Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway Remedial Investigation

FOOD WEB MODEL MEMORANDUM 3
PRELIMINARY MODEL RESULTS

For submittal to

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

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Table of Contents

List of Tables

List of Figures

List of Acronyms

Acronym	Definition
DOC	dissolved organic carbon
dw	dry weight
Ecology	Washington State Department of Ecology
EFDC	Environmental Fluid Dynamics Computer Code
EPA	US Environmental Protection Agency
ERA	ecological risk assessment
FS	feasibility study
FWM	food web model
HHRA	human health risk assessment
K_{OW}	octanol-water partition coefficient
LDW	Lower Duwamish Waterway
NLOM	non-lipid organic matter

Acronym	Definition
OC_{sed}	organic carbon concentrations in sediment
PCB	polychlorinated biphenyl
POC	particulate organic carbon
QAPP	quality assurance project plan
RBG	risk-based goal
RI	remedial investigation
RM	river mile
SPAF	species predictive accuracy factor
SPD	species percent difference
SQT	sediment quality threshold
SWAC	spatially weighted average concentration
ww	wet weight

1.0 Introduction

A comprehensive dataset of chemical concentrations in sediment and tissue samples has been collected in the Lower Duwamish Waterway (LDW) to define the nature and extent of contamination and to conduct baseline risk assessments for the LDW Phase 2 remedial investigation (RI). These data will also be used to support a food web model (FWM) for the LDW based on the model of Arnot and Gobas (Arnot and Gobas 2004). The FWM is needed for two applications. As part of the RI, risk-based goals (RBGs) for fish and crab tissue[1] will be established based on the results of the ecological and human health risk assessments (ERA and HHRA), and those tissue RBGs will be translated into sediment quality thresholds (SQTs)[2] using the FWM. In the feasibility study (FS), the FWM will also be used as one tool to evaluate residual risks associated with various sediment cleanup alternatives.

Three memoranda that describe the FWM have been prepared to present a rationale for the selection of a model, the modeling approach, and the results of preliminary modeling runs. This document is the third of these three FWM memoranda and focuses on the results of preliminary model runs. The final documentation and application of the FWM will be presented in the Phase 2 RI.

The purpose of this memorandum is to present preliminary results of the FWM to further elucidate model assumptions and sensitivities. The Arnot and Gobas-based FWM (Arnot and Gobas 2004) is being used to estimate the uptake of total PCBs from sediment and water through the food chain for five target species (slender and Dungeness crabs, English sole, shiner surfperch, and Pacific staghorn sculpin). In addition, concentrations of PCBs in the tissues of four other groups of organisms (phytoplankton, zooplankton, benthic invertebrates, and juvenile fish) that are prey for the target species are also predicted. Collectively, the target species and the prey species are referred to as the modeled species. Empirical PCB tissue concentration data in the LDW exist for benthic invertebrates, slender crabs, Dungeness crabs, Pacific staghorn sculpin, shiner surfperch, and English sole. The other modeled species have no empirical PCB tissue concentration data. Total PCB concentrations are being predicted in tissue for these nine categories of fish and invertebrates within the entire LDW and, for some species, within smaller areas of the LDW. Following the identification of input parameter values and data (Section 2), preliminary model runs and analyses that were carried out to evaluate the model's overall performance are:

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[1] Clam RBGs will be developed in the HHRA. The clam RBGs will then be translated into SQTs using biota-sediment accumulation factors.

[2] SQTs are chemical concentrations in sediment associated with specific acceptable risk estimates. SQTs may be derived for a variety of exposure scenarios.

- **LDW-wide model run.** The FWM was run at the LDW-wide (i.e., site-wide) spatial scale, and the performance of the FWM was evaluated relative to empirical data. Methods and results are discussed in Section 3.0.
- **Dietary scenarios.** The FWM was run with several dietary scenarios to assess the sensitivity and model performance. Methods and results are discussed in Section 4.0.
- **Sensitivity analyses.** Sensitivity analyses were conducted at the LDW-wide spatial scale to determine: a) parameters to which the FWM is most sensitive, and b) how sensitive the model is to the plausible ranges of certain parameter values. The FWM was also run with a range of total PCB water column concentrations to test model performance within that range, and to conduct a preliminary investigation into the sensitivity of the FWM to total PCB concentrations in water. This analysis was conducted to provide additional information to decide whether additional water column data should be collected this summer. Methods and results are discussed in Section 5.0.
- **Uncertainty analysis.** An uncertainty analysis was conducted at the LDW-wide spatial scale to characterize the combined effect of the uncertainty associated with each input parameter. Methods and results are discussed in Section 6.0.
- **Smaller spatial scale model runs.** The FWM was run at a smaller spatial scale (referred to as modeling areas) for all modeled species. Methods and results are discussed in Section 7.0.

Based on the preliminary results, several parameters and assumptions were identified for further consideration during calibration of the FWM. These parameters and assumptions are discussed in Section 8.0. The steps to finalize the FWM after the submittal of this memorandum are presented in Section 9.0.

The results presented in this memorandum and the results that will be presented in the Phase 2 RI are likely to be different for three reasons. First, some of the key input parameters to the FWM are still being developed. For example, the concentration of polychlorinated biphenyls (PCBs) in sediment is being determined through interpolation of the baseline surface sediment dataset. Both the baseline dataset and the interpolation methodology are being discussed with the US Environmental Protection Agency (EPA) and the Washington Department of Ecology (Ecology) at this time. Second, the concentrations of PCBs in water will ultimately be provided by King County based on output from the Environmental Fluid Dynamics Computer Code (EFDC) hydrodynamic model. Further calibration of this model is ongoing this spring to incorporate water and sediment data collected over the past year. Third, the FWM will likely be calibrated prior to its application in the Phase 2 RI. Refinements to the calibration will be based on the results of the preliminary sensitivity/uncertainty analyses and the dietary scenarios presented in this memorandum as well as updated sediment and water inputs, as discussed above. The purpose of calibration, which will be conducted in consultation with EPA and Ecology, is to achieve the best fit using empirical data from the LDW, while remaining within reasonable assumptions for key input parameters. The overall process that will be followed prior to the presentation of the FWM results in the Phase 2 RI is presented in this memorandum (Section 9), and will also be discussed with stakeholders.

2.0 Selection of Parameter Values

The Gobas and Arnot (2004) model requires input values for 36 parameters to predict concentrations of hydrophobic chemicals in aquatic organisms. Some parameters are species-specific and thus require more than one value. This section and Appendix A present the initial values selected for the FWM. As discussed in the FWM Memorandum 2 (Windward 2005b), these initial values form the basis for preliminary model runs and preliminary uncertainty and sensitivity analyses. If needed to meet the model performance goal (i.e., predictions within a factor of 3 of empirical data), these initial parameter values will be modified in consultation with EPA and Ecology prior to their final application in the Phase 2 RI.

For this memorandum, the FWM is being used to predict the total PCB concentrations[3] in the tissues of the five target species (slender and Dungeness crabs, English sole, shiner surfperch, and Pacific staghorn sculpin) in the LDW. In addition, PCB concentrations in the tissue of four species groups (phytoplankton, zooplankton, benthic invertebrates, and juvenile fish) are being predicted by the model as prey for the target species. Each species has its own set of parameter values to define its biological state (e.g., lipid content, water content, and weight[4]) and diet. The same values for environmental parameters that define the chemical and physical conditions of the LDW (e.g., water temperature, oxygen concentration) are being used for each species. Chemical-specific parameter values (e.g., K_{OW}) are also required for the chemical being modeled (e.g., total PCBs). Because total PCBs include a mixture of individual PCBs congeners, parameters such as K_{OW} were estimated from available PCB congener data (see Section A.3 in Appendix A)

Values for each of the FWM parameters appropriate for the LDW were selected from three major source categories: site-specific data, literature data, or default values used or cited in Arnot and Gobas (2004) or in a San Francisco Bay application of the same model

[3] As discussed in the second deliverable, the FWM may later be used to predict concentrations of other chemicals if these chemicals are found to be risk drivers.

[4] Weight is calculated in several different ways (e.g., average of individual LDW samples or literature-based). For fish and crabs, the weight represents the average adult weight of that species in the LDW. For zooplankton, it represents an average weight of all zooplankton captured in a Puget Sound inlet over a year period. Thus, the value chosen for the weight zooplankton parameter does not necessarily represent realistic expected size ranges that are actually consumed by target species in the LDW, but was chosen from values available in the literature for the region.

(Gobas and Arnot 2005). Values for six species-specific parameters, including organism weight, lipid content, non-lipid organic matter content, water content, diets, and fraction of pore water and overlying water ventilated, were derived from either LDW or literature data (Appendix A, Table A-5-1). Values for eight parameters, including total PCB and organic carbon concentrations in sediment (OC_{sed}), total PCB concentration in water, and five water quality parameters, were derived from LDW data (Appendix A, Table A-2-1). Two chemical-specific parameters, including K_{OW} and Henry's Law Constant, were determined from the literature (Appendix A, Table A-3-1). Twenty parameter values were default values, as cited in Arnot and Gobas (2004) or Gobas and Arnot (2005). The majority of parameters with default values are constants in the model equations, except for the rate constant for metabolic transformation of PCBs and the density of lipids and water (Appendix A, Table A-4-1). The initial set of input parameter values used in the analyses reported here was determined for the LDW as a whole. Different parameter values may be used in later modeling of smaller areas of the LDW. Parameter names, symbols, units, selected values, comments, and source information for the initial set of input values are presented in Appendix A.

Modeled species diets are restricted to the compartments selected for the FWM. Each compartment is a surrogate dietary item for the organisms consumed by modeled species. As specified in FWM Memorandum 1, these dietary surrogates include sediment, phytoplankton, zooplankton, benthic invertebrates, and small prey fish (Windward 2005a). For all model runs other than those exploring various dietary scenarios, the proportions of each dietary surrogate in modeled species diets are those specified in dietary scenario 1, which is one of several plausible dietary scenarios investigated (Section 4.0).

Input parameter values were derived for the LDW at two spatial scales: the LDW-wide spatial scale and the modeling area spatial scale (Figure 2-1).[5] Modeling areas (Areas M1 to M4) were defined as fish and crab tissue sampling areas extended out to the center point between tissue sampling areas. At the modeling area scale, the FWM was run separately for each modeling area. All species were modeled at both spatial scales. Parameter values that were changed with scale included the total PCB and OC_{sed} concentrations in sediment, fish and invertebrate lipid and water contents, and fish and crab weights. When output data for total PCB concentrations in water are available from EFDC, this input parameter will also be based on the specific modeling areas.

[5] The LDW-wide spatial scale was defined as River Mile (RM) 0 to RM 5.0. Modeling areas were as follows: M1 (RM 0.0 to RM 1.3), M2 (RM 1.3 to RM 2.65), M3 (RM 2.65 to RM 3.95), and M4 (RM 3.95 to RM 5.0).

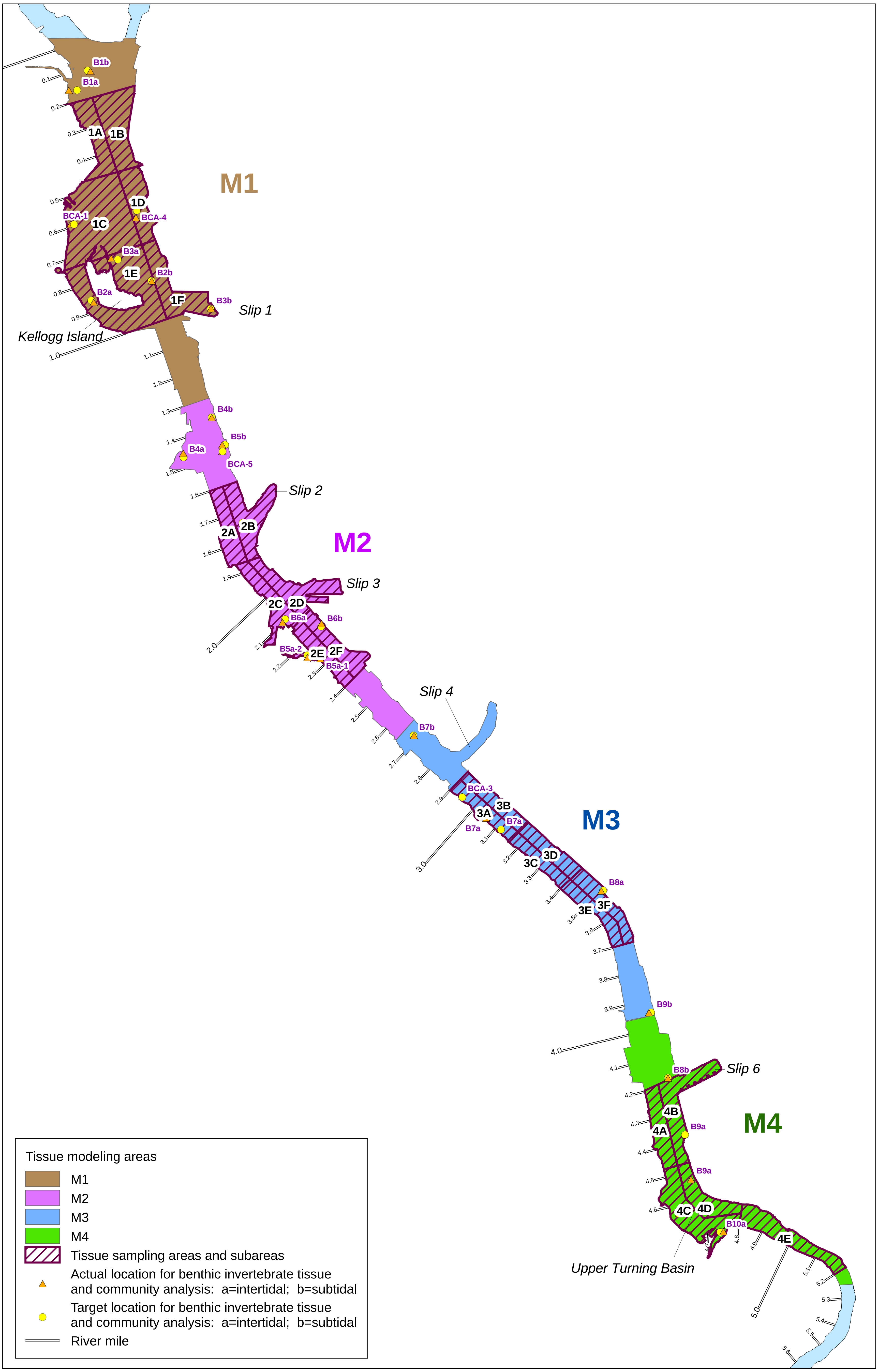

Figure 2-1. Lower Duwamish Waterway modeling areas

Windward environmental LLC

Prepared by STS 04/07/06 Map 2109

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In addition to the LDW-wide and modeling area scales, shiner surfperch and Pacific staghorn sculpin will also be modeled in the future at the subarea scale, which is smaller than the modeling area (Figure 2-1). These two target species will be evaluated at this scale because it is possible that the foraging range for these species may be smaller than a modeling area, although the sizes of their foraging ranges are uncertain.[6] Unlike the other targeted species (i.e., slender and Dungeness crabs, English sole), for which composite tissue samples were available only for entire tissue sampling areas, Phase 2 tissue data are available for shiner surfperch and Pacific staghorn sculpin from each of the tissue sampling subareas shown in Figure 2-1. Thus, FWM predictions can be compared to empirical data for the latter species at this scale. This subarea scale was not investigated for this memorandum because total PCB concentrations in water were not yet available at a subarea scale. The total PCB concentrations in water will be generated by the EFDC model following recalibration with an updated sediment and water data. EFDC predictions of PCB water concentrations at smaller spatial scales will be available in the spring of 2006.

When the water data are available, a subset of the tissue sampling subareas will be modeled for shiner surfperch and Pacific staghorn sculpin. Subareas T1-B, T1-E, T2-B, T2-E, T3-B, T3-F, T4-A, and T4-D have been selected for modeling because they provide spatial coverage of the LDW and represent a range of total PCB concentrations in tissue and sediment (Figure 2-2).

