	2.4
Pr	23	3.1E-03	1.6E-03	2.7	21	4.3E-03	2.5E-03	3.6	15	6.3E-03	3.8E-03	3.9
Rb	24	4.5E-01	2.3E-01	5.2	26	5.8E-01	3.4E-01	4.3	15	5.4E-01	3.2E-01	3.4
Re	10	4.9E-02	2.4E-02	38.5	15	7.5E-02	4.4E-02	7.7	10	3.2E-01	1.9E-01	5.4
Sb	23	3.6E-02	1.8E-02	2.7	21	4.4E-02	2.6E-02	3.4	15	2.4E-02	1.4E-02	3.1
Sc	7	1.2E-02	6.0E-03	3.1	4	2.2E-02	1.3E-02	1.6	7	4.1E-02	2.5E-02	2.8
Se	3	1.2E-01	6.2E-02	1.7	2	2.2E-01	1.3E-01	2.2				
Sm	24	3.6E-03	1.8E-03	2.7	26	5.0E-03	3.0E-03	3.7	15	5.3E-03	3.2E-03	3.5
Sr	24	7.6E-01	3.8E-01	3.1	26	1.1E+00	6.5E-01	2.9	15	1.3E+00	7.9E-01	2.1

Element	Generic Conifer Terrestrial CR				Generic Deciduous Shrub Terrestrial CR				Generic Deciduous Tree CR			
	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD	Count	Dry Weight GM (kg_{dw}/kg_{dw})	Fresh Weight GM (kg_{dw}/kg_{fw})	GSD
Tb	23	3.6E-03	1.8E-03	2.5	21	3.3E-03	1.9E-03	3.0	15	5.5E-03	3.3E-03	3.6
Te	6	3.4E-02	1.7E-02	1.7	9	7.8E-02	4.6E-02	2.4	5	6.1E-02	3.7E-02	1.2
Th	24	4.6E-03	2.3E-03	3.6	26	2.2E-03	1.3E-03	2.1	15	2.8E-03	1.7E-03	2.5
Tl	23	3.1E-02	1.6E-02	6.2	21	1.5E-02	8.9E-03	2.9	15	1.9E-02	1.1E-02	2.6
Tm	17	2.9E-03	1.5E-03	2.6	21	1.8E-03	1.1E-03	2.8	12	2.5E-03	1.5E-03	3.2
U	24	5.3E-03	2.7E-03	3.0	26	3.9E-03	2.3E-03	2.4	15	5.6E-03	3.3E-03	2.3
V	24	4.8E-03	2.4E-03	3.0	10	5.6E-03	3.3E-03	3.0	6	5.6E-03	3.4E-03	2.8
Y	24	5.2E-03	2.6E-03	2.9	26	5.8E-03	3.4E-03	4.5	15	6.8E-03	4.1E-03	3.9
Yb	24	3.6E-03	1.8E-03	2.7	25	2.6E-03	1.5E-03	3.3	15	3.4E-03	2.0E-03	3.4
Zn	24	5.1E-01	2.6E-01	2.9	26	4.1E-01	2.4E-01	3.6	15	2.1E-01	1.3E-01	2.4
Zr	11	3.3E-02	1.6E-02	3.3	7	5.6E-02	3.3E-02	2.6	6	4.4E-02	2.6E-02	2.9
Pb-210					9	5.2E-01	3.1E-01	1.9	2	5.2E-01	3.1E-01	1.8
Po-210	1	4.1E+00	2.1E+00		12	5.1E-01	3.0E-01	2.8	2	4.2E-01	2.5E-01	2.3
Ra-226	10	4.5E-02	2.3E-02	3.2	8	4.9E-02	2.9E-02	2.1	4	1.0E-01	6.0E-02	3.7

A.2.13 Summary of Concentration Ratios

Table A.13 summarises the resulting CRs shown in Table A.1 to A.12, which are used in the assessment model.

Table A.13: Summary of Aquatic and Terrestrial Concentration Ratios Derived using Canadian Data

