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PORTLAND HARBOR RI/FS
COMPREHENSIVE ROUND 2 SITE CHARACTERIZATION SUMMARY AND DATA GAPS ANALYSIS REPORT

FEBRUARY 21, 2007

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VOLUME VI
Appendices D, E, and F

Prepared for
The Lower Willamette Group

Prepared by
Integral Consulting Inc.
Windward Environmental LLC
Kennedy/Jenks Consultants
Anchor Environmental L.L.C.

USEPA SF
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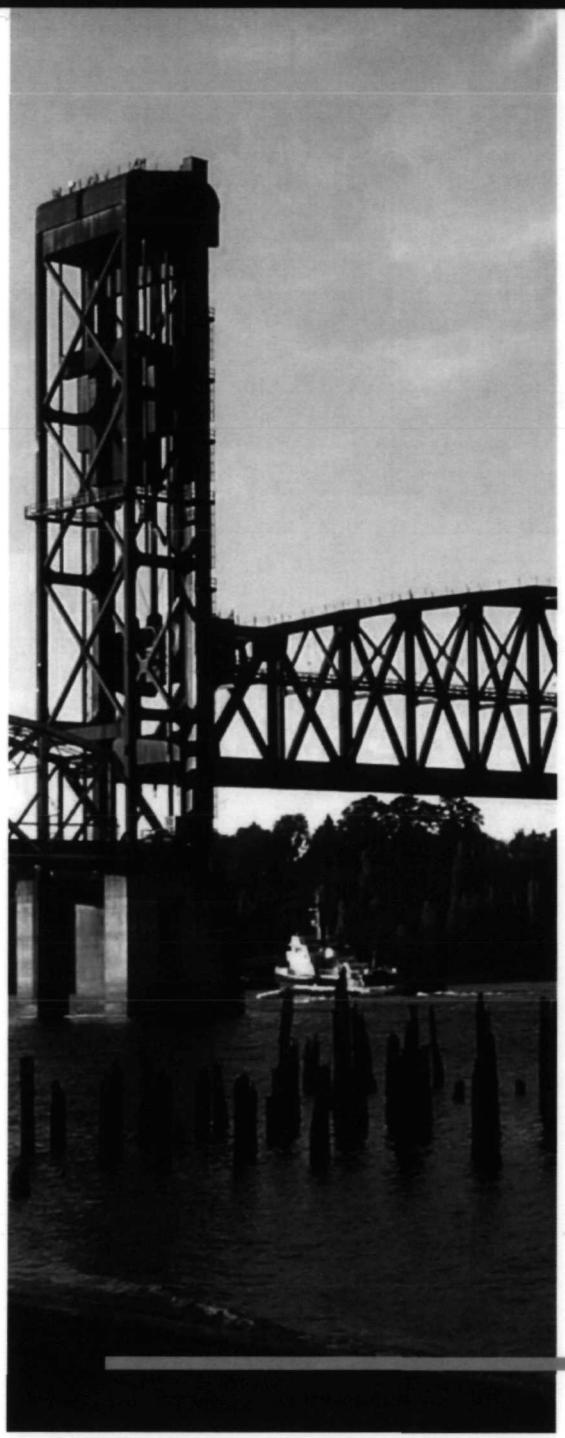

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Appendix D

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PORTLAND HARBOR RI/FS

COMPREHENSIVE ROUND 2 SITE CHARACTERIZATION SUMMARY AND DATA GAPS ANALYSIS REPORT

APPENDIX D
LOADING, FATE AND TRANSPORT

February 21, 2007

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PORTLAND HARBOR RI/FS

COMPREHENSIVE ROUND 2 SITE CHARACTERIZATION SUMMARY AND DATA GAPS ANALYSIS REPORT

APPENDIX D

LOADING, FATE, AND TRANSPORT SUPPORTING INFORMATION AND CALCULATIONS

February 21, 2007

Prepared for
The Lower Willamette Group

Prepared by
Integral Consulting Inc.

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1.0 INTRODUCTION

This appendix presents the calculations performed to estimate current loading, fate, and transport terms as part of the Round 2 Comprehensive Report.[1] An overview of loading, fate, and transport processes that are relevant for the Study Area, and the approaches to assess the applicable mechanisms, are presented in Section 7 of the main report. Additional details of the calculation methods, including all assumptions and the results, are presented here. Specifically, estimates for the following current loading terms are presented in this appendix:

- Upstream loading estimates for surface water
- Preliminary stormwater loading estimates
- Upland groundwater plume loading estimates
- Estimates of advective transfer of sediment contamination to surface water via discharging groundwater
- Atmospheric deposition.

In addition to these mass loading/transfer estimates, two supporting items are included in this appendix:

- Data tables of available upland soils chemistry to support a future evaluation of bank erosion loading
- A geochemical analysis of arsenic, barium, and manganese in transition zone water (TZW).

[1] The focus of this analysis is on current loading terms to the Study Area and current in-river fate and transport processes. It is recognized that each loading term has a corresponding historical component that may be very significant to the Study Area; however, limited quantitative data are available to support estimates of these historical terms. Therefore, historical loading is discussed only qualitatively in this Round 2 Report. Section 5 provides a qualitative discussion of some historical sources. Historical sources are discussed again in Section 11.1, relative to current loading terms, citing stratigraphy-based comparisons of sediment concentration statistics to support the discussions.

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2.0 UPSTREAM SURFACE WATER LOADING ESTIMATES

The mass loading rate of selected chemicals in surface water was estimated using a semi-quantitative approach as described in Section 7.1.1.1 of the main report, which details data sources, equations, and assumptions. The purpose of this exercise was to estimate the chemical mass flux entering the Study Area at river mile (RM) 11 via dissolved and suspended loads in upstream surface water. Additionally, the change in chemical mass flux was estimated over the Study Area at RM 6.3 and RM 4.

The results of these calculations (expressed in units of kg/year) are presented in this appendix for dissolved, particulate, and total loads for all sampling methods (XAD and peristaltic). Results for RM 4, RM 6.3, and RM 11 are presented in Tables D2-1, D2-2, and D2-3, respectively.

The loading rate estimates are also presented graphically in two ways: (1) loading rate as a function of river flow rate (Figures D2-1 through D2-5), and (2) loading rate as a function of location within the Study Area (by river mile) (Figures D2-6 through D2-10).[2]

Discussion of these results is presented in Section 11 in the context of the conceptual site model (CSM).

[2] The loading of polycyclic aromatic hydrocarbons (PAHs) presented in figures is limited to data obtained from XAD samples because the smaller volumes associated with peristaltic samples resulted in several undetected values. In addition, it should be noted that total dioxins/furans are expressed and reported as both total dioxin/furan congeners and total dioxin/furan homologs. The basis for this convention is the fact that the number of individual congeners used by the laboratory to calculate the homologs is greater than the number of individual congeners reported. Therefore, the loading rates of total dioxin/furan homologs are approximately one order of magnitude greater than the rates calculated for total dioxin/furan congeners.

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3.0 STORMWATER LOADING ESTIMATES

The approach to developing stormwater chemical loading estimates and the interpretation of results are summarized in Sections 7 and 11 of the main report, respectively. This appendix contains additional detail describing the approach and presents the calculation results in Table D3-1 for low-, mid-, and high- range estimates.

The loading calculations were conducted for the overall drainage basin to the Site, with no attempt to differentiate loads for various sub-basins or outfalls. The delineation of basins and associated characteristics is still in progress.

3.1 LOADING CALCULATION METHODS

Sufficient information currently exists on the overall Site drainage basin to make very general estimates of the volumes of water draining to the overall Site. Only very limited site-specific information on chemical concentrations in stormwater and suspended solids is currently available from a small number of sub-basins. Consequently, estimates of stormwater loads for this report are very generalized and are primarily based on available literature information.

Because the stormwater loading approach presented here is very general and includes numerous assumptions, a large range of possible loading estimates is presented with a discussion of associated uncertainties. This information was generated to provide insight into the relative potential importance of stormwater as a source and the need for further study.

As described in Section 7 of the main report, site-specific information on land use and drainage areas from Section 5 of the main report were combined with literature values on stormwater concentrations (augmented by site-specific values where available and applicable) for various chemicals and land uses to yield a range of loading estimates using the Simple Method[3] (Schueler 1987).

[3] Schueler's Simple Method was developed to help understand the relative contributions of various types of land uses for chemicals such as metals and nutrients and is not commonly applied to organic chemicals on the chemical of interest (COI) list for this Site. The method was originally intended for use in relatively small basins to evaluate the impacts of new developments on water quality. Thus, the Simple Method is not specifically designed for use in developing site-wide loads of toxic chemicals from large urbanized areas for a relatively large segment of a river. Despite these limitations, the Simple Method provides a means to calculate a range of potential stormwater loads using general site information and is a useful first step in understanding the potential importance of stormwater as a source to the site.

The Simple Method for estimating loads is determined from:

$$L = R * C * A$$

where:
L = Annual load (kg/yr)
R = Annual runoff per unit area (cm/yr)
C = Chemical concentration (mg/L)
A = Area (ha)

Unit conversion is necessary to yield units of kg. The R value is determined from:

$$R = P * Pj * Rv$$

where:
P = Annual rainfall (cm/yr)
Pj = Fraction of annual rainfall events that produce runoff (usually 0.9)
Rv = Runoff coefficient (unitless)

The P value was set at the annual average rainfall for Portland (42.54 in. = 107.63 cm), obtained from WRCC (2006), for all calculations. The value for A (area) was obtained from the overall drainage basin information presented in Section 5 of the main report (see Table D3-2). Rv was calculated based on a correlation relationship with impervious cover in the basin developed by Schueler (1987); these values are shown in Table D3-3. Impervious cover values were assigned to each land use category available from the Basin Characterization report based on SMRC (2006) urban data for such typical land uses (Table D3-3).

The value for C was obtained from a variety of stormwater pollutant studies. Table D3-3 shows values used in loading estimates. Tables D3-4, D3-5, D3-6, and D3-7 show the information sources for these values. The data reduction methods to determine the values used in Table D3-3 are further discussed below. Studies that examined concentrations from various types of land uses were associated with each of the land use categories available from Section 5 of the main report; these are shown in Table D3-2. The Simple Method calculation was conducted individually for each land use area, and these loads were summed to obtain a total load estimate for the Site drainage basin, as shown in Table D3-1.

The availability of pollutant loading data varies across the combined ecological and human health lists of initial chemicals of concern (iCOCs). The literature was initially reviewed to determine which chemicals were relatively well-represented in the literature. Based on this review, all readily available data were compiled on the following chemicals: arsenic, copper, lead, mercury, zinc, bis(2-ethylhexyl)phthalate (BEHP), dichloro-diphenyl-trichloroethane (DDT), polycyclic aromatic hydrocarbons

(PAHs), polychlorinated biphenyls (PCBs), and phenol[4]. In addition, stormwater total suspended solids (TSS) data were compiled from the literature so that information from in-line sediment trap chemical concentrations could be converted to water concentrations and included in the data set.

Stormwater investigations have typically focused on metals and nutrients; consequently, the number of available metals data points for each land use was usually in the hundreds. In contrast, there were typically only a few data points per land use for most of the organic chemicals, with some exceptions. The implications of any data set limitations for the overall evaluation are discussed in detail in Section 3.3.

The range of C values for each chemical and each land use was also considered by applying the maximum, median or mean (depending on the data source), and minimum reported values. The methods for utilizing literature values and assigning them to high, mid, or low categories for each land use type are further described below.

3.2 REVIEW OF LOADING CALCULATION TABLES

The land use categories come directly from the geographic information system (GIS) layers obtained from the sources noted in Section 3.3. Generally, these categories are self-explanatory, with some exceptions. For the purposes of this evaluation, "mixed use" is defined as a mixture of primarily residential and commercial areas. "Parks/open space" represents open and generally undeveloped areas that occur within the overall drainage basin (e.g., Forest Park, other parks). A review of the locations designated as "rural" within the overall drainage basin revealed that most of this area corresponds to the Balch Creek area, which is very similar to Forest Park in terms of actual land use. Given the similarities between parks/open space and rural designations within the Site drainage basin, these two land uses are treated similarly in the land use loading analysis. "Single-family" land use in the GIS information is equated to "residential" land use literature data for the purposes of this analysis.

Also, as noted in Section 4 of the main report, an additional land use category identified from national and local stormwater studies as having unique effects on stormwater is major transportation (e.g., highways and freeways). The City has conducted evaluations of actual transportation land uses (e.g., major arterials and highways) and prepared GIS overlays of these uses within the Site drainage, which have not yet been assessed by the Lower Willamette Group (LWG). Some refinement of the zoning-based land use maps used in this report is needed to define more accurately the coverage from major transportation land uses and will be conducted for the remedial

[4] Phenol was not identified as an iCOC or potential iCOC, but was included as an initial target analyte during the preliminary stormwater literature data research, and is included here to provide additional insight into the overall stormwater loading term.

investigation (RI). Currently, these transportation corridors are grouped with the other categories of land use shown in Table D3-2.

Table D3-2 contains the calculation of runoff volumes for each land use. Section 4 of the main report presents Table 7.1-3, which shows the acreages of land use within each identified basin and the total land use acreages for the overall basin draining to the Site. For the purposes of calculating runoff volumes to the river, controlled combined sewerage overflows (CSOs) and discharge to treatment were not included because most or all of the stormwater generated in these areas is diverted to treatment systems that do not discharge to the river. Uncharacterized areas and areas of known infiltration/sheet flow were assumed to contribute runoff to the river and were included in estimates of runoff volumes. Runoff volumes were obtained by multiplying the land use acreage in Table D3-2 by the annual runoff depth for each land use shown in Table D3-3 to obtain a total annual runoff volume in liters (using appropriate conversion factors).

Table D3-3 shows the physical and chemical data determined from literature for each land use. The following assumptions and reasoning were used to determine these values:

- "Physical Data" for each land use were derived from the sources noted in Section 3.3.

- The "Chemical Data" portion of the table shows the chemistry values used, including water data that were used directly and sediment trap or catch basin data that were used to estimate water concentrations based on a range of TSS values. Within this section of the table, the "Water Chemistry Data (mg/L)" portion utilizes values from stormwater chemistry measurements summarized in Tables D3-4, D3-5, and D3-6.

    - Because no "multi-family" data were available for most chemicals, values for "mixed use" were used as the closest approximation to this land use, unless otherwise noted. Mixed use is often a combination of commercial, institutional, and residential areas representing somewhat higher proportions of impervious surfaces than single-family residential. Multi-family use also tends to have higher impervious surface proportions, so this assumption appears to provide a reasonable first approximation of loading for these areas.

    - Similarly, because very limited "rural" data were available, values for "parks/open space" were used. As discussed above, within the overall drainage basin the actual land uses in these two categories are very similar.

- Mid-range TSS, copper, and zinc values come from local Portland studies shown in Table D3-5 (Association of Clean Water Agencies [ACWA]; Woodward Clyde 1997) and high and low values come from national studies shown in Table D3-4 (National Stormwater Quality Database [NSQD]; Maestre and Pitt 2005), unless otherwise noted. National studies were used for high and low values because the local study did not provide these values in a readily discernible format for these chemicals.

    - For the industrial mid-range values, an average of the ACWA "in-pipe" and "instream" industrial values was used.

    - For mixed use mid-range values, an average of the ACWA residential and commercial values was used, since a category similar to "mixed use" was not available from the ACWA study.

    - For mixed use low and high values, values from the NSQD "mixed residential" category were used because it appeared to be most similar to the definition for "mixed use" discussed above for this analysis.

- Arsenic, lead, and mercury values come from the NSQD study because summary information on these chemicals was not readily available from the ACWA study.

- BEHP stormwater data in Table D3-6 are extremely limited, with only two values for commercial, one for residential, and two general urban results. Consequently, several broad assumptions were made that allow for a limited differentiation of loads by land use:

    - The high and low values for commercial use were set based on the two available values, and the mid-range value for commercial was based on the midpoint general urban value.

    - Industrial and mixed land use values were set equal to commercial land use values except that the high industrial value was set equal to the maximum of the data set, which was from a general urban data source.

    - Park/open space and rural values were assumed to be zero for low, mid-range, and high.

    - The single-family (residential) mid-range value was based on the single available residential value, while the single-family low

value was set at half of the commercial value and the single-family high value was set at the average of the commercial mid-range and high values.

- DDT stormwater data (Table D3-6) were highly variable across studies and showed no patterns of consistently higher or lower values with a particular land use. Consequently, the low, mid-range, and high values across all studies were used for every land use except park/open space and rural, which was set to zero. Typically, agricultural areas would be expected to have higher legacy DDT levels, but since the vast majority of the "rural" land use within the overall basin does not appear to be former or existing agricultural lands, the zero assumption for this land use appears more appropriate.

- PAH data (Table D3-6) from Portland studies were used preferentially across all land use categories such that low and mid-range values came directly from Woodward Clyde (1993). However, high values from studies from other cities were used to recognize that higher range inputs are possible given the relatively limited data set from Portland studies. This approach was used for commercial, industrial, and single-family land uses. Only two park/open space values were available across all studies, so these were used as the high and low values for this and the rural land use categories. The mid-range value for parks/open space and rural use was set at the average of the low and high values.

- PCB stormwater data (Table D3-6) were also relatively limited, and most of the values came from one Swiss study (Rossi et al. 2004). There was considerable variability in PCB ranges across land uses, with substantial overlap among low values for all land uses, including results from samples of rainwater. This suggests that there is an ambient low level of PCBs in urban areas (including rainwater falling in these areas). Therefore, the same low value was used for all land uses. Mid-range and high values across all studies of industrial, multi-family, and single-family areas were used for the remaining loading values for these land uses. Mixed use and commercial loading values were set equal to multi-family values in the absence of more land-use-specific data. Rainwater values were used for mid-range and high open space/park and rural loading values. The end result of these extrapolations is that there is little differentiation between the different types of urban land uses (except industrial), particularly in the low and mid-range estimates (similar to DDT data set).

- Data for phenol (Table D3-6) were very limited, but not particularly variable across land uses, perhaps in part due to a large number of values at or near the detection limits of the studies. Because of this lack of differentiation, the phenol data were treated analogously to DDT (discussed above).

- The "Extrapolated Water from Sediment Data" portion of Table D3-7 contains water values that were determined by multiplying each literature sediment chemical concentration by a TSS concentration for stormwater (with unit conversions) to yield a concentration in mg/L. These calculated water values were used to augment the literature stormwater values. Consistent with the handling of stormwater values, extrapolated water values from sediment data for rural land use were set equal to the values available for open space/park. Similarly, multi-family values were set equal to the values available for mixed use.

- The "Water Chemistry Data" and the "Extrapolated Water from Sediment Data" were combined in Table D3-3, titled "Combined Ranges for Water." These final combined ranges were the concentrations used in the loading estimates in Table D3-1, and were determined as follows:

  - Because stormwater data sources for metals assumed zero for the low value, the sediment-extrapolated data were used to fill in the lower end of these metals ranges. The lowest available (non-zero) value for each chemical and land use from the "Extrapolated Water from Sediment" section was used as the low value for the "Combined Ranges" section of Table D3-3. This is based on the fact that the sediment-extrapolated metals concentrations estimates are, in most cases, quite low in comparison to available stormwater results.

  - Similarly, to obtain the combined low estimates of organic chemical concentrations, the lower of either water-based or sediment-extrapolated values was used. The same approach was used for high range combined estimates (i.e., the higher of either water or sediment-extrapolated values was used).

A review of the combined ranges in Table D3-3 used for the loading estimates reveals that in some cases the rank order of the chemical concentrations is counterintuitive, particularly for the low-range estimates. For many chemicals, the highest low-range estimates are for multi-family and mixed land uses, and industrial and commercial chemical concentrations are relatively lower. This is expected to be an artifact of the amount of data available for each land use type. Where relatively more data are available (e.g., industrial, residential, and commercial), more low outliers are available.

No adjustments were made to the low ranges in response to this observation, recognizing the overall uncertainty of the literature-based summed loading estimate.

Table D3-7 contains the extrapolation of water concentrations based on sediment and TSS data. The sediment data come from the studies shown in the columns to the right of the table. The TSS data come from data in Tables D3-4 and D3-5. Local ACWA data (Table D3-5) were used for all mid-range TSS values. Because the ACWA report cited does not include minimum and maximum (or similar) summary estimates for TSS, Table D3-5 (NSQD) TSS data were used for low and high estimates in Table D3-7.

3.3 LITERATURE DATA ISSUES AND REPRESENTATIVENESS

In cases discussed above, the literature data set for stormwater chemical concentrations is very limited. In general, a larger data set can be expected to provide a larger range of estimates, which would be more likely to encompass the possible conditions at this Site. Also, in many cases, the literature values were from national or international studies, as opposed to preferable (possibly more representative) local studies.

The representativeness of data sources for each of the chemicals evaluated is discussed below. In general, the discussion is organized by adequacy of the data sets, starting with chemicals for which more representative data sets were available.

3.3.1 TSS

TSS is a supporting measure in the calculation of water concentrations extrapolated from sediment data. In general, TSS is a fairly well understood parameter for stormwater runoff. The NSQD nationwide database is extensive and includes hundreds of samples for each of a variety of land use categories. In addition, considerable local data of the same type are available and summarized in the ACWA study. Readily available ACWA TSS data noted in Table D3-5 were used for mid-range estimates as discussed above. The national database in Table D3-4 was used for high and low estimates to allow for consideration of a wide range of potential conditions, whether they have been specifically measured in Portland or not. Given the robustness of both these data sets, TSS data are expected to be one of the least uncertain parameters in the stormwater loading evaluation.

3.3.2 Metals

Like TSS, metals are widely sampled both nationally and locally in stormwater. The numbers of samples and range of conditions sampled are very similar to the situation for TSS. Consequently, available local study mean values were used for mid-range estimates, and national data were used for high and low estimates to capture a wider range of potential stormwater loads.

A smaller data set, including a number of local measurements, was also available for metals in sediment and catch basin sediments. These data produced relatively low water concentration estimates that were useful for setting lower-bound metals concentrations. In addition, some of the local catch basin results contained some relatively high chemical concentrations (even after conversion to water values) that appear suitable for capturing the potential upper range of potential loads for some types of local industrial land uses.

It is expected that the estimated metals loading rates by stormwater encompass the actual loading rates for the Study Area. Further, the large number of data points from local studies available for mid-range estimates suggests that these estimates may be closest to actual loading rates for the Study Area, and the lower and upper range estimates are expected to be underestimates and overestimates, respectively.

3.3.3 PAHs

Although a considerably smaller data set was available for this chemical class as compared to metals, the total number of data points was much greater than for the other organic chemicals evaluated. In addition, local water and catch basin sediment data were available for PAHs. Catch basin sediment PAH data included some relatively high values associated with specific industrial sites. Further, the entire data set included a wider range of land uses than other organic chemical data sets. Consequently, this allowed determination for commercial, industrial, and single-family land uses based on local data. For other land uses, national and local data were either used directly or extrapolated. Similar to the approach for metals, the highest and lowest values available across national data and local data were used for high and low estimates to capture more of the entire potential range of site PAH loads.

Overall, the PAH data set is expected to be reasonable for estimation of stormwater loads to the Study Area. It is recognized that catch basin sediment data include some high PAH concentrations, and it is expected that the predicted range of stormwater concentrations may be exceeded at some local industrial sites that represent larger upland sources of PAHs. However, the total stormwater runoff load of PAHs to the Study Area is still expected to be captured by the range of estimates provided.

3.3.4 Other Organic Chemicals

The data sets for BEHP, DDT, PCBs, and phenol are similar in that they have relatively limited and sporadic available data from a small number of studies. In each case, the loading estimates rely on a few data points that do not encompass the land use categories established for this effort. Consequently, broad assumptions regarding the range of values (low through high) were made and often applied regardless of land use type. Thus, the estimates for these chemicals are far more uncertain than for the chemicals discussed above.

BEHP, phenol, and particularly DDT were widely sampled for the Portland National Pollutant Discharge Elimination System (NPDES) stormwater studies in the 1990s; however, they were detected only a few times each. For DDT in particular, this lack of detection is an artifact of limitations in laboratory detection limits. Similarly, other studies reported only a few detections; thus, the range of values within the overall data set appears to be determined mostly by detection limits. Further, in the case of one study (Parker et al. 2000), some of the higher DDT concentrations observed appear to be related to historical agricultural land uses, as opposed to current land uses. As such, the overall range of loads for general urban land uses may be overestimated to some extent by these loading estimates. However, it should be cautioned that specific industrial sites that are not included in these data sets may routinely exceed the ranges used in this evaluation for these chemicals and may be important contributors to the overall Site load.

The PCB data set is slightly more robust due to one extensive study conducted in Switzerland (Rossi et al. 2004). This study included detailed evaluations of several types of land uses as well as rainwater. This study found that there was a general "ambient" load of PCBs from air deposition in the urban areas studied and a pattern of increased loading for some specific land uses. This observation was used to set a minimum PCB concentration for all land uses (even open space) in Portland Harbor and to set the upper-range estimates of PCB concentrations for some land uses. However, the extent to which conditions in Switzerland may apply to Portland are unknown and there may be regional or even global factors that could cause (1) more or less "ambient" load of PCBs in Portland and/or (2) different stormwater concentration patterns relative to various land use types.

3.4 CONCLUSIONS

The overall reliability of this evaluation for the purposes of decision making is somewhat limited. The stormwater loading estimates are used in comparison to other qualitative to semi-quantitative source loading estimates in Section 11.1 of the main report to support the primary purpose of the Round 2 Report: data gaps identification for the RI. In this respect, the above loading analysis is useful for identifying the importance of stormwater as a loading term for metals and potentially PAHs, relative to other evaluated loading terms. For the organic chemicals evaluated, a very large range of loading estimates was generated, due to data limitations and necessary assumptions. Therefore, for these organic chemicals, this analysis is sufficient to identify that site-specific stormwater concentrations for these chemicals are likely needed to better understand the importance of stormwater loading relative to other potential sources.

4.0 GROUNDWATER LOADING ESTIMATES

The following subsections present the approach and results of calculations to estimate the effect of groundwater on loading (and transfer) of chemicals to (or within) the Study Area. Section 4.1 presents the approach and results of an assessment of the annual loading rate of chemicals to the water column originating from upland groundwater plumes. Section 4.2 presents the approach and results of an assessment of the loading from the entire Study Area to the water column of chemicals originating in sediment through the processes of desorption and advection.

4.1 UPLAND GROUNDWATER PLUME LOADING ESTIMATES

This section presents approach details, calculations, and results of the upland groundwater plume loading estimates generally described in Section 7.1.3. For each of the nine TZW study sites investigated during Round 2 (see Section 4 discussion), groundwater chemical loading rates to surface water were calculated to provide estimates of loading from upland groundwater contaminant plumes to surface water.

As discussed in Section 7.1.3, these estimates assume that observed TZW concentrations are entirely attributable to upland groundwater. In some cases, the only likely pathway for a chemical to enter the transition zone is via the groundwater pathway, originating from upland groundwater plumes (e.g., certain site-specific groundwater volatile organic compounds [VOCs]). For this situation, these loading estimates are expected to be reasonably good approximations of mass loading from groundwater plumes to surface water. In contrast, many chemicals observed in TZW (e.g., PAHs, DDT) have in-river sources as well as upland groundwater sources. For these chemicals, the estimates provided here are likely to be highly conservative overestimates of the total loading to surface water from upland groundwater plumes.

4.1.1 Data Sources

As described in Section 7.1.3, data provided in the Groundwater Pathway Assessment Transition Zone Water Site Characterization Summary Report (GWPA TZW SCSR) (Integral 2006) were used to generate the plume loading estimates. Specifically, three types of information were used:

1. Measured TZW chemical concentrations from 127 sample locations at the nine study sites were used to estimate chemical concentrations. These samples represent the complete data set for the sample depth interval from 0 to 38 cm below mud line (bml) (see Map 2.1-4). The sampling methods included in this data set are small-volume peepers, Trident, and Geoprobe®. Both unfiltered and filtered (where available) results were evaluated.

2. Seventy flow-meter measurements (24 hour, 15-minute interval records from ultrasonic seepage meters capable of positive and negative readings) were used to estimate groundwater flux. The 24-hour average seepage rates are presented spatially on Map D4-1. In the design of the TZW study (Integral 2004), seepage meters were purposefully placed at locations where there was an indication (based on Trident temperature measurements, sediment texture, or screening results) of higher flow rates. As such, the seepage meter measurements are expected to be biased high.

3. Twenty-eight site-specific flow zone areas generated from interpretation of multiple lines of evidence, including TZW chemistry results, seepage meter data, discharge mapping temperature data, sediment textures, sediment chemistry, and upland stratigraphy, were used to group data sets for the calculations. These flow zones are presented with discussions supporting the interpretations in the GWPA TZW SCSR (Integral 2006). The zones[5] are also presented in this appendix in support of the approach discussion that follows.

4.1.2 Approach

As generally described in Section 7.1.3, groundwater plume chemical loads to surface water were estimated based on observed TZW chemical concentrations and seepage meter flow rates. Loading estimates were prepared for each flow zone area using the following general equation:

$$\text{Load (kg/yr)} = C\ (\mu g/L) \times Q\ (ft^3/yr) \times 28.32\ (L/ft^3) \times 10\text{-}9\ (kg/ug)$$

where C is the chemical concentration in the TZW and Q is the groundwater discharge flow rate to surface water. The total loading estimates for the nine study areas were generated by summing the loading estimates for each individual flow zone. The analyte list considered for these loading calculations is described in Section 7.1.4.1 of the main report and includes the analytes presented in Table 7.1-5.

The approach to estimating concentrations and flow rates within each flow zone is presented in the following subsections.

[5] The flow zones defined for the Gasco site in the GWPA TZW SCSR (Integral 2006) were indeterminate; due to the concurrent in-river remedial action, access limitations prevented completion of the planned Round 2 sampling and seepage measurement at the Gasco site. To allow for estimation of loading rates over this area, the flow zones designated at the Gasco site in the GWPA TZW SCSR (Integral 2006) were extended over the unstudied area to provide more complete spatial coverage of the offshore area at the site. These interpretations are presented graphically in Appendix D Figure D4-3. It is recognized that this approach adds uncertainty to the loading estimate by requiring extended inference of the concentrations and flow rates.

4.1.2.1 TZW Concentrations

As described above, TZW sample data from the sample depth interval from 0 to 38 cm bml were used as the concentration terms in the loading calculations. These data were assigned to flow zones based on sample location. For flow zones containing multiple TZW samples, Thiessen polygons[6] were developed around each TZW sample location within the flow zone. The concentration of each sample was then applied to the corresponding partial area of the flow zone. The flow zones, TZW samples, and corresponding Thiessen polygons are presented in Figures D4-1 through D4-7.

In a small number of cases, more than one TZW sample was collected at a single location for a given analyte. In this case, the maximum observed concentration was used in the calculations. Chemical concentrations below laboratory reported detection limits were assigned a value of zero. Additionally, if an analyte was not sampled at a given location (i.e., not on the site-specific Round 2 TZW analyte list because it was not an analyte of interest for the groundwater pathway), loading estimates for the flow zones associated with that site were not generated.

The approach to assigning TZW concentrations to Thiessen polygons was modified in two cases to adjust for potential outlier concentrations that dominate the loading estimate and obscure the uncertainty associated with the overall estimate. Specifically, at Arkema sampling location AP03B, the measured concentration of chloroform in TZW was 770,000 µg/L, which is more than three orders of magnitude higher than the next highest sample result for chloroform (AP03D, 580 µg/L; see Figure D4-5). The Thiessen polygon area corresponding to location AP03B is ~3,400 ft^2, which is expected to be a significant overestimate of the area associated with this concentration. Similarly, TCE was measured at Siltronic sample location GP67 at a concentration of 88,500 µg/L, which is more than three orders of magnitude higher than the next highest sample in the same offshore area, GP68 (43.5 µg/L) (Figure D4-3). The Thiessen polygon area corresponding to location GP67 is ~1,800 ft^2, which is expected to be a significant overestimate of the area associated with this concentration. For both of these cases, the upper loading estimate was determined by applying the measured concentration and maximum flow estimate, following the approach prescribed throughout the TZW loading analysis for calculation of maximum load. To determine the lower loading rate estimate for chloroform and TCE, these concentration values were replaced with the second highest observed concentration at the given site, and the calculation was completed as prescribed for all other upland groundwater plume loading estimates. This modified approach produced a larger range of potential loading rates, which is considered to be a better representation of the uncertainty associated with spatial representativeness of the particular samples. The uncertainty represented by this

[6] Thiessen polygons are formed as a network of polygons generated around seed points. In this case, the seed points are sampling locations. The polygon around each seed point delineates all areas that are closer to the seed point than any other seed point.

large range also highlights the influence of individual high concentration TZW samples to greatly influence the loading estimate.

To assess the effects of filtration, calculations were performed with both unfiltered and filtered data sets[7]. The unfiltered data set consisted of unfiltered push-probe (Trident and Geoprobe®) samples, as well as small-volume peeper samples. The filtered data set consisted of the available 0.45-µm filtered push-probe sampling results and the small-volume peeper results. Due to sample volume limitations, filtered Trident chemical concentrations were not collected for all analytes at all locations. Therefore, at these locations, to generate a complete data set for estimation of the filtered load, the collocated unfiltered push-probe chemical concentration was assigned (considered a conservatively high concentration estimate for the filtered concentration).

4.1.2.2 Groundwater Discharge Flow Rates

In each flow zone, loads were calculated for both mean and maximum flow rates to produce a range of loading estimates. Mean and maximum observed seepage flux rates (q_{mean} and q_{max}) were assigned to each flow zone based on available seepage meter data within each zone. In order to apply conservatively high discharge rates to the loading estimates, seepage meter locations with negative average seepage rates (i.e., net recharge from the river to the groundwater) were not included in the estimation of the q_{mean} for each flow zone. Of the 28 flow zones identified offshore of the nine study sites, five did not include direct seepage meter measurements. Flow rates were applied to these five zones using professional judgment, based on flows in similar or adjacent zones.

Mean and maximum seepage meter flux rates (q_{mean} and q_{max}, in units of cm/d) were converted to annual flow rates (Q_{mean} and Q_{max} in ft^3/yr) for each sample polygon area, according to the following equation:

$$Q\ (ft^3/yr) = q\ (cm/d) \times A\ (ft^2) \times 0.03281 (ft/cm) \times 365\ (d/yr)$$

Table D4-1 summarizes sample polygon areas, mean and maximum groundwater flow rates, and calculated groundwater discharge volumes.

4.1.3 Results

Based on the calculations described above, loading estimates for each analyte were generated for the mean and maximum flow rate conditions for both filtered and

[7] Following sample collection protocols, filtered samples of VOCs, total petroleum hydrocarbon (TPH) gas, perchlorate, and cyanide were not collected. For these analytes, filtered data loading estimates were not generated.

unfiltered data. Therefore, a total of four sets of loading estimates were produced. These results are presented in Table D4-2.

Loading calculation results indicate that the range in seepage rates (Q_{mean} and Q_{max}) applied to the calculation causes, on average, a difference in total estimated load of only 32 percent, ranging from a difference of 1.4 percent to 59 percent for all 76 analytes, filtered and unfiltered. Loads calculated with Q_{max} were greater than loads calculated with Q_{mean} in all cases. Further, the difference between filtered and unfiltered total loads averages 31 percent, with a range from 0 percent to 91 percent for all 76 analytes, using both Q_{mean} and Q_{max}. In all but three cases (magnesium, mercury, and sodium), unfiltered total loads were greater than or equal to filtered total loads. Based on this analysis, total loads calculated with maximum estimates of flow rates and unfiltered concentrations provide the upper bound of possible upland groundwater plume loads to TZW. Use of filtered TZW concentrations and mean flow rates provides a lower, but possibly more realistic, estimate of total loads.

These estimates are considered conservatively high approximations of upland groundwater plume loading to surface water for the following reasons:

- Because there is no attempt made in these estimates to distinguish the origin of the chemicals in the TZW, the calculations are expected to be overestimates of upland plume loading to surface water for chemicals that also have other sources, including partitioning from sediments (e.g., polycyclic aromatic hydrocarbons [PAHs], pesticides, metals, and others).
- The ranges of discharge rates applied to the calculations were purposefully selected to represent the high end of observed seepage rates. As described above, this included generation of mean flow rate values that excluded all negative (recharge) seepage meter results.
- Selective placement of seepage meters in locations of expected high groundwater flow creates a high bias for discharge rates.
- The TZW concentration estimates do not account for any additional chemical attenuation to sediments that may occur in the upper 38 cm bml.
- Unfiltered results were considered (even in the filtered set, where filtered results were unavailable), and these values are expected to overestimate mobile TZW concentrations for hydrophobic analytes including pesticides and PAHs.
- Similarly to the bias inherent in the seepage meter placement, TZW samples were, by design, preferentially collected in locations where higher chemical concentrations were expected. This sampling design is likely to lead to an overestimation of loading rates because these concentrations were applied to larger (polygon) areas.

4.2 GROUNDWATER DISCHARGE ADVECTIVE LOADING ESTIMATES

This section presents the estimation of loading of selected chemicals to surface water by the mechanism of groundwater advection through contaminated sediments. This process is differentiated from the groundwater plume loading estimates (presented in Section 4.1 of this appendix) in that upland groundwater plumes are not considered the source of the chemicals loading to surface water. As such, the groundwater advection term is considered an in-river fate and transport process, moving chemicals from sediment into surface water (described further in Section 7.2.1.3.2 of the main Round 2 Report).

The approach to estimation of the groundwater advection term for select chemicals is presented in the following subsections. The results are also presented. A detailed discussion of the results, in the context of other loading terms and fate and transport processes in the river, is described in the CSM section of the main report (Section 11.1).

4.2.1 Approach

The advective loading term was estimated here using sediment concentrations, equilibrium partitioning calculations, and estimated groundwater flux rates to produce a kg/yr loading rate for the Study Area for the analytes presented in Table D4-5.

4.2.1.1 Sediment Chemical Distribution

Thiessen polygon GIS maps were used to represent the chemical distribution in sediment over the Study Area. Each Thiessen polygon map comprises a complete network of polygons covering the entire Study Area (from RM 2 to RM 11), with each sediment sample represented by a single polygon. Because not all chemicals were measured at each sample location, the number and size of polygons for each chemical may differ, though the total area delineated always corresponds to the water surface area of the entire Study Area (~91,524,000 ft^2). For a detailed discussion of the generation of the Thiessen polygons, see Section 9 of the main Round 2 Report.

Two approaches, or discharge area models, were used to estimate a range of sediment areas over which discharge may be occurring. The first discharge area model (entire river model) assumes uniform discharge of groundwater to the entire surface area of the river from RM 2 to RM 11 (equivalent to the entire surface area of the Thiessen polygon sets, or approximately 91,524,000 ft^2). The second discharge area model (navigation channel excluded model) assumes that all groundwater discharge occurs in nearshore areas from the water's edge to the navigational channel boundary. (This assumption was based primarily on the shape of the channel cross-section.) To calculate the sediment area in this model, only those channel areas (and associated Thiessen polygons) lying outside of the navigation channel were considered. Figure D4-8 shows an example of the Thiessen polygon layer for benzo(a)pyrene (BAP), with the navigation channel region shaded in blue. The total Thiessen polygon area

excluding the navigation channel was determined to be approximately 43,090,000 ft^2. Consideration of both discharge area models yields a range of chemical mass flux estimates.

4.2.1.2 Porewater Concentration Estimates

An assumption of equilibrium[8] was made to estimate porewater concentrations (C_{TZW}) from sediment concentrations (C_{sed}), applying the organic partitioning coefficient for the chemical (K_{oc}) and the fraction of organic carbon in the sediments (f_{oc}). The equilibrium relationship is described by the following equation (see Section 7.2.2.1.1 in the main Round 2 Report for additional discussion):

$$C_{sed} = K_{oc} f_{oc} C_{TZW}$$

Because the sediment concentrations in the Thiessen polygons are bulk chemical concentrations (including the total mass of sediment and porewater in the bulk sample), the concentration must be corrected to generate the sediment concentration (C_{sed}). This requires assumption of equilibrium and consideration of the fraction of total solids in each sample. The following equation relates the bulk sediment concentration to the concentration in the porewater and sediment:

$$C_{bulk} = C_{sed} \cdot \frac{\%solids}{100} + C_{TZW} \cdot \left(1 - \frac{\%solids}{100}\right)$$

Replacing the C_{sed} term with the equilibrium partitioning relationship and solving for C_{TZW} produces the following equation, which can be used to estimate the porewater concentrations from the bulk sediment concentration:

$$C_{TZW} = \frac{C_{bulk}}{1 + (K_{oc} f_{oc} - 1) \cdot \frac{\%solids}{100}}$$

From this equation, values for K_{oc}, f_{oc}, and percent solids are needed. K_{oc} values are chemical-specific and were developed by compiling literature K_{oc} values for each analyte. Literature values were compiled from the following sources:

- EPA Soil Screening Guidance (EPA 1996b)
- ORNL Risk Assess Info System (ORNL 2006)

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[8] Because arsenic is not expected to behave according to organic matter partitioning theory, K_{oc} equilibrium estimation of the TZW concentrations is not appropriate for this analyte. A detailed analysis of arsenic geochemistry in TZW is presented in Appendix E, Section 7. Based on the results of this analysis, the median observed TZW concentration for arsenic was applied uniformly to all polygons.

- ATSDR K_{oc} values (ATSDR 2006)
- Others including EPA (2003), Hilal et al. (1994), Di Toro et al. (1991).

Recognizing the significant variability in published K_{oc} values for many of the analytes, the compiled values were assessed to identify a range of K_{oc} values to apply to each calculation. The compiled K_{oc} values and applied ranges are presented in Table D4-4.

Values for f_{oc}, and percent solids were retrieved from the site characterization and risk assessment (SCRA) database for each sediment polygon and linked in GIS to support the calculations. For samples that did not have reported f_{oc} values, f_{oc} values were assigned using spatial overlay and assignment of correlated values from the PCB data set (which contained complete coverage of f_{oc} measurements). Where percent solids values were missing, the maximum percent solids values for the data set were applied. This assumption was made to err on the side of generating conservatively high estimates of concentration in porewater.

It should be noted that C_{bulk} concentrations reported as non-detect were assigned a value of zero for the purposes of these loading calculations. For totaled concentrations (e.g., total PCBs), the summing rules for the risk assessments were first applied to generate the total concentration, then concentrations were set to zero only if all analytes in the sum were below detection limits.

4.2.1.3 Groundwater Discharge Rate Estimates

The groundwater discharge rate estimate was generated by making simplifying assumptions, reviewing available hydrogeologic data from the CSMs, and applying Darcy's Law to generate an estimated total discharge rate to the river.

Two assumptions are inherent in the use of these Thiessen polygons for estimation of loading to surface water by groundwater advection. First, it is assumed that actual concentration variations within each polygon are minimal and the variability in sediment concentrations is adequately captured by the sampling design. Second, it is assumed that projecting the actual sediment surface area (at the angle of the mudline) to the river surface does not significantly change the chemical distribution represented by the polygons. Both of these assumptions are considered reasonable for calculation of advective groundwater loading to surface water.

It was further assumed for the loading calculations that groundwater discharges uniformly through sediments. It is recognized that this assumption is not a true representation of reality, and that discharge rates are a function of sediment texture and stratigraphic pathway; however, for a first approximation of this loading term, the assumption is considered reasonable.

The current CSMs and CSM addenda were reviewed to compile the hydrogeologic information presented in Table D4-3. Specifically, the CSMs were reviewed for the following types of groundwater information presented, where available, for each site:

- Number of wells
- Aquifer units present
- Groundwater flow direction
- Depth to groundwater
- Depth of the aquifer(s)
- Saturated thickness
- Horizontal gradient
- Vertical gradient
- Hydraulic conductivity
- Transmissivity
- Groundwater velocity.

Darcy's Law describes the relationship between groundwater flow rate (Q), the porosity of the medium (as represented by the hydraulic conductivity, K), the hydraulic gradient ($\Delta h/\Delta l$), and the cross-sectional area to the flow:

$$Q = -K*A*(\Delta h/\Delta l)$$

The unit flux (q) can be estimated as $q = Q/A = -K*(\Delta h/\Delta l)$.

Therefore, to estimate the total groundwater flow rate (Q) to the river, a representative hydraulic conductivity and hydraulic gradient are needed. Additionally, the total cross-sectional area perpendicular to the groundwater flow over the entire study area is needed. Based on information presented in Table D4-3, unit flux values were generated for unconsolidated alluvium by multiplying the reported hydraulic conductivity by the reported hydraulic gradient. The results unit flux values ranged from 0.003 ft/d to 1.92 ft/d. Discarding the lowest and the highest values, the unit flux values ranged from 0.0625 ft/d to 0.15 ft/d, with an average of 0.10 ft/d.

The cross-sectional area of flow was assumed to cover both banks of the river over the complete 9 miles of the Study Area. The average saturated thickness was conservatively assumed to be 60 ft (saturated thickness, as reported in Table D4-3 varies from <1 ft to >60 ft [the full depth of the channel]). Consequently, the cross-sectional area was estimated to be:

$$9 \text{ miles} * 5{,}280 \text{ ft/mile} * 2 \text{ river banks} * 60 \text{ ft} = 5.7E6 \text{ ft}^2.$$

Multiplying the average unit flux by the total cross-sectional area produces the estimated total flow rate of groundwater to the river within the Study Area of 5.7E5 ft^3/d (6.6 cfs). This value is the total flow rate divided evenly over the sediment polygons (and respective estimated TZW concentrations) to estimate the groundwater advective load to the river.

To determine a unit volumetric flux rate of groundwater through sediments under each discharge area model described above in Section 4.2.1.1, the total groundwater discharge to the river was divided by the surface area included in each model. The estimated unit volumetric flux applied to the discharge area model that includes the entire surface area of the river is ~1.1 ft/yr. The estimated unit volumetric flux applied to the discharge area model with the navigational channel excluded is estimated to be ~2.4 ft/yr.

The estimated groundwater discharge rate used in the advective loading calculations[9] was compared with the flow rates determined from the seepage meter measurements[10] as part of the groundwater plume loading estimates. The results indicate that, for the areas evaluated, the Darcy's Law estimate of unit discharge rate through sediments is roughly 20 percent of the unit discharge rate based on seepage meter measurements for groundwater plume discharge areas. The conservative nature of the seepage meter unit discharge estimates explains the disparity between the two flow estimates. First, in the design of the TZW study, seepage meters were purposefully placed at locations where there was an indication (based on Trident temperature measurements, sediment texture, or screening results) of higher flow rates. As such, the seepage meter measurements are expected to be biased high. Second, the mean flow rate values were generated by first discarding any negative seepage meter results (this approach was taken to purposefully generate conservatively high estimates to assess the groundwater plume loading term). Overall, the general agreement between the magnitude of unit flux rates developed using these two very different approaches to flow rate estimation is encouraging.

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[9] Specifically, the groundwater discharge rate used in the comparison was that calculated assuming groundwater discharge occurs primarily through sediments in the nearshore areas extending to the navigational channel.

[10] Of the range of flow rates applied to the upland groundwater plume loading calculations, the mean flow rates (excluding all negative seepage meter measurements) were used in this comparison.