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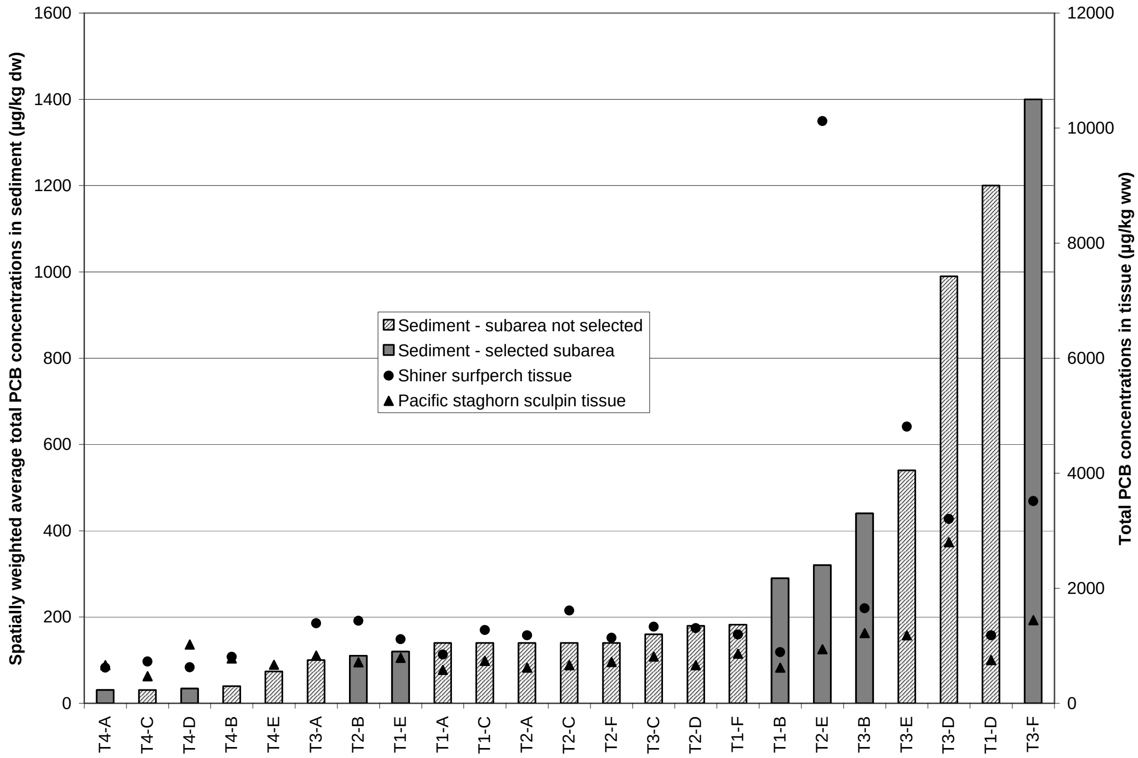
[6] Local fish experts expressed opinions at a March 31, 2004, meeting that foraging movements for target species may be as large as the LDW or as small as a tissue subarea.

Figure 2-2. Total PCB concentrations in tissue sampling subareas



Parameter values that will differ between the modeling area and the subarea spatial scales will include total PCB concentrations in sediment and water as well as OC_{sed} concentrations in sediment. Fish weight, lipid, and water content data from the corresponding modeling area will be used at a subarea scale because these parameters are not expected to vary among fish sampling subareas within the corresponding modeling area. Predicted shiner surfperch and Pacific staghorn sculpin total PCB tissue concentrations from a given subarea model will be compared to empirical data from the corresponding subarea.

3.0 Application of the FWM at the LDW-Wide Scale

The FWM was run at the LDW-wide spatial scale to test the model's ability to predict total PCB concentrations in tissue for the target species being modeled. The LDW-wide spatial scale integrates the exposure of modeled species throughout the LDW regardless of foraging ranges. Application of the FWM to smaller spatial scales is discussed in Sections 7.0 and 8.0.

3.1 METHODS

Preliminary runs of the FWM were conducted with the initial set of input parameter values presented in Appendix A (Tables A-1-2, A-2-1, A-2-2, A-2-3, A-3-1, and A-4-1). The initial set of input parameter values included dietary scenario 1, which is one of several plausible dietary scenarios investigated (Section 4.0). Predicted total PCB tissue concentrations were compared to available empirical data for five fish and crab species using two model performance metrics, the species predictive accuracy factor (SPAF), which was discussed in detail in FWM Memorandum 2 (Windward 2005b), and the percent difference metric. Below are equations describing the SPAF and percent difference metrics.

The species predictive accuracy factor (SPAF) is the ratio of predicted to empirical tissue chemical concentrations. If predicted tissue chemical concentrations were higher than empirical tissue chemical concentrations, then Equation 3-1 was used to calculate the SPAF:

$$SPAF = \frac{PTCC}{ETCC}$$ **Equation 3-1**

where:

PTCC = predicted tissue chemical concentration
ETCC = empirical tissue chemical concentration

If predicted tissue chemical concentrations were lower than empirical tissue chemical concentrations, then Equation 3-2 was used to calculate the SPAF:

$$SPAF = \frac{ETCC}{PTCC}$$ **Equation 3-2**

The percent difference is a model performance metric that measures the difference of the predicted and empirical tissue chemical concentration relative to the magnitude of the empirical tissue chemical concentration. It is calculated as follows:

$$\% \text{ difference} = \frac{\text{PTCC} - \text{ETCC}}{\text{ETCC}} \qquad \textbf{Equation 3-3}$$

Three empirical datasets are available for comparison to predicted results (Table 3-1). Two of these datasets were collected as part of the Phase 2 RI (fish and crab tissue samples were collected in 2004 and 2005). The third dataset combines data from numerous studies conducted since 1990 (these data are referred to as historical data). Total PCB concentrations in the 2004 Phase 2 fish and crab samples were generally higher than those in historical samples or the 2005 Phase 2 fish and crab samples (Table 3-1). In this memorandum, the results of the FWM are generally compared to mean total PCB concentrations from all three datasets combined to simplify the presentation of results. To assess the performance of the model relative to specific datasets, model runs are also compared to total PCB concentrations for historical and Phase 2 (2004 and 2005) data separately for the LDW-wide results in Section 3-2. The empirical tissue data used in these comparisons are discussed further in Appendix A, Section A.2.3. The dataset(s) to be used to calibrate the FWM will be discussed with EPA and Ecology prior to calibration, as discussed in Section 8.0.

Predicted total PCB concentrations in benthic invertebrate tissues were not compared directly to empirical data. As described in the quality assurance project plan (QAPP) for the collection and analysis of benthic invertebrate tissue (Windward 2004), locations for benthic invertebrate tissue sampling were selected to provide good spatial coverage and to represent the full range of total PCB concentrations in sediment. The sampling locations were not selected to provide a representative sample of total PCB tissue concentrations in the benthic invertebrate community throughout the LDW. A tissue-sediment regression was derived from the co-located sediment and benthic invertebrate tissue data (Appendix A), and used to estimate the most appropriate site-specific total PCB tissue concentration for comparison to values predicted by the FWM. The resulting regression equation was then applied to the spatially weighted average concentration (SWAC) of total PCBs in sediment to estimate a representative site-wide total PCB concentration in benthic invertebrate tissues. Details of this approach are presented in Section A.2.4 of Appendix A. SWAC values used both for the LDW-wide model runs as well as the modeling-area-scale runs were based on preliminary IDW interpolations. Subsequent IDW interpolations are likely to result in different values that will be used in the FWM applications for the RI/FS.

Table 3-1. Available empirical total PCB data for target species from LDW tissue sampling areas

Species	Tissue Type	Location	Historical					Phase 2 (2004)					Phase 2 (2005)				
			N	No. per Composite	Total PCBs (µg/kg ww) Min	Max	Avg	N	No. per Composite	Total PCBs (µg/kg ww) Min	Max	Avg	N	No. per Composite	Total PCBs (µg/kg ww) Min	Max	Avg
Dungeness crab	Whole-body[a]	T1	1	3	640	640	640	1	15[b]	1,400	1,400	1,400	1	5[b]	450	450	450
		T2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
		T3	nd	nd	nd	nd	nd	1	15 [b]	1,600	1,600	1,600	1	5[b]	420	420	420
		T4	nd	nd	nd	nd	nd	1	6[b]	1,900	1,900	1,900	1	5[b]	420	420	420
		LDW-wide	1	3	640	640	640	3	6 – 15[b]	1,400	1,900	1,600	3	5[b]	420	450	430
Slender crab	Whole-body[a]	T1	nd	nd	nd	nd	nd	1	16[b]	650	650	650	nd	nd	nd	nd	nd
		T2	nd	nd	nd	nd	nd	2	15[b]	750	800	780	1	10[b]	250	250	250
		T3	nd	nd	nd	nd	nd	1	18[b]	630	630	630	nd	nd	nd	nd	nd
		T4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
		LDW-wide	nd	nd	nd	nd	nd	4	15 – 18[b]	630	800	710	1	10[b]	250	250	250
Shiner surfperch	Whole-body	T1	3	10	350	620	500	6	9 – 10	970	1,830	1,400	6	10	530	960	780
		T2	nd	nd	nd	nd	nd	6	9 – 10	1,260	18,400	4,300	6	10	660	2,000	1,300
		T3	2	1	940	2,100	1,500	6	10	1,280	8,800	3,800	6	10	700	2,400	1,500
		T4	nd	nd	nd	nd	nd	6	10	640	960	800	4	10	540	600	580
		LDW-wide	5	1 – 10	350	2,100	900	24	9 – 10	640	18,400	2,600	22	10	530	2,400	1,100
English sole	Whole-body	T1	nd	nd	nd	nd	nd	6	5	2,700	4,700	3,700	6[c]	5	1,120	2,200	1,600
		T2	nd	nd	nd	nd	nd	6	5	3,300	4,200	3,900	6[c]	5	1,600	2,400	2,000
		T3	nd	nd	nd	nd	nd	6	5	1,320	4,300	2,600	6[c]	5	610	2,200	1,400
		T4	nd	nd	nd	nd	nd	3	5	1,640	1,800	1,700	3[c]	5	910	1,180	1,000
		LDW-wide	nd	nd	nd	nd	nd	21	5	1,320	4,700	3,200	21[c]	5	610	2,400	1,600

Species	Tissue Type	Location	Historical					Phase 2 (2004)					Phase 2 (2005)				
			N	No. per Composite	Total PCBs (µg/kg ww)			N	No. per Composite	Total PCBs (µg/kg ww)			N	No. per Composite	Total PCBs (µg/kg ww)		
					Min	Max	Avg			Min	Max	Avg			Min	Max	Avg
Pacific staghorn sculpin	Whole-body	T1	nd	nd	nd	nd	nd	6	10	580	860	730	1	10	720	720	720
		T2	nd	nd	nd	nd	nd	6	7 – 10	620	1,260	770	1	10	620	620	620
		T3	nd	nd	nd	nd	nd	6	10	810	2,800	1,500	1	10	590	590	590
		T4	nd	nd	nd	nd	nd	6	8 – 10	510	1,300	780	1	10	430	430	430
		LDW-wide	nd	nd	nd	nd	nd	24	7 – 10	510	2,800	950	4	10	430	720	590

[a] Each whole-body crab total PCB concentration was estimated by combining the total PCB concentration in the composite hepatopancreas sample with the total PCB concentration in the corresponding edible meat composite samples (one or more samples) that were collected from the same crabs. Therefore, a single whole-body crab total PCB concentration was calculated for each composite hepatopancreas sample. Whole-body total PCB concentrations were calculated assuming 69% (by weight) edible meat and 31% hepatopancreas, based on the relative weights of these tissues in a 16.6-cm Dungeness crab dissected by Windward in 2004.

[b] This number of crabs per composite sample represents the number of hepatopancreas samples per whole-body calculated composite sample. The number of edible meat samples ranged from five to fifteen per whole-body calculated composite sample.

[c] One half of the samples from each tissue sampling area were calculated as the weighted average of fillet and remainder composite samples collected for comparison between fillet and whole-body total PCB concentrations, as specified in the quality assurance project plan (QAPP) (Windward 2005c) and the data report (Windward 2006 in prep).

N – Number of composite samples

nd – no data

No empirical tissue data are available for phytoplankton, zooplankton, or juvenile fish. Concentrations of PCBs in tissues of these organism groups were modeled to estimate dietary concentrations for other modeled species.

3.2 RESULTS

The total PCB concentrations in all modeled target species were predicted within a factor of 3.2 of empirical data (Table 3-2). As discussed in FWM deliverable 2, for the initial calibration, a performance criterion of predictions "within a factor of 5 of empirical data" (< 5 and > -5 for all SPAFs) was presented. A model performance criterion of "within a factor of 5" for all species was set for Gobas models on the Fox River (ThermoRetec 2001) and Hudson River (TAMS 2000). The goal for the final calibration phase was established as "within a factor of 3" of empirical tissue data. A model parameterization that at least meets the model performance criterion (i.e., within a factor of 5) will be used in the RI/FS.

Thus, the model performance criterion of "within a factor of 5 of empirical data" was met in the preliminary runs of the FWM at the scale of the entire waterway. Furthermore, the model performance goal of "within a factor of 3," outlined in FWM Memorandum 2 was met for all species but one (i.e., Pacific staghorn sculpin). Despite these initial successes, additional steps will be taken with the FWM to further refine predictions at the LDW-wide or smaller scale. These steps are discussed in Sections 8.0 and 9.0.

Table 3-2. Preliminary model run results for the LDW-wide scale compared to mean empirical total PCB concentrations (all datasets combined)

Species	Mean Empirical Total PCB Concentration (µg/kg ww)[a]	Model-Predicted Total PCB Concentration (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Various phytoplankton	nd	47	na	na	na
Various zooplankton	nd	73	na	na	na
Benthic invertebrates	170[d]	311	83%	1.8	+
Juvenile fish	nd	1,315	na	na	na
Slender crab	620	893	44%	1.4	+
Dungeness crab	980	2,705	176%	2.8	+
Pacific staghorn sculpin	900	2,921	225%	3.2	+
Shiner surfperch	1,800	1,986	10%	1.1	+
English sole	2,300	2,752	20%	1.2	+

Species	Mean Empirical Total PCB Concentration (µg/kg ww)[a]	Model-Predicted Total PCB Concentration (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
All Species					
Mean			93%	1.9	
Maximum			225%	3.2	
Minimum			10%	1.1	

[a] Mean empirical data are represented by an average of all three empirical datasets over all LDW tissue samples for a given species. Data are discussed further in Appendix A, Section A.2.3.

[b] The percent difference is the difference between the predicted and empirical tissue chemical concentrations divided by the empirical tissue chemical concentration.

