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Appendix E

Methodology for Developing Target Floodplain Soil PCB Concentrations Associated with the IMPGs for Mink

APPENDIX E

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1. Introduction

The Interim Media Protection Goals (IMPGs) approved by the U.S. Environmental Protection Agency (EPA) for piscivorous mammals (mink and otter) include a range of 0.984 to 2.43 milligrams per kilogram (mg/kg) for polychlorinated biphenyls (PCBs), applicable to the dietary items of those mammals (GE, 2006). These IMPGs were based on an assessment of potential risks to the American mink (*Mustela vison*), as described in EPA's Ecological Risk Assessment (ERA; EPA, 2004). EPA directed GE, in its conditional approval letter for the CMS Proposal, to use mink as the representative species for evaluating achievement of these IMPGs in the Corrective Measures Study (CMS). However, because the IMPGs apply to PCB concentrations in the tissue of the mink's prey, these IMPGs cannot be applied directly in the CMS, but need to be translated into media that are subject to evaluation in the CMS. This is complicated by the fact that the mink's prey consists of a highly diverse mixture of aquatic and terrestrial organisms. As a result, the total PCB concentration in the mink's diet is affected by sediment PCB concentrations and floodplain soil PCB concentrations, and the concentrations in one such medium will affect the allowable concentration in the other medium. In its conditional approval letter for the CMS Proposal, EPA directed GE to develop a methodology for determining target floodplain soil concentrations associated with the mink IMPGs based on a range of assumed sediment concentrations.

GE initially proposed such a methodology in the CMS Proposal Supplement (ARCADIS BBL and QEA, 2007b). In its July 11, 2007 conditional approval letter for that Supplement, EPA directed GE to make a number of changes in that methodology. After GE invoked dispute resolution on several of those directives, EPA modified some of its directives in a letter dated August 29, 2007. This Appendix describes the revised methodology that has been used, in accordance with EPA's July 11, 2007 conditional approval letter (as modified in its August 29, 2007 letter), to develop target floodplain soil levels associated with the IMPGs for mink.

To convert the dietary IMPG values into target floodplain soil concentrations, the first step was to select a range of target sediment PCB concentrations that fall within the range of other sediment IMPGs (e.g., based on human direct contact and other ecological receptors). The target sediment concentrations selected were 1, 3, and 5 mg/kg. Using these target sediment concentrations (i.e., assuming that the sediment concentrations are at these levels), the floodplain soil concentrations associated with achieving the high and low ends of the dietary IMPG range (rounded to 0.98 and 2.4 mg/kg) in mink prey were then calculated.

The underlying equations, assumptions, and results of this analysis are detailed below. The target PCB concentrations have been developed for the Housatonic River floodplain from data obtained in the Primary Study Area (PSA), which consists of subreaches 5A, 5B, 5C, and 6, as well as the backwaters in the lower part of Reach 5 (referred to as Reach 5D). Based on EPA's letter dated August 29, 2007, these subreaches have been combined into the following two averaging areas: Reach 5A/5B and Reach 5C/5D/6. Although GE considers that the habitat contained in these two areas is too small to support a local population of mink, GE has used this approach in accordance with EPA's directive. Consequently, separate target PCB soil concentrations protective of mink have been developed for these two averaging areas; these target concentrations vary depending on the assumed sediment PCB concentration in the same area. As further directed by EPA, the target soil concentrations conservatively assume that the mink forage exclusively within the defined Rest of River floodplain (i.e., the 1 mg/kg PCB isopleth), rather than also in areas outside that isopleth, even though foraging in tributaries and uncontaminated areas outside the isopleth is likely. The resulting target floodplain soil concentrations have been used in evaluating the ability of floodplain remedial alternatives to achieve the mink IMPGs in the PSA, and have also been used in making such evaluations on a screening-level basis for further downstream areas.

2. Derivation of Equation for Target Soil PCB Concentrations

The objective was to derive an equation that estimates target soil PCB concentrations protective of mink at a given target sediment PCB concentration. Such an equation must account for the uptake of PCBs by mink prey from both the river sediments and floodplain soils. The equation must subtract the PCB contribution of the aquatic prey items (based on target sediment levels of 1, 3, or 5 mg/kg) from the allowable PCB concentration in the total prey (based on the IMPGs) to determine the allowable concentration of PCBs from terrestrial prey items. The derivation of such an equation requires first quantifying the fraction of each prey item in the mink's diet and each item's associated PCB tissue concentrations to estimate the total PCB concentration in the prey.

The diet-based IMPG is related to PCB concentrations in the aquatic and terrestrial prey of mink as follows:

$$C_p = (P_i \times C_i) + (P_f \times C_f) + (P_a \times C_a) + (P_{ab} \times C_{ab}) + (P_{tb} \times C_{tb}) + (P_{am} \times C_{am}) + (P_{tm} \times C_{tm}) \quad \text{Eqn. 1}$$

where

C_p = target PCB concentration in total mink prey, set equal to the EPA-approved IMPG values (mg PCBs/kg diet)

P_i= proportion of diet from aquatic invertebrates

P_f = proportion of diet from fish

P_a= proportion of diet from amphibians and reptiles

P_{ab}= proportion of diet from aquatic birds

P_{tb}= proportion of diet from terrestrial birds

P_{am}= proportion of diet from aquatic mammals

P_{tm}= proportion of diet from terrestrial mammals

C_i= PCB concentration in aquatic invertebrates (mg PCBs/kg invertebrate)

C_f = PCB concentration in fish (mg PCBs/kg fish)

C_a= PCB concentration in amphibians and reptiles (mg PCBs/kg amphibian/reptile)

C_{ab}= PCB concentration in aquatic birds (mg PCBs/kg bird)

C_{tb}= PCB concentration in terrestrial birds (mg PCBs/kg bird)

C_{am}= PCB concentration in aquatic mammals (mg PCBs/kg mammal)

C_{tm}= PCB concentration in terrestrial mammals (mg PCBs/kg mammal)

This equation is similar to the one used in Section 3.7 of the revised IMPG Proposal (GE, 2006), except that birds and mammals are split into aquatic and terrestrial components to account for the separate source of PCBs for these groups.

Having defined the relationship between the mink's total dietary exposure and the tissue concentrations in the individual prey items, it is necessary to define the relationships between the prey and the PCB concentrations in the sediments and soils to which they are exposed. For organisms exposed to sediment, multiplication factors (known as biota-sediment accumulation factors [BSAFs]) represent the relationship between the lipid-normalized concentration of PCBs in aquatic prey and the organic carbon (OC)-normalized concentration of PCBs in sediment (Ankley et al. 1992). Using aquatic invertebrate prey of the mink as an example, the BSAF is as follows:

$BSAF_i = (C_i / LIPID_i) / (C_{sed} / FOC_{sed})$ Eqn. 2

where

$BSAF_i$ = biota-sediment accumulation factor for aquatic invertebrates (kg OC/kg lipid)

C_i = PCB concentration in aquatic invertebrates (mg PCBs/kg invertebrate)

$LIPID_i$ = fraction of body weight in lipids for aquatic invertebrates (kg lipid/kg invertebrate)

C_{sed} = PCB concentration in sediment (mg PCBs/kg sediment)

FOC_{sed} = fraction of total organic carbon in sediment (kg total OC/kg sediment)

Solving Equation 2 for the PCB concentration in aquatic invertebrate prey, C_i, yields:

$C_i = BSAF_i \times C_{sed} \times (LIPID_i/FOC_{sed})$ Eqn. 3

For organisms exposed to soil, the relationship between the soil and tissue concentrations is usually described by bioaccumulation factors (BAFs) instead of BSAFs. BAFs are typically not based on lipid-normalized tissue and OC-normalized soil concentrations. Using terrestrial mammalian prey as an example, the BAF is calculated as follows:

$BAF_{tm} = C_{tm}/C_{soil}$ Eqn. 4

where

BAF_{tm} = soil-to-terrestrial mammal bioaccumulation factor (kg soil/kg mammal)

C_{tm} = PCB concentration in terrestrial mammal tissue (mg PCBs/kg mammal)

C_{soil} = PCB concentration in floodplain soil (mg PCBs/kg soil)

Solving Equation 4 for concentration of PCBs in terrestrial mammalian prey yields

$C_{tm} = BAF_{tm} \times C_{soil}$ Eqn. 5

After developing a relationship similar to Equation 3 for each aquatic prey item and a relationship similar to Equation 5 for each terrestrial prey item, all the sediment-prey and soil-prey relationships can be substituted into Equation 1 as follows:

$C_p = [(P_i \times BSAF_i \times C_{sed} \times LIPID_i / FOC_{sed}) + (P_f \times BSAF_f \times C_{sed} \times LIPID_f / FOC_{sed}) + (P_a \times BSAF_a \times C_{sed} \times LIPID_a / FOC_{sed}) + (P_{ab} \times BSAF_{ab} \times C_{sed} \times LIPID_{ab} / FOC_{sed}) + (P_{tb} \times BAF_{tb} \times C_{soil}) + (P_{am} \times BSAF_{am} \times C_{sed} \times LIPID_{am} / FOC_{sed}) + (P_{tm} \times BAF_{tm} \times C_{soil})]$ Eqn. 6

where

$BSAF_i$= biota-sediment accumulation factor for aquatic invertebrates (kg OC/kg lipid)

