Appendix D

Basis for Target Floodplain Soil Concentrations Associated with PCB IMPG for Insectivorous Birds

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The Interim Media Protection Goals (IMPGs) specified in General Electric's (GE's) revised IMPG Proposal (GE, 2006) and approved by the United States Environmental Protection Agency (EPA) for insectivorous birds were based on EPA's assessment of potential risks to the wood duck (which was selected as a representative species for the insectivorous birds that reside and breed in the Rest of River area), as described in EPA's Ecological Risk Assessment (ERA; EPA, 2004). Those IMPGs apply to concentrations in wood duck invertebrate prey, which consists of both aquatic and terrestrial organisms. The IMPGs for wood duck invertebrate prey are 4.4 milligrams per kilogram (mg/kg) for polychlorinated biphenyls (PCBs) and 14 to 22 nanograms per kilogram (ng/kg) for dioxin toxicity equivalents (TEQs). Consistent with EPA's April 13, 2007 conditional approval letter for GE's Corrective Measures Study (CMS) Proposal (Condition 27), GE's evaluations in the CMS have focused on the IMPGs for total PCBs. Therefore, the IMPGs for TEQs are not further discussed.

As discussed in the text of this CMS Report, in order to be used to evaluate remedial alternatives, the IMPG for PCBs in wood duck invertebrate prey needed to be converted into corresponding PCB concentrations in media subject to evaluation in the CMS – namely, sediments and floodplain soils. This procedure was complicated by the fact that the invertebrate portion of the wood duck's diet consists of an aquatic invertebrate component (related to sediment and water column) and a terrestrial invertebrate component (related to floodplain soil). Thus, when calculating target sediment and floodplain soil concentrations associated with the prey-based IMPGs, the concentration in one component affects the allowable concentration in the other components – i.e., a higher concentration in sediments will require a lower concentration in soil in order to achieve the IMPG, and vice versa. Thus, it is not possible to derive a target concentration in one medium without knowing the concentration in the other.

In these circumstances, GE first selected 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). Those selected target PCB concentrations were 1, 3, and 5 mg/kg. GE then calculated target floodplain soil concentrations associated with achieving the PCB IMPG of 4.4 mg/kg in wood duck invertebrate prey assuming that the sediment PCB concentrations are equal to the selected target values. These calculations were initially presented in Appendix A to the CMS Proposal. However, EPA's April 13, 2007 conditional approval letter provided several comments on those calculations and directed GE to revise the calculations of target floodplain soil levels.

Based on those comments, this appendix describes the revised procedure used to calculate the target floodplain soil levels and presents revised calculations and target levels. These revised calculations were based on assumed target sediment concentrations of 1, 3, and 5 mg/kg. In accordance with EPA's comments, revised target floodplain soil concentrations have been calculated separately for each of the four subreaches of the Primary Study Area (PSA) (i.e., Reaches 5A, 5B, 5C/5D, and 6), due to subreach-specific differences in the total organic carbon content (TOC) of the surface sediments and in the biota-sediment accumulation factors (BSAFs).[1] The underlying equations, input variables, and results of this analysis are summarized in Table D-1 and are detailed below.

Derivation of Equation for Target Soil PCB Concentrations

As detailed in Attachment 29 of the revised IMPG Proposal, the prey-based IMPG is related to PCB concentrations in aquatic and terrestrial invertebrates as follows:

$$C_i = [(P_{ai} \times C_{ai}) + (P_{ti} \times C_{ti})] / (P_{ai} + P_{ti}) \qquad \text{Eqn. 1}$$

Where:

C_i = concentration of PCBs in invertebrate prey of wood ducks (mg/kg)

P_{ai} = proportion of wood duck diet comprised of aquatic invertebrates (unitless)

C_{ai} = concentration of PCBs in aquatic invertebrates (mg/kg)

P_{ti} = proportion of wood duck diet comprised of terrestrial invertebrates (unitless)

C_{ti} = concentration of PCBs in terrestrial invertebrates (mg/kg).

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[1] These target floodplain soil concentrations have been applied in a more general way to the floodplain in further downstream reaches, as described in the text of this Report.