4.2.1.4 Calculation of Mass Loading Rate to Surface Water

The two unit flux rates for the two assumed areas of groundwater discharge were used to estimate annual chemical mass loading rates to the river. For each Thiessen polygon, the unit groundwater flux rates were multiplied by the area of the polygon and by the estimated porewater concentration to produce an annual load for that polygon, using the following equation:

$$MassLoad_{polygon}(kg/yr) = C_{TZW,polygon}(\mu g/L) \times A_{polygon}(ft^2) \times q(ft/y) \times 28.32(L/ft^3)$$

Where C_{TZW} is the estimated chemical concentration in the porewater, A is the area of the polygon, and q is the estimated annual volumetric unit groundwater flux rate. The calculated load for each polygon was then summed to produce a harbor-wide annual load estimate for each model discharge area and the range of K_{oc} values.

4.2.2 Results

Table D4-5 summarizes the results of these calculations. Some trends are apparent from Table D4-5. First, the variability in the available K_{oc} values for a given chemical has a significant influence on the range of load estimates for that chemical. Load estimates for some chemicals (e.g. aldrin, dieldrin) span three orders of magnitude, matching the span of literature K_{oc} values for those chemicals. The load estimates for other chemicals (e.g., BEHP and the hexachlorocyclohexane [HCH] group) are less variable, again reflecting the narrower range of K_{oc} values reported in the literature for those chemicals.

The sensitivity of the loading estimates to the groundwater discharge area is also evident. When groundwater discharge to the whole river is assumed, the estimated load is typically lower when compared to the estimated load using only the nearshore area. This result matches expectations based on the general trend of higher sediment sample concentrations closer to the shore. There are, however, several exceptions to this trend: total chlordanes, γ-HCH, BAP, total PAHs, and hexachlorobenzene all show higher total load estimates when groundwater is assumed to discharge through the entire river. Additional analysis of these results is presented in Section 11 of the main report.

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5.0 ATMOSPHERIC DEPOSITION LOADING ESTIMATES

As described in Section 7.1.4 of the main report, atmospheric deposition is a potential source term for loading of initial chemicals of concern (iCOCs) to the Study Area. This section presents the analysis performed to generate qualitative to semi-quantitative air deposition loading estimates, including the detailed approach, data sources, results, and a discussion of uncertainty. Air deposition to land, which could subsequently be transported to the Study Area via stormwater runoff, is not included in this analysis and is considered as part of the stormwater analysis (Section 7.1.2 of the main report). Additional literature information about the mechanism of atmospheric loading can be found in a variety of references including Wesley and Hicks (2000), Seinfeld and Pandis (1998), and Bidleman (1988).

5.1 APPROACH

As discussed in Section 7.1.4 of the main report, atmospheric deposition is the sum of both wet and dry deposition rates. Under conditions of no precipitation, gases and particles are deposited to the Earth's surface in a process known as dry deposition. During precipitation events, gases and particles can be scavenged by rain droplets, frozen precipitation elements (freezing rain or snow), or fog droplets that deposit to the surface. This latter process is known as wet deposition. The following subsections present the details of the approach applied to assess dry and wet deposition loading to the Study Area.

5.1.1 Dry Deposition

The flux of an analyte to a surface from dry deposition can be estimated as

$$F_i = v_{d,i}\, C_i\, A$$

where F_i is the mass flux to the surface (kg y^{-1}) for species *i*, $v_{d,i}$ is the deposition velocity (cm s^{-1}) for species *i*, C_i is the bulk air concentration of species *i* (μg m^{-3}) measured at some reference height from the depositing surface, and A is the surface area (m^2) (Seinfeld and Pandis 1998). (Note that unit conversions are necessary to ensure dimensional consistency.)

The deposition velocity term parameterizes the fundamental processes that transport a depositing species to the surface. The rate at which a species is deposited to a surface depends on the level of atmospheric turbulence, chemical properties of the depositing species (e.g., molecular diffusivity, water solubility, and vapor pressure) and properties of the surface. Gases may absorb reversibly or irreversibly to the surface; the same is true for species loosely absorbed to particles (i.e., species that could be removed from the particle by reaction with the depositing surface). Particles—and thus species tightly

bound to particles—will adhere to the surface; particles deposited to water will be subject to the general processes affecting suspended solids.

Of the three terms used in the calculation of mass flux to the study area surface,[11] the surface area is known with the greatest certainty and has the smallest temporal variability (varies a few percent at most with seasonal flow rates and tidal changes). Because of the number and complexity of the physical and chemical processes embedded in the deposition velocity parameter, this term can be difficult to specify properly (Seinfeld and Pandis 1998). In particular, most measurements of deposition velocity are made on engineered surfaces or land; extrapolation to natural water surfaces is uncertain (Rathbun 2000). Concentration is also difficult to specify as it can vary temporally and spatially, sometimes considerably. Concentration can be estimated through measurements or models, both of which have associated uncertainties. The general approach used in this section to estimate mass flux to the Study Area is to capture the uncertainty and variability of both the deposition velocity and concentration by employing a set of estimates for each parameter meant to express a central tendency and an upper- and lower-bound estimate.[12] These results are reported in Appendix E, Section 5.4. The upper-bound estimates of deposition velocity and concentration are combined to provide an upper-bound estimate of mass flux; an analogous procedure is used to provide a lower-bound mass flux estimate. Given the uncertainty and variability inherent in each of the input parameters, where a central estimate can be provided, this estimate is uncertain at least within the upper- and lower-bound ranges presented.

5.1.2 Wet Deposition

For certain analytes, wet deposition can be an important term in total atmospheric loading. Three fundamental steps describe the wet deposition process: 1) transport of the species (gas or particle) to the precipitation element; 2) uptake (or "scavenging") of the species by the precipitation element; and 3) delivery of the species to the Earth's surface. Accurate determination of wet deposition flux is significantly more challenging than for dry deposition for several reasons. First, almost all of these processes can be reversible. For instance, particles scavenged by rain droplets may be re-aerosolized by evaporation of the rain droplet during its descent to the Earth. Second, these processes occur across a huge range of physical scales (e.g. from oxidation/reduction [redox] reactions within rain droplets to macroscale processes such as synoptic weather). Third, the presence of multiple phases of both precipitation elements and chemicals can affect the rate of uptake of the species by a precipitation element by orders of magnitude (Poster and Baker 1996). Finally, the size of particulate analytes and precipitation

[11]The Study Area surface is assumed to be the river water surface from RM 2 to RM 11; i.e., riverbanks and upland zones are not included.

[12]The surface area of the Study Area is treated as a point estimate in these calculations, ignoring any potential variability and uncertainty in its estimation.

elements greatly influences the rate of precipitation scavenging. For these and other reasons, Seinfeld and Pandis (1998) have called wet deposition "one of the most complex atmospheric processes."

Owing to the complexity of the wet deposition process, semi-quantitative estimation of wet deposition loading for all target analytes was not feasible within the scope of the Round 2 report. However, a preliminary accounting of the importance of wet deposition is presented relative to the estimated dry deposition estimates, based on results from other studies (see Section 5.3 of this appendix).

5.2 DATA SOURCES

An online search for dry-phase particulate deposition velocity values employed Google Scholar and the search engine for the journal *Environmental Science and Technology*. The ideal estimate of v_d is species-specific and based on evaluation of deposition to a water surface. Both measured and modeled values of v_d were considered. Estimates of deposition velocity of all target analytes to water were not available. For target analytes without estimates for deposition to water, available estimates of deposition to land were utilized. For analytes without any species-specific estimates, EPA guidance was consulted for default ranges of deposition velocity (typically to a land surface) for groups of similar analytes, including pesticides, dioxin/furan congeners, organic pollutants, and PAHs (EPA 2005). Where EPA guidance was not available for a group of analytes, scientific judgment was used to estimate a range of reasonable deposition velocities.

Deposition velocities were available through a primary or secondary source for all analytes except some metals. As metals will preferentially adsorb to particles, and particle deposition velocity only depends on particle size (i.e., mean mass diameter), which is well-constrained, there is strong scientific basis for the range applied. Table D5-1 reports the range of estimates of deposition velocity for all target analytes for which primary or secondary sources or scientific judgment provide a reasonable basis for the preliminary estimation of mass flux to the study area, as well as the source of each estimate. Where available, the surface type, location of the v_d measurement, and other relevant details of the estimate are noted in the table.

An online search was conducted to obtain relevant ambient air concentrations of target analytes. Preference was given to data sources in the following order:

1. Measured pollutant concentrations in Portland, primarily from the Department of Environmental Quality (DEQ) LASAR database
2. Concentrations modeled in EPA's National Air Toxics Assessment (NATA) database based on 1996 and 1999 emissions inventories

3. Concentrations obtained from an EPA database of measurements made in two rural counties in Oregon (Linn and Klamath counties)

For certain iCOCs (PCB toxic equivalent concentration [TEQ], dioxin TEQ, dieldrin, DDE, and DDT), no measured or modeled concentration estimates were available in Oregon. In order to make approximate, preliminary atmospheric loading estimates for these species, concentrations measured in urban areas of California (PCB TEQ and dioxin TEQ), and locations in Michigan (dieldrin, DDE, and DDT) were used, with preference given to the most recent available concentration estimates. Table D5-2 reports the range of concentration estimates and data sources for all target analytes for which data were available. Also noted are the year of estimate and its sampled or modeled location.

5.3 RESULTS

Table D5-3 reports the estimates of atmospheric dry deposition loading rates to the Study Area. For most analytes, Table D5-3 provides minimum, maximum, and central tendency estimates of dry deposition loading. For a few species, due to data limitations, only a single estimate could be made. Comparisons of these estimates of atmospheric loading to other loading terms are provided in Section 11.1 of the main report.

The atmospheric loading estimates presented in Table D5-3 do not include wet deposition loading. Applying analyses conducted in other locations, the degree of underestimation can be evaluated for a few species. For PAHs, studies on the Great Lakes have estimated wet deposition to contribute 10-25 percent to total atmospheric loading (dry plus wet deposition) (McVeety and Hites 1988; Franz et al. 1998). For PCBs, wet deposition loading to the Great Lakes has been estimated to be 5-20 percent of total atmospheric loading (Franz et al. 1998). On the other hand, for dioxins and furans, a study in Germany estimated that wet deposition accounted for 50-85 percent of total atmospheric deposition (Schroder et al. 1997). Therefore, while the estimates of dry deposition loading presented here do not include wet deposition loading, for PAHs and PCBs the increase from wet deposition appears to be modest, and for dioxins, the net result should be within a factor of 2-4. For other analytes, additional investigation would be needed to assess the additional loading from wet deposition.

In order to further examine atmospheric deposition loading to the Study Area, the potential impact of revolatilization was tested for two organic pollutants—benzene and 1,2-dichlorobenzene—that exhibit a range of volatility (as expressed by their Henry's Law constants). Employing an approach recommended by EPA (EPA 2005), a first-order volatilization rate from the river surface was estimated. Impact of volatilization was evaluated for low and high river flow conditions, in which the transport times

through the Study Area are estimated to be approximately 80 and 13 hours, respectively.[13] In both scenarios, the VOCs were assumed to be fully mixed through the full depth of the water column. Entering the volatilization rates for each analyte into the equation for time-varying concentration of a pollutant undergoing first-order decay (i.e., $C = C_0 \times e^{-kt}$), one can solve for the volatilization half-life of each chemical and for the proportion of initial concentration remaining in the river after transport through the Study Area under each flow condition. The calculated half-lives for benzene and 1,2-dichlorobenzene were 8.15 hrs and 24 hrs, respectively. Under low-flow conditions (i.e., relatively long residence time), nearly 100 percent and 90 percent of the initial concentrations of benzene and 1,2-dichlorobenzene, respectively, were estimated to volatilize within the 80-hour transport time. Under high-flow conditions (i.e., relatively shorter residence time), approximately two-thirds and one-third of the initial concentrations of benzene and 1,2-dichlorobenzene were estimated to remain in the river after 13 hours of transport. These estimates demonstrate that most of the VOC mass that enters the water column as a result of atmospheric deposition will be revolatilized over time scales representative of the transport time of river water through the Study Area. This underscores the importance of considering the subsequent fate and transport of atmospherically deposited analytes in providing perspective on the permanence of atmospherically deposited species.

5.4 DISCUSSION OF UNCERTAINTY

For many analytes, there is considerable uncertainty in the presented estimates of dry deposition to the Study Area. The simple equation for calculating dry deposition flux belies the complexity of the topic. The lack of site-specific, analyte-specific, and temporally-proximate data inputs also places significant limitations on making accurate estimates. Our approach to evaluating uncertainty is to estimate low and high bounds using the best information available. However, even these bounds may not fully capture the range of potential loading for certain analytes. Additionally, the often large ranges can provide limited insight into the relevance of the loading term to the system.

The following list summarizes some of the uncertainties regarding the ambient concentration values employed in this report (see Table D5-2 for a detailed list of characteristics of the data source for each analyte):

[13]These transport times were based on the long-term hydrograph for the USGS Morrison Street Bridge gauge. Low flow is represented by ~10,000 cfs conditions and high-flow by ~60,000 cfs conditions. After calculating a distance-weighted average cross-sectional area of the river (~61,000 ft^2 based on data provided in Section 4.5 of the main report), river velocities of 0.05 and 0.3 m/s characterize the low- and high-flow conditions, respectively. For the 9-mile distance of the Study Area, average transport times characteristic of low- and high-flow conditions were estimated to be 80 and 13 hours, respectively.

- Old or distant data sources had to be used for some pollutants (analytes most affected: metals, VOCs, pesticides, dioxins, PCB TEQs)
- The low- or high-bound estimate for some analytes is defined by the detection limit (analytes most affected: VOCs, PAHs).

The following list summarizes some of the uncertainties regarding the dry deposition velocity values used in this report (see Table D5-1 for a detailed list of characteristics of the data source for each analyte):

- The estimates used for many analytes are not species-specific (analytes most affected: organic compounds, metals, PAHs, pesticides)
- The behavior of individual species within combined groups may differ from the group-average behavior (analytes most affected: PCBs, dioxins)
- Literature values were used for species that partition between the gaseous and particulate phase without assessment of whether the assumed partitioning from the literature source is reflective of conditions expected in Portland (analytes most affected: metals, PAHs, PCBs, dioxins)
- For those species in the particulate phase, site-specific knowledge of the particle size distribution was not assessed (analytes most affected: metals, PAHs, PCBs, dioxins)
- Due to limited data availability, dry deposition velocities to land were utilized for some species, whereas the deposition velocity to water could substantially differ (analytes most affected: organic compounds, metals, pesticides).

6.0 RIVERBANK EROSION DATA

Loading estimates for riverbank erosion are not being prepared as part of the Round 2 Comprehensive Report, as discussed in Section 7.1.6 of the main report. The LWG has reviewed multiple sources of information for potential bank soil chemistry results. These efforts included review of individual Site Summaries, summarization of beach and/or bank data collected by the LWG through 2006, and inquiry with DEQ for specific relevant site information. The data found to date are summarized in Table D6-1, and a detailed data flat file compiled for several sites is delivered electronically with this document (Attachment 1 to Appendix D). Map D6-1 presents the bank soil sampling locations sampled to date relative to the bank categories described in Section 7.1.6 of the main report.

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7.0 GEOCHEMICAL ANALYSIS OF ARSENIC, BARIUM, AND MANGANESE IN TRANSITION ZONE WATER

Transition zone water samples were collected in the fall of 2005 offshore of nine upland sites (ARCO, Arkema Chlorate Plant, Arkema Acid Plant, ExxonMobil, Gasco, Gunderson, Kinder Morgan, Rhone Poulenc, Siltronic, and Willbridge) along the Willamette River as part of Round 2 of the Portland Harbor Superfund Site remedial investigation (Integral 2006). Concentrations of arsenic, barium, and manganese were above human health and/or ecological screening levels in many of the TZW samples from all nine upland sites. The ubiquity of these metals/metalloids in TZW raises questions regarding whether their occurrence is a function of natural conditions (i.e., background) or the result of chemical releases to the Site. Chemical releases may be direct sources of metals (e.g., historical use of arsenical pesticides) or may alter geochemical conditions in upland groundwater, TZW, and/or sediments, leading indirectly to releases of metals by mineral dissolution. This appendix presents an analysis of the geochemical conditions likely affecting the solubility of these metals/metalloids in the TZW, with the objective of illuminating the likely controls affecting the origin, transport, and fate of the metals/metalloids in the subsurface environment of the Lower Willamette River.

7.1 GEOCHEMICAL CONTROLS ON METALS/METALLOIDS IN AQUEOUS ENVIRONMENTS

Geochemical processes often mediate the aqueous concentrations of metals/metalloids in groundwater and sediments. The most important geochemical processes for many metals/metalloids are mineral precipitation/dissolution reactions and chemical adsorption to the surfaces of aquifer/sediment grains. Depending on the geochemical conditions, these processes can act either as a source or a sink of aqueous-phase inorganic constituents. The relative importance of these processes in a given aqueous system is strongly dependent on solution chemistry and aqueous speciation, pH, and redox state.

7.1.1 Mineral Solubility

Inorganic chemicals can occur as ions, molecules, solid phases (minerals), adsorbed phases, or gases in the groundwater/TZW environment, with the relative distribution of chemical mass among these phases being a function of the system's thermodynamic energy and reaction kinetics. Thermodynamic constants, such as solubility products and equilibrium partition coefficients, describe the chemical energy of interaction between various chemical species and may be used to determine the relative distribution, or speciation, of the chemicals under thermodynamic equilibrium conditions. Ions in the groundwater/TZW environment will tend to distribute between aqueous, solid, and gas phases in a manner that minimizes the potential chemical energy

(i.e., they tend to move toward thermodynamic equilibrium). However, some reactions are kinetically limited and occur very slowly; and, as a result, may not exert a significant control on chemical concentrations in a transient environment (e.g., flowing groundwater/TZW).

Under thermodynamic equilibrium, a given mineral will tend to precipitate or dissolve depending on the presence or absence of the mineral in the sediment matrix and on the relative aqueous-phase concentrations of the individual ions that make up the mineral phase. As an example, the mineral rhodochrosite ($MnCO_{3(s)}$) precipitates (and dissolves) according to the following reaction:

$$MnCO_{3(s)} + H^+ \Leftrightarrow Mn^{2+} + HCO_3^-$$

The solubility of a mineral at equilibrium is defined by the mineral solubility product, or K_{sp}. For rhodochrosite, K_{sp} is defined by the concentrations of manganese (Mn^{2+}), bicarbonate (HCO_3^-), and the hydrogen ion (H^+):

$$K_{sp} = \frac{[Mn^{2+}] \times [HCO_3^-]}{[H^+]}$$

where the brackets denote activity (at low ionic strength, activity ≅ molar concentration) of the given species under equilibrium conditions. Therefore, at equilibrium, the concentration of manganese in groundwater or TZW in contact with rhodochrosite is a function of the solution bicarbonate concentration and pH.

The conditions of any solution can be described using the ion activity product, Q_{sp}. The ion activity product is defined in the same manner as the solubility product, only it is based on the actual activities of the species present, which may or may not be at equilibrium. The tendency for a mineral to precipitate or dissolve under specific conditions in the environment is described by the saturation index (SI), which is defined as follows:

$$SI = \log\left(\frac{Q_{sp}}{K_{sp}}\right)$$

SI values of 0 indicate that the water is in equilibrium with the mineral phase. Non-zero SI values indicate that the water is not at equilibrium. Positive SI values indicate that supersaturated conditions are present, and the tendency would be for the mineral to precipitate from solution. Negative SI values indicate undersaturated conditions and a tendency for the mineral (if present) to dissolve into solution. However, either under-

or oversaturated conditions may be maintained for long periods of time due to kinetic limitations.

Activity diagrams are a useful tool for evaluating likely aqueous and solid-phase geochemical controls on the speciation of a given metal/metalloid. These diagrams demonstrate the stability fields of minerals and aqueous species over a range of conditions. The two primary variables affecting aqueous geochemistry are the redox state, measured as Eh (or oxidation-reduction potential [ORP]), and hydrogen ion activity, measured as pH. One of the most common forms of activity diagrams are Eh-pH diagrams, where stability fields are plotted over a range of Eh values (typically -0.75 to 1.25 V) and pH values (0 to 14). These diagrams are used to illustrate the predominant aqueous and mineral phases that are the most stable thermodynamically and likely to be influencing metal/metalloid chemistry over a range of Eh and pH conditions.

Evaluation of potential geochemical controls on metal/metalloid solubility based on the specific water chemistry measured in a given water sample is a complex, multi-variate problem. Computer models, such as Geochemist's Workbench (GWB; Bethke 2006), are typically applied to assess geochemical conditions that are likely important for an observed water chemistry.

7.1.2 Adsorption Processes

Adsorption processes often exert significant limitations on metal/metalloid mobility in aqueous subsurface environments. Common adsorbents in natural systems include iron, aluminum, and manganese hydrous oxides; amorphous silicates; and organic material (EPRI 1984). Iron hydrous oxides are often of particular importance, as they are frequently present in environmental systems as amorphous mineral coatings on soil and sediment grains and are characterized by high surface areas. Iron hydrous oxides and other oxide minerals are amphoteric, meaning that their surface charges can vary from positive to negative as a function of solution pH. A result of this surface charge is that oxide mineral surfaces have the ability to complex with protons (H^+) and hydroxide (OH^-) ions from solution—favoring H^+ at lower pH and OH^- at higher pH. This results in the development of charged sorption sites capable of binding with ions, such as dissolved metals, due to electrostatic interactions. Cations (such as Ba^{2+}, Fe^{2+} and Mn^{2+}) are favorably adsorbed at higher pH values (which result in negatively charged oxide surfaces), while anions (such as AsO_4^{2-}) are more favorably adsorbed at lower pH values.

The affinity of metals/metalloids to adsorb to a given oxide surface and the influence of pH on adsorption efficiency vary by element and as a function of the water chemistry. Arsenic and barium are both known to adsorb to iron hydrous oxide minerals (Kabata-Pendias and Pendias 1992). Arsenic, which is typically present as an anion in environmental waters, is preferentially adsorbed under more acidic conditions; while

barium, which exists as a cation in environmental waters, is preferentially adsorbed under basic conditions (Stumm 1992).

Solution chemistry can significantly affect the tendency for a given metal to adsorb to mineral surfaces in the environment. For example, the formation of aqueous complexes can limit the availability of a given metal/metalloid for adsorption. Further, other ions may be present that can compete for the limited number of sorption sites on the mineral surface. A common example is competitive adsorption of phosphate (PO_4^{3-}) and arsenic. Phosphate and arsenic behave similarly in environmental systems, and it has been commonly observed that phosphate effectively competes with arsenic for ion adsorption sites (e.g., Peryea and Kammereck1997). This competition results in decreased sorption and increased transport of arsenic through the environment

7.1.3 Microbiological Interactions

Generally speaking, microorganisms gain energy through the process of respiration during which the microorganisms transfer electrons from organic carbon to a terminal electron acceptor (TEA). Oxygen is the most common and thermodynamically favorable of the TEAs, and aerobic respiration predominates in open systems (i.e., systems at equilibrium with the atmosphere). Because oxygen has limited solubility in water, it is often depleted in groundwater and TZW environments not in contact with the atmosphere. Frequently there is sufficient organic carbon present in these systems to support a reduced environment as microbial respiration shifts to an alternate TEA (i.e., anaerobic conditions). Common TEAs in groundwater systems, listed in order of energy potential, include nitrate (NO_3^-), ferric iron (Fe^{3+}), sulfate (SO_4^{2-}), and carbon dioxide (CO_2) (methanogenesis).

Owing in part to its abundance in subsurface systems, ferric iron (Fe^{3+}) is one of the more important TEAs from a geochemical perspective (Chapelle 1993). As discussed in Section 7.2.2 of this appendix, ferric iron (Fe^{3+}) is commonly present in saturated soil and sediment as hydrous oxide minerals. As microorganisms transfer electrons to Fe^{3+}, it is reduced to ferrous iron (Fe^{2+}), causing iron hydrous oxide to dissolve. This dissolution will result in the release of species sorbed to the mineral surface, including metals and metalloids such as arsenic. Similar to Fe^{3+}, oxidized forms of manganese (e.g., $MnO_{4(s)}$) can serve as TEAs, resulting in the reduction of Mn^{4+} and a release of Mn^{2+} from the aquifer/sediment matrix to the groundwater/TZW solution.

In the event that nitrate and ferric iron are depleted in a given groundwater/TZW system, sulfate-reducing conditions can be established. Under these conditions, sulfate (SO_4^{2-}), is reduced to sulfide (S^{2-}). When metal ions are present, sulfate-reducing conditions can result in the precipitation of highly insoluble metal-sulfide minerals.

Although iron-reducing and sulfate-reducing conditions can be associated with sites where degradable organic chemicals (e.g., petroleum hydrocarbons) are present,

reducing conditions frequently occur naturally due to influences of native organic carbon sources (e.g., organic matter in sediments and aquifer materials, infiltration of organic-rich water from a surface water body or wetlands). Sediments and the TZW environment in the Willamette River are influenced by both anthropogenic sources (e.g., over-water releases, influx of contaminated groundwater, stormwater discharge) and natural sources of organic matter (e.g., organic detritus). ORP measurements in TZW indicate that, in the areas investigated, the transition zone is primarily characterized by reducing conditions (Figure D7-1). These ORP conditions and the frequent presence of dissolved iron in TZW samples suggest that sufficient organic carbon is present in the sediments to deplete oxygen and support iron-reducing conditions. Sulfate-reducing conditions also likely occur in some locations; however, sulfate-reducing conditions typically occur at ORPs of <-300 mV (Vogel et al. 1987), and the TZW ORP data suggest that only a small number of TZW samples approach such conditions.

Sediment profile imaging (SPI) data collected throughout the river sediments are also consistent with a reduced sediment environment. Figure D7-2 presents, as an example of the typical sediment profile in the study area, an SPI image collected in silty sediments at SPI location 31A just offshore of the ARCO site, near TZW sampling location R2-AR-2. The image shows the uppermost ~15 cm of the sediment profile. Two zones are visible—a lighter, brownish colored zone in the near-surface sediments and darker, grayish sediments at depth. The visible transition is referred to as the apparent Redox Potential Discontinuity Depth (RPDD); in this image it occurs at approximately 3.2 cm. The near-surface sediments are lighter colored due the presence of iron hydrous oxide mineral coatings on the sediment particles, which is consistent with a mechanism in which iron precipitates from solution as the reduced TZW interacts with oxygenated river water. The darker zone at depth is below the apparent RPDD and indicates a reduced TZW environment. The apparent RPDD has been mapped for sediments throughout the Portland Harbor Study Area (SEA 2002). The RPDD is typically ~3 cm below the sediment surface, but can range from less than a centimeter to more than 20 cm. The open areas below the RPDD on Figure D7-2 are methane voids and indicate methanogenic conditions. Methanogenic conditions have been observed on a widespread basis in SPI images of shallow sediments in Portland Harbor, particularly in nearshore depositional areas (Integral 2002).

Microbial activity can also significantly influence the geochemical environment of TZW and groundwater through the production of alkalinity. A primary end product of respiration is carbon dioxide (CO_2). In closed systems (i.e., water not directly in contact with the atmosphere), these processes can lead to an oversaturation of CO_2 and, in turn, the formation of carbonate/bicarbonate alkalinity. This process provides pH-buffering capacity to the water (helping to maintain circum-neutral pH conditions) and can drive the formation of carbonate minerals.

7.2 TRANSITION ZONE WATER CHEMISTRY

The major ion chemistry of the TZW samples is discussed in detail in the Round 2 GWPA TZW SCSR (Integral 2006). The majority of the TZW samples are reduced (average ORP of -54 mV), calcium-carbonate waters of neutral pH (Figure D7-1). Table D7-1 presents a summary of the concentrations/levels of arsenic, barium, manganese, iron, pH, alkalinity, and ORP recorded in the TZW samples.

Figure D7-3 presents the arsenic, barium, and manganese concentrations measured in TZW[14] from each site, with the sites presented in order of river mile location along the x-axis of the chart. In general, the concentrations of these metals were similar across all nine of the sites, although a few samples from some of the sites were found to have higher concentrations of the metals. Of particular note are barium and manganese in TZW samples offshore of the Arkema Chlorate Plant. The Chlorate Plant TZW samples are highly saline and several exhibited elevated barium and manganese concentrations compared to those observed in TZW from the other sites. Arsenic, on the other hand, was below detection limits in several of the Chlorate Plant TZW samples, but was detected in all of the TZW samples from the other sites.

7.2.1 Statistical Evaluation of Arsenic, Barium, and Manganese in TZW and Upland Groundwater

Statistical testing was performed to determine (a) whether concentrations of arsenic, barium, and manganese in TZW differed significantly among the nine study sites; and (b) whether concentrations of these metals in TZW differed from concentrations measured in upland groundwater. Results of this evaluation are discussed in this subsection.

Non-parametric statistical analysis using the Kruskall-Wallace Test was performed to evaluate whether the arsenic, barium, and manganese concentrations in filtered shallow (< 38 cm bml) Trident and small-volume peeper TZW samples from any one site differed from those at the other sites at a significance level of 0.05 ($p \leq 0.05$, Table D7-2). For manganese, no statistically significant differences were identified in TZW from any one site compared with the rest of the sites. Non-parametric statistical testing did, however, identify statistically significant differences with respect to barium and, potentially, arsenic (depending on the treatment of non-detects). Exclusion of the Arkema Chlorate Plant from the analysis eliminated the statistical significance for barium and arsenic, indicating that the concentrations of arsenic and barium in TZW at the Chlorate Plant are different from those at the other eight sites.

[14] Filtered Trident samples and small-volume peepers.

In addition to the non-parametric testing, the distributions of the TZW data sets were tested for normality or lognormality. No data sets passed tests for normality at the 0.05 level. Further, distribution testing and visual inspection of the data indicated that the arsenic data do not fit a lognormal distribution (Figure D7-4). Barium passed tests for lognormality at the 0.05 level (Figure D7-5). Analysis of Variance (ANOVA) testing of the barium data set based on a lognormal distribution resulted in a p-value of 0.00592—indicating that differences in barium concentrations among the sites are statistically significant. As illustrated in Figure D7-5, it is apparent that this difference is a result of the Arkema Chlorate Plant data, a conclusion that is consistent with the non-parametric testing. Although the entire manganese data set does not pass lognormality testing, the manganese data set was found to approach a lognormal distribution when the Arkema Chlorate Plant data were excluded (Figure D7-6). ANOVA testing for the manganese data set (log-transformed), excluding the Arkema Chlorate Plant, resulted in a p-value of 0.117, which suggests that differences in manganese concentrations among the sites are not statistically significant (Figure D7-6).

Arsenic, barium, and manganese concentrations in filtered Trident and small-volume peeper TZW samples were also compared to available data for these metals in upland groundwater. (The upland groundwater data used for this analysis consists of all available data from the nine Round 2 TZW study sites [Integral 2005] collected from both nearshore and further upland wells Table D7-3 provides a statistical summary of this data set.) Note that due to the varied spatial distribution, sample depth, and collection methods represented in the compiled upland groundwater data set, this initial statistical comparison of upland groundwater and TZW metal concentrations is considered a preliminary analysis that will be used in support of other lines of evidence in the geochemical analysis. Metals concentrations in TZW and upland groundwater at each site were compared statistically using the Mann-Whitney U-test, with all TZW and upland groundwater values below laboratory detection limits set to zero. The largest upland groundwater data set exists for arsenic, with upland groundwater data available for all sites except Gunderson (Figure D7-7). Based on the available data, arsenic concentrations measured in upland groundwater and TZW are statistically different at the $p \leq 0.05$ level at the Arkema ($p = 0.043$), ExxonMobil ($p = 0.008$) and Siltronic ($p = 0.034$) sites. For barium, upland data were available for four sites: ARCO, Kinder Morgan, Siltronic, and Willbridge (Figure D7-8). Statistical analysis of these data identified a statistically significant difference between barium concentrations in upland groundwater and TZW only at the Willbridge site ($p = 0.013$). Note that, at the Willbridge site, only unfiltered (total) barium sample results were available for upland groundwater; therefore, the Mann-Whitney U test comparison of total upland barium with dissolved TZW barium may account for the observed difference in upland and TZW concentrations. The limited upland groundwater data set for manganese includes the Arkema, Rhone Poulenc, and Siltronic sites (Figure D7-9). Statistical comparison showed a statistically significant difference between upland and TZW concentrations of manganese at Siltronic ($p= 0.0003$) only.

In summary, based on the available data, it cannot be concluded that differences in concentrations of arsenic, barium, and manganese measured in TZW and upland groundwater are statistically significant at the $p \leq 0.05$ level, with the exception of arsenic at Arkema, ExxonMobil, and Siltronic; barium at Willbridge; and manganese at Siltronic. These comparisons between TZW and upland groundwater concentrations are viewed as tentative due to limitations on upland groundwater data available for this analysis.

7.2.2 Evaluation of Geochemical Controls for Arsenic, Barium, and Manganese in TZW

The identification of geochemical factors affecting or controlling the concentrations of arsenic, barium, and manganese in the TZW followed two paths. The first path involved investigation of the correlation between TZW metal concentrations and measured variables that could be expected to exert an influence upon the geochemistry. The second path involved geochemical modeling of the TZW to identify the most important aqueous species and minerals, determine equilibrium speciation, and calculate mineral saturation states.

7.2.2.5 Correlations among Arsenic, Barium, and Zinc Concentrations and Other Parameters

Detailed chemical analysis of TZW samples has produced a significant body of data available for use in the investigation of geochemical controls. This analysis was used to assess relationships between dissolved metals concentrations (arsenic, barium, iron, and manganese) in TZW and four primary geochemical variables (pH, ORP, alkalinity, and sediment total organic carbon). These comparisons, shown in Figures D7-10, D7-11, D7-12, and D7-13, yielded the following observations:

- pH (Figure D7-10): No clear patterns or trends are apparent in metals concentrations as a function of pH.
- ORP (Figure D7-11): Concentrations of arsenic, iron, and manganese appear to be generally higher in TZW samples with negative ORP (reducing conditions) than in the small group of samples with positive ORP (oxidizing conditions). This pattern may also exist for barium, but it is less apparent based on Figure D7-11. These observations suggest that microbial activity leading to reducing conditions may increase the aqueous solubility of these metals. These effects are discussed further in Section 7.2.2.2.
- Alkalinity (Figure D7-12): Metals concentrations show a general trend of increasing concentrations with alkalinity (with the exception of samples from the Arkema Chlorate Plant). Again, this is consistent with enhanced microbial activity, which produces alkalinity, as discussed above, increasing the aqueous solubility of these metals.

- Sediment TOC (Figure D7-13): In general, metals concentrations do not show clear apparent trends with sediment TOC content. Based on visual inspection of Figure D7-13, however, it is possible that there may be a weak association between TOC values greater than 1 percent and the higher range of measured concentrations of barium, iron, and manganese in TZW. This weak relationship is absent for arsenic. Map 4.4-4 (Section 4) presents contoured surface sediment texture information and indicates that the substantial majority of sediments in the Study Area have a TOC content greater than 1 percent. The median TOC content for all surface sediment samples in the Study Area is 1.75 percent (Table 6.1-1, Section 1). While clear correlations between sediment TOC and metals concentrations are not evident from Figure D7-13, sediment TOC (and other organic carbon sources) do appear to influence geochemical conditions, as discussed below, and therefore may indirectly influence the solubility and mobility of these metals.

To explore associations between chemically reducing conditions and organic carbon sources in the TZW environment, ORP in TZW was compared with TOC content and two indices of organic chemical contamination, TPH and TPAH, in collocated sediment samples (Figure D7-14a). These comparisons show that reducing conditions in TZW (negative ORP values) are frequently associated with higher sediment TOC and also with higher concentrations of TPH and TPAH in sediments. Figure D7-14b, which presents a parallel comparison of ORP with concentrations of TPH and TPAH in TZW, reveals a similar pattern. These observations are consistent with the expectation that organic carbon sources (either naturally occurring as TOC or introduced as TPH and/or TPAH) promote higher levels of microbial activity, leading to chemically reducing conditions.

Finally, TPH and TPAH concentrations in TZW were compared with concentrations of arsenic, barium, iron, and manganese in TZW. These comparisons, presented in Figures D7-15 and D7-16, indicate an apparent correlation between barium concentrations and TPH/TPAH in TZW at most of the study sites. Concentrations of arsenic, iron, and manganese in TZW, on the other hand, are generally not well correlated to TPH and TPAH concentrations. A limited exception is offshore of Siltronic and Gasco, where somewhat higher manganese concentrations may be associated with higher TPH and TPAH concentrations in TZW.

7.2.2.6 Geochemical Modeling

Geochemical modeling was performed to provide a better understanding of geochemical controls on the fate and transport of the metals in the TZW. Modeling was performed at two different levels. First, Eh-pH activity diagrams were created for each metal. These diagrams identify the species, either aqueous or mineral phase, that should dominate metal speciation and/or control solubility. Second, more detailed modeling was

performed to predict speciation within the aqueous phase and to calculate the saturation index for minerals controlling metal solubility.

Selection of appropriate modeling parameters is important to ensure applicable results. Whenever possible, the modeling relied on measured data from TZW samples. This data set consisted of metal concentrations (arsenic, barium, iron, and manganese), primary cations (Na^+, K^+, Mg^{2+}, and Ca^{2+}), primary anions (Cl^-, SO_4^{2-}), alkalinity, pH, and ORP. In addition, it was assumed that the system was not in contact with, and hence not in equilibrium with, the atmosphere. This assumption greatly affects two primary variables—ORP and alkalinity—that significantly influence geochemical modeling results. Under this assumption, ORP will not be controlled by atmospheric oxygen, and the alkalinity will not be controlled by equilibrium with atmospheric carbon dioxide.

All of the geochemical modeling assumed a temperature of 10° C and no contact with the atmosphere (f_{CO2}=0, f_{02}=0). Since the analysis was focused on the speciation of dissolved species, and the relation of this speciation to thermodynamic conditions, no solid mineral phases were assumed to be present. The chemical data set was input into the "Spec8" module of GWB. The model output included speciation information, e.g., activities of the three carbonate species [H_2CO_3], [HCO_3^-], [CO_3^{2-}], and mineral saturation indices. To create Eh-pH diagrams, aqueous species activities were taken from the "Spec8" results and entered into the "Act2" module of GWB. The species activities chosen for the activity diagrams were median values from the complete set of TZW samples.

7.2.2.6.1 Arsenic

Groundwater in the Willamette River Valley is known to contain areas with high levels of naturally occurring arsenic (Hinkle and Polette 1998). Arsenic is a redox-sensitive species, existing at the +3 and +5 oxidation states in aqueous environmental conditions. Under oxidizing conditions the As(V) species (H_3AsO_4, $H_2AsO_4^-$, $H_2AsO_4^-$, $HAsO_4^{2-}$, AsO_4^{3-}) predominate, while under reducing conditions the As(III) species (H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$, AsO_3^{3-}) predominate (EPRI 1984). Arsenic is generally highly soluble, with few mineral phases exerting controls on aqueous arsenic concentrations under typical environmental conditions. Arsenic sulfide minerals, such as orpiment ($As_2S_{3(s)}$) and realgar ($As_4S_{4(s)}$) can be important under reducing and acidic conditions (EPRI 1984). Past research has suggested that the solubility of arsenic in the environment is limited by the formation of a highly insoluble barium-arsenate species ($Ba_3(AsO_4)_{2(s)}$) (Chukhlantsev 1956). However, this solubility product has been long suspected to be questionable (EPRI 1984). More recent research suggests the mineral phase may be much less stable (Essington 1988)—a suggestion that has been supported by a recent study of groundwater with naturally occurring arsenic (Planer-Friedrich et al. 2001).

Although arsenic minerals are generally highly soluble, adsorption reactions to sediment/aquifer mineral grain surfaces frequently limit dissolved arsenic concentrations (Kabata-Pendias and Pendias 1992). Arsenic is particularly strongly adsorbed to iron oxide minerals, with the As(V) species having a greater affinity for the oxide surface than the As(III) species. Because arsenic is frequently present as an anion under typical environmental conditions, its sorption to oxide surfaces is favored at pH < 9 (Stumm 1992).

Figure D7-17 presents two stability diagrams for arsenic based on median water quality conditions recorded in the TZW samples. The upper diagram on the figure includes barium species, and the lower diagram excludes these species for the reasons described below. The stability diagrams suggest that under typical TZW conditions, arsenic is likely to be present as aqueous $As(OH)_3$ or precipitating as barium-arsenate [$Ba_3(AsO_4)_{2(s)}$]. The SI values calculated for individual TZW samples indicate substantial oversaturation (SIs from 4 to 10) for $Ba_3(AsO_4)_{2(s)}$ in many of the TZW samples (Table D7-4), suggesting that this species is not controlling aqueous solubility of arsenic in the TZW. This could be the result of kinetic limitations on precipitation reactions, but most likely reflects erroneous thermodynamic data for this mineral (EPRI 1984). Planer-Friedrich et al. (2001) calculated similar very high SIs for natural waters in Mexico using standard thermodynamic databases; however, upon altering these databases to reflect more accurate solubility products, they calculated SIs for the barium arsenate species of approximately -20. For the geochemical modeling described herein, the arsenic stability diagram was re-calculated excluding the barium arsenate species. With this assumption, the stability diagram indicates that aqueous arsenic hydroxide species are most important for the TZW samples (Figure D7-17). The only mineral phases that might control the arsenic solubility are the arseno-sulfides orpiment and realgar. However, these phases only occur under conditions that are more reducing than any recorded at all but one of the TZW locations investigated.

This geochemical speciation analysis indicates that mineral solubility controls are unlikely to be exerting significant influence on arsenic in the sediment/TZW environment. There is some evidence, however, that adsorptive processes are important factors for dissolved arsenic concentrations in TZW. As illustrated in Figure D7-18, arsenic concentrations show a rough apparent correlation to iron concentrations in the TZW samples. Further, the concentrations of both arsenic and iron tend to be elevated under reduced TZW conditions (Figure D7-11). Collectively, these data suggest that iron oxide minerals that may be or have been present are dissolving—resulting in the release of adsorbed arsenic to groundwater/TZW. (However, as presented in Figure D7-19 and Table D7-4, the iron carbonate mineral siderite [$FeCO_3$] is stable under the Eh-pH conditions observed in most TZW samples.) Arsenic also shows a general correlation to dissolved manganese (Figure D7-20), suggesting that dissolution of dissolved manganese oxide and concomitant release of adsorbed arsenic may also be an important process affecting dissolved arsenic concentrations in the TZW. It should be

noted that some fraction, if not all, of the dissolved iron and manganese in the TZW will re-precipitate as hydrous oxide minerals upon migration to the oxidized zone of the near-surface sediments of the river. Therefore, it is likely that dissolved arsenic present in TZW will tend to re-adsorb to the iron and manganese hydrous oxides before discharging to the surface water column.

As discussed previously, microbial processes driven by naturally occurring and/or anthropogenic organic carbon in the sediment/TZW environment are likely responsible for the reduced conditions in the TZW. These conditions can result in higher concentrations of dissolved arsenic, iron, and manganese than an oxidized environment. Further, as illustrated in Figure D7-12, arsenic concentrations tend to correlate with TZW alkalinity. This potentially reflects microbial activity in the TZW/sediment environment (alkalinity is a result of the production of CO2 from respiration; see Section 7.1.3), resulting in reducing conditions and subsequent dissolution of oxide minerals.

As discussed previously, concentrations of arsenic, iron, and manganese are not well correlated to TPH or TPAH concentration in the TZW samples (Figures D7-15 and D7-16), suggesting that other factors (e.g., naturally occurring organic materials) are capable of producing conditions in the TZW environment that favor the dissolution of iron and manganese oxides and the possible concomitant release of arsenic. In turn, this may suggest that arsenic concentrations in TZW can be explained by natural factors—a conclusion that is consistent with the presence of similarly elevated concentrations of arsenic in TZW across all nine sites and in upland groundwater (Section 7.2.1).

7.2.2.6.2 Barium

Barium is an alkaline earth cation that exists only at the +2 valence state in aqueous environments (EPRI 1984). The typical concentration of barium in basalt is 315 ppm (Faure 1991). Barium typically exhibits limited mobility in the environment due to its strong tendency to form sulfate and carbonate minerals. Barite ($BaSO_{4(s)}$) and witherite ($BaCO_{3(s)}$) are the predominant naturally occurring mineral forms of barium (Deer et al. 1966). Figure D7-21 presents the predominant mineral phases predicted for barium in TZW over a range of Eh and pH conditions. Similar to the predicted mineral phases of arsenic, $Ba_3(AsO_4)_{2(s)}$ is predicted to be a dominant phase (Figure D7-21); however, as discussed above for arsenic, it is thought that this prediction is based on erroneous thermodynamic data and that this mineral is not a significant control on barium in TZW. Disregarding the barium arsenate mineral phase, the predicted dominant species in the TZW is witherite, although at higher sulfate concentrations or lower pH, the dominant species can shift to barite.

As summarized in Table D7-4 and Figure D7-22, the majority of the TZW samples are slightly oversaturated with respect to witherite (SIs up to 3), with a minority undersaturated. This suggests that witherite solubility is controlling the dissolved

concentrations of barium in TZW at these sites. This conclusion is supported by the strong correlation between dissolved barium and alkalinity concentrations measured in the TZW samples Figure D7-12. In upland groundwater, the recorded pH and alkalinity (Table D7-3) are also consistent with witherite solubility controls.

Barite is undersaturated in the large majority of the TZW samples—suggesting that the TZW environment predominantly favors the dissolution of barite from the sediments (if present). Exceptions to this are offshore of the Arkema Chlorate Plant and at one location each offshore the Arkema Acid Plant and Rhone Poulenc sites, where TZW samples are oversaturated with respect to barite (Figure D7-23). As discussed previously, an apparent correlation exists between barium concentrations an TPH and TPAH concentrations in TZW (Figure D7-15 and D7-16). Higher barium concentrations in TZW also appear to be weakly associated with the higher range of sediment TOC content (Figure D7-13). These observations suggest that barium solubility is increased in the presence of organic carbon sources (either naturally occurring as TOC or introduced as TPH and/or TPAH).

7.2.2.6.3 Manganese

Manganese is a common trace element in the lithosphere, with an average crustal abundance of 1400 ppm (Faure 1991). It is frequently present as oxide minerals (e.g., pyrolusite [$MnO_{2\,(s)}$]) in soils (Kabata-Pendias and Pendias 1992), although rhodochrosite [$MnCO_{3(s)}$] may control manganese solubility in reduced, alkaline environments (EPRI 1984). Manganese is a redox-sensitive species, with the +2, +3, and +4 oxidation states being the most important in the environment (EPRI 1984). Basalts, such as the Columbia River Basalt underlying the study location, have an average manganese composition of 1,750 ppm (Faure 1991).

Figure D7-24 presents a manganese activity diagram, which illustrates the predominant aqueous and mineral phases likely to be present in the TZW samples over a range of Eh and pH conditions. Under the circum-neutral pH and reducing conditions that characterize the majority of the TZW samples, the most important mineral phase for manganese is rhodochrosite. Aqueous Mn^{++} is the dominant phase for a lesser number of the TZW samples. This finding is supported by the results of detailed speciation modeling, in which mineral SIs are calculated based on the water chemistry recorded in each individual TZW sample. As summarized in Table D7-4 and Figure D7-25, the SI of rhodochrosite varies consistently between approximately 2 and -2 (weakly oversaturated to weakly undersaturated) across the range of TZW samples. These indices suggest that the aqueous concentrations of manganese in TZW from all nine of the sites are maintained at near-equilibrium with rhodochrosite in the sediment. Solubility control by rhodochrosite is further evidenced in Figure D7-12, which shows a strong relationship between manganese and alkalinity in TZW, with the possible exception of several of the TZW samples from offshore of the Arkema Acid Plant and Chlorate Plant, which displayed higher alkalinity than samples from other locations.