$BSAF_f$ = biota-sediment accumulation factor for fish (kg OC/kg lipid)

$BSAF_a$= biota-sediment accumulation factor for amphibians and reptiles (kg OC/kg lipid)

$BSAF_{ab}$= biota-sediment accumulation factor for aquatic birds (kg OC/kg lipid)

BAF_{tb}= bioaccumulation factor from soil for terrestrial birds (kg soil/kg birds)

$BSAF_{am}$= biota-sediment accumulation factor for aquatic mammals (kg OC/kg lipid)

BAF_{tm}= bioaccumulation factor from soil for terrestrial mammals (kg soil/kg mammal)

$LIPID_i$= lipid content of aquatic invertebrates (kg lipid/kg invertebrate)

$LIPID_f$ = lipid content of fish (kg lipid/kg fish)

$LIPID_a$= lipid content of amphibians and reptiles (kg lipid/kg amphibian/reptile)

$LIPID_{ab}$= lipid content of aquatic birds (kg lipid/kg bird)

$LIPID_{am}$= lipid content of aquatic mammals (kg lipid/kg mammal)

Solving Equation 6 for C_{soil} yields:

$C_{soil} = \{C_p - [(C_{sed} / FOC_{sed}) \times [(P_i \times BSAF_i \times LIPID_i) + (P_f \times BSAF_f \times LIPID_f) + (P_a \times BSAF_a \times LIPID_a) + (P_{ab} \times BSAF_{ab} \times LIPID_{ab}) + (P_{am} \times BSAF_{am} \times LIPID_{am})]]]\} / [(P_{tb} \times BAF_{tb}) + (P_{tm} \times BAF_{tm})]$ Eqn. 7

However, this equation does not completely represent the relationship between the mink's dietary exposure and the sediment and soil concentrations of PCBs because aquatic birds in the mink's diet (mainly waterfowl) feed not only on aquatic invertebrates (as indicated in Equations 6 and 7) but also on terrestrial invertebrates (e.g., as shown for wood duck [*Aix sponsa*] in Vol. 5, Table G.2-33 of the ERA). To account for this, the total PCB concentration in the aquatic bird must be split into two components, one defined by uptake from sediments using a BSAF and one defined by uptake from soils using a BAF. It was assumed that the total concentration in the aquatic bird (C_{ab}) could be represented by the following equation:

$$C_{ab} = C_{aba} + C_{abt} \quad \text{Eqn. 8}$$

where

C_{aba} = concentration of PCBs in aquatic birds that is derived from the aquatic portion of their diet (mg PCBs/kg bird)

C_{abt} = concentration of PCBs in aquatic birds that is derived from the terrestrial portion of their diet (mg PCBs/kg bird)

Data are unavailable for C_{aba} and C_{abt} in aquatic bird tissue, but these terms can be calculated if $BSAF_{ab}$ and BAF_{ab} are known; details on calculation of $BSAF_{ab}$ and BAF_{ab} and associated assumptions are described in Section E.3 (Input Data and Assumptions) below. Conceptually, C_{aba} and C_{abt} are equal to the proportion of the diet consisting of aquatic or terrestrial prey multiplied by the estimated concentration of PCBs in a theoretical aquatic bird feeding exclusively (100%) on aquatic or terrestrial prey items, respectively, as follows:

$$C_{aba} = P_{aba} \times C_{ab,100\%aquatic\ prey} \quad \text{Eqn. 9}$$

$$C_{abt} = P_{abt} \times C_{ab,100\%terrestrial\ prey} \quad \text{Eqn. 10}$$

where

P_{aba} = the proportion of the aquatic bird invertebrate diet consisting of aquatic invertebrates = 0.74

P_{abt} = the proportion of the aquatic bird invertebrate diet consisting of terrestrial invertebrates = 0.26

$C_{ab,100\%aquatic\ prey}$ = PCB concentration in aquatic bird feeding exclusively on aquatic prey

$C_{ab,100\%terrestrialprey}$ = PCB concentration in aquatic bird feeding exclusively on terrestrial prey

The proportions, P_{aba} and P_{abt}, were obtained from the diet of the wood duck (Table G.2-33 of the ERA), the species used to represent aquatic birds. The proportion of the wood duck's diet that is vegetation (24% during pre-egg laying period) was not included because it was assumed that PCB accumulation through that route is minimal compared to bioaccumulation from consumption of invertebrates.

Using the approach in Equation 3 for aquatic prey-derived PCB concentrations and Equation 5 for terrestrial prey-derived PCB concentrations, it follows that:

$$C_{ab100\%aquatic\ prey} = BSAF_{ab} \times C_{sed} \times (LIPID_{ab}/FOC_{sed} \qquad \text{Eqn. 11}$$

$$C_{ab100\%terrestrial\ prey} = BAF_{ab} \times C_{soil} \qquad \text{Eqn. 12}$$

Substituting Equations 11 and 12 into Equations 9 and 10 yields:

$$C_{aba} = P_{aba} \times [BSAF_{ab} \times C_{sed} \times (LIPID_{ab}/FOC_{sed})] \qquad \text{Eqn. 13}$$

$$C_{abt} = P_{abt} \times [BAF_{ab} \times C_{soil}] \qquad \text{Eqn. 14}$$

The aquatic bird PCB concentration, C_{ab}, can be calculated by substituting Equations 13 and 14 into Equation 8:

$$C_{ab} = [P_{aba} \times BSAF_{ab} \times C_{sed} \times (LIPID_{ab}/FOC_{sed})] + [P_{abt} \times BAF_{ab} \times C_{soil}] \qquad \text{Eqn. 15}$$

Finally, substituting Equation 15 for C_{ab} in Equation 1, followed by the derivation of Equations 6 and 7 using the same approach outlined previously, yields the final correct equation for calculating the target soil concentration (revised version of Equation 7):

$$C_{soil} = \{C_p - (C_{sed}/FOC_{sed}) \times [(P_i \times BSAF_i \times LIPID_i) + (P_f \times BSAF_f \times LIPID_f) + (P_a \times BSAF_a \times LIPID_a) + (P_{ab} \times P_{aba} \times BSAF_{ab} \times LIPID_{ab}) + (P_{am} \times BSAF_{am} \times LIPID_{am})]\} / [(P_{ab} \times P_{abt} \times BAF_{ab}) + (P_{tb} \times BAF_{tb}) + (P_{tm} \times BAF_{tm})] \qquad \text{Eqn. 16}$$

Equation 16 was used to calculate the target soil concentration associated with the high and low IMPG values of 0.98 and 2.4 mg/kg for the prey of mink, based on the following input data and assumptions regarding each of the equation's variables.

3. Input Data and Assumptions

Input values were selected based on site-specific data from the combined Reaches 5A/5B and 5C/5D/6, as presented in the ERA, the RCRA Facility Investigation Report (RFI Report; BBL and QEA, 2003), and supporting studies and datasets. In a few cases, where site-specific data were not available, data from another PCB river/floodplain site, the Kalamazoo River in Michigan, were used. The input values used in Equation 16 are listed in Table E-1, with more detailed supporting information provided in Tables E-2 through E-8. The input data and assumptions used to derive these values are described below.

Foraging Range of Mink

As directed by EPA, the method conservatively assumes that 100% of the foraging range of mink is contained within the 1 mg PCBs/kg soil isopleth, even though the percentage most likely is lower.

Acceptable PCB Concentration in Diet (C_p)

The target PCB concentrations in the mink diet were set equal to the high and low ends of the EPA-approved IMPG range, 0.98 and 2.4 mg/kg, as described in the revised IMPG Proposal (GE, 2006).

Dietary Composition (*P*)

As previously noted, the ERA indicated that the mink diet is diverse and includes aquatic invertebrates, fish, mammals, birds, and amphibians and reptiles. In addition, the mammal and bird portions of the diet include both aquatic and terrestrial species. Representative species for each of these prey groups were chosen to develop bioaccumulation factors. The species chosen were selected based on both known preferences in the mink diet and availability of data for those species, preferably in the PSA. For example, crayfish were selected to represent aquatic invertebrates because they are listed as the primary aquatic invertebrate in the mink diet for many studies (Table I-2.1 of the ERA) and because tissue data from the PSA were available. The short-tailed shrew (*Blarina brevicauda*) and white-footed mouse (*Peromyscus leucopus*) were selected to represent the terrestrial mammals in the diet. The wood duck represented the aquatic birds, and the house wren (*Troglodytes aedon*), black-capped chickadee (*Poecile atricapilla*), and American robin (*Turdus migratorius*) represented the terrestrial birds. The muskrat (*Ondatra zibethicus*) represented aquatic mammals. Tissue PCB concentration data were available from the PSA for each of those species except the muskrat. The muskrat was selected even though data from the PSA were not available because it is a primary aquatic mammal in the mink diet (based on volumetric data in Table I.2-2 of the ERA).