In order to differentiate between aquatic invertebrate prey that primarily reside in the water column and those that inhabit both the water column and the sediment (epibenthic organisms), Equation 1 is further broken out as:

$$C_i = [(P_{ei} \times C_{ei}) + (P_{wi} \times C_{wi}) + (P_{ti} \times C_{ti})] / (P_{ei} + P_{wi} + P_{ti}) \qquad \text{Eqn. 2}$$

Where:

P_{ei} = proportion of wood duck diet comprised of epibenthic invertebrates (unitless)

C_{ei} = concentration of PCBs in epibenthic invertebrates (mg/kg)

P_{wi} = proportion of wood duck diet comprised of water column invertebrates (unitless)

C_{wi} = concentration of PCBs in water column invertebrates (mg/kg)

P_{ti} = proportion of wood duck diet comprised of terrestrial invertebrates (unitless)

C_{ti} = concentration of PCBs in terrestrial invertebrates (mg/kg).

The lipid-normalized concentration of PCBs in epibenthic and water column invertebrates may be related to the organic carbon-normalized concentration of PCBs in sediment as follows (Ankley et al., 1992):

$$BSAF = (C_i / L) / (C_{sed} / TOC) \qquad \text{Eqn. 3}$$

Where:

BSAF = biota-sediment accumulation factor (unitless)

L = lipid content of invertebrates (%)

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

TOC = total organic carbon content of sediment (%)

As detailed further below, separate BSAFs have been calculated for epibenthic and water column invertebrates and for different subreaches of the river. One would not expect a strong correlation between PCB concentrations in water column invertebrates and those in sediments given that such invertebrates are not in direct contact with sediment. Nonetheless, because water column invertebrates are about 20% of the wood duck pre-laying diet (Drobney and Fredrickson, 1979, as tabulated in the ERA at Vol. 5, Table G.2-

35), use of a BSAF specific to water column invertebrates allows more complete consideration of bioaccumulation of PCBs from sediment into all components of the wood duck diet.

Equation 3 can be rearranged to:

$$C_i = BSAF \times C_{sed} \times 1/TOC \times L \qquad \text{Eqn. 4}$$

For the terrestrial component of the wood duck diet, the concentration of PCBs can be expressed as:

$$C_{ti} = BAF_{ti} \times C_{soil} \qquad \text{Eqn. 5}$$

Where:

BAF_{ti} = soil-to-terrestrial invertebrate bioaccumulation factor (unitless)

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

Unlike the calculations of BSAFs, this relationship has not been normalized based on TOC and/or lipid content or varied by subreach due to the limited available empirical data on co-located soil and terrestrial invertebrate PCB concentrations, as further discussed below. In this situation, Equation 5 is the simplest model that yields the strongest relationship between the soil and terrestrial invertebrate PCB concentrations.

Equations 4 and 5 may be substituted into Equation 2 to yield:

$$C_i = [(P_{ei} \times BSAF_{ei} \times C_{sed} \times 1/TOC \times L_{ei}) + (P_{wi} \times BSAF_{wi} \times C_{sed} \times 1/TOC \times L_{ei})$$

$$+ (P_{ti} \times BAF \times C_{soil})] / (P_{ei} + P_{wi} + P_{ti}) \qquad \text{Eqn. 6}$$

Solving Equation 6 for C_{soil} yields:

$$C_{soil} = C_i \times (P_{ti} + P_{wi} + P_{ei}) - [(P_{wi} \times BSAF_{wi} \times L_{wi} \times C_{sed} \times 1/TOC) +$$

$$(P_{ei} \times BSAF_{ei} \times L_{ei} \times C_{sed} \times 1/TOC)] / P_{ti} \times BAF_{ti} \qquad \text{Eqn. 7}$$

As shown in Table D-1, Equation 7 was used to calculate subreach-specific target floodplain soil concentrations associated with the IMPG of 4.4 mg/kg for wood duck prey and sediment concentrations of 1, 3, and 5 mg/kg, based on the following assumptions regarding each of the equation's variables.

Assumptions

Input values for Equation 7 were preferentially selected based on site-specific data, as presented in the ERA and supporting studies and datasets. The bases for all input assumptions are detailed below.

C_i – The target PCB concentration in the wood duck invertebrate prey was set equal to the EPA-approved IMPG of 4.4 mg/kg, derived in the revised IMPG Proposal (GE 2006, Appendix D, Attachment 29).