[c] The species predictive accuracy factor (or SPAF) is the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

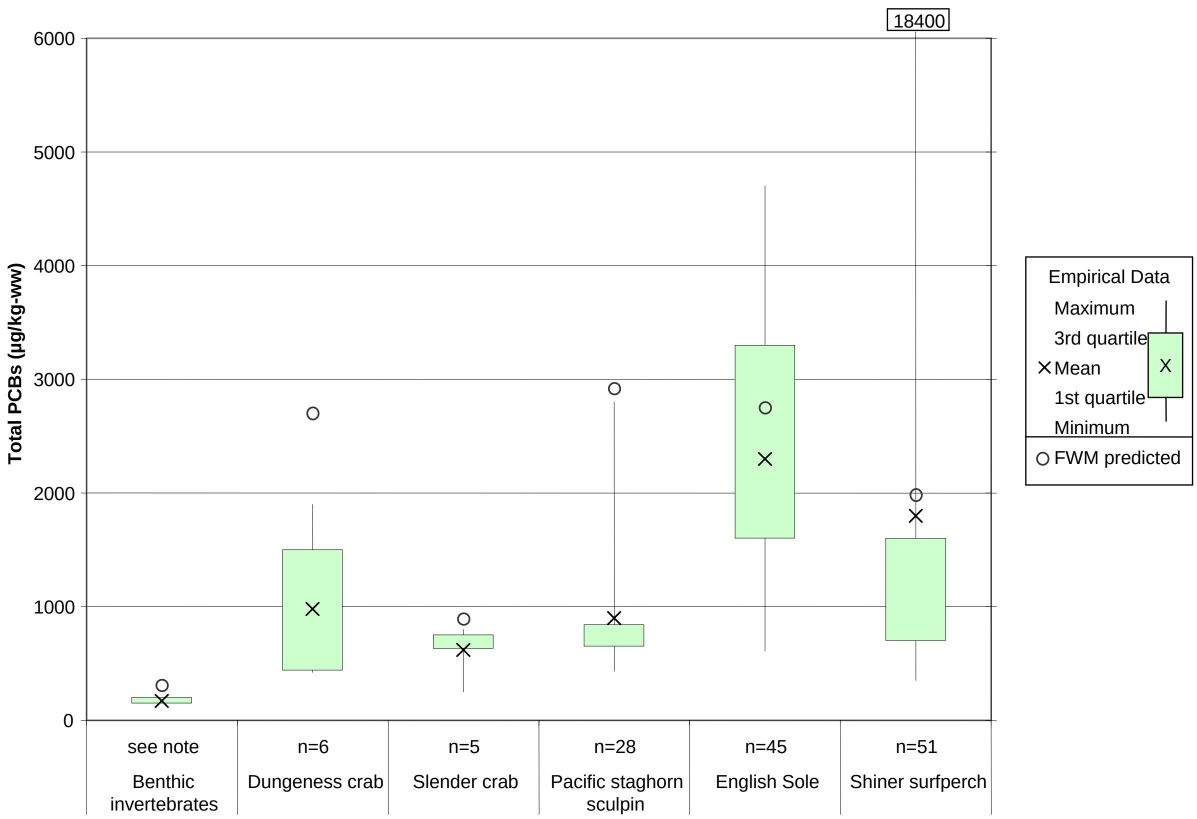
[d] Concentration predicted from sediment-tissue total PCB regression at an LDW-wide total PCB SWAC of 250 µg/kg dw.

na – not applicable

nd – no data

All predicted concentrations were greater than the mean empirical data (all datasets combined) for each species (Figure 3-1). Thus, based on the initial set of parameters, the FWM is consistently over-predicting by varying degrees or the LDW-wide scale. Predictions for shiner surfperch, English sole, and slender crab were within a factor of 1.5 of empirical data. Implications of using different datasets are discussed in Section 8.0.

Figure 3-1. Preliminary model run results for the LDW-wide scale compared to empirical total PCB concentrations (all datasets combined)



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the LDW-wide SWAC for total PCBs.

Preliminary FWM results were also compared to the 2004 and 2005 datasets separately because the total PCB concentrations in tissue were consistently lower in 2005 than in 2004 (Tables 3-1 and 3-3 and Figure 3-2). The model performance when compared to the 2004 dataset was generally similar to that for all datasets combined, although some species (shiner surfperch and English sole) were slightly underpredicted rather than slightly overpredicted. The model performance when compared to the 2005 dataset is similar to that for the combined datasets for shiner surfperch and English sole. However, the model-predicted total PCB concentrations for slender crab, Dungeness crab, and Pacific staghorn sculpin were much higher than the empirical data from 2005 (with SPAFs ranging from 3.6 to 6.3). Implications of using different datasets are discussed in Section 8.0.

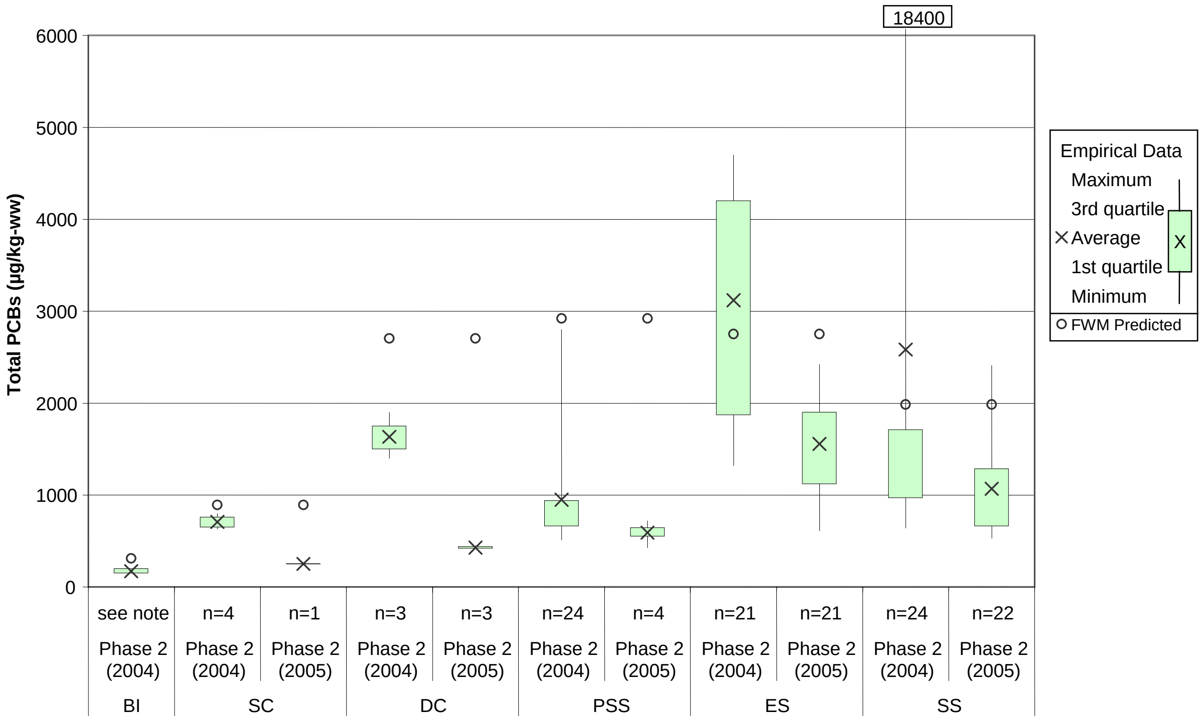
Table 3-3. Preliminary fish and crab model run results for the LDW-wide scale compared to 2004 and 2005 mean empirical total PCB concentrations

Species	Phase 2 (2004) Empirical Total PCB Concentration (µg/kg ww)	Phase 2 (2005) Empirical Total PCB Concentration (µg/kg ww)	Model-Predicted Total PCB Concentration (µg/kg ww)	2004 Data			2005 Data		
				% Difference[a]	Species Predictive Accuracy Factor[b]	Overprediction (+) Underprediction (-)	% Difference[a]	Species Predictive Accuracy Factor[b]	Overprediction (+) or Underprediction (-)
Slender crab	710	250	893	26%	1.3	+	257%	3.6	+
Dungeness crab	1,600	430	2,705	69%	1.7	+	529%	6.3	+
Pacific staghorn sculpin	950	590	2,921	207%	3.1	+	395%	5.0	+
Shiner surfperch	2,600	1,100	1,986	-24%	1.3	-	81%	1.8	+
English sole	3,100	1,600	2,752	-11%	1.1	-	72%	1.7	+
All Species									
Mean				53%	1.7		267%	3.7	
Maximum				207%	3.1		529%	6.3	
Minimum				-11%	1.1		72%	1.7	

[a] The percent difference is the difference between the predicted and empirical tissue chemical concentrations divided by the empirical tissue chemical concentration.

[b] The SPAF is the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

Figure 3-2. Preliminary model run results for the LDW-wide scale compared to Phase 2 (2004 and 2005) empirical total PCB concentrations



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the LDW-wide SWAC for total PCBs.

BI – benthic invertebrates

SC – slender crab

DC – Dungeness crab

PSS – Pacific staghorn sculpin

ES – English sole

SS – shiner surfperch

4.0 Dietary Scenarios

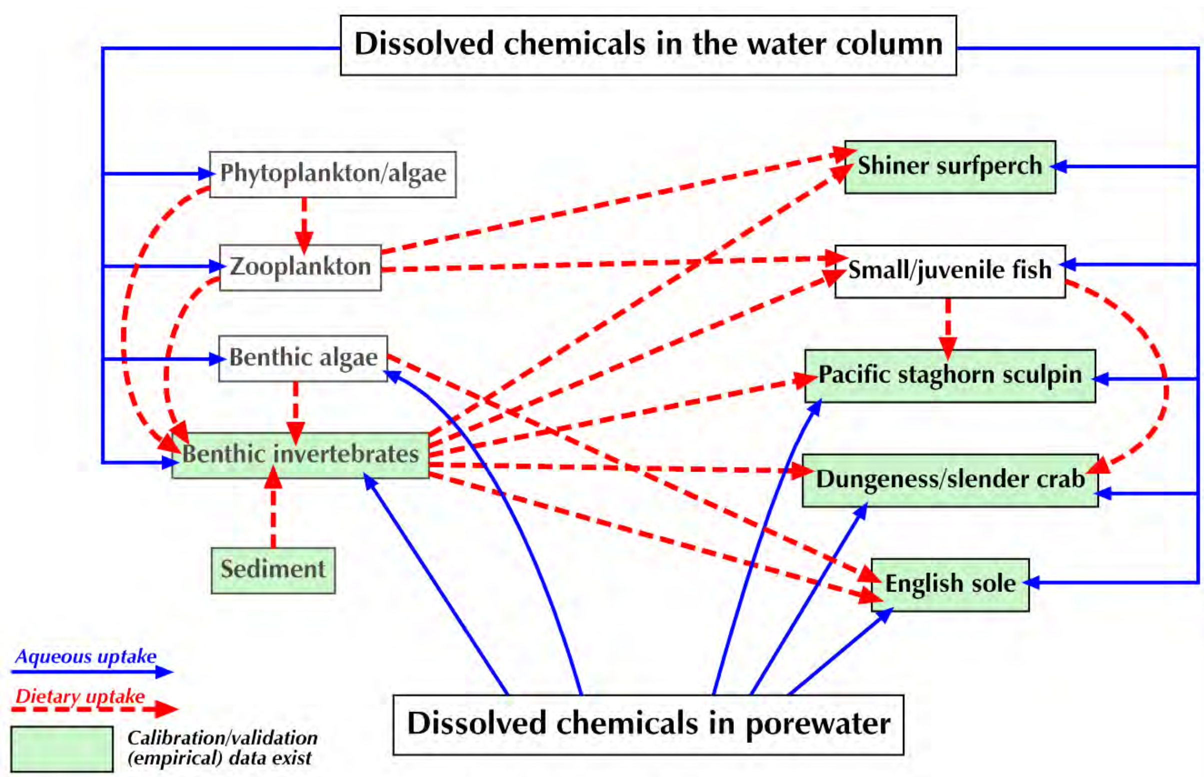
Up to four plausible dietary scenarios for each target species were used as model inputs on an LDW-wide scale. Different dietary scenarios were input because there is uncertainty regarding the diets of the species being modeled and because dietary assumptions can be important in model performance. The results of these preliminary model runs will be assessed, in consultation with EPA and Ecology, to select a dietary scenario for use in the model runs for the Phase 2 RI (see Sections 8.0 and 9.0).

Diets of fish and crabs are difficult to characterize because they vary by location, season, age, and size class. Diets are also difficult to quantify in terms of mass or volume fractions because stomach content analyses favor items that are digested more slowly. In addition, certain feeding habits, such as scavenging, or extensive mastication of the food items, makes food-item species identification difficult.

Thus, simplifying assumptions must be made when estimating diets because ecosystems are complex and dynamic environments that cannot be fully characterized in a quantitative manner without a high level of uncertainty. Simplified food web models and dietary assumptions were developed for the three fish species and two crab species (Figure 4-1 as an example). Various boxes or "compartments" are included in the dietary scenarios, each representing a group of species or abiotic media that may influence chemical transfer and bioaccumulation.

Ecology, behavior, feeding observation studies, stomach content analyses were considered in the creation of the simplified uptake routes and plausible dietary scenarios developed to reflect average diets. These scenarios are discussed in this section (see Appendix A, Section A.3.1).

Figure 4-1. Simplified dietary and aqueous uptake routes for LDW biota (dietary scenario 1 as an example)



4.1 METHODS

Dietary items of the modeled species are restricted to the model compartments (e.g., benthic invertebrates, sediment) selected for the FWM. Each compartment modeled may be used as a surrogate dietary item for the items actually consumed by modeled species. It should be noted, however, that a given modeled species cannot have a fraction of its diet from its own model compartment (e.g., benthic invertebrates are not allowed to consume benthic invertebrates if there is only one benthic invertebrate compartment). This is a limitation of the current version of the model, which is in Excel®. In addition to compartments for target species, model compartments representing dietary components include sediment, phytoplankton, zooplankton, benthic invertebrates, and juvenile fish, as specified in FWM Memorandum 1 (Windward 2005a). In some cases, where a tissue type reported in the literature to be consumed by a modeled species is lacking in the LDW database, the surrogate tissue was selected. For example, Pacific staghorn sculpin are expected to eat shrimp, but measured or estimated concentrations in shrimp are not available, so the fraction of shrimp in the sculpin diet was substituted with estimates of PCBs in either benthic invertebrate tissue (dietary scenario 1) or in zooplankton (dietary scenario 2).

Four different dietary scenarios were modeled. The FWM was run with the initial set of input values held constant while dietary assumptions were changed for each scenario run.

4.1.1 Fish and crab dietary scenarios

Four dietary scenarios are presented for the fish and crab species modeled (Table 4-1. Appendix Table A-2-3). In general, dietary scenarios 1 and 2 were statistical estimates of the organisms' diets based on stomach content analyses presented in the literature. Dietary scenario 2 was the same as dietary scenario 1, except that crab or shrimp prey items in the dietary studies were represented by the zooplankton compartment instead of the benthic invertebrates compartment. A surrogate prey item was needed for juvenile crabs and shrimp because they are not included as a model compartment in the simplified food web developed for the LDW, primarily because no data were available for these species/life stages in the LDW. Zooplankton are a reasonable surrogate because zooplankton, juvenile crabs, and especially shrimp are primarily exposed to PCBs in the water column versus other benthic invertebrates that receive most of their exposure through association with sediment. All target fish and crab species are opportunistic feeders and may consume juvenile crab and/or shrimp to some extent. Dietary scenario 3 was created from studies that considered organism ecology and behavior in addition to the literature presenting stomach content analyses. Dietary scenario 3 was the only scenario that included sediment as a fraction of the diet, and all fish and crab species were therefore assumed to consume 10% sediment by weight for this scenario. Dungeness crabs were the only species with a fourth dietary scenario. This scenario was based on an additional literature source that quantified stomach contents using a different metric (Gotshall 1977).