The assumed proportions of fish, mammals, birds, invertebrates, and amphibians and reptiles in the mink diet were derived from the values used in the ERA (Vol. 6, Table I.2-2). The further delineation of aquatic versus terrestrial birds and mammals was derived based on the mean percentages averaged across diet studies reported in Table I.2-1 of the ERA. The specific species and proportions of each dietary item were set as follows:

P_i – proportion of mink diet consisting of aquatic invertebrates (represented by crayfish) = 0.36

P_f – proportion of mink diet consisting of fish (represented by fish in the size class of 7 to 20 cm) = 0.23

P_a – proportion of mink diet consisting of amphibians and reptiles (represented by wood frogs, leopard frogs, and bullfrogs) = 0.15

P_{ab} – proportion of mink diet consisting of aquatic birds (represented by the wood duck) = 0.08[1]

P_{tb} – proportion of mink diet consisting of terrestrial birds (represented by chickadees, robins, and wrens) = 0.03

P_{am} – proportion of mink diet consisting of aquatic mammals (represented by the muskrat) = 0.07

P_{tm} – proportion of mink diet consisting of terrestrial mammals (represented by shrews and mice) = 0.08

Concentration in Sediment (C_{sed})

It was necessary to assume a range of target concentrations of sediment to calculate protective soil concentrations. For the purpose of this assessment, C_{sed} was fixed at 1, 3, and 5 mg/kg, and Equation 16 was solved for the corresponding C_{soil} values.

[1] The proportion in the aquatic bird diet is further split into aquatic-feeding and terrestrial-feeding components.

Biota-Sediment Accumulation Factors (BSAFs)

BSAFs were calculated for each of the aquatic prey types represented in the mink's diet. For aquatic invertebrates, amphibians and reptiles, and aquatic mammals, BSAFs were calculated for each tissue sample in the database, which represented an individual animal, except for some frog samples. For some frog samples (i.e., all 7 wood frog tissue samples and for 8 of the 15 leopard frog samples in Table E-4), the tissue samples in the database represented tissue composites of more than one individual from the same pond. In accordance with EPA's letter of August 29, 2007, the higher of the median or geometric mean of the individual BSAFs was used to represent bioaccumulation for each of these prey types. In contrast, for the fish and aquatic birds, a single BSAF was calculated for each averaging area rather than using individual BSAFs. For fish, the food chain model (FCM) previously developed by EPA for the Rest of River (EPA, 2006) was used to calculate the BSAF. For aquatic birds, individual BSAFs were not used because of high overlap in home ranges of individual ducks and lack of information about specific feeding locations. Details on these methods and the derivation of BSAFs for each prey item are discussed below. In all analyses, half of the reported detection limit was used for non-detects of analytes.

$BSAF_i$ - The BSAF for aquatic invertebrates was based on BSAFs reported in the RFI Report (Figure 8.34 in that report). Those values were developed using PCB concentrations and lipid measurements in site-specific crayfish tissue. Concentrations of OC-normalized PCBs in river sediment (0 to 6 inches) were averaged by river mile and co-located with crayfish tissue concentrations to calculate individual BSAF values. The higher of the median or geometric mean of these individual BSAFs (Table E-2) for each averaging area (i.e., Reach 5A/5B and Reach 5C/5D/6) was used in the final target soil calculation.

$BSAF_f$ – The FCM developed by EPA for the Rest of River modeling (EPA, 2006) was used to calculate the $BSAF_f$. The FCM calculates PCB concentrations in fish of multiple trophic levels as a function of dissolved- and particulate-phase PCB exposure concentrations from sediment and the water column, and accounts for many factors, including the lipid content in fish and fraction of total organic carbon (FOC) in the sediments. Because mink feed frequently in backwater areas, PCBs and FOC in the backwater areas of each subreach were included when calculating predicted concentrations in the fish tissue for each averaging area. Fish sizes were limited to age classes that correspond to the sizes eaten by mink, 7 to 20 cm (as specified in the ERA). The fish species simulated by the FCM were averaged to produce a weighted composite mink exposure concentration based on an assumed mink fish diet of 2/3 predatory fish (largemouth bass in the model) and 1/3 bottom and forage fish (average of model results for brown bullhead, sunfish, white sucker, and cyprinids), based on Alexander (1977).

The calculation of the $BSAF_f$ with FCM involved several steps. Sediment PCB concentrations (specified on an OC-normalized basis) change daily in the FCM based on inputs from the PCB fate and transport model (EPA, 2006). Annual estimates of OC-normalized surface sediment (averaged over reach-specific exposure depths that were in the range of 3 to 6 inches) and lipid-normalized fish tissue concentrations in each subreach were calculated by averaging the daily modeled concentrations over the autumn period (when the majority of fish tissue data were collected) for each year of the 26-year model validation period (1979 through 2004). The autumn estimate was assumed to represent an annual estimate (a comparison of these two values indicated they were very similar). Each annual subreach estimate was combined into one value for each averaging area, weighting the average by subreach length. A regression line (with the intercept forced through zero) was fit through the resultant 26 annual estimates of lipid-normalized fish PCB concentrations and OC-normalized sediment PCB concentrations for each averaging area. The slope of each regression was used as the final $BSAF_f$ for each averaging area (Table E-3).

$BSAF_a$ – Each of the frog species assumed to represent the amphibian and reptile portion of the mink diet is potentially exposed to sediments and soils. However, for the purpose of this analysis, it was assumed that each frog's primary route of exposure was from aquatic sources. Site-specific tissue data for each of these frog species were compiled and paired with sediment data to derive individual BSAFs. The wood frog and leopard frog tissue samples were collected from discrete, small ponds, and the individual BSAFs for those species were developed by matching each individual (or composite) frog tissue concentration with the spatially weighted average surface sediment concentration (0 to 6 inches) in the pond from which that frog tissue sample was collected. For the bullfrogs (which were collected from the larger Woods Pond and from backwaters of the river), individual tissue concentrations were matched with the co-located or closest available surface (0- to 6-inch) sediment sample to derive individual BSAFs (Table E-4). For all bullfrogs and some individual leopard frogs, it was necessary to calculate the whole-body concentration from a tissue-mass weighted average of the concentrations reported for individual body parts (e.g., ovary, leg, and offal) before estimating the individual sample $BSAF_a$. The final BSAF for amphibians for each averaging area was the higher of the median or geometric mean of these individual BSAFs, after combining data for all three frog species from that area.

$BSAF_{ab}$ – Because measured aquatic bird PCB concentrations are a mixture of PCB uptake from terrestrial and aquatic sources, the derivation of the $BSAF_{ab}$ and the BAF_{ab} for aquatic birds differs from that used for the other species. The $BSAF_{ab}$ represents the bioaccumulation of PCBs by the wood duck based on consumption of only aquatic

invertebrates, whereas the BAF_{ab} represents the bioaccumulation by the wood duck based on consumption of only terrestrial invertebrates.

To calculate the $BSAF_{ab}$, first it was assumed that $BSAF_{ab}$ for the sediment equals the bioaccumulation factor for the soil (BAF_{ab}) when the BAF_{ab} is lipid- and OC-normalized in the same manner that the $BSAF_f$ was normalized. This requires multiplying the BAF_{ab} by $FOC_{soil}/LIPID_{ab}$ (see section on Bioaccumulation Factors for Soil, below, for the derivation of lipid- and OC-normalized BAF_{ab}). Thus, it is assumed that:

$$BSAF_{ab} = BAF_{ab} \times FOC_{soil}/LIPID_{ab} \qquad \text{Eqn. 17}$$

The justification for this assumption is that the dominant type of food was the same for both aquatic- and terrestrial-feeding waterfowl (invertebrates), and thus the relative bioaccumulation of PCBs in the bird should be similar in both aquatic and terrestrial habitats, as long as both bioaccumulation factors are normalized for lipid content and FOC. Also, this assumption was required to solve for $BSAF_{ab}$ because it reduces the number of unknown variables in Equation 18 below.

The equation used to calculate the $BSAF_{ab}$ for aquatic birds feeding on aquatic invertebrates was derived from the following equation, which is similar to Equation 15 except that lipid and FOC terms are added (that could cancel out) to create a lipid- and OC-normalized BAF_{ab}:

$$C_{ab} = [P_{aba} \times BSAF_{ab} \times C_{sed} \times (LIPID_{ab}/FOC_{sed})] + [P_{abt} \times (BAF_{ab} \times FOC_{soil}/LIPID_{ab}) \times C_{soil} \times LIPID_{ab}/FOC_{soil}] \qquad \text{Eqn. 18}$$

Based on the assumption in Equation 17, $BSAF_{ab}$ can be substituted for the lipid- and OC-normalized BAF_{ab} (BAF_{ab} x $FOC_{soil}/LIPID_{ab}$) in Equation 18 and factored out to yield:

$$C_{ab} = BSAF_{ab} \times \{[P_{aba} \times C_{sed} \times (LIPID_{ab}/FOC_{sed})] + [P_{abt} \times C_{soil} \times (LIPID_{ab}/FOC_{soil})]$$

Eqn. 19

Solving for $BSAF_{ab}$ in Equation 19 yields:

$$BSAF_{ab} = C_{ab}/\{LIPID_{ab} \times [(P_{aba} \times C_{sed}/FOC_{sed}) + (P_{abt} \times C_{soil}/FOC_{soil})]\} \qquad \text{Eqn. 20}$$