P_{ei} – The proportion of wood duck diet composed of epibenthic invertebrates was set equal to 0.367, based on Drobney and Fredrickson's (1979) diet data for the wood duck's pre-laying period (and as tabulated in the ERA at Vol. 5, Table G.2-35). Assignment of individual taxa in the wood duck's diet to the category of epibenthic or water column groups followed EPA's Food Chain Model (FCM) designations (EPA, 2006, pp. 2.4-1, 2.4-2 and Table 2.4-1).

P_{wi} - The proportion of wood duck diet composed of water column invertebrates was set equal to 0.197, also based on Drobney and Fredrickson's (1979) diet data for the wood duck's pre-laying period (and as tabulated in the ERA at Vol. 5, Table G.2-35). Assignment of individual taxa in the wood duck's diet to the category of epibenthic or water column groups followed EPA's FCM designations (EPA 2006, pp. 2.4-1, 2.4-1 and Table 2.4-1). P_{ei} and P_{wi} sum to 0.564, consistent with the ERA's assumption regarding the proportion of the wood duck diet composed of aquatic invertebrates (Vol. 5, Table G.2-33).

P_{ti} – The proportion of wood duck diet composed of terrestrial invertebrates was set equal to 0.196, consistent with the ERA (Vol. 5, Table G.2-33) and based on the diet during the pre-laying period (Drobney and Fredrickson, 1979; Drobney, 1980).

C_{sed} - Given the inter-related but unknown values of C_{sed} and C_{soil}, it was necessary to hold C_{sed} at fixed target levels in order to generate the C_{soil} values that are associated with each sediment concentration. Values of 1, 3, and 5 mg/kg were selected as example target sediment concentrations as discussed above.

BSAF – Biota-sediment accumulation factors for epibenthic invertebrates and water column invertebrates in Reaches 5A, 5B, 5C/5D, and 6 were calculated using EPA's FCM (EPA, 2006), based on simulations for 26 years (1979 through 2004) and average BSAFs for April through July of each year. The April through July period was selected because it encompasses the range from earliest nest initiation date to latest nest initiation date in Massachusetts (Grice and Rogers, 1965) and thus reflects the most active period of the wood duck's breeding season. Modeled BSAFs for water column feeders and epibenthic organisms are plotted in Figures D-1 and D-2, respectively, for each subreach of the PSA. BSAFs are also tabulated in Table D-1.

L_{ei} – The lipid content of epibenthic invertebrates was set equal to 1.5%, consistent with the findings of the FCM (EPA, 2006, Appendix C.1, pp. 1-5).

L_{wi} – The lipid content of water column invertebrates was set equal to 2%, consistent with the findings of the FCM (EPA, 2006, Appendix C.1, pp. 1-5).

TOC – As shown in Table B-1, subreach-specific values for the total organic carbon content of surface sediments (top 6 inches) were employed, based on the approved RCRA Facility Investigation (RFI) Report (QEA and BBL. 2003, Table 4-3).

BAF – A bioaccumulation factor of 0.31 was calculated from EPA's dataset for concentrations of PCBs in eight co-located litter invertebrate and composite soil samples collected from three sampling stations (13, 14, and 15) within the PSA (ERA, Vol 6, Appendix L). The underlying data are reproduced in Table D-2. Although EPA contractors had sampled both earthworms and litter invertebrates from these three stations, earthworm data were excluded from the BAF calculation because they are not a component of wood ducks' pre-laying diet (ERA, Vol. 5, Table G.2-35). The BAF of 0.31 reflects the median of BAFs calculated from all litter invertebrate results. Reach-specific BAFs were not calculated or applied due to the very low sample sizes per subreach (n = 0 to 3). However, as discussed below, the BAF of 0.31 is quite conservative compared to BAFs reported in the literature for terrestrial invertebrates.

Results

The target floodplain soil concentrations calculated using the above approach for each subreach and target sediment concentration are detailed in Table D-1 and summarized below:

Target Floodplain Soil Concentrations (mg/kg) Associated with IMPG for Wood Ducks

Assumed Sediment Concentration	Reach 5A	Reach 5B	Reach 5C/5D	Reach 6
1 mg/kg	50	48	53	**53**
3 mg/kg	39	33	49	**50**
5 mg/kg	**29**	**18**	**46**	**46**

Discussion

Of the input variables used to generate the target soil concentrations, the most significant uncertainty and variability are associated with the BSAF and the BAFs. In order to verify the appropriateness of the BSAF and BAFs applied, published papers and site-specific studies on bioaccumulation of PCBs by aquatic and terrestrial invertebrates that form significant portions of the wood duck diet were reviewed. As further detailed below, the literature review confirmed the appropriateness of the selected values.

