Fox River Food (FRFood) Model Documentation Memorandum

Lower Fox River, Wisconsin Remedial Investigation and Feasibility Study

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Prepared for:

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July 13, 2001

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1 Introduction: FRFood

The Fox River Food (FRFood) bioaccumulation model is a mathematical description of polychlorinated biphenyl (PCB) transfer within the food web of the Lower Fox River and the first two zones of Green Bay (zones 1 and 2). The model is designed to take the output of sediment and water concentrations of PCBs from the Whole Lower Fox River Model (wLFRM) and the Enhanced Green Bay Toxics Model (GBTOXe) (described in Appendices B1 and C1, respectively, to the Model Documentation Report) to estimate concentrations in multiple trophic levels in the aquatic food web (i.e., benthic insects, phytoplankton, zooplankton, and fish).

FRFood supports the overall Remedial Investigation and Feasibility Study (RI/FS) for the Lower Fox River and Green Bay in two ways: 1) to estimate risk-based sediment quality thresholds (SQTs) that would be protective of human health and ecological receptors, and 2) as a projection tool to estimate long-term human health and ecological risk reduction from selected remedial action levels in the RI/FS. Development of SQTs is discussed in Section 7 of the *Draft Baseline Human Health and Ecological Risk Assessment* (BLRA) (ThermoRetec, 2001a), and are applied in the selection of the remedial action levels in Section 5 of the *Draft Feasibility Study* (FS) (ThermoRetec, 2001b). Projected PCB concentrations from FRFood, as well as wLFRM, GBTOXe, and the Green Bay Food (GBFood) bioaccumulation model, are used in Sections 8 through 10 of the FS to assess alternative-specific risks, and to compare the relative reductions of PCBs in water and fish tissue.

This memorandum presents the mathematical foundation of the model, inputs to the model, the calibration of the model relative to evaluation metrics established by the Wisconsin Department of Natural Resources (WDNR) and the Fox River Group, and the results of the specific alternative projections described in the Feasibility Study.

1.1 Structure of FRFood

FRFood is based upon the algorithms originally developed for Lake Ontario PCBs (Gobas *et al.*, 1993). Since its development, the model has been used extensively throughout the Great Lakes, which was a primary reason for its selection. To date, examples of where this model has been applied include:

- The model was developed for Great Lakes food chains and has been previously validated using both Lake Ontario and Green Bay PCB and food web data.

- EPA made extensive use of the Gobas model to derive bioaccumulation factors, bioconcentration factors, and food chain multipliers in the development of the GLWQI criteria (EPA, 1993 and 1994).

- The Gobas model was used in the 1996 RI/FS for the Lower Fox River and found to yield reasonably good results between predicted and measured fish tissue PCB concentrations (GAS/SAIC, 1996).

- A modified version of the Gobas model was used for the Ecological Risk Assessment for the Sheboygan River, Wisconsin, and also found reasonable similarity between predicted and measured PCB levels in fish (EVS, 1998).

- The Gobas algorithms were used to project future PCB concentrations in fish for the Hudson River (EPA, 2000).

In 1993, Gobas introduced his methods by modeling a food web in Lake Ontario. He compared predicted levels of PCBs in a Lake Ontario food web to published observed data (Oliver and Niimi, 1988), and found that predicted versus observed PCB concentrations were within a factor of five for all organisms. The model was particularly accurate in determining PCB levels in higher trophic levels (all fish), where predicted levels of PCBs versus observed differed by less than a factor of two.

Both the Gobas model (1993), and a similar model constructed by Thomann *et al.* (1989, 1992) have gained general scientific acceptance and are now being used in scientific and regulatory applications to predict concentrations of hydrophobic organic contaminants in aquatic food webs (Burkhard, 1998). Burkhard (1998) reviewed the predictive capabilities of these two models compared to field-collected fish data from Lake Ontario and concluded that while both models provided similar results, the Gobas model provided slightly better predictions.

While the Gobas model was developed specifically for application in lake systems, the mathematical relationships have been successfully applied to predicting fish tissue concentrations in some river systems. As noted above, the 1996 RI/FS for the Fox River found good correlation between predicted and observed fish tissue concentrations. Likewise, a good fit between predicted and observed fish tissue concentration was observed when the model was used to describe the bioaccumulation of PCBs in Hudson River ecosystems (EPA, 2000), and the Sheboygan River (EVS, 1998). In part, this may be because the lock and dam system on the Fox and Hudson rivers creates a series of large “pools” that behave more like reservoir- or lake-like systems (e.g., Little Lake Butte des Morts).

The Gobas model assumes that equilibrium steady states exist between water and plankton, and between sediment and benthic invertebrates. Lipid-normalized phytoplankton and zooplankton concentrations are assumed to equal organic carbon-normalized water concentrations. Lipid-normalized benthic invertebrate concentrations are estimated to equal organic carbon-normalized sediment concentrations. Non-equilibrium steady-state concentrations in fish are calculated assuming mass balance where contaminant uptake from diet and gill ventilation is equal to loss through gill ventilation, egestion, metabolic breakdown, and dilution by growth.

Since 1993, several improvements/additions to the Gobas model have been suggested, including a time-dependent response to changes in PCB levels which incorporated age classes to organisms (Gobas *et al.*, 1995) and a more sophisticated model to describe bioaccumulation of PCBs in zooplankton and benthic invertebrates (Morrison *et al.*, 1996). Morrison *et al.* (1996) improved modeled zooplankton and benthic invertebrate bioaccumulation by considering PCB intake from diet (by filter feeding and consumption of detritus) and gill ventilation, and loss through gill ventilation, egestion, metabolic breakdown, and dilution by growth. A verification of an entire aquatic food web using the 1993 Gobas model and improved zooplankton and benthic invertebrate model was published in 1997 (Morrison *et al.*, 1997). All verification attempts found that estimated concentrations of PCBs typically fell well within an order of magnitude of observed results. However, these modifications were not incorporated into FRFood due to: 1) the lack of site-specific input parameters necessary to implement those modifications, and 2) the generally good agreement between predicted and observed PCB fish tissue concentrations using the 1993 version of the model.

1.2 Model Architecture

The modeling framework for FRFood is a series of mathematical equations, which are described in Section 2. FRFood is a database application written in Visual Basic for Applications (VBA) 5 and hosted in Microsoft (MS) Access 97. The application can be run on Windows 95/98/Me/2000 or NT 4 workstations. Recommended computer specifications are a Pentium 200 with 64 megabytes (MB) of Random Access Memory (RAM). Minimum requirements are Pentium 133 with 16 MB of RAM.

The reversible Fox River bioaccumulation model was developed in MS Access. Because of its open architecture, formulas for calculating rate constants can be changed, and there is no limitation to the number of organisms/life stages to be modeled. Any input variables can be changed, including environmental data, feeding preferences, and the known concentration, and calculations are performed to predict the unknown concentrations.

1.3 Memorandum Organization

This memorandum is organized to present the mathematical framework of the model (Section 2), calibration and application to the river and bay (Section 3), the results of remedial alternative modeling scenarios (Section 4), and a comparison of FRFood model output in zones 1 and 2 to that from GBFood (Section 5).

2 FRFood Model Structure

The FRFood Model is mathematically based on the Gobas model (1993) which describes a food web that includes biological uptake routes through water to phytoplankton and zooplankton, as well as through sediment to benthic infauna. These pelagic and benthic invertebrates are the prey base for fish which may result in trophic transfer of contaminants. This section briefly presents the equations taken from Gobas (1993), with modifications consistent with the 1994 application used in previous assessments of the Fox River, that were used to describe organic contaminant uptake and bioconcentration in invertebrates and fish. Neither the Gobas model nor the FRFood Model predicts contaminant concentrations in piscivorous birds or mammals, or humans (i.e., fish consumers).

2.1 Phytoplankton and Zooplankton

Phytoplankton and zooplankton contaminant concentrations are assumed to be in chemical equilibrium with bioavailable concentrations in water. This concentration is determined by using a simple partitioning equation. First, the bioavailable concentration of the contaminant in water is calculated by the following equation.

$$C_{fdw} = C_{tw} * f_d \tag{1}$$

and

$$f_d = \frac{1}{(1 + SS_{tw} * OC_{ss} * K_{ow})} \tag{2}$$

where:

- f_d = fraction of the contaminant that is freely distributed in the water (dimensionless),
- SS_{tw} = concentration of suspended solids in total water (in kilograms per liter [kg/L]),
- OC_{ss} = concentration of organic carbon in suspended solids (in grams per gram [g/g]),
- K_{ow} = organic carbon/water (freely-dissolved basis) partition coefficient for the chemical (dimensionless),

C_{tw} = total concentration of the contaminant in the water (in grams per liter [g/L]), and

C_{fdw} = freely-dissolved concentration of the contaminant in the water (g/L).

The simple equation partitioning freely-dissolved contaminants between plankton (both phytoplankton and zooplankton) and water is determined by the K_{ow} of the contaminant. The ratio of the lipid-normalized concentration of contaminant in phytoplankton and zooplankton to the bioavailable concentration of contaminant in water is equivalent to the K_{ow} of the contaminant.

$$\frac{(C_p/L_p)}{C_{fdw}} = K_{ow} \tag{3}$$

where:

C_p = concentration of contaminant in phytoplankton or zooplankton (in grams per kilogram [g/kg]), and

L_p = fraction of lipid in phytoplankton or zooplankton (in kilograms per kilogram [kg/kg]).

Therefore,

$$C_p = K_{ow} * C_{fdw} * L_p \tag{4}$$

2.2 Benthic Invertebrates

Benthic invertebrate contaminant concentrations are assumed to be in chemical equilibrium with sediment. A simple partitioning equation assumes the contaminant concentration in benthic organisms, corrected for their lipid concentration, is equivalent to the contaminant concentration in the sediment corrected for organic carbon content.

$$\frac{C_b}{L_b} = \frac{C_{sed}}{OC_{sed}} \tag{5}$$

where:

C_b = concentration of contaminant in benthic invertebrates (g/kg),

L_b = fraction of lipid in benthic invertebrates (kg/kg),

C_{sed} = chemical concentration in sediment (g/kg), and

OC_{sed} = fraction of organic carbon in sediment (g/g).

Therefore,

$$C_b = \frac{L_b * C_{sed}}{OC_{sed}} \qquad (6)$$

2.3 Fish

Bioaccumulation in fish is described by Gobas in a steady-state equation in which contaminant uptake through gill ventilation and diet are set equal to contaminant elimination due to gill ventilation, egestion, metabolic breakdown, and dilution through growth. The contaminant uptake is calculated by the following equation.

$$C_{f\,(uptake)} = k_1 * C_{fdw} + k_d * C_d \qquad (7)$$

where:

k_1 = gill uptake rate constant (in liters per kilogram [L/kg] × days),

C_{fdw} = freely-dissolved concentration of the contaminant in the water (g/kg),

k_d = dietary uptake rate constant (kg food/kg fish/day), and

C_d = concentration of contaminant in the diet (g/kg).

The concentration of contaminant in the diet for a species is calculated by multiplying the concentration of contaminant in each consumed species by the fraction the species represents it represents in the diet and then summing the concentrations in each of these dietary components. This is represented mathematically by the formula:

$$C_d = \Sigma(x_i * C_{di}) \qquad (8)$$

where:

x_i = fraction of fish's diet represented by component i (dimensionless) (the sum of all x_i for a species equals 1), and

C_{di} = concentration of contaminant in component i (g/kg).

Contaminant elimination is calculated by the following equation.

$$C_{f\,(elimination)} = (k_2 + k_e + k_m + k_g) * C_f \qquad (9)$$

where:

k_2 = gill elimination rate constant (1/day),
k_e = egestion rate constant (kg feces/kg fish/day),
k_m = metabolic transformation rate (1/day),
k_g = growth rate (1/day), and
C_f = concentration of contaminant in the fish (g/kg).

Setting contaminant uptake ($C_{f\,(uptake)}$) equal to elimination ($C_{f\,(elimination)}$) results in the following equation.

$$(k_1 * C_{fdw}) + (k_d * C_d) = (k_2 + k_e + k_m + k_g) * C_f \qquad \textbf{(10)}$$

The concentration of contaminant in the fish can then be calculated by:

$$C_f = \frac{(k_1 * C_{fdw}) + (k_d * C_d)}{(k_2 + k_e + k_m + k_g)} \qquad \textbf{(11)}$$

Rate constants for the FRFood bioaccumulation model are calculated using the equations identified in the 1993 version of the Gobas model.

2.4 Unique Properties of the FRFood Model

Although the Gobas model was used as a basis for the FRFood Model, several features of the model were revised to allow for more flexibility, including:

- Developing a reversible model that could calculate sediment concentrations based on fish tissue;
- Allowing site-specific parameters as inputs, including sediment and water concentrations;
- Allowing for increased flexibility in adding different organisms and multiple growth stages to the model (a previously available electronic version of the model was limited to two plankton organisms, three benthic organisms, and five fish);

- Allowing for electronic upload of data (a previously available electronic version of the model saved a record of input and output data, but didn't allow for electronic upload of data into the model);

- Allowing for calculations employing a series of spatial or temporal input data; and

- Allowing for corrections/modifications to be made to formulas.

The development of the reversible FRFood Model for total PCBs has the ability to predict sediment concentrations from a given fish tissue concentration. In the past, bioaccumulation models have been used to calculate fish tissue concentrations for the development of biota sediment accumulation factors (BSAFs), which were then used to back-calculate sediment concentrations for selected fish tissue concentrations (Boese and Lee, 1992; Pelka, 1998). This approach is valid, provided the BSAF does not vary with sediment contaminant concentrations, because data do suggest that BSAFs are dependent on sediment concentrations. Constant BSAFs are found when model assumptions define a simple, linear relationship between sediment and water contaminant concentrations, or when water concentrations are set so low as to contribute negligible contaminant loading to fish.

Additional modifications were also made to the model in order to more accurately depict food web dynamics in the Lower Fox River and Green Bay. This included a comprehensive review of the Lower Fox River and Green Bay food webs: prey species, percent composition of diets of various predator species, and lipid contents and weights of the prey and predators of the system.

Finally, additional modifications to the original model were warranted in order to facilitate data inputs to the model, as well as to incorporate changes/updates to the original mathematical formulas used to estimate uptake.

Instead of requiring input of the sediment and total water contaminant concentrations, the reversible FRFood Model allows for input of the contaminant concentration in any compartment, including sediment, water, freely available contaminant in water, or any tissue. The key to creating the reversible version of the bioaccumulation model was to organize the collection of equations used to describe the partitioning and bioaccumulation of contaminants and to solve them as a system.