Data used to calculate the $BSAF_{ab}$ included: (1) the average PCB concentration (C_{ab}) and average lipid content of wood ducks ($LIPID_{ab}$) in Reaches 5 and 6; and (2) the spatially weighted average PCB (C_{sed}, C_{soil}) and FOC (FOC_{sed}, FOC_{soil}) concentrations in the sediment and soil (top 0-6 inches) in wood duck habitat in Reaches 5 and 6 (see Appendix B, Table B-4 of the CMS Proposal [ARCADIS BBL and QEA, 2007a] for total organic carbon [TOC] polygon data in sediment). It was assumed all of the river and its backwaters in these reaches were potential aquatic bird habitat and that suitable aquatic bird habitat in the floodplain excluded areas defined as unsuitable wood duck habitat on Figure 4-7 in Section 4.2.3.3 of the main Revised CMS Report (based on criteria defined by Woodlot Alternatives 2002). It is important to note that the tissue data for wood duck in the EPA database were identified by reach (i.e., Reaches 5 and 6), not by subreach (i.e., Reaches 5A, 5B, 5C, and 5D) (Table E-5); thus, it was not possible to calculate tissue concentrations associated with Reach 5A/5B versus Reach 5C/5D/6. In addition, it was not possible to co-locate tissue and sediment data other than by reach. Therefore, the available tissue and lipid data were averaged across each of the reaches, and the averages were paired with the average sediment data for each reach to derive a single $BSAF_{ab}$ for each reach. Accordingly, the BSAFs for this species reflect the relationship between the lipid-normalized average concentration in tissue and the OC-normalized average concentration in soils in Reach 5 (including 5C and 5D) and Reach 6, rather than the median or geometric mean of individual BSAFs. The resultant $BSAF_{ab}$ for Reach 5 was applied to Reach 5A/5B, and the $BSAF_{ab}$ for Reach 6 was applied to Reach 5C/5D/6. This reach adjustment provided an approximated aquatic bird BSAF (and BAF) and lipid content for each averaging area. In this connection, it should be noted that, in developing the PCB target soil concentrations, the FOC in the sediment for each averaging area was the same value for all species, including the aquatic bird (i.e., only one FOC value was used in Equation 16).

Because only duck breast and liver tissue data were available, the ERA presented three methods for estimating whole-body PCB tissue concentrations (Appendix I, Section I.2.1.5.3). For the purpose of this evaluation and to be consistent with whole-body data presented in Appendix L of the ERA, whole-body tissue concentrations were based on the assumption that the lipid-normalized PCB concentrations of the breast tissue are the same as the lipid-normalized concentrations of the offal.

$BSAF_{am}$ – Given the absence of site-specific data on aquatic mammals, the BSAF for aquatic mammals was derived from data collected for the Kalamazoo River, Michigan (Table E-6), in an area that has PCBs in sediments and floodplain soils (Kay et al. 2005). Individual BSAFs were calculated by pairing the tissue concentration of each muskrat trapped with the average sediment concentration (top 6 inches) of samples located within the muskrat foraging range (~ 300 m distance of the trapping location or, in the absence of data within 300 m, the closest sediment sample). The higher of the median or geometric mean of these individual BSAFs was used for both averaging areas.

Bioaccumulation Factors for Soil (BAFs)

BAFs, representing the ratio of the PCB concentration in tissue to the PCB concentration in soil, were calculated for each of the terrestrial-feeding taxonomic groups included in the mink's diet, specifically songbirds, small mammals, and terrestrial-feeding aquatic birds. Similar to the method used for the aquatic species, BAFs were derived for each individual terrestrial animal and then combined by taxonomic group for each averaging area to develop one BAF for each such group in each averaging area. Except for the aquatic birds, the median or geometric mean of the individual BAFs, whichever was higher, was used as the BAF for each prey component in each averaging area. A more detailed description of the methods used for each prey type is provided below.

BAF_{tb} - The bioaccumulation factor for adult terrestrial birds could not be calculated directly from site-specific data because PCB tissue concentrations in adults were unavailable. However, PCB concentrations in eggs were available for three species: American robins, house wrens, and black-capped chickadees. To estimate PCB concentrations in adults, an adult-to-egg ratio observed in house wrens from the Kalamazoo River (0.51; Neigh et al. 2006) was applied to the PCB estimates in eggs for the Housatonic River floodplain.

The house wren and black-capped chickadee eggs were obtained from tree swallow boxes in three main nest box locations described in the ERA. A buffer with a distance of 56 m (to approximate 1-hectare foraging areas) was placed around the cluster of nests in each of the three locations, and the spatially weighted average surface soil PCB concentrations (0 to 6 inches) were calculated for the soils within each of the three buffers. The estimated adult-tissue PCB concentrations developed from an egg in each nest found in each area were paired with the average soil PCB concentrations in the buffer (Table E-7) to develop individual BAFs. The robin eggs were collected from nests identified during a robin productivity study (Arcadis G&M 2002). To derive BAFs for robins, the tissue concentrations for these birds were paired with the average soil PCB concentration estimated from samples within 25 m of the nest (or with the PCB concentration in the closest soil sample if no soil samples were available within 25 m of the nest). To develop the final terrestrial bird BAF for each averaging area, the data for all three species were pooled (Table E-7), and the higher of the geometric mean or median value of the individual BAFs for that area was selected.

BAF_{tm} - The bioaccumulation factor for terrestrial mammals (BAF_{tm}) was based on site-specific tissue data for the short-tailed shrew and white-footed mouse and on spatially weighted surface-soil PCB concentrations (0 to 6 inches) within 35 m of the sampling location for each animal. Individual BAFs were calculated for each of the available tissue samples (Table E-8). To develop the final BAF for terrestrial mammals in each averaging area, the data for both species were combined and the higher of the geometric mean or median value of the individual BAFs for that area was selected.

BAF_{ab} - The calculation of the bioaccumulation factor for aquatic birds feeding on terrestrial prey (BAF_{ab}) differs from the calculation of BAFs for the other terrestrial species because the PCB concentration in the aquatic bird is a composite of PCBs coming from aquatic and terrestrial prey – unlike the PCB concentrations in terrestrial birds and mammals, which are assumed to bioaccumulate PCBs exclusively from terrestrial prey. Therefore, the PCB accumulation that comes from aquatic prey ($BSAF_{ab}$) must be accounted for before the BAF_{ab} can be calculated.

To derive BAF_{ab}, it was assumed that uptake of PCBs from terrestrial invertebrates by an aquatic bird is a process similar to that same bird's uptake of PCBs from aquatic invertebrates. Consequently, unlike the BAFs for the other terrestrial species, BAF_{ab} was assumed to be affected by the lipid content and soil FOC as follows:

$$\text{Lipid- and OC-normalized } BAF_{ab} = (C_{ab}/LIPID_{ab}) / (C_{soil} / FOC_{soil}) \qquad \text{Eqn. 21}$$

where

FOC_{soil} = fraction of total organic carbon in soil (kg total OC/kg soil)

Substituting the un-normalized BAF_{ab} for C_{ab}/C_{soil} (by definition $BAF_{ab} = C_{ab}/C_{soil}$ for an aquatic bird feeding 100% on terrestrial invertebrates) into Equation 21 yields:

$$\text{Lipid- and OC-normalized } BAF_{ab} = BAF_{ab} \times (FOC_{soil}/LIPID_{ab}) \qquad \text{Eqn. 22}$$

Based on the assumption stated previously that the $BSAF_{ab}$ equals the normalized BAF_{ab}

$$BSAF_{ab} = BAF_{ab} \times FOC_{soil}/LIPID_{ab} \qquad \text{Eqn. 23}$$

the un-normalized BAF_{ab} can be calculated after re-arranging Equation 23 as follows:

$$BAF_{ab} = BSAF_{ab} \times LIPID_{ab}/FOC_{soil} \qquad \text{Eqn. 24}$$

The un-normalized BAF_{ab} also can be calculated using the following equation:

$$BAF_{ab} = C_{abt}/(C_{soil} \times P_{abt}) \qquad \text{Eqn. 25}$$

This shows that the BAF_{ab} represents the bioaccumulation of PCBs into an aquatic bird feeding 100% on terrestrial food sources. In Equation 25, P_{abt} is the proportion of the bird diet that is terrestrial, which is required in the equation to mathematically increase the intake rate of terrestrial food from the actual partial rate to the theoretical rate of 100% of the diet.

As noted previously in the discussion of the $BSAF_{ab}$, the available wood duck tissue concentrations could not be separated by subreach; therefore, the BAFs for aquatic birds reflect the relationships between the reach-specific average PCB and lipid concentrations in tissue and the average PCB and FOC concentrations in soils across Reaches 5 (including 5C and 5D) and 6, rather than the median or geometric mean of individual BAFs. Areas containing unsuitable wood duck habitat (as shown on Figure 4-7 in Section 4.2.3.3 of the main Revised CMS Report, based on criteria defined by Woodlot Alternatives, 2002) were excluded from the calculation of the average soil PCB and FOC concentrations because the ducks would not feed in those areas. The resultant BAF for Reach 5 was applied to Reach 5A/5B and the BAF for Reach 6 was applied to Reach 5C/5D/6.

Lipid ($LIPID_i$, $LIPID_f$, $LIPID_a$, $LIPID_{ab}$, $LIPID_{am}$)

The lipid content of each aquatic prey species used in Equation 16 was derived by averaging the available tissue data across all individuals on which the BSAF calculations for an averaging area were based. The lipid data for each individual for each species are presented in Tables E-2 to E-6, except Table E-3, where an average from the FCM is reported.