Element	Aquatic CRs (L/kg$_{fw}$)			Terrestrial CRs (kg$_{dw}$/kg$_{fw}$)									
	Canada Goose	Pond-weeds	Fish	Canada Goose	Rabbit	Caribou	Moose	White-tailed Deer	White Cedar	Arctic Willow	Berries (Fruit)	Lichen	Sedges
Bi				2.9E-03				8.3E-03	5.3E-03		1.5E-03	6.3E-02	8.8E-02
Ca (Ra)	1.6E+01	2.9E+02	8.3E+02	5.7E-02	7.1E-03	2.0E-02	3.7E-02	2.2E-02	1.8E-01	6.7E-01	6.8E-02	1.7E+00	2.8E-01
Cl			1.3E+03			1.8E+00							
Cs	1.8E+04	2.1E+03	1.4E+04	8.1E-02	5.4E-03	1.1E+00	1.6E-02	9.6E-02	6.6E-03	4.9E-03	5.5E-03	3.8E-01	1.0E-02
I	3.9E+01	3.7E+01	3.7E+01								7.0E-04		
Mn (Tc)	1.3E+02		2.0E+04	3.2E-03	1.2E-04	2.4E-03	1.6E-03	1.3E-03	1.6E-02	4.2E-02	8.1E-02	7.5E-01	3.6E-02
Mo	8.6E+01	1.3E+02	1.1E+02	1.0E-01	1.1E-02	8.6E-04	2.5E-02	1.7E-02	2.7E-02	6.2E-02	2.0E-02	7.6E-01	1.2E+00
Nb	3.1E+02	2.0E+03	5.0E+01	1.2E-02		4.4E-04	2.7E-03	1.6E-03	8.6E-04	2.7E-04	5.7E-04	1.3E-02	1.2E-03
Ni	3.5E+02	5.8E+02	3.2E+02	4.9E-02			1.8E-02	1.3E-02	1.8E-02	2.1E-02	6.9E-03	1.6E-01	4.6E-02
Pb	2.4E+02	4.4E+02	1.1E+02	4.7E-03	2.1E-04		1.1E-01	2.2E-03	3.0E-03	5.0E-03	1.9E-04	1.8E-01	2.2E-03
Po-210												1.0E+01	1.8E-01
Ra-226									1.1E-02				2.4E-02
Re (Tc)	2.6E+02	5.6E+00	1.1E+01	2.7E-01				4.4E-02	1.5E-01	1.9E-02		5.2E-03	8.5E-02
Sb	2.7E+01	2.3E+01	5.5E+01	4.9E-02		9.8E-03	1.7E-02	4.2E-02	1.5E-02	1.1E-02	3.3E-03		3.1E-02
Se	6.9E+00		2.1E+01	3.5E-01	2.0E-02	7.0E-01	3.7E-01	2.8E-01	7.1E-02	8.0E-02			
Sm	7.2E+01	5.1E+02	1.1E+02	2.1E-03	6.0E-06	1.1E-05	1.1E-04	1.9E-04	2.0E-03	4.6E-04	8.5E-05	6.9E-02	8.8E-04
Sn	3.8E+01	2.9E+01		4.3E-02			1.8E-01	5.2E-01			2.7E-02		
Sr (Ra)	1.2E+01	2.6E+02	3.0E+02	2.1E-02	7.2E-03	3.8E-03	2.6E-03	2.5E-03	2.2E-01	2.2E-01	1.7E-02	8.1E-01	1.7E-01
Th	7.6E+02	1.0E+03	4.4E+02	7.1E-03					2.3E-03	5.9E-04		3.0E-02	9.2E-04
U	1.1E+01	2.1E+02	5.4E+01	9.1E-04	2.3E-04	2.5E-04		4.5E-04	4.2E-03	6.3E-04	2.3E-04	5.8E-02	1.5E-03
Zr	2.7E+01	7.2E+01	3.0E+02	1.2E-01	1.1E-02	7.2E-04			5.3E-03		1.4E-02	3.9E-01	

The element in brackets are the elements of concern that correspond (are surrogates) to the elements shown.

A.3 TISSUE/FOOD CONCENTRATION RATIOS

Tissue/Food CRs are used in the derivation of TFs. The methodology for deriving TFs is described in Section 3.3.2.

A.3.1 Canada Goose

The values reported in Table B.1 appear in the Table 9 of Sheppard et al. (2012), with the exception of the GSD for the muscle/feed CR and the muscle/feed CR corrected for grit ingestion. These are derived from the original data used for Sheppard et al. (2012), for which the details of the sampling and analysis methods are described in the report. This correction is only require when the feed (stomach content) concentrations are used in the ratio, and is necessary because birds ingest grit to aid in comminution of food. The goose stomach material was on average 0.855 ash (ash is the mass not lost by combustion at 450°C, expressed as ash/dry weight), whereas plant material is on average 0.125 ash. Therefore the stomach material included 0.73 ash and was by difference 0.27 vegetative material. The muscle/feed CR corrected for grit ingestion was the product of the unadjusted value and 0.27, assuming no elemental uptake from the grit, which is plausible because large durable grit particles would be preferred if the grit was purposefully ingested for comminution.