The BSAFs used in the analysis (0.20 to 1.3) were derived from the FCM and vary according to prey type and river subreach. Other sources of BSAFs considered but rejected for this analysis include empirical data from the ERA (tree swallow stomach content data, D-net invertebrate data, and a 7-day *Lumbriculus* bioaccumulation study), BSAFs generated for the Kalamazoo River site, and theoretical predictions based on equilibrium partitioning. These potential sources are discussed below.

<u>Data from ERA</u>: Empirically derived BSAFs require consideration of co-located data on concentrations of PCBs in sediment and invertebrates, as well as invertebrate lipid content and sediment TOC. The tree swallow stomach contents analyzed for PCBs as part of the ERA cannot be used to generate BSAFs because it is not possible to link the tree swallow prey samples to specific sediment sampling locations from which the prey were harvested by individual tree swallows. Although assumptions could theoretically be made through spatial averaging of sediment concentrations within foraging distance of each tree swallow's

nest box, considerable variability would result because prey concentrations differ among collections from closely located nest boxes (which would share virtually the same foraging area). Similarly, co-located sediment samples also were lacking for the invertebrates collected for the ERA using D-nets. While the 7-day *Lumbriculus variegatus* bioaccumulation study conducted as part of the ERA does have co-located sediment and invertebrate data, that study is limited for purposes of generating wood duck target levels because *Lumbriculus* is not a component of the wood duck diet and because seven days is not likely a sufficient test duration to achieve steady state.

<u>Data from Kalamazoo River</u>: Kay et al. (2005) used empirical data to generate BSAFs for benthic invertebrates, aquatic emergent insects, and several other types of organisms for total PCBs for the Kalamazoo River site and a reference site. The lipid-normalized BSAF for benthic invertebrates and aquatic emergent insects from the Kalamazoo River were 0.439 and 0.18, respectively, while those from the reference site were somewhat higher (1.15 and 0.597, respectively) (Kay et al., 2005). Because these BSAFs are not specific to the Housatonic River, they are less applicable to this analysis than those generated by the FCM. However, they do offer a bounding range of BSAFs that illustrates that the BSAFs generated by the FCM are within the range supported by empirically derived BSAFs for total PCBs.

<u>Equilibrium Partitioning</u>: The ERA (Vol. 4, p. D-39) reported that equilibrium partitioning theory for PCBs yields a BSAF of approximately 2 for benthic invertebrates (Parkerton 1993, McFarland 1994). The RFI Report (QEA and BBL, 2003, p. 8-51) noted that average or median BSAFs for benthic organisms generally lie between 1.5 and 3 for PCBs with logarithm of octanol-water partitioning coefficients (log Kow) in the range of 6 to 7 (Tracey and Hansen, 1996; QEA, 1999; Wong et al., 2001). However, equilibrium partitioning theory alone may not be sufficient to explain variability in uptake of PCBs by aquatic organisms, especially water column and epibenthic species. Furthermore, Di Toro et al. (1991) noted that equilibrium partitioning theory is a relatively poor predictor of uptake when sediment TOC is very low (i.e., less than 0.2%). Although TOC in the different subreaches of the PSA is at least an order of magnitude higher than that minimum threshold (see Table D-1), it is possible that this limitation of equilibrium partitioning theory would cause it to perform less well in subreaches with relatively low TOC than in those with much higher TOC.

For all of these reasons, the model-derived BSAFs were judged most applicable to the estimation of target floodplain soil concentrations protective of wood ducks.

The BAF used in the analysis (0.31) is the median of calculated BAFs from eight co-located litter invertebrate and floodplain soil samples collected within the PSA as part of the ERA.

The majority of published studies on bioaccumulation of PCBs by terrestrial invertebrates focus on earthworms. As previously discussed, because earthworms are not a significant portion of the wood duck's diet, they were excluded from the calculation of site-specific BAFs. Published earthworm bioaccumulation studies were excluded from the literature review for the same reason, which left two pertinent articles (Blankenship et al., 2005. and Paine et al.. 1993).