The fugacity-based model of PCB bioaccumulation by Campfens and Mackay (1997) served as a blueprint for the organization used in the FRFood Model. To reduce the complexity of the mathematics, Equation (11) was simplified to the following:

$$C_f = W * C_{fdw} + D * C_d \tag{12}$$

where:

$$W = \frac{k_1}{(k_2 + k_e + k_m + k_g)} \tag{13}$$

$$D = \frac{k_d}{(k_2 + k_e + k_m + k_g)} \tag{14}$$

As indicated in Equation (8), C_d represents a summation of organism concentrations proportioned by the dietary composition of the species. As an illustration, in a food web made up of one plankton, one benthic organism, and two fish, C_d would expand out to the following equations for Fish 1 (C_{d1}) and Fish 2 (C_{d2}).

$$C_{d1} = x_{p1} * C_p + x_{b1} * C_b + x_{f11} * C_{f1} + x_{f21} * C_{f2} \tag{15}$$

$$C_{d2} = x_{p2} * C_p + x_{b2} * C_b + x_{f12} * C_{f1} + x_{f22} * C_{f2} \tag{16}$$

Substituting Equation (12) into Equation (15), where W, D, and C_f for the first fish are represented as W_1, D_1, and C_{f1}, the rearranged equation is as follows:

$$- x_{p1} * C_p - x_{b1} * C_b + (1/D_1 - x_{f11}) * C_{f1} - x_{f21} * C_{f2} = (W_1/D_1) * C_{fdw} \tag{17}$$

The substitution of Equation (12) into both equations (15) and (16) can be represented as a matrix with the following structure:

$$\begin{pmatrix} -x_{p1} & -x_{b1} & (1/D_1 - x_{f11}) & -x_{f21} \\ -x_{p2} & -x_{b2} & -x_{f12} & (1/D_2 - x_{f22}) \end{pmatrix} * \begin{pmatrix} C_p \\ C_b \\ C_{f1} \\ C_{f2} \end{pmatrix} = \begin{pmatrix} W_1/D_1 \\ W_2/D_2 \end{pmatrix} * (C_{fdw}) \tag{18}$$

This matrix approach was used to simplify the other equations, using the following steps:

Substitute Equation (2) into Equation (1) and simplify to get:

$$C_{tw} = A_1 * C_{fdw} \tag{19}$$

where:

$$A_1 = 1 + SS_{tw} * OC_{ss} * K_{ow} \tag{20}$$

If the ratio of contaminant in sediment to contaminant in total water can be set to f_{sed} then:

$$C_{sed} = A_2 * C_{fdw} \tag{21}$$

where:

$$A_2 = f_{sed} * (1 + SS_{tw} * OC_{ss} * K_{ow}) \tag{22}$$

Equation (4) can be simplified to:

$$C_p = A_3 * C_{fdw} \tag{23}$$

where:

$$A_3 = K_{ow} * L_p \tag{24}$$

Combining equations (21) and (6) yields:

$$C_b = A_4 * C_{fdw} \tag{25}$$

where:

$$A_4 = \frac{L_b * (f_{sed} * (1 + SS_{tw} * OC_{ss} * K_{ow})}{OC_{sed}} \tag{26}$$

The equations describing contaminants in water (19) and sediment (21) and the bioconcentration of contaminants in plankton (23) and benthic (25) organisms can be combined with Equation (18), resulting in the following matrix:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -x_{p1} & -x_{b1} & (1/D_1 - x_{f11}) & -x_{f21} \\ 0 & 0 & -x_{p2} & -x_{b2} & -x_{f12} & (1/D_2 - x_{f22}) \end{pmatrix} * \begin{pmatrix} C_{tw} \\ C_{sed} \\ C_p \\ C_b \\ C_{f1} \\ C_{f2} \end{pmatrix} = \begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ W_1/D_1 \\ W_2/D_2 \end{pmatrix} * (C_{fdw}) \quad \textbf{(27)}$$

Equation (27) represents the entire distribution of contaminants throughout the defined ecosystem. If the food web is defined, and all chemical data, environmental data, and rate constants are known, there are seven potential unknowns—the seven contaminant concentrations. Since there are six equations, if one concentration is known, the equations can be expanded out and solved for the six remaining unknowns through successive substitution. The addition of each organism to the food web adds one additional unknown and one additional equation to the system resulting in a system that remains solvable.

The FRFood Model employs the Gauss-Jordan elimination technique for solving the system of equations.

This technique uses addition and multiplication steps to solve for the unknowns by reducing the system to the reduced row echelon form where the solution for each unknown is available on inspection. The technique requires that the right-hand side of equation should equal a value (rather than including an unknown variable). Equation (27) is currently set up assuming C_{fdw} is known. To change the system to solve for another unknown requires switching the location of C_{fdw} and its coefficient matrix with the known concentration and its coefficient matrix. For example, if C_{f1} is known, Equation (27) would be modified as follows:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & -A_1 & 0 \\ 0 & 1 & 0 & 0 & -A_2 & 0 \\ 0 & 0 & 1 & 0 & -A_3 & 0 \\ 0 & 0 & 0 & 1 & -A_4 & 0 \\ 0 & 0 & -x_{p1} & -x_{b1} & -W_1/D_1 & -x_{f12} \\ 0 & 0 & -x_{p2} & -x_{b2} & -W_2/D_2 & (1/D_2 - x_{f22}) \end{pmatrix} * \begin{pmatrix} C_{tw} \\ C_{sed} \\ C_p \\ C_b \\ C_{fdw} \\ C_{f2} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -(1/D_1 - x_{f11}) \\ x_{f21} \end{pmatrix} * (C_{f1}) \quad \textbf{(28)}$$

3 Application to the Lower Fox River and Green Bay

FRFood was structured to use site-specific information on physical and chemical properties where available, and to use information from the scientific literature and/or the Technical Memorandum series to augment or supplement the site-specific information. The parameterization of the model is described below.

3.1 Reaches and Zones of the River and Bay

The FRFood Model was applied to the following river reaches and zones of Green Bay:

- **Little Lake Butte des Morts Reach:** the river reach from the outlet of Lake Winnebago to the city of Appleton, including Little Lake Butte des Morts (LLBdM);

- **Appleton to Little Rapids Reach:** the river reach from approximately Appleton to Wrightstown;

- **Little Rapids to De Pere Reach:** the section of the river from Little Rapids to the De Pere dam;

- **De Pere to Green Bay Reach (Green Bay Zone 1):** the approximately 11 km (7 miles) of river downstream from De Pere to the mouth of Green Bay; and

- **Green Bay Zone 2:** defined as the lower bay area to a line transversing the bay at Little Tail Point (approximately 13 km or 8 miles).

A more detailed description of these geographic units may be found in Section 1 of the Remedial Investigation (ThermoRetec, 2001c).

3.2 FRFood Model Inputs

3.2.1 Food Web Structure

Identification and documentation of the important food webs for all of the Fox River and Green Bay are given in WDNR Technical Memorandum 7c (WDNR, 2001). That memorandum represents a detailed review of the scientific literature and applies the knowledge of the regional fisheries biologists on the habitats, species, and predator/prey relationships for the food webs in the river and bay. For the purposes of the FRFood Model, two distinct food webs were described in the Lower Fox River and southern Green Bay: one for above the De Pere dam and one for below the dam (Green Bay zones 1 and 2). These food web models include both benthic and pelagic uptake routes.

The food webs identified for the Lower Fox River and Green Bay are identified on Figures 3-1 and 3-2, respectively. Using the detailed descriptions of species and food webs in Technical Memorandum 7c, a literature search was conducted to develop a range of values for diet composition (species and percent prey based on weight or volume of prey), weight, and lipid content. The range of values are presented in Table 3-1.

3.3 FRFood Model Calibration

Calibration of the FRFood Model was conducted using site-specific total PCB data for sediment and water as well as site-specific dietary relationships and lipids. Dietary inputs were generally based on average consumption, but modified for calibration purposes. All site analytical values were derived from the Fox River Database (FRDB), which is described in Section 2 of the Remedial Investigation. Lipid concentrations for fish were the average concentration on a reach-specific basis for each species selected. The output was checked against both single-point estimates (i.e., using reach-wide sediment and water averages), and then by using the calibration output from wLFRM and GBTOXe as input. In both cases, the FRFood Model output was compared to actual measured fish concentrations from Little Lake Butte des Morts, Little Rapids to De Pere, De Pere to Green Bay (Green Bay Zone 1), and Green Bay Zone 2. There were only sufficient data for these four sites to validate the model.

3.3.1 Calibration Metrics

Model calibration was deemed adequate when the output was within the model evaluation metrics used in the Green Bay Mass Balance Study and agreed upon by the WDNR in cooperation with the Fox River Group of Companies (Limno-Tech, 1998). These are defined in the WDNR Technical Memorandum 1 (ThermoRetec, 2001d Appendix A). A goal is to achieve agreement of plus or minus one-half order of magnitude for fish.

Input parameters, both physical and dietary, for each species and each of the areas are presented in Tables 3-2 through 3-5.

3.3.2 Point Calibration

Point calibration involved using the site-wide average sediment and water concentrations derived in the Risk Assessment, and varying diets and lipids within the published range of values (Table 3-1) until total PCBs in the modeled fish species matched the observed values as closely as possible.

Sediment and water concentrations derived from the FRDB were used as inputs to the model for each reach (discussed in Section 6.4 of the BLRA). Dietary inputs for the food web species were generally based on average consumption, but modified as necessary for calibration purposes within the range of parameters specified in Table 3-1. Lipid concentrations for fish were also treated as a calibration variable. These are discussed below.

Migration and Residency Time

For Green Bay zones 1 and 2, fish were assumed to receive 100 percent of their PCB exposure within the combined area of Green Bay Zones 1 and 2. Migration was not considered because the zones were combined. This is in contrast to GBFood, where the model was calibrated based upon an assumption of the time individual fish may migrate in and out of Zone 1 from Zone 2. Migration issues are covered in Technical Memorandum 7c. Differences between the two models are discussed further in Section 5.

Point Estimates of Sediment and Water

Sediment-weighted average concentrations (SWAC) were used as input to the FRFood Model. The surface sediment interpolated total PCB concentrations (I_d) from the bed maps (see BLRA Section 2.3) were selected over non-interpolated total PCB sediment concentrations, because between river reaches, the spatial degree of PCB analysis conducted on sediment in each area varied. Additionally, interpolated sediment concentrations defined concentrations of total PCBs in the biologically active zone, the top 10 centimeters (cm), using the surface SWAC normalized total PCB concentrations between river reaches.

PCB concentration inputs for water were based upon the filtered fraction of water samples collected and reported in the FRDB. Filtered water total PCB concentrations were used rather than estimated water total PCB concentrations, because when filtered and estimated total water concentrations of total PCBs were compared it was found that water concentrations of total PCBs varied seasonally over time. Filtered water total PCB concentrations varied less than estimated total water concentrations. The variation was observed to be dependent on the degree of phytoplankton production. In order to not have PCB concentrations in phytoplankton counted twice, filtered water concentrations rather than total water concentrations were used as inputs in the calibration for the FRFood Model.

Point inputs of sediment and water for each reach/zone are given in Tables 3-2 through 3-5. Both the arithmetic mean and the 95 percent upper confidence limit (95% UCL) derived from the sediment interpolation or dissolved water data were used to test model calibration.

Food Web and Lipid Inputs

Final calibrated dietary inputs for the food webs are presented in Tables 3-2 through 3-5. The food web and the dietary inputs for the modeled fish species are the same for the upper three reaches above the De Pere dam (Tables 3-2 and 3-3). Lipid concentrations for the reaches above De Pere were input as the arithmetic average of all species-specific data in the FRDB (Tables 3-2 through 3-4). Young-of-the-year were assigned the same lipid values as the measured adults.

Point Calibration Results

The comparison of FRFood Model output to the mean and 95% UCL whole fish tissue concentrations collected by reach are shown in Table 3-6. For all reaches and zones, the calibrated output of FRFood Model were well within one-half order of magnitude of observed concentrations of total PCBs. Within the upper reaches, the point calibrations provided good estimates that were within the range of observed values, and generally between 0.6 to 1.5 times of the mean or 95% UCL. While yellow perch were within one-half order of magnitude of the observed values, the model predictions were 1.6 to 4 times those observed. It should be noted that there are limited observations of perch; a single observation in both Little Lake Butte des Morts and one in Little Rapids to De Pere.

For Green Bay zones 1 and 2, FRFood predictions for walleye, perch, and carp were within the range of observed values. Predicted tissue concentrations were 0.6 to 2.2 times observed values. Forage fish were (alewife, shiners, shad, and smelt) generally under-predicted; between 0.3 and 1.2 times the observed fish tissue values.

Based upon these observed/predicted results compared to the model evaluation metric, the FRFood Model was judged suitable for use.

3.3.3 Calibration against wLFRM and GBTOXe

As a check to ensure that the point calibration results effectively projected fish tissue total PCB concentrations that would be generated by both wLFRM and GBTOXe, the calibration results from those two fate simulations were used as input into FRFood. The total PCBs in water and surface sediment PCB concentrations were used as input, and the output from FRFood was compared against measured fish tissue concentrations over the calibration period. The output was then compared against the model evaluation metric of one-half order of magnitude for fish.

For the Fox River, wLFRM was calibrated to data collected between 1989 and 1995 (see Appendix B1 of the Model Documentation Report). The 5-year projections of dissolved PCBs in water and the total PCBs in the 0- to 10-cm surface sediments from wLFRM were used as input to FRFood. GBTOXe was calibrated only over a single year (1989) using data generated during the Green Bay Mass Balance Study (see Appendix C1 of the Model Documentation Report). For GBTOXe, only the inputs from Zone 2 of PCBs dissolved in water and in the surface sediments in the 0- to 10-cm layer were used as inputs. All other input parameters used in the point projections were held constant.

wLFRM/FRFood Projections

Output from the combined wLFRM/FRFood met the model evaluation metric, relative to measured fish tissue concentrations on the river. Figure 3-3 shows the calibration projections for 1989 through 1995, with measured values and projected trend lines for walleye and carp to 1998 in Little Lake Butte des Morts Reach. Oscillations within the figures reflect within-year variability in total PCB concentrations. FRFood predicts that fish will accumulate or depurate PCBs to come into equilibrium with the total PCBs available to the food chain. Total PCBs during the winter months are lower due to low river flow, low resuspension events, and to lack of phytoplankton uptake (and hence food chain transfer) of PCBs. Peaks in the graphics represent the high levels of total PCBs during the late spring/summer period.

For Little Lake Butte des Morts Reach, the projected walleye and carp predicted were well within the observed range of data for both fish species over the calibration period. There were only three tissue samples in 1989 which were below the projected concentrations. However, for carp in 1992, the projected value of 3,864 milligrams per kilogram (mg/kg) matches well (90%) to the observed mean value of 4,250 mg/kg (range 542 to 11,400 mg/kg). For walleye, the projected average of 2,067 mg/kg in 1992 is within 1.3 times the observed mean of 1,500 mg/kg (range 200 to 3,800 mg/kg) in the same time period. Projected trendlines from the model show that these are representative of values observed for carp in 1996 and both species in 1998.

Projections for the De Pere to Green Bay Reach (Green Bay Zone 1) are shown on Figure 3-4 and Figure 3-5. One anomaly of the projections are the increasing tissue concentrations over the calibration period. This is in contrast to the findings of the Time Trends Analysis (in the Remedial Investigation) which found fish tissue concentrations generally stable, or decreasing in this reach. The explanation lies in the wLFRM calibration. The wLFRM was calibrated to match the suspended sediment loads and export of total PCBs to Green Bay. As a result of that, the bedded sediment concentrations were allowed to float upward. This upward trend is reflected in the fish here in the calibration period.

In Zone 1, modeled forage fish (alewife, gizzard shad) and yellow perch are shown on Figure 3-4. As can be seen from the figure, concentrations of PCBs increase over the calibration period for yellow perch, but are generally constant for the forage fish species. At the beginning of the calibration period, observed values for alewife and shad are higher—generally two to three times higher than the predicted values. However, at the end of the calibration period, the observed forage fish values are within the range of predicted values. Yellow perch values, however, are over-predicted by the model; up to three times the observed values. For carp and walleye, there is a generally good correlation between observed and predicted values (Figure 3-5). For both carp and walleye, the projected values are within 86 and 96 percent, respectively, of the observed values. The mean projected carp concentration was 5,172 mg/kg, with a mean observed concentration of 5,981 mg/kg (range 1,100 to 13,000 mg/kg). For walleye, the projected average over the calibration period was 7,578 mg/kg, while the mean observed concentration was 7,916 mg/kg (range 3,200 to 19,000 mg/kg).