Table A.14: Tissue/Food Concentration Ratio for Canada Goose

Element	Tissue/Food CR (kg_{dw}/kg_{fw})		
	GM	GSD	GM corrected for grit
Ag	1.7E-02	1.5	4.7E-03
As	8.6E-02	1.8	2.3E-02
Au	4.9E-01	2.7	1.3E-01
B	1.9E-02	1.7	5.1E-03
Ba	2.7E-03	2.5	7.2E-04
Be	2.0E-03	3.7	5.3E-04
Bi	2.0E-02		5.3E-03
Ca	2.5E-02	1.7	6.7E-03
Cd	2.1E-01	1.5	5.7E-02
Ce	3.6E-03	2.3	9.7E-04
Co	5.0E-03	1.6	1.4E-03
Cr	2.4E-03	1.5	6.6E-04
Cs	5.6E-02	12.8	1.5E-02
Cu	1.9E-01	1.6	5.2E-02
Dy	4.2E-03	3.4	1.1E-03
Er	3.8E-03	3.4	1.0E-03
Eu	3.1E-03	3.1	8.2E-04
Fe	1.9E-02	1.5	5.0E-03
Ga	2.6E-03	2.0	7.1E-04
Gd	4.8E-03	3.0	1.3E-03
Hf	6.5E-03	1.6	1.8E-03
Ho	4.0E-03	3.3	1.1E-03
I	5.4E-01	2.0	1.5E-01
In	3.0E-02	1.6	8.0E-03
K	3.4E-01	1.3	9.1E-02
La	3.5E-03	2.1	9.3E-04
Li	7.9E-03	5.5	2.1E-03
Lu	1.1E-02	1.8	2.9E-03
Mg	2.9E-01	1.6	7.9E-02

Element	Tissue/Food CR (kg_{dw}/kg_{fw})		
	GM	GSD	GM corrected for grit
Mn	7.6E-03	1.8	2.1E-03
Mo	1.0E-02	1.6	2.7E-03
Na	9.9E-02	1.2	2.7E-02
Nb	4.4E-03	3.1	1.2E-03
Nd	4.3E-03	2.9	1.2E-03
Ni	3.0E-03	1.4	8.1E-04
Pb	9.1E-03	2.0	2.5E-03
Pr	4.0E-03	2.6	1.1E-03
Rb	1.6E-01	1.6	4.4E-02
Re	1.4E-01	2.0	3.9E-02
Sb	3.5E-02	4.1	9.4E-03
Sc	2.7E-03	4.1	7.4E-04
Sm	5.0E-03	3.1	1.4E-03
Sn	6.3E-02	1.9	1.7E-02
Sr	2.1E-03	2.8	5.8E-04
Ta	4.2E-01	13.6	1.1E-01
Tb	5.1E-03	3.1	1.4E-03
Te	1.4E-01	1.6	3.9E-02
Th	4.8E-03	1.4	1.3E-03
Ti	4.0E-03	3.7	1.1E-03
Tl	3.5E-02	3.4	9.5E-03
Tm	3.3E-03	3.5	8.9E-04
U	2.5E-03	2.1	6.7E-04
V	4.1E-03	2.9	1.1E-03
W	7.4E-03	3.6	2.0E-03
Y	3.7E-03	3.3	1.0E-03
Yb	2.9E-03	3.6	7.9E-04
Zn	4.1E+00	1.8	1.1E+00
Zr	2.8E-03	2.9	7.7E-04

A.3.2 Rabbit, Caribou, Moose, Elk and White-Tailed Deer

The fractional daily transfer and muscle/feed CRs for rabbit, caribou, moose, elk and white-tailed deer were largely as reported in Sheppard et al. (2012), or taken from the same dataset used to generate the data in Sheppard et al. (2012). Details of the sampling and analysis methods for the original data are described in Sheppard et al. (2012).

Table A.15: Tissue/Food Concentration Ratios for Mammals

Element	Rabbit (kg_{dw}/kg_{fw}) n=1	Caribou (kg_{dw}/kg_{fw}) n=1	Moose (kg_{dw}/kg_{fw}) n=1	Elk (kg_{dw}/kg_{fw}) n=1	White-Tailed Deer (kg_{dw}/kg_{fw}) n=11	
					GM	GSD
Ag	3.4E-02[a]	3.3E-03[a]			6.1E-02	5.5
Al						
As	6.1E-02	2.9E-02[a]	1.6E-01[a]	2.8E-01[a]	3.9E-02	1.4
Au					2.7E+00	
B		1.8E-02[a]	1.3E-02[a]	8.8E-03[a]	7.0E-03	1.7
Ba						
Be				5.5E-03	1.8E-02	1.6
Bi					5.0E-01	4.7
Ca	5.3E-03	1.1E-02	6.8E-03	2.9E-03[a]	3.0E-03	1.7
Cd	8.9E-03	1.9E-02	2.6E-02	7.2E-03	2.0E-02	2.1
Ce	1.6E-03	1.3E-03	7.9E-03	1.2E-03	1.2E-02	2.1