Table 4-1. Fraction of dietary surrogates consumed by modeled fish and crab species in the four dietary scenarios investigated

Species	Dietary Surrogate	Fraction of Diet by Scenario[a]				Sources
		Scenario 1[b,c]	Scenario 2[b,d]	Scenario 3[e]	Scenario 4[c]	
Dungeness crab	zooplankton	0	0.48	0	0	Stevens et al. (1982) for scenarios 1 and 2; Gotshall (1977) for scenario 4
	benthic invertebrates	0.63	0.16	0.75	0.75	
	juvenile fish	0.37	0.36	0.15	0.25	
	sediment	0	0	0.10	0	
	total	1.0	1.0	1.0	1.0	
Slender crab	zooplankton	0	0.12	0	na	Bernard (1979)
	benthic invertebrates	0.99	0.87	0.90	na	
	juvenile fish	0.01	0.01	0	na	
	sediment	0	0	0.10	na	
	total	1.0	1.0	1.0	na	
Juvenile fish	zooplankton	0.07	0.17	0.05	na	Fresh et al. (1979); Miller et al. (1977); Wingert et al. (1979)
	benthic invertebrates	0.93	0.83	0.85	na	
	sediment	0	0	0.10	na	
	total	1.0	1.0	1.0	na	
Shiner surfperch	zooplankton	0.14	0.21	0.10	na	Fresh et al. (1979); Miller et al. (1977); Wingert et al. (1979)
	benthic invertebrates	0.86	0.79	0.80	na	
	sediment	0	0	0.10	na	
	total	1.0	1.0	1.0	na	
English sole	phytoplankton/ algae	0.08	0.07	0	na	Fresh et al. (1979); Wingert et al. (1979)
	zooplankton	0	0.05	0	na	
	benthic invertebrates	0.92	0.88	0.90	na	
	sediment	0	0	0.10	na	
	total	1.0	1.0	1.0	na	

Species	Dietary Surrogate	Fraction of Diet by Scenario[a]				Sources
		Scenario 1[b,c]	Scenario 2[b,d]	Scenario 3[e]	Scenario 4[c]	
Pacific staghorn sculpin	zooplankton	0	0.37	0.25	na	Fresh et al. (1979); Miller et al. (1977); Wingert et al. (1979)
	benthic invertebrates	0.56	0.19	0.50	na	
	fish	0.44	0.44	0.15	na	
	sediment	0	0	0.10	0	
	total	1.0	1.0	1.0	na	

a Average over all studies.

b Unidentifiable prey items excluded from calculation.

c Crab and shrimp prey were assigned to the benthic invertebrate compartment.

d Crab and shrimp prey were assigned to the zooplankton compartment.

e Integration of available data; 10% sediment consumption was assumed. For Pacific staghorn sculpin, crab and shrimp prey were assigned to the zooplankton compartment.

na – not available; no scenario investigated

4.1.2 Benthic invertebrate dietary scenarios

Benthic invertebrate communities in the LDW are composed of many species from many phyla within multiple feeding guilds. Dominant feeding guilds for each taxon were assigned using the literature. Assigned feeding guilds included deposit feeders (including detritivores), suspension feeders, and carnivores. Feeding guilds were assigned to each phylum (LDW subtidal samples only), and then the percent of each sample represented by each feeding guild was determined based on the percent by weight that each phylum represented of the total. Average percent feeding guilds were calculated for all 10 LDW subtidal benthic samples. Because the FWM does not allow modeled species to eat tissue within the same compartment (i.e., have a fraction of their diet from their own model compartment), and only one benthic invertebrate compartment was created, sediment was used as a surrogate for benthic invertebrate prey consumed by carnivores. A "detritus" compartment was not modeled because there were insufficient data to generate values for such a compartment. Sediment was used as a surrogate for detritus consumed by deposit feeders. Dietary scenario 1 was constructed assuming that carnivores consumed 100% sediment, suspension feeders consumed 30% zooplankton and 70% phytoplankton/algae, and deposit feeders consumed 100% sediment. For a more detailed description of methods used to generate dietary scenarios for benthic invertebrates, see Appendix A, Section A.2.5. For specific dietary scenario information, see Appendix A, Table A-2-3.

Dietary scenario 2 assigned different dietary surrogates for the carnivore feeding guild. Specifically, benthic invertebrate carnivores (such as the polychaetes *Glycinde armigera* and *Eteone californica*) were assigned the dietary surrogates of sediment and zooplankton (50% for each) compared to 100% sediment in dietary scenario 1.

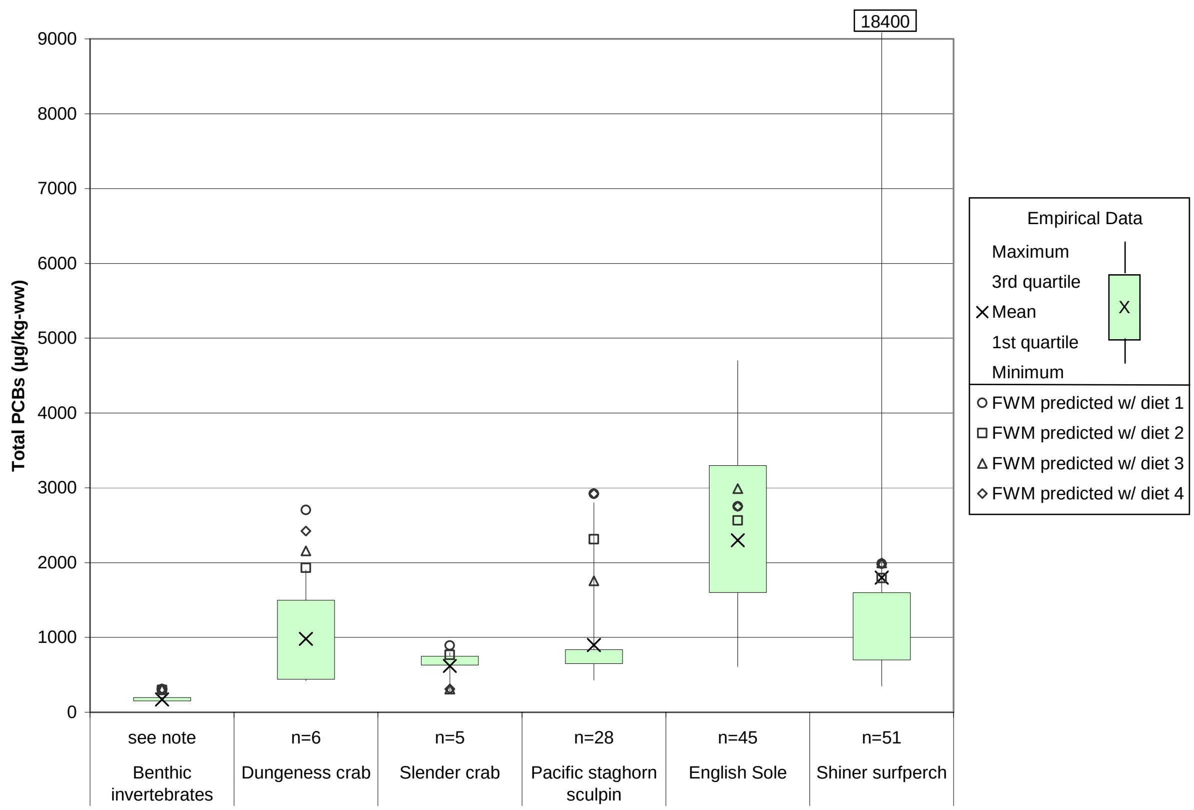
Zooplankton were used as a surrogate prey that could be exposed to PCBs primarily through the water column

See Appendix A for details on the creation of fish and crab diets (Section A.3.1) and benthic invertebrate diets (Section A.2.5).

4.2 RESULTS

Of the four dietary scenarios, dietary scenario 2 resulted in the lowest SPAFs for all species, except Pacific staghorn sculpin, for which dietary scenario 3 performed best (Figure 4-2, Tables 4-1 and 4-2). Dietary scenario 2 used zooplankton as a surrogate for shrimp and juvenile crab, which is a better approximation than using benthic invertebrates as a surrogate (as was done for all other dietary scenarios with the exception of dietary scenario 3 for Pacific staghorn sculpin). The diet in dietary scenario 3 assumed lower fish consumption than the other scenarios, classified shrimp as zooplankton, and assumed sculpin ingest some sediment incidentally.

Figure 4-2. Preliminary model run results for the LDW-wide scale, assuming various dietary scenarios, compared to empirical total PCB concentrations (all datasets combined)



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the LDW-wide SWAC for total PCBs.

Table 4-2. Preliminary LDW-wide model results compared to empirical total PCB concentrations (all datasets combined) for four dietary scenarios

Species[a]	Mean Empirical Total PCBs in Tissue (µg/kg ww)	Model-Predicted Total PCBs in Tissue (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Dietary Scenario 1					
Benthic invertebrates	170	311	83%	1.8	+
Juvenile fish	nd	1,315	na	na	na
Slender crab	620	893	44%	1.4	+
Dungeness crab	980	2,705	176%	2.8	+
Pacific staghorn sculpin	900	2,921	225%	3.2	+
Shiner surfperch	1,800[c]	1,986	10%	1.1	+
English sole	2,300	2,752	20%	1.2	+
All Species					
Mean			93%	1.9	
Maximum			225%	3.2	
Minimum			10%	1.1	
Dietary Scenario 2					
Benthic invertebrates	170	296	**74%**	**1.7**	+
Juvenile fish	nd	1,164	na	na	na
Slender crab	620	767	**24%**	**1.2**	+
Dungeness crab	980	1,930	**97%**	**2.0**	+
Pacific staghorn sculpin	900	2,314	157%	2.6	+
Shiner surfperch	1,800	1,794	**-0.3%**	**1.0**	-
English sole	2,300	2,565	**12%**	**1.1**	+
All Species					
Mean			**61%**	**1.6**	
Maximum			**157%**	**2.6**	
Minimum			**-0.3%**	**1.0**	
Dietary Scenario 3					
Benthic invertebrates [d]	170	311	83%	1.8	+
Juvenile fish	nd	1,303	na	na	na
Slender crab	620	880	42%	1.4	+
Dungeness crab	980	2,157	120%	2.2	+
Pacific staghorn sculpin	900	1,757	**95%**	**2**	+
Shiner surfperch	1,800	1,998	11%	1.1	+
English sole	2,300	2,990	30%	1.3	+

Species[a]	Mean Empirical Total PCBs in Tissue (µg/kg ww)	Model-Predicted Total PCBs in Tissue (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
All Species					
Mean			64%	1.6	
Maximum			120%	2.2	
Minimum			11%	1.1	
Dietary Scenario 4[e]					
Dungeness crab	980	2,421	147%	2.5	+

[a] Phytoplankton have no diet and zooplankton only have one dietary scenario, thus they are not included in this table.

[b] Percent difference is the difference between the predicted and empirical tissue chemical concentrations divided by the empirical tissue chemical concentration.

[c] The SPAF is defined as the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

[d] Benthic invertebrates were run with dietary assumptions from scenario 1 in scenario 3**.**

[e] Only Dungeness crab has a fourth dietary scenario.

Bold values indicate the best-performing scenarios.

na – not applicable

nd – no data

ww – wet weight

5.0 Sensitivity Analyses

The analysis of model sensitivity involves the investigation of how changes in input parameters affect model output and identifies parameters that most influence model predictions. This analysis provides the basis for determining calibration parameters and for selecting parameters to be evaluated in the uncertainty analysis. Future calibration efforts will focus on the parameters to which the model is most sensitive to determine if values for these parameters should be reassessed and altered, if appropriate, to improve model performance.

Following methods outlined in FWM Memorandum 2 (Windward 2005b), model sensitivity was investigated using two analyses (see Appendix B, Table B-1-1):

- reducing the values of 29 input parameter values by 10%
- altering the value of each of 21 parameters according to its plausible range (using upper- and lower-bound estimates of the mean)

In order to investigate how sensitive the FWM is to total PCBs concentrations in the water column (C_{WT}), a series of water scenarios were run (Section 5.2). Sensitivity of the FWM to C_{WT} is being addressed in more detail than other input parameters to provide additional information to decide whether additional water data should be collected in summer 2006 to support the FWM.

5.1 10% Reduction and Upper- and Lower-Bound Sensitivity Analyses

5.1.1 Methods

In the first analysis (reduction of input parameter values by 10%), all parameter values were changed equally, regardless of the parameter's inherent variability or uncertainty about parameter values. This analysis identified the parameters to which the model output is most sensitive as a result of the mathematical formulation of the FWM. The second analysis (altering input parameter values to the upper and lower bound estimates of the mean) evaluated how known or estimated plausible ranges for parameter values influenced model predictions. This second analysis helped identify the parameters to which the model output is most sensitive as a result of potential variability in the parameter values associated with uncertainty or natural variability in combination with the FWM's mathematical formulation. The plausible range was either generated from empirical data or estimated from literature (see Appendix B). Thus, the plausible range, particularly in the case of site-specific data, such as lipid content, reflects the variability of collected empirical data, but does not account for the full range of true variability or for uncertainty (due to measurement error, etc.)

For both sensitivity analyses, results were evaluated using the species percent difference (SPD). The SPD is a measure of the difference between the prediction for a given species using the initial set of parameter values and the prediction with a specific parameter value altered. The SPD metric is defined as follows:

$$SPD = \frac{NPTC - IPTC}{IPTC} \times 100$$ **Equation 5-1**

where:

SPD = species percent difference
NPTC = new predicted tissue concentration
IPTC = initial predicted tissue concentration

Changes in parameter values that increase the predicted tissue concentration will yield a positive SPD and those that decrease the predicted tissue concentration will yield a negative SPD.

In both types of sensitivity analyses, the FWM was run many times, changing one parameter value at a time. The 10% reduction analysis was conducted for most input parameters (29 parameters, see Appendix B, Table B-1-1), and the plausible range analysis was conducted for input parameters for which site-specific or literature empirical range information was available (21 parameters, see Appendix B, Table B-1-1). The complete list of parameters tested and the values and process for selection of values used in each analysis are presented in Appendix B.

For the 10% sensitivity analysis, results were ranked by maximum SPD, and any parameter with a maximum SPD of 8% or more for any species was selected for inclusion in the uncertainty analysis. The threshold of an 8% change in predicted tissue concentration (for any one species) with a 10% change in parameter value was selected, based on best professional judgment, to ensure that parameters to which the model is moderately sensitive are included. A greater than 1:1 response between parameter value change and model prediction change is considered highly sensitive (Arnot 2006).

Also identified were parameters that, when run at the upper or lower end of their plausible range, results in a percentage change that is substantial relative to the change caused by other parameters or relative to the magnitude of change in the input value. These parameters should be considered for evaluation in the uncertainty analysis. In order to select parameters for the uncertainty analysis, results of the plausible range sensitivity analysis were ranked by maximum SPD and the distribution of results was evaluated to see if any patterns or break points arose from the results. Parameters were also ranked according to a relative response ratio (SPD divided by percent change in parameter value). This metric can be compared to the 10% sensitivity analysis to see if percent changes in model predictions were the same for small or large changes in parameter values. All tables in Section 5.1.2 rank results for target species only. Maximum responses for all species are ranked in Appendix B (Table B-3-2).

5.1.2 Results

This section presents a summary of the results of the two sensitivity analyses performed. Full results are presented in Appendix B.

5.1.2.1 Selection of parameters for inclusion in the uncertainty analysis

The results of the 10% reduction sensitivity analysis are presented in Table 5-1. Any parameter identified in the 10% sensitivity analysis as having a maximum species percent difference (SPD) equal to or greater than 8% was included in the uncertainty analysis (see Section 6.0). Thus, the top nine parameters in Table 5-1 were screened into the uncertainty analysis.[7] An exception to the 8% rule was made for K_{OW}. It was selected for inclusion in the uncertainty analysis because it was close to the 8% threshold (7% SPD for Pacific staghorn sculpin), and because it is a key chemical-specific parameter with substantial uncertainty. An additional exception is that the food ingestion rate (G_D), with a maximum SPD of 14%, was not included in the uncertainty analysis. G_D is calculated by an equation within the FWM, and Crystal Ball®, the software used to run the Monte Carlo uncertainty analysis (Section 6.0), cannot test parameters defined by equations.

Table 5-1. Species percent differences for fish and crab species based on a 10% reduction to FWM input parameters

Parameter	Maximum SPD	Species with Maximum Change	Minimum SPD	Mean SPD
Dietary absorption efficiency of lipids (alpha)	-24%	PSS	-10%	-14%
Water content	18%	SC	2%	5%
Lipid density	17%	PSS	10%	13%
Food ingestion rate (G_D)	-14%	PSS	-10%	-12%
Lipid content	-14%	PSS	-9%	-11%
Dissolved oxygen (DO)	-11%	PSS	-7%	-9%
Water column temperature	-10%	PSS	-6%	-8%
Dietary absorption efficiency of NLOM (beta)	-9%	DC	-6%	-7%
Sediment PCB concentration	-8%	SC	-8%	-8%
K_{OW} (octanol water partition coefficient)	-7%	PSS	-4%	-5%
Growth rate constant (k_G)	4%	ES	2%	3%
Sediment organic carbon (OC_{sed})	4%	ES	4%	4%
β (MAF, proportionality constant for sorption capacity of NLOM)	-4%	SC	-1%	-2%

[7] When the responses of phytoplankton, zooplankton, and benthic invertebrates are included in the ranking (Appendix B, Table B-3-1), PCB water concentration was also above the 8% threshold.

