

APPENDIX C. DEVELOPMENT OF CHEMICAL-SPECIFIC METABOLIC BIOTRANSFORMATION RATE CONSTANT DISTRIBUTIONS

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1 Introduction

This appendix discusses the development of metabolic biotransformation rate constant (K_M) distributions for use in the bioaccumulation model and describes the available information regarding K_M values for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), tetrachlorobiphenyl (tetraCB), and 1,2,3,4,6,7,8-heptachlorodibenzofuran (HpCDF) for both fish and invertebrates (including blue crab and small benthic invertebrates). Table 1-1 summarizes the chemical-species combinations for which non-zero metabolic rates were used in the bioaccumulation model.

Table 1-1. Summary of metabolic rate constants

Chemical	Use of Metabolic Rate Constants by Species					
	Fish				Invertebrates	
	Small Fish ^a	Carp	American Eel (both sizes)	Other Fish (catfish, white perch, bass)	Benthic Invertebrates	Blue Crab
2,3,7,8-TCDD	x	x	x	x	x	x
TetraCB			x		x	
1,2,3,4,6,7,8-HpCDF	x	x	x	x	x	x

^a Includes both small forage fish and small filter-feeding fish.

HpCDF – 1,2,3,4,6,7,8-heptachlorodibenzofuran

TCDD – 2,3,7,8-tetrachlorodibenzo-*p*-dioxin

TetraCB – tetrachlorobiphenyl

The remainder of this appendix presents an overview of the primary sources of information for developing K_M values (Section 2), the development of values for 2,3,7,8-TCDD, tetraCB, and 1,2,3,4,6,7,8-HpCDF (Sections 3 through 5), and a brief discussion of processes related to metabolism that may influence chemical concentrations in fish/invertebrate tissue (Section 6).

2 Primary Sources for Derivation of K_M Values

K_M values for 2,3,7,8-TCDD, tetraCB, and 1,2,3,4,6,7,8-HpCDF for use in the bioaccumulation model were developed using three primary sources of information:

- ◆ **Available information in literature** – Available information in literature was reviewed to evaluate whether chemicals are metabolized by various species, and to select K_M values for use in the Lower Passaic River study Area (LPRSA) bioaccumulation model. Arnot et al. (2008a) compiled a database of fish biotransformation rates that was used as the primary source for assigning K_M values for the LPRSA. The paper presented a comprehensive review of available laboratory data on the metabolic biotransformation of non-ionic organic chemicals by fish; it also provided and applied methodology for

estimating metabolic rate constants from the data. A summary of Arnot et al. (2008a) is provided in Section 2.1.

- ◆ **Review of empirical tissue data from the LPRSA** – Empirical tissue data were evaluated to determine whether different species uptake and/or metabolize chemicals differently. This evaluation (presented in Section 2.2) helps provide information about how the K_M values should relate to one another across species and chemicals.
- ◆ **Precedent** – When available, the use of K_M values for modeled chemicals in bioaccumulation models developed for other sites was also considered.

2.1 ARNOT ET AL. (2008A) K_M DATABASE

The objectives of Arnot et al. (2008a) were to develop a whole-body *in vivo* metabolic biotransformation rate constant (K_M) database, to develop and apply methods to provide guidance in the selection of K_M values, and to explore influences that contribute to differences in K_M values. The authors' approach was to gather bioconcentration factors (BCFs), elimination rate constants (k_T), and half-life ($t_{1/2}$) data from published and online databases and peer-reviewed literature. The mass balance estimation method was applied to the comprehensive dataset to derive K_M values.

Overall, the Arnot et al. (2008a) assessment included 4,700 BCF values for 840 chemicals and 700 k_T or $t_{1/2}$ values for 340 chemicals. After data review and model determinations, 1,535 K_M values were estimated for 702 chemicals. The diverse K_M database includes values for polychlorinated biphenyls (PCBs), dioxins, furans, aliphatic and aromatic hydrocarbons, amines, imides, alcohols, phenols ethers, ketones and esters. While the database includes 25 different test species, the majority of the data are from bioassays with common carp (41%) and rainbow trout (38%). Organism wet weights ranged from 6.6 mg to 1.1 kg and test temperatures ranged from 8 to 30°C. Data were normalized to median values of 10 g wet weight (ww) and 15°C to minimize potential errors in mass and temperature scaling coefficients.