Based upon both the point calibrations and the calibrations using the output from the hydrodynamic model, the FRFood Model was deemed suitable for projections within the Lower Fox River.

GBTOXe/FRFood Projections

The projected fish tissue results for the combined GBTOXe/FRFood models for Zone 2 is given on Figures 3-6 and 3-7. FRFood was not used in the FS for projecting fish tissue concentrations as a result of implemented remedial alternatives. That function was accomplished by GBFood. FRFood was used to estimate sediment quality thresholds, and those were generated based upon the results of the point calibrations. The Zone 2 calibration check was simply to determine the relative magnitude of under-/over-estimation of potential results relative to the estimated SQTs.

While FRFood meets the model metric in Zone 2 (plus or minus one-half order of magnitude), the estimated forage fish concentrations were only between 33 and 51 percent of the observed concentrations (Figure 3-6). For both carp and walleye, the projected values are within 75 and 60 percent, respectively, of the observed values (Figure 3-7). While FRFood could have been specifically recalibrated for Zone 2, the goal here was to determine if the model projections were adequate for estimating SQTs for Green Bay. The conclusion here is that having met the metrics, the model is deemed adequate for that purpose. Further refinement or calibrations were unnecessary as the projection effort for Green Bay was accomplished by GBFood.

Figure 3-1 Food Web Model
Lower Fox River - Little Lake Butte des Morts to the De Pere Dam

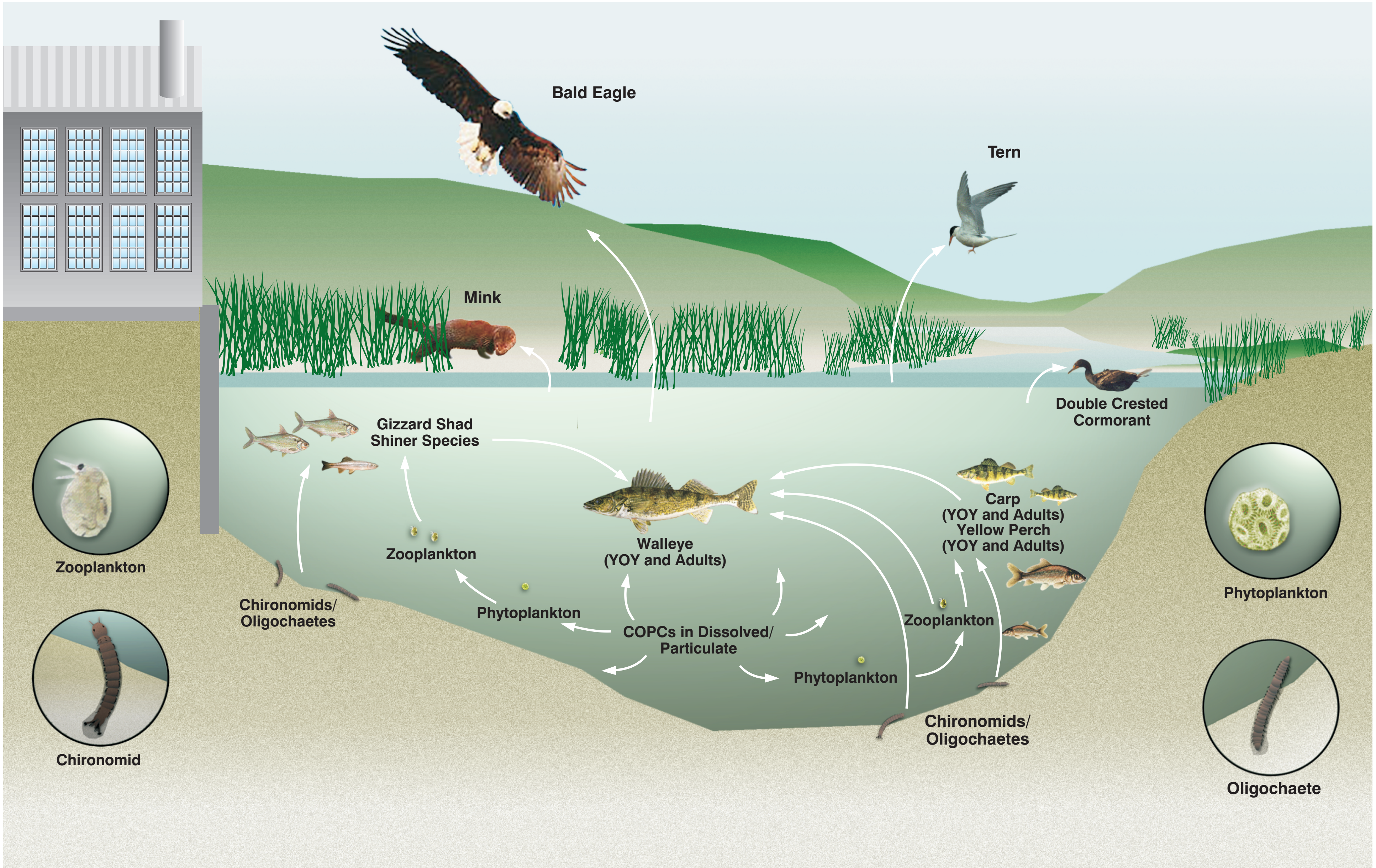
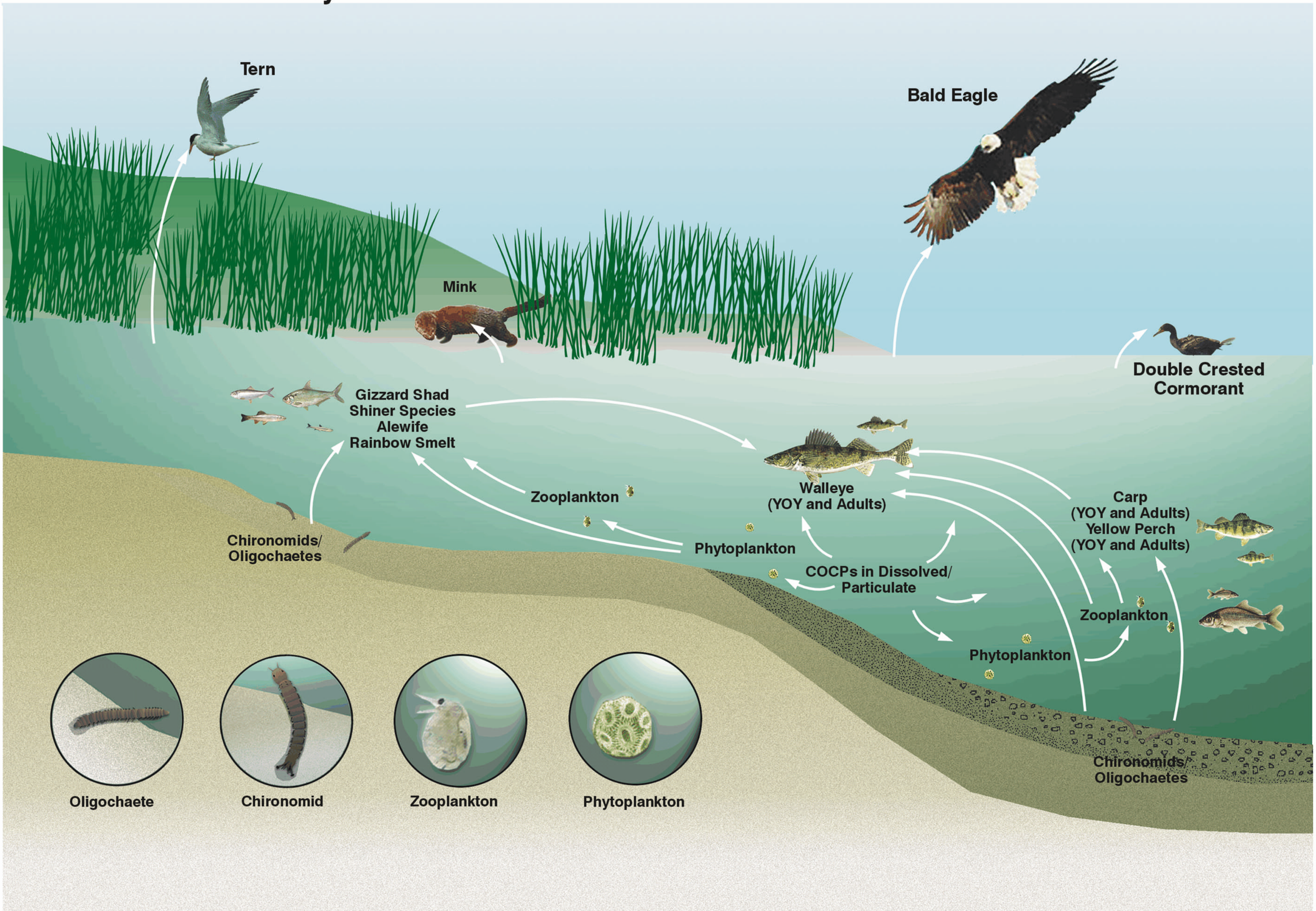


Figure 3-2. Food Web Model
Green Bay - Zones 1 and 2



BrickTudorStudios/FoodWebFigure3_2

Figure 3-3 FRFood Calibration: Little Lake Butte des Morts Predicted vs. Observed Total PCBs in Walleye and Carp 1989–1998

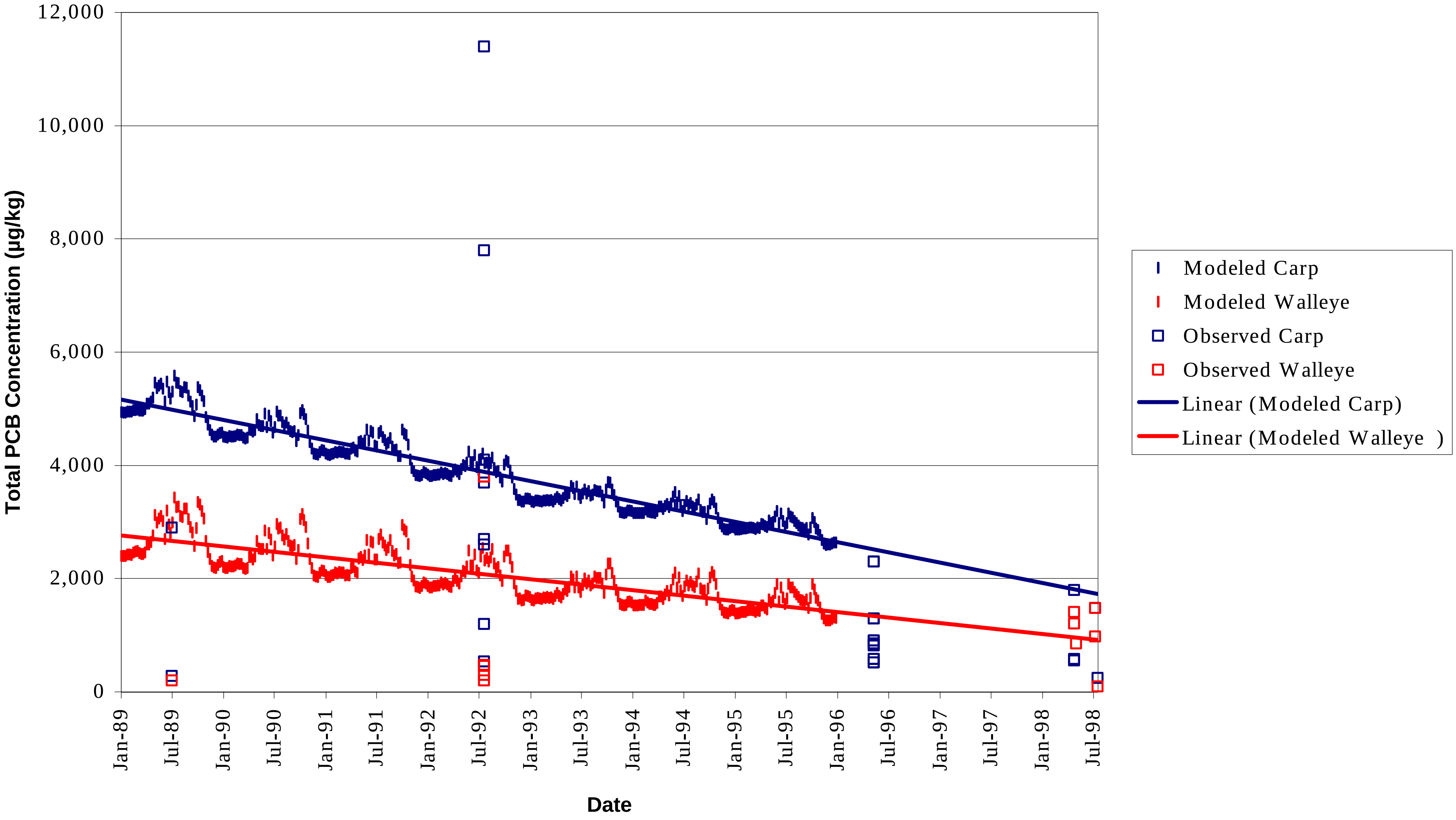


Figure 3-4 FRFood Calibration: De Pere to Green Bay Reach Predicted vs. Observed Total PCBs in Gizzard Shad, Yellow Perch, and Alewife 1989–1998

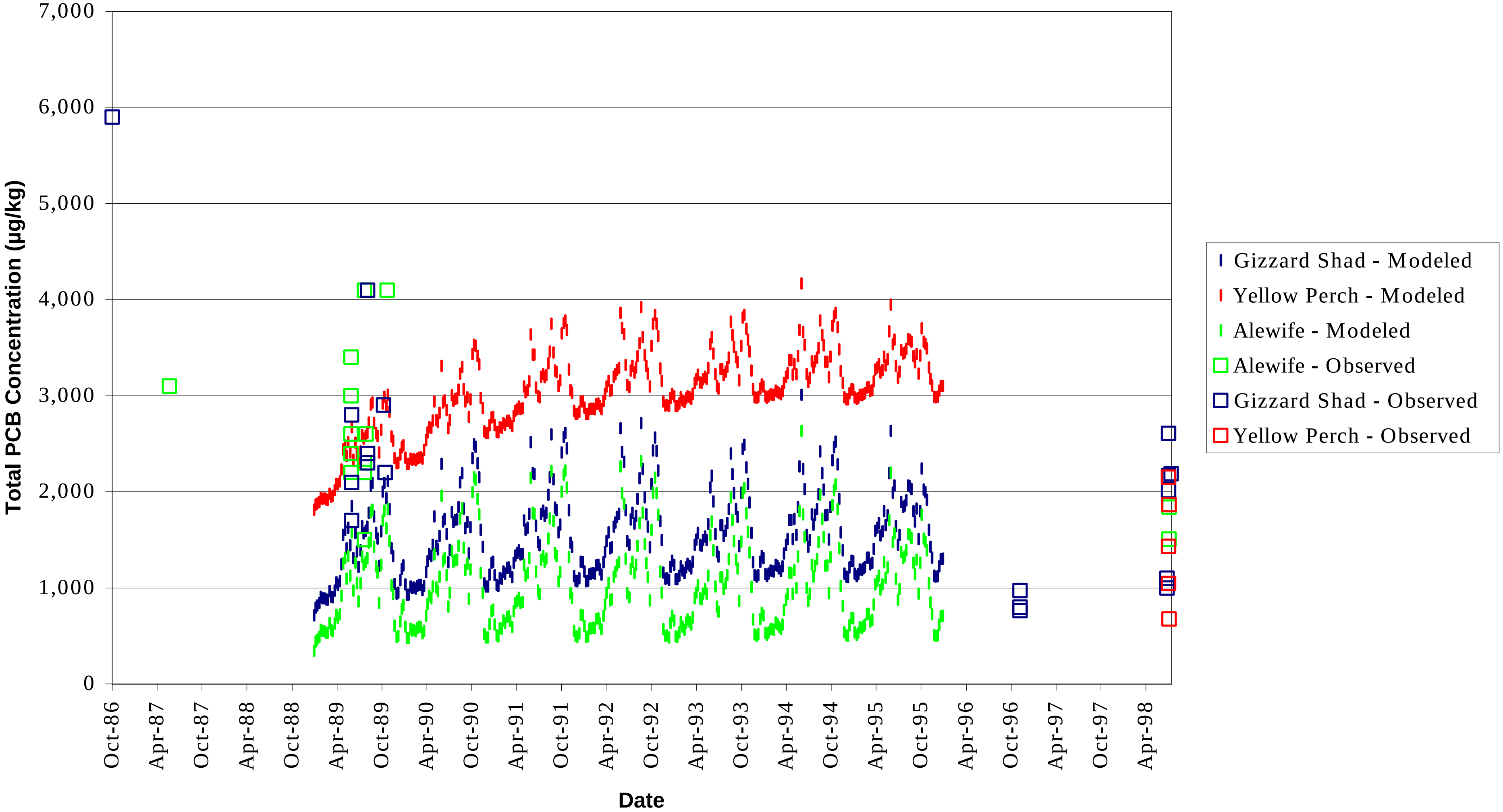


Figure 3-5 FRFood Calibration: De Pere to Green Bay Reach Predicted vs. Observed Total PCBs in Walleye and Carp 1989–1998