PARAMETER	MAXIMUM SPD	SPECIES WITH MAXIMUM CHANGE	MINIMUM SPD	MEAN SPD
PCB concentration in porewater	-3%	ES	-2%	-3%
Organism weight	-3%	PSS	-2%	-2%
Porewater, fraction ventilated	-2%	ES	-2%	-2%
Water PCB concentration	-2%	SS	-2%	-2%
β_{OC} (proportionality constant for sorption capacity of NLOC)	1.8%	ES	1.2%	1.3%
DOC concentration in water column	0.7%	SS	0.6%	0.6%
D_{DOC} (disequilibrium factor for DOC partitioning)	0.7%	SS	0.6%	0.6%
α_{DOC} (proportionality constant for DOC)	0.7%	SS	0.6%	0.6%
k_M (rate constant for PCB metabolic transformation)	0.5%	ES	0.2%	0.3%
POC concentration in water column	0.41%	SS	0.32%	0.37%
D_{POC} (disequilibrium factor for POC partitioning)	0.41%	SS	0.32%	0.37%
α_{POC} (proportionality constant for POC)	0.41%	SS	0.32%	0.37%
A (phytoplankton/algae uptake constant)	0.07%	ES	0.04%	0.05%
B (phytoplankton/algae uptake constant)	0.002%	ES	0.001%	0.001%
Dietary absorption efficiency of water (chi)	-0.0003%	DC/SC	-0.0002%	-0.0003%
Water density	-0.000041%	PSS	-0.00001%	-0.00001%

DC – Dungeness crab

ES – English sole

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

SPD – species percent difference

DOC – dissolved organic carbon

POC – particulate organic carbon

Results for the plausible range sensitivity analysis using upper- and lower-bound parameter estimates are presented in Tables 5-2 and 5-3. Table 5-2 presents the variability in model output as a function of variability in each input parameter. Table 5-3 presents the results ranked according to the relative response ratio. By normalizing the magnitude of response to the magnitude of change in input values, this ranking provides insight into the sensitivity of the FWM similar to the 10% change sensitivity analysis. All parameters selected based on the 10% change sensitivity analysis were also identified in the plausible range analysis. In addition, some parameters, beyond those selected in the 10% change analysis, were identified in the plausible range analysis, such as water column temperature and water PCB concentration. The relative response ratio results for the plausible range analysis were consistent with the 10% change sensitivity in that the all parameters with a maximum SPD of 8% or greater for the 10% change sensitivity analysis (Table 5-1, equivalent to a relative response ratio of 0.8 or greater) had a relative response ratio of 0.8 or greater in plausible range analysis (Table 5-3).

Table 5-2. Results of the plausible range sensitivity analysis for predicted fish and crab total PCB concentrations

Parameter	Maximum SPD	Species with Maximum Change	Minimum SPD	Mean SPD
Dietary absorption efficiency of lipids (alpha) (upper)	67%	DC	1%	20%
Dietary absorption efficiency of lipids (alpha) (lower)	-54%	DC	-3%	-19%
Dietary absorption efficiency of NLOM (beta) (lower)	-43%	DC	-22%	-29%
Sediment PCB concentration (upper)	42%	SC	40%	41%
Sediment PCB concentration (lower)	-42%	SC	-40%	-41%
Lipid content (upper)	33%	DC	11%	16%
Lipid content (lower)	-31%	DC	-11%	-16%
Dietary absorption efficiency of NLOM (beta) (upper)	28%	DC	12%	18%
Weight (lower)	-25%	DC	-16%	-19%
Lipid density (lower)	20%	PSS	12%	15%
Porewater, fraction ventilated (lower)	-17%	ES	-16%	-17%
Weight (upper)	17%	DC	13%	15%
Lipid density (upper)	-15%	PSS	-9%	-12%
Water column temperature (upper)	12%	PSS	8%	10%
Water column temperature (lower)	-12%	PSS	-8%	-9%
Water PCB concentration (upper)	11%	SS	9%	10%
β (MAF – proportionality constant for sorption capacity of NLOM) (upper)	11%	SC	3%	6%
β (MAF – proportionality constant for sorption capacity of NLOM) (lower)	-11%	SC	-4%	-6%
Dissolved oxygen (DO) (lower)	-10%	PSS	-6%	-8%
Dissolved oxygen (DO) (upper)	10%	PSS	6%	8%
Porewater, fraction ventilated (upper)	8%	ES	6%	6%
α_{DOC} (proportionality constant for DOC) (upper)	-7%	SS	-5%	-6%
K_{OW} (lower)	-6%	PSS	-3%	-5%
K_{OW} (upper)	6%	PSS	3%	4%
α_{DOC} (proportionality constant for DOC) (lower)	6%	SS	4%	5%
Water PCB concentration (lower)	-5%	SS	-4%	-5%
α_{POC} (proportionality constant for POC) (upper)	-5%	SS	-4%	-4%
Water content (lower)	4%	JF	0%	2%
Water content (upper)	-4%	SC	0%	-2%

Parameter	Maximum SPD	Species with Maximum Change	Minimum SPD	Mean SPD
Sediment organic carbon (OC_{sed}) (lower)	3%	ES	3%	3%
α_{POC} (proportionality constant for DOC) (lower)	3%	SS	2%	2%
POC concentration in water column (lower)	2%	SS	2%	2%
Sediment organic carbon (OC_{sed}) (upper)	-1.9%	ES	-1.8%	-1.8%
POC concentration in water column (upper)	-1.5%	SS	-1.2%	-1.4%
DOC concentration in water column (lower)	1.4%	SS	1.0%	1.2%
DOC concentration in water column (upper)	-0.91%	SS	-0.71%	-0.81%
A (phytoplankton/algae uptake constant) (lower)	0.26%	ES	0.15%	0.19%
A (phytoplankton/algae uptake constant) (upper)	-0.22%	ES	-0.13%	-0.16%
B (phytoplankton/algae uptake constant) (lower)	0.010%	ES	0.006%	0.008%
B (phytoplankton/algae uptake constant) (upper)	-0.010%	ES	-0.006%	-0.008%
Water density (upper) (seawater)	0.000007%	PSS	0.000001%	0.000002%

DC – Dungeness crab

ES – English sole

JF – juvenile fish

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

SPD – species percent difference

DOC – dissolved organic carbon

POC – particulate organic carbon

Table 5-3. Relative response ratio for upper and lower bound sensitivity analyses for fish and crab species

Parameter	Relative Response Ratio		Response to Changes in Input Values			% Change in Parameter Input Values	
	Maximum[a]	Mean[b]	Maximum SPD	Species with Maximum SPD	Mean SPD	Mean	Maximum[c]
Dietary absorption efficiency of lipids (alpha) (upper)	2.4	0.9	67%	DC	20%	23%	28%
Water content (upper)	-2.2	-1.3	-4%	SC	-2%	2%	2%
Lipid density (lower)	1.8	-1.4	-20%	PSS	15%	-11%	
Lipid density (upper)	-1.4	-1.1	-15%	PSS	-12%	11%	
Dissolved oxygen (DO) (upper)	1.1	0.9	10%	PSS	8%	9%	
Dissolved oxygen (DO) (lower)	1.1	0.9	-10%	PSS	-8%	-9%	
Water column temperature (upper)	1.1	0.9	12%	PSS	10%	11%	

Parameter	Relative Response Ratio		Response to Changes in Input Values			% Change in Parameter Input Values	
	Maximum[a]	Mean[b]	Maximum SPD	Species with Maximum SPD	Mean SPD	Mean	Maximum[c]
Dietary absorption efficiency of NLOM (beta) (upper)	1.0	1.1	28%	DC	18%	17%	28%
Water column temperature (lower)	1.0	0.7	-12%	PSS	-9%	-12%	
Lipid content (upper)	0.9	0.9	33%	DC	16%	18%	39%
Sediment PCB concentration (lower)	0.8	0.8	-42%	SC	-41%	-50%	
Sediment PCB concentration (upper)	0.8	0.8	42%	SC	41%	50%	
Lipid content (lower)	0.8	1.0	-31%	DC	-16%	-16%	-39%
Water content (lower)	0.7	-1.1	-4%	JF	2%	-2%	-6%
K_{OW} (lower)	0.7	0.6	-6%	PSS	-5%	-9%	
Dietary absorption efficiency of lipids (alpha) (lower)	0.7	0.4	-54%	DC	-19%	-52%	-80%
K_{OW} (upper)	0.6	0.4	6%	PSS	4%	10%	
Dietary absorption efficiency of NLOM (beta) (lower)	0.5	0.8	-43%	DC	-29%	-36%	-80%
β (MAF - proportionality constant for sorption capacity of NLOM) (lower)	0.4	0.2	-11%	SC	-6%	-29%	
β (MAF - proportionality constant for sorption capacity of NLOM) (upper)	0.4	0.2	11%	SC	6%	29%	
OC_{sed} (lower)	-0.4	-0.4	3%	ES	3%	-8%	
Porewater, fraction ventilated (lower)	0.3	0.3	-17%	ES	-17%	-55%	-50%
OC_{sed} (upper)	-0.3	-0.3	-1.9%	ES	-1.80%	6%	
Weight (lower)	0.3	0.7	-25%	DC	-19%	-29%	-77%
Weight (upper)	0.3	0.3	17%	DC	15%	57%	55%
Water PCB concentration (lower)	0.2	0.2	-5%	SS	-5%	-25%	
Water PCB concentration (upper)	0.2	0.18	11%	SS	10%	55%	
α_{DOC} (proportionality constant for DOC) (lower)	0.1	-0.08	-6%	SS	5%	-63%	
Porewater, fraction ventilated (upper)	0.08	0.08	8%	ES	6%	75%	100%
DOC (lower)	0.08	-0.07	-1.4%	SS	1.20%	-18%	
DOC (upper)	0.07	-0.06	0.91%	SS	-0.81%	14%	
α_{POC} (proportionality	-0.05	-0.03	3%	SS	2%	-60%	

	Relative Response Ratio		Response to Changes in Input Values			% Change in Parameter Input Values	
Parameter	Maximum[a]	Mean[b]	Maximum SPD	Species with Maximum SPD	Mean SPD	Mean	Maximum[c]
constant for POC) (lower)							
α_{DOC} (proportionality constant for DOC) (upper)	-0.05	-0.04	-7%	SS	-6%	150%	
POC (lower)	-0.04	-0.04	2%	SS	2%	-45%	
POC (upper)	-0.04	-0.03	-1.50%	SS	-1.40%	41%	
α_{POC} (proportionality constant for POC) (upper)	-0.03	-0.03	-5%	SS	-4%	149%	
A (phytoplankton/ algae uptake constant) (lower)	0.01	0.01	0.26%	ES	0.19%	33%	
A (phytoplankton/ algae uptake constant) (upper)	0.01	0.00	-0.22%	ES	-0.16%	-33%	
B (phytoplankton/ algae uptake constant) (upper)	0.0001	-0.0001	0.01%	ES	-0.01%	67%	
B (phytoplankton/ algae uptake constant) (lower)	0.0001	0.0001	-0.01%	ES	-0.01%	-67%	
Water density (upper) (seawater)	0.000004	0.000001	0.000007%	PSS	0.000002%	2%	

[a] Maximum percent change used for species-specific parameters only.

[b] Calculated as the mean species percent difference divided by the mean percent change in parameter value.

[c] Percent change for species-specific parameters only.

DC – Dungeness crab

ES – English sole

JF – juvenile fish

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

SPD – species percent difference

DOC – dissolved organic carbon

POC – particulate organic carbon

Of the 21 parameters evaluated in the upper- and lower-bound analyses, 11 had maximum responses for fish and crab species greater than 8% (Table 5-2). Five of the parameters had maximum responses greater than 20%. Six of the parameters had maximum responses between 10 and 20%. Three of the parameters had maximum responses between 5 and 10%, and seven of the parameters had maximum responses between 0 and 5%. A 10% change in predicted tissue concentrations is considered to be an important change if only one parameter is altered, and thus 10% was selected as the threshold for the upper- and lower-bound analysis.

With the threshold for further analysis at 10%, 11 parameters were selected for inclusion in the uncertainty analysis. When maximum SPDs resulting from the plausible range analysis were ranked for all species (Table B-3-2), three additional parameters had maximum SPDs of 10% or greater (Appendix B). Two of these parameters (α_{DOC} and α_{POC}) are environmental parameters related to the bioavailability of PCBs in water. They were not included in the uncertainty analysis because they are constants in equations in the FWM rather than true input parameters, and Crystal Ball®, the software used to run the Monte Carlo uncertainty analysis (Section 6.0) cannot test parameters within equations. The phytoplankton/algae uptake constant (A) was included in the uncertainty analysis as a result of advice from Jon Arnot based on his previous experience with other model applications (Arnot 2005). Table 5-4 presents all the parameters selected for the uncertainty analysis and the rationale for their inclusion.

Table 5-4. Parameters selected for the uncertainty analysis

Parameters Selected for the Uncertainty Analyses	Rationale for Inclusion
A (phytoplankton/algae uptake constant)	Advice from Jon Arnot (2005) and plausible range results (Table B-3-2)
β (MAF, proportionality constant for sorption capacity of NLOM)	Plausible range results (Tables 5-2 and B-3-2)
Dietary absorption efficiency of lipids (alpha)	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
Dietary absorption efficiency of NLOM (beta)	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
Dissolved oxygen	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
K_{ow}	10% results (Table B-3-1) and because K_{OW} is included in numerous equations in the model
Lipid content	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
Lipid density	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
POC	Plausible range results (Tables 5-2 and B-3-2)
Porewater, fraction ventilated	Selected because parameter is highly uncertain (middle of ranking for plausible range, all species)
Sediment PCB concentration	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
Temperature water column	10% and plausible range results (Tables 5-1. B-3-1, and B-3-2),
Water content	10% and plausible range results (Tables 5-1. B-3-1, and B-3-2),
Water PCB concentration	Plausible range results (Tables 5-2 and B-3-2); 10% results (Table B-3-1)
Weight	Plausible range results (Tables 5-2 and B-3-2)

5.1.2.2 Evaluation of model sensitivity to parameters

Table 5-4 presents parameters selected for the uncertainty analyses, but also serves as a list of sensitive parameters for the FWM. This list of parameters will serve as a guide for future calibration. Parameters to which the FWM is most sensitive and have the highest potential variability or uncertainty will have the greatest impact on predicted

PCB tissue concentrations during calibration. Those parameters with a combination of high sensitivity and high uncertainty (e.g., dietary absorption efficiency of lipids) will be calibrated to ensure that a selected parameter value is falling within a true range of plausible mean values. Parameters to which phytoplankton are sensitive, but fish and crab are not (i.e., phytoplankton A and α_{DOC} and α_{POC}), will not be useful parameters for calibrating the FWM for target species. Phytoplankton will not be calibrated because no empirical PCB tissue data exist for this model compartment.

5.2 WATER SCENARIOS

This section presents the results of preliminary model runs to assess the sensitivity of the FWM to total PCB concentrations in the water column. Water sensitivity is being addressed in more detail than other input parameters to provide additional information to decide whether additional water data should be collected in 2006 to support the FWM. The need for collection of additional surface water data will be determined in late spring 2006 based on: 1) the sensitivity of the FWM to total PCB concentrations in water, 2) the relative uncertainty in model predictions attributable to the uncertainty in total PCB concentrations in water versus other parameters, and 3) the variability of total PCB concentrations in water over smaller spatial scales, as predicted by the EFDC model and magnitude of effect on FWM predictions.