For use in the bioaccumulation model, because organism weight and temperature can play a role in the observed K_M values, the adjustment of the K_M values was considered. A new K_M value (i.e., $k_{M,desired}$) adjusted for a different weight or temperature was calculated using Equation 1.

$$k_{M,desired} = k_{M,N} \left(\frac{W_{desired}}{W_N} \right)^{-0.25} \times \exp [0.01(T_{desired} - T_N)] \quad \text{Equation 1}$$

Where:

$k_{M,N}$ = the normalized K_M value from Arnot et al (2008a)

W_N = the normalized mass of the organism (0.01 kg)

$W_{desired}$ = the desired organism mass (kg)

T_N = the normalized water temperature (15 °C)

$T_{desired}$ = the desired site-specific water temperature

For the purposes of the LPRSA bioaccumulation model, the normalized temperature of 15°C used by Arnot et al. (2008a) was considered reasonable, so only the weight adjustment was considered.

2.2 EVALUATION OF LPRSA TISSUE DATA

One method of evaluating the expected relationship among K_M values across chemicals and species was to calculate a ratio between tissue and sediment concentrations in the LPRSA. For this exercise, the river mile (RM) 6 to RM 14.7 modeling area was used. For each species evaluated in the bioaccumulation model, the ratio of the average empirical tissue concentration to the sediment concentration in this area was calculated. These ratios were compared to evaluate whether the bioaccumulation potential and/or metabolic biotransformation may differ among the various species and chemicals. The results of this comparison are presented in Table 2-1, which is ordered based on the ratio of tissue to sediment concentrations for 2,3,7,8-TCDD (highest for carp and lowest for American eel). The ratio pattern for the other two chemicals is similar, although some differences exist. The shading in Table 2-1 is intended to highlight these differences.

Table 2-1. Ratios of fish tissue to sediment concentrations for 2,3,7,8-TCDD in the RM 6 to RM 14.7 modeling area

Species Group	Count of Tissue Samples	2,3,7,8-TCDD		TetraCB		1,2,3,4,6,7,8-HpCDF	
		Average Tissue Conc. (µg/kg ww)	Ratio of Tissue to Sediment Conc.	Average Tissue Conc. (µg/kg ww)	Ratio of Tissue to Sediment Conc.	Average Tissue Conc. (µg/kg ww)	Ratio of Tissue to Sediment Conc.
Carp	11	0.44	0.32	1,100	2.0	0.0086	0.016
White perch	8	0.15	0.11	480	0.9	0.0011	0.002
Catfish	27	0.12	0.09	340	0.6	0.0010	0.002
Bass	4	0.88	0.06	250	0.5	0.0004	0.0007
Small forage fish	13	0.048	0.03	150	0.3	0.0051	0.009
Blue crab	21	0.042	0.03	47	0.09	0.0023	0.004
American eel (large)	6	0.31	0.02	210	0.4	0.0014	0.003
American eel (small)	6	0.013	0.01	170	0.3	0.0011	0.002

Note: Shading indicates gradation of ratios, with darker reds indicating higher values. Sediment values for this evaluation were the CFT model values for the RM 6 to RM 14.7 modeling area: 1.39 µg/kg dw for 2,3,7,8-TCDD, 549 µg/kg dw for tetraCB, and 0.55 µg/kg dw for 1,2,3,4,6,7,8-HpCDF.

CFT – chemical fate and transport

dw – dry weight

HpCDF – 1,2,3,4,6,7,8-heptachlorodibenzofuran

LPRSA – Lower Passaic River Study Area

RM – river mile

SWAC – spatially weighted average concentration

TCDD – 2,3,7,8-tetrachlorodibenzo-*p*-dioxin

TetraCB – tetrachlorobiphenyl

ww – wet weight

In general, higher ratios of tissue to sediment concentrations may indicate lower metabolic rates or increased bioaccumulation based on diets. Some examples include the following:

- ◆ **Differences in metabolism or uptake** – Differences in the ratios, such as the low ratio for American eel, may indicate that bioaccumulation potential and/or metabolic biotransformation differ among species. Eel forage for food much like carp (i.e., near or within the sediment), yet the ratio of tissue to sediment concentrations is the lowest of all species investigated (Van der Oost et al. 1996).
- ◆ **Diets** – Carp diets are closely tied to sediment (i.e., carp feed by foraging in the sediment for food; thus, their diet is composed primarily of sediment, near-bottom particulates, and benthic invertebrates). For all three chemicals, the tissue to sediment ratio is highest for carp. Conversely, diets for bass (which have a lower ratio) are less closely linked to sediment (and more closely linked to water column exposures), because their diet is composed of a higher fraction of small fish and higher-trophic-level benthic invertebrates.