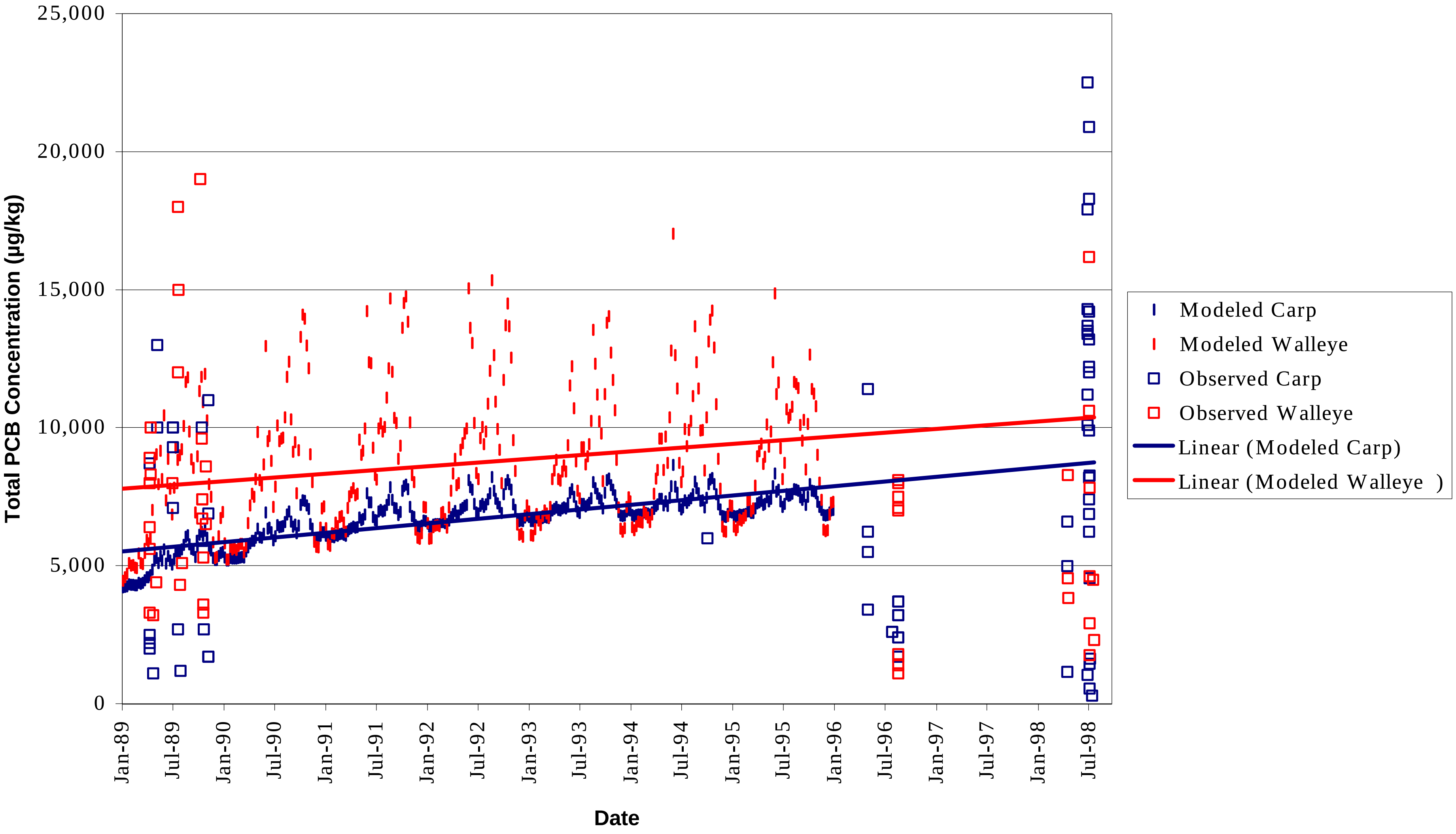


Figure 3-6 FRFood Calibration: Green Bay Zone 2
Predicted vs. Observed Concentrations in Forage Fish
1989–1990

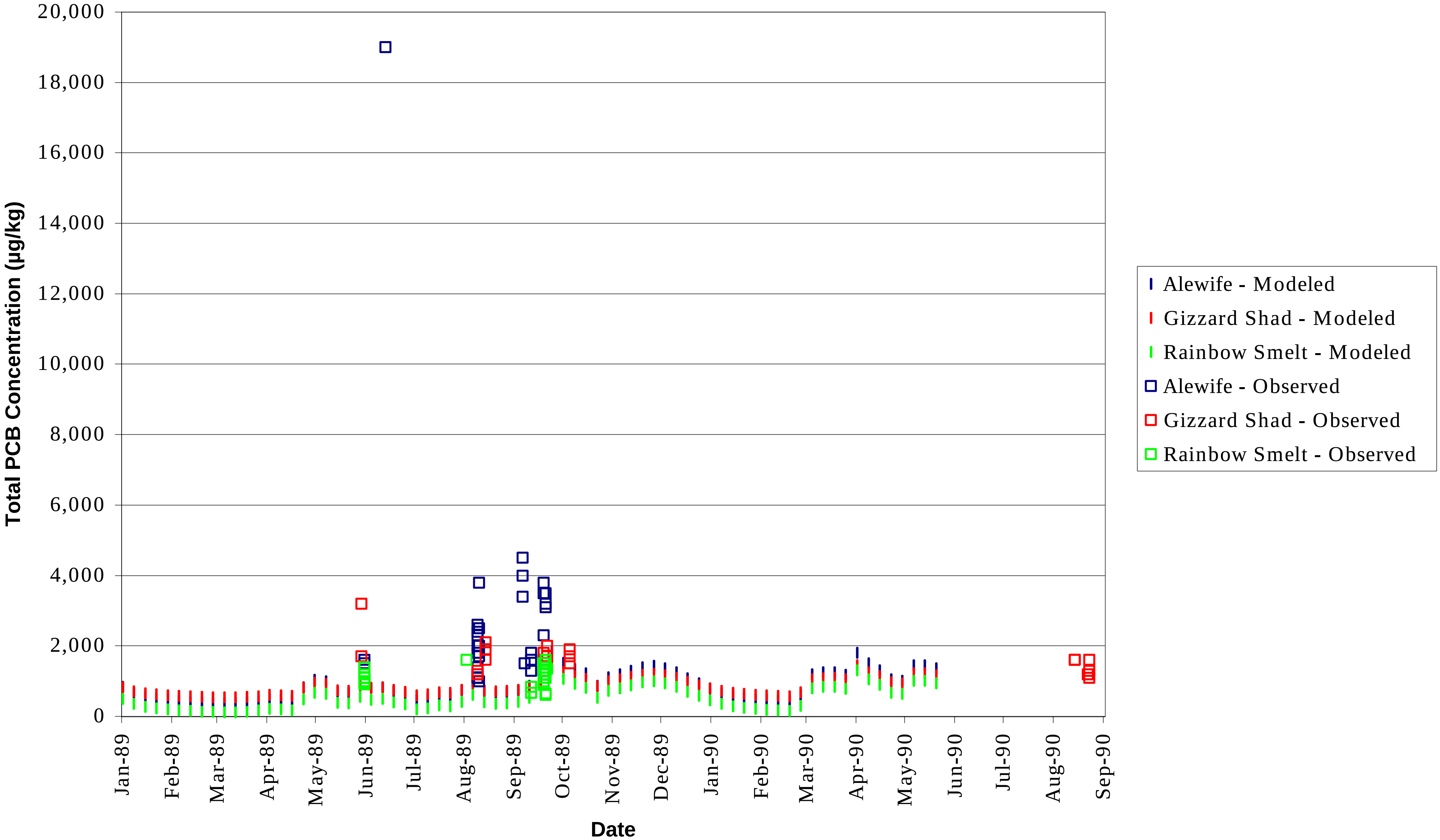


Figure 3-7 FRFood Calibration: Green Bay Zone 2 Predicted vs. Observed Concentrations in Walleye and Carp 1989–1990

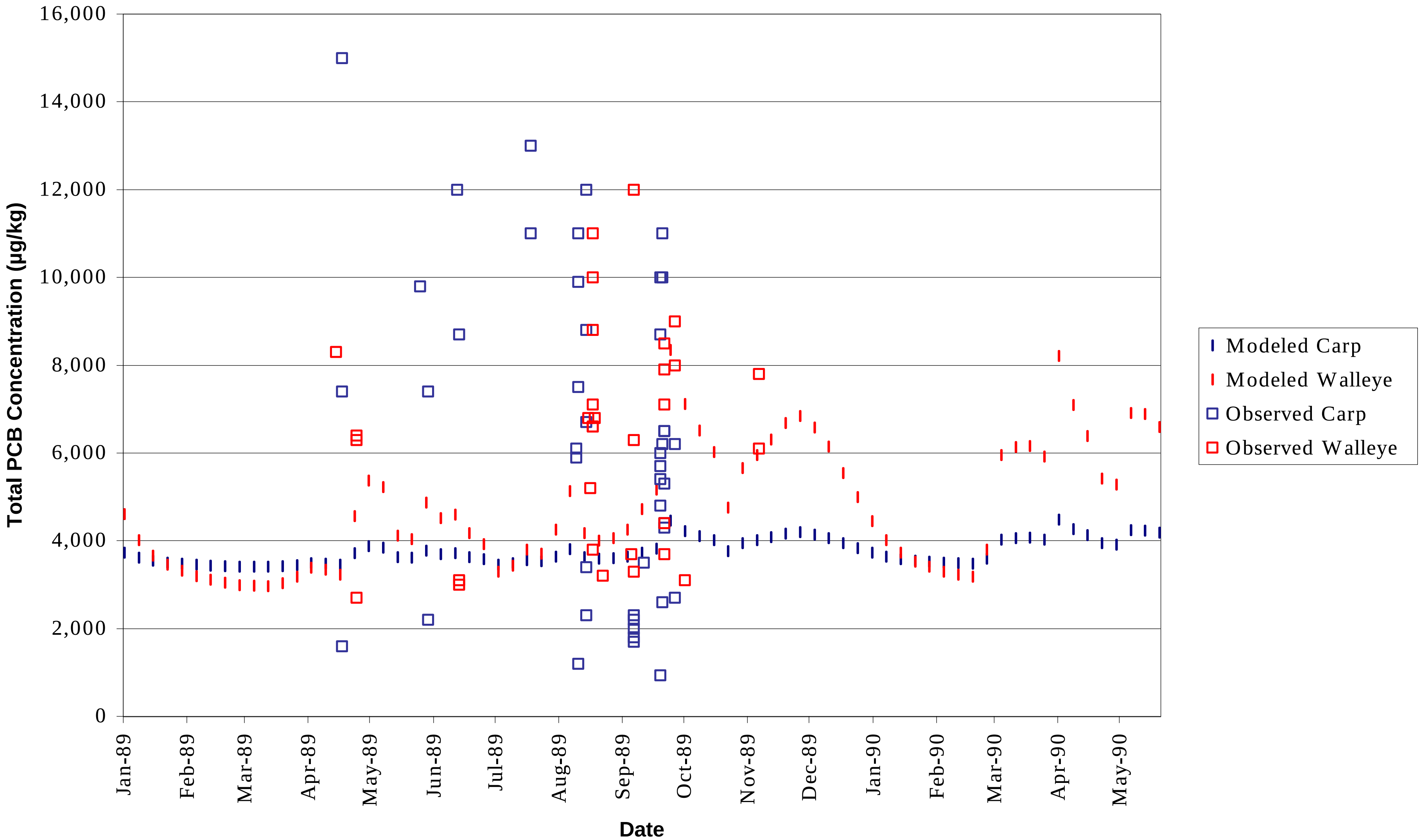
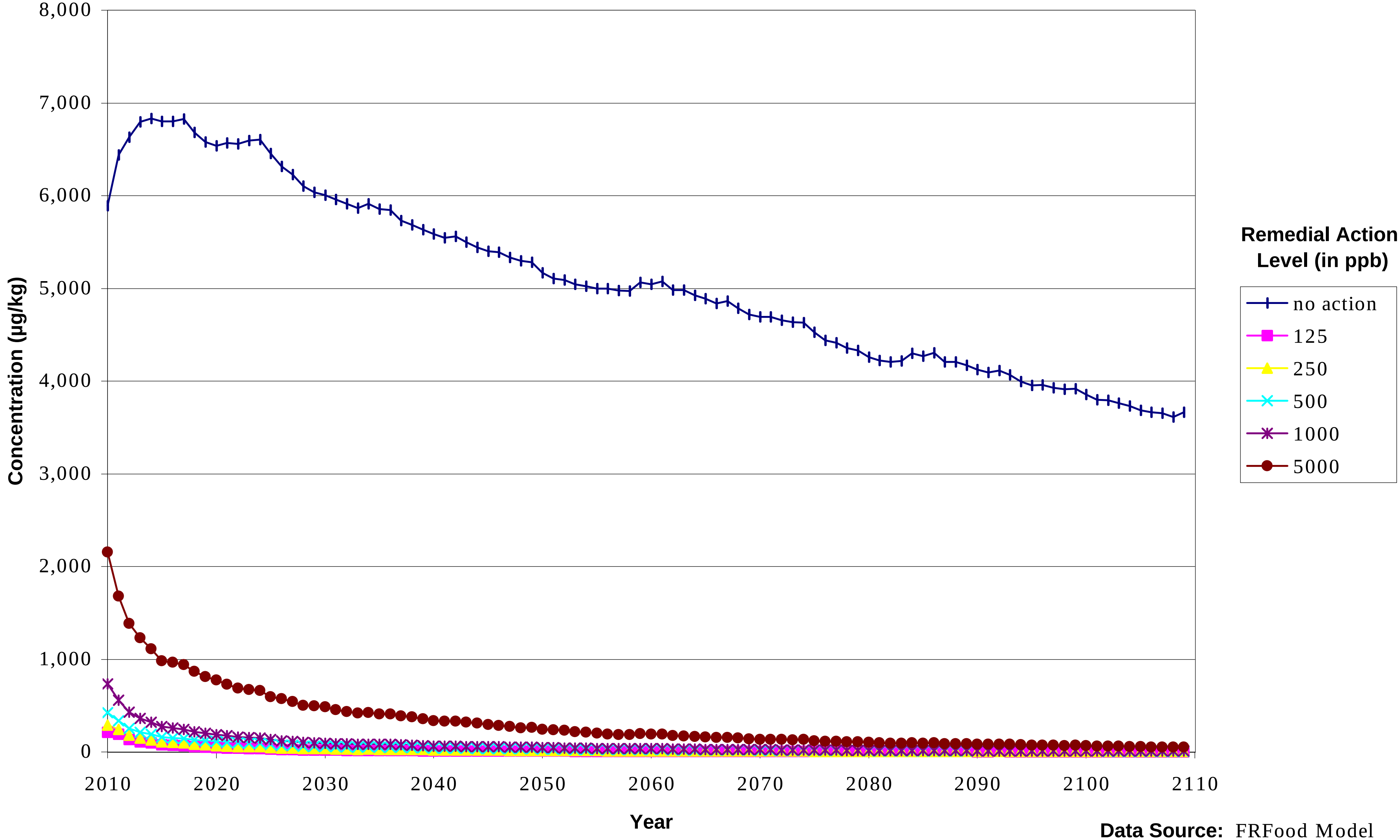
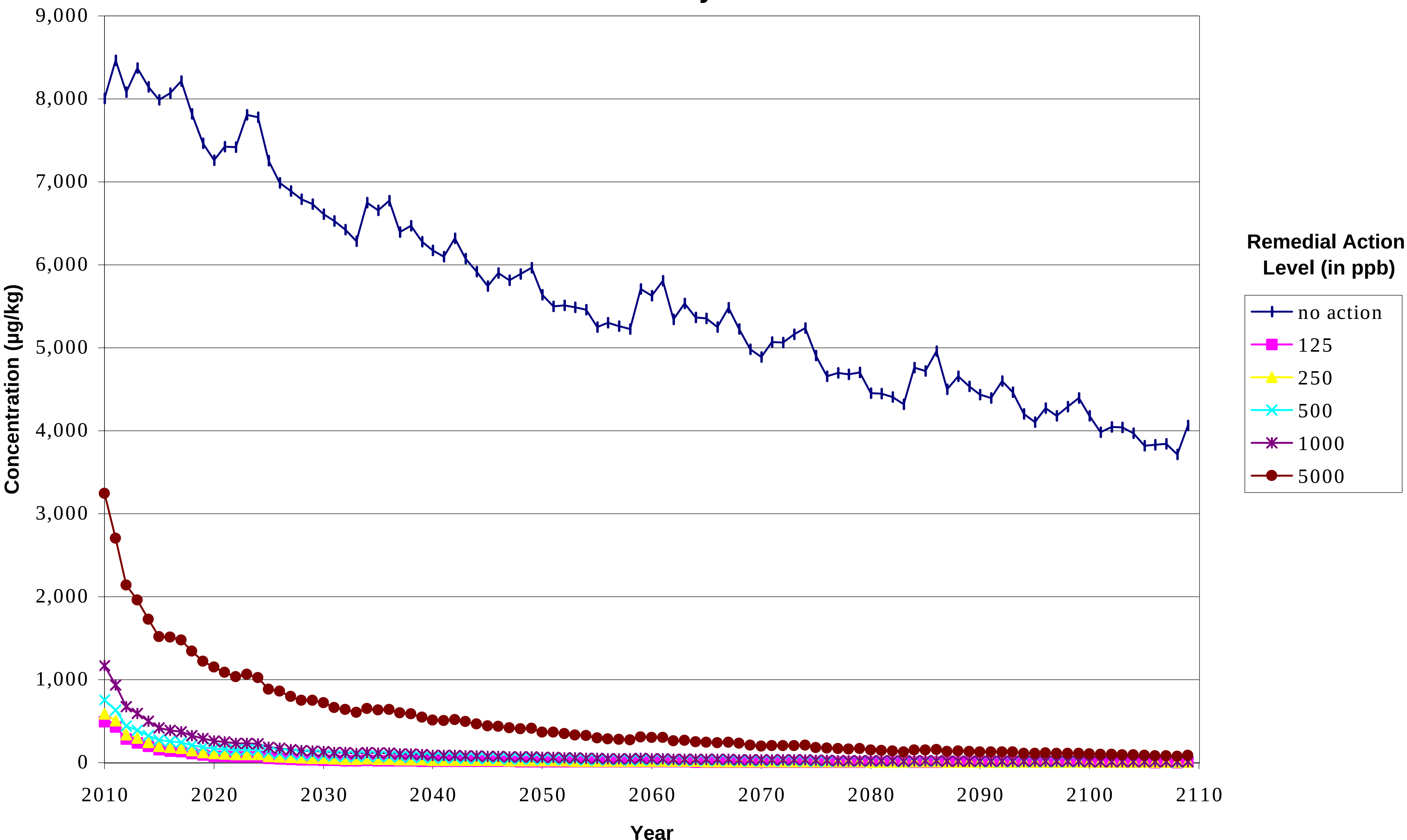