Blankenship et al. (2005) reported total PCB concentrations for above-ground terrestrial invertebrates (excluding earthworms) and co-located soil samples collected from the Kalamazoo River Superfund Site. Arithmetic mean concentrations of total PCBs in terrestrial invertebrates and soil were reported to be 0.34 and 6.5 mg/kg, respectively, which yield a BAF of 0.05. Geometric mean concentrations in invertebrates and soil were 0.10 and 4.7 mg/kg, respectively, which yield a BAF of 0.02. In a 14-day bioaccumulation test on uptake of Aroclor 1254 in soil by house crickets, Paine et al. (1993) observed BAFs ranging from 0.07 to 0.19 for soil concentrations ranging from 100 to 2,000 mg/kg. The BAF associated with the lowest soil concentration (100 mg/kg) was 0.11. Relative to these two studies, the site-specific BAF of 0.31 is quite conservative.[2] Use of the highest of the literature-derived BAF (0.19) would increase the target soil levels by 1.6-fold.

In conclusion, target floodplain soil PCB concentrations that are associated with the four selected target sediment concentrations and based on the PCB IMPG of 4.4 mg/kg in the invertebrate prey of wood ducks range from 18 to 53 mg/kg, depending on the subreach and target sediment concentration.[3] This analysis is based on site-specific data and is conservative relative to available data published in the peer-reviewed literature.

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[2] The BAF and the target soil concentration are inversely related, such that higher BAFs will yield lower target soils concentrations.

[3] See Section 5.2.3.3 of text for discussion of the application of these target concentrations to the subreaches within the PSA and to further downstream reaches.

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Table D-1. Derivation of Target Floodplain Soil Concentrations Associated with PCB IMPG for Wood Ducks

Subreach	Sediment Concentration C_{sed} (mg/kg)	Organic Carbon Concentration TOC_{sed} (%)	Biota-Sediment Accumulation Factor (Water Column Organisms) $BSAF_{wi}$	Biota-Sediment Accumulation Factor (Epibenthic Organisms) $BSAF_{ei}$	Lipids (Water Column Organisms) L_{wi} (%)	Lipids (Epibenthic Organisms) L_{ei} (%)	Target Soil Concentration C_{soil} (mg/kg)
5A	1	1.4	0.202	0.665	2.0	1.5	50
5A	3	1.4	0.202	0.665	2.0	1.5	39
5A	5	1.4	0.202	0.665	2.0	1.5	29
5B	1	1.4	0.409	0.849	2.0	1.5	48
5B	3	1.4	0.409	0.849	2.0	1.5	33
5B	5	1.4	0.409	0.849	2.0	1.5	18
5C/5D	1	8.0	0.608	1.226	2.0	1.5	53
5C/5D	3	8.0	0.608	1.226	2.0	1.5	49
5C/5D	5	8.0	0.608	1.226	2.0	1.5	46
6	1	8.0	0.469	1.267	2.0	1.5	53
6	3	8.0	0.469	1.267	2.0	1.5	50
6	5	8.0	0.469	1.267	2.0	1.5	46

Notes:

$$IMPG = C_{soil} = \frac{\left\{C_i \times (P_{ti} + P_{wi} + P_{ei}) - \left[\left(P_{wi} \times BSAF_{wi} \times L_{wi} \times C_{sed} \times \frac{1}{TOC}\right) + \left(P_{ei} \times BSAF_{ei} \times L_{ei} \times C_{sed} \times \frac{1}{TOC}\right)\right]\right\}}{P_{ti} \times BAF_{ti}}$$

Basis for all assumptions detailed in text.

$P_{ti} = 0.196$ $C_i = 4.4$ mg/kg

$P_{wi} = 0.197$ $BAF_{ti} = 0.31$

$P_{ei} = 0.367$

Table D-2. Litter Invertebrate-Floodplain Soil PCB Bioaccumulation Factors

Field Sample ID	Date Collected	Sample Plot	Litter Invert. PCB Conc. (mg/kg)	Co-located Surface (0-6") Soil PCB Conc. (mg/kg)	Bioaccumulation Factor
H3-TW13LI01-0-0G10	08/10/00	13-1 and 13-3	4.1	9.6	0.42
H3-TW13LI02-0-0G10	08/10/00	13-9	3.6	10.8	0.33
H3-TW13LI03-0-0G11	08/11/00	13-7	4.9	16.3	0.30
H3-TW14LI01-0-0G15	08/15/00	14-4, 14-5, and 14-6	3.8	34.9	0.11
H3-TW14LI02-0-0G15	08/15/00	14-1, 14-2, and 14-3	3.5	66.1	0.05
H3-TW14LI03-0-0G16	08/16/00	14-1 and 14-8	2.3	69.8	0.03
H3-TW15LI01-0-0G09	08/09/00	15	1.4	0.8	1.81
H3-TW15LI02-0-0G10	08/10/00	15	2.8	0.8	3.58