The results of this evaluation are also helpful when ratios are compared across chemicals. Ratios are much higher for tetraCB than for the other two chemicals, indicating (as suspected) that PCBs are not metabolized, or are metabolized at a lower rate than, dioxins/furans. Blue crab appears to be a possible exception – the low ratio value relative to those of other species for tetraCB indicates that crab may metabolize PCBs. Furthermore, 1,2,3,4,6,7,8-HpCDF has lower ratios as compared with 2,3,7,8-TCDD, indicating that metabolic rates are likely higher for HpCDF. This evaluation is discussed further herein in relation to the development of the K_M values.

3 Metabolic Biotransformation Rate Constants for 2,3,7,8-TCDD

This section presents the selected K_M values for 2,3,7,8-TCDD and the process used to develop these values. Table 3-1 provides a summary of the selected metabolic rate distributions. More details and the rationale for these distributions are provided in the subsections that follow.

Table 3-1. Summary of K_M distributions for 2,3,7,8-TCDD

Species	K_M Distribution	
	Nominal Value	Acceptable Range
Fish		
Small fish	0.013	0.002–0.082
Carp	0.003	0.0004–0.013
American eel (both size classes)	0.006	0.0005–0.045
Other fish (catfish, white perch, bass)	0.006	0.0005–0.045
Invertebrates		
Small benthic invertebrates	0.013	0.007–0.024
Blue crab	0.006	0.0005–0.045

K_M – metabolic biotransformation rate constant

TCDD – tetrachlorodibenzo-*p*-dioxin

3.1 DISTRIBUTION DEVELOPMENT FOR FISH

A total of seven entries for 2,3,7,8-TCDD were available in the Arnot et al. (2008a) database: three for carp, two for fathead minnow, and one each for guppy and rainbow trout (Table 3-2). All of these data were classified as category 1, indicating a very high level of confidence in the studies.

Table 3-2. Fish K_M values for 2,3,7,8-TCDD from Arnot et al. (2008a)

Species	Temperature and Body Weight-normalized K _M Values			Data Category ^b
	Best Estimate	Estimated Percentiles ^a		
		2.5 th Percentile	97.5 th Percentile	
Common carp	0.019	0.0063	0.057	1
	0.014	0.0044	0.048	1
	0.008	0.0016	0.035	1
Fathead minnow	0.009	0.0030	0.027	1
	0.007	0.0022	0.024	1
Guppy	0.008	0.0016	0.044	1
Rainbow trout	0.024	0.0071	0.082	1
Summary (all)	0.013 (average)	0.0016 (lowest)	0.082 (highest)	-
Summary (carp only)	0.014 (average)	0.0016 (lowest)	0.057 (highest)	-

^a Estimated percentiles are as reported in Arnot et al. (2008a).

^b A data category ranging from 1 (indicating a very high level of confidence) to 5 (indicating a low level of confidence) or 6 (indicating an uncertain level of confidence) was assigned to each study (Arnot et al. 2008a).

K_M – metabolism biotransformation rate constant

TCDD – tetrachlorodibenzo-*p*-dioxin

Next, the summary values in Table 3-2 were adjusted for the body weights for the LPRSA bioaccumulation model species using Equation 1. For carp, species-specific values were available from Arnot et al. (2008a), so only those values were used when developing weight-adjusted K_M values for carp. For the other three species, the

averages and ranges across all seven studies were used. Model weights and weight-adjusted K_M values are presented in Table 3-3. In addition, this table presents the selected K_M values for each modeled species (or group of modeled species) for use in the bioaccumulation model.