Figure 3-8 Total Annual Average PCB Concentrations in Carp
100-year Projections
De Pere to Green Bay Reach



Data Source: FRFood Model

Figure 3-9 Total Annual Average PCB Concentrations in Walleye
100-year Projections
De Pere to Green Bay Reach



Data Source: FRFood Model

Figure 3-10 FRFood and GBFood Projected Walleye Total PCB Concentrations in Green Bay Zone 2 100-year No Action Alternative

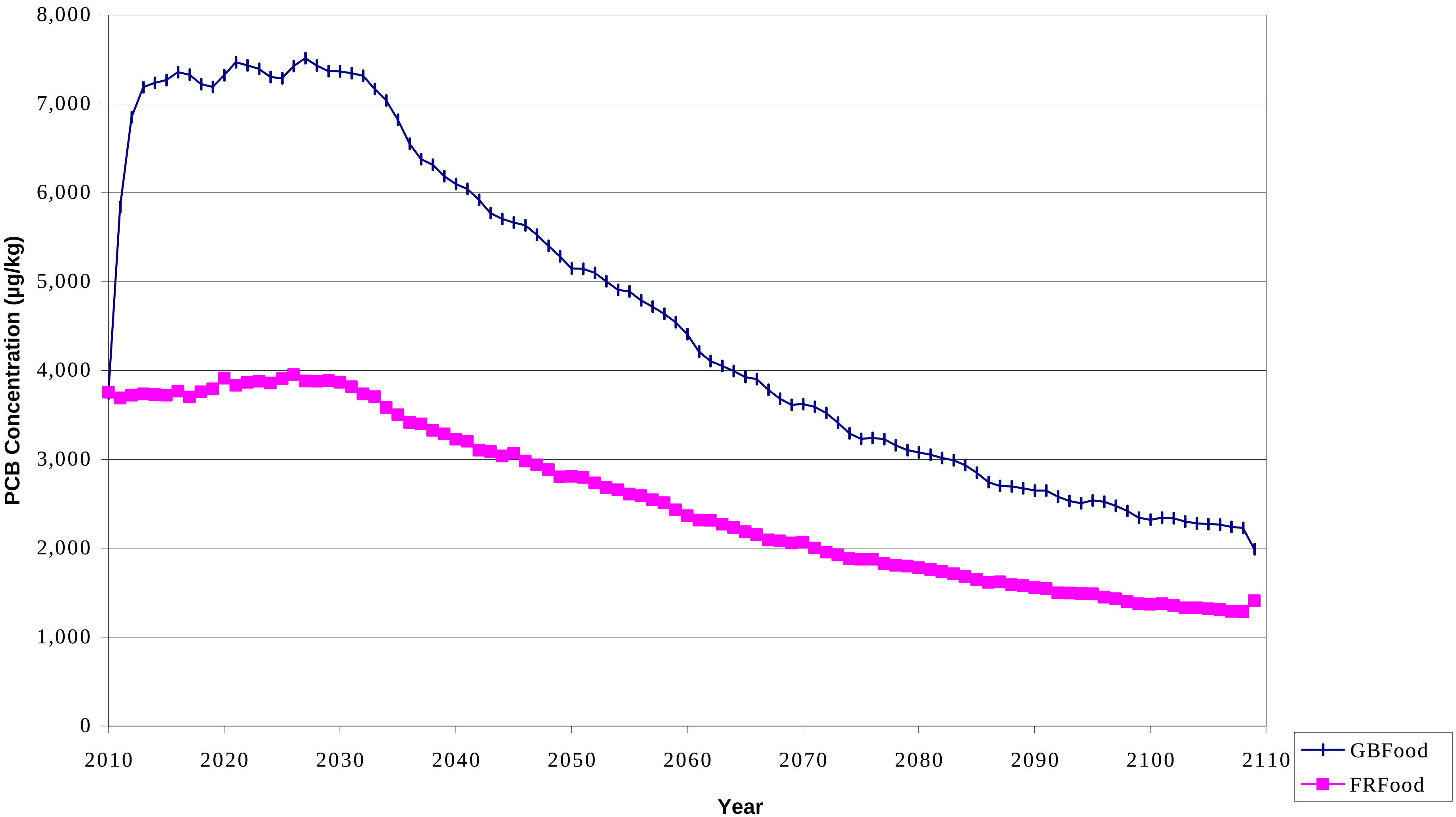


Table 3-1 References Reviewed for Potential Input Parameter to the Lower Fox River Bioaccumulation Model

Organisms	Dietary Composition (based on weight or volume)	Whole Fish Lipid Content (%)	Weight (kg)
Plankton			
Zooplankton		5 (Gobas, 1993)	0 (Campfens and Mackay, 1997)
Benthic Organisms			
Oligochaetes		1 (Campfens and Mackay, 1997)	0.0001 (Campfens and Mackay, 1997)
Chironomids		2 (Zaranko *et al.*, 1997)	
Fish			
Rainbow Smelt	25%–100% zooplankton, 0%–25% alewife (Mills *et al.*, 1995; Price, 1963)	1.7–9.8 (site-specific data)	0.085 (Seagrant web page)
Gizzard Shad	10%–70% zooplankton, 10%–90% algae, 10% benthic invertebrates (Muth and Busch, 1989; Kolok *et al.*, 1996; Exponent, 1999)	2.5–19.0 (site-specific data)	0.025 (Levine *et al.*, 1995)
Emerald Shiner	90% zooplankton, 5% algae, 5% chironomids (Muth and Busch, 1989)	5.1–6.2 (site-specific data)	
Carp			
YOY[1]	14%–100% benthic invertebrates, 10%–60% plankton (Weber and Otis, 1984; Exponent, 1999)		0.00629 (Weber and Otis, 1984)
adults	14%–100% benthic invertebrates, 25%–45% plankton (Scott and Crossman, 1993)	0.8–25.4 (site-specific data)	1.4–6.8 (Scott and Crossman, 1973)
Alewife			
YOY	20%–90% copepods, 10%–80% cladocerans (Hewett and Stewart, 1989; Urban and Brandt, 1993)		avg. = 0.00071 (Flath and Diana, 1985)
adults	25%–93% plankton, 7%–20% benthic invertebrates (Gobas *et al.*, 1995; Hewett and Stewart, 1989; Exponent, 1999)	2.5–17.0 (site-specific data)	0.056 $\pm$ 0.007 (Hewett and Stewart, 1989)
Perch			
YOY and adults	40%–100% benthic invertebrates, 60% plankton (Scott and Crossman, 1973; Weber and Otis, 1984; Exponent, 1999; Carlander, 1997)	2.2–6.1 (site-specific data)	0.01–0.588 (Wells and Jorgenson, 1983)
Walleye			
YOY	0%–96% rainbow smelt, 0%–78% gizzard shad, 0%–20% emerald shiner, 0%–80% white perch, 0%–29% yellow perch, 0%–28% white sucker, 0%–24% benthic invertebrates (Wolfert and Bur, 1992; Exponent, 1999; Carlander, 1997)		0.04 (Magnuson and Smith, 1987)
adults	10% plankton, 14%–24% benthic invertebrates, 12%–100% alewife, 0%–76% rainbow smelt, 0%–74% gizzard shad, 0%–1% sculpin, 0%–38% white sucker, 0%–44% yellow perch, 0%–23% small mouth bass (Magnuson and Smith, 1987; Wolfert and Bur, 1992)	0.4–23.2 (site-specific data)	2.3 (site-specific data)

Note:

[1] YOY - Young-of-the-year.

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Table 3-2 Inputs to the FRFood Model for Model Calibration in Little Lake Butte des Morts Reach

A. Diet

Prey	Receptors							
	Shiner Species	Gizzard Shad	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
	Muth & Busch, 1989	Muth & Busch, 1989; Kolok *et al.*, 1996	Carlander, 1997; Scott & Crossman, 1973	Carlander, 1997	Weber & Otis, 1984	Scott & Crossman, 1973	Carlander, 1997; Wolfert & Bur, 1992	Wolfert & Bur, 1992; Magnuson & Smith, 1987
Phytoplankton	0.7	1		0.3	0.3			0.1
Zooplankton	0.2		0.9	0.4	0.4	0.45	0.05	
Chironomids	0.1		0.1	0.3	0.3	0.35	0.1	0.2
Oligochaetes						0.2		
Emerald Shiner							0.4	0.25
Gizzard Shad							0.45	0.45

B. Lipid Concentrations

Lipids (%)	Receptor							
	Shiner Species	Gizzard Shad	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
Lipid Used in Model	5.4	12.0	4.4	4.4	7.6	7.6	7.3	7.3
Mean Lipids for this Reach	5.4	12.0		4.4		7.6		7.3
Mean Lipids over All Areas	5.6	7.3		3.4		10.1		9.7

C. Sediment and Water Total PCB Concentrations

Media	Mean (ppb)	95% UCL (ppb)	Average TOC (%)
Water (filtered)	0.011	0.015	
Sediment (I_d)	3,699	3,749	14

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Table 3-3 Inputs to the FRFood Model for Model Calibration in Little Rapids to De Pere Reach

A. Diet

Prey	Receptors							
	Shiner Species Muth & Busch, 1989	Gizzard Shad Muth & Busch, 1989; Kolok *et al.*, 1996	Yellow Perch YOY Carlander, 1997; Scott & Crossman, 1973	Yellow Perch Adult Carlander, 1997	Carp YOY Weber & Otis, 1984	Carp Adult Scott & Crossman, 1973	Walleye YOY Carlander, 1997; Wolfert & Bur, 1992	Walleye Adult Wolfert & Bur, 1992; Magnuson & Smith, 1987
Phytoplankton	0.7	0.7		0.3	0.3			0.1
Zooplankton	0.2	0.3	0.9	0.4	0.4	0.45	0.05	
Chironomids	0.1		0.1	0.3	0.3	0.35	0.1	0.2
Oligochaetes						0.2		
Emerald Shiner							0.4	0.25
Gizzard Shad							0.45	0.45

B. Lipid Concentrations

Lipids (%)	Receptor							
	Shiner Species	Gizzard Shad	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
Lipid Used in Model	7.0	2.8	2.2	2.2	6.9	6.9	8.1	8.1
Mean Lipids for this Reach	7.0	2.8		2.2		6.9		8.1
Mean Lipids over All Areas	5.6	7.3		3.4		10.1		9.7

C. Sediment and Water Total PCB Concentrations

Media	Mean (ppb)	95% UCL (ppb)	Average TOC (%)
Water (filtered)	0.011	0.012	
Sediment (I_d)	2,078	2,112	5.3

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Table 3-4 Inputs to the FRFood Model for Model Calibration in Green Bay Zone 1

A. Diet

Prey	Receptors										
	Rainbow Smelt Mills *et al.*, 1995	Gizzard Shad * Muth & Busch, 1989; Kolok *et al.*, 1996	Shiner Species Muth & Busch, 1989	Alewife YOY Hewett & Stewart, 1989; Urban & Brandt, 1993	Alewife Adult Hewett & Stewart, 1989	Yellow Perch YOY Carlander, 1997; Scott & Crossman, 1973	Yellow Perch Adult Carlander, 1997	Carp YOY Weber & Otis, 1984	Carp Adult Scott & Crossman, 1973	Walleye YOY Carlander, 1997; Wolfert & Bur, 1992	Walleye Adult Wolfert & Bur, 1992; Magnusun & Smith, 1987
Phytoplankton		0.3	0.6				0.3	0.3			
Zooplankton	0.9	0.6	0.3	1	0.95	0.9	0.4	0.4	0.45	0.05	
Chironomids		0.1	0.1		0.05	0.1	0.3	0.3	0.35	0.3	0.1
Oligochaetes									0.2		
Yellow Perch YOY											
Alewife YOY	0.1									0.15	
Alewife adult											0.1
Rainbow Smelt										0.1	0.1
Emerald Shiner											
Gizzard Shad										0.4	0.7

B. Lipid Concentrations

Prey	Receptor										
	Rainbow Smelt	Gizzard Shad	Shiner Species	Alewife YOY	Alewife Adult	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
Lipid Used in Model	4.6 *	7.1	6	5.7	5.7	4.5	4.5	9.2	9.2	10.7	10.7
Mean Lipids for this Reach	4.6 *	7.1	5.6/6.1		5.7		4.5		9.2		10.7
Mean Lipids over All Areas	4.6	7.3	5.6		8.6		3.4		10.1		9.7

Note:

* Zone 2 average; rainbow smelt were not caught in Zone 1.