Calculated SI values (Table D7-4) indicate that TZW is undersaturated with respect to manganese oxide minerals (SI range: -16.4 to -4.6; SI median: -7.0). As a result, if manganese oxides are present in the sediment matrix, they would tend to dissolve into solution under the geochemical conditions measured in TZW, suggesting a possible source of the dissolved manganese. Migration of manganese present in upland groundwater (e.g., from the weathering of parent rocks and derived sediments) to the transition zone is another possible source. As discussed previously, manganese concentrations in TZW are not well correlated to TPH or TPAH concentrations in the TZW samples (Figures D7-15 and D7-16). This suggests that other factors (e.g., naturally occurring organic materials) are capable of producing reducing conditions in the TZW environment, and the subsequent dissolution of manganese oxide minerals.

The available upland groundwater data set is insufficient to perform geochemical modeling for the upland groundwater data. However, the alkalinity and pH values observed in upland groundwater (Table D7-3) are consistent with rhodochrosite solubility controls (Figure D7-24). This finding, coupled with the similarity of manganese concentrations between TZW and upland groundwater, suggests that manganese is likely naturally occurring in aquifer materials and river sediments throughout the Study Area and is unrelated to current or historical activities at the sites. The exception to this conclusion is offshore of the Arkema site; where manganese is elevated in TZW relative to upland groundwater concentrations.

7.2.3 Conclusions

An evaluation of TZW and available uplands groundwater data was performed to assess the geochemical conditions likely affecting the origin, transport, and fate of arsenic, barium, and manganese in the subsurface environment of the lower Willamette River. Key findings of this evaluation are summarized below.

- No statistically significant differences were identified in TZW concentrations of arsenic, barium, and manganese across the nine study sites, with the exception of the Arkema Chlorate Plant.
- Based on an initial analysis of available upland groundwater data from the nine study sites, it cannot be concluded that differences in concentrations of arsenic, barium, and manganese in TZW and upland groundwater are statistically significant at the $p \leq 0.05$ level, with the exception of arsenic at Arkema, ExxonMobil, and Siltronic; barium at Willbridge; and manganese at Siltronic. (Comparisons between TZW and upland groundwater concentrations are viewed as tentative due to limitations on upland groundwater data available for this analysis.)
- Concentrations of metals in TZW appear to be positively correlated with alkalinity. Metals concentrations are also generally higher in TZW samples with negative ORP (reducing conditions) than positive ORP (oxidizing conditions).

No trends or patterns are apparent in metals concentrations as a function of pH. These observations are consistent with increased levels of microbial activity—resulting in reducing conditions and the production of alkalinity—creating geochemical conditions that increase the aqueous solubility of the metals.

- Reducing conditions in TZW, which tend to increase the solubility of arsenic, barium, iron, and manganese, are frequently associated with higher sediment TOC content and with higher concentrations of TPH and TPAH in TZW and sediment. These observations are consistent with the expectation that organic carbon sources (either naturally occurring as TOC or introduced as TPH and/or TPAH) promote increased levels of microbial activity, leading to chemically reducing conditions.
- An apparent correlation exists between barium concentrations and TPH/TPAH in TZW at most of the study sites. Concentrations of arsenic, iron, and manganese in TZW, on the other hand, are generally not well correlated to TPH and TPAH concentrations. A limited exception is offshore of Siltronic and Gasco, where somewhat higher manganese concentrations may be associated with higher TPH and TPAH concentrations in TZW.
- Arsenic in TZW is not maintained in equilibrium with any arsenic mineral phases that would control its aqueous solubility. However, the geochemical environment of both TZW and uplands groundwater was found to be generally consistent with iron- and manganese-reducing conditions—suggesting that elevated arsenic concentrations in these waters may be the result of dissolution of iron and manganese hydrous oxides and concomitant release of adsorbed arsenic.
- Barium in TZW from all nine sites is maintained at approximate equilibrium with the carbonate mineral witherite and is undersaturated with respect to the sulfate mineral barite. Barite, the most abundant barium mineral in the earth's crust, is moderately to strongly undersaturated in the chemically reducing conditions typical of the transition zone. Dissolution of barite from the sediment matrix, if present, is a potential source of barium in TZW. These geochemical controls are consistent with the generally alkaline and reduced conditions of the TZW and suggest that microbial interactions may be of importance.
- Manganese in TZW from all nine sites is maintained at approximate equilibrium with the manganese carbonate mineral rhodochrosite and is undersaturated with respect to manganese oxide minerals. If manganese oxides are naturally present in sediments, their dissolution under the geochemical conditions measured in TZW may be a source of manganese in TZW. These geochemical controls are consistent with the moderate alkalinity and reduced conditions of the TZW and suggest that microbial interactions may be of importance.

- Re-precipitation of hydrous manganese and iron oxides minerals above the redox potential depth in near-surface sediments may be a removal mechanism for dissolved manganese and arsenic as TZW migrates into the oxidized zone of near-surface sediments.

Overall, geochemical conditions in the TZW environment, and the resulting solubility controls on concentrations of arsenic, barium, and manganese, appear to be influenced by the presence of organic carbon sources (either natural or introduced) and associated microbial activity. Because natural organic carbon is abundant in shallow sediments in the Study Area (see Map 4.4-4 and Table 6.1-1), it is considered likely that natural conditions in the majority of the Study Area can account for the geochemical conditions that control the observed concentrations of these metals in TZW.

8.0 REFERENCES

AHI. 1987. Assessment of the loading of toxic contaminants to the San Francisco Bay Delta. Aquatic Habitat Institute. Richmond, CA. http://www.sfei.org/reports/AHI/LoadingOfToxic1987.pdf

ATSDR. 2002a. Toxicological Profile for Aldrin/Dieldrin. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. Atlanta, GA.

ATSDR. 2002b. Toxicological Profile for DDT, DDE, DDD. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. Atlanta, GA.

ATSDR. 2006. Agency for Toxic Substances Disease Registry. Finalized Toxicological Profiles. Accessed March, 2006. URL: http://www.atsdr.cdc.gov/

Bethke, C.M. 2006. The Geochemist's Workbench® Reference Manual. http://www.geology.uiuc.edu/Hydrogeology/pdf/GWBreference.pdf.

Bidleman, T.F. 1988. Atmospheric processes: Wet and dry deposition of organic compounds are controlled by their vapor-particle partitioning. *Environ. Sci. Technol.* 22:361-367.

Burton, G.A., and R.E. Pitt. 2002. Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers. Lewis Publishers, Boca Raton, FL.

CARB. 2004. California Ambient Dioxin Air Monitoring Program (CADAMP). 2004 Results. California Air Resources Board. Sacramento, CA. http://www.arb.ca.gov/pub/dioxin/cadamp.php

Chapelle, F.H. 1993. *Ground-water microbiology and geochemistry.* John Wiley & Sons, Inc., New York, NY.

Chu, M. 1993. Quality of Stormwater Runoff from Urbanized Houston Metropolitan Area. Texas A&M University. http://gbic.tamug.edu/

Chukhlantsev, V.G., 1956. Solubility products of arsenates. *J. Inorg. Chem.* (USSR) 1:1975-1982.

City of Portland. 2005. 2000-2004 Catch Basin Solids Data Summary Memorandum. Prepared for Dawn Sanders, City of Portland. Prepared by D. Lacey, J. Sellers, and L. Maxwell, CH2M Hill. City of Portland Bureau of Environmental Services, Portland, OR.

Deer, W.A., R.A. Howie, and J. Zussman. 1966. *An introduction to the rock forming minerals.* Longman House, Essex, England.

DEQ. 2006. Laboratory Analytical Storage and Retrieval (LASAR) website. Oregon Department of Environmental Quality. Verion 1.33. URL: http://www.deq.state.or.us/wq/lasar/LasarHome.htm

Di Toro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, N.A. Thomas, and P.R. Paquin. 1991. Technical basis for the equilibrium partitioning method for establishing sediment quality criteria. *Environ. Toxicol. Chem.* 11:1541-1583.

EPA. 1996a. NATA Monitored Ambient Concentrations. U.S. Environmental Protection Agency, Washington, DC. URL: http://earth1.epa.gov/ttn/atw/nata/montcomp.html

EPA. 1996b. Soil Screening Guidance: Technical Background Document. EPA/540/R-96/128. NTIS PB96-963502. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC.

EPA. 1997. Mercury Study Report to Congress, Volumes I through VIII. EPA/452/R-97-001. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards and Office of Research and Development, Washington DC.

EPA. 1999. 1999 Modeled Ambient Concentrations. National Air Toxics Assessment. U.S. Environmental Protection Agency, Washington, DC. URL: http://www.epa.gov/ttn/atw/nata1999/nsata99.html

EPA. 2003. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA-600-R-02-013. U.S. Environmental Protection Agency, Office of Research and Development. Washington, DC.

EPA. 2005. Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. EPA-530-R-05-006. U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response, Washington DC.

EPRI. 1984. Chemical attenuation rates, coefficients, and constants in leachate migration. EPRI EA-3356. Prepared for the Electrical Power Research Institute. Batelle Pacific Northwest Laboratories, Richland, WA.

Essington, M.E. 1988. Solubility of barium arsenate. *Soil Sci. Soc. Am. J.* 52(6) 1566-1570.

Faure, G. 1991. *Principles and applications of inorganic geochemistry.* Macmillan Publishing Co., New York, NY.

Franz, T.P., S.J. Eisenreich, and T.M. Holsen. 1998. Dry deposition of particulate polychlorinated biphenyls and polycyclic aromatic hydrocarbons to Lake Michigan. *Environ. Sci. Technol.* 32:3681-3688.

Hilal, S.H., L. Carreira, and S.W. Karickhoff. 1994. Estimation of chemical reactivity and parameters and physical properties of organic molecules using SPARC. In: *Quantitative Treatments of Solute/Solvent Interactions,* Volume 1. P. Politzer and J.S. Murry (eds.). Elsevier, Amsterdam. pp. 291-348.

Hinkle, S.R., and D.J. Polette. 1998. Arsenic in ground water of the Willamette Basin, Oregon, U.S. Geological Survey, Water-Resources Investigations Report 98-4205.

Integral. 2004. Portland Harbor RI/FS Field Sampling Plan, Groundwater Pathway Assessment Pilot Study. Prepared for the Lower Willamette Group, Portland, OR. Integral Consulting Inc., Mercer Island, WA.

Integral. 2005. Portland Harbor RI/FS Groundwater Pathway Assessment Sampling and Analysis Plan. Draft April 22, 2005. IC05-0013. Prepared for the Lower Willamette Group, Portland, OR. Integral Consulting Inc., Mercer Island, WA.

Integral. 2006. Portland Harbor RI/FS Field Sampling Plan, Round 2 Groundwater Pathway Assessment Transition Zone Water Site Characterization Summary Report. Draft. IC06-0020. Prepared for the Lower Willamette Group, Portland, OR. Integral Consulting Inc., Mercer Island, WA.

Kabata-Pendias, A., and H. Pendias. 1992. *Trace elements in soils and plants.* 2nd ed. CRC Press, Boca Raton, FL.

Lodge, K.B. and P.M. Cook. 1989. Partitioning Studies of Dioxin Between Sediment and Water: the Measurement of K_{oc} for Lake Ontario Sediment. *Chemosphere* 19(1-6):439-444.

Maestre, A., and R. Pitt. 2005. The National Stormwater Quality Database, Version 1.1: A Compilation and Analysis of NPDES Stormwater Monitoring Information.

McVeety, B.D., and R.A. Hites. 1988. Atmospheric deposition of polycyclic aromatic hydrocarbons to water surfaces: A mass balance approach. *Atmosph. Environ.* 22: 511-536.

Norton, D. 1998. 1998 Sediment Trap Monitoring of Suspended Particulates in Stormwater Discharges to Thea Foss Waterway. Washington State Department of Ecology Report #98-336. Olympia, WA.

Ogura, I., S. Masunaga, and J. Nakanishi. Parameters characterizing atmospheric behavior of PCDDs/PCDFs. *Organohalogen Compounds* 52:483-486.

ORNL. 2006. ORNL Risk Assessment Information System. Online searchable database. Accessed on August 2, 2006. URL: http://risk.lsd.ornl.gov/cgi-bin/tox/TOX_select?select=csf.

Parker, J.T.C., K.D. Fossum, and T.L. Ingersoll. 2000. Chemical Characteristics of Urban Stormwater Sediments and Implications for Environmental Management, Maricopa County, Arizona. Environmental Management 26(1):99-115.

Peryea, F.J., and R. Kammereck. 1997. Phosphate-enhanced movement of arsenic out of lead arsenate-contaminated topsoil and through uncontaminated subsoil. *Water, Air Soil Poll.* 93(1-4):243-254.

Pitt, R., F. Richard, M. Lalor, and M. Brown. 1995. Urban stormwater toxic pollutants: Assessment, sources, and treatability. *Water Environ. Res.* 67:260-275

Planer-Friedrich B., M.A. Armienta, and B.J. Merkel. 2001. Origin of arsenic in the groundwater of the Rioverde Basin, Mexico. *Environ. Geol.* (40):1290-1298.

Poster, D.L., and J.E. Baker. 1996. Influence of submicron particles on hydrophobic organic contaminants in precipitation: 2. Scavenging of polycyclic aromatic hydrocarbons by rain. *Environ. Sci. Technol.* 30:349-354.

Rathbun, R.E. 2000. Transport, behavior and fate of volatile organic compounds in streams. Critical Reviews. *Environ. Sci. Technol.* 30(2):129-295.

San Francisco Estuary Institute. 2005. San Francisco Bay Atmospheric Deposition Pilot Study Part 3: Dry Deposition of PAHs and PCBs. SFEI Contribution #408. July 6, 2005.

Rossi, L., L. de Elancastro, T. Kupper, and J. Tarradellas. 2004. Urban stormwater contamination by polychlorinated biphenyls (PCBs) and its importance for urban water systems in Switzerland. *Sci. Total Environ.* 322:179-189.

Schnoor, J.L., P.S. Thorne, and W. Powers. 2002. Iowa Concentrated Animal Feeding Operations Air Quality Study, Chapter 5. Fate and Transport of Air Pollutants from CAFOs. Iowa State University and the University of Iowa Study Group. http://www.ehsrc.uiowa.edu/CAFOstudy.htm

Schroder, J., K. Welsch-Pausch, and M.S. McLachlan. 1997. Measurements of atmospheric deposition of polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) to a soil. *Atmosph.Environ.* 31:2983-2989.

Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

SEA. 2002. Sediment Profile Image Survey of Lower Willamette River. Prepared for Lower Willamette Group, Portland, OR. Striplin Environmental Associates, Inc., Olympia, WA.

SFEI. 2005. San Francisco Estuary Institute. San Francisco Bay Atmospheric Deposition Pilot Study Part 3: Dry Deposition of PAHs and PCBs. SFEI Contribution #408. July 6, 2005.

Seinfeld, J.H., and S.N. Pandis. 1998. *Atmospheric chemistry and physics: From air pollution to climate change.* Wiley, New York.

Slater, R.M. and D.J. Spedding. 1981. Transport of dieldrin between air and water. *Arch. Environ. Contam. Toxicol.* 10(1):25-33.

SMRC. 2006. Website at http://www.stormwatercenter.net/. Accessed on November 1, 2006. Storm Water Manager's Resource Center, Ellicot City, MD.

Stumm, W. 1992. *Chemistry of the solid-water interface.* John Wiley & Sons, Inc., New York, NY.

Vogel, T.M., C.S. Criddle, and P.L. McCarty. 1987. Transformations of halogenated aliphatic compounds. *Environ. Sci. Technol.* 21:722-736.

Wesley, M.L., and B.B. Hicks. 2000. A review of the current status of knowledge on dry deposition. *Atmosph. Environ.* 34:2261-2282.

WRCC. 2006. Western Regional Climate Center Website at http://www.wrcc.dri.edu/. Accessed on November 1, 2006.

Woodward-Clyde. 1993. Final Data Report, Data from Storms Monitored between May 1991 and January 1993. NPDES Stormwater Monitoring Program, Portland, Oregon. Prepared for City of Portland Bureau of Environmental Services, Portland, OR. Woodward-Clyde Consultants, Portland, OR.

Woodward-Clyde. 1997. Final Report Analysis of Oregon Urban Runoff Water Quality Monitoring Data Collected from 1990 to 1996. Prepared for the Oregon Association of Clean Water Agencies, Portland OR. Woodward-Clyde Consultants, Portland, OR.

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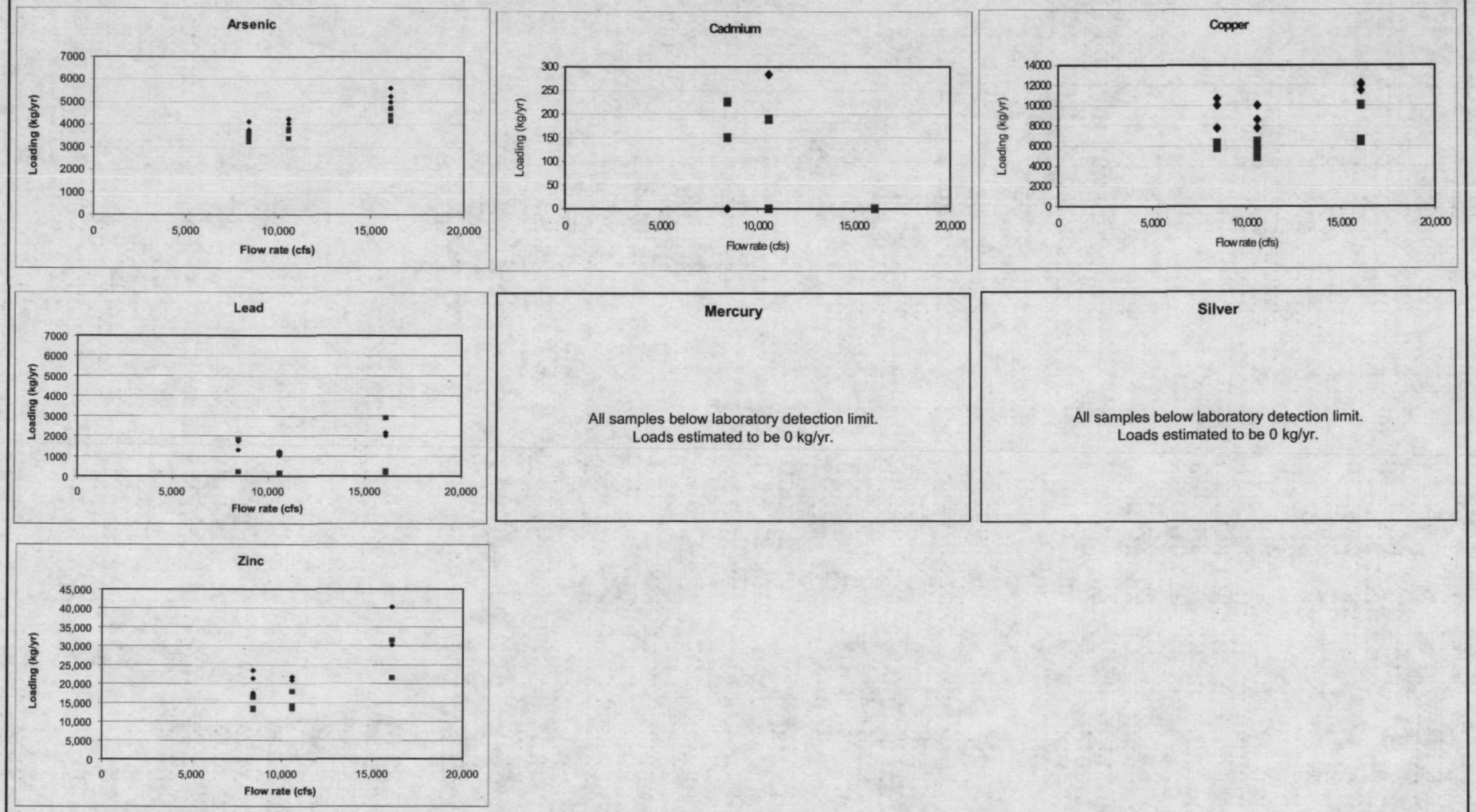

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Figure D2-1
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Comprehensive Round 2 Report
Surface Water Loading by Flow Rate
Metals

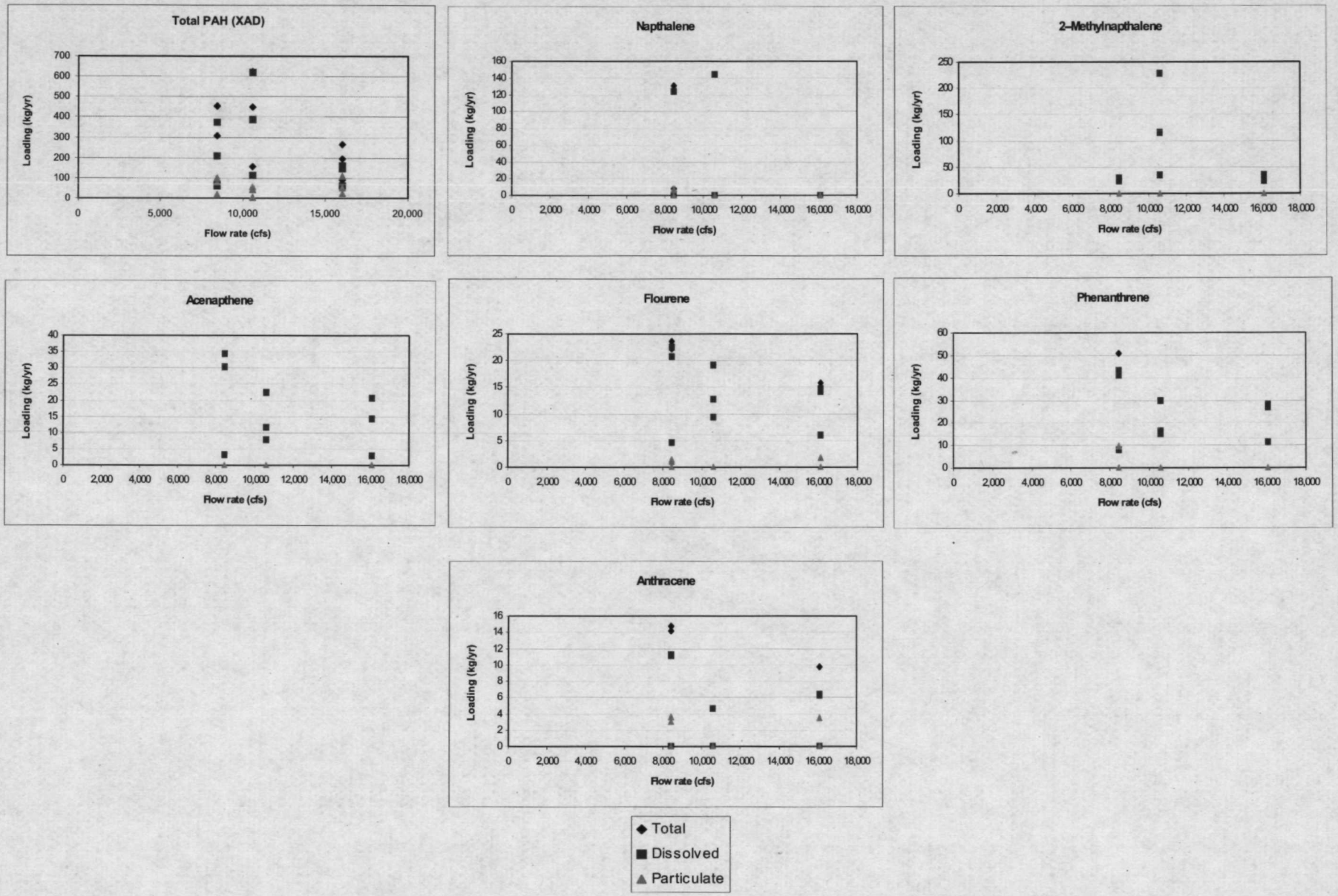

Figure D2-2a
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by Flow Rate
LPAHs

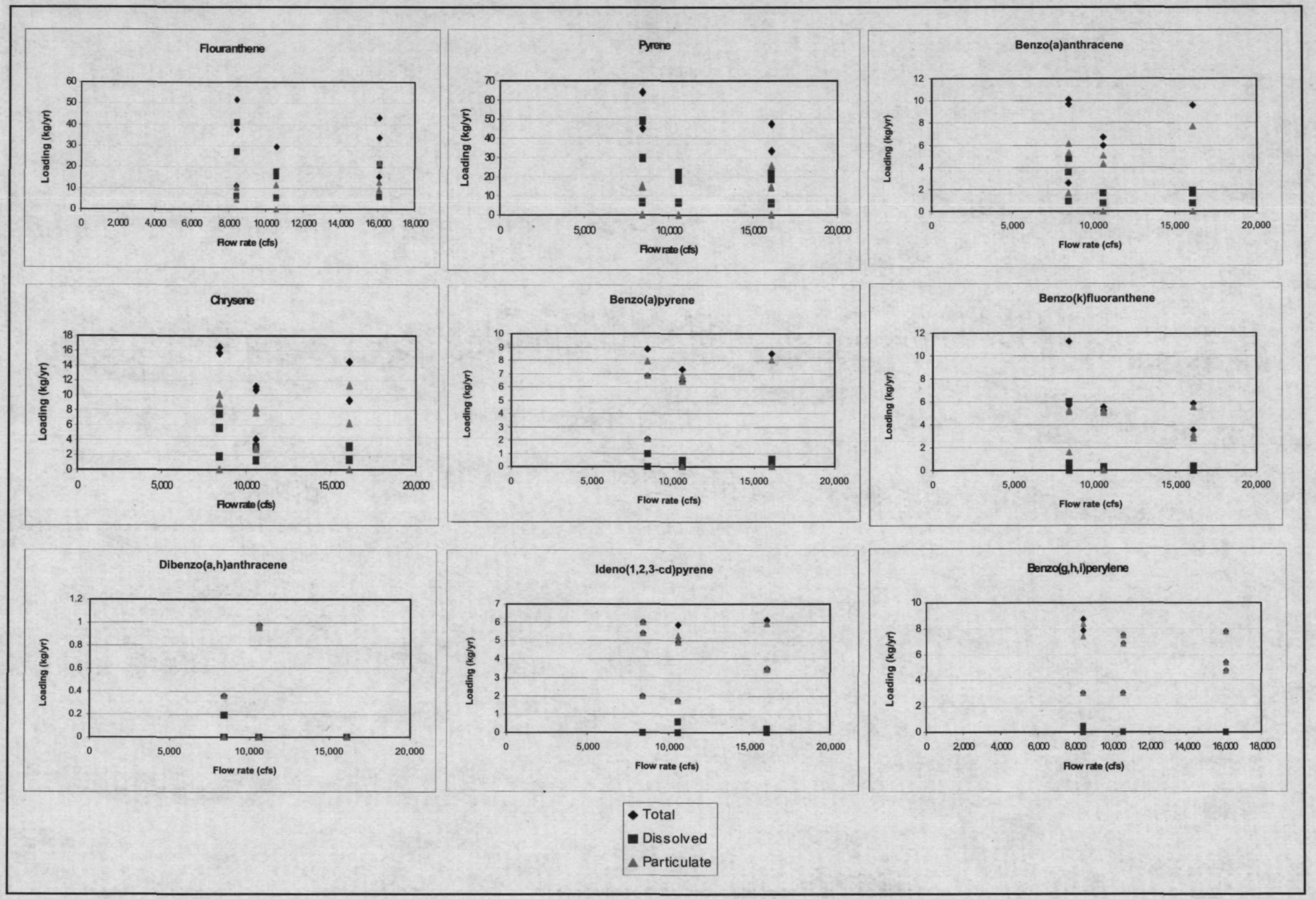

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Figure D2-2b
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by Flow Rate
HPAHs

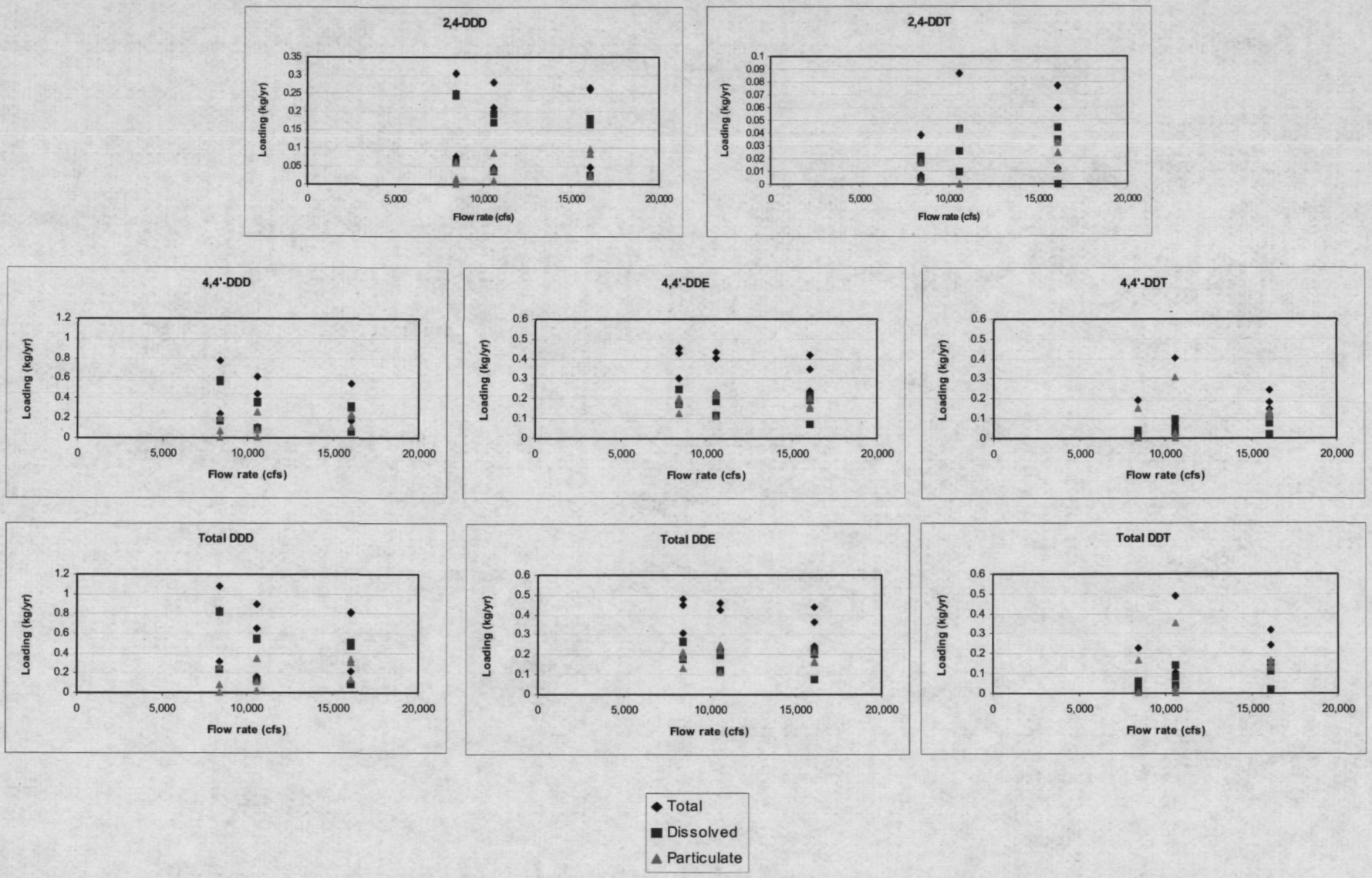

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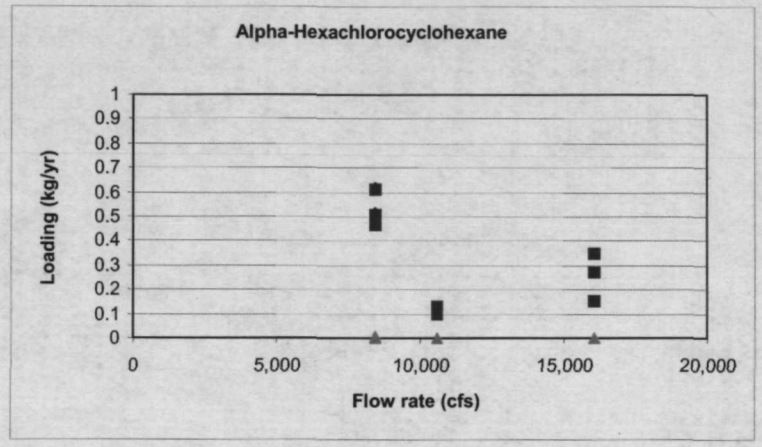
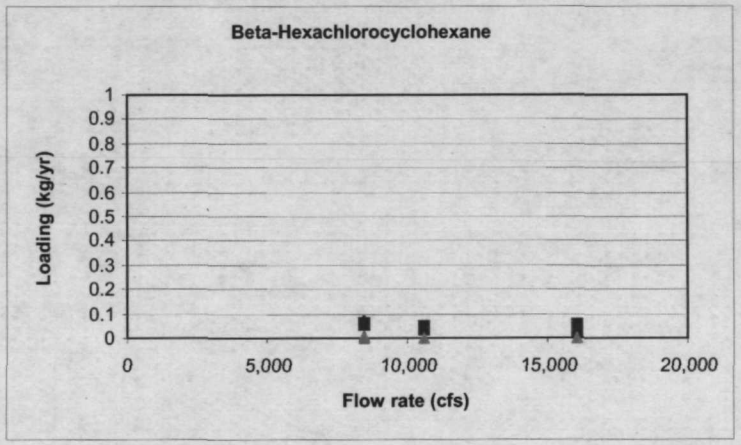
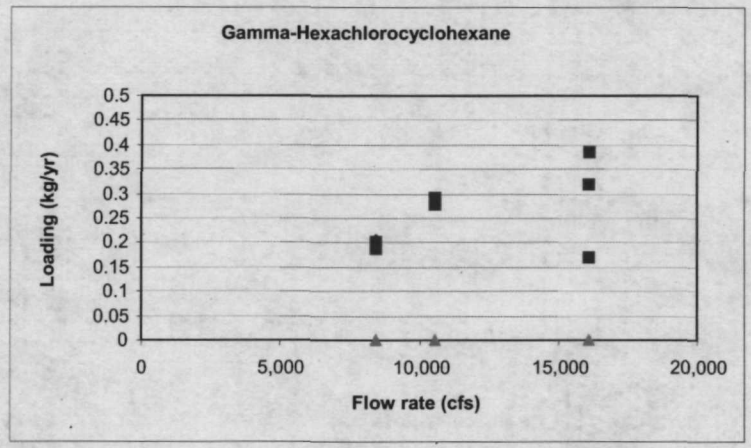
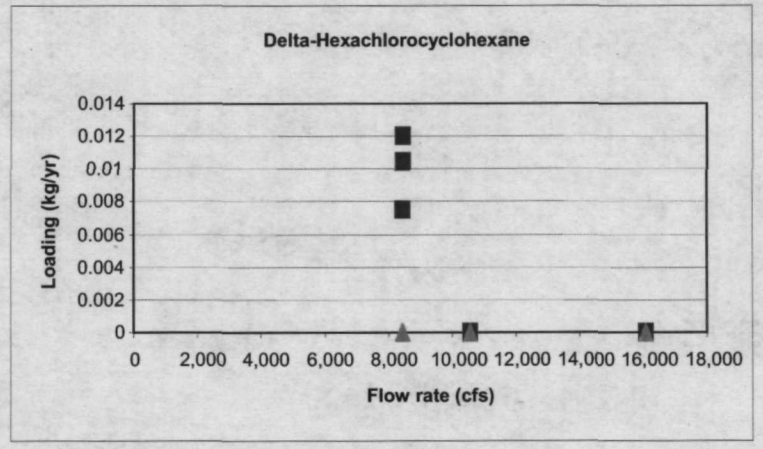
Figure D2-3
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by Flow Rate
DDx Pesticides









◆ Total
■ Dissolved
▲ Particulate

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Figure D2-4a
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by Flow Rate
Non-DDx Pesticides, Hexachlorocyclohexanes

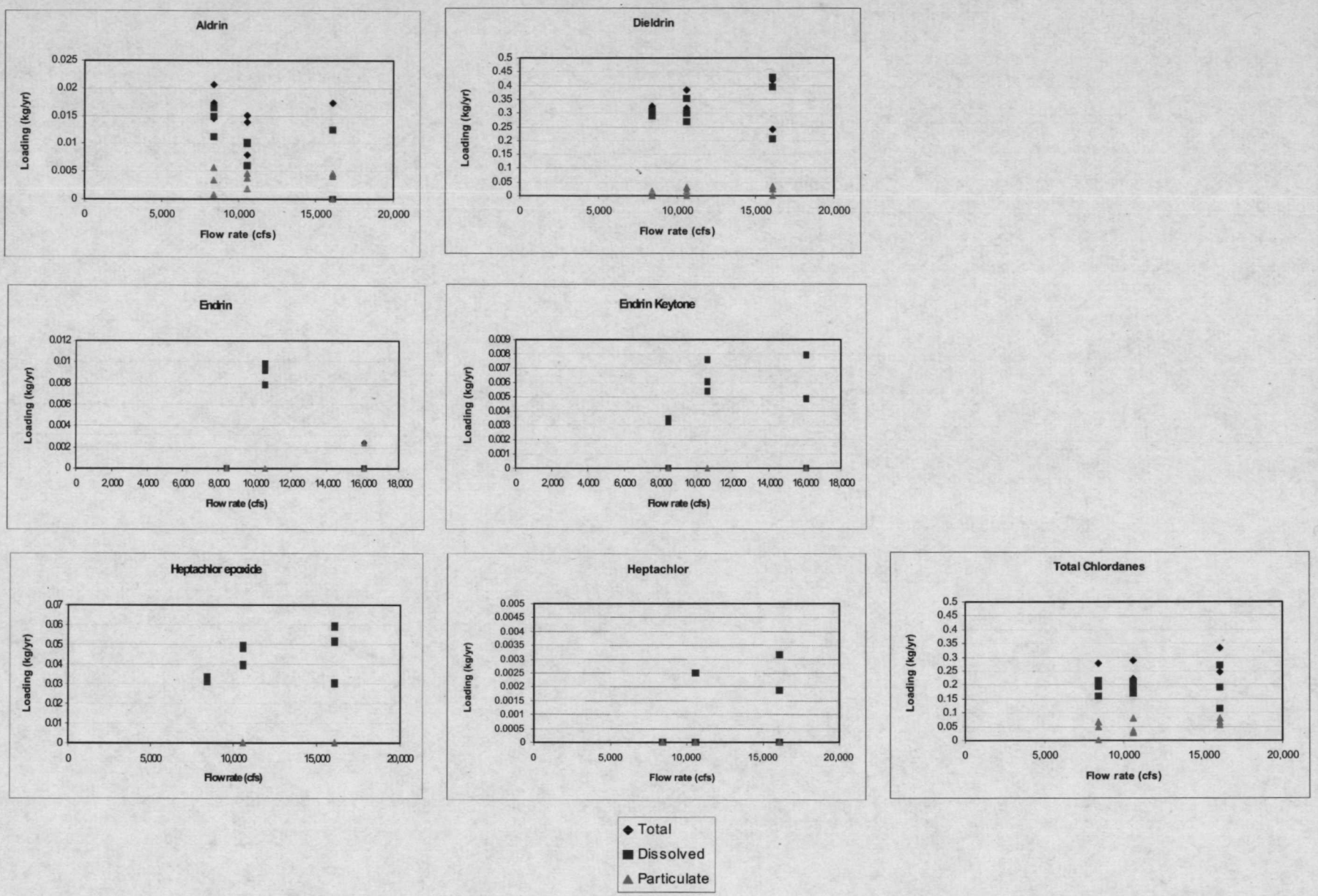

Figure D2-4b
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by Flow Rate
Non-DDx Pesticides

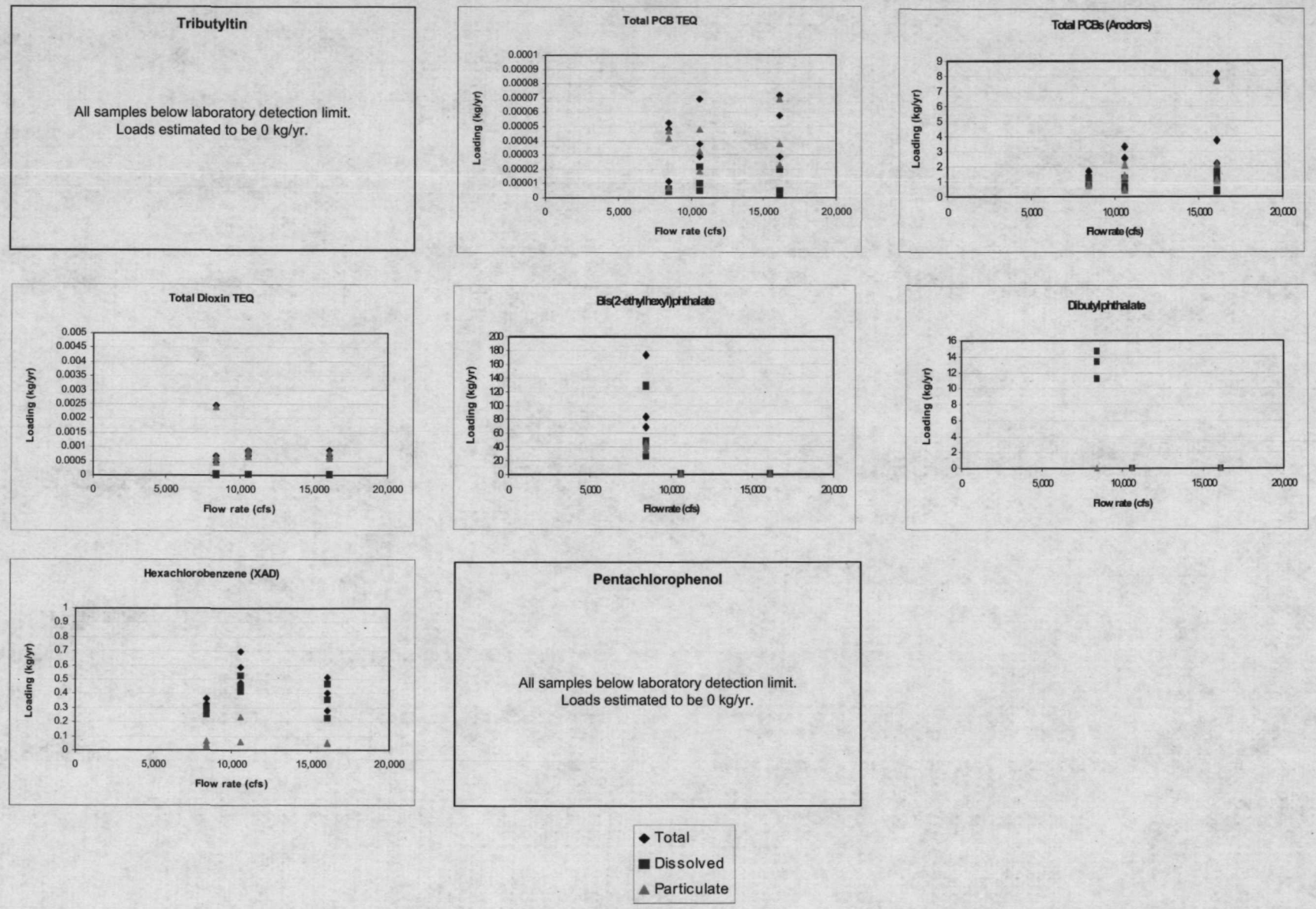

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Figure D2-5
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by Flow Rate
Butyltins, Dioxins, PCBs, Phthalates and SVOCs

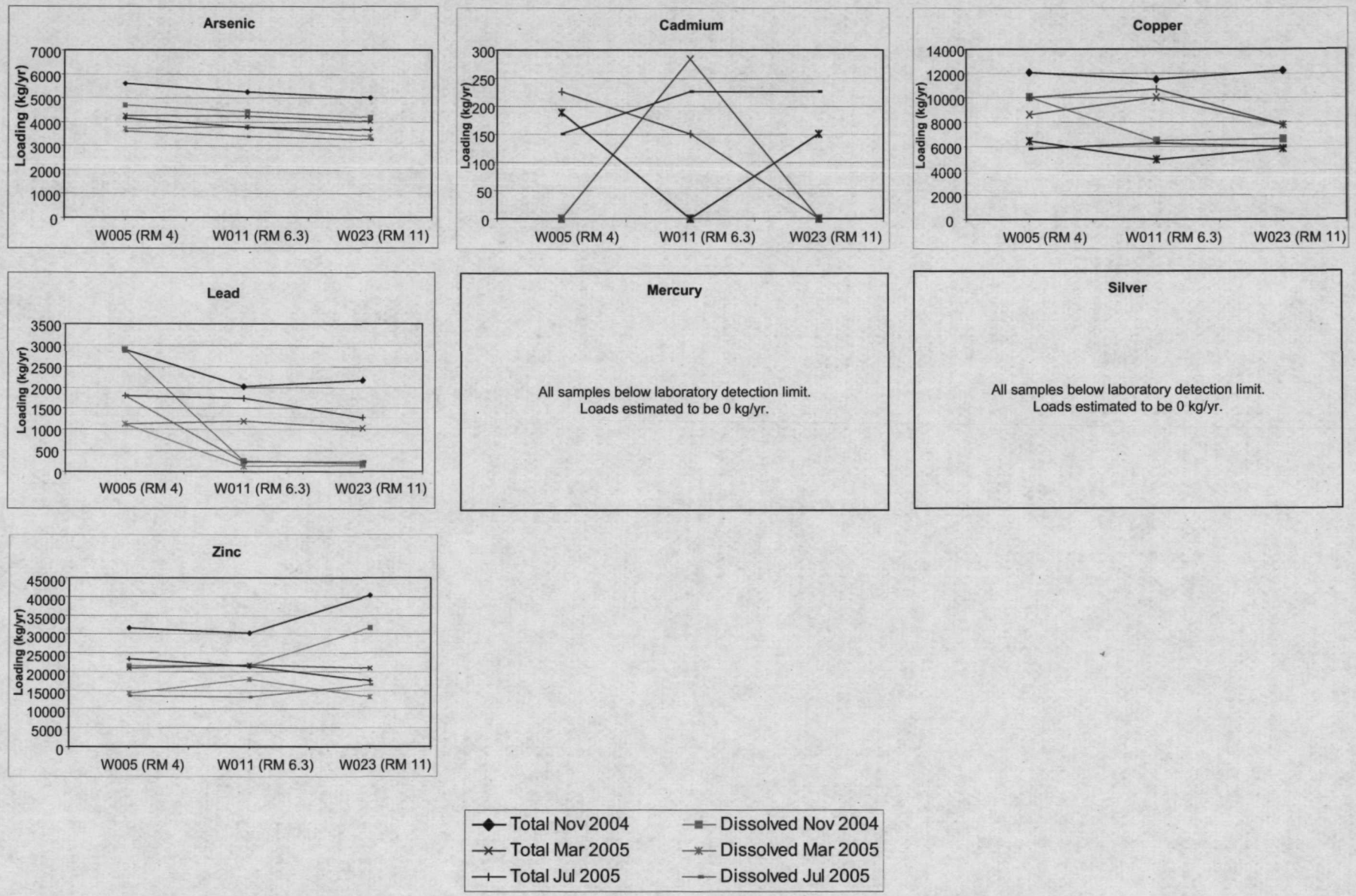

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Figure D2-6
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by River Mile
Metals