Table 3-3. Weight-adjusted K_M values for 2,3,7,8-TCDD

LPRSA Species	Model Weight (kg) ^a	Normalized K _M Values	Weight-adjusted K _M Values		
			Average	Low-end Value	High-end Value
Adjusted values (using normalized K _M values for all species)					
Small American eel	0.13	Average: 0.013 Range: 0.002–0.082	0.007	0.0009	0.043
Large American eel	0.39		0.005	0.0006	0.033
Catfish	0.93		0.004	0.0005	0.026
White perch	0.11		0.007	0.0009	0.045
Bass	0.29		0.006	0.0007	0.035
Adjusted values (using normalized K _M values for only carp)					
Carp	3.1	Average: 0.014 Range: 0.0016–0.057	0.003	0.0004	0.013
Selected values by model species					
Small fish (used normalized values from Arnot et al. (2008a) because fish were similar in weight to the 10-g-normalized value)			0.013	0.002	0.082
All other fish and blue crab (used weighted-adjusted values for eel [both size classes], catfish, white perch, and bass)			0.006 (average)	0.0005 (lowest value)	0.045 (highest value)
Carp (used weight-adjusted values for carp)			0.003	0.0004	0.013

^a Weights are as presented in Table 3-10 of the main report.

K_M – metabolism biotransformation rate constant

LPRSA – Lower Passaic River Study Area

TCDD – tetrachlorodibenzo-*p*-dioxin

The following is a discussion of the development of the K_M values for 2,3,7,8-TCDD for each species:

- ◆ **Small fish** – No species-specific small fish data were available. The model weights for the two groups of small fish included in the model (i.e., small filter-feeding fish and small forage fish) ranged from about 3 to 7 g. Thus, because the adjusted values were similar to the normalized values, and because of the considerable range in small fish sizes, the normalized K_M values taken from Arnot et al. (2008a) (i.e., nominal value of 0.013 and range of 0.002 to 0.082) were used in the bioaccumulation model.
- ◆ **Carp** – For carp, species-specific estimated rates were available from three studies (Arnot et al. 2008a). The nominal value of the distribution was set equal to the average of the weight-adjusted best estimate (0.003), and the range was set equal to the weight-adjusted lowest 2.5th percentile and highest 97.5th

percentile (0.004 to 0.013) (Table 3-3). The lower K_M values for carp relative to other species are consistent with the higher tissue-to-sediment ratios observed for the LPRSA (Table 2-1).

- ◆ **Other fish species (i.e., American eel, catfish, white perch, and bass)** – For all other fish species, the nominal value of the distribution was set equal to the average of the weight-adjusted best estimate (0.006), and the range was set equal to the weight-adjusted lowest 2.5th percentile and highest 97.5th percentile (0.005 to 0.045) (Table 3-3).
- ◆ **American eel** – Although no species-specific K_M information was available for eel in Arnot et al. (2008a), LPRSA empirical tissue data (Table 2-1) and other literature information (Van der Oost et al. 1996) supported the use of a different K_M value for eel than for other species. Thus, while the initial distribution used for eel was the same one used for other fish (catfish, white perch, and bass), the K_M value for eel in the bioaccumulation model was allowed to be calibrated separately. Justification for this decision includes the following:
 - ◆ In a study of the bioaccumulation patterns of various organic compounds in European eel (a species closely related to American eel) (Van der Oost et al. 1996), the bioaccumulation of dioxins/furans was found to be extremely low. The authors concluded that this result was most likely due to reduced uptake, effective metabolic biotransformation, or both. Although this study was not sufficient to develop an eel-specific K_M value, its results support the use of a different (i.e., higher) K_M value for eel.
 - ◆ The LPRSA empirical tissue data evaluation (Table 2-1) supports the possibility that K_M values for eel may be different. Among the 2,3,7,8-TCDD species ratios, the tissue-to-sediment ratios were the lowest for the two eel size classes, possibly indicating reduced uptake and/or effective metabolic clearance.

3.2 EVALUATION OF METABOLISM IN INVERTEBRATES

Support for the metabolic biotransformation (or inefficient uptake) of dioxins/furans by invertebrates can be found in the results of work performed for the Contaminant Assessment and Reduction Project (CARP) for the New York/New Jersey Harbor estuary (HydroQual 2007). In that study, biota-sediment accumulation factors (BSAFs) for PCB homologues and dioxin/furan congeners for blue crab, clams, and worms were calculated using field-collected tissue data and model-calculated sediment concentrations. The resulting BSAFs were plotted against the octanol-water partition coefficient (K_{OW}) for the two chemical groups (i.e., PCBs and dioxins/furans). The calculated BSAFs for dioxin/furan congeners for clams, crabs, and worms were approximately 10 times lower than those for PCBs (for chemicals with similar K_{OW} values). The HydroQual (2007) report stated that “this suggests that either there is an

inefficient transfer of dioxin/furan congeners from sediment, or that worms also possess the capacity to metabolize dioxin and furan congeners.” A similar summary was provided for clams and crabs in the same report. It should be noted that the report did not include metabolic biotransformation by zooplankton, based on a similar comparison of empirical tissue concentrations and modeled dissolved water concentrations for PCBs and dioxins/furans. This is consistent with the assumption that the K_M for zooplankton is equal to 0 in the LPRSA bioaccumulation model.