C. Sediment and Water Total PCB Concentrations

Media	Mean (ppb)	95% UCL (ppb)	Average TOC (%)
Water (filtered)	0.017	0.018	
Sediment (I_d)	2,959	2,984	5

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Table 3-5 Inputs to the FRFood Model for Model Calibration in Green Bay Zone 2

A. Diet

Prey	Receptors										
	Rainbow Smelt	Gizzard Shad *	Shiner Species	Alewife YOY	Alewife Adult	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
	Mills *et al.*, 1995	Muth & Busch, 1989; Kolok *et al.*, 1996	Muth & Busch, 1989	Hewett & Stewart, 1989; Urban & Brandt, 1993	Hewett & Stewart, 1989	Carlander, 1997; Scott & Crossman, 1973	Carlander, 1997	Weber & Otis, 1984	Scott & Crossman, 1973	Carlander, 1997; Wolfert & Bur, 1992	Wolfert & Bur, 1992; Magnuson & Smith, 1987
Phytoplankton		0.3	0.6				0.3	0.3			
Zooplankton	0.9	0.6	0.3	1	0.95	0.9	0.4	0.4	0.45	0.05	
Chironomids		0.1	0.1		0.05	0.1	0.3	0.3	0.35	0.3	0.1
Oligochaetes									0.2		
Yellow Perch YOY											
Alewife YOY	0.1									0.15	
Alewife adult											0.1
Rainbow Smelt										0.1	0.1
Emerald Shiner											
Gizzard Shad										0.4	0.7

B. Lipid Concentrations

Prey	Receptor										
	Rainbow Smelt	Gizzard Shad	Shiner Species	Alewife YOY	Alewife Adult	Yellow Perch YOY	Yellow Perch Adult	Carp YOY	Carp Adult	Walleye YOY	Walleye Adult
Lipid Used in Model	4.6	6.9	6	9.8	9.8	3.2	3.2	11.3	11.3	10.4	10.4
Mean Lipids for this Reach	4.6	6.9	—	—	9.8	—	3.2	—	11.3	—	10.4
Mean Lipids over All Areas	4.6	7.3	5.6		8.6		3.4		10.1		9.7

C. Sediment and Water Total PCB Concentrations

Media	Mean (ppb)	95% UCL (ppb)	Average TOC (%)
Water (filtered)	0.0048	0.0054	
Sediment (I_d)	1,132	1,154	1.5

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Table 3-6 Lower Fox River Bioaccumulation Model Calibration

Location	Species	Number of Samples	Number of Detects	Detection Frequency	Observed Total PCB Mean	Observed Total PCB 95% UCL		Predicted Total PCB Mean	Predicted Total PCB 95% UCL	Units
Little Lake Butte des Morts										
	Water (filtered)	46	40	87	0.011	0.015				µg/L
	Surface Sediments (I_d)	51,261	51,261	100	3,699	3,749				µg/kg
	Gizzard Shad	4	4	100	296	530	*	263	358	µg/kg
	Golden Shiner	2	2	100	993	1,140	*	723	868	µg/kg
	Yellow Perch	1	1	100	363	363	*	1,266	1,443	µg/kg
	Carp	30	30	100	1,992	2,957		2,374	2,639	µg/kg
	Walleye	13	11	85	1,159	3,800	*	1,756	2,109	µg/kg
Little Rapids to De Pere										
	Water (filtered)	98	97	99	0	0				µg/L
	Surface Sediments (I_d)	37,060	37,060	100	2,078	2,112				µg/kg
	Gizzard Shad	3	3	100	347	370	*	318	347	ug/kg
	Golden Shiner	2	2	100	1,020	1,036	*	997	1,046	ug/kg
	Yellow Perch	1	1	100	627	627	*	1,017	1,055	µg/kg
	Carp	20	20	100	3,919	5,800		3,038	3,135	µg/kg
	Walleye	4	4	100	3,179	4,587	*	3,881	4,079	µg/kg
Green Bay Zone 1										
	Water (filtered)	143	142	99	0	0				µg/L
	Surface Sediments (I_d)	51,963	51,963	100	2,959	2,984				µg/kg
	Alewife	13	13	100	2,596	3,018		1,491	1,566	µg/kg
	Gizzard Shad	18	18	100	2,017	2,369		1,560	1,613	µg/kg
	Common Shiner	5	5	100	3,520	3,846		1,572	1,636	µg/kg
	Emerald Shiner	5	5	100	3,520	3,846		1,572	1,636	µg/kg
	Golden Shiner	2	2	100	1,385	1,443	*	1,572	1,636	µg/kg
	Yellow Perch	5	5	100	1,435	2,005		2,552	2,610	µg/kg
	Carp	66	66	100	7,203	8,286		5,352	5,454	µg/kg
	Walleye	51	51	100	6,902	8,414		9,091	9,419	µg/kg
Green Bay Zone 2										
	Water (filtered)	63	63	100	0.0048	0.0054				µg/L
	Surface Sediments (I_d)	11,566	11,566	100	1,132	2,984				µg/kg
	Alewife	38	38	100	2,600	3,374		923	992	µg/kg
	Gizzard Shad	32	32	100	1,759	1,906		1,184	1,230	µg/kg
	Rainbow Smelt	33	33	100	1,049	1,152		410	462	µg/kg
	Yellow Perch	4	4	100	920	1,637	*	2,028	2,084	µg/kg
	Carp	49	49	100	5,875	8,914		6,267	6,425	µg/kg
	Walleye	40	40	100	6,076	6,790		6,473	6,750	µg/kg

Note:

* Maximum concentration and not the 95% UCL.

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Table 3-7 Reach-specific and River-wide Total PCB Water:Sediment Ratios

Location	Media	Year	Minimum	Maximum	Average
Little Lake Butte des Morts	Sediment	1989	25	130000	13535
Little Lake Butte des Morts	Water	1989/90	0.0015	0.0592	0.0276
Water-to-sediment Ratio			6.00E-05	4.55E-07	2.04E-06
Appleton to Little Rapids	Sediment	1989	50	57000	3651
Appleton to Little Rapids	Water	1989/90	0.00004	0.0710	0.0168
Water-to-sediment Ratio			8.00E-07	1.25E-06	4.60E-06
Little Rapids to De Pere	Sediment	1989	80	33000	3873
Little Rapids to De Pere	Water	1989/90	0.0004	0.1240	0.0411
Water-to-sediment Ratio			5.00E-06	3.76E-06	1.06E-05
Green Bay Zone 1	Sediment	1989	20	18700	2700
Green Bay Zone 1	Water	1989/90	0.0038	0.1940	0.0609
Water-to-sediment Ratio			1.91E-04	1.04E-05	2.26E-05
Green Bay Zone 2					
Water-to-sediment Ratio		GBTOXe*	5.26E-07	2.43E-05	8.47E-06

Notes:

Water represents the estimated total PCB concentration.
Zone 2 sediment:water ratios estimated from GBTOXe output.
Concentrations in units of ppb.

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Table 3-8 Ratio of PCB Concentrations in Fillet to Whole Body for Different Species

Study and Species	Fillet-to-whole Fish Ratio
Lower Fox River	
Walleye	0.17
Carp	0.53*
Perch	0.17
White Bass	0.44
White Sucker	0.48
Parkerton et al. (1993)	
Perch	0.04 *
Walleye	0.1 *
Bevelmeir et al. (1997)	
Black Bass	0.43
Amhreim et al. (1999)	
Coho Salmon	0.59
Rainbow Trout	0.68
Niimi and Oliver (1983)	
Rainbow Trout	0.34
Connolly (1991)	
Flounder	0.18
Connolly et al. (1992)	
Brown Trout	1
Brown Trout	0.88
Brown Trout	0.57
Coho Salmon	0.89
Walleye adult	0.09
Channel Catfish	0.59
Drum	0.32
Perch	0.04

Notes:

CPCB-f - Concentration of PCB in fish fillet.

CPCB-wb - Concentration of PCB in whole body of fish.

* Fillet-to-whole body ratios selected.

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Table 3-9 Sediment Quality Thresholds Estimated for Human Health Effects at a 10^{-5} Cancer Risk* and a Hazard Index of 1.0

	Fish Parameters	Sediment Quality Thresholds			
	Fillet-to-whole Fish Ratio	Recreational Anglers: (West *et al.*, 1989; West *et al.*, 1993)		High-intake Fish Consumers: (West *et al.*, 1993; Hutchison and Kraft, 1994)	
		RME µg/kg	CTE µg/kg	RME µg/kg	CTE µg/kg
Sediment Quality Thresholds for Risk of 10^{-5}*					
Carp	0.53	***16***	***180***	***11***	***57***
Walleye	0.17	***21***	***143***	***14***	***75***
Yellow Perch	0.17	***105***	***677***	***68***	***356***
Sediment Quality Thresholds for HI of 1.0					
Carp	0.53	***44***	***180***	***28***	***90***
Walleye	0.17	***58***	***238***	***37***	***119***
Yellow Perch	0.17	***276***	***1,128***	***175***	***564***

Notes:

**** SQTs for cancer risks of 10^{-4} and 10^{-6} are an order of magnitude higher, and lower, respectively.***

RME indicates reasonable maximum exposure and CTE indicates central tendency exposure.

Sediment Quality Thresholds are bolded and in italics.

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Table 3-10 Derivation of Bird Biomagnification Factors (BMFs) for Total PCBs

Location	Bird Species	Bird Tissue	Total PCB (µg/kg) RME	Fish Species	Fish Tissue	Total PCB (µg/kg) RME	BMF RME
Appleton to Little Rapids	Bald Eagle	egg	36,000	carp	whole	3,606	9.98
Zone 2	Double-crested Cormorant	egg	21,127	alewife	whole	3,182	6.64
Zone 2	Double-crested Cormorant	whole	13,870	alewife	whole	3,182	4.36
Zone 2	Common Tern	egg	5,963	alewife	whole	3,182	1.87
Zone 2	Forster's Tern	egg	6,234	alewife	whole	3,182	1.96
Zone 3B	Double-crested Cormorant	whole	15,000	alewife	whole	2,375	6.32
Zone 3A	Bald Eagle	egg	13,000	carp	whole	3,974	3.27

Species	RME BMF	TRVs Reproduction NOAEC (µg/kg)	TRVs Reproduction LOAEC (µg/kg)	TRVs Deformity NOAEC (µg/kg)	TRVs Deformity LOAEC (µg/kg)	RME Whole Fish Concentrations (µg/kg) Reproduction NOAEC (µg/kg)	RME Whole Fish Concentrations (µg/kg) Reproduction LOAEC (µg/kg)	RME Whole Fish Concentrations (µg/kg) Deformity NOAEC (µg/kg)	RME Whole Fish Concentrations (µg/kg) Deformity LOAEC (µg/kg)
Common Tern	1.87	4,700	7,600	800	8,000	2,508	4,055	427	4,269
Forster's Tern	1.96	4,700	7,600	800	8,000	2,399	3,879	408	4,083
Double-crested Cormorant	5.77	4,700	7,600	800	8,000	814	1,317	139	1,386
Bald Eagle	6.63	4,700	7,600	800	8,000	709	1,147	121	1,207

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Table 3-11 Sediment Quality Thresholds Estimated for Ecological Effects

Species	Effect	Whole Fish Concentration (μg/kg ww)	Estimated SQT (μg/kg)
benthic invertebrates	Threshold Effect Concentration (TEL)	—	31.6
walleye	NOAEC - fry growth and mortality LOAEC - fry growth and mortality	760 7,600	176 1,759
carp	NOAEC - fry growth and mortality LOAEC - fry growth and mortality	760 7,600	363 3,633
common tern	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	2,508 4,055 427 4,269	3,073 4,969 523 5,231
Forster's tern	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	2,399 3,879 408 4,083	2,940 4,753 500 5,003
double-crested cormorant	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	814 1,317 139 1,386	997 1,614 170 1,698
bald eagle	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	709 1,147 121 1,207	339 548 58 577
mink	NOAEC - reproduction and kit survival LOAEC - reproduction and kit survival	50 500	24 239

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Table 3-12 Remedial Action Level Projection Simulations

Fox River Remedial Action (µg/kg)	Green Bay Remedial Action (µg/kg)		
	No Action	1,000	500
No Action	✓	—	—
5,000	✓	—	—
1,000	✓	✓	—
500	✓	✓	✓
250	✓	✓	✓
125	✓	✓	✓
Schedule H	✓	—	—
Schedule I	✓	—	—

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Table 3-13 Variable Fox River PCB Action Levels (ug/kg) for Schedules H & I

Schedule	Reach 1 Little Lake Butte des Morts	Reach 2 Appleton to Little Rapids	Reach 3 Little Rapids to De Pere	Reach 4 De Pere to Green Bay
H	500	No Action	250	250
I	1,000	No Action	500	500

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Table 3-14 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Little Lake Butte des Morts Reach

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	<1	<1	<1	<1	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	5	<1	<1	<1	<1	<1
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	16	6	<1	<1	<1	<1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	4	<1	<1	<1	<1	<1
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	6	<1	<1	<1	<1	<1
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	12	3	<1	<1	<1	<1
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	12	3	<1	<1	<1	<1
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	16	5	<1	<1	<1	<1
377	carp	human health	CTE hazard index of 1.0	recreational angler	48	28	<1	<1	<1	<1
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	27	12	<1	<1	<1	<1
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	53	31	<1	<1	<1	<1
288	walleye	human health	RME hazard index of 1.0	recreational angler	33	16	<1	<1	<1	<1
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	66	42	4	<1	<1	<1
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	66	43	4	<1	<1	<1
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	72	47	6	2	<1	<1
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	48	28	<1	<1	<1	<1
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	88	63	12	7	<1	<1
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	67	43	5	2	<1	<1
92	carp	human health	CTE hazard index of 1.0	recreational angler	>100	71	16	12	2	<1
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	80	56	10	5	<1	<1
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	>100	88	23	19	5	2
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	78	18	15	3	2
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	34	30	11	7
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	43	38	18	13
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	65	56	30	25
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	43	38	18	13
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	58	49	25	20
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	85	>100
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
4,083	gizzard shad	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
3,879	gizzard shad	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
2,399	gizzard shad	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	16	5	<1	<1	<1	<1
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	17	6	<1	<1	<1	<1
760	walleye	ecological	NOAEC	fish	11	3	<1	<1	<1	<1
760	carp	ecological	NOAEC	fish	28	12	<1	<1	<1	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	30	13	<1	<1	<1	<1
500	carp	ecological	LOAEC	piscivorous mammal	38	19	<1	<1	<1	<1
408	gizzard shad	ecological	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
121	carp	ecological	NOAEC	carnivorous bird deformity	87	62	12	7	< 1	< 1
50	carp	ecological	NOAEC	piscivorous mammal	>100	96	26	22	6	3
223	sediment	ecological	TEL	sediment invertebrate	>100	>100	60	52	26	21

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.