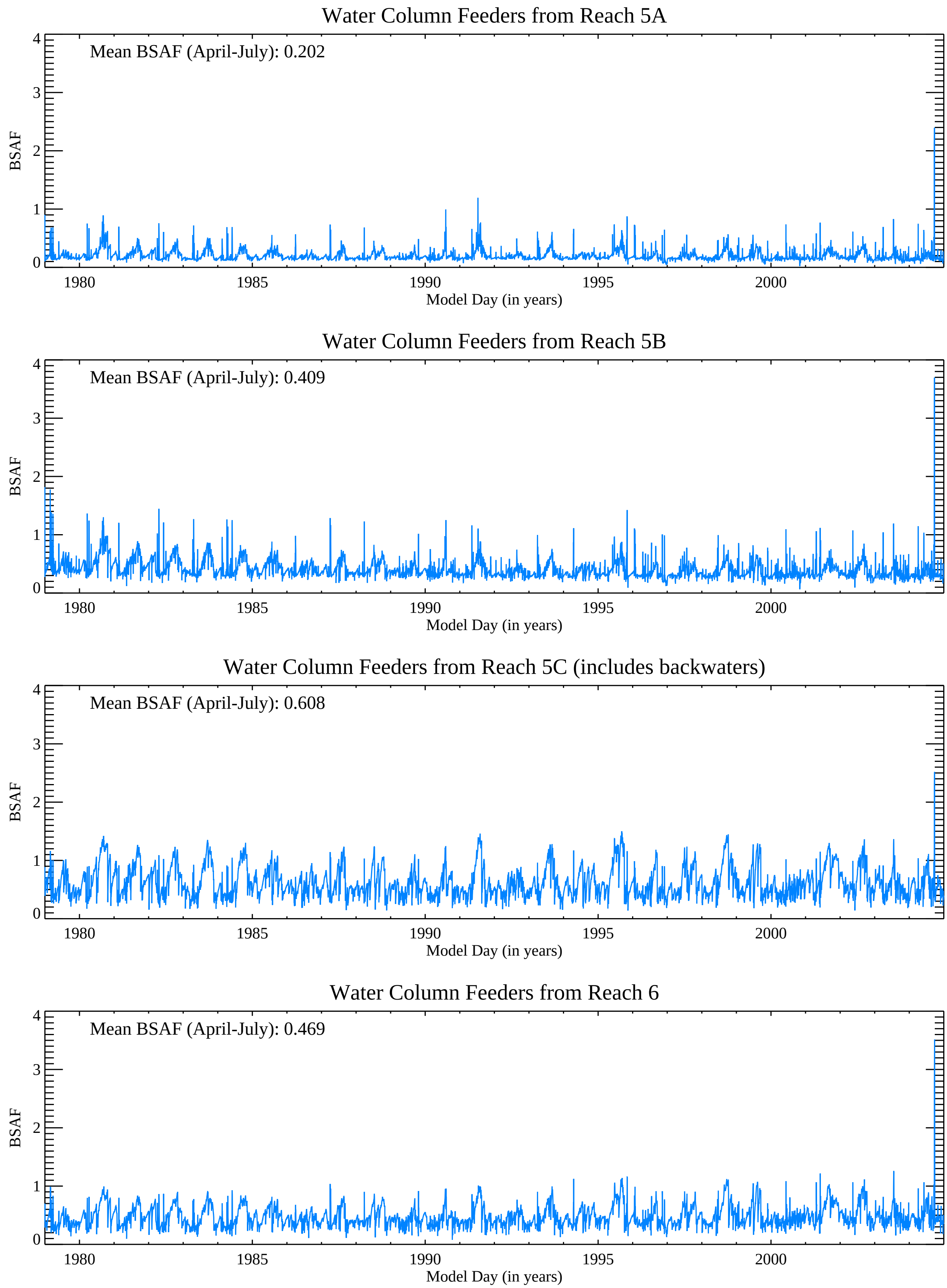

Figure D-1. Biota-Sediment Accumulation Factors Derived from Food Chain Model

Notes: Values for mean BSAF were calculated from all years (1979 to 2004) from days between Apr. 1st through July. 31st.