CYP450 1A¹ expression is not known to occur in benthic invertebrates. It is possible that benthic invertebrates metabolize 2,3,7,8-TCDD by a different route than do vertebrates. One study (Zhang et al. 2011), which measured the uptake and elimination of a dioxin compound for invertebrates, was found as part of the literature search. In this study, radiotracers were used to measure the uptake, assimilation efficiency, and elimination of 1,2,3,4,7,8-hexachlorodibenzo-*p*-dioxin (HxCDD)² in marine phytoplankton, copepods, and fish. The half-life of 1,2,3,4,7,8-HxCDD in copepods of 2 to 25 days was less than that observed for fish in other studies (Zhang et al. 2011). According to Zhang et al. (2011), the results suggested that these invertebrates have a rapid metabolic biotransformation rate due to their small size; the results may also indicate that copepods have an efficient elimination system for removing or metabolizing 1,2,3,4,7,8-HxCDD.

Based on the supporting information summarized, non-zero K_M values were applied for 2,3,7,8-TCDD for both benthic invertebrates and blue crab. No invertebrate-specific rates could be identified, so the K_M distribution developed for small fish was used for benthic invertebrates, and the distribution developed for other fish was used for blue crab.

4 Metabolic Biotransformation Rate Constants for TetraCB

This section presents the selected K_M values for tetraCB and the process used to develop these values. Table 4-1 provides a summary of the selected metabolic rate distributions. More details and the rationale for these distributions are provided in the subsections that follow.

¹ CYP450 1A1 is the most important enzyme in TCDD metabolism for vertebrates.

² Zhang et al. (2011) did not identify the specific dioxin compound that was evaluated in this study. In a personal communication, the authors (Wang 2014) clarified that the compound used in their study was 1,2,3,4,7,8-HxCDD.

Table 4-1. Summary of selected K_M distributions for tetraCB

Species	K_M Distribution	
	Nominal Value	Acceptable Range
Fish		
American eel (both size classes)	0.002	0.0004–0.014
Other fish (small fish, carp, catfish, white perch, bass)	0	na
Invertebrates		
Small benthic invertebrates	0	na
Blue crab	0.002	0.0004–0.014

K_M – metabolic biotransformation rate constant

na – not applicable

tetraCB – tetrachlorobiphenyl

4.1 EVALUATION OF METABOLISM IN FISH

In numerous previous applications of bioaccumulation models, the metabolic biotransformation of PCBs by fish has been assumed to be equal to zero (Arnot and Gobas 2004; Gobas and Arnot 2010; Windward 2010; HydroQual 2007). This precedent was used as the starting point for determining K_M values for tetraCB.

The calculated tissue-to-sediment ratios for tetraCB are higher than those for the two dioxin/furans, further supporting the conclusion that metabolism of tetraCB is limited or non-existent for most species. The pattern across species for tetraCB is similar to that for 2,3,7,8-TCDD in that the ratio is highest for carp and lowest for bass, American eel, and blue crab (Table 2-1). Taking into account feeding strategies and diets, this comparison provides evidence that the bioaccumulation potential and/or metabolic biotransformation of some species (e.g., blue crab and American eel) may be different than that of most fish. In addition to the evaluation of LPRSA tissue data (Table 2-1), available information from literature regarding the ability of fish to metabolize PCBs was reviewed, although relatively little relevant information was available on this topic (metabolism for blue crab is addressed in Section 4.2).

A review conducted by Brown (1992) examined the activity of the enzyme cytochrome P-4502B (P4502B), which is likely important in the metabolic biotransformation of certain PCBs (including several tetraCBs), by reviewing capillary gas chromatograms (GCs) from previous investigations. Brown (1992) looked at the activity of this enzyme (and attempted to quantify the magnitude of activity, when present) in 54 aquatic species, including mollusks, annelids, arthropods, echinoderms, and fish. Of the 32 species of fish evaluated, only 4 (i.e., American eel, cunner, red-breasted sunfish, and winter flounder) showed P4502B activity. The fish species included in this evaluation are presented in Table 4-2; species modeled as part of the LPRSA bioaccumulation model are in bold.