[2] Fish concentrations are whole body.

CTE - Central Tendency Exposure

LOAEC - Lowest Observed Adverse Effect Concentration

NOAEC - No Observed Adverse Effect Concentration

RME - Reasonable Maximum Exposure

TEL - Threshold Effect Level

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Table 3-15 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Appleton to Little Rapids Reach

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	<1	<1	<1	<1	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	5	<1	<1	<1	<1	<1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	<1	<1	<1	<1	<1	<1
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	2	<1	<1	<1	<1	<1
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	2	<1	<1	<1	<1	<1
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	5	<1	<1	<1	<1	<1
377	carp	human health	CTE hazard index of 1.0	recreational angler	28	16	3	<1	<1	<1
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	12	6	<1	<1	<1	<1
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	31	18	4	2	<1	<1
288	walleye	human health	RME hazard index of 1.0	recreational angler	17	9	<1	<1	<1	<1
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	38	28	7	5	1	<1
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	40	28	7	5	1	<1
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	43	35	9	7	3	<1
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	28	17	3	2	<1	<1
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	57	41	14	13	7	4
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	41	30	8	6	2	<1
92	carp	human health	RME hazard index of 1.0	recreational angler	63	47	18	15	10	6
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	53	37	12	10	5	2
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	78	59	25	21	15	11
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	67	53	20	17	13	9
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	100	78	37	31	20	16
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	91	45	40	25	20
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	63	54	35	28
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	91	45	40	25	20
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	57	48	31	25
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	71	60
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	87	81
7,600	walleye	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
4,083	gizzard shad	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
3,879	gizzard shad	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
2,399	gizzard shad	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	5	<1	<1	<1	<1	<1
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	5	<1	<1	<1	<1	<1
760	walleye	ecological	NOAEC	fish	2	<1	<1	<1	<1	<1
760	carp	ecological	NOAEC	fish	11	5	<1	<1	<1	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	13	6	<1	<1	<1	<1
500	carp	ecological	LOAEC	piscivorous mammal	20	11	1	<1	<1	<1
408	gizzard shad	ecological	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
121	carp	ecological	NOAEC	carnivorous bird deformity	56	41	14	12	7	4
50	carp	ecological	NOAEC	piscivorous mammal	81	63	28	24	16	13
771	sediment	ecological	TEL	sediment invertebrate	81	63	28	24	16	13

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.

[2] Fish concentrations are whole body.

CTE - Central Tendency Exposure

LOAEC - Lowest Observed Adverse Effect Concentration

NOAEC - No Observed Adverse Effect Concentration

RME - Reasonable Maximum Exposure

TEL - Threshold Effect Level

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Table 3-16 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Little Rapids to De Pere Reach

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	<1	<1	<1	<1	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	11	2	<1	<1	<1	<1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	9	2	<1	<1	<1	<1
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	11	2	<1	<1	<1	<1
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	30	6	<1	<1	<1	<1
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	30	6	<1	<1	<1	<1
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	36	10	<1	<1	<1	<1
377	carp	human health	CTE hazard index of 1.0	recreational angler	66	26	2	<1	<1	<1
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	62	22	2	<1	<1	<1
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	70	30	3	<1	<1	<1
288	walleye	human health	RME hazard index of 1.0	recreational angler	72	31	3	<1	<1	<1
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	92	43	6	<1	<1	<1
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	93	43	6	<1	<1	<1
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	51	9	2	<1	<1
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	48	8	2	1	<1
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	67	18	8	4	<1
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	66	18	8	4	2
92	carp	human health	RME hazard index of 1.0	recreational angler	>100	78	25	13	9	2
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	86	28	16	12	4
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	36	22	16	8
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	43	30	26	15
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	48	37	30	18
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	60	46	38	25
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	78	66	58	38
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	78	66	56	38
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	91	83	68	47
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	>100	72
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	83
7,600	walleye	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
4,083	gizzard shad	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
3,879	gizzard shad	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
2,399	gizzard shad	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	11	2	<1	<1	<1	<1
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	13	2	<1	<1	<1	<1
760	walleye	ecological	NOAEC	fish	27	5	<1	<1	<1	<1
760	carp	ecological	NOAEC	fish	31	6	<1	<1	<1	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	34	9	<1	<1	<1	<1
500	carp	ecological	LOAEC	piscivorous mammal	52	16	<1	<1	<1	<1
408	gizzard shad	ecological	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
121	carp	ecological	NOAEC	carnivorous bird deformity	>100	66	17	7	4	<1
50	carp	ecological	NOAEC	piscivorous mammal	>100	>100	39	26	20	11
596	sediment	ecological	TEL	sediment invertebrate	>100	>100	46	33	28	16

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.

[2] Fish concentrations are whole body.

CTE - Central Tendency Exposure

LOAEC - Lowest Observed Adverse Effect Concentration

NOAEC - No Observed Adverse Effect Concentration

RME - Reasonable Maximum Exposure

TEL - Threshold Effect Level

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Table 3-17 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): De Pere to Green Bay Reach

Media Threshold Concentration (µg/kg)[1]	Media[2]	Threshold Type	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	< 1	< 1	< 1	< 1	< 1	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	66	< 1	< 1	< 1	< 1	< 1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	> 100	< 1	< 1	< 1	< 1	< 1
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	> 100	3	< 1	< 1	< 1	< 1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	> 100	3	< 1	< 1	< 1	< 1
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	> 100	3	< 1	< 1	< 1	< 1
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	> 100	9	< 1	< 1	< 1	< 1
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	> 100	9	< 1	< 1	< 1	< 1
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	> 100	13	2	< 1	< 1	< 1
377	carp	human health	CTE hazard index of 1.0	recreational angler	> 100	22	2	< 1	< 1	< 1
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	> 100	20	3	2	< 1	< 1
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	> 100	23	3	< 1	< 1	< 1
288	walleye	human health	RME hazard index of 1.0	recreational angler	> 100	28	5	2	< 2	< 1
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	> 100	38	6	2	< 1	< 1
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	> 100	38	7	2	< 1	< 1
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	> 100	41	9	3	2	< 1
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	> 100	41	10	5	3	2
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	> 100	60	15	8	4	2
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	> 100	60	16	10	6	4
92	carp	human health	RME hazard index of 1.0	recreational angler	> 100	66	18	11	5	3
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	> 100	72	22	13	10	6
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	> 100	88	28	18	10	6
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	> 100	98	38	28	16	13
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	> 100	> 100	43	33	16	11
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	> 100	> 100	58	45	23	16
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	> 100	> 100	78	66	41	27
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	> 100	> 100	77	66	41	27
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	> 100	> 100	91	83	58	38
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	> 100	> 100	> 100	> 100	85	63
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	> 100	> 100	> 100	> 100	> 100	72
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1
7,600	carp	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	> 100	3	< 1	< 1	< 1	< 1
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	> 100	3	< 1	< 1	< 1	< 1
760	walleye	ecological	NOAEC	fish	> 100	8	< 1	< 1	< 1	< 1
760	carp	ecological	NOAEC	fish	> 100	8	< 1	< 1	< 1	< 1
709	carp	ecological	NOAEC	carnivorous bird hatching success	> 100	10	< 1	< 1	< 1	< 1
500	carp	ecological	LOAEC	piscivorous mammal	> 100	16	2	< 1	< 1	< 1
408	alewife	ecological	NOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1
121	carp	ecological	NOAEC	carnivorous bird deformity	> 100	60	15	8	4	2
50	carp	ecological	NOAEC	piscivorous mammal	> 100	91	33	18	13	7
632	sediment	ecological	TEL	sediment invertebrate	> 100	93	37	23	13	6

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.
[2] Fish concentrations are whole body.
CTE - Central Tendency Exposure
LOAEC - Lowest Observed Adverse Effect Concentration
NOAEC - No Observed Adverse Effect Concentration
RME - Reasonable Maximum Exposure
TEL - Threshold Effect Level

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Table 3-18 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Lower Fox River H Schedule Remedial Action Level and Green Bay No Action

Media Threshold Concentration (μg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Little Lake Butte des Morts	Appleton	Little Rapids	De Pere	Zone 2	Zone 3A	Zone 3B	Zone 4
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	32	2	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	<1	<1	<1	60	17	3	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	NA	NA	NA	NA
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	2	<1	<1	NA	NA	NA	NA
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	<1	<1	<1	7	>100	99	49	74
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	<1	<1	<1	7	>100	99	54	99
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	<1	2	2	12	>100	>100	79	99
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	<1	2	2	12	>100	>100	79	99
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	<1	4	7	16	>100	>100	93	>100
377	carp	human health	CTE hazard index of 1.0	recreational angler	<1	14	2	7	NA	NA	NA	NA
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	<1	8	12	23	>100	>100	>100	>100
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	<1	15	7	10	NA	NA	NA	NA
288	walleye	human health	RME hazard index of 1.0	recreational angler	<1	11	16	24	>100	>100	>100	>100
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	2	22	10	16	NA	NA	NA	NA
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	2	23	16	16	NA	NA	NA	NA
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	4	26	16	16	NA	NA	NA	NA
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	1	17	25	35	>100	>100	>100	>100
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	10	36	24	24	NA	NA	NA	NA
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	9	29	35	42	>100	>100	>100	>100
92	carp	human health	RME hazard index of 1.0	recreational angler	14	37	32	35	NA	NA	NA	NA
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	10	34	42	52	>100	>100	>100	>100
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	21	46	38	35	NA	NA	NA	NA
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	20	45	57	70	>100	>100	>100	>100
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	33	58	51	45	NA	NA	NA	NA
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	42	66	62	59	NA	NA	NA	NA
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	61	92	84	84	NA	NA	NA	NA
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	50	80	100	100	>100	>100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	64	100	100	100	>100	>100	>100	>100
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	NA	NA	NA	NA
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	NA	NA	NA	NA
7,600	walleye	ecological	LOAEC	fish	<1	<1	<1	<1	29	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1	<1	<1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1	<1	<1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1	<1	<1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	23	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	<1	2	<1	<1	>100	99	47	69
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	<1	2	<1	<1	>100	99	50	80
760	walleye	ecological	NOAEC	fish	<1	2	1	10	>100	>100	74	99
760	carp	ecological	NOAEC	fish	<1	6	<1	<1	73	5	4	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	<1	7	<1	<1	>100	>100	79	99
500	carp/walleye [3]	ecological	LOAEC	piscivorous mammal	<1	10	<1	2	>100	>100	99	>100
500	alewife	ecological	LOAEC	piscivorous mammal	NA	NA	NA	NA	98	28	21	2
408	alewife	ecological	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	>100	42	31	5
121	carp	ecological	NOAEC	carnivorous bird deformity	<1	36	24	24	>100	>100	>100	>100
50	carp/walleye [3]	ecological	NOAEC	piscivorous mammal	25	50	42	37	>100	>100	>100	>100
50	alewife	ecological	NOAEC	piscivorous mammal	NA	NA	NA	NA	>100	>100	>100	>100

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.

[2] Fish concentrations are whole body.

[3] Carp is the fish for the river and walleye is the fish for the bay.

CTE - Central Tendency Exposure

LOAEC - Lowest Observed Adverse Effect Concentration

NA - Not Applicable

NOAEC - No Observed Adverse Effect Concentration

RME - Reasonable Maximum Exposure

TEL - Threshold Effect Level

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Table 3-19 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Lower Fox River Schedule I Remedial Action Level and Green Bay No Action

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Little Lake Butte des Morts	Appleton	Little Rapids	De Pere	Zone 2	Zone 3A	Zone 3B	Zone 4
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	32	2	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	<1	<1	<1	60	17	3	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	NA	NA	NA	NA
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	2	<1	<1	NA	NA	NA	NA
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	<1	<1	<1	7	>100	99	49	74
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	<1	<1	<1	7	>100	99	54	99
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	<1	2	4	12	>100	>100	79	99
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	<1	2	7	12	>100	>100	79	99
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	<1	4	7	16	>100	>100	93	>100
377	carp	human health	CTE hazard index of 1.0	recreational angler	1	14	7	7	NA	NA	NA	NA
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	<1	9	12	23	>100	>100	>100	>100
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	2	15	7	10	NA	NA	NA	NA
288	walleye	human health	RME hazard index of 1.0	recreational angler	1	11	16	32	>100	>100	>100	>100
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	5	23	16	16	NA	NA	NA	NA
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	5	23	16	16	NA	NA	NA	NA
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	8	27	16	16	NA	NA	NA	NA
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	4	17	26	35	>100	>100	>100	>100
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	14	36	26	28	NA	NA	NA	NA
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	9	29	35	45	>100	>100	>100	>100
92	carp	human health	RME hazard index of 1.0	recreational angler	17	38	32	35	NA	NA	NA	NA
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	14	36	42	59	>100	>100	>100	>100
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	25	48	42	42	NA	NA	NA	NA
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	25	45	62	84	>100	>100	>100	>100
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	37	61	55	59	NA	NA	NA	NA
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	51	67	67	70	NA	NA	NA	NA
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	70	92	92	95	NA	NA	NA	NA
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	58	80	100	100	>100	>100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	70	100	100	>100	>100	>100	>100	>100
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	NA	NA	NA	NA
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	NA	NA	NA	NA
7,600	walleye	ecological	LOAEC	fish	<1	<1	<1	<1	29	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1	<1	<1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1	<1	<1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1	<1	<1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	23	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	<1	2	<1	<1	>100	99	47	69
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	<1	2	<1	<1	>100	99	50	80
760	walleye	ecological	NOAEC	fish	<1	2	2	10	>100	>100	74	99
760	carp	ecological	NOAEC	fish	<1	7	<1	<1	73	5	4	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	<1	7	<1	1	>100	>100	79	99
500	carp/walleye [3]	ecological	LOAEC	piscivorous mammal	<1	10	1	7	>100	>100	99	>100
500	alewife	ecological	LOAEC	piscivorous mammal	NA	NA	NA	NA	98	28	21	2
408	alewife	ecological	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	>100	42	31	5
121	carp	ecological	NOAEC	carnivorous bird deformity	14	36	26	25	>100	>100	>100	>100
50	carp/walleye [3]	ecological	NOAEC	piscivorous mammal	29	52	45	45	>100	>100	>100	>100
50	alewife	ecological	NOAEC	piscivorous mammal	NA	NA	NA	NA	>100	>100	>100	>100

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.
[2] Fish concentrations are whole body.
[3] Carp is the fish for the river and walleye is the fish for the bay.
CTE - Central Tendency Exposure
LOAEC - Lowest Observed Adverse Effect Concentration
NA - Not Applicable
NOAEC - No Observed Adverse Effect Concentration
RME - Reasonable Maximum Exposure
TEL - Threshold Effect Level

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4 FRFOOD Sediment Quality Thresholds and Remedial Alternative Projections

FRFood was used for very specific purposes within the BLRA and in the FS. Thus, much of the material generated by the application of FRFood appears in the following documents and sections:

- Sediment quality thresholds in Section 7 of the BLRA,
- Development of Remedial Action Objectives (RAOs) in Section 5 of the FS, and
- Projection of future risks in the Alternative-specific Risk Assessment in Section 8 of the FS.