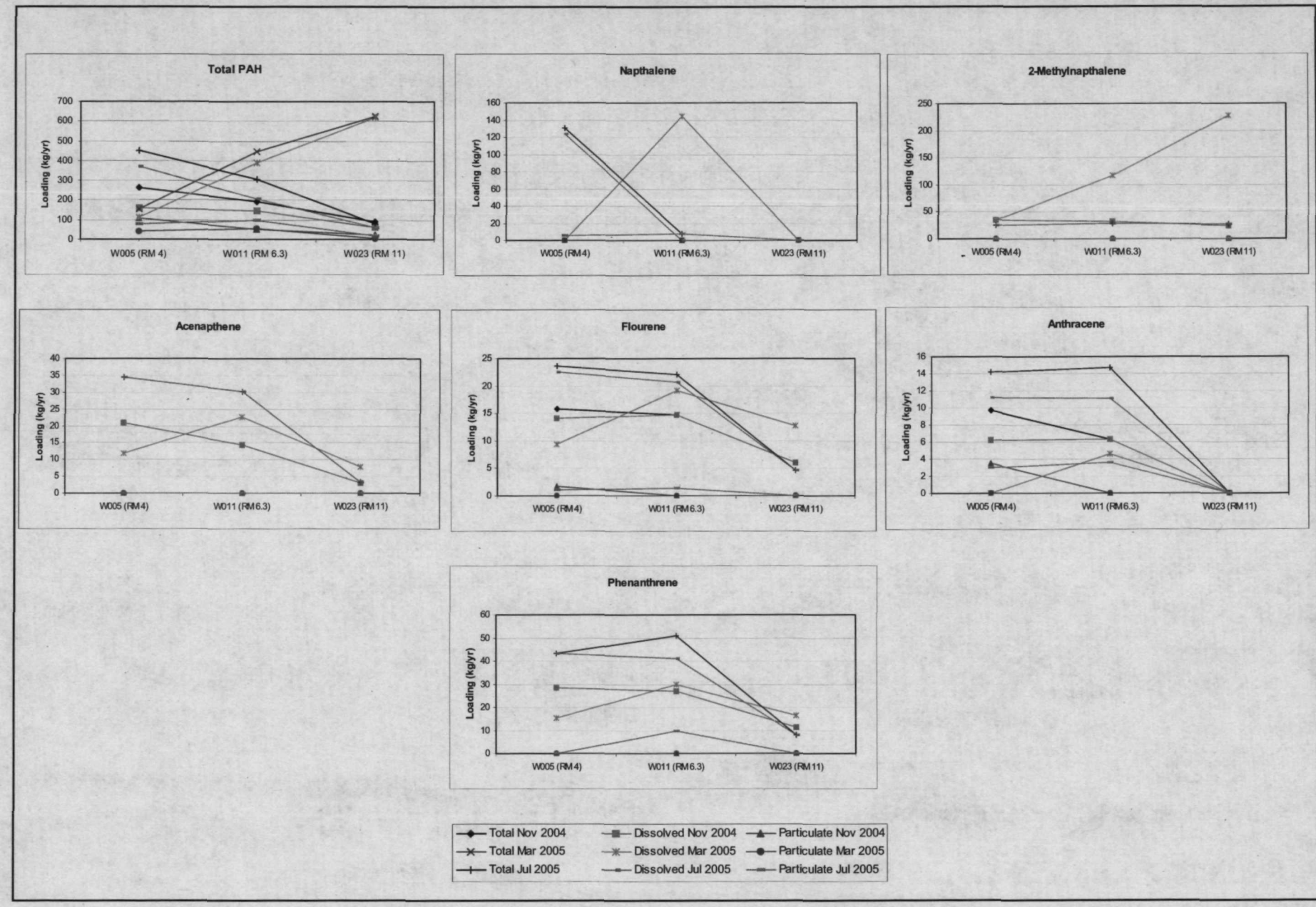

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Figure D2-7a
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by River Mile
LPAHs

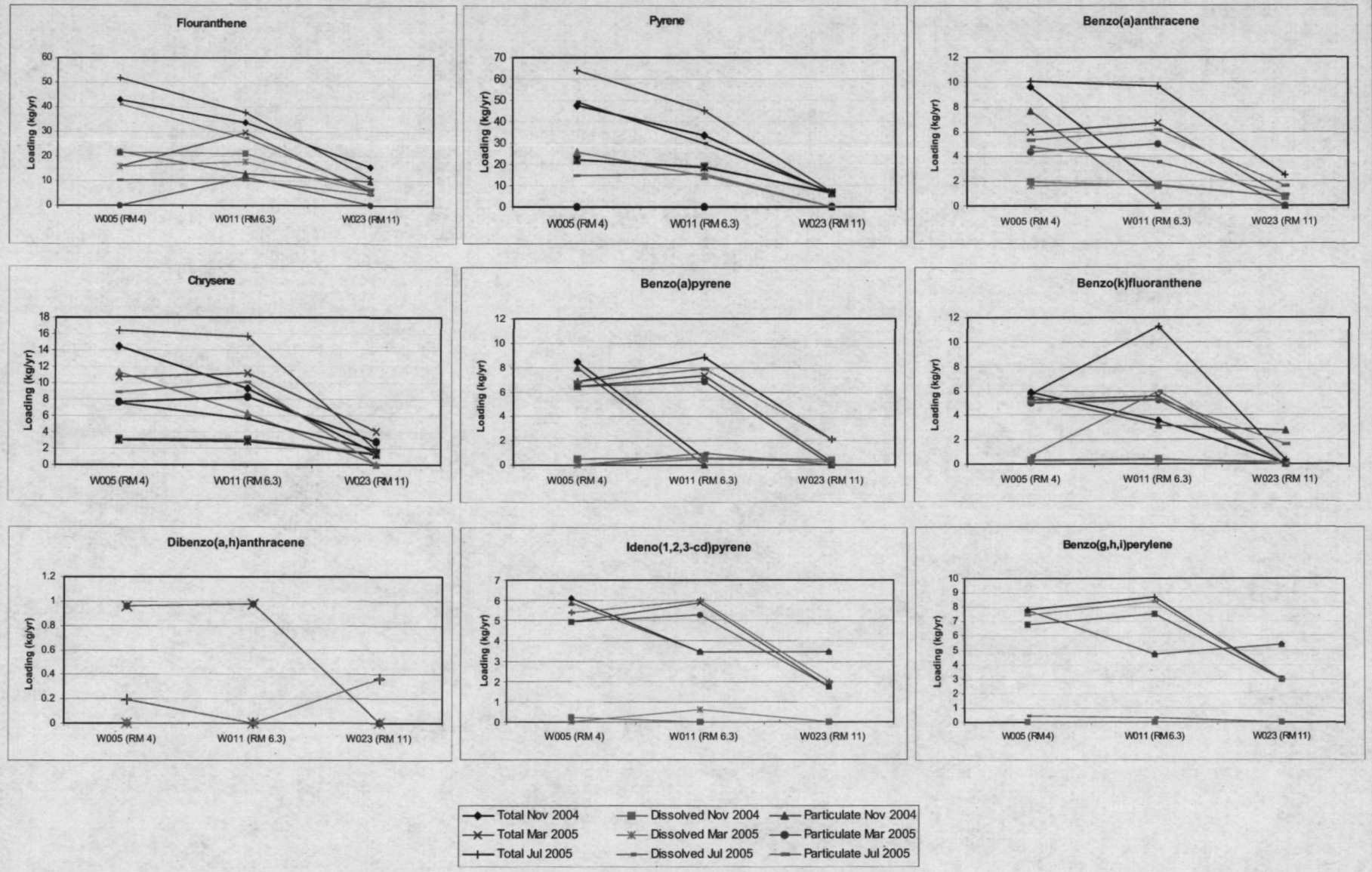

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Figure D2-7b
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by River Mile
HPAHs

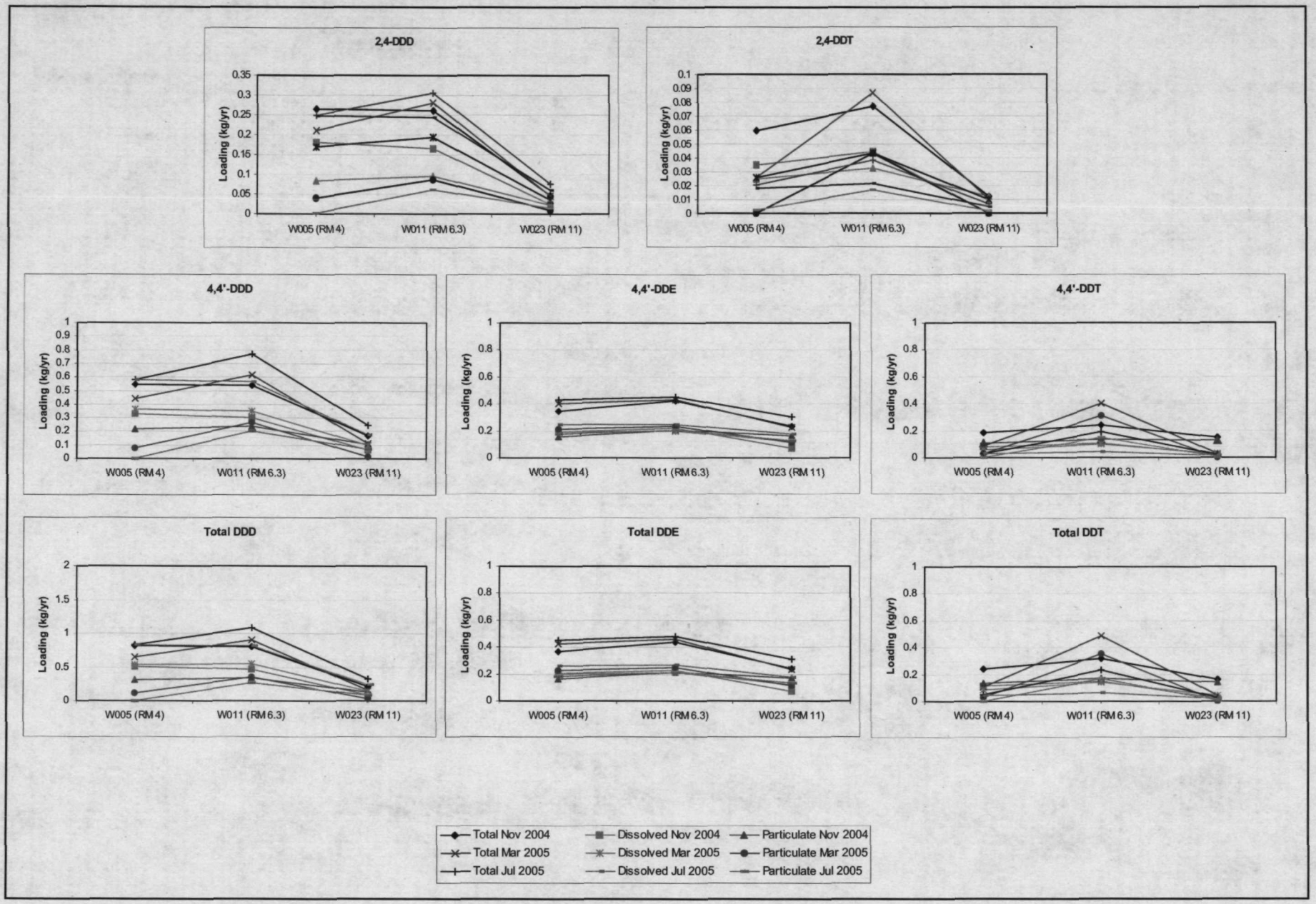

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Figure D2-8
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by River Mile
DDx Pesticides

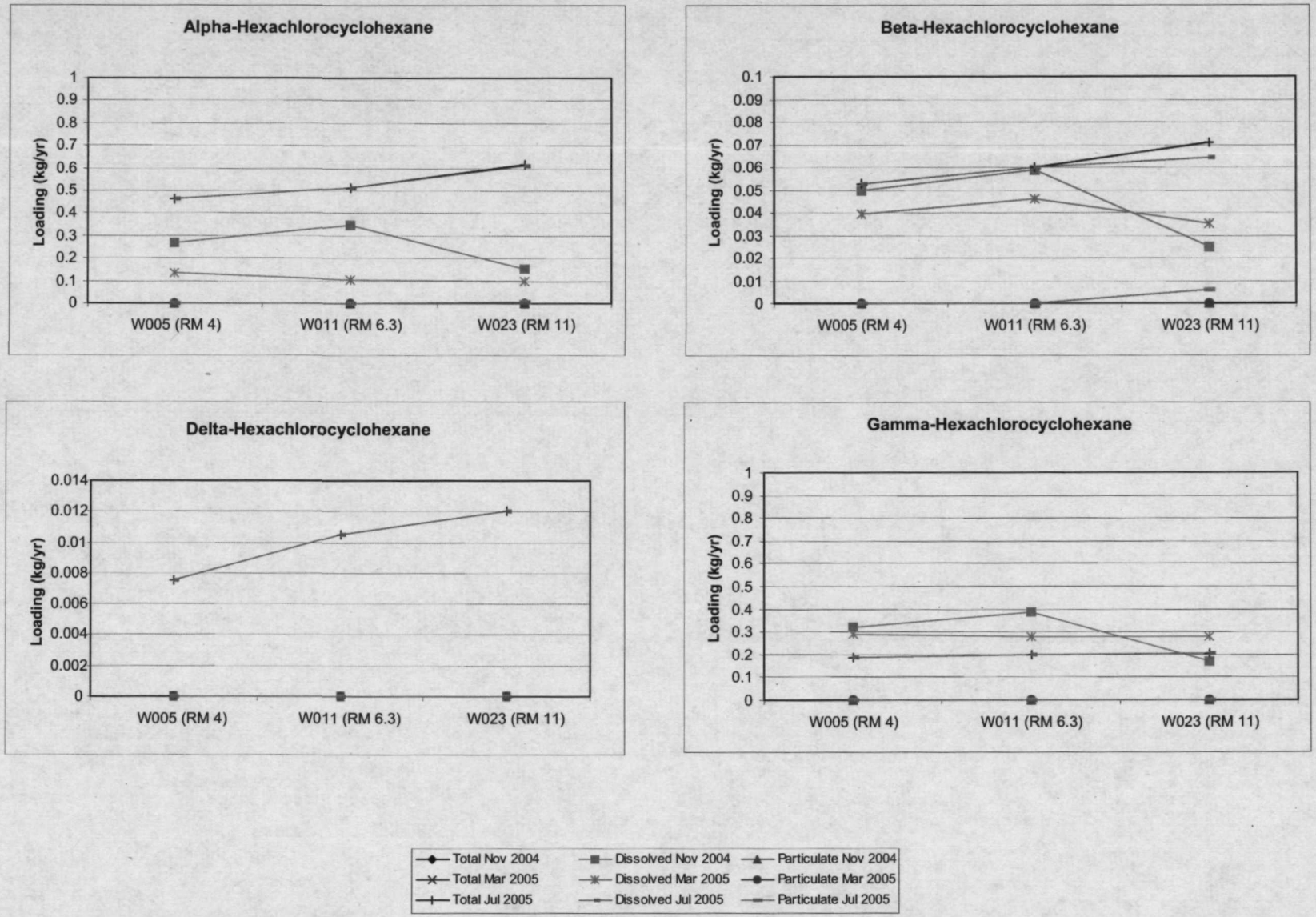

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Figure D2-9a
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by River Mile
Non-DDx Pesticides, Hexachlorocyclohexanes

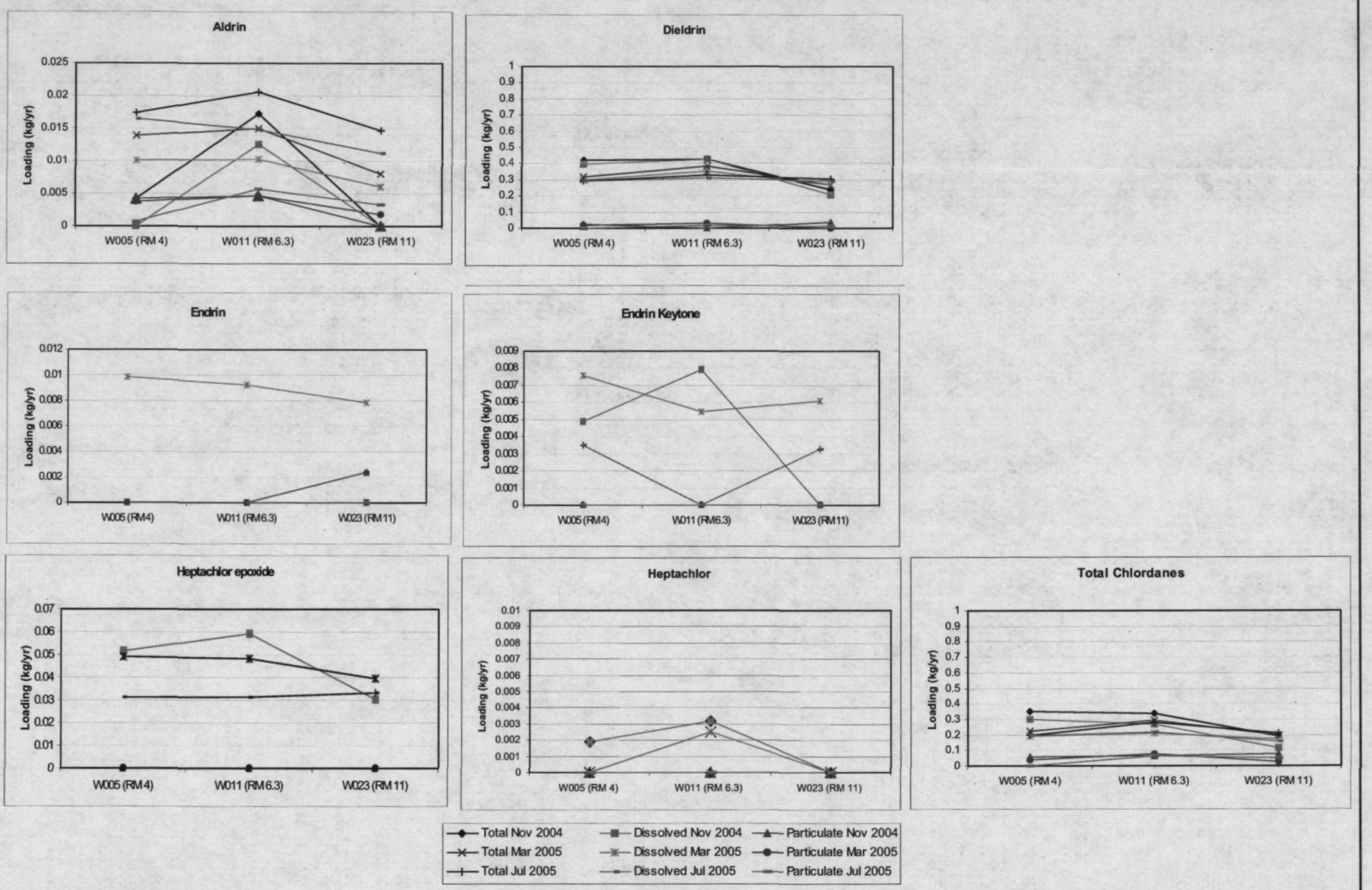

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Figure D2-9b
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by River Mile
Non-DDx Pesticides

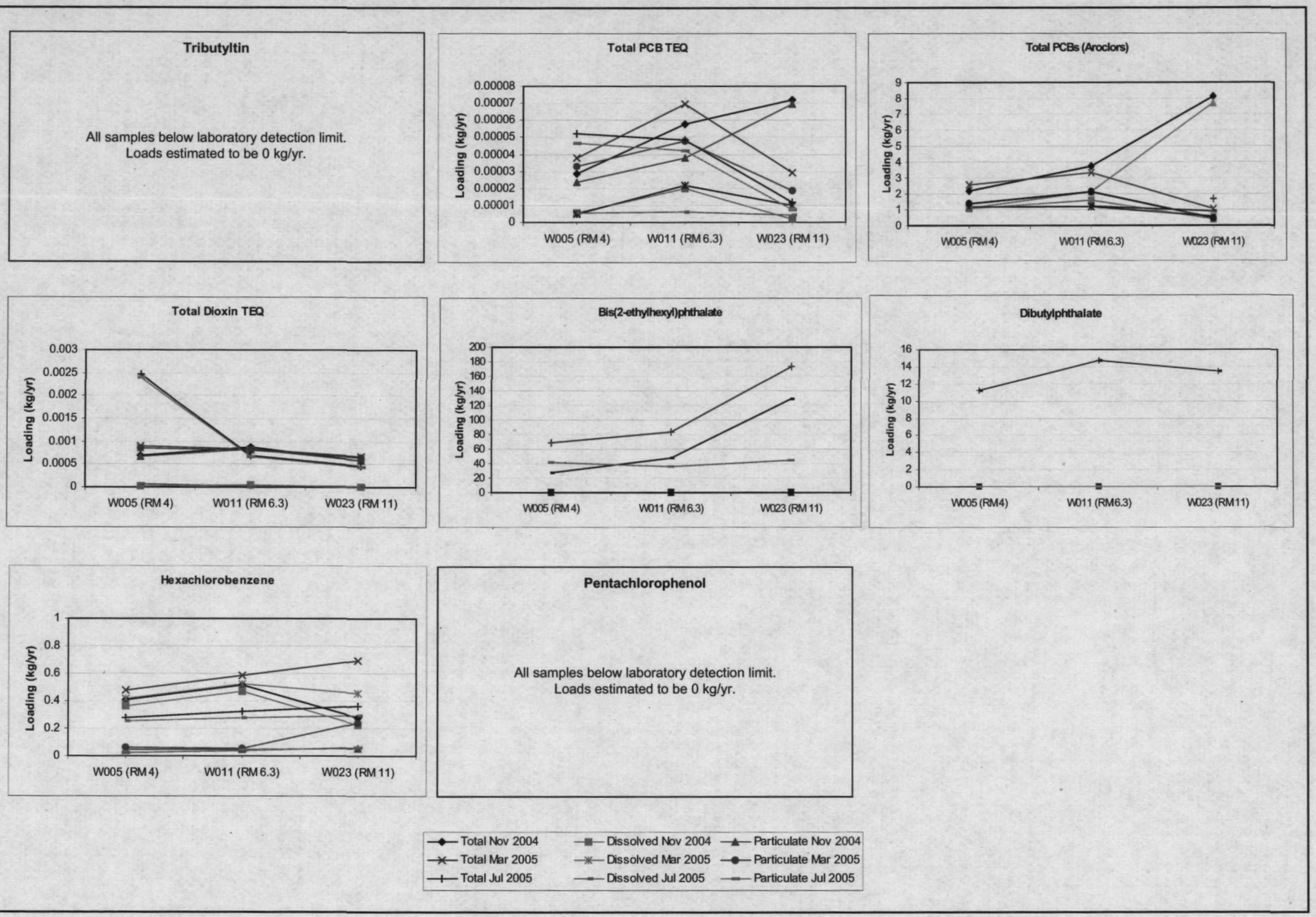

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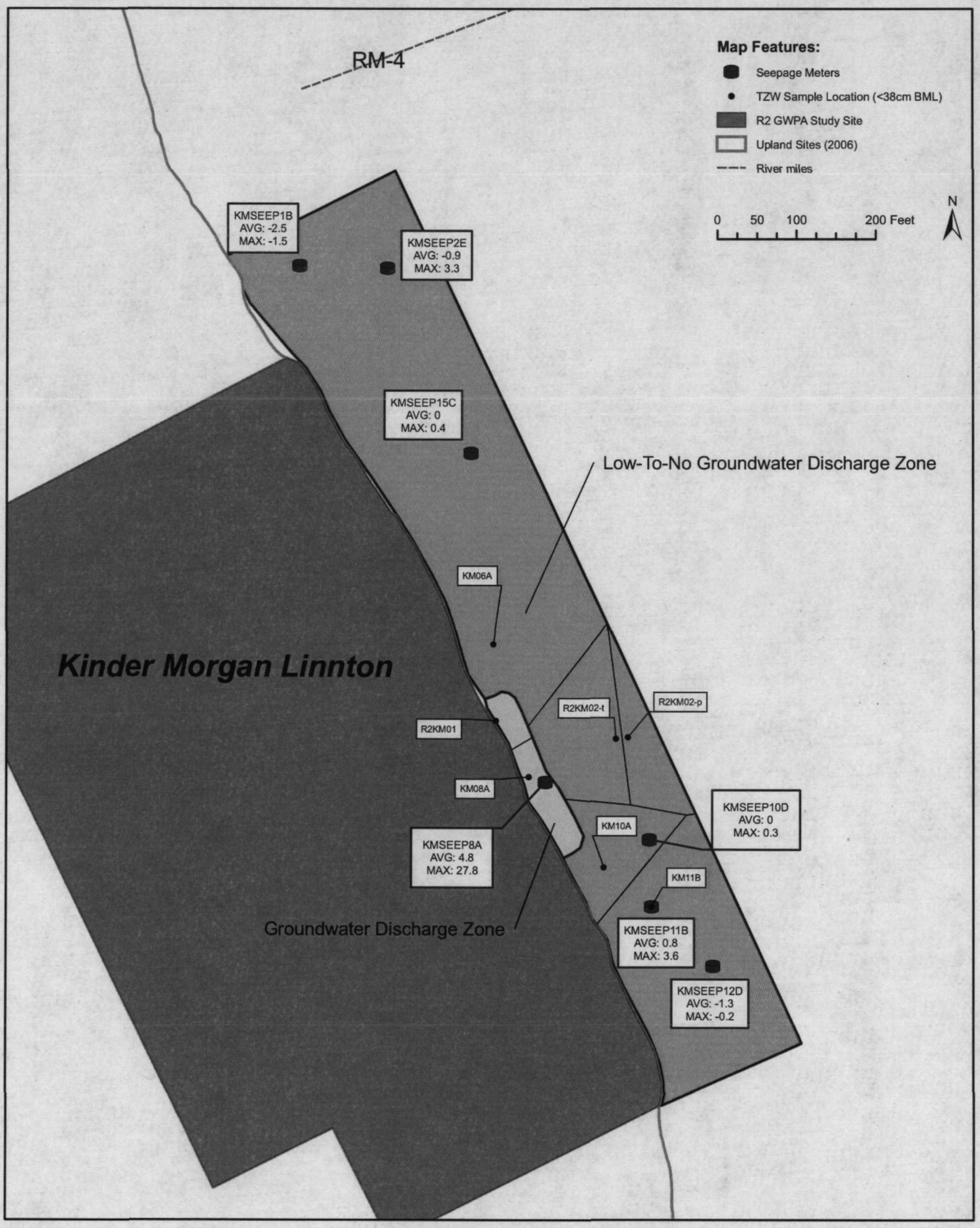
Figure D2-10
Portland Harbor RI/FS
Comprehensive Round 2 Report
Surface Water Loading by River Mile
Butyltins, Dioxins, PCBs, Phthalates and SVOCs



integral consulting inc.

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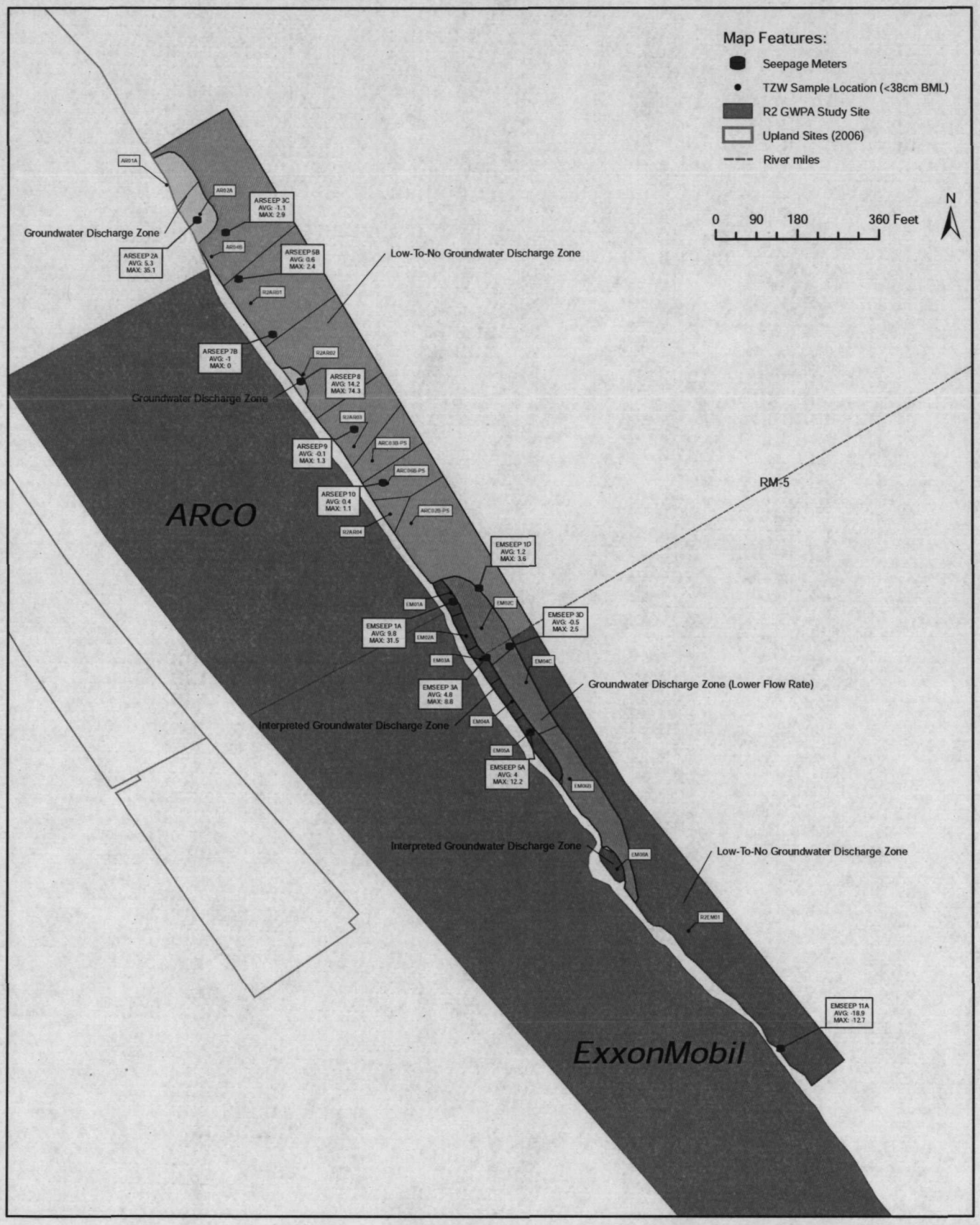
FEATURE SOURCES:
Property and Taxlot Boundaries: Metro RLIS

t Indicates sample collected by Trident sampler
p Indicates sample collected by small volume peeper
PS Indicates sample collected during the GWPA Pilot Study

Figure D4-1
Portland Harbor RI/FS
Comprehensive Round 2 Report
Groundwater Plume Loading Estimate Approach
Kinder Morgan Linnton TZW Study Area



FEATURE SOURCES:
Property and Taxlot Boundaries: Metro RLIS

t Indicates sample collected by Trident sampler
p Indicates sample collected by small volume peeper
PS Indicates sample collected during the GWPA Pilot Study

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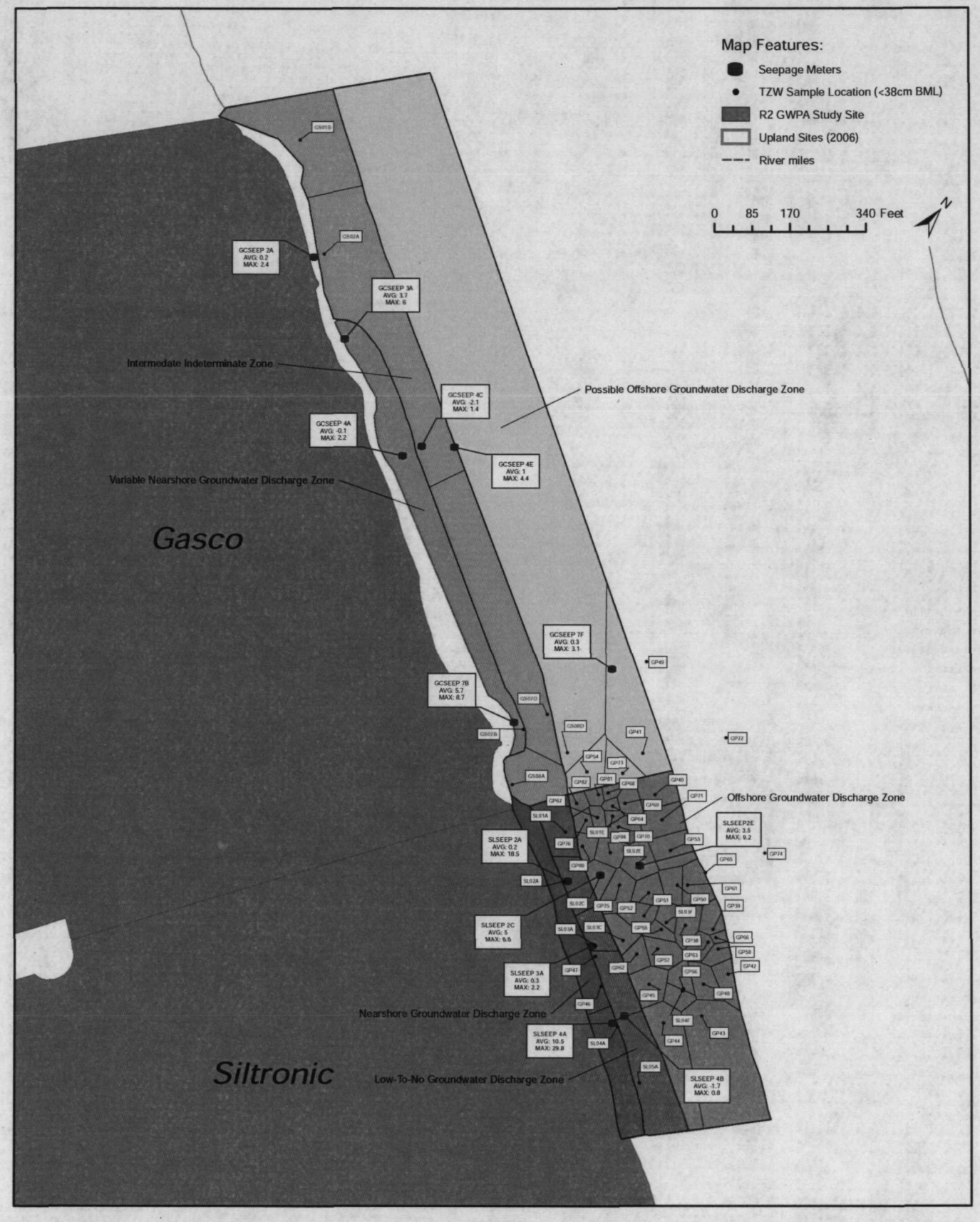
Figure D4-2
Portland Harbor RI/FS
Comprehensive Round 2 Report
Groundwater Plume Loading Estimate Approach
ARCO and ExxonMobil TZW Study Areas



FEATURE SOURCES:
Property and Taxlot Boundaries: Metro RLIS

t Indicates sample collected by Trident sampler
p Indicates sample collected by small volume peeper
PS Indicates sample collected during the GWPA Pilot Study

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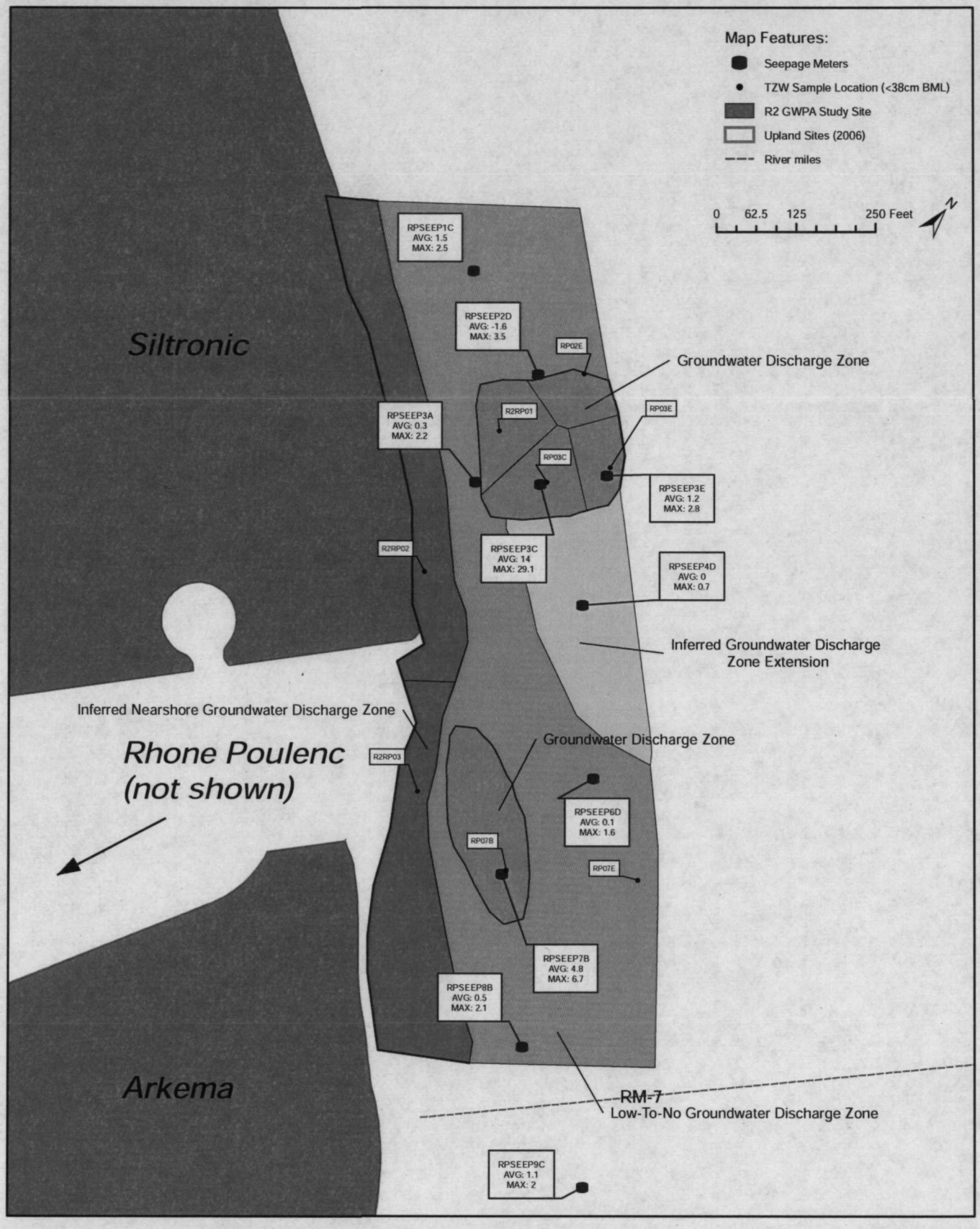
Figure D4-3
Portland Harbor RI/FS
Comprehensive Round 2 Report
Groundwater Plume Loading Estimate Approach
Gasco and Siltronic TZW Study Areas



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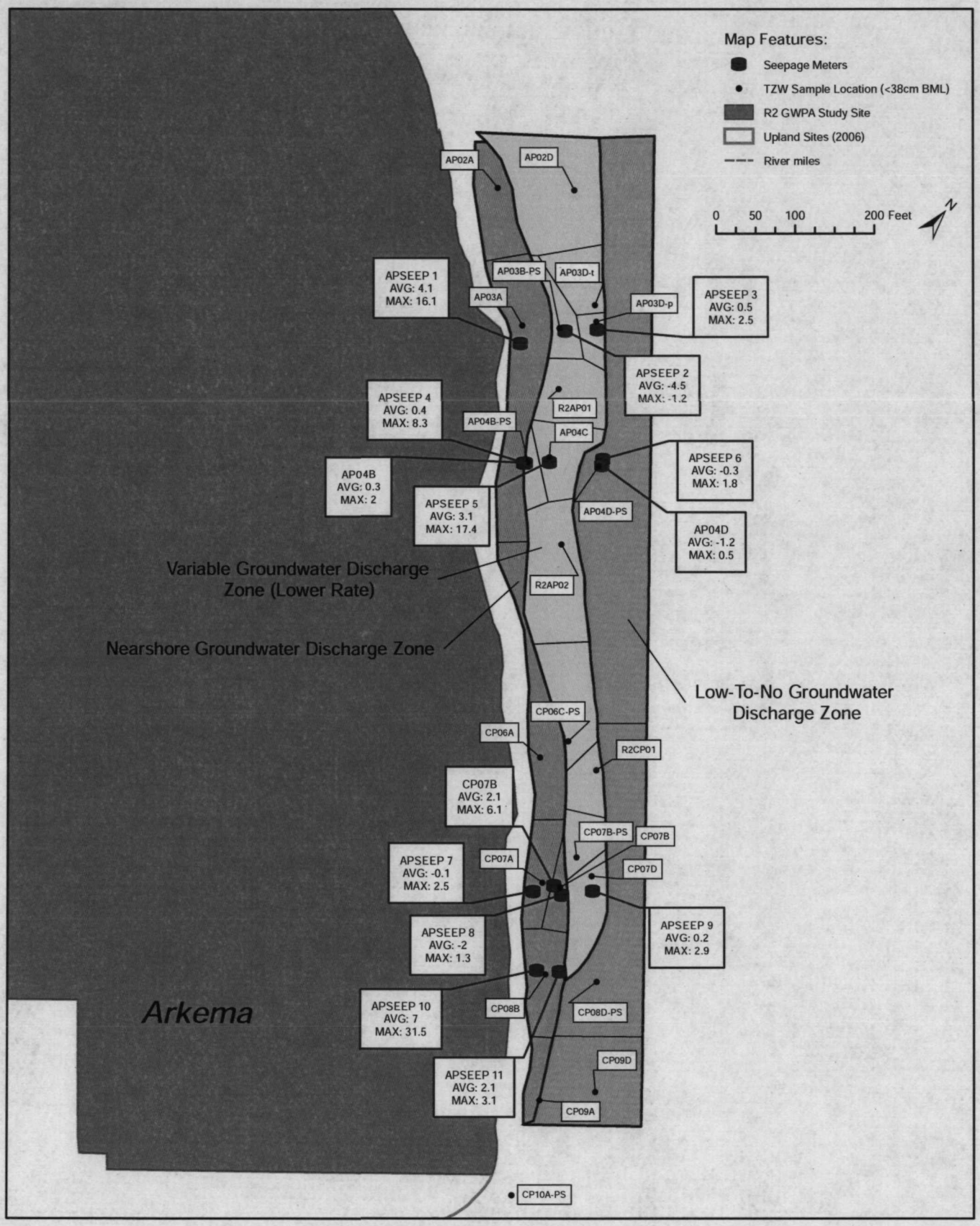
FEATURE SOURCES:
Property and Taxlot Boundaries: Metro RLIS

t Indicates sample collected by Trident sampler
p Indicates sample collected by small volume peeper
PS Indicates sample collected during the GWPA Pilot Study

Figure D4-4
Portland Harbor RI/FS
Comprehensive Round 2 Report
Groundwater Plume Loading Estimate Approach
Rhone Poulenc TZW Study Area



FEATURE SOURCES:
Property and Taxlot Boundaries: Metro RLIS

t Indicates sample collected by Trident sampler
p Indicates sample collected by small volume peeper
PS Indicates sample collected during the GWPA Pilot Study

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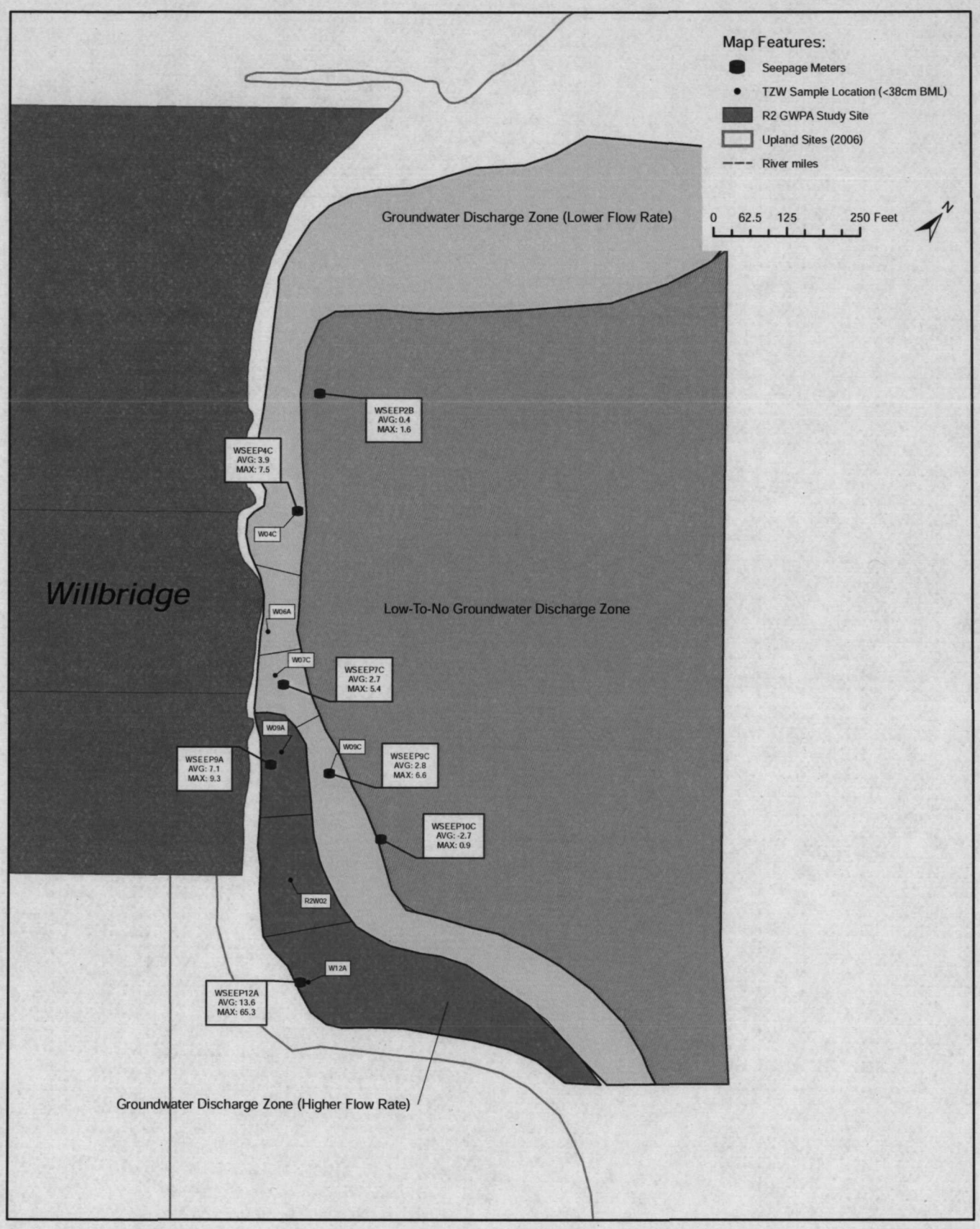
Figure D4-5
Portland Harbor RI/FS
Comprehensive Round 2 Report
Groundwater Plume Loading Estimate Approach
Arkema TZW Study Area



FEATURE SOURCES:
Property and Taxlot Boundaries: Metro RLIS

t Indicates sample collected by Trident sampler
p Indicates sample collected by small volume peeper
PS Indicates sample collected during the GWPA Pilot Study