Table 4-2. Summary of P4502B activity in fish

Species Evaluated in Brown (1992)			
Species for which No P4502B Activity was Observed			Species for which P4502B Activity was Observed
American shad	Goldfish	Sheepshead minnow	American eel
Arctic cod	Lake trout	Smallmouth bass	Cunner
Atlantic silversides	Largemouth bass	Striped bass	Red-breasted sunfish
Atlantic tomcod	Lizardfish	Striped killifish	Winter flounder
Bloater	Menhaden	Tautog	
Bluefish	Mummichog	Walleye	
Brown bullhead	Naked goby	White catfish	
Carp	Northern pike	White perch	
Crevalle jack	Pumpkinseed	Yellow perch	
Fathead minnow			

Source: Brown (1992)

Bold identifies species that were modeled as part of the LPRSA bioaccumulation model.

LPRSA – Lower Passaic River Study Area

P4502B – cytochrome P-4502B

A literature search was performed to look for additional, more recent investigations of P4502B activity in fish. This search returned limited results. However, one study (Koenig et al. 2012), which evaluated the role of P4502B-mediated metabolic biotransformation in several species of crustaceans and non-eel species of fish, was found. The species of fish evaluated were reported to lack P4502B-like enzymes, even though, in contrast, the crustaceans evaluated exhibited activity for these types of enzymes. Thus, Koenig et al. (2012) concluded that the differences in PCB profiles between the fish and crustaceans could be linked to variations in P4502B-mediated metabolic biotransformation.

As discussed, the available literature information and LPRSA data suggest that unlike most fish species, American eel express P4502B, which is associated with the metabolic biotransformation of some PCBs, including several tetraCBs. Thus, a distribution for eel was developed for use in the bioaccumulation model (see Section 4.3).

4.2 EVALUATION OF METABOLISM IN INVERTEBRATES

As part of developing K_M values for tetraCB, a literature search was conducted for studies on the metabolic biotransformation of tetraCB by aquatic invertebrates. This search yielded relatively few articles, most of which focused on the metabolic biotransformation of PCBs by crabs or other decapods. Key points associated with invertebrates and the metabolic biotransformation of tetraCBs are as follows:

- ◆ Species-specific studies (Porte and Albaiges 1993; Bodin et al. 2007) indicated that several crab species (i.e., *Macropipus tuberculatus*, *Necora puber*, and *Cancer pagurus*) have a strong capacity to metabolize certain PCB congeners relative to that of mussels and fish.

- ◆ TetraCB includes several congeners found to be strongly metabolized in crab (Porte and Albaiges 1993). The position of chlorines on the PCBs is an apparent determinant of metabolic biotransformation (Finley et al. 1997; Porte and Albaiges 1993), with the enzyme cytochrome P4502B likely being important in that process (Brown 1992; Bodin et al. 2008; Bodin et al. 2007).
- ◆ Brown (1992) reported that P4502B activity was not observed in any of the mollusk, annelid, or echinoderm species evaluated but was observed in some larger crustaceans (particularly lobster and blue crab).³

Overall, the literature indicated that lower-chlorinated PCBs are likely metabolized to some extent in crab but that metabolic biotransformation is minimal in most other invertebrates. Thus, the K_M values for tetraCB for the small benthic invertebrates was assumed to be equal to zero. This was consistent with the assumptions for PCBs used in previous applications of bioaccumulation models (Arnot and Gobas 2004; Gobas and Arnot 2010; Windward 2010; HydroQual 2007). The development of a tetraCB K_M distribution for blue crab is discussed in Section 4.3.

4.3 DISTRIBUTION DEVELOPMENT FOR EEL AND CRAB

K_M distributions for tetraCB for both American eel and blue crab were developed using the available K_M values for tetraCB congeners from Arnot et al. (2008b). As indicated in Table 4-3, nearly all of the available K_M values were based on studies of rainbow trout; rates were not available for any of the fish evaluated in the LPRSA bioaccumulation model. Steps for distribution development were as follows:

- ◆ **Compilation of data** – Average best estimate, 2.5th percentile-, and 97.5th percentile-normalized K_M values for the available tetraCB PCB congeners were compiled from Arnot et al. (2008b) (Table 4-3).
- ◆ **Calculate weight-adjusted values** – Weight-adjusted K_M values were calculated based on the average weight of 0.22 kg for the three model compartments for which the distribution was applied (small eel [0.13 kg], blue crab [0.15 kg], and large eel [0.39 kg]) using Equation 1 (Table 4-4).
- ◆ **Calculate overall tetraCB K_M values using percent contribution of tetraCB sum to sediment** – To take into account the prevalence of the various tetraCB congeners in the LPRSA, the percent contribution to tetraCB sum in sediment was calculated for each congener (Table 4-4). These values were then used to calculate a weighted average K_M value for tetraCBs.