5.2.1 Methods

The FWM with the initial set of input values was run at the LDW-wide spatial scale five times with five different total PCB concentrations in water (1, 2, 3, 5, and 10 ng/L). These concentrations were selected to evaluate model sensitivity at empirical concentrations detected in the LDW in August 2005 (1 to 3 ng/L) and to evaluate model sensitivity at higher concentrations (up to 10 ng/L). The PCB concentrations in water to be used in the model runs for the Phase 2 RI will ultimately be determined based on output from the recalibrated EFDC model (as discussed in Sections 8.0 and 9.0).

5.2.2 Results

To assess the sensitivity of the FWM to changes in total PCB concentrations in water, total PCB concentrations in tissue were predicted using each of the five different total PCB concentrations in water. These predictions were then compared to empirical data to assess both FWM performance (as measured by SPAFs; Table 5-5) and the sensitivity of the WM to variation in total PCB water concentrations (i.e., differences in predictions of total PCB tissue concentrations relative to differences in total PCB water concentrations; Table 5-6).

Model performance (as measured by SPAFs) was best for the lowest water concentration (1 ng/L) (Table 5-5; Figure 5-1). This result is consistent with the fact that the FWM is generally over-predicting (Section 3.2) based on the initial set of parameters (which assumed a water concentration of 2 ng/L). At the highest water concentration (10 ng/L), the average SPAF was 3.3 (with species-specific SPAFs ranging from 2.0 to 5.7) compared to an average SPAF of 1.8 (with species-specific SPAFs ranging from 1.9 to 2.9) for the 1 ng/L scenario.

Table 5-5. Preliminary LDW-wide FWM results for five water scenarios compared to empirical total PCB tissue concentrations (all data sets combined)

Species	Mean Empirical Total PCBs Tissue Concentration[a] (µg/kg ww)	Model-Predicted Total PCBs Tissue Concentration (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Water Scenario with 1 ng/L Total PCBs in Water					
Various phytoplankton	nd	24	na	na	na
Various zooplankton	nd	36	na	na	na
Benthic invertebrates	170[d]	290	71%	1.7	+
Juvenile fish	nd	1,186	na	na	na
Slender crab	620	822	33%	1.3	+
Dungeness crab	980	2,453	150%	2.5	+
Pacific staghorn sculpin	900	2,641	193%	2.9	+
Shiner surfperch	1,800	1,781	-1%	1.0	-
English sole	2,300	2,527	10%	1.1	+
All Species					
Mean			76%	1.8	
Maximum			193%	2.9	
Minimum			-1%	1.0	
Water Scenario with 2 ng/L Total PCBs in Water					
Various phytoplankton	nd	47	na	na	na
Various zooplankton	nd	73	na	na	na
Benthic invertebrates	170[d]	311	83%	1.8	+
Juvenile fish	nd	1,315	na	na	na
Slender crab	620	893	44%	1.4	+
Dungeness crab	980	2,705	176%	2.8	+
Pacific staghorn sculpin	900	2,921	225%	3.2	+
Shiner surfperch	1,800	1,986	10%	1.1	+
English sole	2,300	2,752	20%	1.2	+
All Species					
Mean			93%	1.9	
Maximum			225%	3.2	
Minimum			10%	1.1	
Water Scenario with 3 ng/L Total PCBs in Water					
Various phytoplankton	nd	71	na	na	na
Various zooplankton	nd	109	na	na	na
Benthic invertebrates	170[d]	332	95%	2.0	+
Juvenile fish	nd	1,444	na	na	na
Slender crab	620	964	55%	1.6	+

SPECIES	MEAN EMPIRICAL TOTAL PCBS TISSUE CONCENTRATION[a] (µg/kg ww)	MODEL-PREDICTED TOTAL PCBS TISSUE CONCENTRATION (µg/kg ww)	% DIFFERENCE[b]	SPECIES PREDICTIVE ACCURACY FACTOR[c]	OVERPREDICTION (+) OR UNDERPREDICTION (-)
Dungeness crab	980	2,958	202%	3.0	+
Pacific staghorn sculpin	900	3,202	256%	3.6	+
Shiner surfperch	1,800	2,190	22%	1.2	+
English sole	2,300	2,976	29%	1.3	+
All Species					
Mean			110%	2.1	
Maximum			256%	3.6	
Minimum			22%	1.2	
Water Scenario 5 ng/L Total PCBs in Water					
Various phytoplankton	nd	118	na	na	na
Various zooplankton	nd	181	na	na	na
Benthic invertebrates	170[b]	373	119%	2.2	+
Juvenile fish	nd	1,702	na	na	na
Slender crab	620	1,106	78%	1.8	+
Dungeness crab	980	3,463	253%	3.5	+
Pacific staghorn sculpin	900	3,762	318%	4.2	+
Shiner surfperch	1,800	2,598	44%	1.4	+
English sole	2,300	3,426	49%	1.5	+
All Species					
Mean			144%	2.4	
Maximum			318%	4.2	
Minimum			44%	1.4	
Water Scenario 10 ng/L Total PCBs in Water					
Various phytoplankton	nd	236	na	na	na
Various zooplankton	nd	363	na	na	na
Benthic invertebrates	170[b]	477	181%	2.8	+
Juvenile fish	nd	2,347	na	na	na
Slender crab	620	1,461	136%	2.4	+
Dungeness crab	980	4,725	383%	4.8	+
Pacific staghorn sculpin	900	5,162	474%	5.7	+
Shiner surfperch	1,800	3,618	101%	2.0	+
English sole	2,300	4,549	98%	2.0	+
All Species					
Mean			228%	3.3	
Maximum			474%	5.7	
Minimum			98%	2.0	

a Empirical data from historical and Phase 2 (2004 and 2005) combined.

b The percent difference is the difference between the predicted and empirical tissue chemical concentration divided by the empirical tissue chemical concentration.

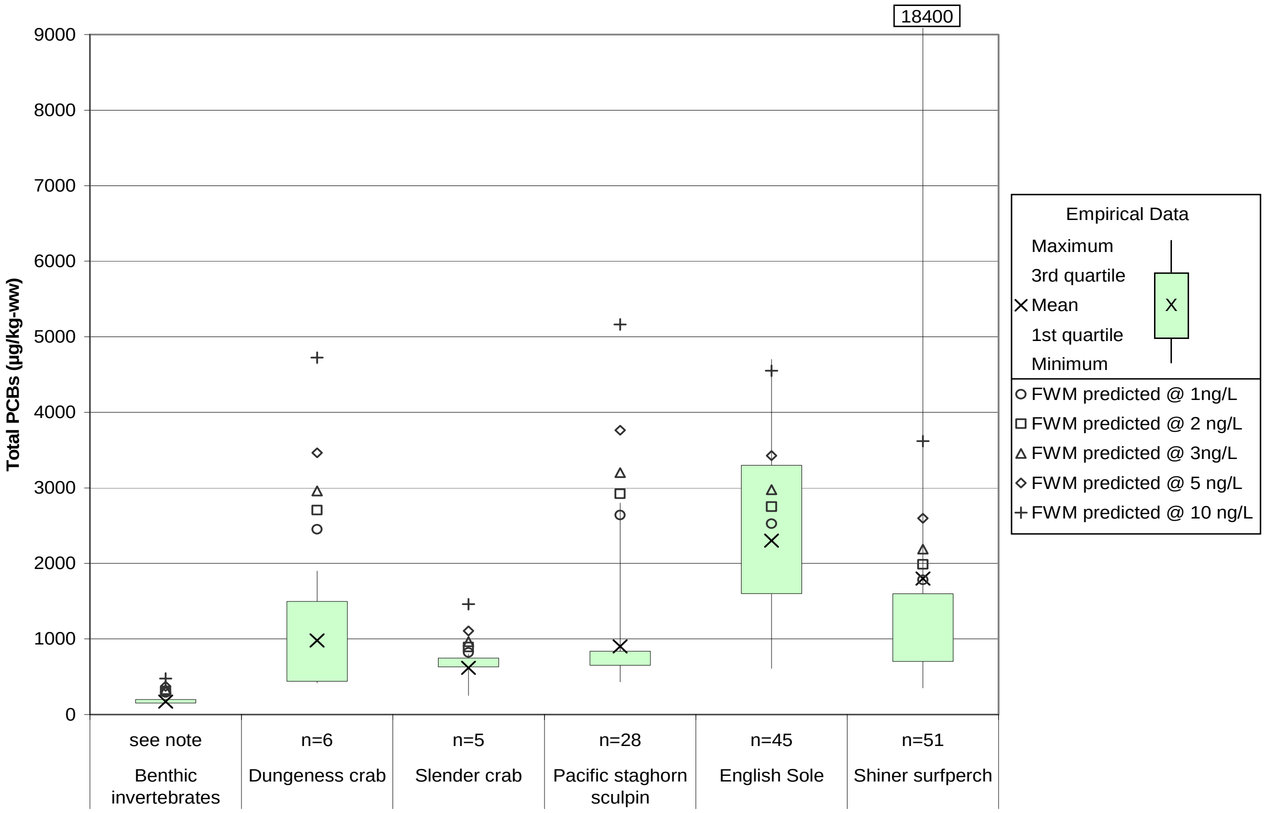
c The SPAF is defined as the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

d Concentration predicted from sediment-tissue PCB regression at an LDW-wide PCB SWAC of 250 µg/kg dw.

na – not applicable – no data

ww – wet weight

Figure 5-1. Preliminary model run results for the LDW-wide scale for five water scenarios compared to empirical total PCB tissue concentrations (all data sets combined)



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the LDW-wide SWAC for PCBs.

Table 5-6 presents predicted total PCB concentrations in tissue for the five water concentrations and reports the factor by which predictions at each water concentration differ from tissue predictions at 1 ng/L. These results indicate that predicted total PCB tissue concentrations in species with high water dependencies (e.g., phytoplankton) are highly sensitive to total PCB water concentrations (i.e., a 10-fold change in the total PCB water concentration resulted in a 10-fold change in the predicted total PCB concentration in phytoplankton). The FWM was less sensitive to water concentrations when predicting total PCB concentrations for crab and fish tissues (i.e., a 10-fold change in the water concentration resulted in a two-fold change in the predicted total PCB concentration in crabs or fish).

Table 5-6. Model sensitivity to total PCB concentration in water based on preliminary LDW-wide model runs for five water scenarios

Species	Water Scenarios								
	1 ng/L PCB Concentration in Water	2 ng/L PCB Concentration in Water		3 ng/L PCB Concentration in Water		5 ng/L PCB Concentration in Water		10 ng/L PCB Concentration in Water	
	Model Predicted Total PCBs in Tissue (µg/kg ww)	Model Predicted Total PCBs in Tissue (µg/kg ww)	Factor Difference (between 2 and 1 ng/L)	Model Predicted Total PCBs in Tissue (µg/kg ww)	Factor Difference (between 3 and 1 ng/L)	Model Predicted Total PCBs in Tissue (µg/kg ww)	Factor Difference (between 5 and 1 ng/L)	Model Predicted Total PCBs in Tissue (µg/kg ww)	Factor Difference (between 10 and 1 ng/L)
Various phytoplankton	24	47	2.0	71	3.0	118	5.0	236	10
Various zooplankton	36	73	2.0	109	3.0	181	5.0	363	10
Benthic invertebrates	290	311	1.1	332	1.1	373	1.3	477	1.6
Juvenile fish	1,186	1,315	1.1	1,444	1.2	1,702	1.4	2,347	2.0
Slender crab	822	893	1.1	964	1.2	1,106	1.3	1,461	1.8
Dungeness crab	2,453	2,705	1.1	2,958	1.2	3,463	1.4	4,725	1.9
Pacific staghorn sculpin	2,641	2,921	1.1	3,202	1.2	3,762	1.4	5,162	2.0
Shiner surfperch	1,781	1,986	1.1	2,190	1.2	2,598	1.5	3,618	2.0
English sole	2,527	2,752	1.1	2,976	1.2	3,426	1.4	4,549	1.8
All Species									
Average factor difference			1.3		1.6		2.2		3.7
Maximum factor difference			2.0		3.0		5.0		10
Minimum factor difference			1.1		1.1		1.3		1.6

ww – wet weight

6.0 Uncertainty Analysis

An uncertainty analysis evaluates the effect of uncertainty in input parameters on model output. The purpose of this uncertainty analysis was to characterize quantitatively the combined effect of selected parameters' uncertainties on the prediction of total PCB concentrations in tissue. Parameters were selected based on the results of the sensitivity analyses (see Section 5.0). As discussed in FWM Memorandum 2 (Windward 2005b), the uncertainty analysis was performed by Monte Carlo simulation using Decisioneering® Crystal Ball® Version 7.0 software for the LDW-wide scale. The results of the uncertainty analysis can be used to evaluate confidence in model output (e.g., what is the distribution of model estimates when the uncertainty in input parameters is considered?).

6.1 METHODS

In Monte Carlo simulation modeling, probability distributions, rather than point estimates, are assigned for input parameters if sufficient data are available to describe the distribution and if the FWM is sensitive to a given parameter. The probability distributions reflect the relative likelihood of different values for each parameter. For the purpose of this analysis, parameter uncertainty includes both uncertainty (because of insufficient information) and variability (because of inherent differences in parameter values).

Using Crystal Ball® software, the Monte Carlo version of the FWM was run 10,000 times. During each model iteration, different combinations of values for each input parameter were randomly selected from the probability distribution for each parameter. In contrast to the sensitivity analysis where only one parameter was varied at a time, all parameters in the Monte Carlo uncertainty analysis are varied simultaneously during each model iteration. Output from this uncertainty analysis consists of distributions of the relative probability of predicted tissue concentrations for each species based on the distributions of FWM input parameter values. This information is useful for calibrating the FWM and interpreting model results.

6.1.1 Assigning distributions for model parameters

The first step in running the Monte Carlo model is the development of parameter distributions. Parameters were included in the uncertainty analysis if they were identified as sensitive in the sensitivity analysis (Section 5.0). Because these parameters have the greatest effect on model output, they were further investigated in the uncertainty analysis.

The same datasets used to develop the initial set of values for the FWM and the sensitivity analyses were used to identify distributions for parameters included in the uncertainty analysis. In assigning these distributions, relevant data for each parameter were considered. As recommended by MacIntosh et al. (1994), the assignment of a distribution was influenced by the quality of the available data. The approaches for developing distributions to represent variability and uncertainty of each parameter, as well as actual distribution assignment for each parameter, are described in detail in Appendix C. Distributions were developed for 10 non-species-specific environmental, chemical, and biological parameters, and 45 species-specific parameters (e.g., nine lipid content parameters, one for each of the nine modeled species). The distributions were selected such that the initial set of model values for the LDW-wide scale (as described in Section 3.1 and Appendix A) were always the mean or mode of the distribution assigned for the parameters included in the uncertainty analysis (Appendix C). These distributions were entered into the Monte Carlo version of the FWM.