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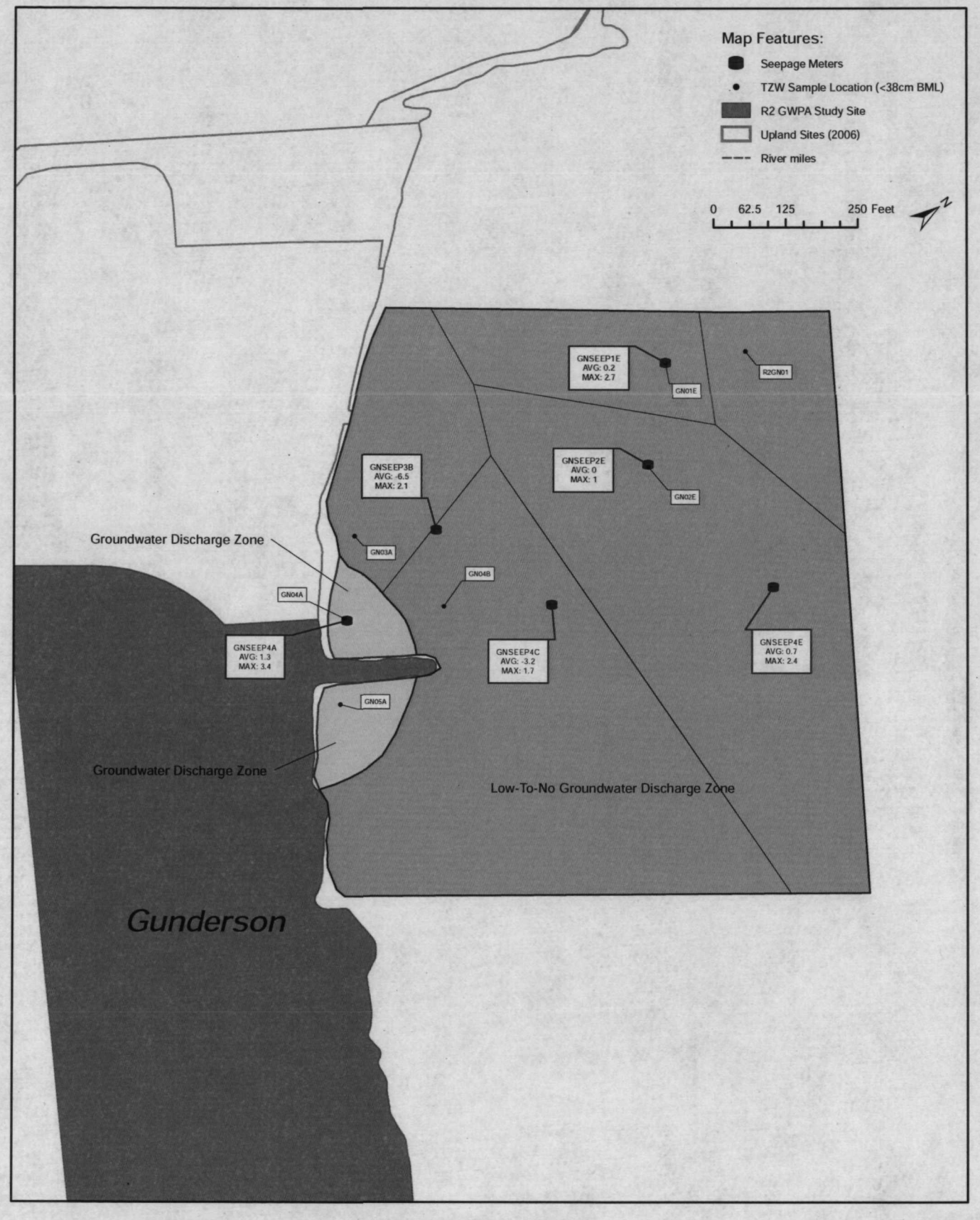
Figure D4-6
Portland Harbor RI/FS
Comprehensive Round 2 Report
Groundwater Plume Loading Estimate Approach
Willbridge TZW Study Area



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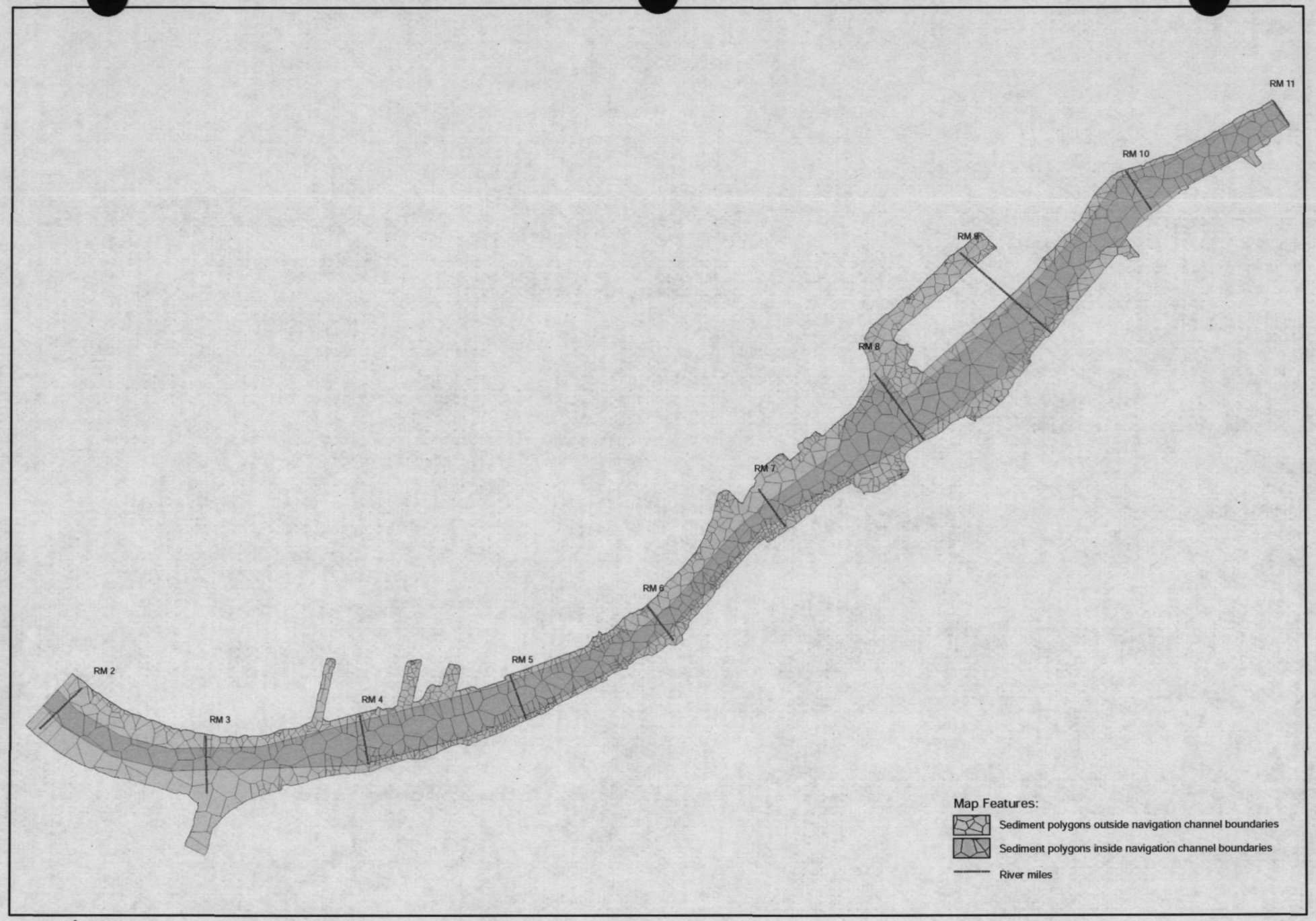
FEATURE SOURCES:
Property and Taxlot Boundaries: Metro RLIS

t Indicates sample collected by Trident sampler
p Indicates sample collected by small volume peeper
PS Indicates sample collected during the GWPA Pilot Study

Figure D4-7
Portland Harbor RI/FS
Comprehensive Round 2 Report
Groundwater Plume Loading Estimate Approach
Gunderson TZW Study Area



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N

0 2,250 4,500 9,000 Feet

Figure D4-8
Portland Harbor RI/FS
Comprehensive Round 2 Report
Advective Loading Calculation Areas Example

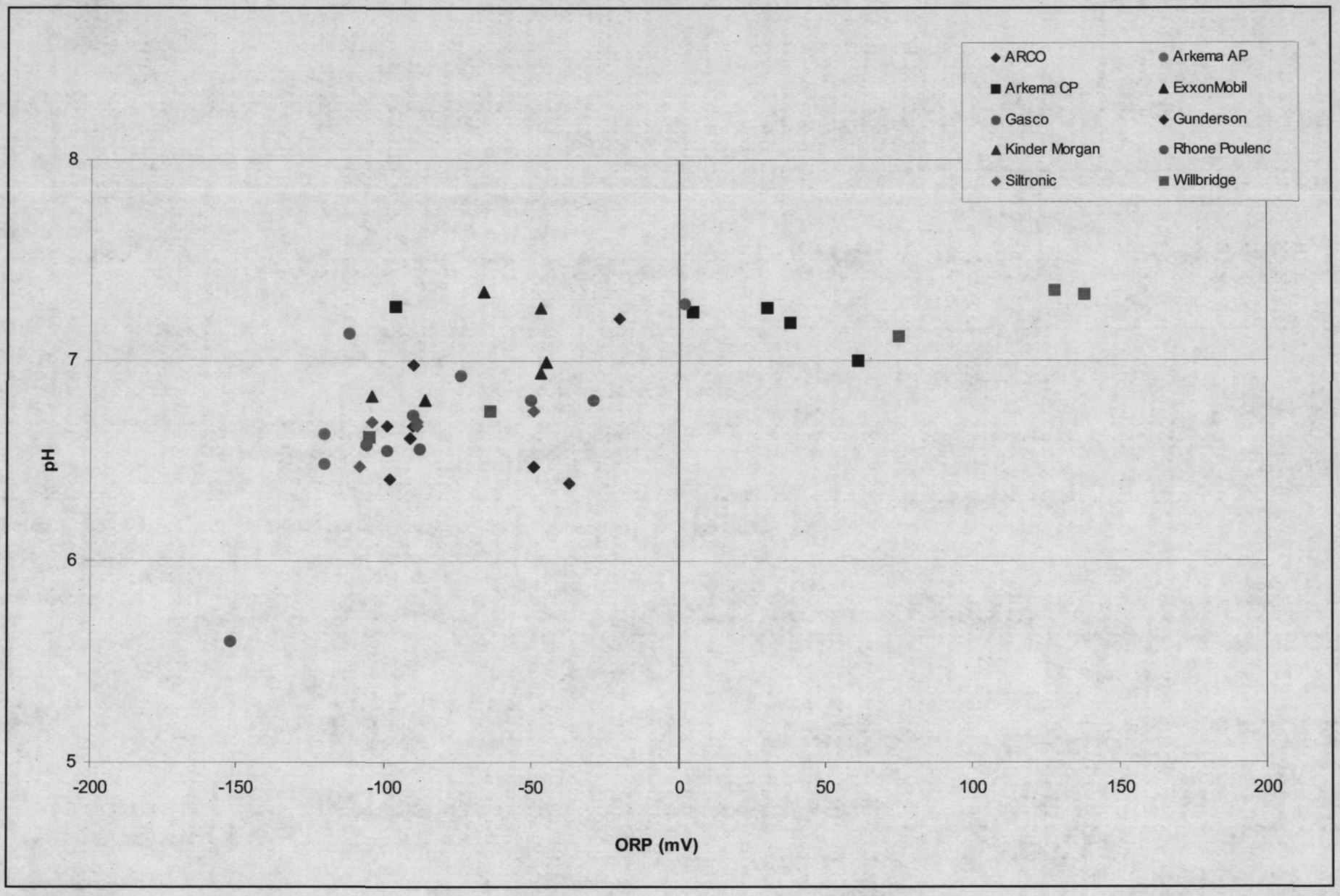

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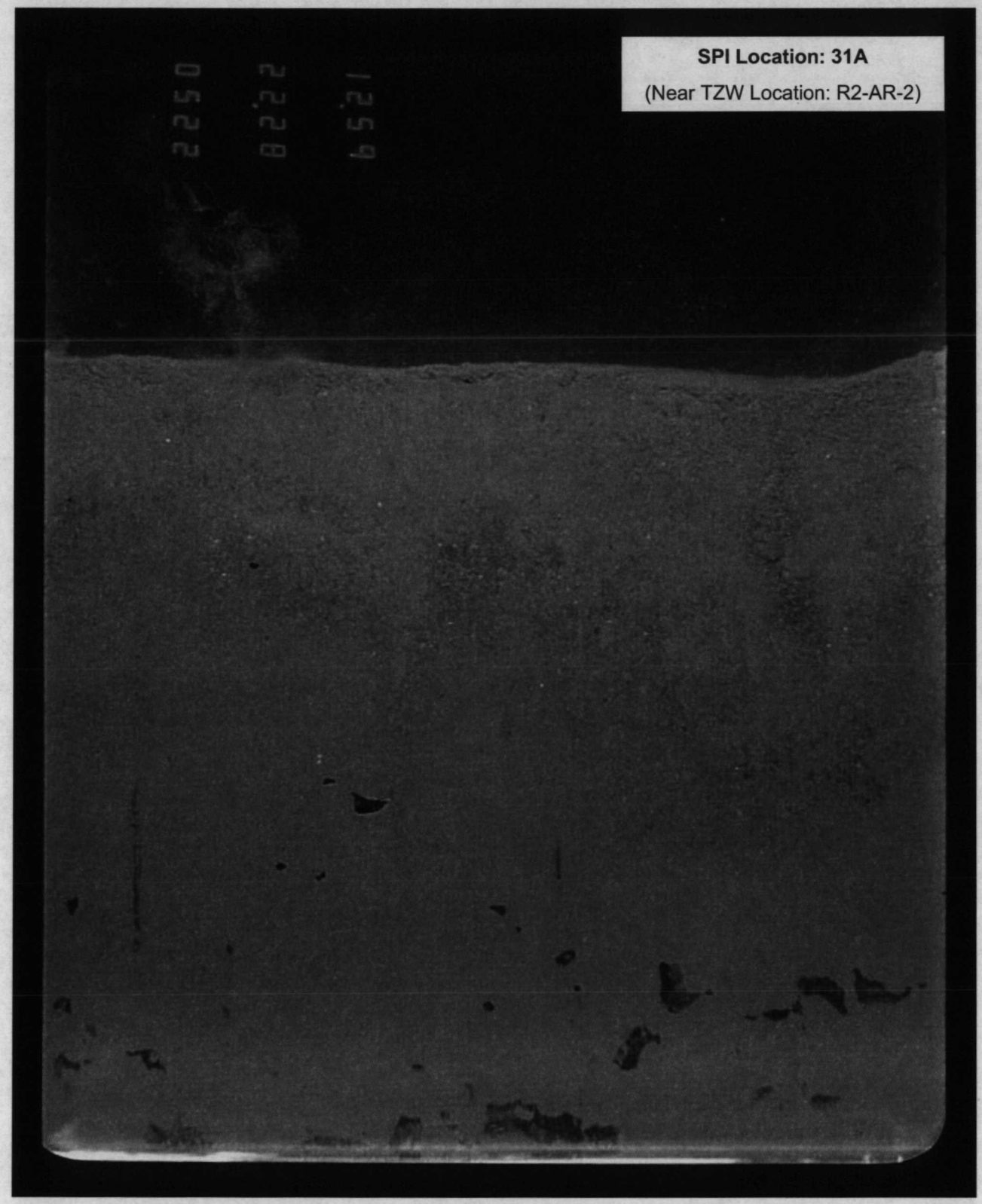
Figure D7-1
Portland Harbor RI/FS
Comprehensive Round 2 Report
pH versus ORP in TZW



Note: depth of sediment profile shown is ~15 cm

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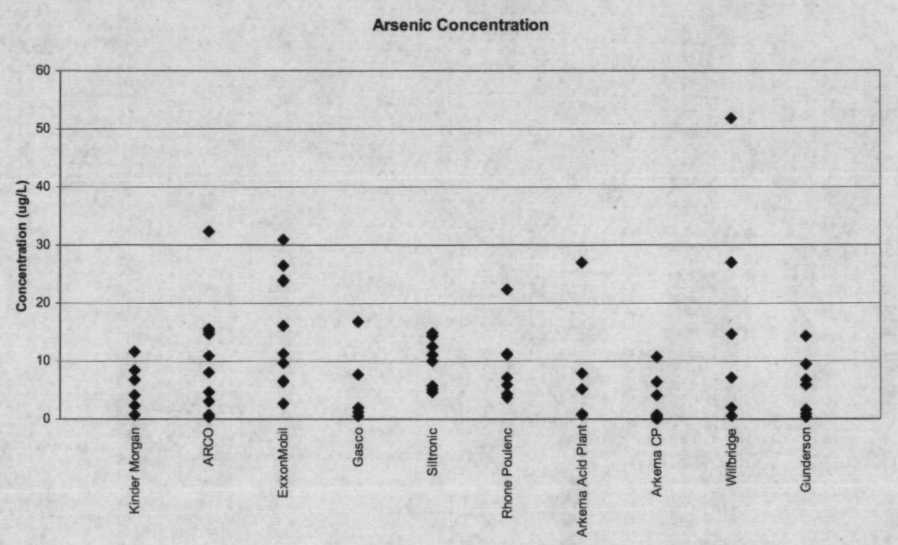
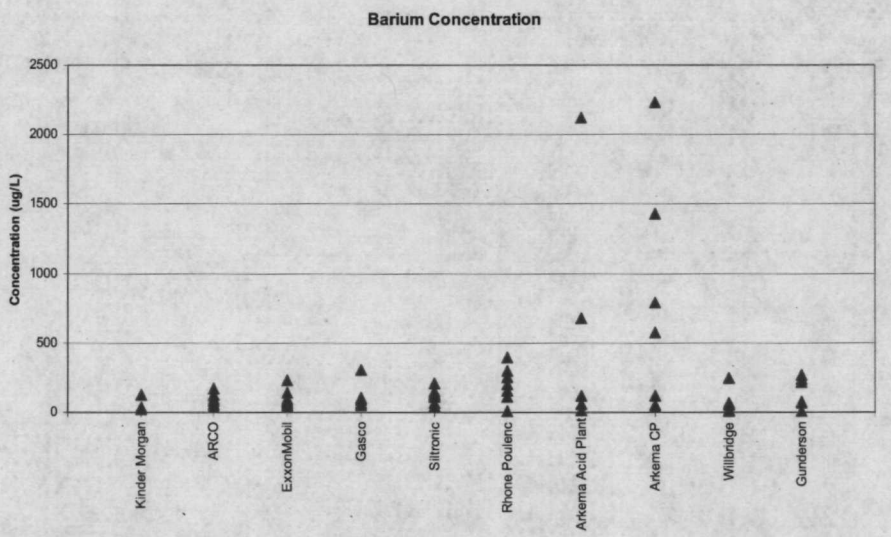
Figure D7-2
Portland Harbor RI/FS
Comprehensive Round 2 Report
Sediment Profile Image
Illustrating the Apparent Redox Potential Depth
in Willamette River Bed Sediments





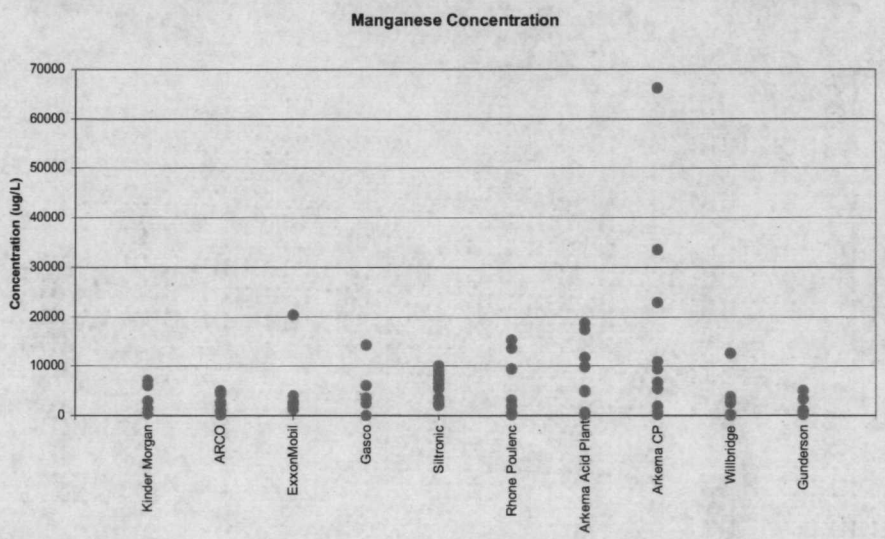


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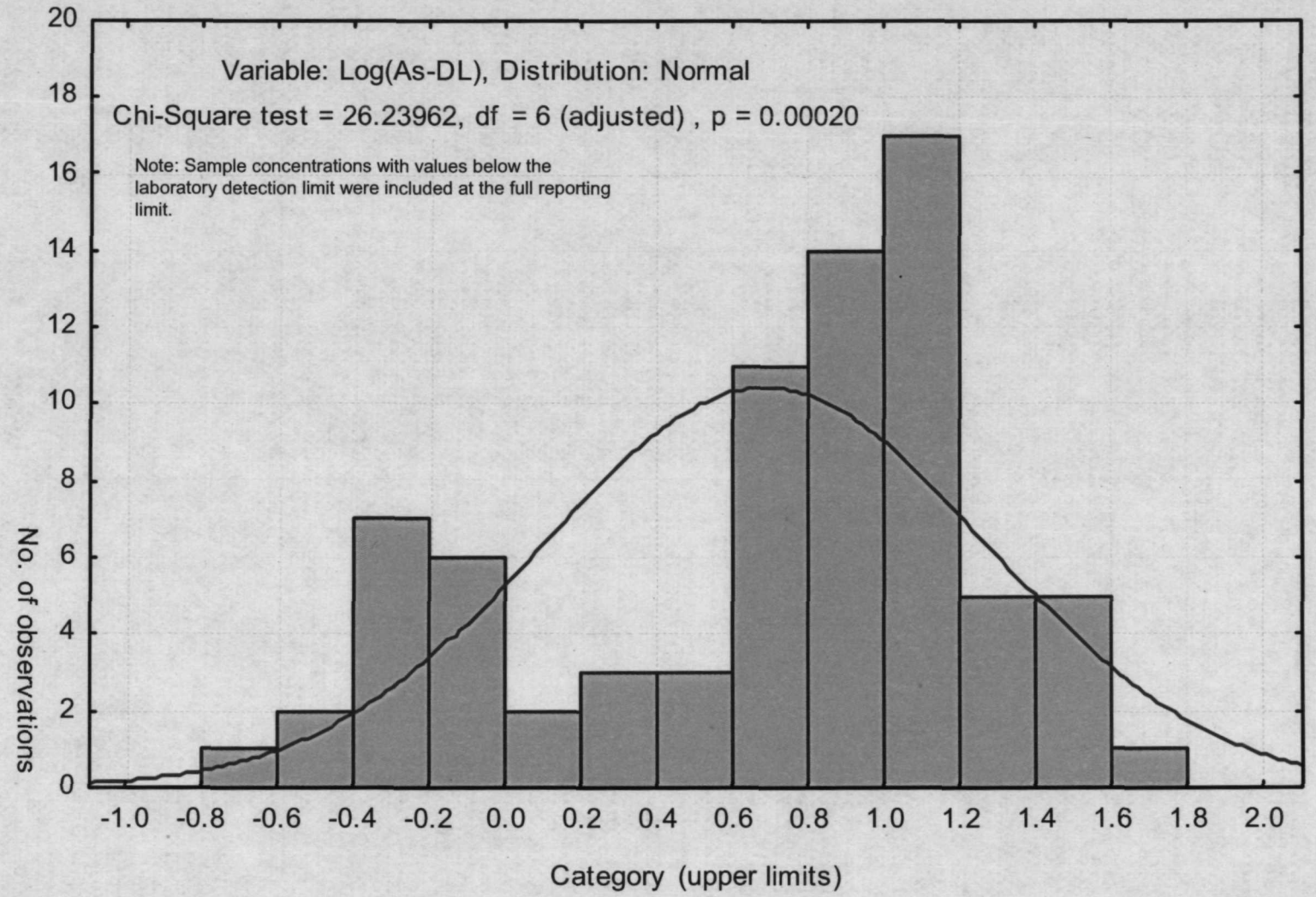
Figure D7-3
Portland Harbor RI/FS
Comprehensive Round 2 Report
Concentrations of Dissolved Arsenic, Barium, and Manganese Observed in TZW by Site

Arsenic – Test for Log-normality



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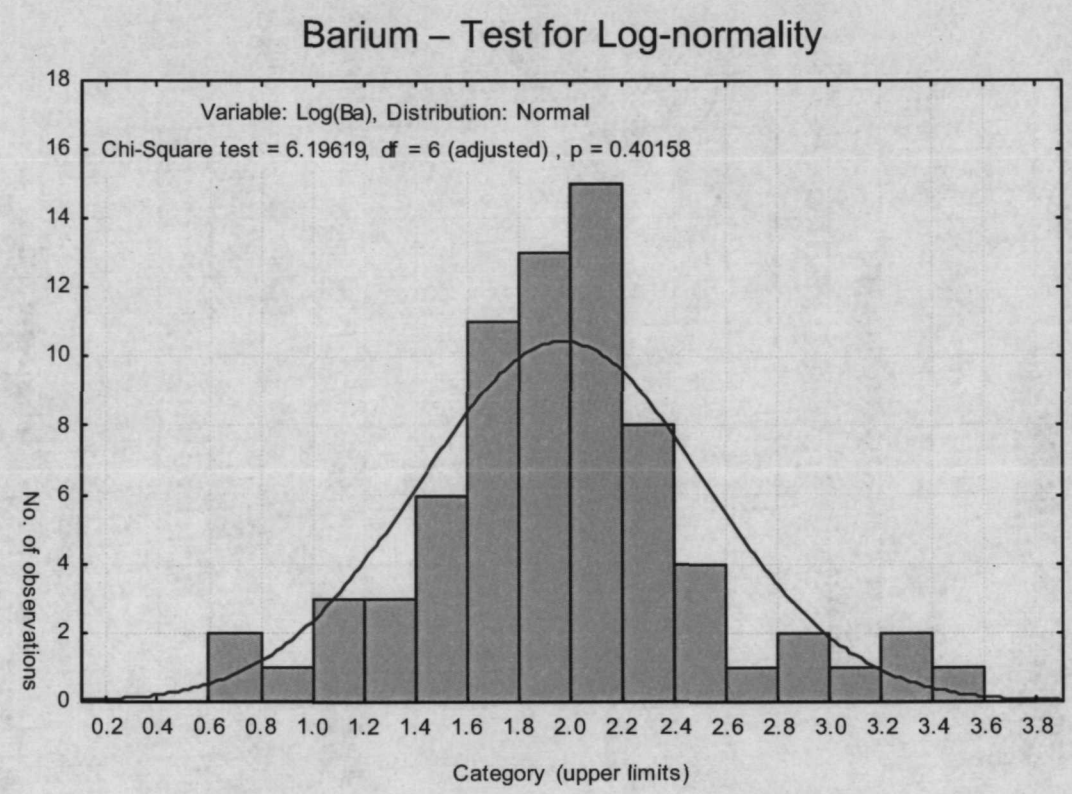
DRAFT
DO NOT CITE OR QUOTE
Privileged and Confidential. Work Product Prepared in Anticipation of Litigation.

Figure D7-4
Portland Harbor RI/FS
Comprehensive Round 2 Report
Test for Log-normality – Arsenic in TZW



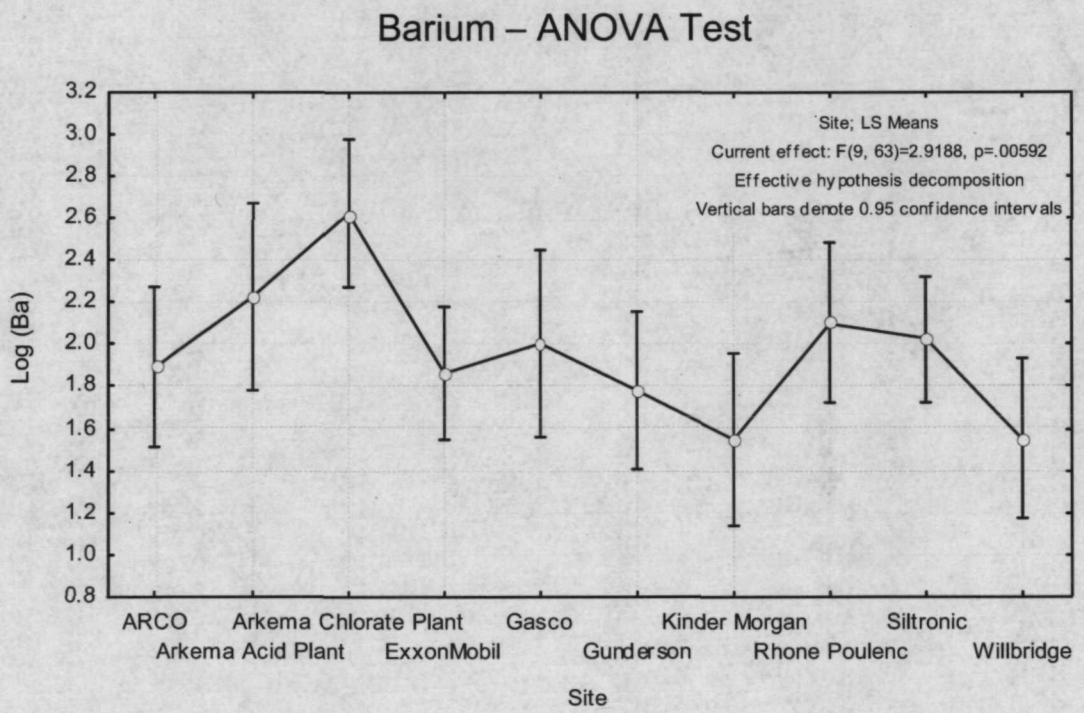


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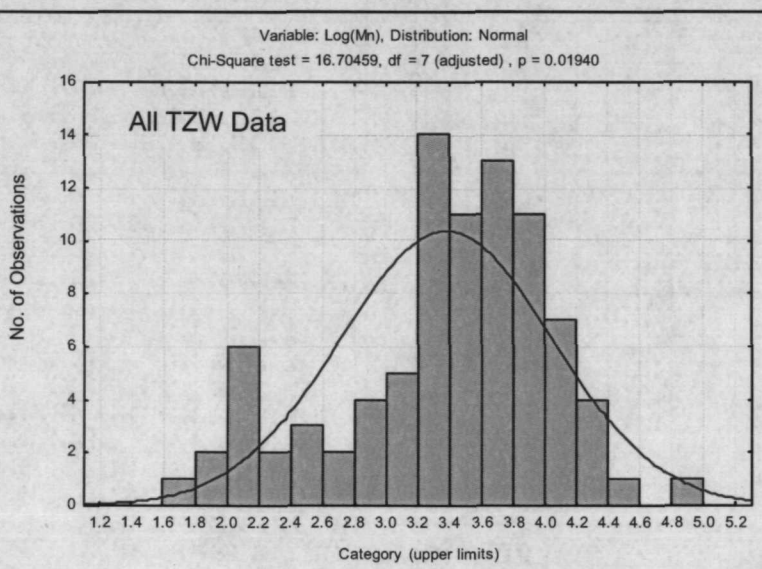
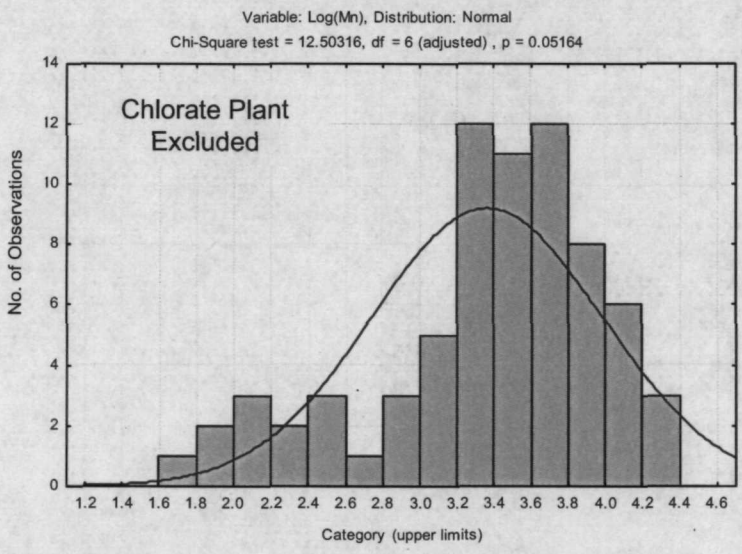
Figure D7-5
Portland Harbor RI/FS
Comprehensive Round 2 Report
Test for Log-normality and ANOVA Testing – Barium in TZW





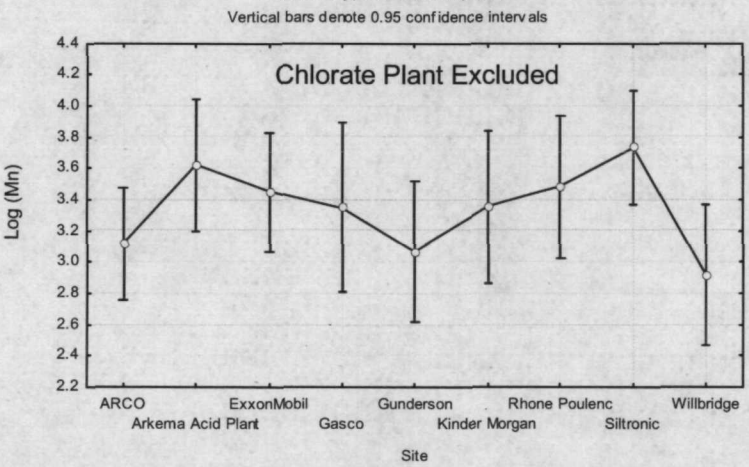


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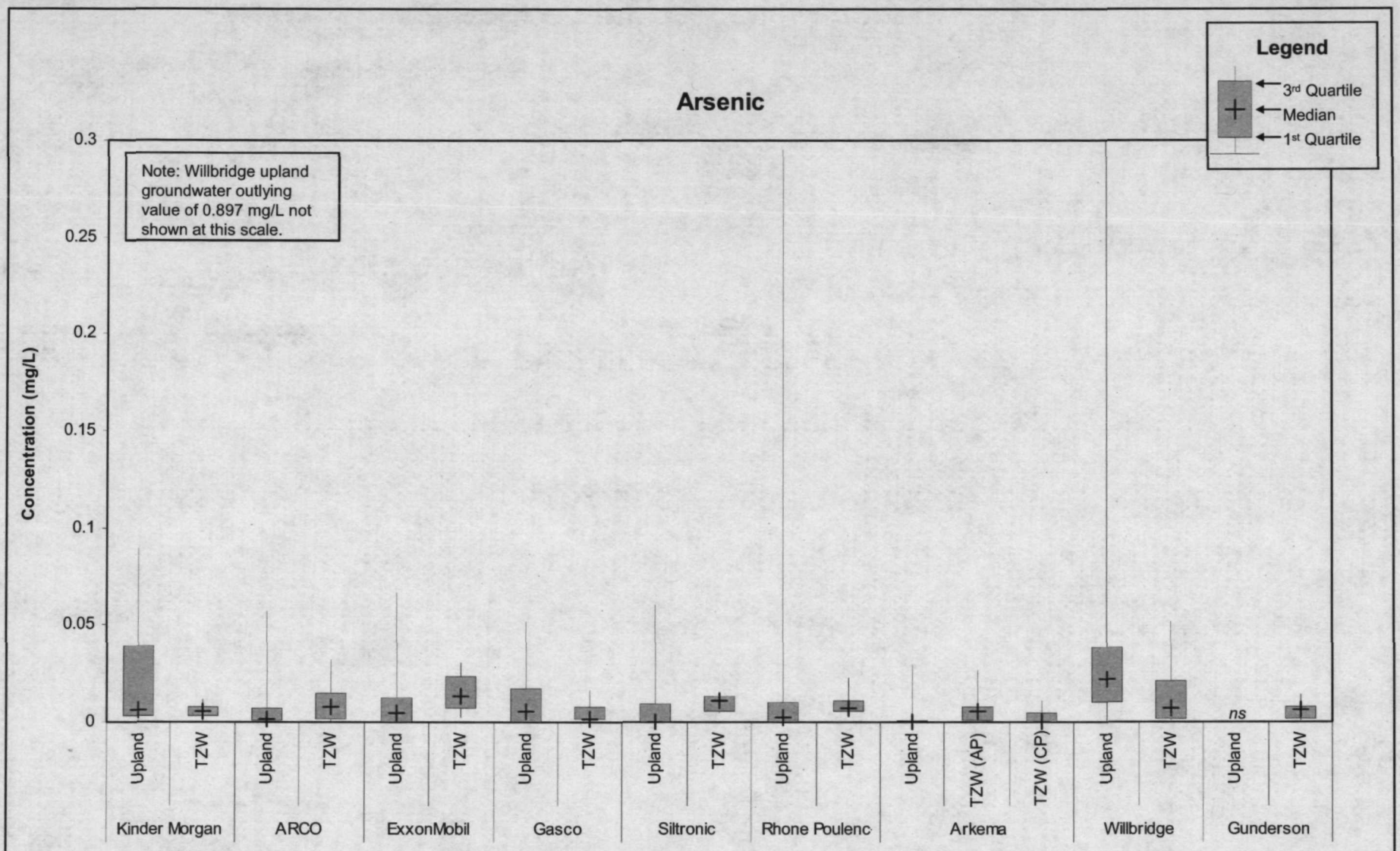
Figure D7-6
Portland Harbor RI/FS
Comprehensive Round 2 Report
Test for Log-normality and
ANOVA Testing – Manganese in TZW



Notes:

ns Indicates that the analyte was not sampled at this site.

All TZW and upland groundwater non-detect values plotted at 0.

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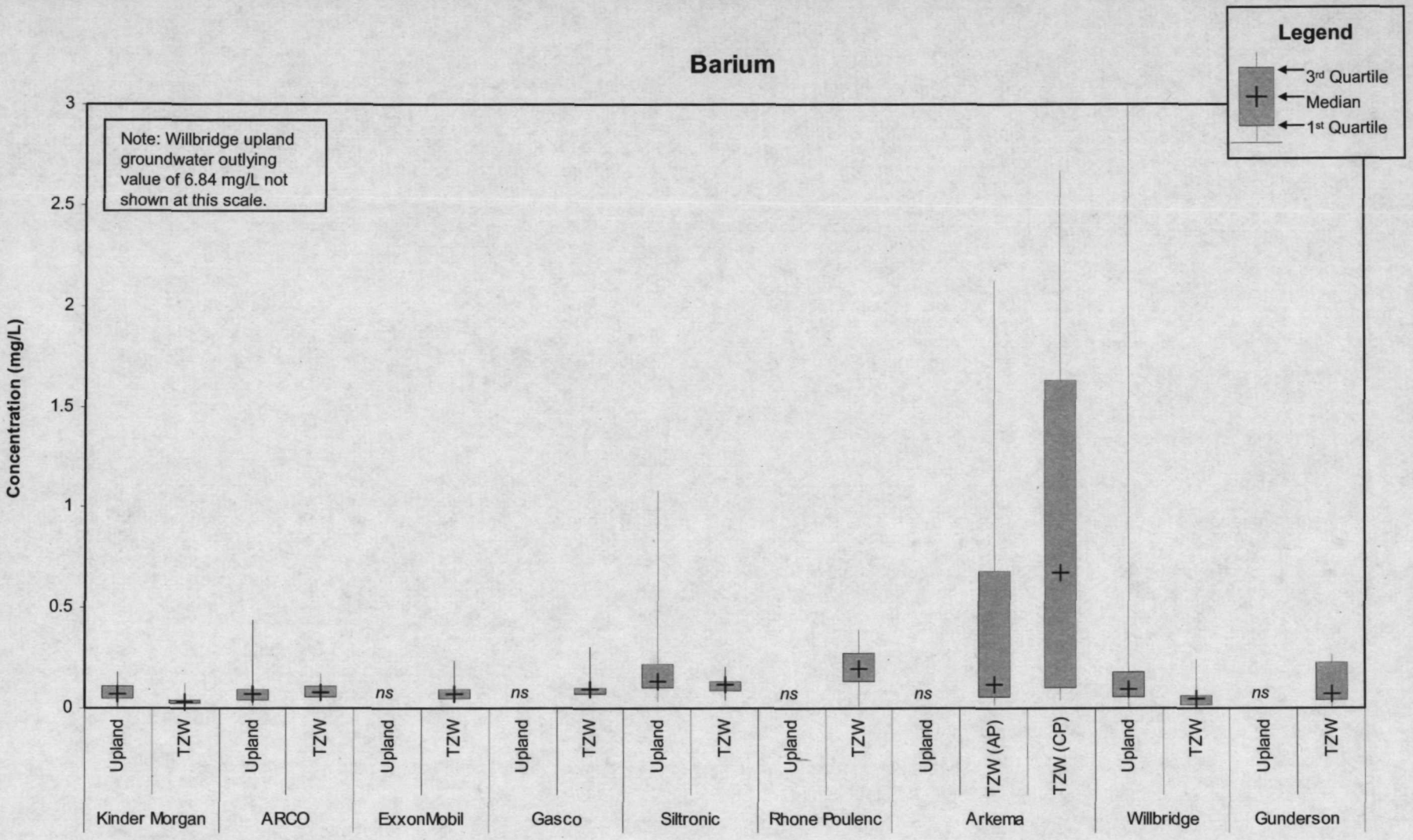
Figure D7-7
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic Box Plot



Notes:

ns Indicates that the analyte was not sampled at this site.

All TZW and upland groundwater non-detect values plotted at 0.

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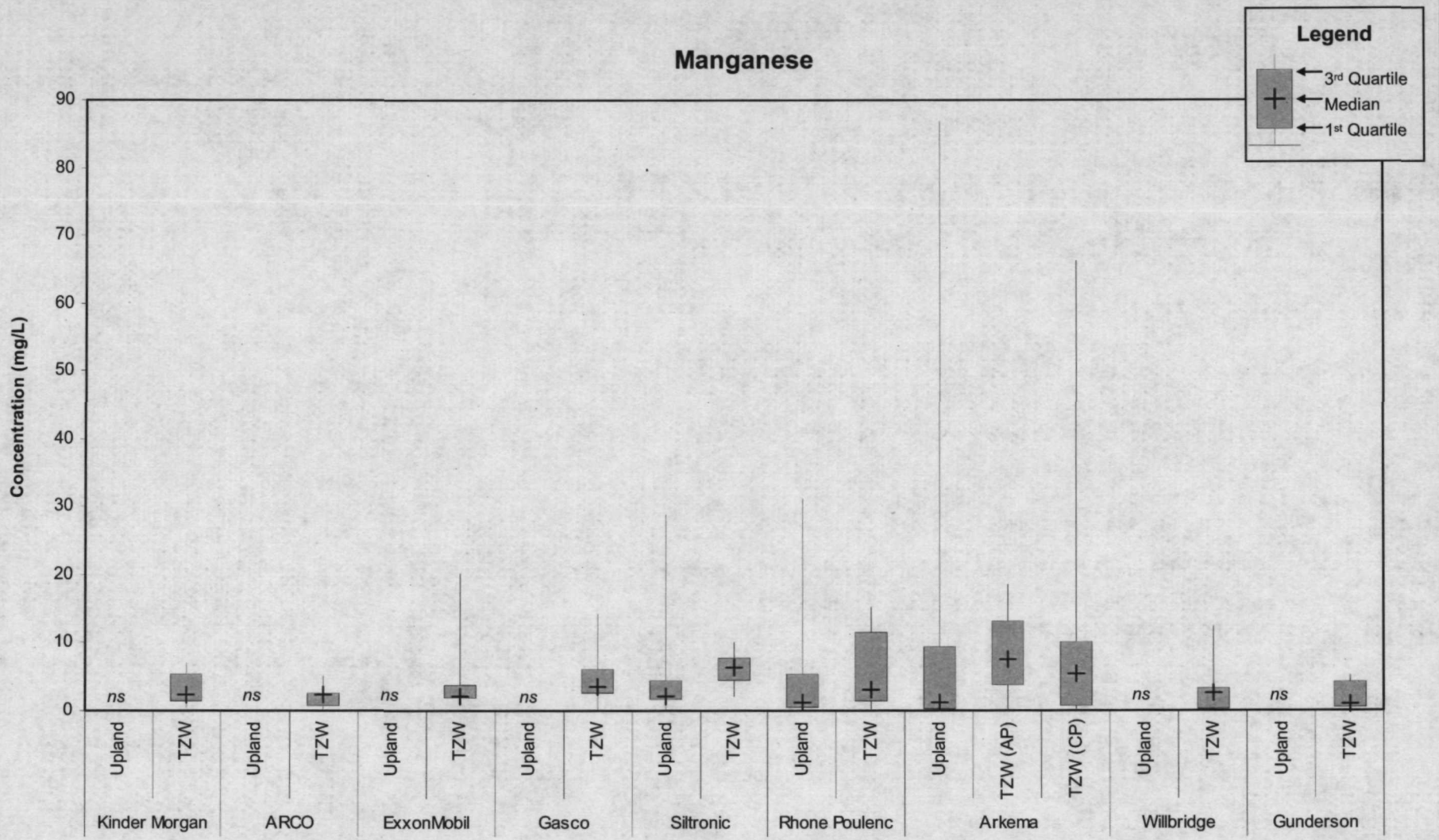
Figure D7-8
Portland Harbor RI/FS
Comprehensive Round 2 Report
Barium Box Plot



Notes:

ns Indicates that the analyte was not sampled at this site.

All TZW and upland groundwater non-detect values plotted at 0.