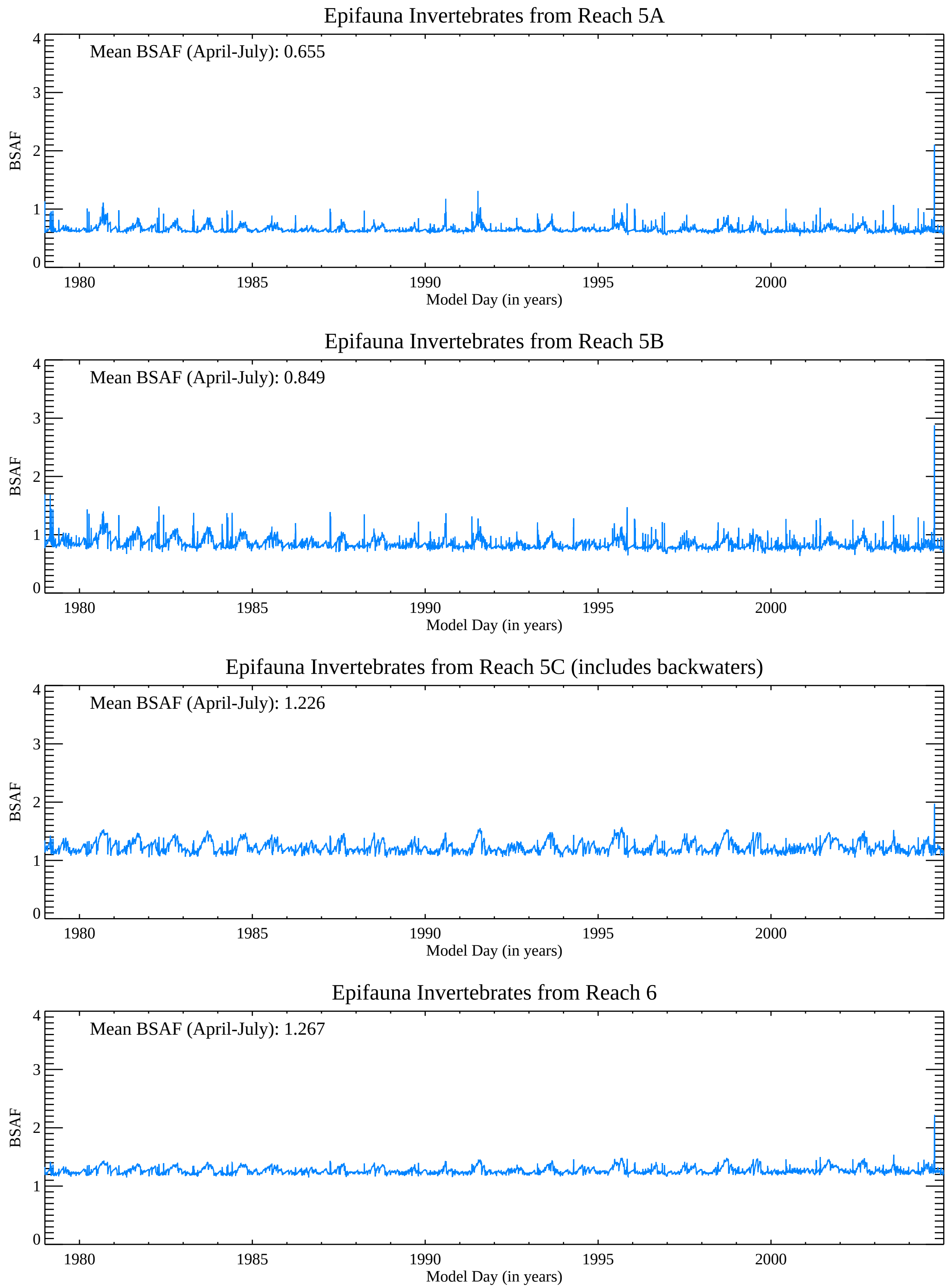

Figure D-2. Biota-Sediment Accumulation Factors Derived from Food Chain Model

Notes: Values for mean BSAF were calculated from all years (1979 to 2004) from days between Apr. 1st through July. 31st.

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