6.1.2 Correlation

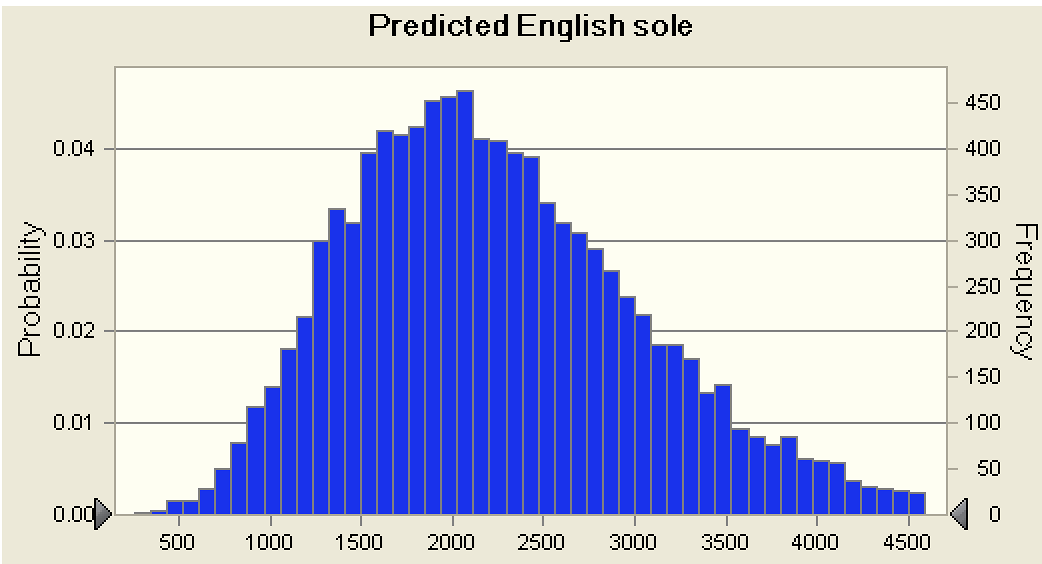
Some parameters, such as percent lipids and water content, are expected to be correlated in organisms. The assignment of correlation coefficients for correlated parameters prevents improbable combinations of values. For example, if water content and lipid content are inversely correlated, a combination of high lipid content and high water content values will not be allowed. Thus, inclusion of correlations in the FWM for these parameters reduces the likelihood of unrealistic combinations of different parameters during model iterations. To evaluate correlations, data that can be reasonably matched (in time and location or by sample specimens) must be available and be similarly robust in terms of number of samples and data quality. For parameter pairs expected to be correlated for biological or environmental reasons, a correlation test was performed if adequate data for the test were available. Correlation coefficients were calculated for several water quality parameters (i.e., water temperature, dissolved oxygen, and particulate organic carbon) and biological parameters (i.e., species lipid content and water content) and included in the Monte Carlo version of the model. The assignment of parameter correlations is discussed in detail in Appendix C.

6.2 RESULTS

The results of the Monte Carlo modeling are distributions of predicted total PCB tissue concentrations for the five target species. These distributions describe the uncertainty of the FWM in predictions for different species.

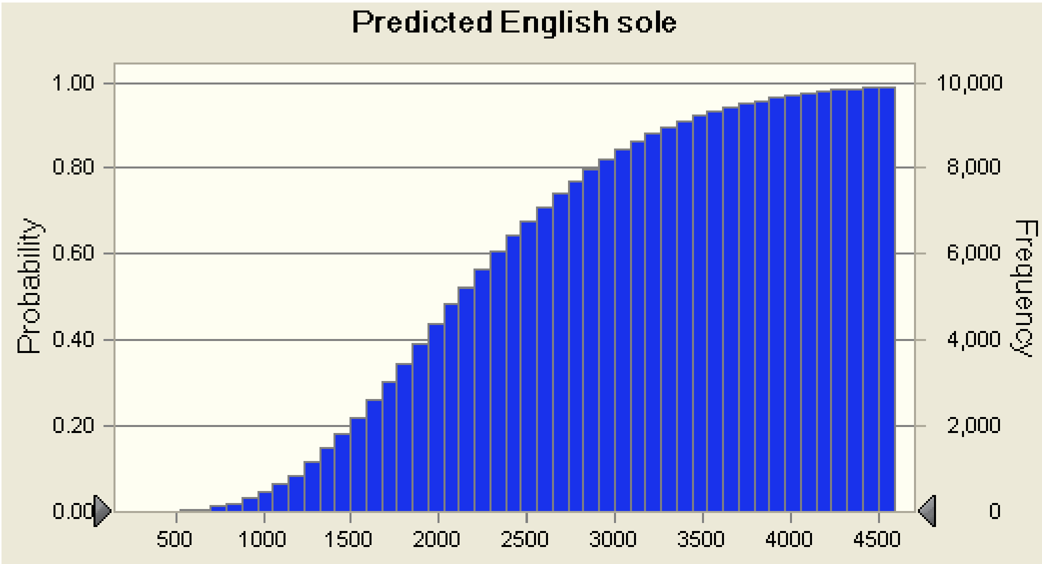
An example of the Monte Carlo model output is presented in Figure 6-1. The output in this example is a frequency distribution of model predictions of total PCB concentrations in English sole tissue. Figure 6-2 shows the same English sole predictions as a cumulative frequency distribution. In both figures, the left y-axis indicates the probability of particular output values, and the right y-axis indicates the frequency of output values. Note that the total number of output values is 10,000 (the number of model iterations). The cumulative frequency presentation is commonly used for Monte Carlo model results because it allows the viewer to easily identify different percentiles of prediction likelihood. For example, the 95th percentile probability is approximately 3,800 µg/kg ww for English sole (i.e., 95% of the Monte Carlo model results are below 3,800 µg/kg ww).

Figure 6-1. Frequency distribution results from the Monte Carlo model showing the relative probabilities of predicted total PCB concentrations in English sole tissue



Total PCB concentration in tissue (µg/kg-ww)

Figure 6-2. Cumulative frequency results from the Monte Carlo model showing predicted total PCB concentrations in English sole tissue



Total PCB concentration in English sole tissue (µg/kg-ww)

Table 6-1 provides a summary of model output and a comparison of predictions to empirical data for all modeled species. The 5th, 50th, and 95th percentiles and mean of the model predictions provide a general description of the model output. The full range of model output includes the extreme minimum and maximum predictions from the FWM, which are also among the least likely model predictions.

Table 6-1. Results of the preliminary uncertainty assessment conducted on an LDW-wide scale

Species	Uncertainty Assessment Results					Empirical Tissue Data			Source of Empirical Data
	5th Percentile Predicted Total PCB Concentration in Tissue (µg/kg ww)	50th Percentile (Median) Predicted Total PCB Concentration in Tissue (µg/kg ww)	95th Percentile Predicted Total PCB Concentration in Tissue (µg/kg ww)	Range of Predicted Total PCB Concentration in Tissue (µg/kg ww)	Mean of Predicted Total PCB Concentration in Tissue (µg/kg ww)	Mean Empirical Total PCB Concentration in Tissue (µg/kg ww)	Median Empirical Total PCB Concentration in Tissue (µg/kg ww)	Range of Empirical total PCB Concentration in Tissue (µg/kg ww)	
Phytoplankton	28	45	66	8 – 93	46	nd	nd	nd	
Zooplankton	36	69	116	7 – 192	71	nd	nd	nd	
Benthic invertebrates	117	253	459	16 – 807	266	170[a]	na	136 – 200[a]	Predicted based on a SWAC of 250 µg/kg dw total PCBs in sediment and a tissue-sediment regression derived from 20 co-located benthic invertebrate and surface sediment samples collected in Phase 2 (2004)
Juvenile fish	488	1,047	1,925	150 – 3,695	1,107	nd	nd	nd	
Slender crab	281	571	1,101	56 – 2,608	614	620[b]	650[b]	250 – 800[b]	Phase 2 (2004, 2005) data
Dungeness crab	465	1,596	3,910	30 – 10,377	1,816	1,000[b]	640[b]	420 – 1,900[b]	Historical and Phase 2 (2004, 2005) data
Pacific staghorn sculpin	1,021	2,277	4,269	325 – 7,972	2,411	900	720	430 – 2,800	Phase 2 (2004, 2005) data
Shiner surfperch	703	1,552	2,863	175 – 4,940	1,637	1,800	1,120	350 – 18,000	Historical and Phase 2 (2004, 2005) data
English sole	1,075	2,152	3,796	259 – 7,294	2,257	2,300	1,885	610 – 4,700	Phase 2 (2004, 2005) data

[a] Concentration predicted from sediment-tissue PCB regression at an LDW-wide total PCB SWAC of 250 µg/kg dw (for mean) or plausible range of 125 to 375 µg/kg dw. See Appendix B (Section B.2.2) for details on range selection.

[b] Based on mean Phase 2 (2004, 2005) data. Whole-body total PCB concentrations in crabs were calculated as weighted means [(0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)].

dw – dry weight
na – Not applicable – insufficient information to calculate median (range based on upper and lower estimated concentrations [see footnote a]).
nd – no data
SWAC – spatially weighted average concentration
ww – wet weight

The predicted means presented in Table 6-1 differ from the predicted concentrations presented in Table 3-2 because the values in the Table 6-1 are the mean of 10,000 estimates generated by the Monte Carlo analysis. Table 3-2 presents the best single estimate using the model. The predicted tissue concentrations in Table 3-2 are higher than the predicted means in Table 6-1. This difference reflects the parameter distributions included in the Monte Carlo model, which overall were skewed to the left (see Appendix C for details on distributions).

Dungeness crab was the species with the widest range of predicted total PCB concentrations. The range is probably widest for Dungeness crab for two reasons. First, invertebrates have wider ranges than fish for some key estimated parameters (such dietary absorption of lipids and NLOM). Second, Dungeness crab is a higher-trophic-level species and thus has more uncertain parameters contributing to the distribution than phytoplankton, for example. In future FWM calibration, efforts will be directed toward refining the model parameters that should create the greatest reductions in the model's uncertainty. Knowing which species have the largest range of output from the Monte Carlo model can be useful for focusing these efforts.

The range of empirical total PCB concentrations for shiner surfperch was much greater than that for other species, and the model predictions did not bound this range (Table 6-1). In particular, there was one shiner surfperch sample with an exceptionally high concentration (18,000 µg/kg). The Monte Carlo model predictions did not bound the highest empirical total PCB concentration for shiner surfperch.

Comparison of several other predicted and empirical summary statistics provides confidence in the distributional shape of the output and predictive capability of the uncertainty model. In all cases, species-specific predicted means exceeded predicted medians (50th percentile). Means were also greater than medians in empirical data on a species-specific basis, indicating that there is some similarity between empirical and predicted distributions. In addition, the 5th and 95th percentiles of predicted tissue concentrations were, with the exception of shiner surfperch, within a factor of 3 or better of the empirical minimum and maximum concentrations, respectively. Taken together, these results indicate that the model, with uncertainty considered, provides predictions that are consistent with the variability of empirical total PCB concentrations in fish and crab tissue.

In summary, the Monte Carlo model results bolster overall confidence in model predictions because the predicted distribution of total PCB tissue concentrations is similar to the distribution of empirical total PCB tissue concentrations. The Monte Carlo model results may be used to focus future modeling efforts on parameters important for species with the largest variations between empirical and predicted tissue concentration distributions, based on both the shape of the distributions and the numerical values. In addition to potentially improving future single-point "best estimate" model predictions (non-Monte Carlo model runs), calibration efforts may also help reduce the uncertainty for some parameters, and therefore, reduce the variability of model output (uncertainty range) in future Monte Carlo model analyses. The modeling presented in this memorandum has been performed on an initial model input parameterization (see Section 2.0). Once the FWM is calibrated, the variability in the Monte Carlo output will be reassessed and summarized in the Phase 2 RI.

7.0 Smaller Spatial Scales

In addition to the LDW-wide scale, the FWM was also run at the smaller spatial scale of the four modeling areas (Figure 2-1). This section presents the results of the modeling-area-scale runs.

Modeling areas were defined as the four fish and crab tissue sampling areas extended out to the center point between tissue sampling areas (Figure 2-1). This scale was selected because it represents a smaller scale than the LDW-wide scale that can still be directly compared to empirical data on a similar scale from the LDW. Most of the modeled species are likely to have foraging areas that are smaller than the entire LDW based on consultation with local fish experts, although uncertainty exists regarding the absolute size of these areas. Therefore, two different spatial scales are being modeled (i.e., LDW-wide and modeling area scales). This section presents the results of the modeling area scale runs.

7.1 METHODS

Input parameter values that were changed from those used in the LDW-wide scale in order to run the FWM on the modeling area spatial scale included the total PCB concentration in sediment, the organic carbon content of the sediment, fish and invertebrate lipid contents and water contents, and fish and crab weights. Otherwise, all input parameter values used in the preliminary LDW-wide model runs were used (including dietary scenario 1). Specific parameter values for the modeling areas are presented in the input parameter value tables in Appendix A (Tables A-1-2, A-2-1, A-2-2, A-2-3, A-3-1, and A-4-1). Predicted total PCB concentrations in tissue were compared to empirical data from the area modeled.

7.2 RESULTS

Table 7-1 and Figure 7-1 present initial model results for the four modeling areas. Predicted total PCB concentrations in fish and crab tissue were generally within a factor of 3 and less than 200% different from empirical total PCB concentrations for most species. Predictions for Dungeness crabs and Pacific staghorn sculpin were generally higher than empirical data, but were still within a factor of 5 and less than 400% different from empirical concentrations for all modeling areas. Further refinement of the FWM will be conducted for Dungeness crabs and Pacific staghorn sculpin if this scale is deemed appropriate for these target species.

Table 7-1. Preliminary model run results at the modeling area scale compared to empirical total PCB tissue concentrations (all data sets combined)

Species	Mean Empirical Total PCB Concentration in Tissue (µg/kg ww)[a]	Model-Predicted Total PCB Concentration in Tissue (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Modeling Area 1					
Phytoplankton	nd	47	na	na	na
Zooplankton	nd	73	na	na	na
Benthic invertebrates	180	363	102%	2.0	+
Juvenile fish	nd	1,483	na	na	na
Slender crab	650	947	46%	1.5	+
Dungeness crab	830	3,569	330%	4.3	+
Pacific staghorn sculpin	720	3,392	371%	4.7	+
Shiner surfperch	970	2,100	116%	2.2	+
English sole	2,600	2,970	14%	1.1	+
All Species					
Mean			163%	2.6	
Maximum			371%	4.7	
Minimum			14%	1.1	
Modeling Area 2					
Phytoplankton	nd	47	na	na	na
Zooplankton	nd	73	na	na	na
Benthic invertebrates	150	253	69%	1.7	+
Juvenile fish	nd	1,037	na	nc	na
Slender crab	600	661	10%	1.1	+
Dungeness crab	nd	2,048	na	na	na
Pacific staghorn sculpin	750	2,343	212%	3.1	+
Shiner surfperch	2,800	1,592	-43%	1.8	-
English sole	2,900	2,319	-20%	1.3	-
All Species					
Mean			46%	1.8	
Maximum			212%	3.1	
Minimum			-43%	1.1	
Modeling Area 3					
Phytoplankton	nd	47	na	na	na
Zooplankton	nd	73	na	na	na
Benthic invertebrates	220	426	94%	1.9	+
Juvenile fish	nd	1,892	na	na	na
Slender crab	630	1,272	102%	2	+
Dungeness crab	1,000	3,131	213%	3.1	+
Pacific staghorn sculpin	1,400	3,919	180%	2.8	+
Shiner surfperch	2,700	2,938	9%	1.1	+
English sole	2,000	3,893	95%	1.9	+
All Species					
Mean			115%	2.1	
Maximum			213%	3.2	

Species	Mean Empirical Total PCB Concentration in Tissue (µg/kg ww)[a]	Model-Predicted Total PCB Concentration in Tissue (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Minimum			9%	1.1	
Modeling Area 4					
Phytoplankton	nd	47	na	na	na
Zooplankton	nd	73	na	na	na
Benthic invertebrates	92	76	-17%	1.2	-
Juvenile fish	nd	409	na	na	na
Slender crab	nd	257	na	na	na
Dungeness crab	1,200	774	-36%	1.6	-
Pacific staghorn sculpin	730	842	15%	1.2	+
Shiner surfperch	840	661	-21%	1.3	-
English sole	1,400	781	-44%	1.8	-
All Species					
Mean			-21%	1.4	
Maximum			15%	1.8	
Minimum			-44%	1.2	

[a] Empirical data from historical and Phase 2 (2004 and 2005) combined. Empirical data were not directly used for benthic invertebrates. Instead, the concentrations presented for benthic invertebrates are based on a tissue/sediment regression.