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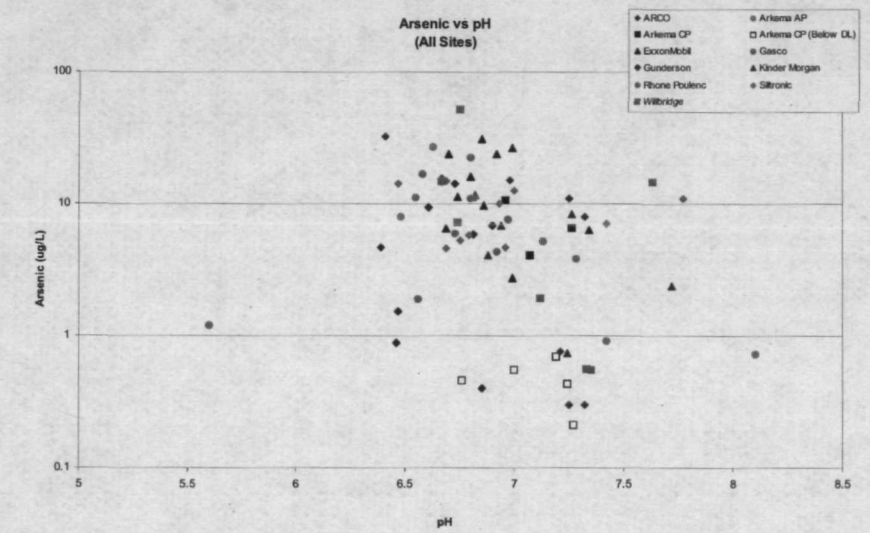
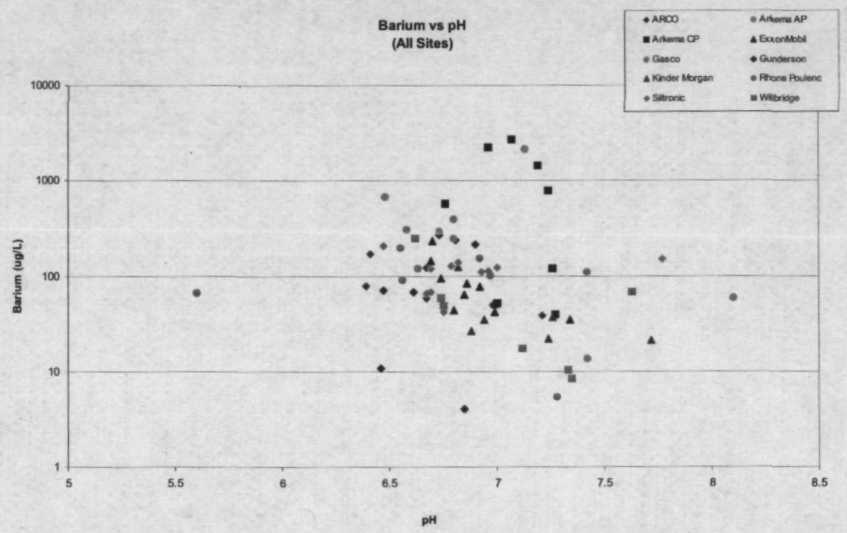
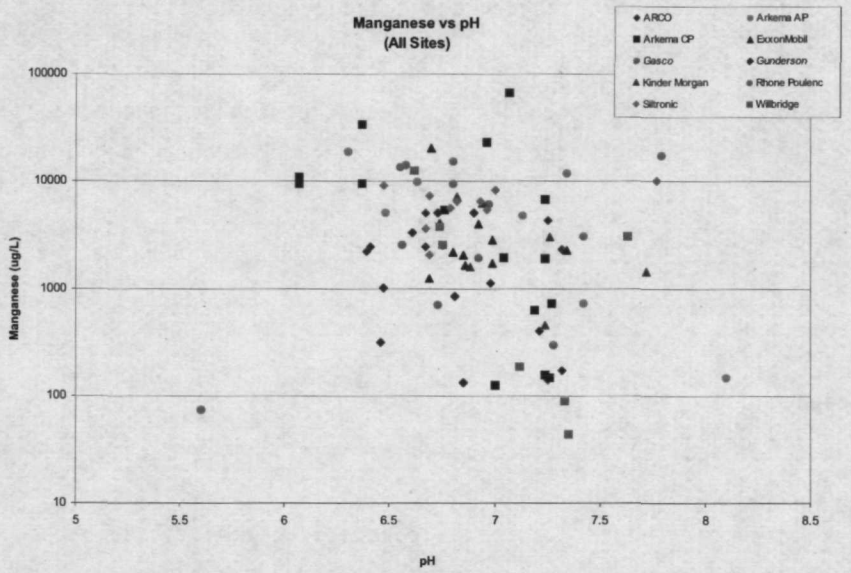
Figure D7-9
Portland Harbor RI/FS
Comprehensive Round 2 Report
Manganese Box Plot







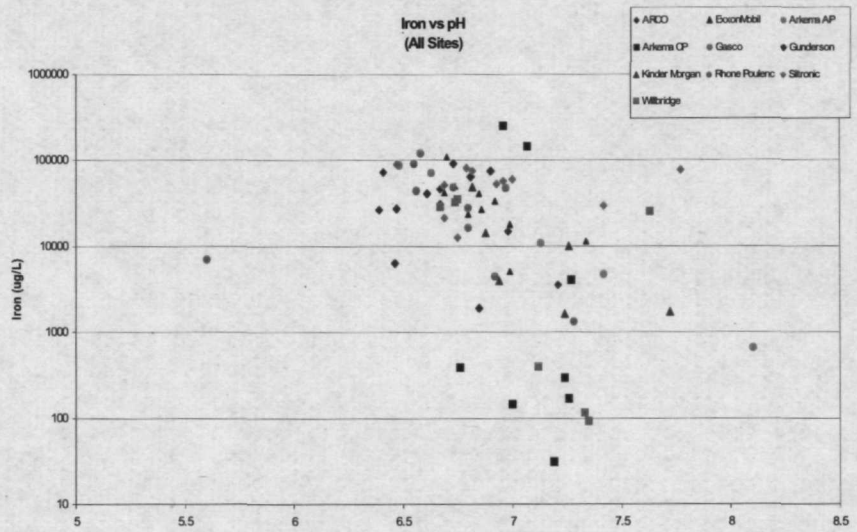


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Figure D7-10
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic, Barium, Iron, and Manganese Concentrations
versus pH in TZW

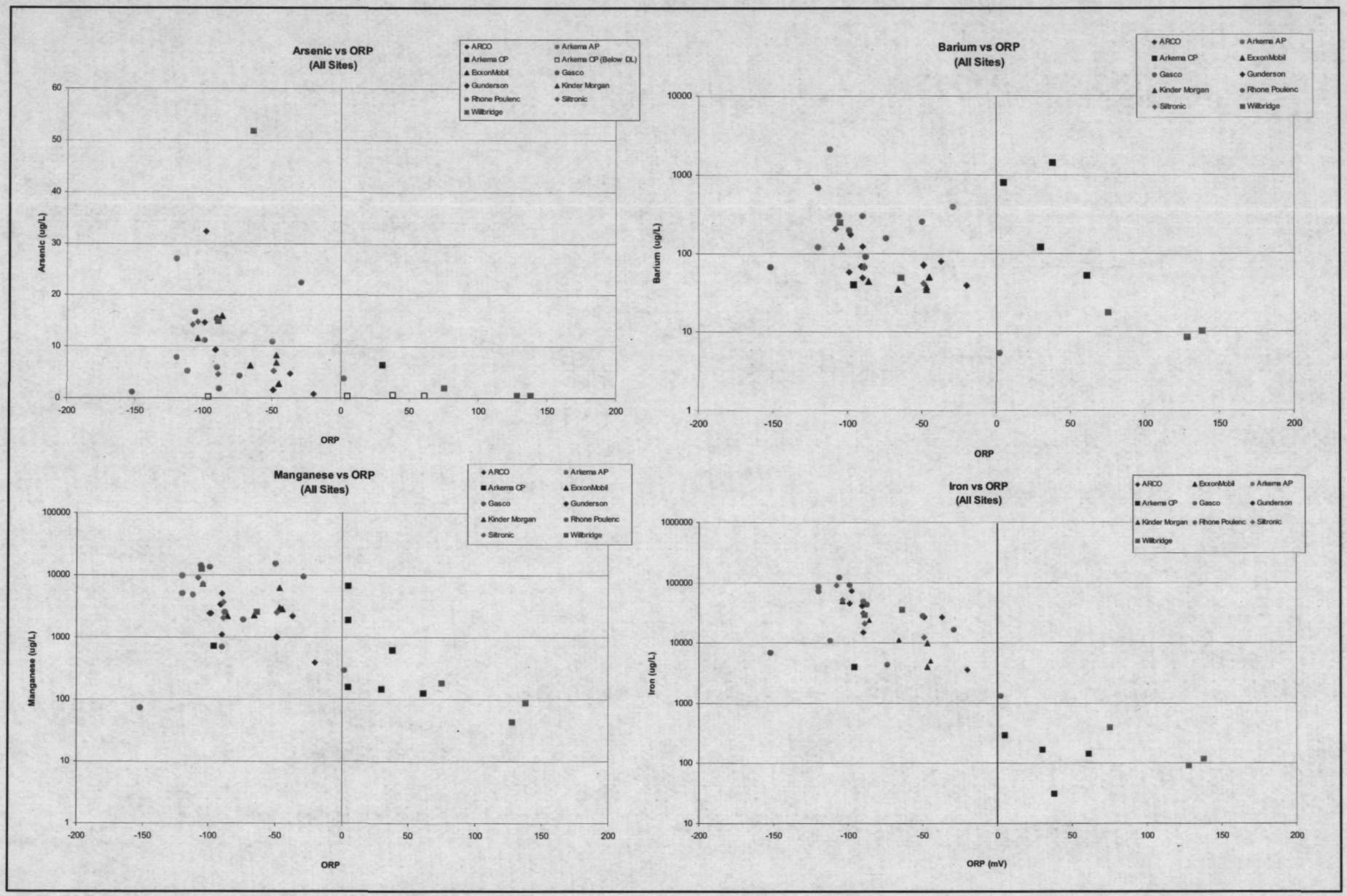

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Figure D7-11
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic, Barium, Iron, and Manganese Concentrations versus ORP in TZW

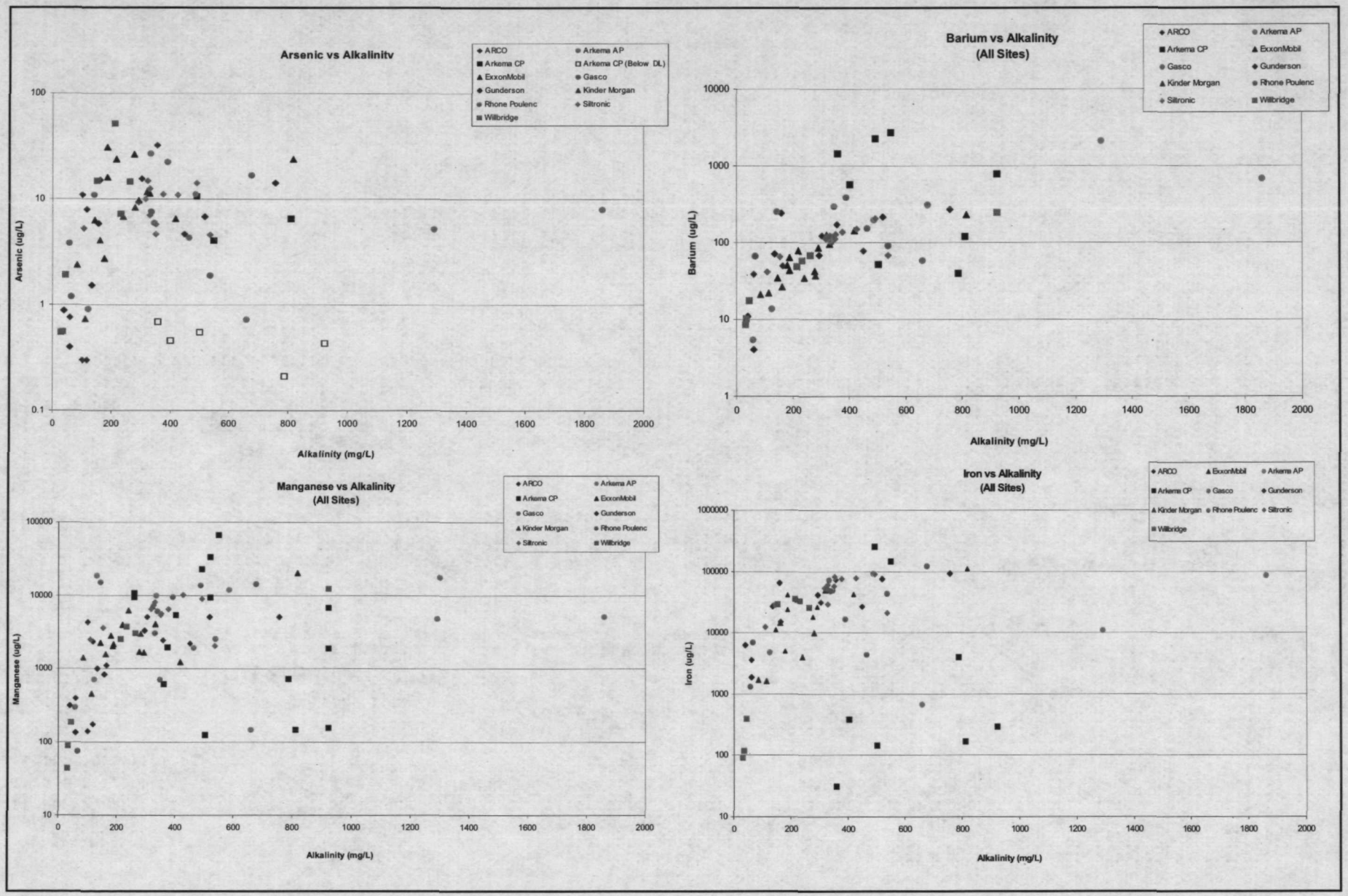

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Figure D7-12
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic, Barium, Iron, and Manganese Concentrations
versus Alkalinity in TZW

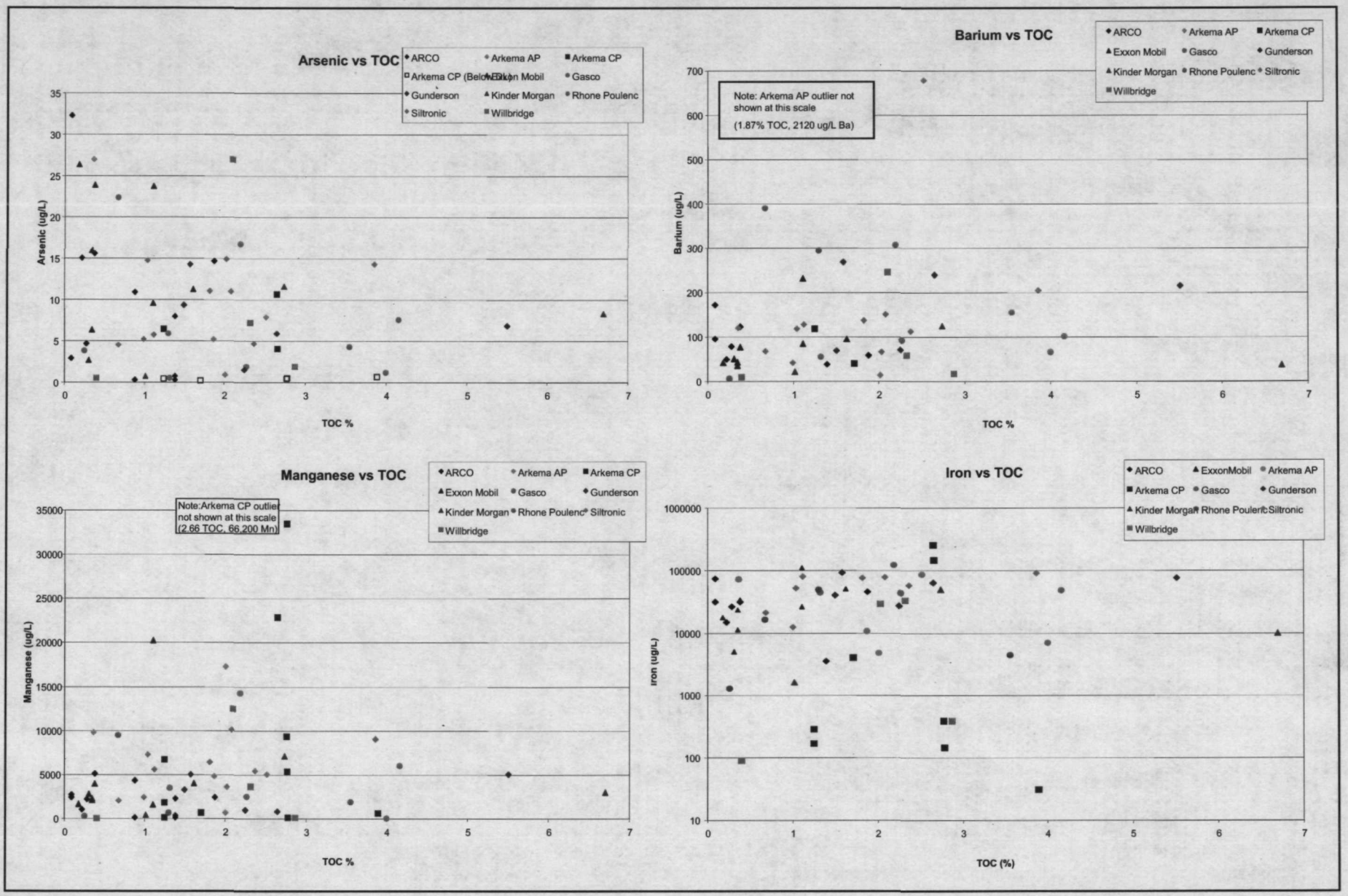

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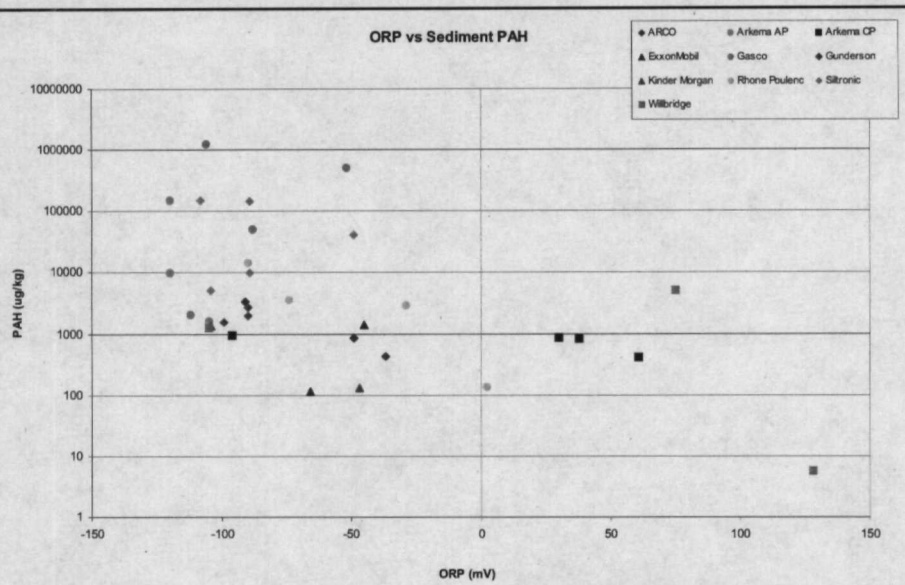
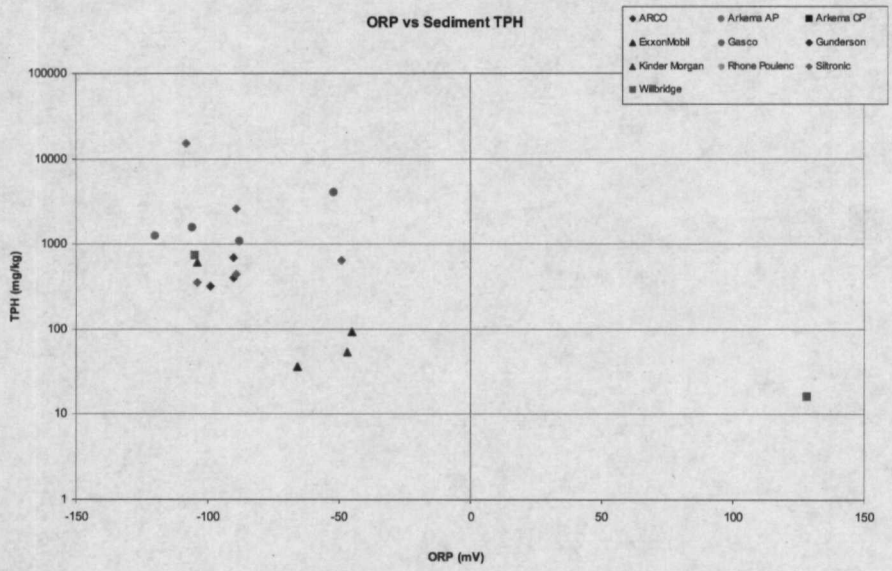
Figure D7-13
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic, Barium, Iron, and Manganese Concentrations
in TZW versus Collocated Sediment TOC





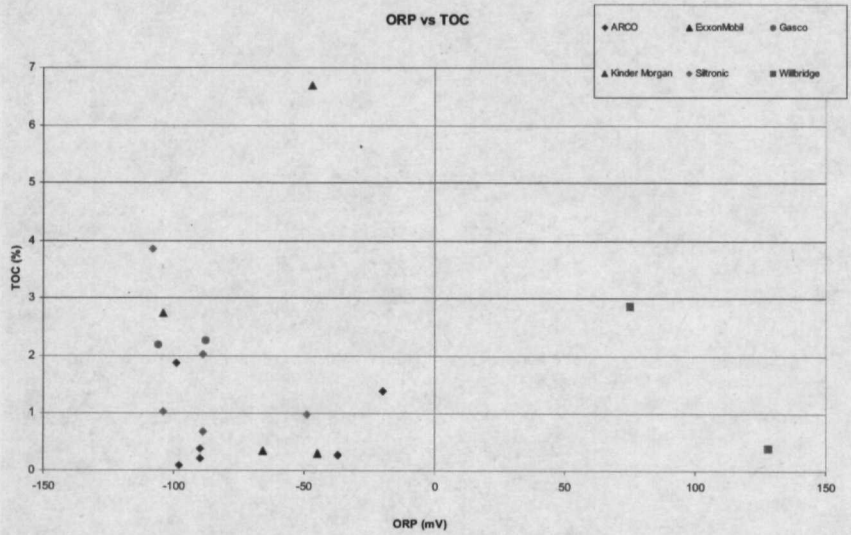


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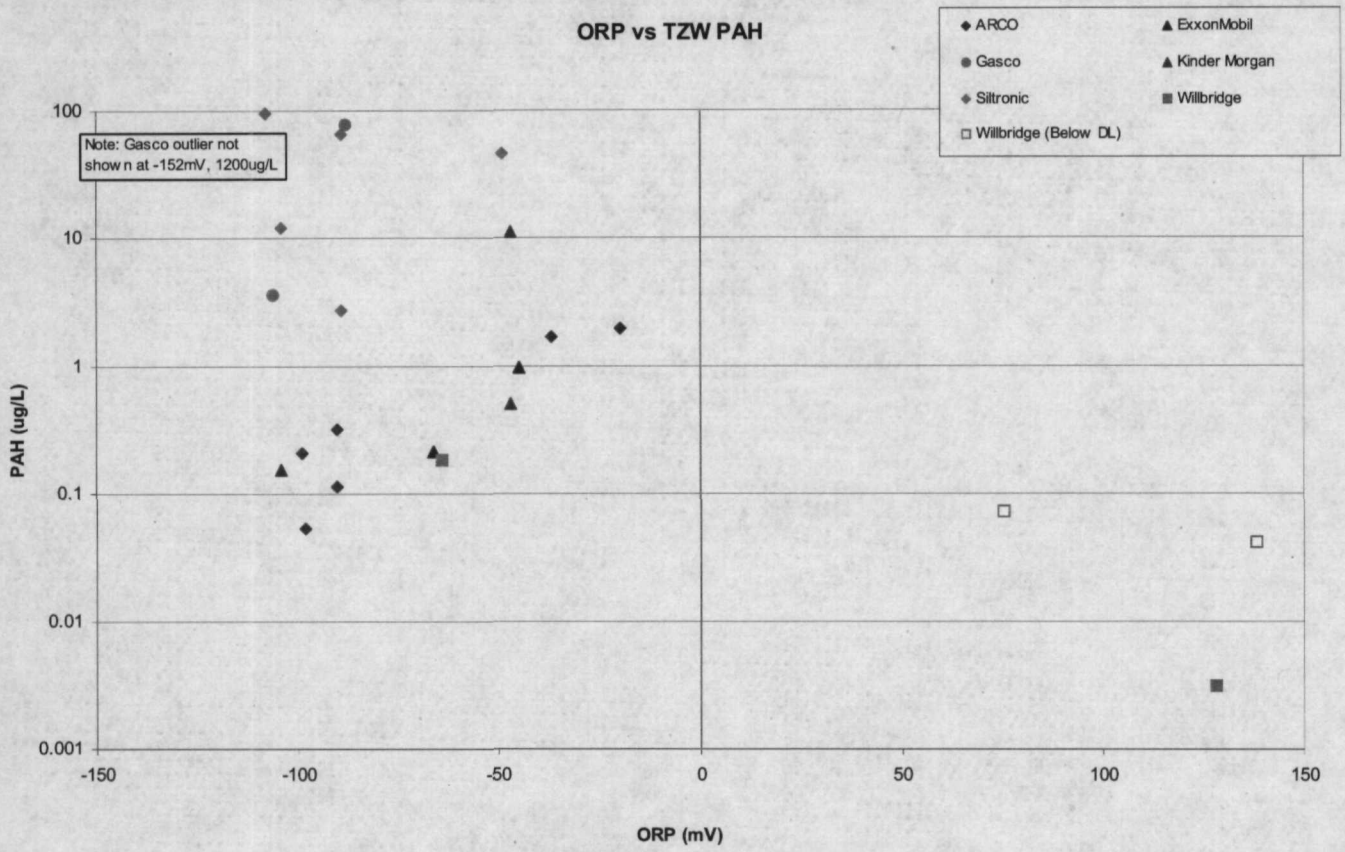
Figure D7-14a
Portland Harbor RI/FS
Comprehensive Round 2 Report
ORP versus Total PAHs, Total TPH,
and TOC in Sediment



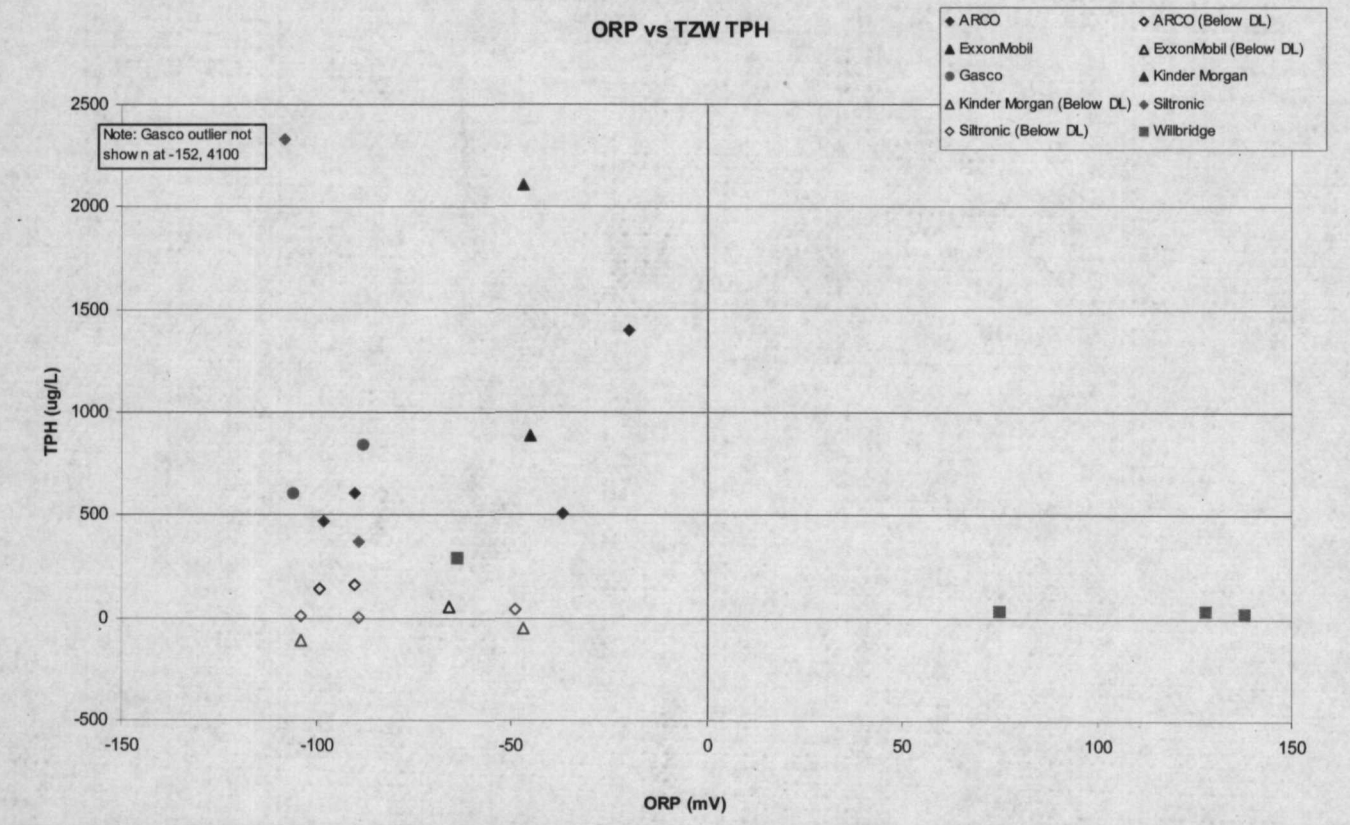


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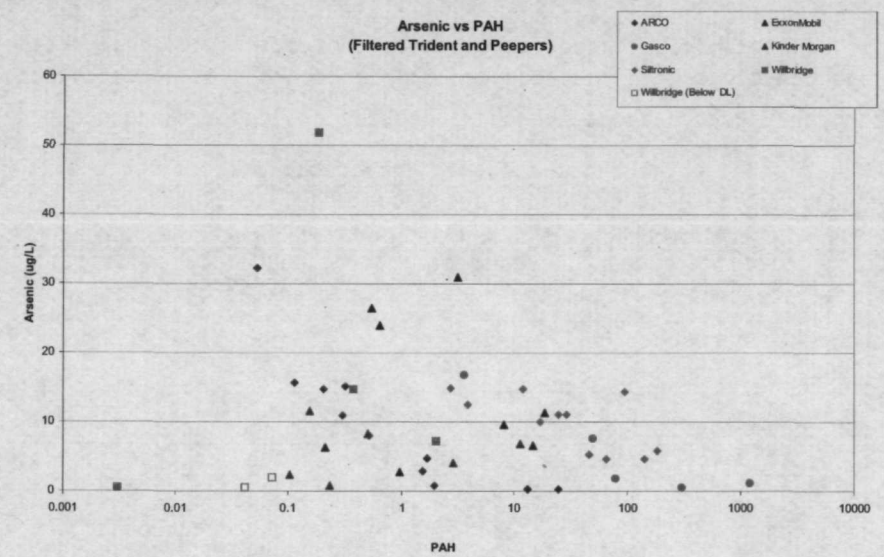
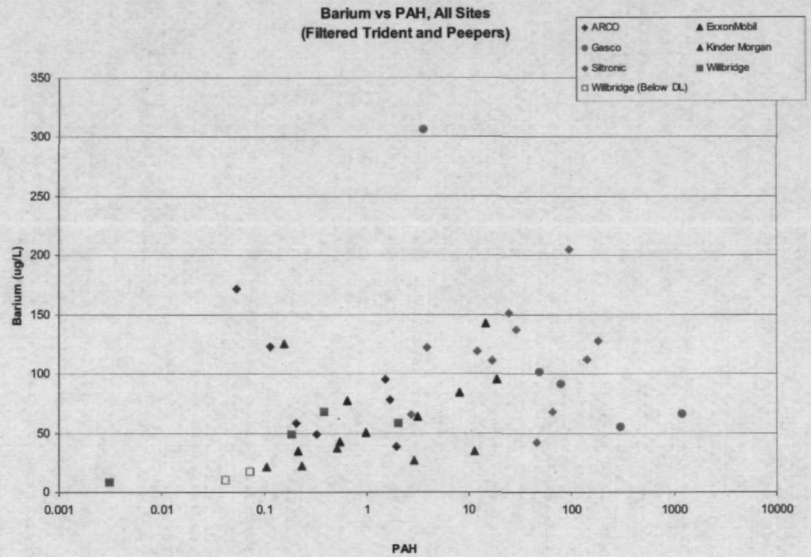
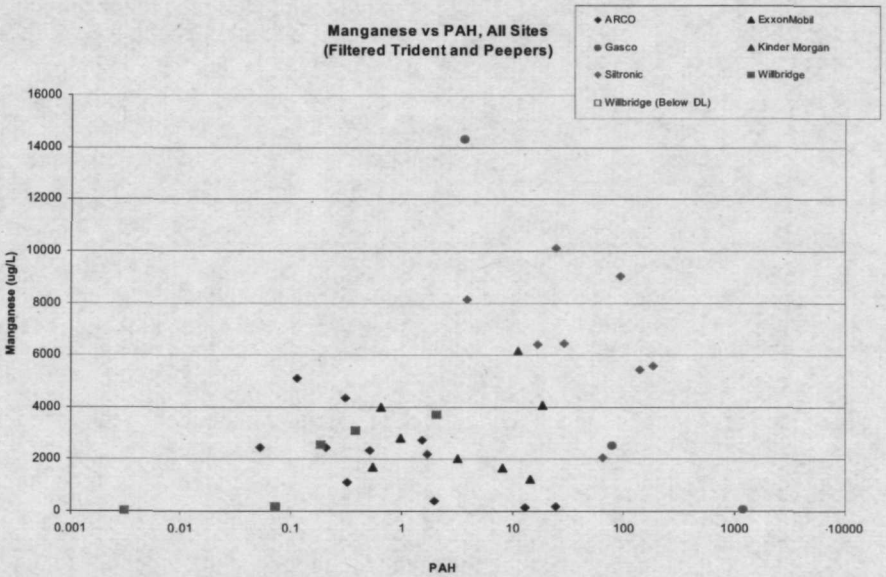
Figure D7-14b
Portland Harbor RI/FS
Comprehensive Round 2 Report
ORP versus Total PAHs and Total TPH in TZW







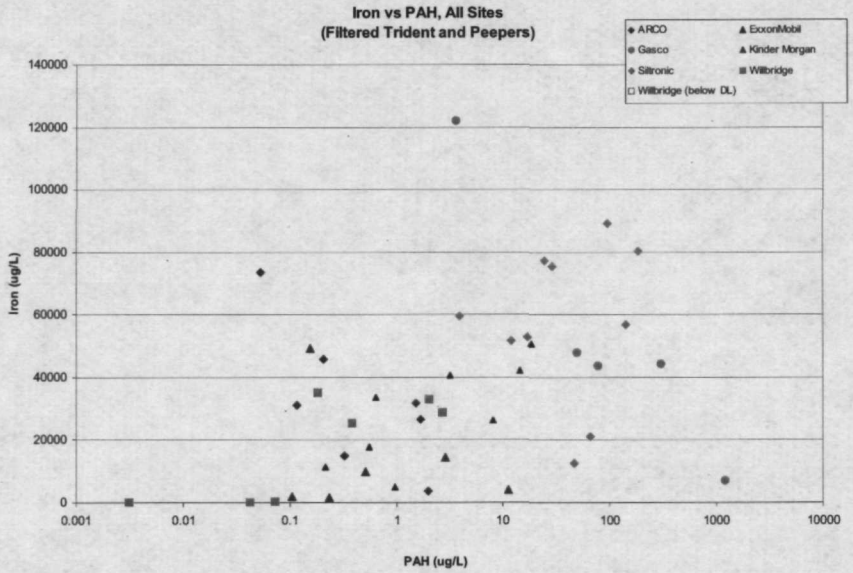


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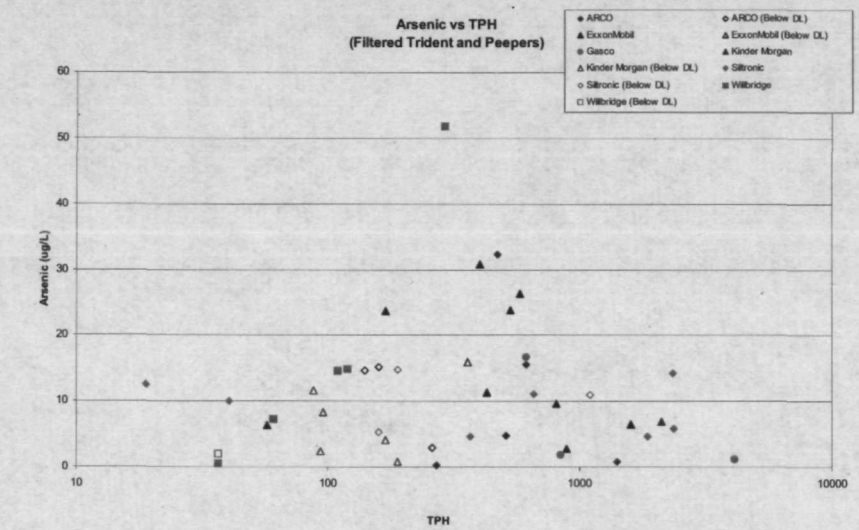
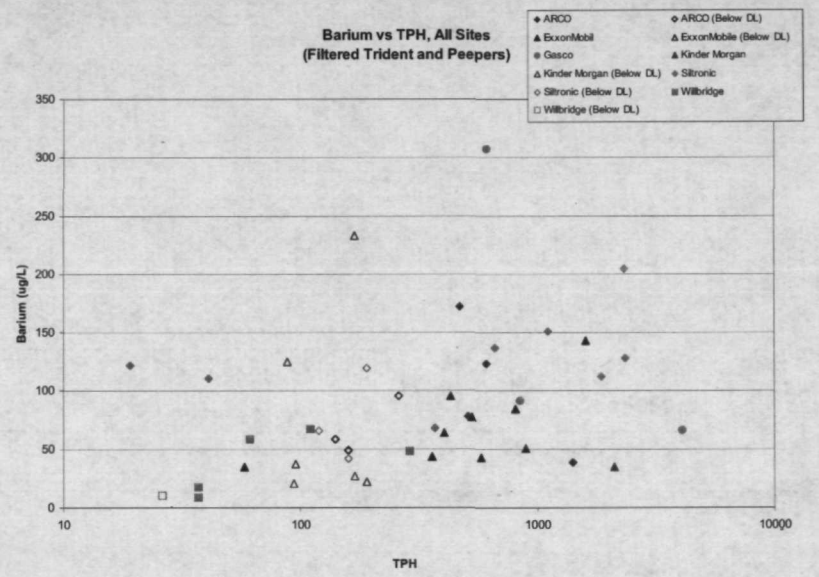
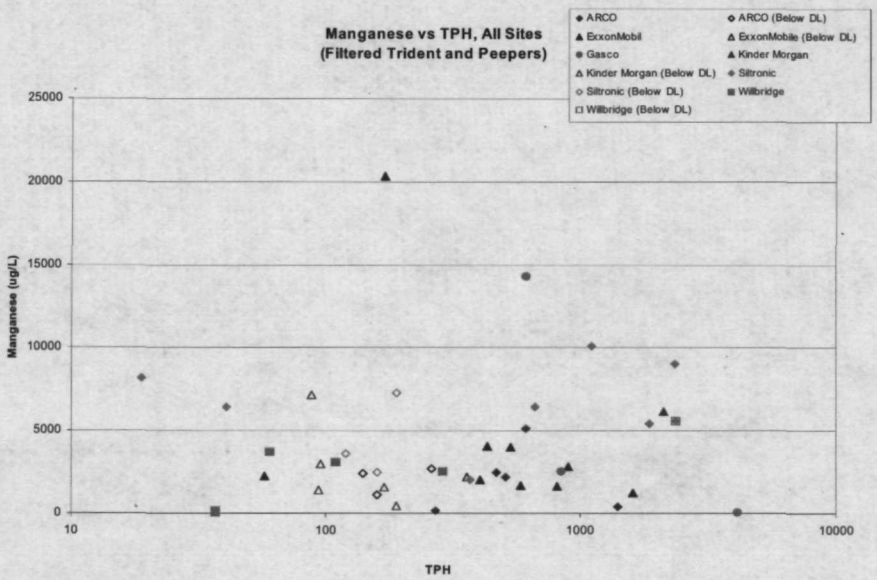
Figure D7-15
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic, Barium, Iron, and Manganese Concentrations
versus Total PAH in TZW







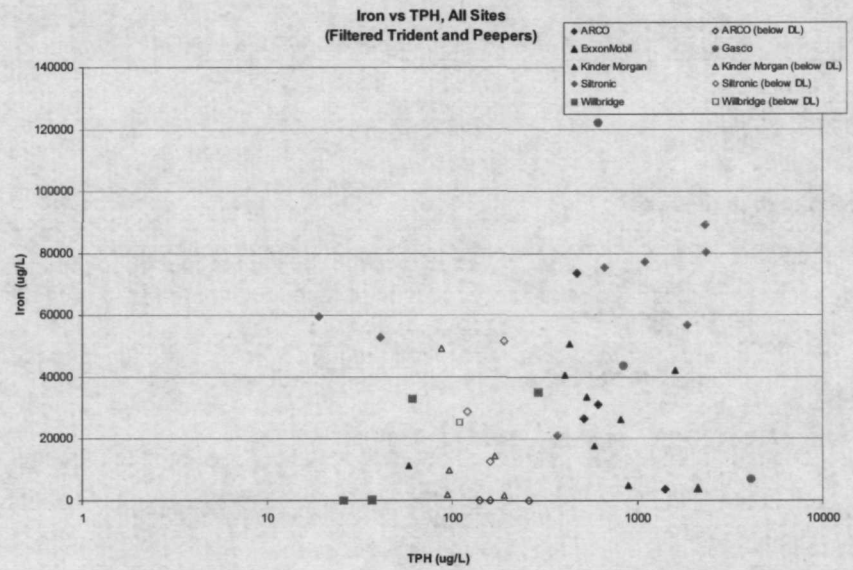


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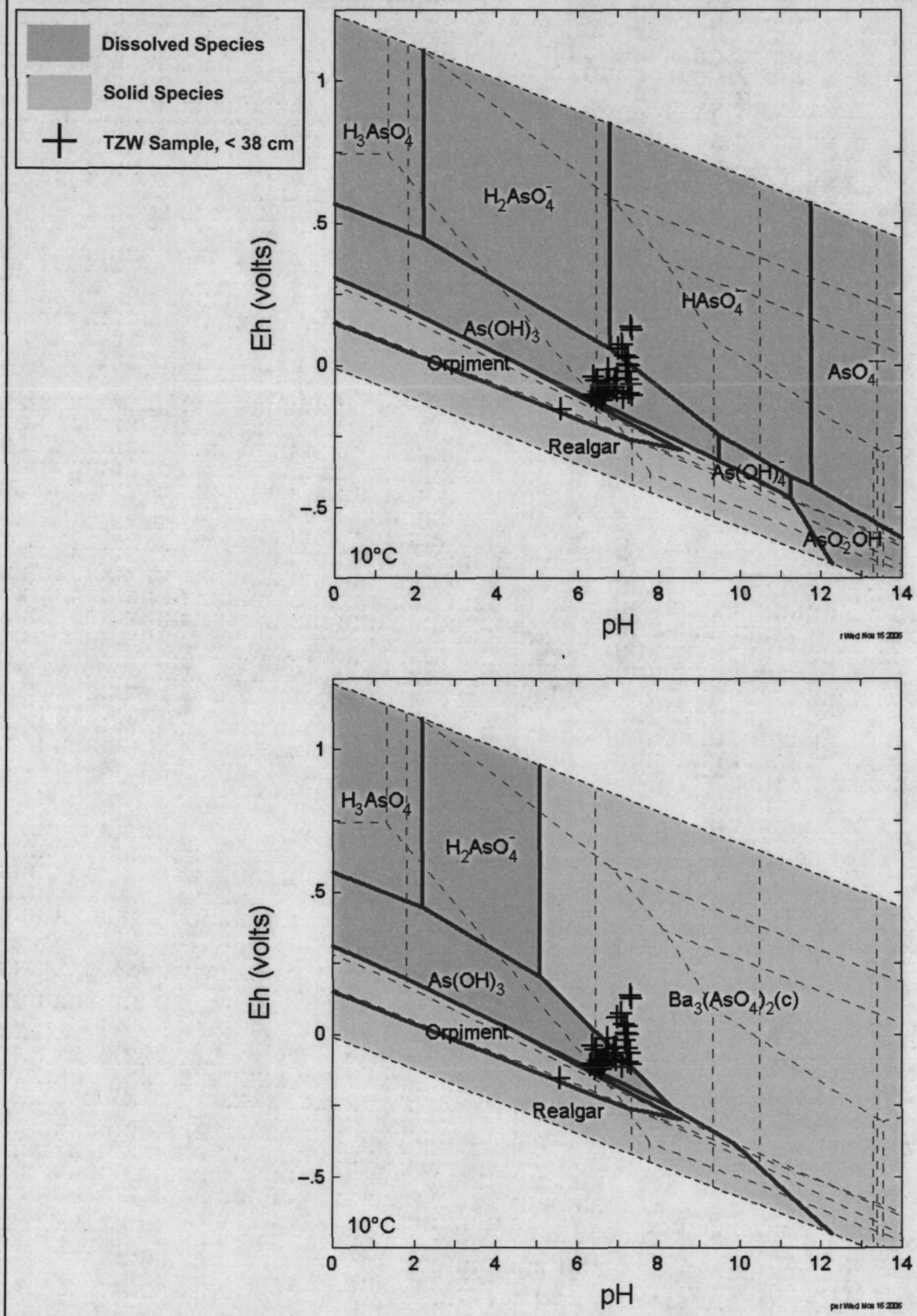
Figure D7-16
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic, Barium, Iron, and Manganese Concentrations
versus Total Petroleum Hydrocarbons in TZW



P = 1.013 bars , $a[H_2O] = 1$, $[As(OH)_3] = 10^{-7.08}$ (speciates), $[Ba^{++}] = 10^{-6.35}$ (speciates), $[Mn^{++}] = 10^{-4.47}$(speciates) , $[Ca^{++}] = 10^{-3.03}$, $[Cl^-] = 10^{-3.66}$, $[Fe^{++}] = 10^{-3.32}$ (speciates), $[HCO_3^-] = 10^{-2.28}$ (speciates), $[K^+] = 10^{-4.05}$, $[Mg^{++}] = 10^{-3.21}$,$[Na^+] = 10^{-3.14}$, $[SO_4^{--}] = 10^{-5.43}$ (speciates)

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Figure D7-17
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic Eh-pH Stability Diagrams