Element	Rabbit (kg$_{dw}$/kg$_{fw}$) n=1	Caribou (kg$_{dw}$/kg$_{fw}$) n=1	Moose (kg$_{dw}$/kg$_{fw}$) n=1	Elk (kg$_{dw}$/kg$_{fw}$) n=1	White-Tailed Deer (kg$_{dw}$/kg$_{fw}$) n=11	
					GM	GSD
Cl	8.0E-02					
Co	1.8E-02	1.1E-02	7.9E-02	1.5E-02	8.3E-03	2
Cr	1.9E-02	8.9E-04	1.7E-01	4.2E-02	1.0E-01	2.1
Cs	2.3E-01	3.1E+00	1.2E+00	2.6E+00	5.3E-01	1.9
Cu	2.2E-02	3.5E-01	2.0E-01	1.2E-01	3.1E-01	1.5
Dy	4.6E-04[a]	1.2E-04[a]	1.4E-02[a]	2.9E-03	8.6E-03	1.8
Er		1.9E-04[a]	1.1E-02[a]		8.4E-03	1.9
Eu	6.2E-03[a]	3.0E-04[a]	2.5E-03[a]		6.1E-03	2
Fe	1.3E-02	2.2E-02	8.6E-01	1.6E-01[a]	2.9E-01	1.6
Ga	2.6E-03[a]	8.0E-04[a]				
Gd					1.6E-02	
Ge						
Hf			1.0E+00[a]	2.4E-01[a]		
Hg		4.6E-02[a]			1.2E-01	1.4
Ho	3.3E-04[a]	1.1E-04	1.8E-02[a]	2.4E-03[a]	8.5E-03	1.9
I	1.1E-02	1.0E-02[a]	8.8E-02	1.4E-02[a]	1.4E-02	1.7
In		1.4E+00	1.1E+00		1.5E-01	2.8
K	2.6E-01	2.5E-03	3.2E-01	1.8E-01	2.5E-01	2.8
La	2.3E-03		1.2E-02	2.0E-03[a]	8.2E-03	1.4
Li		1.5E-03	2.3E-02	2.9E-02	1.8E-02	2.7
Lu						
Mg	7.2E-02	2.6E-01	3.0E-01	1.7E-01	1.2E-01	1.8
Mn	4.2E-04	2.3E-03	7.7E-04	1.0E-03	1.4E-03	1.8
Mo	4.9E-03	1.7E-02	1.9E-02	1.8E-03	6.7E-03	3
Na	1.6E-01	2.7E-01	3.5E-02	4.3E-02	3.3E-02	1.5
Nb		1.2E-03	7.2E-02		2.0E-02	1.7
Nd	0.0E+00	6.8E-05	8.9E-03	1.0E-03	1.0E-02	2
Ni			1.0E-01		6.5E-02	1.6
Pb	7.5E-03		1.4E+01		6.9E-02	20.4
Pr					1.3E-02	1.6
Rb	4.0E-01	3.2E+00	6.0E-01	2.3E-01	2.5E-01	1.6
Re				1.9E-02	1.3E-02	1.5
Sb		1.1E-02	2.5E-01	4.7E-02	1.6E-01	8.8
Sc					1.9E-02	1.8
Se	7.2E-01	1.0E+00	6.5E-01	1.4E+00	3.9E-01	1.6
Sm	8.3E-04	9.5E-05	2.1E-02	5.7E-03	1.5E-02	1.6
Sn						
Sr	1.3E-02	1.4E-03	8.8E-04	7.1E-04	7.6E-04	1.6
Ta		1.1E-02			2.9E-02	1.5
Tb	4.9E-03	2.7E-04	3.6E-02	5.7E-03	1.1E-02	1.6
Te		4.8E-02	1.7E-01		1.6E-01	1.7
Th						
Ti		8.1E-05	2.4E-02			
Tl	4.9E-02	4.0E-02			3.0E-02	2
Tm						
U	3.7E-04	2.1E-03			2.4E-02	
V					2.9E-02	4.9
W					7.1E-02	
Y	4.9E-04	3.3E-04	2.1E-02	5.3E-03	9.9E-03	1.7
Yb						
Zn	7.0E-02	1.4E+00	1.0E+00	8.3E-01	9.8E-01	1.4
Zr	1.5E-02	6.2E-04				

a. Originate from same dataset as Sheppard et al. (2012), but not listed.
b. Table 21, Sheppard et al. (2012)
c. Table 22, Sheppard et al. (2012)
d. Table 11, Sheppard et al. (2012)
e. Table 12, Sheppard et al. (2012)
f. Table 10, Sheppard et al. (2012)