Fraction Organic Carbon (FOC)

The estimate of the FOC in sediments that was used in Equation 16 was the spatially weighted average FOC value for surface sediments within Reaches 5A/5B and 5C/5D/6, including the mainstream of the river and its adjacent backwaters.

4. Results

Estimated target floodplain soil PCB concentrations associated with the upper and lower bounds of the mink IMPGs at the three target sediment PCB concentrations are presented in Table E-9 for each averaging area. In cases where the calculated value was negative, the target floodplain soil concentration is listed as "not achievable," indicating that, at that target sediment PCB concentration, the PCB contribution from aquatic prey alone would exceed the IMPG, and thus the IMPG cannot be attained regardless of the floodplain soil PCB concentration. For Reach 5A/5B, the estimated target floodplain soil PCB concentrations associated with the three target sediment concentrations range from not achievable to approximately 3.4 mg/kg for the low-end IMPG of 0.98 mg/kg and from not achievable to approximately 17 mg/kg for the high-end IMPG of 2.4 mg/kg, depending on the sediment concentration. For Reach 5C/5D/6, the target soil concentrations range from not achievable to approximately 7 mg/kg for the low-end IMPG and from approximately 12 mg/kg to 20 mg/kg for the high-end IMPG, depending on the sediment concentration.

Table E-9. Target Floodplain Soil PCB Concentrations Associated with Mink IMPG.

Target Sediment PCB Concentration (mg/kg)	Target Soil PCB Concentration (mg/kg) for IMPG = 0.98 mg/kg	Target Soil PCB Concentration (mg/kg) for IMPG = 2.4 mg/kg
Reach 5A/5B		
1	3.42	16.63
3	not achievable	5.12
5	not achievable	not achievable
Reach 5C/5D/6		
1	6.87	19.55
3	2.98	15.66
5	not achievable	11.78

5. Sensitivities, Uncertainties, and Conservatism in Model

The model used in these calculations is sensitive to changes in the BAFs and BSAFs. At low target sediment concentrations, the model output is more sensitive to estimates of the terrestrial BAFs than the aquatic BSAFs, particularly considering that tissue concentrations of PCBs in terrestrial birds and mammals are higher on average than for aquatic animals (Tables E-2 to E-8). However, at higher sediment concentrations, the aquatic animals, particularly the fish, have a stronger influence. The model is also sensitive to large changes in the sediment FOC, which varies greatly between the river and backwaters. For this reason, it was important to include the backwater habitat of the mink in the model. Uncertainty exists with the terrestrial passerine data, because only nest (eggs and chicks) data were available, and the proportionality factor that was multiplied by the egg PCB concentrations to obtain adult PCB concentrations was obtained from data from the Kalamazoo River floodplain (Neigh et al., 2006). Additionally, BSAFs for muskrat were based on data from the Kalamazoo River.

Use of the FCM to obtain fish tissue concentrations of PCBs has some limitations. First, for many of the fish species included in the analysis (e.g., sunfish), tissue concentrations are more closely correlated with PCB concentrations in the water column than with those in sediment. As a result, actual PCB concentrations in tissue samples from these species may be lower than those predicted by the linear relationship with sediment in the predictive model. Second, the range of sediment PCB concentrations in Reaches 5 and 6 for which the FCM was calibrated is much higher than the target sediment concentrations of 1 to 5 mg/kg. Supplemental analyses suggest the model could underestimate bottom-fish concentrations (e.g., suckers, bullheads) at low sediment concentrations by up to a factor of two. Third, the accuracy of the model in predicting fish tissue concentrations in the backwaters is unknown because no fish have been collected in those areas to compare to model results.

As noted above, the model assumes that mink forage exclusively within the 1 mg/kg PCB isopleth. In fact, however, very few mink likely forage entirely within that area without also foraging in tributaries and other areas outside the 1 mg/kg isopleth. Thus, this model is highly conservative.

6. References

Alexander, G.R. 1977. Food of vertebrate predators on trout waters of north central lower Michigan. *Michigan Academician* 10:187-195.

Ankley, G.T. P.M. Cook, A.R. Carlson, D.J. Call, J.A. Sorensen, H.F. Corcoran, and R.A. Hoke. 1992. Bioaccumulation of PCBs from sediments by oligochaetes and fishes: Comparison of laboratory and field studies. *Can. J. Fish. Aquat. Sci.* 49:2080-2085.

ARCADIS BBL and QEA. 2007a. Corrective Measures Study Proposal. Prepared on behalf of the General Electric Company, Pittsfield, MA. February 2007.

ARCADIS BBL and QEA. 2007b. Corrective Measures Study Proposal Supplement. Prepared on behalf of the General Electric Company, Pittsfield, MA. May 2007.

ARCADIS G&M, Inc. 2002. Robin Productivity in the Housatonic River Watershed, Berkshire County, Massachusetts. Prepared for General Electric Company.

BBL and QEA. 2003. Housatonic River, Rest of River, RCRA Facility Investigation Report (RFI Report). Prepared on behalf of the General Electric Company, Pittsfield, MA. September 2003.

EPA. 2004. Ecological Risk Assessment for General Electric (GE)/Housatonic River Site, Rest of River (ERA). Prepared by Weston Solutions, Inc., West Chester, PA, for the U.S. Army Corps of Engineers, New England District, and the U.S. Environmental Protection Agency, New England Region. November 2004.

EPA. 2006. Final Model Documentation Report: Modeling Study of PCB Contamination in the Housatonic River. Prepared by Weston Solutions, Inc., West Chester, PA, for the U.S. Army Corps of Engineers, New England District, and the U.S. Environmental Protection Agency, New England Region. November 2006.

GE. 2006. Interim Media Protection Goals Proposal for the Housatonic River, Rest of River. Submitted to EPA by General Electric Company, Pittsfield, MA. Revised March 9.

Kay, D.P., A.L. Blankenship, K.K. Coady, A.M. Neigh, M.J. Zwiernik, S.D. Millsap, K. Strause, C. Park, P. Bradley, J. L. Newsted, P.D. Jones, and J.P. Giesy. 2005. Differential accumulation of polychlorinated biphenyl congeners in the aquatic food web at the Kalamazoo River Superfund site, Michigan. *Environ. Sci. Technol.* 39:5964-5974.

Neigh, A.A., M. J. Zwiernik, P.W. Bradley, D.P. Kay, P.D. Jones, R.R.Holem, A.L. Blankenship, K.D. Strause, J.L. Newsted, and J. P. Giesy. 2006. Accumulation of polychlorinated biphenyls from floodplain soils by passerine birds. *Environmental Toxicology and Chemistry* 25(6):1503-1511.

Woodlot Alternatives. 2002. Ecological Characterization of the Housatonic River. Prepared for EPA. September 2002.

Table E-1 – Description of Variables in Equation 16, which Predicts Target Soil Concentrations Protective of Mink

Variable	Description (units in parentheses)	Value for Reach 5A/5B	Value for Reach 5C/5D/6	Basis
C_p	Target concentration of PCBs in prey (mg/kg)	0.98-2.4		IMPG Proposal
P_i	Proportion of mink diet comprised of aquatic invertebrates	0.36		ERA
P_f	Proportion of mink diet comprised of fish	0.23		ERA
P_a	Proportion of mink diet comprised of amphibians and reptiles	0.15		ERA
P_{ab}	Proportion of mink diet comprised of aquatic birds	0.08		Table I.1-2, ERA
P_{tb}	Proportion of mink diet comprised of terrestrial birds	0.03		Table I.1-2, ERA
P_{am}	Proportion of mink diet comprised of aquatic mammals	0.07		Table I.2-2, ERA
P_{tm}	Proportion of mink diet comprised of terrestrial mammals	0.08		Table I.2-2, ERA
P_{aba}	Proportion of aquatic bird diet comprised of aquatic prey	0.74		ERA
P_{abt}	Proportion of aquatic bird diet comprised of terrestrial prey	0.26		ERA
C_{sed}	Target concentrations of PCBs in sediment (mg/kg)	1,3,5		Range assumed
$BSAF_i$	Biota-sediment accumulation factor for aquatic invertebrates (kg organic carbon/kg lipid)	0.56	1.23	Table E-2
$BSAF_f$	Biota-sediment accumulation factor for fish (kg organic carbon/kg lipid)	1.32	1.33	Table E-3
$BSAF_a$	Biota-sediment accumulation factor for amphibians and reptiles (kg organic carbon/kg lipid)	0.55	2.36	Table E-4
$BSAF_{ab}$	Biota-sediment accumulation factor for aquatic birds feeding on aquatic prey (kg organic carbon/kg lipid)	1.72	0.318	Table E-5
$BSAF_{am}$	Biota-sediment accumulation factor for aquatic mammals (kg organic carbon/kg lipid)	0.57		Table E-6
BAF_{tb}	Bioaccumulation factor from soil for terrestrial birds (kg soil/kg bird)	2.43	1.13	Table E-7
BAF_{tm}	Bioaccumulation factor from soil for terrestrial mammals (kg soil/kg bird)	0.339	0.918	Table E-8
BAF_{ab}	Bioaccumulation factor from soil for aquatic birds feeding on terrestrial prey (kg soil/kg bird)	0.348	0.208	Table E-5
$LIPID_i$	Proportion of lipids in invertebrates	0.011	0.009	Table E-2
$LIPID_f$	Proportion of lipids in fish	0.030	0.030	Table E-3
$LIPID_a$	Proportion of lipids in amphibians and reptiles	0.017	0.011	Table E-4
$LIPID_{ab}$	Proportion of lipids in aquatic birds	0.017	0.062	Table E-5
$LIPID_{am}$	Proportion of lipids in aquatic mammals	0.024		Table E-6
FOC_{sed}	Fraction of organic carbon in sediment (kg total carbon/kg sediment)	0.025	0.089	Spatially-weighted value for averaging areas