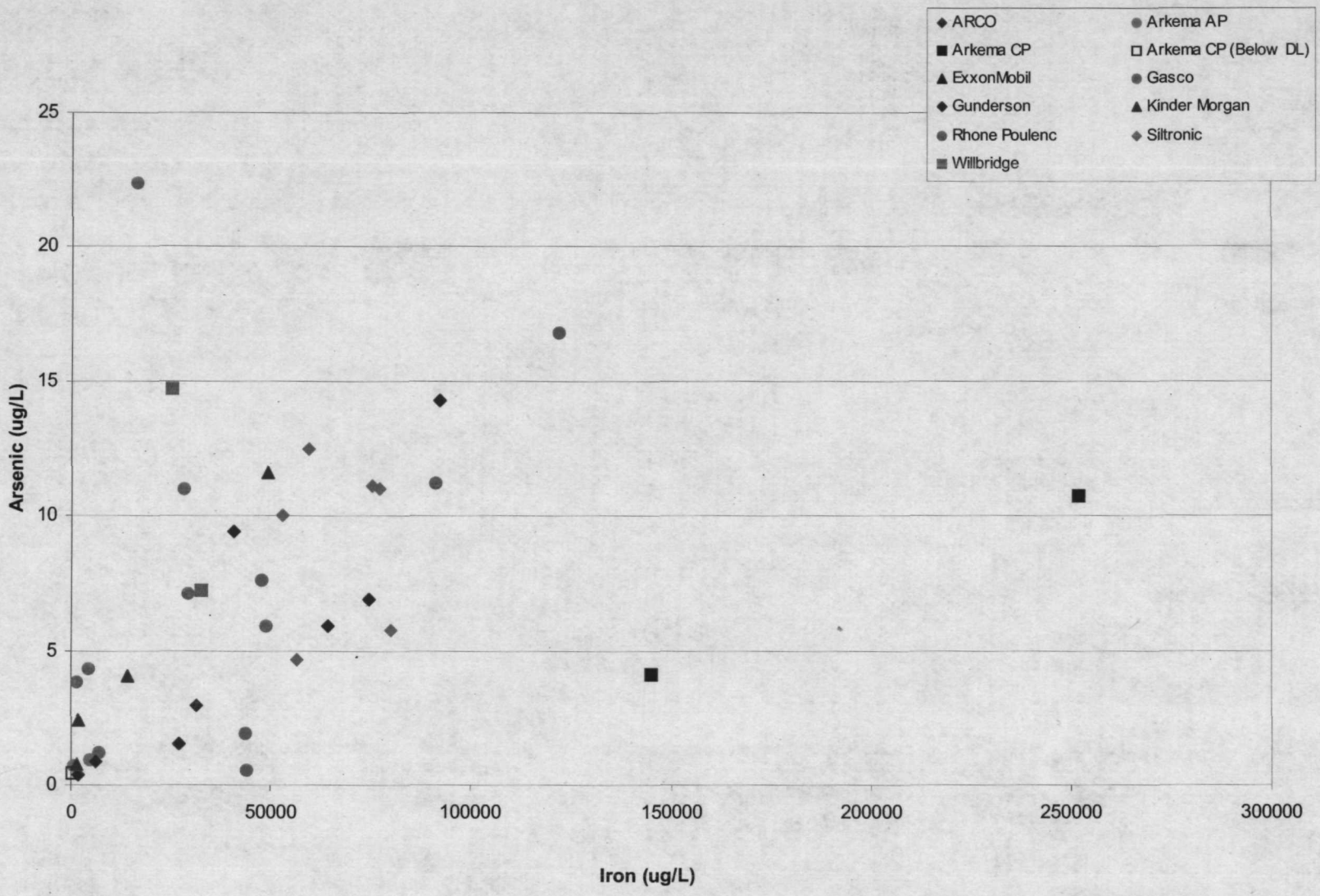

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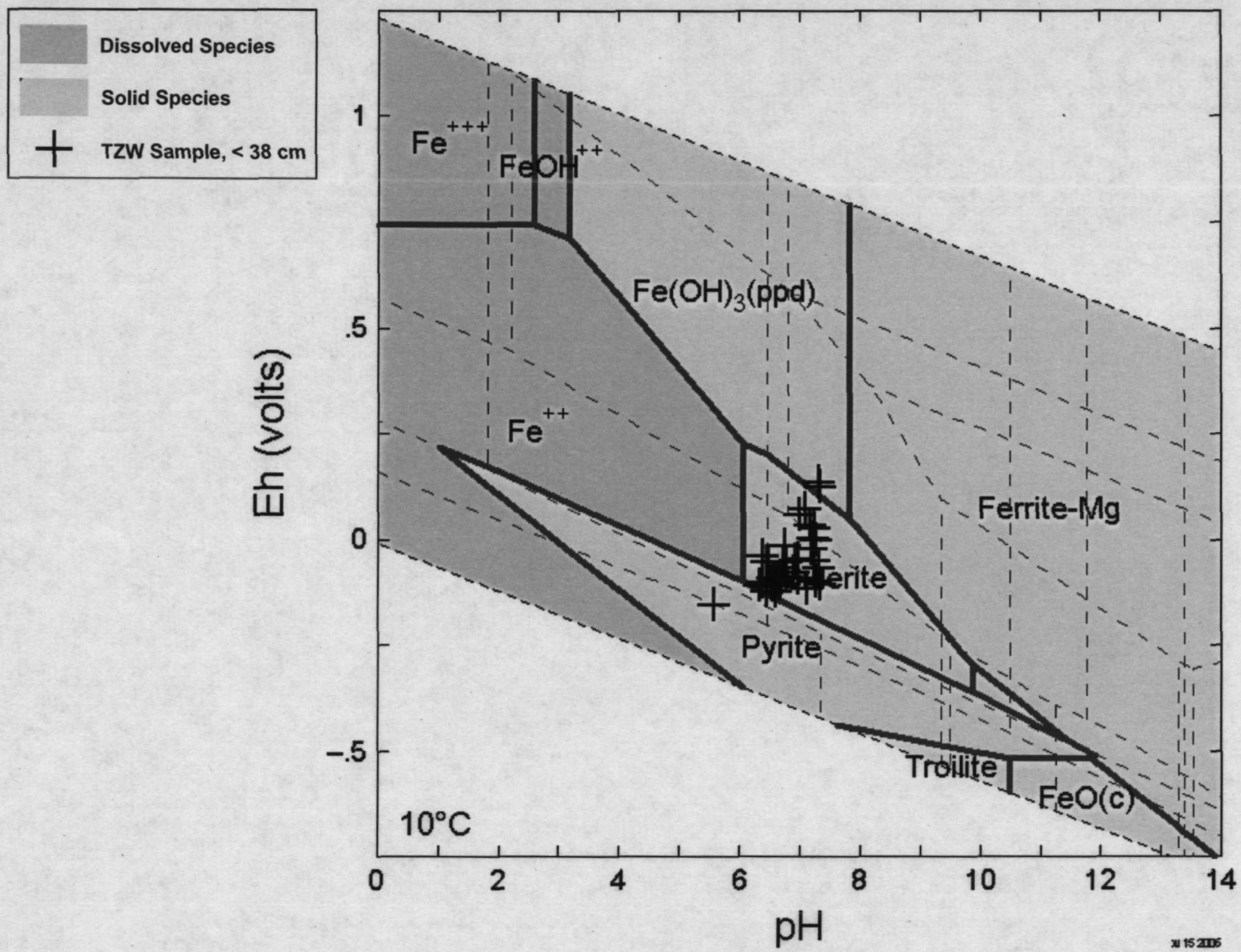
Figure D7-18
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic Concentration versus Iron Concentration
in TZW Samples



P = 1.013 bars , $a[H_2O] = 1$, $[As(OH)_3] = 10^{-7.08}$ (speciates), $[Ba^{++}] = 10^{-6.35}$ (speciates), $[Mn^{++}] = 10^{-4.47}$(speciates) , $[Ca^{++}] = 10^{-3.03}$, $[Cl^-] = 10^{-3.66}$, $[Fe^{++}] = 10^{-3.32}$ (speciates), $[HCO_3^-] = 10^{-2.28}$ (speciates), $[K^+] = 10^{-4.05}$, $[Mg^{++}] = 10^{-3.21}$,$[Na^+] = 10^{-3.14}$, $[SO_4^{--}] = 10^{-5.43}$ (speciates)

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Figure D7-19
Portland Harbor RI/FS
Comprehensive Round 2 Report
Iron Eh-pH Stability Diagram

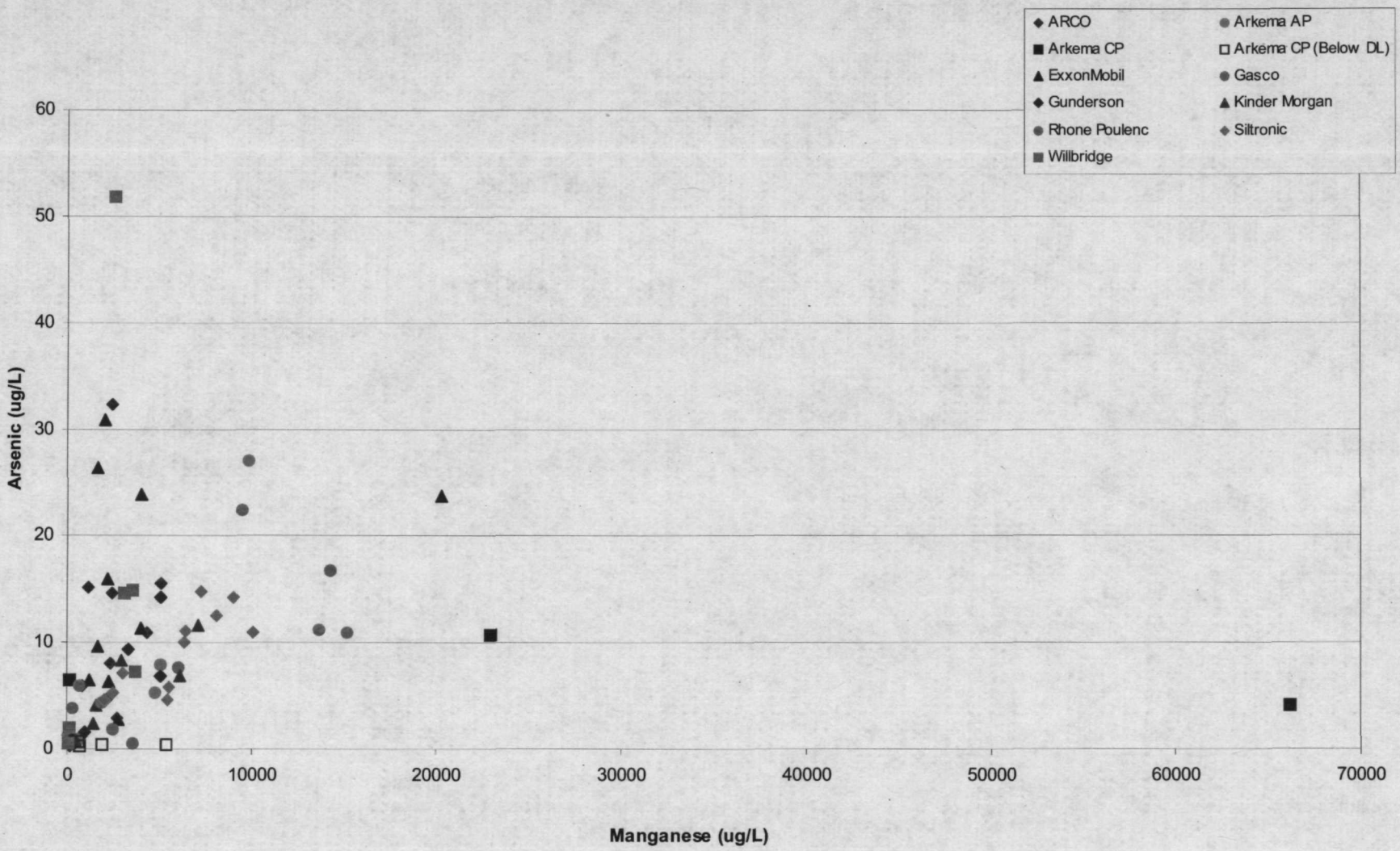

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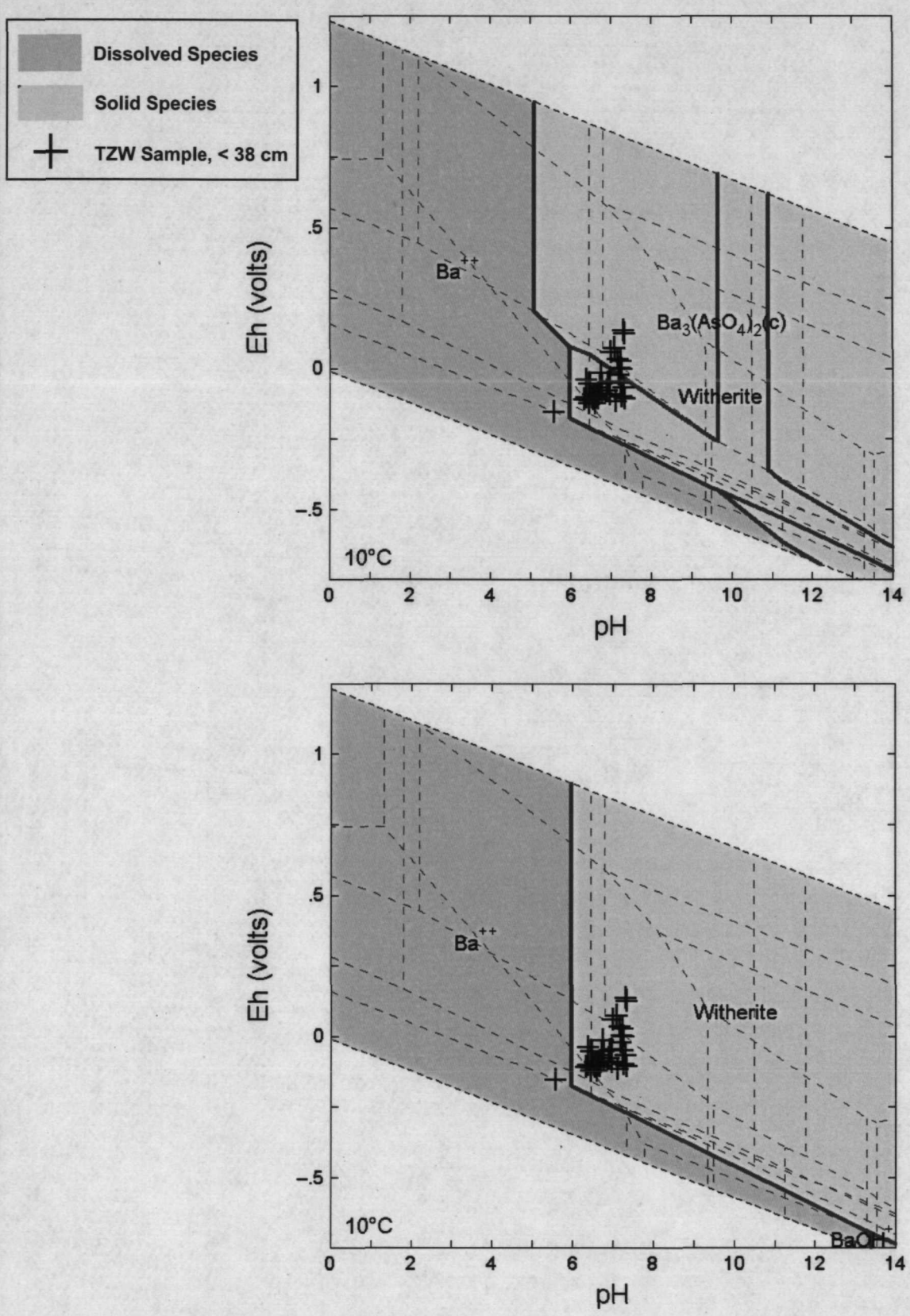
Figure D7-20
Portland Harbor RI/FS
Comprehensive Round 2 Report
Arsenic versus Manganese Concentrations
in TZW Samples



P = 1.013 bars , $a[H_2O] = 1$, $[As(OH)_3] = 10^{-7.08}$ (speciates), $[Ba^{++}] = 10^{-6.35}$ (speciates), $[Mn^{++}] = 10^{-4.47}$(speciates) , $[Ca^{++}] = 10^{-3.03}$, $[Cl^-] = 10^{-3.66}$, $[Fe^{++}] = 10^{-3.32}$ (speciates), $[HCO_3^-] = 10^{-2.28}$ (speciates), $[K^+] = 10^{-4.05}$, $[Mg^{++}] = 10^{-3.21}$,$[Na^+] = 10^{-3.14}$, $[SO_4^{--}] = 10^{-5.43}$ (speciates)

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Figure D7-21
Portland Harbor RI/FS
Comprehensive Round 2 Report
Barium Eh-pH Stability Diagrams

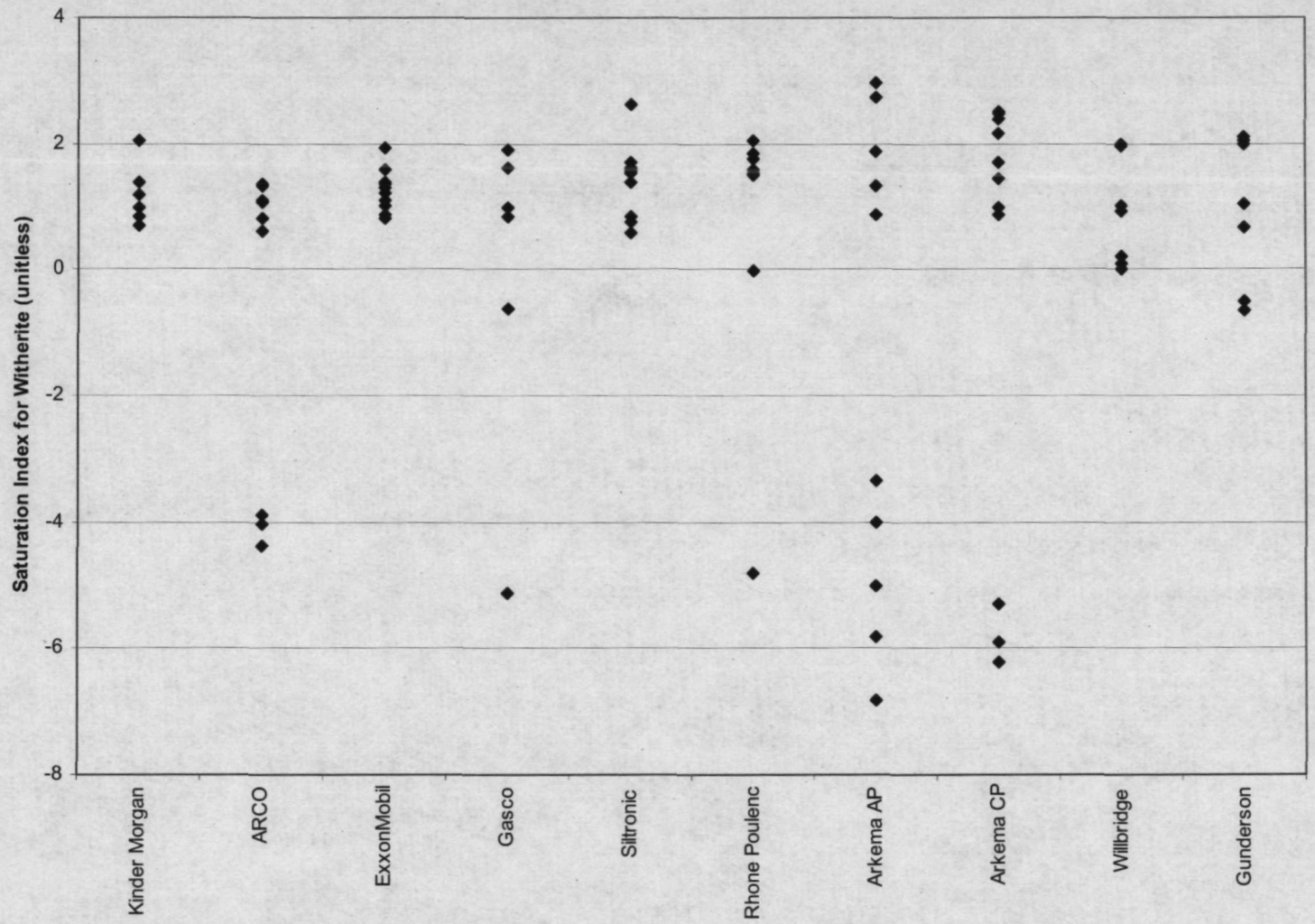

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Figure D7-22
Portland Harbor RI/FS
Comprehensive Round 2 Report
Saturation Indices for Witherite in TZW by Site

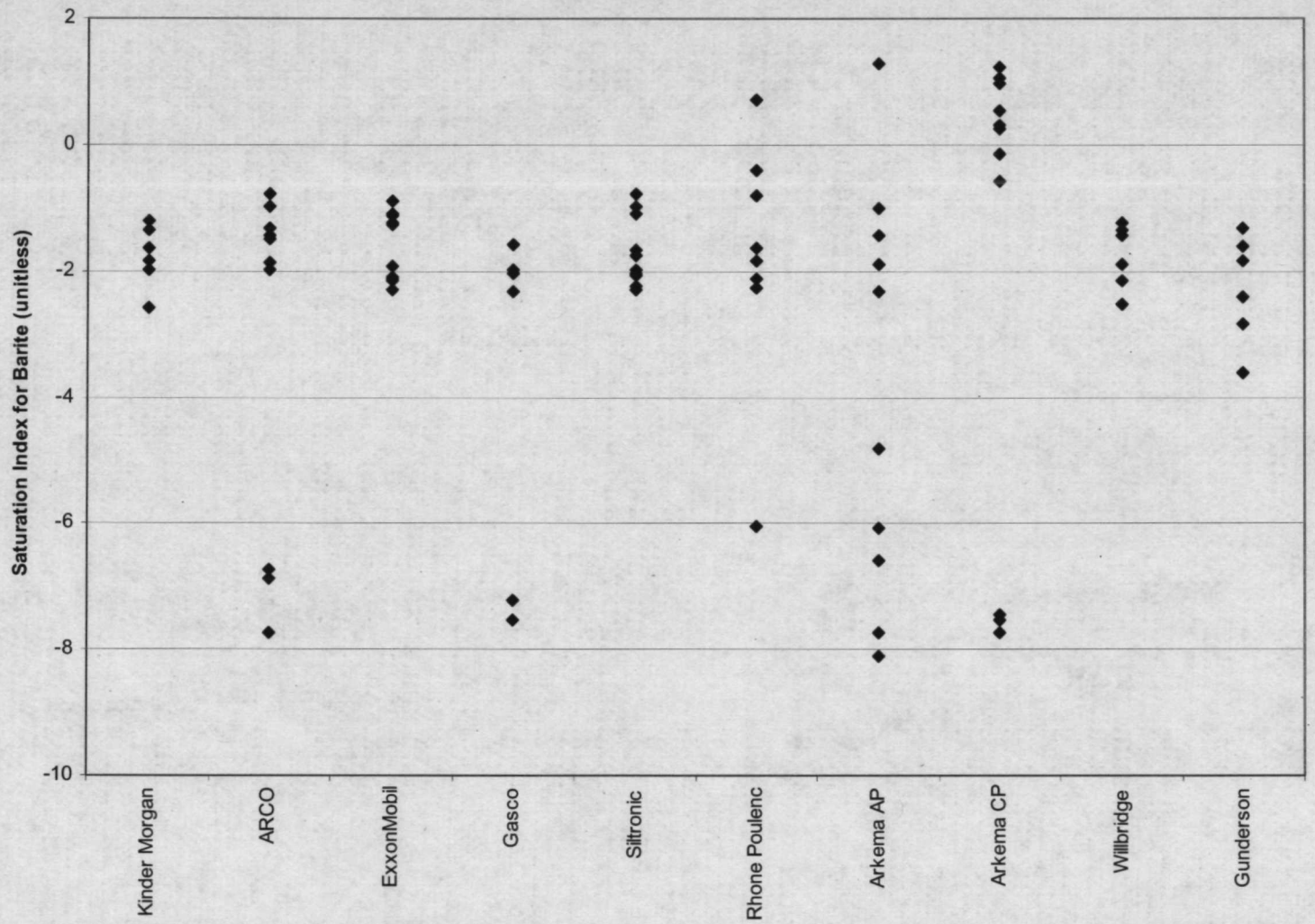

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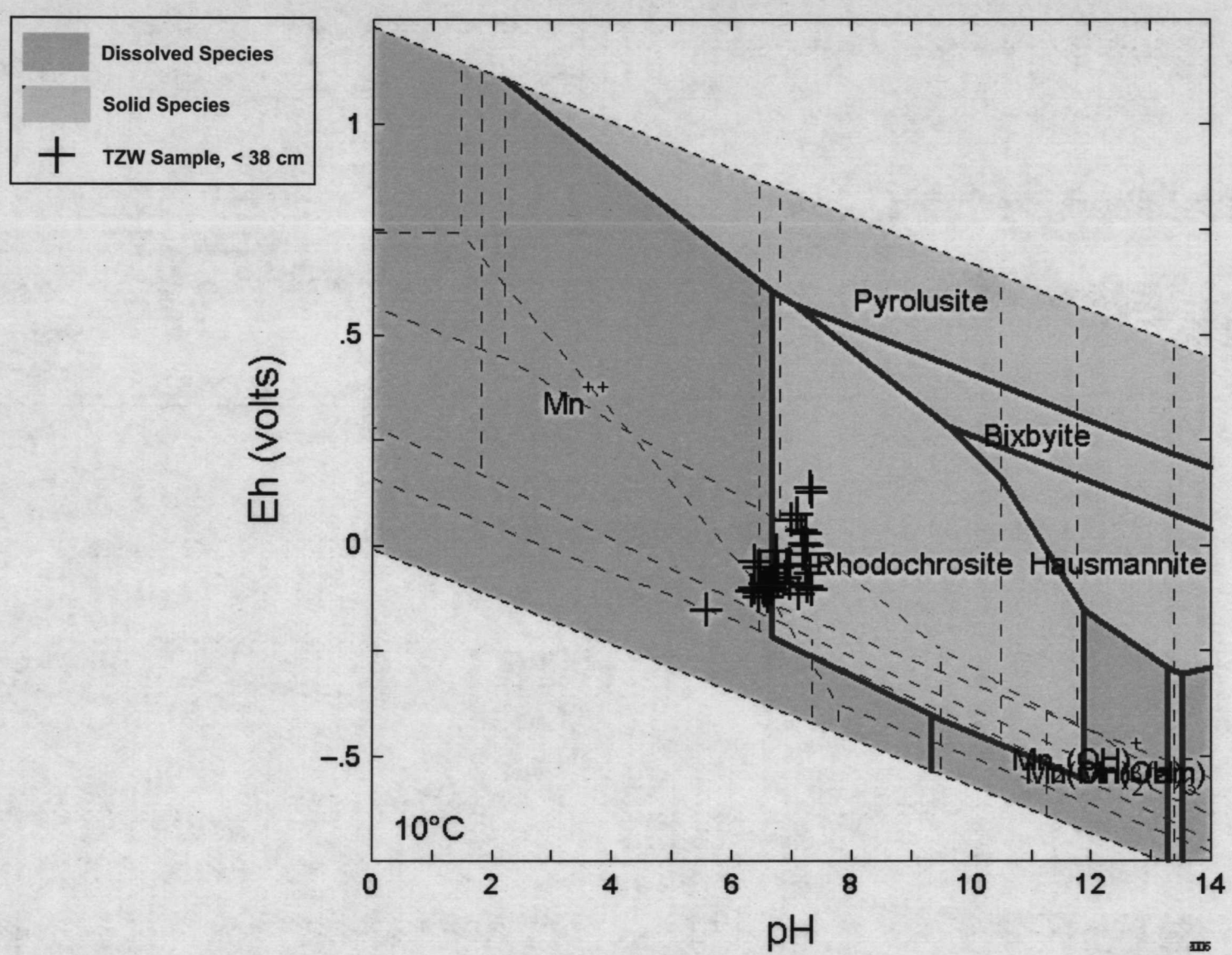
Figure D7-23
Portland Harbor RI/FS
Comprehensive Round 2 Report
Saturation Indices for Barite in TZW by Site



P = 1.013 bars , $a[H_2O] = 1$, $[As(OH)_3] = 10^{-7.08}$ (speciates), $[Ba^{++}] = 10^{-6.35}$ (speciates), $[Mn^{++}] = 10^{-4.47}$(speciates) , $[Ca^{++}] = 10^{-3.03}$, $[Cl^-] = 10^{-3.66}$, $[Fe^{++}] = 10^{-3.32}$ (speciates), $[HCO_3^-] = 10^{-2.28}$ (speciates), $[K^+] = 10^{-4.05}$, $[Mg^{++}] = 10^{-3.21}$,$[Na^+] = 10^{-3.14}$, $[SO_4^{--}] = 10^{-5.43}$ (speciates)

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Figure D7-24
Portland Harbor RI/FS
Comprehensive Round 2 Report
Manganese Eh-pH Stability Diagram

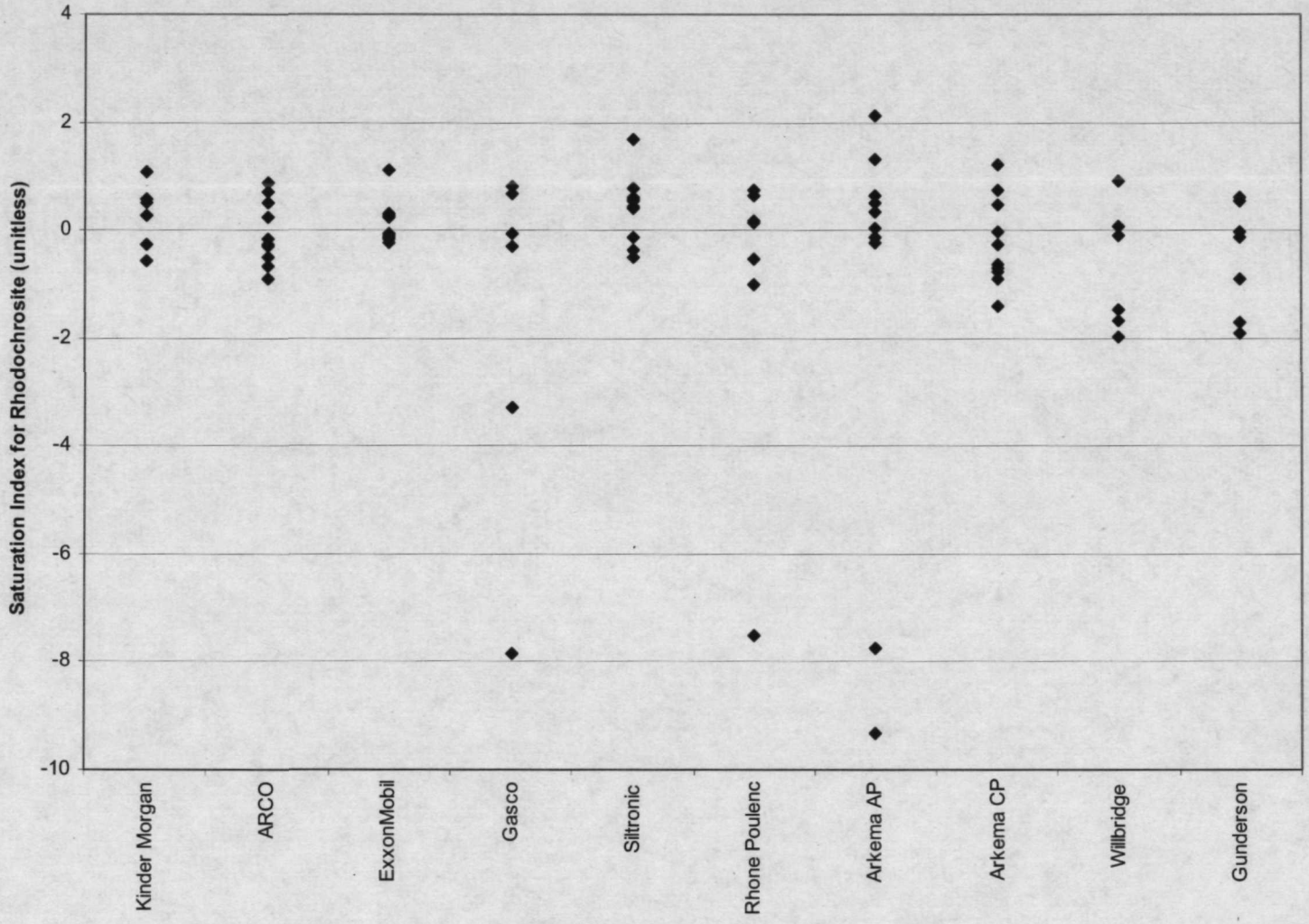

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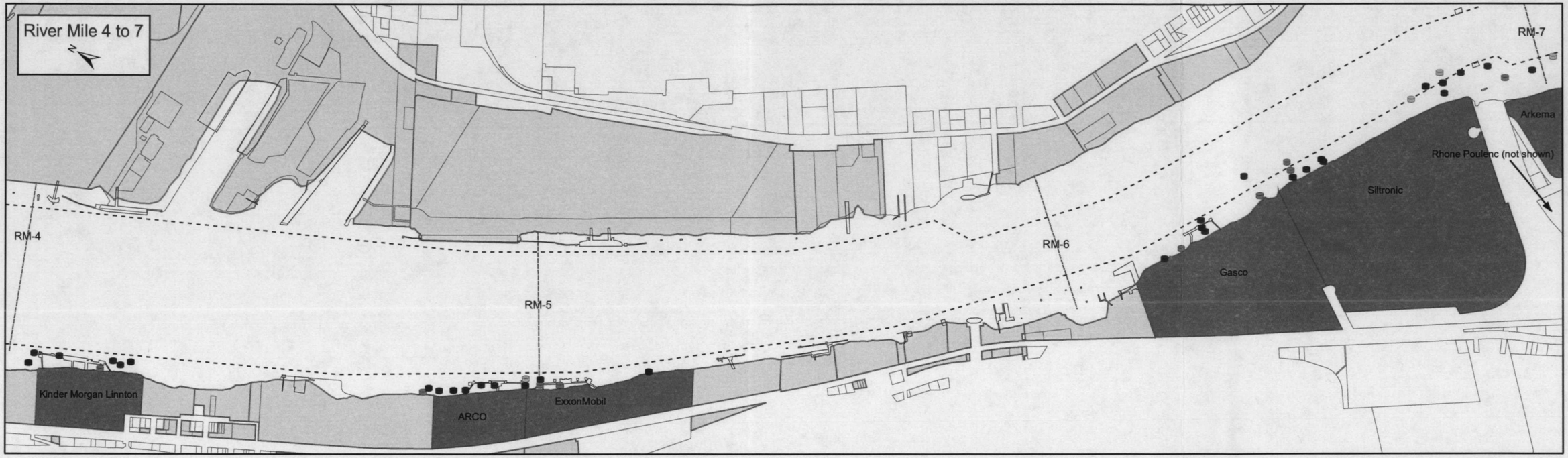
Figure D7-25
Portland Harbor RI/FS
Comprehensive Round 2 Report
Saturation Indices for Rhodochrosite in TZW by Site



Seepage Meters

Average Discharge (cm/d)

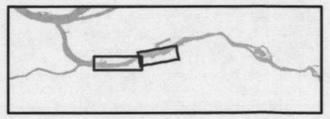
- -18.9 - -1.0
- -0.9 - 1.0
- 1.1 - 3.0
- 3.1 - 6.0
- 6.1 - 14.2

Map Features:

- Docks and Structures
- River miles
- Navigation Channel
- Upland Sites (2006)
- Waterfront Taxlots
- R2 GWPA Study Site

0 250 500 750 1,000 Feet

FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS .
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.



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LWG LOWER WILLAMETTE GROUP

Map D4-1
Portland Harbor RI/FS
Comprehensive Round 2 Report
Transition Zone Water
Seepage Meter Locations

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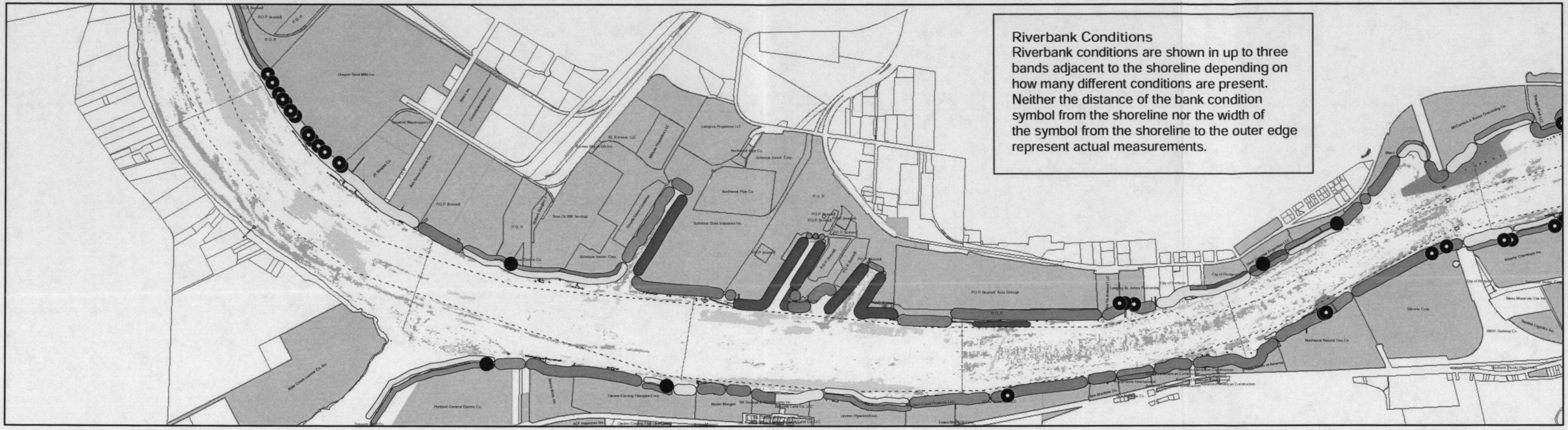

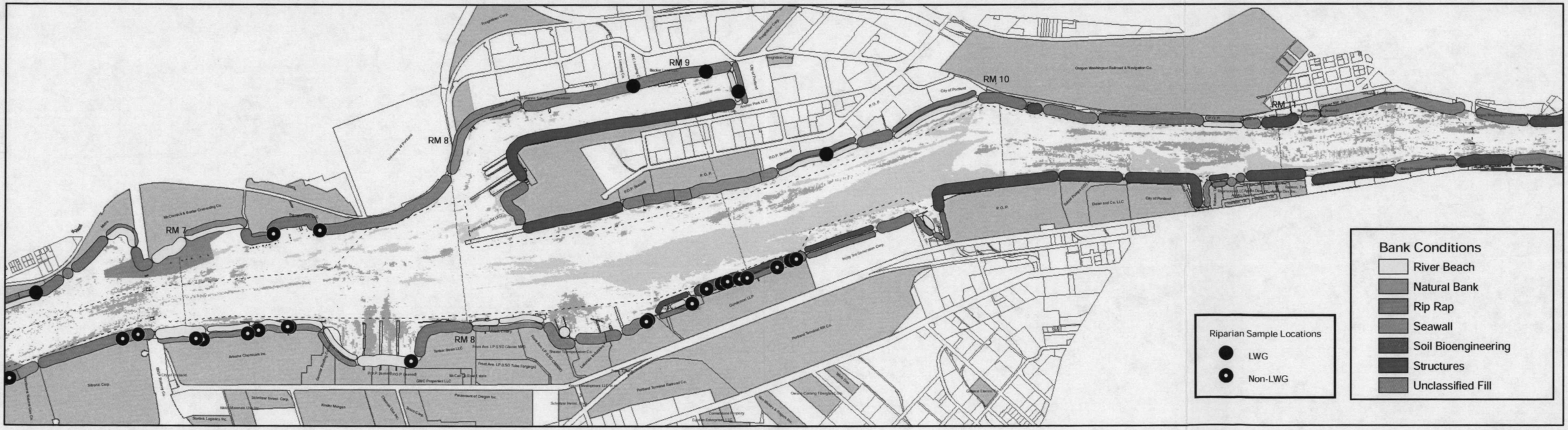

Map Document: (P:\Projects\LWG-Map-Projects\Round2_Reporting\Map NV 5.3.mxd)
11/14/2006 -- 11:00:06 AM

integral consulting inc.

LWG Lower Willamette Group

N

0 1,000 2,000 3,000 Feet

FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS.
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.
Riverbank conditions: Windward LLC

Map Features
- River Miles
- Navigation Channel
- Docks and Structures
- Capping
- Waterfront Taxlots

Bathymetric Change
- -22 - -0.49 Shoaling
- -0.5 - 0.5
- 0.51 - 37 Deepening
- Upland Sites (2006)

Map **D6-1**
Portland Harbor RI/FS
Comprehensive Round 2 Report
Riverbank Sampling Stations (+11 to +22 NAVD88)
Relative to Bank Conditions

Table D2-1. Loading Rate Estimates for Surface Water Flowing into RM 4.

Analyte	Sample Type	November 2004 Estimated Loading (kg/yr)			March 2005 Estimated Loading (kg/yr)			July 2005 Estimated Loading (kg/yr)		
		Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]
Metals										
Arsenic	Peristaltic	4.71E+03	--	5.60E+03	3.72E+03	--	4.27E+03	3 62E+03	--	4.14E+03
Cadmium	Peristaltic	0	--	0	0	--	0	0	--	0
Copper	Peristaltic	1.01E+04	--	1 21E+04	5.67E+03	--	8.60E+03	--	--	--
Lead	Peristaltic	445	--	2.90E+03	104	--	1.13E+03	226	--	1810
Mercury	Peristaltic	0	--	0	0	--	0	0	--	0
Silver	Peristaltic	0	--	359	0	--	0	0	--	0
Zinc	Peristaltic	2.15E+04	--	3.16E+04	1.42E+04	--	2.08E+04	1.35E+04	--	2.35E+04
Butyltins										
Tributyltin	Peristaltic	--	--	0	--	--	0	--	--	0
Tributyltin	XAD	0	0	0	0	0	0	0	0	0
PCBs										
Total PCB TEQ	XAD	5 27E-06	2.33E-05	2.85E-05	4.97E-06	3.28E-05	3.78E-05	5 75E-06	4.66E-05	5.23E-05
Total PCB Aroclors	XAD	1.08	1.09	2.17	1.18	1.38	2.56	--	--	--
Dioxins/Furans										
Total Dioxin TEQ	XAD	2.51E-05	6.65E-04	6.90E-04	2 74E-05	8.63E-04	8.91E-04	7.49E-05	2.39E-03	2.46E-03
Pesticides										
2,4'-DDD	XAD	0.181	0.0840	0.265	0.170	0.0407	0.211	0.248	1.88E-03	0.250
2,4'-DDT	XAD	0.0348	0.0247	0.0595	0.0258	0	0.0258	0.0180	2.38E-03	0.0204
4,4'-DDD	XAD	0.328	0.220	0.547	0.365	0.0761	0.441	0.580	3.05E-03	0.583
4,4'-DDE	XAD	0.192	0.154	0.346	0.187	0.215	0.402	0.249	0.179	0.427
4,4'-DDT	XAD	0.0750	0.108	0 183	0.0553	0.0261	0 0814	0.0277	0	0.0277
Aldrin	XAD	0	4.25E-03	4.25E-03	0.0101	3.84E-03	0.0140	0.0166	8.06E-04	0.0174
alpha-Hexachlorocyclohexane	XAD	0.269	0	0.269	0.133	0	0.133	0.462	3.16E-04	0.462
beta-Hexachlorocyclohexane	XAD	0 0494	0	0.0494	0.0396	0	0.0396	0.0528	0	0.0528
delta-Hexachlorocyclohexane	XAD	0	0	0	0	0	0	0 00957	0	0.00957
Dieldrin	XAD	0.395	0 0240	0.419	0.302	0.0180	0.320	0.295	0	0.295
Endrin	XAD	0	0	0	0.00983	0	0.00983	--	--	--
Endrin Keytone	XAD	0.00487	0	0 00487	0.00759	0	0.00759	0.00347	0	0.00347
gamma-Hexachlorocyclohexane	XAD	0.320	0	0.320	0.290	0	0.290	0 188	0	0.188
Heptachlor	XAD	1.87E-03	0	1.87E-03	0	0	0	0	0	0
Heptachlor Epoxide	XAD	0.0516	0	0.0516	0.0492	0	0.0492	0.0313	--	--
Total chlordanes	XAD	0.192	0.0550	0 247	0.188	0.0358	0.224	0.195	7.61E-04	0 196
Total of 2,4' and 4,4'-DDD	XAD	0.509	0.304	0.812	0.535	0.117	0.652	0 828	4.93E-03	0.833
Total of 2,4' and 4,4'-DDE	XAD	0.202	0.162	0.364	0.199	0.224	0.423	0.263	0.186	0.448
Total of 2,4' and 4,4'-DDT	XAD	0.110	0.132	0.242	0.0811	0 0261	0.107	0.0457	2.38E-03	0.0481
Total of 2,4' and 4,4'-DDD, -DDE, -DDT	XAD	0.821	0.598	1.418	0 8153	0.3669	1.182	1.1365	1.93E-01	1.3295
Polycyclic Aromatic Hydrocarbons										
2-Methylnaphthalene	Peristaltic	--	--	0	--	--	0	--	--	0
2-Methylnaphthalene	XAD	34.8	0	34.8	34.3	0	34 3	24.8	0	24.8
Acenaphthene	Peristaltic	--	--	0	--	--	0	--	--	0
Acenaphthene	XAD	20.8	0	20.8	11.7	0	11.7	34.4	0	34 4
Anthracene	Peristaltic	--	--	0	--	--	0	--	--	0
Anthracene	XAD	6.22	3.48	9.70	0	0	0	11.2	2.98	14 2
Benzo(a)anthracene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(a)anthracene	XAD	1.91	7.69	9.60	1 62	4.33	5.95	4.77	5.30	10.1
Benzo(a)pyrene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(a)pyrene	XAD	0.501	7.97	8 47	0	6.41	6.41	0	6.84	6.84
Benzo(b)fluoranthene	Peristaltic	--	--	--	--	--	--	--	--	--
Benzo(b)fluoranthene	XAD	--	--	--	--	--	--	--	--	--

Table D2-1. Loading Rate Estimates for Surface Water Flowing into RM 4.

		November 2004 Estimated Loading (kg/yr)			March 2005 Estimated Loading (kg/yr)			July 2005 Estimated Loading (kg/yr)		
Analyte	Sample Type	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]
Benzo(g,h,i)perylene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(g,h,i)perylene	XAD	0	7.77	7.77	0	6.80	6.80	0.410	7.43	7.84
Benzo(k)fluoranthene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(k)fluoranthene	XAD	0.316	5.56	5.88	0.225	5.01	5.24	0.607	5.11	5.72
Chrysene	Peristaltic	--	--	0	--	--	0	--	--	0
Chrysene	XAD	3.15	11.3	14.5	3.03	7.69	10.7	7.54	8.89	16.4
Dibenzo(a,h)anthracene	Peristaltic	--	--	0	--	--	0	--	--	0
Dibenzo(a,h)anthracene	XAD	0	0	0	0	0.955	0.955	0.192	0	0.192
Fluoranthene	Peristaltic	--	--	0	--	--	0	--	--	82.9
Fluoranthene	XAD	21.4	21.7	43.1	15.8	0	15.8	41.2	10.5	51.7
Fluorene	Peristaltic	--	--	0	--	--	0	--	--	0
Fluorene	XAD	14.1	1.72	15.8	9.37	0	9.37	22.5	1.14	23.6
Indeno(1,2,3-cd)pyrene	Peristaltic	--	--	0	--	--	0	--	--	0
Indeno(1,2,3-cd)pyrene	XAD	0.210	5.89	6.10	0	4.91	4.91	0	5.41	5.41
Naphthalene	Peristaltic	--	--	0	--	--	0	--	--	0
Naphthalene	XAD	0	0	0	0	0	0	124	6.29	130
Phenanthrene	Peristaltic	--	--	0	--	--	0	--	--	0
Phenanthrene	XAD	28.3	0	28.3	15.2	0	15.2	43.3	0	43.3
Pyrene	Peristaltic	--	--	0	--	--	0	--	--	55.0
Pyrene	XAD	21.8	25.7	47.5	22.1	0	22.1	49.2	14.8	64.0
Total PAHs	Peristaltic	--	--	0	--	--	0	--	--	138
Total PAHs	XAD	159	106	265	114	42.6	156	372	81.3	453
Phthalate esters										
Bis(2-ethylhexyl) phthalate	Peristaltic	--	--	0	--	--	0	--	--	0
Bis(2-ethylhexyl) phthalate	XAD	0	0	0	0	0	0	27.2	41.3	68.5
Dibutyl phthalate	Peristaltic	--	--	0	--	--	0	--	--	0
Dibutyl phthalate	XAD	0	0	0	0	0	0	11.2	0	11.2
Semivolatile Organic Compounds										
Hexachlorobenzene	Peristaltic	--	--	0	--	--	0	--	--	0
Hexachlorobenzene	XAD	0.359	0.0465	0.406	0.417	0.0599	0.477	0.253	0.0269	0.280
Pentachlorophenol	Peristaltic	--	--	0	--	--	0	--	--	0
Pentachlorophenol	XAD	--	--	--	--	--	--	--	--	--

-- Load not estimated

[a] Total loads for analytes sampled with the XAD were calculated as the sum of dissolved and particulate loads

Table D2-2. Loading Rate Estimates for Surface Water Flowing into RM 6.3.