³ Koeing et al. (2012) reported lower levels of P4502B-inducing PCB congeners in one species of shrimp. This was consistent with Brown (1992), which also identified P4502B activity in shrimp.

The distribution was set equal to the average best estimate value of 0.002, with a range of 0.0004 (i.e., the 2.5th percentile estimate) to 0.014 (i.e., the 97.5th percentile estimate) (Table 4-4).

Table 4-3. K_M values for tetraCB congeners

Congener	No. of Studies	Species	Average Normalized K_M from Arnot et al. (2008a) ^a		
			Average	2.5 th Percentile	97.5 th Percentile
PCB 40	5	rainbow trout	0.008	0.001	0.06
PCB 42	4	rainbow trout	0.002	0.0002	0.03
PCB 44	5	rainbow trout	0.007	0.001	0.04
PCB 46	3	rainbow trout	0.005	0.0005	0.07
PCB 52	5	guppy (4), rainbow trout (1)	0.002	0.0002	0.02
PCB 53	1	rainbow trout	0.0008	0.00008	0.008
PCB 56	2	rainbow trout	0.003	0.0005	0.02
PCB 61	1	rainbow trout	0.0009	0.00007	0.01
PCB 64	2	rainbow trout	0.002	0.0001	0.03
PCB 65	1	rainbow trout	0.0004	0.00004	0.004
PCB 66	4	rainbow trout	0.006	0.0009	0.04
PCB 70	3	rainbow trout	0.003	0.0005	0.02
PCB 72	1	rainbow trout	0.0003	0.00005	0.001
PCB 74	3	rainbow trout	0.004	0.0003	0.07
PCB 77	2	rainbow trout	0.03	0.009	0.1

^a Estimated percentiles are as reported in Arnot et al. (2008a).

K_M – metabolism biotransformation rate constant

PCB – polychlorinated biphenyl

tetraCB – tetrachlorobiphenyl

Table 4-4. Calculation of weight-adjusted tetraCB K_M values

Congener	Percent Contribution ^a	Weight-adjusted K_M Values ^b		
		Average	2.5 th Percentile	97.5 th Percentile
PCB 40	7.8%	0.004	0.0005	0.03
PCB 42	4.5%	0.001	0.0001	0.01
PCB 44	19%	0.003	0.0006	0.02
PCB 46	1.1%	0.003	0.0002	0.03
PCB 52	18%	0.0009	0.0001	0.008
PCB 53	0%	0.0004	0.00004	0.004
PCB 56	5.9%	0.002	0.0002	0.01
PCB 61	22%	0.0004	0.00003	0.005
PCB 64	5.9%	0.0009	0.00007	0.01
PCB 65	0%	0.0002	0.000021	0.002
PCB 66	13%	0.003	0.00040	0.02
PCB 70	0%	0.001	0.00022	0.01
PCB 72	0.2%	0.0001	0.00002	0.0007
PCB 74	0%	0.002	0.000125	0.03

Congener	Percent Contribution ^a	Weight-adjusted K _M Values ^b		
		Average	2.5 th Percentile	97.5 th Percentile
PCB 77	2.2%	0.01	0.0041	0.05
Weighted Average		0.002	0.0004	0.014

^a The percent contribution is the percent contribution of each congener to the tetraCB sum in LPRSA sediment.

^b K_M values were adjusted using an average weight of 0.22 kg, which is the average across the three model compartments for which the tetraCB K_M distribution was used (small American eel [0.13 kg], blue crab [0.15 kg], and large American eel [0.39 kg]). Weights are as presented in Table 3-10 of the main report.

K_M – metabolism biotransformation rate constant

LPRSA – Lower Passaic River Study Area

PCB – polychlorinated biphenyl

tetraCB – tetrachlorobiphenyl

5 Metabolic Biotransformation Rate Constants for 1,2,3,4,6,7,8-HpCDF

This section presents the selected K_M values for 1,2,3,4,6,7,8-HpCDF and the process used to develop these values. Table 5-1 provides a summary of the selected metabolic rate distributions. More details and the rationale for these distributions are provided in the subsections that follow.