Note:

1. Values are unitless unless specified.

Table E-2 – Data Used to Calculate $BSAF_i$ and Average Lipid Content of Aquatic Invertebrates (Crayfish)

Field Sample ID	River Mile	Tissue PCB (mg/kg)	Lipid Fraction	Sediment PCB (mg /kg OC)	Individual $BSAF_i$
Reach 5A/5B					
H3-TD05OVWB-F002	132.07	40.35	0.019	3567	0.60
H3-TD05OVWB-M023	132.07	9.94	0.004	3567	0.70
H3-TD05OVWB-M022	132.07	52.14	0.011	3567	1.33
H3-TD05OVWB-M021	132.07	9.42	0.009	3567	0.29
H3-TD05OVWB-M020	132.07	8.08	0.008	3567	0.28
H3-TD05OVWB-M014	132.07	15.93	0.01	3567	0.45
H3-TD05OVWB-M008	132.07	13.12	0.008	3567	0.46
H3-TD05OVWB-M007	132.07	21.85	0.014	3567	0.44
H3-TD05OVWB-M001	132.07	20.09	0.011	3567	0.51
H3-TD05OVWB-F005	132.07	25.79	0.028	3567	0.26
H3-TD07OVWB-F002	130.07	31.59	0.02	1708	0.92
H3-TD07OVWB-M001	130.07	6.63	0.007	1708	0.55
H3-TD07OVWB-M003	130.07	4.35	0.002	1708	1.27
H3-TD07OVWB-M004	130.07	9.67	0.014	1708	0.40
H3-TD07OVWB-M006	130.07	14.84	0.012	1708	0.72
H3-TD07OVWB-M007	130.07	20.40	0.012	1708	1.00
H3-TD07OVWB-M008	130.07	7.40	0.014	1708	0.31
H3-TD07OVWB-M011	130.07	13.67	0.008	1708	1.00
H3-TD07OVWB-M014	130.07	6.81	0.008	1708	0.50
H3-TD07OVWB-M021	130.07	7.47	0.008	1708	0.55
H3-TD11OVWB-F004	126.07	7.22	0.014	1127	0.46
H3-TD11OVWB-F013	126.07	7.51	0.015	1127	0.44
H3-TD11OVWB-F023	126.07	8.08	0.012	1127	0.60
H3-TD11OVWB-F026	126.07	12.68	0.013	1127	0.87
H3-TD11OVWB-F027	126.07	14.73	0.018	1127	0.73
H3-TD11OVWB-M001	126.07	8.64	0.003	1127	2.56
H3-TD11OVWB-M003	126.07	6.83	0.006	1127	1.01
H3-TD11OVWB-M005	126.07	8.21	0.006	1127	1.21
H3-TD11OVWB-M014	126.07	2.59	0.004	1127	0.57
H3-TD11OVWB-M024	126.07	5.75	0.007	1127	0.73
Reach 5C/5D/6					
H3-TD12OVWB-M018	125.07	5.45	0.005	602	1.81
H3-TD12OVWB-M017	125.07	5.65	0.005	602	1.88
H3-TD12OVWB-M015	125.07	5.98	0.008	602	1.24
H3-TD12OVWB-M014	125.07	3.95	0.004	602	1.64
H3-TD12OVWB-M013	125.07	8.51	0.007	602	2.02
H3-TD12OVWB-M011	125.07	6.63	0.008	602	1.38
H3-TD12OVWB-M010	125.07	4.59	0.003	602	2.54
H3-TD12OVWB-F009	125.07	15.84	0.020	602	1.32
H3-TD12OVWB-F007	125.07	6.74	0.009	602	1.25
H3-TD12OVWB-F006	125.07	4.64	0.007	602	1.10

Notes:

1. Data from RFI Report (BBL and QEA, 2003)
2. The average tissue PCB concentration for Reach 5A/5B is 16.98 mg /kg and for Reach 5C/5D/6 is 7.51 mg/kg.
3. The geometric mean of the individual BSAFs is 0.56 in Reach 5A/5B and 1.12 in Reach 5C/5D/6. The median of individual BSAFs is 0.53 in Reach 5A/5B and 1.23 in Reach 5C/5D/6. The higher of the geometric mean or median for the averaging area was used as $BSAF_i$ in the target soil equation (see Table E-1).

Table E-3 – Fish PCB Tissue Concentration, Lipid Fraction, and $BSAF_f$ Predicted from the Food Chain Model (FCM)

Tissue PCB (mg/kg)	Lipid fraction	Sediment PCB (mg/kg)	Sediment FOC	$BSAF_f$
Reach 5A/5B				
33.5	0.030	12.1	0.025	1.32
Reach 5C/5D/6				
39.7	0.030	23.2	0.089	1.33

Note:

1. $BSAF_f$ was derived from the slope of regressions of lipid-normalized PCB concentrations against OC-normalized sediment PCB concentrations obtained from 26 years of estimates produced by the FCM as described in Section E.3. Other data shown are averages of 26 years of inputs and outputs from the FCM.

Table E-4 – Data Used to Calculate $BSAF_a$ and Average Lipid Content of Amphibians

Field Sample ID	Location (Pond ID or State Plane coordinates)	Tissue PCB (mg/kg)	Lipid Fraction	Sediment PCB (mg/kg)	Sediment FOC	Individual $BSAF_a$
Leopard Frog						
Reach 5A/5B						
H3-TO04RP32-0-F003*	W-9A	2.96	0.030	7.5	0.0169	0.22
H3-TA03RP31-0-F001*	E-5	1.31	0.006	19.6	0.0492	0.55
H3-TA04RP32-0-C001	W-9A	3.59	0.016	7.5	0.0169	0.51
H3-TA04RP33-0-C001	W-8	5.39	0.016	43.5	0.0938	0.73
H3-TO04RP32-0-F006*	W-9A	1.18	0.004	7.5	0.0169	0.69
H3-TO08RP35-0-F003*	W-6	0.81	0.019	21.0	0.0505	0.10
H3-TA08RP35-0-C001	W-6	1.76	0.013	21.0	0.0505	0.32
H3-TA08RP34-0-C001	W-7A	2.11	0.019	27.6	0.0492	0.20
H3-TO08RP34-0-F005*	W-7A	0.53	0.018	27.6	0.0492	0.05
H3-TO08RP34-0-F006*	W-7A	7.74	0.015	27.6	0.0492	0.94
Reach 5C/5D/6						
H3-TO12RP39-0-F008*	W-1	0.04	0.007	0.4	0.2630	3.29
H3-TA12RP39-0-C001	W-1	0.15	0.004	0.4	0.2630	25.38
H3-TA10RP36-0-C001	W-4	0.34	0.010	0.4	0.0670	5.75
H3-TA12RP38-0-C001	E-1	3.09	0.013	26.6	0.1110	0.99
H3-TO12RP39-0-F001*	W-1	0.05	0.014	0.4	0.2630	2.23
Wood Frog						
Reach 5A/5B						
H3-TA04RS27-0-C001	18-VP-2	2.92	0.039	4.9	0.0476	0.73
H3-TA05RS28-0-C001	23B-VP-1	0.30	0.018	0.2	0.0763	6.14
H3-TA05RS29-0-C001	23B-VP-2	1.22	0.020	0.3	0.0887	17.98
H3-TA08RS30-0-C001	38-VP-1	1.60	0.008	28.5	0.0023	0.02
H3-TA08RS21-0-C001	38-VP-2	5.34	0.011	32.3	0.0919	1.38
Reach 5C/5D/6						
H3-TA08RS32-0-C001	46-VP-1	0.13	0.015	0.8	0.1196	1.38
H3-TA10RS22-0-C001	46-VP-5	0.59	0.010	1.4	0.0303	1.32
Bullfrog						
Reach 5C/5D/6						
H3-TA12BFTO-0-M004*	56693N,902875E	7.25	0.009	6.1	0.0078	1.05
H3-TA12BFTO-0-M001*	56644N,902903E	6.13	0.011	16.4	0.1031	3.63
H3-TA12BFTO-0-F002*	56634N,903109E	3.48	0.011	2.9	0.0713	7.87
H3-TA12BFTO-0-F003*	56659N,903175E	5.09	0.011	79.2	0.1274	0.78
H3-TA12BFTO-0-F009*	56598N,903768E	5.37	0.018	39.7	0.2671	2.04
H3-TA12BFTO-0-M011*	56557N,903833E	7.56	0.012	0.4	0.0199	28.19
H3-TA12BFTO-0-M010*	56611N,903445E	9.22	0.010	6.7	0.0339	4.82
H3-TA12BFTO-0-M007*	56729N,903326E	2.44	0.006	10.6	0.0295	1.10
H3-TA12BFTO-0-F005*	56675N,903040E	4.49	0.008	68.6	0.0536	0.46
H3-TA12BFTO-0-F008*	56557N,902085E	4.25	0.011	0.4	0.0260	28.81
H4-TA13BFTO-0-M004*	56584N,901272E	6.01	0.007	0.5	0.0254	44.06
H4-TA13BFTO-0-F001*	56576N,901644E	4.27	0.011	54.0	0.0798	0.57
H4-TA13BFTO-0-M003*	56576N,901664E	5.55	0.008	40.0	0.0559	0.99
H4-TA13BFTO-0-M002*	56543N,901693E	5.25	0.007	76.0	0.0820	0.83
H4-TA13BFTO-0-F006*	56751N,901711E	1.48	0.007	205.0	0.1447	0.15
H4-TA13BFTO-0-M011*	56353N,901531E	3.04	0.005	37.9	0.1100	1.62
H4-TA13BFTO-0-F009*	56370N,901448E	3.89	0.016	70.3	0.0751	0.25
H4-TA13BFTO-0-M010*	56254N,901251E	4.35	0.022	11.8	0.0836	1.42
H4-TA13BFTO-0-M008*	56558N,901321E	5.45	0.018	0.5	0.0252	15.65