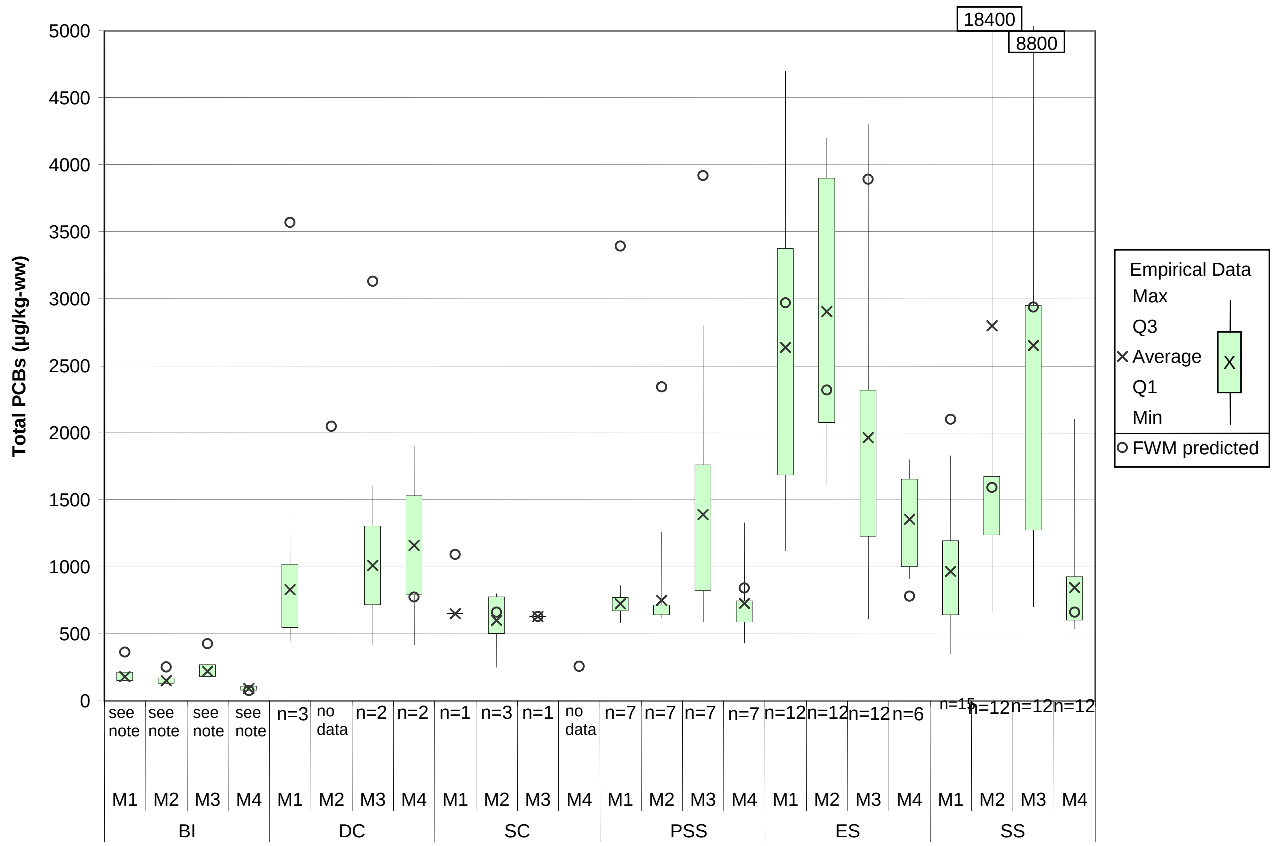
[b] The percent difference is the difference of the predicted and empirical tissue chemical concentration divided by the empirical tissue chemical concentration.

[c] The SPAF is defined as the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

na – not applicable

nd – no data

Figure 7-1. Preliminary model run results at the modeling-area scale compared to empirical total PCB tissue concentrations (all data sets combined)



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the SWACs for total PCBs for each of the four modeling areas.

M1 through M4 – modeling areas 1 through 4

BI – benthic invertebrate

DC – Dungeness crab

ES – English sole

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

Predictions for modeling area 4 were most similar to empirical data, with a mean SPAF of 1.4 and mean percent difference of -21%. For this modeling area, concentrations of total PCBs in all species except Pacific staghorn sculpin were under-predicted. Predictions for modeling area 2 were also similar to empirical data (mean SPAF of 1.8, mean percent difference of 46%). In this area, concentrations for shiner surfperch and English sole were under-predicted, whereas concentrations in benthic invertebrates, slender crabs, and Pacific staghorn sculpin were over-predicted. Modeling area 2 had no empirical data for Dungeness crabs, so the mean SPAF for that modeling area was an average of five instead of six species. Dungeness crabs had higher SPAFs and percent differences than the other modeled species for modeling areas 1 and 3, increasing the mean SPAF and percent difference for those areas.

8.0 Lessons Learned

The purpose of this memorandum is to present preliminary results of the FWM to further elucidate model assumptions and sensitivities. This section presents an overview of key findings as well as key sensitivities and uncertainties to consider in the final phase of the food web modeling to be included in the Phase 2 RI.

8.1 Model Performance

This memorandum presented preliminary model results for five target species (Dungeness crab, slender crab, English sole, shiner surfperch, and Pacific staghorn sculpin). As discussed in Section 1.0, these model results are preliminary pending final resolution of water data, sediment interpolation, and a few other key assumptions in the FWM (e.g., dietary scenarios). In general, however, the predicted concentrations of total PCBs in tissues of the five target species were within a factor of 3.2 of empirical data (all datasets combined) on the LDW-wide scale (Table 3-2), and therefore, met the model performance criterion.

8.2 Future Model Runs

Before its presentation and application in the Phase 2 RI, the FWM will be calibrated to optimize its ability to predict concentrations of PCBs in the tissues of target species. The calibration process will be conducted in consultation with EPA and Ecology. This section describes some of the key results and decisions to be made.

8.2.1 Choice of empirical dataset to evaluate model performance

As discussed in Section 3.1, several datasets are available to evaluate model performance (i.e., historical, Phase 2 [2004], Phase 2 [2005], and a combination of the datasets). Total PCB concentrations in tissue were consistently lower in historical data and data from 2005 compared to 2004 data (Table 3-3 and Figure 3-2). The preliminary results of the FWM presented in this memorandum were generally compared to the combined dataset, although the LDW-wide results were also compared to the 2004 and 2005 data separately.

The FWM performance, on an LDW-wide scale, was generally similar whether it was evaluated using the 2004 dataset or all datasets combined, potentially because the 2004 dataset is the largest dataset available. The model performance when compared to the 2005 dataset was similar to that for the combined datasets for shiner surfperch and English sole. However, the model-predicted total PCB concentrations for slender crab, Dungeness crab, and Pacific staghorn sculpin were higher than the empirical total PCB concentrations for those species in 2005 (with SPAFs ranging from 3.6 to 6.3). These results do not necessarily imply that the 2004 dataset is the most appropriate dataset for calibration. The dataset that will be used as the source of empirical data for calibration of the FWM will be determined through discussions with EPA and Ecology after completion of this memorandum.

8.2.2 Sensitive parameters to focus on for future calibration

One purpose of the sensitivity analyses was to develop a list of parameters ranked according to model sensitivity. Two types of sensitivity analyses were conducted. The first analysis was conducted by changing each input parameter 10% independently and assessing the impact on model output (i.e., predicted total PCB concentrations in tissue). The second analysis was conducted by running the FWM with reasonable upper- and lower-bound input parameter estimates separately and assessing the impact on model output.

The results of these analyses are presented in Table 8-1. In general, calibration will proceed by assessing the variability and uncertainty of each sensitive parameter. Parameters to which the model is sensitive, and which are highly uncertain, have the greatest potential to affect model predictions, while keeping parameter values within reasonable bounds.

Table 8-1. Ranking of the most sensitive input parameters for target species based on the results of the two sensitivity analyses

10% Sensitivity Analysis	Upper- and Lower-Bound Sensitivity Analysis
Most Sensitive Parameters for Target Species (and maximum SPD, absolute value)	Most Sensitive Parameters for Target Species (and maximum SPD, absolute value)
Dietary absorption efficiency of lipids (alpha) (24%)	Dietary absorption efficiency of lipids (alpha) (67%)
Water content (18%)	Dietary absorption efficiency of NLOM (beta) (54%)
Lipid density (17%)	Sediment PCB concentration (42%)
Food ingestion rate (G_D) (14%)	Lipid content (33%)
Lipid content (14%)	Weight (25%)
Dissolved oxygen (DO) (11%)	Lipid density (20%)
Water column temperature (10%)	Porewater, fraction ventilated (17%)
Dietary absorption efficiency of NLOM (beta) (9%)	Water column temperature (12%)
Sediment PCB concentration (8%)	Water PCB concentration (11%)
K_{OW} (7%)	β (MAF, proportionality constant for sorption capacity of NLOM) (11%)

8.2.3 Dietary scenarios

The sensitivity of the FWM and relative model performance to several plausible dietary scenarios was investigated for the five target species (Section 4.0). In general, predictions based on dietary scenario 2 most closely matched empirical data, except for Pacific staghorn sculpin, for which predictions based on dietary scenario 3 most closely matched empirical data.

Using the initial set of input values and dietary scenario 1, total PCB concentrations in tissues of Dungeness crab and Pacific staghorn sculpin were most overpredicted. These species are omnivores and both consume significant proportions of shrimp and juvenile crabs. Both species may also consume small/juvenile fish. The fact that both these species are being overpredicted using dietary scenario 1 may be related to either the designated fraction of juvenile fish in their diet or the fact that benthic invertebrates make a poor surrogate for shrimp and juvenile crabs. Dietary scenarios for these species in particular, and possibly for all target species, will be further investigated in future model runs.

8.2.4 Benthic invertebrate model compartment

Benthic invertebrates are one of the key prey species for the fish and crabs being modeled. Empirical tissue data are available for benthic invertebrates (a total of 20 subtidal and intertidal composite tissue samples). The collection of these data was not designed to provide a representative sampling of PCB concentrations in benthic invertebrate tissue throughout the LDW. Instead, the study was designed to sample various locations and to provide a sampling of the range of PCB concentrations in sediment. The data were collected in this manner to determine the relationship between total PCB concentrations in tissue and sediment through the use of an accumulation factor (or regression).

As a result, there are two different approaches to estimate representative concentrations of total PCBs in benthic invertebrate tissue: 1) using the mechanistic FWM, or 2) using the regression analysis in combination with a spatially weighted average total PCBs concentration in sediment for the LDW scale being evaluated. Both approaches to predicting representative PCB concentrations in benthic invertebrate tissue have uncertainties. Species-specific parameters for benthic invertebrates that could be calibrated in the FWM are diet (including sediment PCB concentrations as a surrogate dietary item), weight, lipid content, NLOM content, or fraction of porewater ventilated. Uncertainties in the regression analysis include sediment PCB concentration and extrapolation of point-by-point relationships between sediment and tissue to LDW-wide conditions.

The FWM is generally overpredicting the concentrations of total PCBs in fish and crabs (Table 3-2). Therefore, because of the uncertainties associated with values for benthic invertebrate input parameters in the FWM and the fact that the model is overpredicting total PCB concentrations in consumers of benthic invertebrates, the sediment-benthic invertebrate tissue regression (described in Appendix A, Section A.2.4) is recommended in place of the Arnot and Gobas benthic invertebrate model compartment for future model runs at the LDW-scale based on the current input values. When the FWM is run at the LDW-wide scale with benthic invertebrate tissue concentrations based on the regression approach, model predictions for all species are more similar to empirical data (Table 8-2). If smaller scales are preferred for certain target species, or if input parameters are changed significantly, this recommendation should be revisited to verify that it still optimizes model performance.

Table 8-2. Model results for LDW-wide scale with initial set of input values using sediment-tissue regression for benthic invertebrates

Species	Mean Empirical Total PCB Concentration in Tissue (µg/kg ww)	Model-Predicted Total PCB Concentration in Tissue (µg/kg ww)	% Difference[a]	Species Predictive Accuracy Factor[b]	Overprediction (+) or Underprediction (-)
Various phytoplankton	nd	47	na	na	na
Various zooplankton	nd	73	na	na	na
Benthic invertebrates	173	173	2%	1.0	+
Juvenile fish	nd	779	na	na	na
Slender crab	620	512	-17%	1.2	-
Dungeness crab	1,000	1,591	59%	1.6	+
Pacific staghorn sculpin	900	1,733	93%	1.9	+
Shiner surfperch	1,800	1,186	-34%	1.5	-
English sole	2,300	1,616	-30%	1.4	-
All Species					
Mean			12%	1.4	
Maximum			93%	1.9	
Minimum			-34%	1.0	

[a] Percent difference is the difference between the predicted and empirical tissue chemical concentrations divided by the empirical tissue chemical concentration.

[b] The SPAF is defined as the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

na – not applicable

nd – no data

8.2.5 Choice of model scale

The FWM was run at two scales for this memorandum (LDW-wide and at the scale of modeling areas). The model will be run at the subarea scale for Pacific staghorn sculpin and shiner surfperch when EFCD model results are available.

Selection of the modeling scale for application in the RI will depend on model performance at a given scale. For example, the ability of the FWM to accurately predict concentrations of PCBs in fish and crab tissues at the LDW-wide scale relative to the ability of the model to accurately predict tissue concentrations when results of modeling at smaller scales are combined will be considered. Application of the FWM for the FS will depend on the scale at which the model provides the best predictive accuracy for the RI, as well as the specific remedial scenarios being evaluated in the residual risk assessment for the FS.

Based on the preliminary results presented in this memorandum (Tables 3-2 and 7-1), model performance generally does not appear to be significantly affected by the modeling scale when compared to the combined empirical dataset.

9.0 Next Steps

This memorandum is the third of the three memoranda prepared to document the development of the FWM. The preliminary results presented in this memorandum will be discussed with EPA, Ecology, and interested stakeholders in April, 2006. In addition, a number of steps will occur prior to the final documentation and application of the FWM in the Phase 2 RI/FS. These steps are listed below.

- **Step 1 – Selection of final SWAC for model runs.** By the end of April 2006, a final decision will be made on the method to be used to generate SWACs for total PCBs in the LDW. This method will be applied to calculate SWACs for total PCBs and OC_{sed} on an LDW-wide basis and for smaller spatial scales, as needed.
- **Step 2 – Recalibration of the EFDC model and decision on the need for additional water data.** In the spring of 2006, King County will be recalibrating the EFDC model using recently collected total PCB water data as well as updated sediment data. The model will predict total PCB concentrations in water for each cell in the model, allowing estimates of total PCB concentration in water at any scale to be modeled by the FWM. These data will be used to characterize the spatial variability of total PCB concentrations in surface water within the LDW. The EFDC model will also be able to provide temporal variability (intra-annual) information. Using the spatial variability information, the sensitivity of the FWM to EFDC-predicted total PCB concentration ranges in water will be tested. Based on these results, the need for additional water data will be determined by June 2006. If collection of additional water data is not considered necessary, the re-calibrated EFDC model predictions of total PCB concentrations in water will be used for future FWM runs.
- **Step 3 – Selection of most accurate and best-performing dietary scenario for each species.** Dietary scenarios (at the LDW-wide spatial scale) will be re-evaluated based on the results of these initial analyses and re-run using updated total PCB concentrations in sediment and water. Based on model performance and supporting dietary information, the most appropriate dietary scenario will be selected for each species.

- **Step 4 – Model runs with updated total PCB water column concentration and dietary scenarios.** The FWM will be re-run at various spatial scales using updated total PCB water and sediment concentrations and selected dietary scenarios for each species. In addition, after EFDC-predicted total PCB concentrations in water are available for each cell of the model in the LDW, average concentrations will be calculated for a subset of fish tissue sampling subareas. These concentrations will be used for FWM runs at a subarea scale for shiner surfperch and Pacific staghorn sculpin. The results of these runs will be discussed with EPA and Ecology to determine if additional calibration of the FWM is warranted to meet project needs.
- **Step 5 – Final documentation and application of the FWM.** After the FWM development is complete, it will be presented in the Phase 2 RI. In the RI, the FWM will be used to generate sediment quality thresholds based on risk-based goals for fish and crab tissue established in the ecological and human health risk assessments. In the FS, the FWM will be used as one tool to evaluate residual risks associated with various sediment cleanup alternatives.

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