In the interest of having a complete document, that material is re-presented here in the FRFood Model Documentation Memorandum.

4.1 Sediment Quality Thresholds

The overall objective of the Fox River RI/FS was to evaluate corrective actions that may be applied to contaminated sediment within the Lower Fox River and Green Bay. Those corrective actions will be based on the projected reductions of risk to human health and the environment. To that end, the risk assessment defined the current (or baseline) human health and ecological risks associated with the chemicals of concern (COCs); PCBs, mercury, and 4,4'-dichlorodiphenyl dichloroethylene (DDE). Of those, PCBs were identified as the principal component of risk to human health and the environment. To facilitate the selection of a remedy that will result in a decrease in those risks, it is necessary to establish a link between levels of PCBs toxic to human and ecological receptors, and the principal source of those PCBs, the Lower Fox River and Green Bay sediment.

FRFood was used to develop sediment quality thresholds (SQTs). SQTs are estimated concentrations that link risk in humans, birds, mammals, and fish with “safe” thresholds of PCBs in sediment. These numeric and site- specific values are developed for each pathway and receptor identified as important by the response agencies of the Lower Fox River and Green Bay (e.g., sport fishing consumption, bald eagles). FRFood was constructed in a manner that allows for projection of sediment concentrations, based upon the input of a desired fish tissue concentration. In Section 7 of the BLRA, fish tissue concentrations that were associated with specific levels of risk (e.g., 10^{-5} cancer risk in high-intake fish consumers), a no observed adverse effect concentration (NOAEC) in the diet of piscivorous birds was input into FRFood, and the corresponding sediment quality concentration was projected. The SQTs themselves are not cleanup criteria, but are an approximation of protective sediment values and can be considered to be "working values" from which to select a remedial action level. SQTs were developed in the BLRA and applied in Section 5 of the FS to identify the remedial action levels that were then applied to alternative development. Only the development of the SQTs is discussed here.

4.1.1 Determining Sediment Quality Thresholds

Estimating Sediment-to-water Ratios

To calculate a PCB SQT from a fish tissue concentration, it was necessary to identify a generalized term relating the concentration of total PCBs in filtered water relative to that found in the sediments. The same water and sediment data used to calibrate the mass balance for the Fox River were used to estimate this term. These data are shown in Table 3-7, and represent the minimum, maximum, and average values computed for the 1989-through-1990 calibration period. For the Lower Fox River, the data suggest that the non-particulate water PCB concentration is between 10^{-6} and 10^{-7} of the bedded sediment concentration. For the De Pere to Green Bay Reach (Green Bay Zone 1), the value lies between 10^{-4} and 10^{-6}. As a general term for developing the river SQTs, a value of 10^{-6} was used to estimate SQTs.

The estimated sediment-to-water ratios for Zone 2 is complicated by the fact that approximately 70 percent of the water in Zone 2 (Long Tail Point to Point Sable) is comprised of water from the Lower Fox River (Brazner and Beals, 1997). To estimate the sediment/water resuspension rates for PCBs, the GBTOXe mass balance model was run using zero PCB loading from the Lower Fox River. Given no loads from the Fox River, the average water column concentrations ranged between 10^{-7} and 10^{-5} of the interpolated sediment concentrations. Given these estimates, a 10^{-6} term is also applicable to Zone 2 sediments.

Because of the uncertainty associated with the sediment-to-water ratio, SQTs may differ by an order of magnitude. For example, walleye NOAEC SQTs based on a sediment-to-water ratio of 10^{-5} are 8 times less than SQTs based on a sediment-to-water ratio of 10^{-6}, and 25 times less than an SQT based on a sediment-to-water ratio of 10^{-7}.

Human Health Sediment Quality Thresholds

Human health PCB SQTs were developed for recreational anglers and high-intake fish consumers at both the 10^{-5} risk level and at a hazard index of 1.0 for walleye, perch, and carp. SQTs were estimated for reasonable maximum exposure (RME) and the central tendency exposure scenarios. SQTs associated with cancer risk levels of 10^{-4} and 10^{-6} are one order of magnitude below, and one order of magnitude higher, respectively, than the SQTs for the 10^{-5} risk level.

To estimate the human health PCB SQT, risk-based fish concentrations (RBFCs) were developed for PCBs in fish fillets (see Section 5.9.9 of the BLRA). Since these RBFCs are expressed as concentrations of PCBs in fillets, it was necessary to convert RBFCs for the fish fillet to RBFCs for whole body fish. Based on data obtained from the literature, the ratio of PCB concentrations in fillet to whole body can be estimated:

$$C_{fish-f} = a_{f-wb} \cdot C_{fish-wb}$$

where:

$C_{fish\text{-}f}$	=	concentration of PCBs in fish fillet (in micrograms per kilogram of fillet [µg/kg-fillet]),
$a_{f\text{-}wb}$	=	ratio of concentrations in fish fillet to concentrations in whole body of fish (kg-fish/kg-fillets), and
$C_{fish\text{-}wb}$	=	concentration of PCBs in whole body of fish (µg/kg-whole body).

Once whole body RBFCs for total PCBs were obtained, these concentrations were used as inputs to the FRFood Model, which then output PCB concentrations in sediment that represent PCB SQTs.

To calculate fillet-to-whole body ratios, both site-specific data and literature-derived ratios were examined. Table 3-8 summarizes ratios of PCB concentrations for fillet and whole body for a number of different fish species. For the Lower Fox River, data were available in the FRDB to estimate fillet-to-whole body ratios for walleye (0.17), carp (0.53), white bass (0.44), and white sucker (0.48). For perch, there were insufficient data to estimate a ratio specific to perch, but the walleye ratio was deemed applicable. Perch are from the same family as walleye (*Percidae*) and have similar lipid values. Table 3-8 also presents the ratios from other studies. The ratios range from 0.04 for perch to 1.0 for brown trout. The perch value of 0.04 from Parkerton *et al.* (1993) for fish collected at Lake Erie and the data used to develop this ratio were not available for review. Thus, the perch value of 0.04 was not used. There is variability within the same species, with ratios ranging from 0.57 to 1.0 for brown trout;

0.59 to 0.89 for coho salmon; 0.34 to 0.68 for rainbow trout; and 0.09 to 0.17 for walleye.

Table 3-9 presents the PCB SQTs associated with a risk level of 10^{-5} and a hazard index of 1.0 for carp, walleye, and perch for the Lower Fox River. These values ranged between 11 µg/kg-sediment PCBs for the high-intake fish consumer eating carp under an RME scenario, to 1,128 µg/kg for a recreational angler eating perch under a central tendency exposure (CTE) scenario. It is important to note that Table 3-9 presents the SQTs associated with a target rate of 10^{-5}; the SQTs associated with cancer ratios of 10^{-6} and 10^{-4} are an order of magnitude lower, or higher, respectively. All three ranges of cancer risks are carried forward into the Feasibility Study to be evaluated as part of the action level selection process, and for the evaluation of remedial alternatives.

Ecological Sediment Quality Thresholds

Total PCB SQTs protective of ecological receptors were derived from the toxicity reference values listed in Table 6-5 of the ecological risk assessment. The total PCB fish Toxicity Reference Value (TRV) for the various receptors were used as inputs to the FRFood Model, and then back-calculated to yield the PCB SQT. Total PCB SQTs were directly derived from the TRVs for fish survival and reproduction and for mink reproduction and kit survival based upon total PCB concentrations in fish as part of their diet. The fish species selected for PCB SQT determinations were walleye and carp, because they are the highest trophic level pelagic and benthic fish present in the river. Sediment quality thresholds that are protective of walleye and carp should also be protective of other fish species present.

For piscivorous and carnivorous birds, TRVs were based on egg or whole body concentrations. Therefore, it was necessary to derive site-specific biomagnification factors (BMFs) to determine what were safe concentrations in fish, their sole or primary prey. For bald eagles, carp were assumed to be the primary prey, and for both tern species and double-crested cormorants, alewife were assumed to be the primary prey. Total PCB concentrations in these bird species (egg or whole body) were compared to primary prey concentrations within the same reach to derive species-specific BMFs. The BMF was calculated by dividing the bird receptor egg or whole body concentration by the fish concentration. To facilitate the calculation of the BMF, it was conservatively assumed that the diet of these bird species was 100 percent alewife, and that all of the PCBs are transferred from fish to eggs. These BMFs were then applied to the total PCB TRVs for birds in order to convert these bird tissue TRVs into fish tissue TRVs. While limitations of the BMF model were discussed previously, there are no kinetic bioaccumulation models that have been validated for fish-to-bird contaminant transfers. The BMF model, used with site-specific data and within this context, is the best approximation of bird contaminant exposure. BMFs and estimated threshold fish tissue concentrations for effects to reproduction and embryo physiology are given in Table 3-10.

Total PCB sediment quality thresholds for fish, birds, and mink are given in Table 3-11. The PCB SQTs range from a low of 24 µg/kg that is protective of mink reproduction and kit survival, to a high of 5,231 µg/kg that corresponds to a lowest observed adverse effect concentration (LOAEC) for common tern deformity.

4.2 Remedial Alternative Projections

For the Feasibility Study, FRFood took the sediment and water output from 100-year simulations of wLFRM to project fish tissue concentrations. The remedial action simulations for the Feasibility Study are given in Table 3-12, and include no action, 125, 250, 500, 1,000, and 5,000 parts per billion (ppb) for each of the reaches. For modeling in the FS, the same action levels were applied to each river reach. For example, under the No Action alternative the models were run assuming that no action had occurred on all four river reaches. Table 3-12 also shows the simulations for Green Bay that were coupled with specific action level simulations in the river. Fish projections from the wLFRM/GBTOXe couplings for Green Bay zones 2 through 4 were accomplished by GBFood.

For the purposes of developing the proposed plan, WDNR requested that two additional simulations be conducted that had reach-specific action levels. These were labeled “Schedule H” and “Schedule I,” and the reach-specific action level used is presented in Table 3-13.

All of the inputs and outputs to FRFood are presented on the compendium CD-ROM that may be found in Appendix E3 to the Model Documentation Report. FRFood output included weekly projections over the 100-year period for total PCB concentrations in phytoplankton, zooplankton, benthic invertebrates, carp, forage fish (shad, smelt, alewife), perch, and walleye.

For the FS, the data extracted from the model was the time in years required for the specific thresholds identified in Tables 3-9 and 3-11 to be achieved. Human health receptors considered were recreational anglers and high-intake fish consumers. Ecological receptors evaluated included: carp as the surrogate representative for benthic fish, walleye as the surrogate representative of pelagic fish, Forster’s terns as the surrogate representative of piscivorous birds, bald eagles as the surrogate representative of carnivorous birds, and mink as the surrogate representative for piscivorous mammals. For each river reach, the time to achieve these human health and ecological thresholds are presented in Tables 3-14 through 3-17.

Representative annualized projections of carp and walleye projections in the De Pere to Green Bay Reach are shown on Figures 3-8 and 3-9, respectively. In both cases, there are large differences between the projections for no action and any of the potential remedial action levels. For both species, the body burdens of total PCBs do not achieve less than 4,000 µg/kg until approximately the end of the 100-year period. All of the projections for the remedial action levels between 5,000 and 125 ppb in sediments achieve most of the fish tissue thresholds identified in Table 3-17, but vary in the amount of time taken to achieve those values. As can be observed on Figure 3-8, there is still a large difference between the projections for the 5,000 ppb action level and the 1,000 to 125 ppb levels. Evaluating those lower four action levels, the years to achieve the fish tissue concentrations are generally similar for the 1,000 and 500 ppb levels, and approximately half the time to achieve the lower two levels (250 and 125 ppb). These observations were generally similar to those observed in the upper four reaches. The specific use of these results is found in Section 8 of the Feasibility Study.

Tables 3-18 and 3-19 show the results for the Schedule H and I remedial action scenarios. Those are not discussed further here.

Use of these data are discussed in Section 8 of the Feasibility Study.

5 Comparison Between FRFOOD and GBFOOD

Two bioaccumulation models are applied in the Feasibility Study: FRFood and GBFood. While either model could have been used for projections throughout all of the Fox River and Green Bay, there was a good deal of previous validation and history behind applications of each model. The Gobas algorithms, upon which the FRFood Model is based, were used in the 1996 RI/FS (GAS/SAIC, 1996), in the 1999 Draft Feasibility Study for the river (ThermoRetec, 1999), and has been used in Wisconsin to assess risks on the Sheboygan River (EVS, 1998). In those applications, as is the case here, the Gobas algorithm was found to provide a good estimation of fish tissue PCB concentrations based upon the available sediment and water data. Other applications of the Gobas algorithms were discussed in Section 1.1.

The GBFood Model also has a history of successful applications, most notably in Green Bay. The algorithms developed by Thomann and colleagues (Thomann, 1989; Thomann *et al.*, 1992) were applied by Connolly *et al.* (1992) as part of the Green Bay Mass Balance Study, and then were updated by HydroQual (1995). The GBFood Model, in its current formulation, is maintained by QEA; other applications of the basic algorithms are discussed in the GBFood Model Documentation Report (Appendix E1).

The steady-state algorithms developed by both Gobas and Thomann share many structural similarities, and were compared directly to each other for predicting bioaccumulation in the Great Lakes. As noted in Section 1, Burkhard (1998) found that both models yielded very similar results.

While the models may share structural similarities, there are some key differences in the algorithm and in the assignment of parameters. Some of these differences include:

- Mathematical algorithms have similarities, but treat issues such as uptake by phytoplankton and zooplankton, metabolic biotransformation rates, and dilution due to growth and metabolism differently (see Burkhard, 1998, for a detailed discussion).

- GBFood includes trout, but not carp, while FRFood includes carp, but not trout.

- GBFood fixed the diet and lipid components; FRFood treated these as calibration parameters.

- GBFood assigned multiple age classes to the various fish species; FRFood only evaluated young of the year (YOY) and adults.

- GBFood treated migration between Zone 1 and Zone 2 as a calibration parameter; FRFood assumed complete residence for exposure.

Both models achieve the metric of plus or minus one-half order of magnitude for the calibration periods in all reaches or zones in which they were applied. FRFood and GBFood do have overlap in zones 1 and 2. As discussed in this memorandum, modeled results for FRFood compared well with observed values in all four reaches. For Zone 1, the projected walleye and carp concentrations were within approximately 90 percent of the observed values. In Zone 2, the FRFood projections of walleye and carp were still less than a factor of two of the observed values (60% and 75%, respectively), but under-predicted forage fish tissue concentrations by as much as a factor of three. For Zone 2, GBFood projections for both forage fish and walleye compared very favorably with observed values.

As a check on the potential projection differences between the two models, the natural attenuation alternative (i.e., no action) projections for walleye in Zone 2 were plotted and compared (Figure 3-10). While the overall trend over time was the same, FRFood projections for walleye in Zone 2 were between 1.6 and 1.8 times lower than those projected by GBFood. The overall trend over time was the same.

6 References

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