Notes:

1. * Estimated whole-body PCB and lipid concentrations came from two body part samples of one frog (ovary + offal for leopard frog and leg + offal for bullfrog). All other samples are whole-body composites of more than one individual. For reconstituted whole body samples, field sample ID shown is chain of custody ID for offal. Data are from EPA database for ERA.
2. Sediment PCB and FOC data are spatially weighted by pond for all but bullfrogs (many bullfrogs were from Woods Pond and large backwaters). PCB and FOC values for bullfrogs came from the co-located or nearest sediment sample.
3. The average tissue PCB concentration for Reach 5A/5B is 2.58 mg/kg and 3.81 mg/kg for Reach 5C/5D/6.
4. The geometric mean of the individual BSAFs is 0.48 in Reach 5A/5B and 2.36 in Reach 5C/5D/6. The median of individual BSAFs is 0.55 in Reach5A/5B and 1.52 in Reach 5C/5D/6. The higher of the geometric mean or median for the averaging area was used as $BSAF_a$ in the soil target equation (see Table E-1).

Table E-5 – Data Used to Calculate the $BSAF_{ab}$, BAF_{ab} and Average Lipid Content of Aquatic Birds (Wood Duck)

Appendix L Location ID	Tissue PCB (mg/kg)	Lipid Fraction	Sediment Spatially-Weighted PCB (mg/kg)	Sediment Spatially-Weighted FOC	Soil Spatially-Weighted PCB (mg/kg)	Soil Spatially-Weighted FOC	$BSAF_{ab}$	BAF_{ab}
Reach 5								
TS002	5.12	0.014	17.1	0.064	17.58	0.084		
TS004	7.16	0.010	17.1	0.064	17.58	0.084		
TS005	6.81	0.008	17.1	0.064	17.58	0.084		
TS007	6.87	0.007	17.1	0.064	17.58	0.084		
TS008	11.16	0.024	17.1	0.064	17.58	0.084		
TS003	4.79	0.024	17.1	0.064	17.58	0.084		
TS001	12.26	0.024	17.1	0.064	17.58	0.084		
TS006	4.87	0.025	17.1	0.064	17.58	0.084		
Average	7.38	0.017	17.1	0.064	17.58	0.084	1.72	0.348
Reach 6								
TS044	1.04	0.023	28.4	0.083	25.04	0.095		
TS039	3.18	0.092	28.4	0.083	25.04	0.095		
TS037	6.09	0.053	28.4	0.083	25.04	0.095		
TS038	17.51	0.073	28.4	0.083	25.04	0.095		
TS041	10.38	0.071	28.4	0.083	25.04	0.095		
TS042	8.70	0.089	28.4	0.083	25.04	0.095		
TS040	5.81	0.131	28.4	0.083	25.04	0.095		
TS010	5.28	0.003	28.4	0.083	25.04	0.095		
TS009	3.89	0.003	28.4	0.083	25.04	0.095		
TS036	3.05	0.044	28.4	0.083	25.04	0.095		
TS043	3.62	0.161	28.4	0.083	25.04	0.095		
TS011	7.75	0.003	28.4	0.083	25.04	0.095		
Average	6.36	0.062	28.4	0.083	25.04	0.095	0.318	0.208

Notes:

1. Data are from EPA database for ERA, which only identifies location for tissue samples as Reach 5 or 6. Thus, for aquatic birds only, the BSAF and the BAF were each calculated for Reach 5 and Reach 6, instead of for reach 5A/5B and 5C/5D/6.
2. Reconstituted whole body lipid and PCBs are from GC (gas chromatograph) values in Appendix L in ERA.
3. The estimate of FOC and PCBs in soil and sediment for each tissue sample is the spatially weighted average for Reach 5 or 6 (excluding unsuitable duck habitat for floodplain soil) and assumes each duck has a large foraging area that encompasses the entire reach.
4. BSAFs for individual ducks were not calculated but rather an average $BSAF_{ab}$ was calculated by entering the average concentration of tissue PCBs (C_{ab}) and lipids ($LIPID_{ab}$) and sediment PCBs (C_{sed}) and FOC (FOC_{sed}) for each reach into the equation: $BSAF_{ab} = C_{ab} / \{LIPID_{ab} \times [(P_{aba} \times C_{sed} / FOC_{sed}) + (P_{abt} \times C_{soil} / FOC_{soil})]\}$. BAF_{ab} was calculated by entering the average concentration of tissue PCBs (C_{ab}) and lipids ($LIPID_{ab}$) and soil PCBs (C_{soil}) and FOC (FOC_{soil}) for each reach into the equation: $BAF_{ab} = BSAF \times (LIPID_{ab} / FOC_{soil})$. See text for derivation of equations.
5. The PCB concentration in duck tissue from aquatic prey (C_{aba}) in Reach 5 averaged 5.79 mg/kg (calculated using equation 13 in text) and from terrestrial prey (C_{abt}) averaged 1.59 mg/kg (calculated using equation 14 in text), which sums to the measured average PCB concentration in the tissue (C_{ab}) of 7.38 mg/kg. Similarly for Reach 6, the PCB concentration from aquatic prey averaged 4.99 mg/kg and from terrestrial prey averaged 1.37 mg/kg, which sums to the measured average PCB concentration (C_{ab}) in the tissue of 6.36 mg/kg.

Table E-6 – Kalamazoo River Data (Trowbridge Area) Used to Calculate the $BSAF_{am}$ and Average Lipid Content of Aquatic Mammals (Muskrat)

Field Sample ID	Tissue PCB (mg/kg)	Lipid Fraction	Sediment Average PCB (mg/kg)	Sediment Average FOC	Individual $BSAF_{am}$
MT0018	0.082	0.020	2.177	0.055	0.10
MT0020	0.036	0.007	2.502	0.069	0.14
MT0021	0.059	0.026	0.011	0.057	11.48
MT0024	0.076	0.019	2.177	0.055	0.10
MT0025	0.014	0.013	2.502	0.069	0.03
MT0026	0.112	0.044	0.017	0.057	8.62
MT0027	0.079	0.043	0.017	0.039	4.24

Notes:

1. Data are from Kalamazoo River PCB database.
2. The geometric mean of the individual BSAFs is 0.14. The median of individual BSAFs is 0.57. The higher of the geometric mean or median was used as $BSAF_{tm}$ for both averaging areas when applied to the target soil equation (see Table E-1).

Table E-7 – Data Used to Calculate the BAF_{tb} for Terrestrial Birds

Field Sample ID	Location (Site or State Plane Coordinate)	Egg Tissue PCB (mg/kg)	Estimated Adult Tissue PCB (mg/kg) [2]	Soil Average PCB (mg/kg)[3]	Individual BAF_{tb}
House Wren					
Reach 5A/5B					
MCM812-E	Canoe Meadows	57.57	29.36	13.8	2.13
MCM815-E	Canoe Meadows	149.44	76.21	13.8	5.52
MCM828-E	Canoe Meadows	45.94	23.43	13.8	1.70
MCM809-E	Canoe Meadows	63.16	32.21	13.8	2.33
MCM816-E	Canoe Meadows	43.30	22.08	13.8	1.60
Black-Capped Chickadee					
Reach 5A/5B					
MCM830-E	Canoe Meadows	17.58	8.97	13.8	0.65
MLR881-P	New Lennox Road	18.18	9.27	24.2	0.38
Reach 5C/5D/6					
MRB842-P	Roaring Brook Road	24.98	12.74	27.6	0.46
American Robin					
Reach 5A/5B					
043-E	56295N, 905724E	162.00	82.62	37.8	2.19
069-E	56261N, 905926E	51.40	26.21	15.0	1.75
009-E	56261N, 905956E	37.50	19.13	0.4	49.80
108-E	56412N, 905970E	86.30	44.01	10.0	4.40
056-E	56497N, 906053E	103.00	52.53	17.0	3.09
110-E	56434N, 906115E	170.00	86.70	40.8	2.13
Reach 5C/5D/6					
022-E	56354N, 903376E	6.70	3.42	0.7	4.88
023-E	56539N, 903474E	18.40	9.38	49.0	0.19
012-E	56215N, 904242E	7.38	3.76	3.7	1.03
049-E	56487N, 905410E	150.00	76.50	18.4	4.16

Notes:

1. Wren and chickadee data from EPA database for ERA. Robin tissue data from GE database for robin productivity study (ARCADIS G&M, Inc., 2002).
2. Soil data were spatially-weighted for wrens and chickadees**.**
3. The estimated average tissue PCB concentration for adult tissue in Reach 5A/5B is 39.44 mg/kg and for Reach 5C/5D/6 is 18.06 mg/kg (assuming adult concentrations are 0.51 of egg concentrations, Neigh et al., 2006).
4. The geometric mean of the individual BAFs is 2.43 in Reach 5A/5B and 1.13 in Reach 5C/5D/6. The median of individual BAFs is 2.13 in Reach 5A/5B and 1.03 in Reach 5C/5D/6. The higher of the geometric mean or median for the averaging area was used as BAF_{tb} in the target soil equation (see Table E-1).