Table 5-1. Summary of K_M distributions for 1,2,3,4,6,7,8-HpCDF

Species	K _M Distribution	
	Nominal Value	Acceptable Range
Fish		
Small fish	0.086	0.031–0.24
Carp	0.036	0.007–0.13
American eel (both size classes)	0.036	0.007–0.13
Other fish (catfish, white perch, and bass)	0.036	0.007–0.13
Invertebrates		
Small benthic invertebrates	0.086	0.031–0.24
Blue crab	0.036	0.007–0.13

HpCDF – heptachlorodibenzofuran

K_M – metabolic biotransformation rate constant

5.1 EVALUATION OF METABOLISM IN INVERTEBRATES

As described for 2,3,7,8-TCDD, the available literature regarding the metabolism of dioxins/furans by invertebrates supports the use of a non-zero K_M value for benthic invertebrates and blue crab. No invertebrate-specific information was available, so the distribution for small fish was used for small benthic invertebrates and the distribution for other fish was used for blue crab (Section 5.2).

5.2 DISTRIBUTION DEVELOPMENT

Using the same process as for 2,3,7,8-TCDD, available studies from Arnot et al. (2008a) were identified (Table 5-2). Only a single study, which looked at metabolic rates for guppy, was available for HpCDF. This study's results were classified as category 1 data, indicating a very high level of confidence in the study. Thus, this study was used to calculate weight-adjusted K_M values for use in the development of distributions for the LPRSA bioaccumulation model. Because limited information was available to develop unique distributions for each species, a single distribution (equal to the average across fish species) was used for fish and blue crab. For small fish and small benthic invertebrates, the values for smaller organisms, as presented in Arnot et al. (2008a) were used to populate the distribution.

Table 5-2. Weight-adjusted K_M values for 1,2,3,4,6,7,8-HpCDF

LPRSA Species	Model Weight (kg) ^a	Normalized K _M Values	Weight-adjusted K _M Values		
			Average	Low-end Value	High-end Value
Adjusted values (using normalized K _M values for all species)					
Small American eel	0.13	Average: 0.086 Range: 0.031–0.24	0.045	0.016	0.13
Carp	3.1		0.021	0.007	0.058
Catfish	0.92		0.028	0.010	0.078
White perch	0.11	Values for single HpCDF study (guppy) from Arnot et al. (2008a)	0.047	0.017	0.13
Large American eel	0.39		0.035	0.012	0.097
Bass	0.29		0.037	0.013	0.10
Selected values by model compartment					
Fish and blue crab (average across fish species)			0.036	0.007	0.13
Small fish and small benthic invertebrates			0.086	0.031	0.24

^a Weights are as presented in Table 3-3 of the main report.

HpCDF – heptachlorodibenzofuran

K_M – metabolism biotransformation rate constant

LPRSA – Lower Passaic River Study Area

TCDD – tetrachlorodibenzo-*p*-dioxin

6 Related Processes that Influence Chemical Concentrations

When reviewing K_M data, it is important to recognize that other processes (e.g., reduced uptake) that influence chemical concentrations in biota are likely to affect metabolic rate data. In a study of European eel (discussed in Section 2.2), Van der Oost et al. (1996) noted that the lower chemical concentrations observed in eel could be the result of reduced uptake, high rates of metabolic biotransformation, or a combination of these processes. For the purpose of the bioaccumulation model, it is not necessarily important to distinguish between the metabolic biotransformation rate

constant and factors that could reduce the uptake of a given chemical, because both processes have the same outcome: a lower concentration of the chemical (i.e., parent/unmetabolized chemical) in biota tissue than might otherwise be expected. However, it is important to acknowledge the overlapping nature of these processes, particularly for parameters such as metabolic biotransformation rate constants, for which species-specific and/or site-specific data are often unavailable.

Rather than attempting to capture all of the processes that exist in a system, the goal of the bioaccumulation model is to replicate the LPRSA system to the extent necessary to accurately predict tissue concentrations. It is important to add sufficient complexity to ensure that the model can replicate the complex natural system without creating an unnecessarily complex model. Thus, in cases where chemical-specific K_M values and other factors result in a reduced uptake of chemicals, it is appropriate to use a single parameter to act as a surrogate for related processes.

7 References

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