Table E-8 – Data Used to Calculate the BAF_{tm} for Terrestrial Mammals

Field Sample ID	Location (State Plane coordinates)	Tissue PCB (mg/kg)	Soil Spatially-Weighted Average PCB (mg/kg)	Individual BAF_{tm}
Short-Tailed Shrew				
Reach 5A/5B				
H3-TM05SS13-0-F001	57072N, 909134E	135.77	26.07	5.21
H3-TM05SS13-0-F002	57061N, 909173E	102.25	28.78	3.55
H3-TM05SS13-0-F003	57024N, 909166E	59.41	37.65	1.58
H3-TM05SS13-0-F004	57090N, 909185E	93.37	24.60	3.80
H3-TM05SS13-0-M001	57099N, 909188E	127.60	23.56	5.42
H3-TM05SS13-0-M002	57099N, 909188E	91.93	23.56	3.90
H3-TM05SS13-0-M003	57064N, 909172E	139.27	28.32	4.92
H3-TM05SS13-0-M004	57039N, 909168E	117.67	32.59	3.61
H3-TM05SS13-0-M005	57057N, 909172E	131.95	29.23	4.51
H3-TM05SS13-0-M006	57087N, 909183E	130.78	24.98	5.24
H3-TM07SS14-0-F001	56803N, 907074E	19.82	36.58	0.54
H3-TM07SS14-0-F002	56802N, 907070E	87.13	37.38	2.33
H3-TM07SS14-0-F004	56802N, 907084E	80.15	33.92	2.36
H3-TM07SS14-0-F005	56848N, 907068E	49.47	31.36	1.58
H3-TM07SS14-0-F009	56797N, 907087E	80.46	33.05	2.43
H3-TM07SS14-0-M001	56810N, 907079E	147.93	35.24	4.20
H3-TM07SS14-0-M003	56802N, 907070E	54.40	37.38	1.46
H3-TM07SS14-0-M004	56769N, 907014E	14.81	27.98	0.53
H3-TM07SS14-0-M005	56807N, 907083E	99.47	34.33	2.90
H3-TM07SS14-0-M006	56821N, 907076E	85.54	35.47	2.41
Reach 5C/5D/6				
H3-TM15SS15-0-F001	56256N, 904032E	7.45	1.25	5.94
H3-TM15SS15-0-F002	56294N, 904065E	4.45	1.27	3.52
H3-TM15SS15-0-M001	56322N, 904094E	5.46	1.12	4.88
H3-TM15SS15-0-M002	56297N, 904140E	10.68	0.71	15.13
White-Footed Mouse				
Reach 5A/5B				
H3-TM05WO13-0-F001	57035N, 909232E	19.98	28.43	0.70
H3-TM05WO13-0-F002	57005N, 909160E	2.44	45.27	0.05
H3-TM05WO13-0-F003	57031N, 909167E	10.10	35.62	0.28
H3-TM05WO13-0-F004	57106N, 909191E	27.39	23.14	1.18
H3-TM05WO13-0-F005	57030N, 909254E	12.43	24.56	0.51
H3-TM05WO13-0-F006	57010N, 909161E	1.63	42.92	0.04
H3-TM05WO13-0-F007	57080N, 909180E	1.92	25.92	0.07
H3-TM05WO13-0-F008	57065N, 909164E	2.10	27.86	0.08
H3-TM05WO13-0-F009	57043N, 909168E	2.15	31.60	0.07
H3-TM05WO13-0-F010	56999N, 909158E	2.00	47.47	0.04
H3-TM05WO13-0-M001	57029N, 909260E	6.02	23.37	0.26
H3-TM05WO13-0-M002	57031N, 909251E	6.76	25.14	0.27
H3-TM05WO13-0-M003	57043N, 909168E	15.38	31.60	0.49
H3-TM05WO13-0-M004	57070N, 909148E	2.38	26.50	0.09
H3-TM05WO13-0-M005	57031N, 909251E	15.98	25.14	0.64
H3-TM05WO13-0-M007	57106N, 909191E	4.50	23.14	0.19
H3-TM05WO13-0-M008	57072N, 909134E	2.42	26.07	0.09
H3-TM05WO13-0-M009	57031N, 909251E	7.94	25.14	0.32
H3-TM05WO13-0-M011	57019N, 909164E	3.61	39.48	0.09
H3-TM05WO13-0-M012	57067N, 909157E	16.72	27.35	0.61
H3-TM07WO14-0-F002	56860N, 907064E	5.56	33.48	0.17
H3-TM07WO14-0-F003	56769N, 907014E	3.72	27.98	0.13

Field Sample ID	Location (State Plane coordinates)	Tissue PCB (mg/kg)	Soil Spatially-Weighted Average PCB (mg/kg)	Individual BAF_{tm}
H3-TM07WO14-0-F004	56812N, 907080E	34.98	35.13	1.00
H3-TM07WO14-0-F005	56764N, 907002E	3.94	20.83	0.19
H3-TM07WO14-0-F007	56830N, 907068E	4.64	35.50	0.13
H3-TM07WO14-0-F010	56808N, 907078E	2.49	35.54	0.07
H3-TM07WO14-0-F011	56794N, 907089E	1.13	32.72	0.03
H3-TM07WO14-0-F013	56830N, 907068E	1.03	35.50	0.03
H3-TM07WO14-0-F014	56803N, 907074E	1.07	36.58	0.03
H3-TM07WO14-0-F018	56860N, 907022E	5.33	50.35	0.11
H3-TM07WO14-0-M003	56846N, 907069E	0.15	31.38	0.00
H3-TM07WO14-0-M004	56920N, 907017E	5.60	34.62	0.16
H3-TM07WO14-0-M005	56846N, 907069E	2.17	31.38	0.07
H3-TM07WO14-0-M006	56821N, 907076E	1.72	35.47	0.05
H3-TM07WO14-0-M007	56921N, 907014E	8.78	33.27	0.26
H3-TM07WO14-0-M009	56800N, 907062E	2.36	38.73	0.06
H3-TM07WO14-0-M010	56851N, 907069E	1.62	31.09	0.05
H3-TM07WO14-0-M011	56855N, 907015E	3.19	52.80	0.06
H3-TM07WO14-0-M017	56906N, 907036E	1.51	40.28	0.04
H3-TM07WO14-0-M018	56765N, 907004E	4.02	22.16	0.18
Reach 5C/5D/6				
H3-TM15WO15-0-F001	56300N, 904144E	0.35	0.69	0.51
H3-TM15WO15-0-F002	56320N, 904088E	0.45	1.18	0.38
H3-TM15WO15-0-F003	56291N, 904155E	1.01	0.66	1.53
H3-TM15WO15-0-F004	56342N, 904064E	0.54	1.96	0.27
H3-TM15WO15-0-F005	56339N, 904064E	0.19	1.97	0.10
H3-TM15WO15-0-F006	56272N, 904045E	0.40	1.33	0.30
H3-TM15WO15-0-M001	56256N, 904032E	1.81	1.25	1.44
H3-TM15WO15-0-M002	56297N, 904140E	0.61	0.71	0.86
H3-TM15WO15-0-M003	56291N, 904155E	0.44	0.66	0.67
H3-TM15WO15-0-M004	56287N, 904059E	0.21	1.29	0.16
H3-TM15WO15-0-M005	56333N, 904075E	1.61	1.73	0.93
H3-TM15WO15-0-M006	56305N, 904136E	0.38	0.71	0.54

Notes:

1. Data from EPA database for ERA.
2. The average tissue PCB concentration for Reach 5A/5B is 35.13 mg/kg and for Reach 5C/5D/6 is 2.25 mg /kg.
3. The geometric mean of the individual BAFs is 0.34 in Reach 5A/5B and 0.92 in Reach 5C/5D/6. The median of individual BAFs is 0.27 in Reach 5A/5B and 0.16 in Reach 5C/5D/6. The higher of the geometric mean or median for the averaging area was used as BAF_{tm} in the target soil equation (see Table E-1).