Analyte	Sample Type	November 2004 Estimated Loading (kg/yr)			March 2005 Estimated Loading (kg/yr)			July 2005 Estimated Loading (kg/yr)		
		Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]
Metals										
Arsenic	Peristaltic	4.42E+03	--	5.24E+03	3.80E+03	--	4.23E+03	3.39E+03	--	3.77E+03
Cadmium	Peristaltic	0	--	0	189	--	284	0	--	0
Copper	Peristaltic	6.46E+03	--	1.15E+04	6.43E+03	--	1.00E+04	--	--	--
Lead	Peristaltic	244	--	2.01E+03	123	--	1.19E+03	226	--	1730
Mercury	Peristaltic	0	--	0	0	--	0	0	--	0
Silver	Peristaltic	0	--	0	0	--	0	0	--	0
Zinc	Peristaltic	2.15E+04	--	3.02E+04	1.80E+04	--	2.17E+04	1.32E+04	--	2.13E+04
Butyltins										
Tributyltin	Peristaltic	--	--	0	--	--	0	--	--	0
Tributyltin	XAD	0	0	0	0	0	0	0	0	0
PCBs										
Total PCB TEQ	XAD	2.01E-05	3.78E-05	5.79E-05	2.16E-05	4.78E-05	6.94E-05	6.19E-06	4.20E-05	4.82E-05
Total PCB Aroclors	XAD	1.59	2.14	3.73	1.20	2.13	3.32	1.22	--	--
Dioxins/Furans										
Total Dioxin TEQ	XAD	4.31E-05	8.27E-04	8.71E-04	4.37E-05	7.97E-04	8.41E-04	3.23E-05	6.65E-04	6.98E-04
Pesticides										
2,4'-DDD	XAD	0.165	0.0958	0.261	0.194	0.0869	0.281	0.244	0.0610	0.305
2,4'-DDT	XAD	0.0444	0.0326	0.0770	0.0434	0.0432	0.0866	0.0215	0.0169	0.0384
4,4'-DDD	XAD	0.300	0.240	0.540	0.351	0.264	0.615	0.568	0.204	0.772
4,4'-DDE	XAD	0.217	0.204	0.421	0.199	0.234	0.433	0.248	0.203	0.451
4,4'-DDT	XAD	0.107	0.134	0.241	0.0955	0.307	0.403	0.0406	0.150	0.191
Aldrin	XAD	0.0125	4.77E-03	0.0173	0.0103	4.76E-03	0.0151	0.0149	5.76E-03	0.0207
alpha-Hexachlorocyclohexane	XAD	0.351	0	0.351	0.105	7.28E-04	0.106	0.509	2.69E-03	0.512
beta-Hexachlorocyclohexane	XAD	0.0588	0	0.0588	0.0462	0	0.0462	0.0602	0	0.0602
delta-Hexachlorocyclohexane	XAD	0	0	0	0	0	0	0.0105	0	0.0105
Dieldrin	XAD	0.430	0	0.430	0.353	0.0303	0.383	0.308	0.0185	0.327
Endrin	XAD	0	0	0	0.00925	0	0.00925	0	--	--
Endrin Keytone	XAD	0.00792	0	0.00792	0.00543	0	0.00543	0	0	0
gamma-Hexachlorocyclohexane	XAD	0.385	0	0.385	0.278	1.03E-03	0.279	0.199	1.58E-03	0.201
Heptachlor	XAD	3.16E-03	0	3.16E-03	2.51E-03	0	2.51E-03	0	0	0
Heptachlor Epoxide	XAD	0.0592	0	0.0592	0.0483	0	0.0483	0.0313	--	--
Total Chlordanes	XAD	0.270	0.0647	0.335	0.211	0.0790	0.290	0.214	0.0656	0.279
Total of 2,4' and 4,4'-DDD	XAD	0.465	0.336	0.801	0.545	0.351	0.895	0.812	0.265	1.08
Total of 2,4' and 4,4'-DDE	XAD	0.227	0.213	0.440	0.214	0.247	0.460	0.265	0.212	0.477
Total of 2,4' and 4,4'-DDT	XAD	0.151	0.167	0.318	0.139	0.350	0.489	0.0621	0.167	0.229
Total of 2,4' and 4,4'-DDD, -DDE, -DDT	XAD	0.844	0.715	1.559	0.8970	0.9479	1.845	1.1394	6.44E-01	1.7833
Polycyclic Aromatic Hydrocarbons										
2-Methylnaphthalene	Peristaltic	--	--	0	--	--	0	--	--	0
2-Methylnaphthalene	XAD	31.2	0	31.2	116	0	116.30	28.5	0	28.5
Acenaphthene	Peristaltic	--	--	0	--	--	0	--	--	0
Acenaphthene	XAD	14.3	0	14.3	22.6	0	22.6	30.3	0	30.3
Anthracene	Peristaltic	--	--	0	--	--	0	--	--	0
Anthracene	XAD	6.34	0	6.34	4.59	0	4.59	11.1	3.65	14.8
Benzo(a)anthracene	Peristaltic	--	--	144	--	--	0	--	--	0
Benzo(a)anthracene	XAD	1.62	0	1.62	1.68	5.01	6.69	3.54	6.11	9.65
Benzo(a)pyrene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(a)pyrene	XAD	0.576	0	0.576	0.458	6.84	7.30	0.942	7.91	8.85

Table D2-2. Loading Rate Estimates for Surface Water Flowing into RM 6.3.

		November 2004 Estimated Loading (kg/yr)			March 2005 Estimated Loading (kg/yr)			July 2005 Estimated Loading (kg/yr)		
Analyte	Sample Type	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]
Benzo(b)fluoranthene	Peristaltic	--	--	--	--	--	--	--	--	--
Benzo(b)fluoranthene	XAD	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(g,h,i)perylene	XAD	0	4.74	4.74	0	7.51	7.51	0.335	8.36	8.70
Benzo(k)fluoranthene	Peristaltic	--	--	96.2	--	--	0	--	--	0
Benzo(k)fluoranthene	XAD	0.365	3.15	3.51	0.321	5.24	5.56	5.99	5.29	11.3
Chrysene	Peristaltic	--	--	111	--	--	0	--	--	0
Chrysene	XAD	3.06	6.25	9.31	2.86	8.30	11.2	5.59	10.1	15.7
Dibenzo(a,h)anthracene	Peristaltic	--	--	0	--	--	0	--	--	0
Dibenzo(a,h)anthracene	XAD	0	0	0	0	0.974	0.974	0	0	0
Fluoranthene	Peristaltic	--	--	144	--	--	0	--	--	98.0
Fluoranthene	XAD	21.0	12.9	33.9	17.9	11.6	29.5	27.3	10.4	37.7
Fluorene	Peristaltic	--	--	0	--	--	0	--	--	0
Fluorene	XAD	14.8	0	14.8	19.1	0	19.1	20.7	1.45	22.2
Indeno(1,2,3-cd)pyrene	Peristaltic	--	--	0	--	--	0	--	--	0
Indeno(1,2,3-cd)pyrene	XAD	0	3.45	3.45	0.587	5.28	5.86	0	6.02	6.02
Naphthalene	Peristaltic	--	--	0	--	--	0	--	--	0
Naphthalene	XAD	0	0	0	145	0	145	0	7.61	7.61
Phenanthrene	Peristaltic	--	--	0	--	--	0	--	--	0
Phenanthrene	XAD	26.8	0	26.8	30.0	0	30.0	41.2	9.72	50.9
Pyrene	Peristaltic	--	--	0	--	--	0	--	--	70.8
Pyrene	XAD	19.0	14.5	33.5	18.5	0	18.5	29.8	15.4	45.1
Total PAH	Peristaltic	--	--	606	--	--	0	--	--	192
Total PAH	XAD	145	49.8	195	389	57.5	447	206	98.9	305
Phthalate esters										
Bis(2-ethylhexyl)phthalate	Peristaltic	--	--	0	--	--	0	--	--	0
Bis(2-ethylhexyl)phthalate	XAD	0	0	0	0	0	0	47.5	35.9	83.4
Dibutyl phthalate	Peristaltic	--	--	0	--	--	0	--	--	0
Dibutyl phthalate	XAD	0	0	0	0	0	0	14.7	0	14.7
SVOCs										
Hexachlorobenzene	Peristaltic	--	--	0	--	--	0	--	--	0
Hexachlorobenzene	XAD	0.468	0.0444	0.513	0.524	0.0576	0.581	0.280	0.0422	0.323
Pentachlorophenol	Peristaltic	--	--	0	--	--	0	--	--	0
Pentachlorophenol	XAD	--	--	--	--	--	--	--	--	--

-- Load not estimated

[a] Total loads for analytes sampled with the XAD were calculated as the sum of dissolved and particulate loads.

Table D2-3. Loading Rate Estimates for Surface Water Flowing into RM 11.

Analyte	Sample Type	November 2004 Estimated Loading (kg/yr)			March 2005 Estimated Loading (kg/yr)			July 2005 Estimated Loading (kg/yr)		
		Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]
Metals										
Arsenic	Peristaltic	4.17E+03	--	5.01E+03	3.40E+03	--	4.03E+03	3.24E+03	--	3.66E+03
Cadmium	Peristaltic	0	--	0	0	--	0	0	--	0
Copper	Peristaltic	6.61E+03	--	1.22E+04	4.92E+03	--	7.75E+03	--	--	--
Lead	Peristaltic	187	--	2.15E+03	151	--	1.03E+03	226	--	1280
Mercury	Peristaltic	0	--	0	0	--	0	0	--	0
Silver	Peristaltic	0	--	0	0	--	0	0	--	0
Zinc	Peristaltic	3.16E+04	--	4.02E+04	1.32E+04	--	2.08E+04	1.64E+04	--	1.75E+04
Butyltins										
Tributyltin	Peristaltic	--	--	0	--	--	0	--	--	0
Tributyltin	XAD	0	0	0	0	0	0	0	0	0
PCBs										
Total PCB TEQ	XAD	2.13E-06	6.95E-05	7.17E-05	1.02E-05	1.88E-05	2.90E-05	4.60E-06	7.20E-06	1.18E-05
Total PCB Aroclors	XAD	0.399	7.72	8.12	0.580	0.468	1.05	0.90	0.77	1.7
Dioxins/Furans										
Total Dioxin TEQ	XAD	7.02E-06	5.70E-04	5.77E-04	2.88E-05	6.51E-04	6.80E-04	1.40E-05	4.42E-04	4.56E-04
Pesticides										
2,4'-DDD	XAD	0.0243	0.0226	0.0468	0.0359	9.64E-03	0.0456	0.0607	0.0152	0.0759
2,4'-DDT	XAD	0	0.0122	0.0122	9.83E-03	0	9.83E-03	4.85E-03	1.82E-03	6.68E-03
4,4'-DDD	XAD	0.0596	0.107	0.166	0.101	0.0123	0.113	0.18	0.0668	0.242
4,4'-DDE	XAD	0.0715	0.164	0.235	0.117	0.110	0.227	0.17	0.128	0.301
4,4'-DDT	XAD	0.0208	0.127	0.148	0.0306	0	0.0306	0.02	4.88E-03	0.0220
Aldrin	XAD	0	0	0	6.11E-03	1.86E-03	7.97E-03	0.01	3.40E-03	0.0146
alpha-Hexachlorocyclohexane	XAD	0.152	0	0.152	0.0974	0	0.0974	0.61	4.91E-03	0.615
beta-Hexachlorocyclohexane	XAD	0.0249	0	0.0249	0.0353	0	0.0353	0.06	6.20E-03	0.0707
delta-Hexachlorocyclohexane	XAD	0	0	0	0	0	0	0.0120	0	0.0120
Dieldrin	XAD	0.205	0.0349	0.240	0.270	0	0.270	0.29	0.0150	0.305
Endrin	XAD	0	0.00241	0.00241	0.00785	0	0.00785	0	0	0
Endrin Keytone	XAD	0	0	0	0.00610	0	0.00610	0	0	0.00362
gamma-Hexachlorocyclohexane	XAD	0.170	0	0.170	0.280	0	0.280	0.20	1.58E-03	0.204
Heptachlor	XAD	0	0	0	0	0	0	0.00	0	0
Heptachlor Epoxide	XAD	0.0303	0	0.0303	0.0395	0	0.0395	0.033	0	0.033
Total Chlordanes	XAD	0.113	0.0790	0.192	0.170	0.0263	0.196	0.16	0.0483	0.210
Total of 2,4' and 4,4'-DDD	XAD	0.0839	0.129	0.213	0.137	0.0219	0.159	0.24	0.0820	0.318
Total of 2,4' and 4,4'-DDE	XAD	0.0738	0.167	0.241	0.121	0.113	0.234	0.18	0.131	0.308
Total of 2,4' and 4,4'-DDT	XAD	0.0208	0.140	0.160	0.0405	0	0.0405	0.02	6.71E-03	0.0287
Total of 2,4' and 4,4'-DDD, -DDE, -DDT	XAD	0.178	0.436	0.615	0.2985	0.1346	0.433	0.4356	2.19E-01	0.6550
Polycyclic Aromatic Hydrocarbons										
2-Methylnaphthalene	Peristaltic	--	--	0	--	--	0	--	--	0
2-Methylnaphthalene	XAD	23.4	0	23.4	228	0	228	27.3	0	27.3
Acenaphthene	Peristaltic	--	--	0	--	--	0	--	--	0
Acenaphthene	XAD	2.97	0	2.97	7.87	0	7.87	3.26	0	3.26
Anthracene	Peristaltic	--	--	0	--	--	0	--	--	0
Anthracene	XAD	0	0	0	0	0	0.0	0.00	0	0
Benzo(a)anthracene	Peristaltic	--	--	144	--	--	0	--	--	0
Benzo(a)anthracene	XAD	0.747	0	0.747	0.712	0	0.712	0.91	1.62	2.53
Benzo(a)pyrene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(a)pyrene	XAD	0.378	0	0.378	0.268	0	0.268	0	2.07	2.07
Benzo(b)fluoranthene	Peristaltic	--	--	--	--	--	--	--	--	--

Table D2-3. Loading Rate Estimates for Surface Water Flowing into RM 11.

		November 2004 Estimated Loading (kg/yr)			March 2005 Estimated Loading (kg/yr)			July 2005 Estimated Loading (kg/yr)		
Analyte	Sample Type	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]	Dissolved	Particulate	Total[a]
Benzo(b)fluoranthene	XAD	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(g,h,i)perylene	XAD	0	5.39	5.39	0	0	0	0	3.01	3.01
Benzo(k)fluoranthene	Peristaltic	--	--	0	--	--	0	--	--	0
Benzo(k)fluoranthene	XAD	0	2.77	2.77	0.148	0	0.148	0	1.58	1.58
Chrysene	Peristaltic	--	--	0	--	--	0	--	0	0
Chrysene	XAD	1.36	0	1.36	1.26	2.81	4.07	1.79	0	1.79
Dibenzo(a,h)anthracene	Peristaltic	--	--	0	--	--	0	--	--	0
Dibenzo(a,h)anthracene	XAD	0	0	0	0	0	0	0	0.359	0.359
Fluoranthene	Peristaltic	--	--	0	--	--	0	--	--	0
Fluoranthene	XAD	5.98	9.57	15.6	5.59	0	5.59	6.58	4.54	11.1
Fluorene	Peristaltic	--	--	0	--	--	0	--	--	0
Fluorene	XAD	5.95	0	5.95	12.8	0	12.8	4.63	0	4.63
Indeno(1,2,3-cd)pyrene	Peristaltic	--	--	0	--	--	0	--	--	0
Indeno(1,2,3-cd)pyrene	XAD	0	3.48	3.48	0	1.75	1.75	0	1.99	1.99
Naphthalene	Peristaltic	--	--	0	--	--	0	--	--	0
Naphthalene	XAD	0	0	0	326	0	326	0	0	0
Phenanthrene	Peristaltic	--	--	0	--	--	0	--	--	0
Phenanthrene	XAD	11.3	0	11.3	16.5	0	16.5	7.91	0	7.91
Pyrene	Peristaltic	--	--	132	--	--	0	--	0	0
Pyrene	XAD	6.21	0	6.21	6.69	0	6.69	6.77	0	6.77
Total PAH	Peristaltic	--	--	407	--	--	0	--	--	0
Total PAH	XAD	62.7	25.4	88.1	619	4.56	624	62.6	17.1	79.7
Phthalate esters										
Bis(2-ethylhexyl) phthalate	Peristaltic	--	--	0	--	--	0	--	--	0
Bis(2-ethylhexyl) phthalate	XAD	0	0	0	0	0	0	129	44.4	173
Dibutyl phthalate	Peristaltic	--	--	0	--	--	0	--	--	0
Dibutyl phthalate	XAD	0	0	0	0	0	0	13.4	0	13.4
Semivolatile Organic Compounds										
Hexachlorobenzene	Peristaltic	--	--	0	--	--	0	--	--	0
Hexachlorobenzene	XAD	0.226	0.0520	0.278	0.456	0.236	0.692	0.30	0.0652	0.361
Pentachlorophenol	Peristaltic	--	--	0	--	--	0	--	--	0
Pentachlorophenol	XAD	--	--	--	--	--	--	--	--	--

-- Load not estimated

[a] Total loads for analytes sampled with the XAD were calculated as the sum of dissolved and particulate loads.

Table D3-1. Summary Loading Estimate (kg/yr) by Land Use Type for Overall Stormwater Drainage Basin.

	Commercial	Industrial	Multi-Family Residential	Mixed Use	Parks/ Open Space	Rural	Single Family Residential	Total
Low Estimate								
Arsenic	1.10E-01	9.74E-01	6.70E-01	2.15E-01	1.04E-01	1.75E-02	5.35E-01	2.63
Copper	3.68E-01	2.01E+01	2.01E+00	6.46E-01	1.04E+00	1.75E-01	2.68E+00	27.06
Lead	1.84E-01	3.09E+00	1.34E+00	4.31E-01	5.22E-01	8.76E-02	1.34E+00	6.99
Mercury	3.86E-04	1.62E-02	2.68E-03	8.61E-04	2.09E-03	3.50E-04	5.35E-03	0.03
Zinc	7.36E-01	1.97E+01	6.70E+00	2.15E+00	2.35E+00	3.94E-01	6.69E+00	38.67
PCBs	1.84E-04	1.61E-02	6.70E-04	2.15E-04	5.22E-04	8.76E-05	1.34E-03	0.02
DDT	7.36E-05	6.50E-03	6.70E-04	2.15E-04	0.00E+00	0.00E+00	1.34E-03	0.01
Total PAHs	8.11E-02	1.19E-01	4.01E+00	1.29E+00	9.46E-02	1.59E-02	1.48E+00	7.09
Bis(2ethylhexyl)phthalate	1.71E-02	1.09E+01	4.29E+00	1.38E+00	0.00E+00	0.00E+00	5.23E+00	21.80
Mid Estimate								
Arsenic	4.60E-01	4.39E+01	2.58E+00	8.28E-01	3.60E+00	6.04E-01	6.27E+00	58.2
Copper	6.40E+00	4.22E+02	1.98E+01	6.35E+00	3.60E+00	6.04E-01	2.93E+01	488.4
Lead	3.60E+00	2.73E+02	1.37E+01	4.42E+00	9.01E+00	1.51E+00	2.51E+01	330.6
Mercury	4.00E-02	2.19E+00	1.72E-01	5.52E-02	5.41E-03	9.08E-04	4.18E-01	2.9
Zinc	3.36E+01	4.95E+03	1.19E+02	3.81E+01	2.25E+01	3.78E+00	2.26E+02	5,396.7
PCBs	7.00E-03	2.54E+00	3.01E-02	9.66E-03	2.25E-02	3.78E-03	7.32E-02	2.7
DDT	2.00E-02	1.10E+00	8.59E-02	2.76E-02	0.00E+00	0.00E+00	2.09E-01	1.4
Total PAHs	1.70E+00	5.46E+02	7.91E+00	2.54E+00	3.63E-01	6.08E-02	5.71E+00	564.7
Bis(2ethylhexyl)phthalate	2.40E+00	1.32E+02	1.03E+01	3.31E+00	0.00E+00	0.00E+00	1.67E+01	164.4
High Estimate								
Arsenic	3.13E+00	6.16E+02	2.27E+01	7.29E+00	6.49E+00	1.09E+00	3.39E+01	690
Copper	1.36E+01	4.92E+04	4.67E+01	1.50E+01	4.50E+01	7.55E+00	1.15E+02	49,491
Lead	1.51E+01	2.50E+03	5.22E+01	1.68E+01	3.96E+01	6.65E+00	1.20E+02	2,751
Mercury	1.04E-01	7.24E+00	4.47E-01	1.44E-01	8.74E-03	1.47E-03	1.17E+00	9
Zinc	1.02E+02	6.45E+04	2.28E+02	7.34E+01	1.30E+02	2.17E+01	5.49E+02	65,649
PCBs	3.50E-02	1.17E+01	1.50E-01	4.83E-02	4.95E-02	8.31E-03	9.41E-01	13
DDT	6.00E-02	3.29E+00	2.58E-01	8.28E-02	1.75E-03	2.93E-04	6.27E-01	4
Total PAHs	2.36E+02	7.69E+04	4.64E+02	1.49E+02	6.31E-01	1.06E-01	1.10E+02	77,816
Bis(2ethylhexyl)phthalate	6.20E+00	6.42E+02	2.66E+01	8.56E+00	0.00E+00	0.00E+00	4.49E+01	728

Table D3-2. Runoff Volumes (liters) by Land Use Type for Overall Site Stormwater Drainage Basin.

Land Use	Acres	Runoff Volume (liters)
Commercial	65.1	2.00E+08
Industrial	3979.4	1.10E+10
Multi-Family Residential	382.5	8.59E+08
Mixed Use	146.0	2.76E+08
Parks/Open Space	4573.7	9.01E+08
Rural	766.8	1.51E+08
Singe Family Residential	1769.0	2.09E+09
Total	11682.5	1.55E+10

Table D3-3. Land Use Physical and Chemical Data from Literature Values.

Data Type	Commercial	Industrial	Multi-Family Residential	Mixed Use	Parks/ Open Space	Rural	Single Family Residential
Physical Data							
Percent Impervious	85	75	60	50	0	0	30
Runoff Coefficient	0.78	0.70	0.57	0.48	0.05	0.05	0.3
Annual Runoff (in.)	29.84	26.78	21.80	18.36	1.91	1.91	11.48
Annual Rainfall (in.)	42.5	42.5	42.5	42.5	42.5	42.5	42.5
Fraction Runoff Events	0.9	0.9	0.9	0.9	0.9	0.9	0.9

	Commercial			Industrial			Multi Family			Mixed Use			Parks Open Space			Rural			Single Family		
Chemical Data	Low	Mid	High	Low	Mid	High	Low	Mid	High	Low	Mid	High	Low	Mid	High	Low	Mid	High	Low	Mid	High
Water Chemisry Data (mg/L)																					
TSS	0.00E+00	9.20E+01	2.15E+02	0.00E+00	1.48E+02	3.40E+02	0.00E+00	7.80E+01	2.77E+02	0.00E+00	7.80E+01	2.77E+02	0.00E+00	5.80E+01	1.94E+02	0.00E+00	5.80E+01	1.94E+02	0.00E+00	6.40E+01	2.25E+02
Arsenic	0.00E+00	2.30E-03	1.56E-02	0.00E+00	4.00E-03	1.52E-02	0.00E+00	3.00E-03	2.64E-02	0.00E+00	3.00E-03	2.64E-02	8.00E-04	4.00E-03	7.20E-03	8.00E-04	4.00E-03	7.20E-03	0.00E+00	3.00E-03	1.62E-02
Copper	0.00E+00	3.20E-02	6.80E-02	0.00E+00	3.85E-02	5.98E-02	0.00E+00	2.30E-02	5.44E-02	0.00E+00	2.30E-02	5.44E-02	0.00E+00	4.00E-03	5.00E-02	0.00E+00	4.00E-03	5.00E-02	0.00E+00	1.40E-02	5.52E-02
Lead	0.00E+00	1.80E-02	7.56E-02	0.00E+00	2.49E-02	7.60E-02	0.00E+00	1.60E-02	6.08E-02	0.00E+00	1.60E-02	6.08E-02	0.00E+00	1.00E-02	4.40E-02	0.00E+00	1.00E-02	4.40E-02	0.00E+00	1.20E-02	5.76E-02
Mercury	0.00E+00	2.00E-04	5.20E-04	0.00E+00	2.00E-04	6.60E-04	0.00E+00	2.00E-04	5.20E-04	0.00E+00	2.00E-04	5.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-04	5.60E-04
Zinc	0.00E+00	1.68E-01	5.10E-01	0.00E+00	4.52E-01	1.24E+00	0.00E+00	1.38E-01	2.66E-01	0.00E+00	1.38E-01	2.66E-01	0.00E+00	2.50E-02	1.44E-01	0.00E+00	2.50E-02	1.44E-01	0.00E+00	1.08E-01	2.63E-01
PCBs	5.00E-06	3.50E-05	1.75E-04	5.00E-06	2.32E-04	1.07E-03	5.00E-06	3.50E-05	1.75E-04	5.00E-06	3.50E-05	1.75E-04	5.00E-06	2.50E-05	5.50E-05	5.00E-06	2.50E-05	5.50E-05	5.00E-06	3.50E-05	7.00E-05
DDT	8.00E-06	1.00E-04	3.00E-04	8.00E-06	1.00E-04	3.00E-04	8.00E-06	1.00E-04	3.00E-04	8.00E-06	1.00E-04	3.00E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-06	1.00E-04	3.00E-04
PAHs	2.22E-03	8.52E-03	1.18E+00	1.48E-02	4.98E-02	3.60E+00	4.67E-03	9.21E-03	5.40E-01	4.67E-03	9.21E-03	5.40E-01	1.05E-04	4.03E-04	7.00E-04	1.05E-04	4.03E-04	7.00E-04	7.08E-04	2.73E-03	5.24E-02
Bis(2ethylhexyl)phthalate	5.00E-03	1.20E-02	3.10E-02	5.00E-03	1.20E-02	3.50E-02	5.00E-03	1.20E-02	3.10E-02	5.00E-03	1.20E-02	3.10E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-03	8.00E-03	2.15E-02
Extrapolated Water from Sediment Data (mg/L)																					
Arsenic	5.52E-04		2.58E-03	8.88E-05		5.61E-02	7.80E-04		4.99E-03	7.80E-04		4.99E-03	1.16E-04		9.70E-04	1.16E-04		9.70E-04	2.56E-04		2.48E-03
Copper	1.84E-03		1.08E-02	1.84E-03		4.49E+00	2.34E-03		1.11E-02	2.34E-03		1.11E-02	1.16E-03		5.82E-03	1.16E-03		5.82E-03	1.28E-03		1.13E-02
Lead	9.20E-04		3.23E-02	2.81E-04		2.28E-01	1.56E-03		1.94E-02	1.56E-03		1.94E-02	5.80E-04		6.79E-03	5.80E-04		6.79E-03	6.40E-04		1.80E-02
Mercury	1.93E-06		5.38E-05	1.48E-06		1.36E-04	3.12E-06		1.39E-05	3.12E-06		1.39E-05	2.32E-06		9.70E-06	2.32E-06		9.70E-06	2.56E-06		1.13E-05
Zinc	3.68E-03		1.18E-01	1.79E-03		5.88E+00	7.80E-03		6.93E-02	7.80E-03		6.93E-02	2.61E-03		1.07E-02	2.61E-03		1.07E-02	3.20E-03		6.75E-02
PCBs	9.20E-07		2.15E-05	1.47E-06		8.47E-04	7.80E-07		2.77E-06	7.80E-07		2.77E-06	5.80E-07		1.94E-06	5.80E-07		1.94E-06	6.40E-07		4.50E-04
DDT	3.68E-07		6.88E-05	5.92E-07		1.36E-05	7.80E-07		8.31E-05	7.80E-07		8.31E-05	5.80E-07		1.94E-06	5.80E-07		1.94E-06	6.40E-07		2.25E-06
PAHs	4.06E-04		3.38E-02	1.08E-05		7.00E+00															
Bis(2ethylhexyl)phthalate	8.56E-05		2.06E-02	9.92E-04		5.85E-02															
Combined Ranges for Water (mg/L)																					
Arsenic	5.52E-04	2.30E-03	1.56E-02	8.88E-05	4.00E-03	5.61E-02	7.80E-04	3.00E-03	2.64E-02	7.80E-04	3.00E-03	2.64E-02	1.16E-04	4.00E-03	7.20E-03	1.16E-04	4.00E-03	7.20E-03	2.56E-04	3.00E-03	1.62E-02
Copper	1.84E-03	3.20E-02	6.80E-02	1.84E-03	3.85E-02	4.49E+00	2.34E-03	2.30E-02	5.44E-02	2.34E-03	2.30E-02	5.44E-02	1.16E-03	4.00E-03	5.00E-02	1.16E-03	4.00E-03	5.00E-02	1.28E-03	1.40E-02	5.52E-02
Lead	9.20E-04	1.80E-02	7.56E-02	2.81E-04	2.49E-02	2.28E-01	1.56E-03	1.60E-02	6.08E-02	1.56E-03	1.60E-02	6.08E-02	5.80E-04	1.00E-02	4.40E-02	5.80E-04	1.00E-02	4.40E-02	6.40E-04	1.20E-02	5.76E-02
Mercury	1.93E-06	2.00E-04	5.20E-04	1.48E-06	2.00E-04	6.60E-04	3.12E-06	2.00E-04	5.20E-04	3.12E-06	2.00E-04	5.20E-04	2.32E-06	6.01E-06	9.70E-06	2.32E-06	6.01E-06	9.70E-06	2.56E-06	2.00E-04	5.60E-04
Zinc	3.68E-03	1.68E-01	5.10E-01	1.79E-03	4.52E-01	5.88E+00	7.80E-03	1.38E-01	2.66E-01	7.80E-03	1.38E-01	2.66E-01	2.61E-03	2.50E-02	1.44E-01	2.61E-03	2.50E-02	1.44E-01	3.20E-03	1.08E-01	2.63E-01
PCBs	9.20E-07	3.50E-05	1.75E-04	1.47E-06	2.32E-04	1.07E-03	7.80E-07	3.50E-05	1.75E-04	7.80E-07	3.50E-05	1.75E-04	5.80E-07	2.50E-05	5.50E-05	5.80E-07	2.50E-05	5.50E-05	6.40E-07	3.50E-05	4.50E-04
DDT	3.68E-07	1.00E-04	3.00E-04	5.92E-07	1.00E-04	3.00E-04	7.80E-07	1.00E-04	3.00E-04	7.80E-07	1.00E-04	3.00E-04	0.00E+00	0.00E+00	1.94E-06	0.00E+00	0.00E+00	1.94E-06	6.40E-07	1.00E-04	3.00E-04
PAHs	4.06E-04	8.52E-03	1.18E+00	1.08E-05	4.98E-02	7.00E+00	4.67E-03	9.21E-03	5.40E-01	4.67E-03	9.21E-03	5.40E-01	1.05E-04	4.03E-04	7.00E-04	1.05E-04	4.03E-04	7.00E-04	7.08E-04	2.73E-03	5.24E-02
Bis(2ethylhexyl)phthalate	8.56E-05	1.20E-02	3.10E-02	9.92E-04	1.20E-02	5.85E-02	5.00E-03	1.20E-02	3.10E-02	5.00E-03	1.20E-02	3.10E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-03	8.00E-03	2.15E-02

Table D3-4. National Stormwater Quality (SWQA) Database[a] Summary Statistics for Total Suspended Solids (TSS) and Metals.

Land Use	TSS (mg/L)	As, total (ug/L)	Cu, total (ug/L)	Pb, total (ug/L)	Hg, total (ug/L)	Zn, total (ug/L)
Overall Summary (3765)						
Number of observations	3493	1507	2722	2949	1014	3007
% of samples above detection	97.9	49.9	87.4	77.7	10.2	96.6
Median	59	3	16	17	0.2	116
Coefficient of variation	1.8	2.6	2.2	1.8	2.5	3.3
Estimated High	271.4	18.6	86.4	78.2	1.2	881.6
Estimated Low	0	0	0	0	0	0
Residential (1042)						
Number of observations	978	395	771	762	275	784
% of samples above detection	98.3	40.8	83.1	69.4	6.9	96.2
Median	49	3	12	12	0.2	73
Coefficient of variation	1.8	2.2	1.8	1.9	0.9	1.3
Estimated High	225.4	16.2	55.2	57.6	0.56	262.8
Estimated Low	0	0	0	0	0	0
Mixed Residential (611)						
Number of observations	582	158	432	500	115	515
% of samples above detection	98.3	65.9	83.8	78.4	15.7	92.6
Median	66	3	16	16	0.2	95
Coefficient of variation	1.6	3.9	1.2	1.4	0.8	0.9
Estimated High	277.2	26.4	54.4	60.8	0.52	266
Estimated Low	0	0	0	0	0	0
Commercial (527)						
Number of observations	503	235	408	399	170	414
% of samples above detection	95.2	33.6	92.9	85.5	6.5	99
Median	43	2.3	17	18	0.2	150
Coefficient of variation	2	2.9	1.5	1.6	0.8	1.2
Estimated High	215	15.64	68	75.6	0.52	510
Estimated Low	0	0	0	0	0	0
Mixed Commercial (324)						
Number of observations	297	139	191	244		243
% of samples above detection	99.7	45.5	93.2	88.1		98.8
Median	54.5	2	17.5	17		131.4
Coefficient of variation	1.3	1	3	1.4		1.7
Estimated High	196.2	6	122.5	64.6	0	578.16
Estimated Low	0	0	0	0	0	0
Industrial (566)						
Number of observations	521	255	455	452	199	473
% of samples above detection	97.7	52.9	88.6	75	13.9	98.9
Median	81	4	20.8	24.9	0.2	199
Coefficient of variation	1.6	1.4	2	1.9	2.7	1.5
Estimated High	340.2	15.2	104	119.52	1.28	796
Estimated Low	0	0	0	0	0	0
Mixed Industrial (218)						
Number of observations	207	93	150	213	58	212
% of samples above detection	100	88.2	90	82.6	22.4	98.6
Median	82	3.5	23	20	0.3	172
Coefficient of variation	1.4	0.9	0.8	1.4	0.6	3.1
Estimated High	311.6	9.8	59.8	76	0.66	1238.4
Estimated Low	0	0	0	0	0	0

Table D3-4. National Stormwater Quality (SWQA) Database[a] Summary Statistics for Total Suspended Solids (TSS) and Metals.

Land Use	TSS (mg/L)	As, total (ug/L)	Cu, total (ug/L)	Pb, total (ug/L)	Hg, total (ug/L)	Zn, total (ug/L)
Institutional (18)						
Number of observations	18			18		18
% of samples above detection	94.4			77.8		100
Median	17			5.75		305
Coefficient of variation	0.83			0.8		0.8
Estimated High	45.22	0	0	14.95	0	793
Estimated Low	0	0	0	0	0	0
Freeways (185)						
Number of observations	134	61	97	107		93
% of samples above detection	99.3	55.7	99	100		96.8
Median	99	2.4	34.7	25		200
Coefficient of variation	2.6	0.7	1	1.5		1
Estimated High	613.8	5.76	104.1	100	0	600
Estimated Low	0	0	0	0	0	0
Mixed Freeways (26)						
Number of observations	23	15	23	23		23
% of samples above detection	100	80	100	56.5		100
Median	88	3	14	10		130
Coefficient of variation	1.1	0.7	1	1.3		0.9
Estimated High	281.6	7.2	42	36	0	364
Estimated Low	0	0	0	0	0	0
Open Space (49)						
Number of observations	44	19	39	45		45
% of samples above detection	95.5	31.6	74.4	42.2		71.1
Median	48.5	4	10	10		40
Coefficient of variation	1.5	0.4	2	1.7		1.3
Estimated High	194	7.2	50	44	0	144
Estimated Low	0	0.8	0	0	0	0
Mixed Open Space (168)						
Number of observations	153	88	108	155	27	156
% of samples above detection	97.4	44.3	89.8	74.2	14.8	98.1
Median	78	3	9	10	0.15	80
Coefficient of variation	1.6	0.9	1	2.3	0.4	1.1
Estimated High	327.6	8.4	27	56	0.27	256
Estimated Low	0	0	0	0	0.03	0

Notes:
[a]Maestre and Pitt. 2005.

Table D3-5. Association of Clean Water Agencies (ACWA) Summary[a] Statistics for Total Suspended Solids (TSS) and Metals.

Land Use	TSS (mg/L)	Total Cu (mg/L)	Total Zn (mg/L)	Dissolved Cu (mg/L)	Total P (mg/L)
In-pipe Industrial	194	0.053	0.629	0.009	0.633
Instream Industrial	102	0.024	0.274	0.007	0.509
Transportation	169	0.035	0.236	0.008	0.376
Commercial	92	0.032	0.168	0.009	0.391
Residential	64	0.014	0.108	0.006	0.365
Open	58	0.004	0.025	0.004	0.166

Notes:
[a]Woodward-Clyde Consultants. 1997.

Table D3-6. Literature Water Chemistry Data for Organic Chemicals by Land Use.

Analyte		Method	Actual Land Use	Categorized Land Use	Conc. (mg/L)	Type
PCBs						
	PCBs [f]	Total	Industrial	Industrial	0.0000050	low
	PCBs [f]	Total	Industrial	Industrial	0.0000600	midpoint
	PCBs [f]	Total	Industrial	Industrial	0.0004030	high
	PCBs [b]	Total	Industrial	Industrial	0.0010700	high
	PCBs [f]	Total	High Density Residential	MultiFamily	0.0000050	low
	PCBs [f]	Total	High Density Residential	MultiFamily	0.0000250	midpoint
	PCBs [f]	Total	High Density Residential	MultiFamily	0.0001750	high
	PCBs [f]	Total	Rainwater	Rainwater	0.0000070	low
	PCBs [f]	Total	Rainwater	Rainwater	0.0000250	midpoint
	PCBs [f]	Total	Rainwater	Rainwater	0.0000550	high
	PCBs [f]	Total	Residential	Single Family	0.0000100	low
	PCBs [f]	Total	Residential	Single Family	0.0000350	midpoint
	PCBs [f]	Total	Residential	Single Family	0.0000700	high
	PCBs [e]	Total	General Urban Range	Urban	0.0000200	single
	PCBs [e]	Total	General Urban Range	Urban	0.0000269	low
	PCBs [e]	Total	General Urban Range	Urban	0.0011200	high
Pesticides						
	DDT [a]	Total	Car Service Roof	Commercial	0.00030	high
	DDT [a]	Total	Commercial Roof	Commercial	0.00030	ND
	DDT [d]	Total	Residential/Commercial	Mixed Use	0.00002	high
	DDT [a]	Total	Apartment Parking	MultiFamily	0.00030	single
	DDT [d]	Total	Residential	Single Family	0.00009	high
	DDT [a]	Total	Residential Roof	Single Family	0.04600	high
	DDT [a]	Total	Residential Roof	Single Family	ND	ND
	DDT [e]	Total	General Urban Range	Urban	0.00001	low
	DDT [e]	Total	General Urban Range	Urban	0.00002	high
	DDT [e]	Total	General Urban Range	Urban	0.00010	single
PAHs						
	PAHs [a]	Total	Car Service Area	Commercial	0.001	low
	PAHs [a]	Total	Commercial Paved	Commercial	0.237	high
	PAHs [a]	Total	Car Service Area	Commercial	0.626	high
	PAHs [a]	Total	Car Service Roof	Commercial	1.182	high
	PAHs [a]	Total	Commercial Paved	Commercial	ND	ND
	PAHs [d]	Total	Commerial	Commerial	0.0022	low
	PAHs [d]	Total	Commerial	Commerial	0.0085	midpoint
	PAHs [d]	Total	Commerial	Commerial	0.0245	high
	PAHs [a]	Total	Industrial Roof	Industrial	0.0076	low
	PAHs [a]	Total	Industrial Storage Area	Industrial	0.0125	high
	PAHs [d]	Total	Industrial	Industrial	0.0148	low
	PAHs [d]	Total	Industrial	Industrial	0.0498	midpoint
	PAHs [d]	Total	Industrial	Industrial	0.0729	high
	PAHs [a]	Total	Industrial Roof	Industrial	0.1550	high
	PAHs [a]	Total	Indust. Grass/Sidewalk	Industrial	3.6000	high
	PAHs [a]	Total	Industrial Roof	Industrial	ND	ND
	PAHs [a]	Total	Industrial Storage Area	Industrial	ND	ND
	PAHs [a]	Total	Indust. Grass/Sidewalk	Industrial	ND	ND
	PAHs [d]	Total	Residential/Commercial	Mixed Use	0.0047	low
	PAHs [d]	Total	Residential/Commercial	Mixed Use	0.0092	midpoint
	PAHs [d]	Total	Residential/Commercial	Mixed Use	0.0143	high
	PAHs [a]	Total	Apartment Parking	MultiFamily	0.0038	low
	PAHs [a]	Total	Apartment Parking	MultiFamily	0.5400	high
	PAHs [d]	Total	Open Space	Parks/Open	0.0001	single

Table D3-6. Literature Water Chemistry Data for Organic Chemicals by Land Use.

Analyte	Method	Actual Land Use	Categorized Land Use	Conc. (mg/L)	Type
PAHs [a]	Total	Park Grass	Parks/Open	0.0007	single
PAHs [d]	Total	Residential	Single Family	0.0007	low
PAHs [d]	Total	Residential	Single Family	0.0027	midpoint
PAHs [d]	Total	Residential	Single Family	0.0086	high
PAHs [a]	Total	Residential Roof	Single Family	0.0284	low
PAHs [a]	Total	Residential Roof	Single Family	0.0524	high
PAHs [a]	Total	Residential Roof	Single Family	ND	ND
PAHs [d]	Total	Transportation	Transportation	0.0065	low
PAHs [d]	Total	Transportation	Transportation	0.0127	midpoint
PAHs [d]	Total	Transportation	Transportation	0.0212	high
PAHs [e]	Total	General Urban Range	Urban	0.0002	low
PAHs [e]	Total	General Urban Range	Urban	0.0033	low
PAHs [e]	Total	General Urban Range	Urban	0.0090	single
PAHs [e]	Total	General Urban Range	Urban	0.0287	midpoint
PAHs [e]	Total	General Urban Range	Urban	0.0543	high
PAHs [e]	Total	General Urban Range	Urban	0.5600	high
Phthalates					
Bis(2ethylhexyl)phthalate [a]	Total	Commercial Storage Area	Commercial	0.005	ND
Bis(2ethylhexyl)phthalate [a]	Total	Commercial Storage Area	Commercial	0.031	high
Bis(2ethylhexyl)phthalate [b]	Total	Residential	Single Family	0.008	single
Bis(2ethylhexyl)phthalate [c]	Total	General Urban Range	Urban	0.012	midpoint
Bis(2ethylhexyl)phthalate [c]	Total	General Urban Range	Urban	0.035	high
Bis(2ethylhexyl)phthalate [a]	Total	Commercial Paved	Commercial	0.021	high
Bis(2ethylhexyl)phthalate [a]	Total	Car Service Roof	Commercial	0.105	high
Bis(2ethylhexyl)phthalate [a]	Total	Commercial Paved	Commercial	ND	ND
Bis(2ethylhexyl)phthalate [b]	Total	Industrial	Industrial	0.058	single
Bis(2ethylhexyl)phthalate [b]	Total	Residential	Single Family	0.005	single
Bis(2ethylhexyl)phthalate [a]	Total	General Urban Range	Urban	0.013	low
Di(n)butyl phthalate [b]	Total	Industrial	Industrial	0.004	single
Di(n)butyl phthalate [b]	Total	Residential	Residential	0.003	single
Di(n)butyl phthalate [a]	Total	Residential Roof	Single Family	0.046	high
Di(n)butyl phthalate [a]	Total	Residential Roof	Single Family	ND	ND

Notes:

[a]Pitt, R., Richard, F., Lalor, M. and Brown, M. 1995. Urban Stormwater Toxic Pollutants: Assessment, Sources, and Treatability. Water Environ. Res. 67:260-275

[b]Burton, G.A. and Pitt, R.E. 2002. Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers. Lewis Publishers. Boca Raton, Florida.

[c]Chu, M. 1993. Quality of Stormwater Runoff from Urbanized Houston Metropolitan Area. Texas A&M University. http://gbic.tamug.edu/

[d]Woodward-Clyde Consultants. 1993. Final Data Report, Data from Storms Monitored between May 1991 and January 1993. NPDES Stormwater Monitoring Program, Portland, Oregon. Prepared for Bureau of Environmental Services, City of Portland, Oregon.

[e]Walker, W.J., R.P. McNutt, and C.K. Maslanka. 1999. The Potential Contribution of Urban Runoff to Surface Sediments in the Passaic River: Sources and Chemical Characteristics. Chemosphere 38(2):363-377.

[f]Rossi, L., L. de Elancastro, T. Kupper, and J. Tarradellas. 2004. Urban stormwater contamination by polychlorinated biphenyls (PCBs) and its importance for urban water systems in Switzerland. Science of the Total Environment 322:179-189.

Table D3-7. Stormwater Sediment Trap Data for Organic Chemicals and Extrapolated Water Concentrations Based on NSQD (Table D3-4) Database and ACWA (Table D3-5) TSS Values.

		Data Sources and Values				Extrapolation to Water Concentration (mg/L)					
						TSS (mg/L) (NSQD+ACWA)			Water Conc. (mg/L)		
Analyte	Method	Actual Landuse	Categorized Landuse	Conc. (mg/kg)	Type	Low	Med	High	Low	Med	High
Metals											
Arsenic [a]	Seds	Commercial	Commercial	6.00E+00	low	0	92	215	0.00E+00	5.52E-04	1.29E-03
Arsenic [a]	Seds	Commercial	Commercial	7.00E+00	midpoint	0	92	215	0.00E+00	6.44E-04	1.51E-03
Arsenic [a]	Seds	Commercial	Commercial	1.20E+01	high	0	92	215	0.00E+00	1.10E-03	2.58E-03
Arsenic [b]	Seds	Industrial	Industrial	6.00E-01	low	0	148	340	0.00E+00	8.88E-05	2.04E-04
Arsenic [a]	Seds	Industrial	Industrial	5.00E+00	low	0	148	340	0.00E+00	7.40E-04	1.70E-03
Arsenic [a]	Seds	Industrial	Industrial	1.20E+01	midpoint	0	148	340	0.00E+00	1.78E-03	4.08E-03
Arsenic [a]	Seds	Industrial	Industrial	1.50E+01	high	0	148	340	0.00E+00	2.22E-03	5.10E-03
Arsenic [b]	Seds	Industrial	Industrial	2.20E+01	midpoint	0	148	340	0.00E+00	3.26E-03	7.48E-03
Arsenic [b]	Seds	Industrial	Industrial	1.65E+02	high	0	148	340	0.00E+00	2.44E-02	5.61E-02
Arsenic [a]	Seds	Commercial/Residential	Mixed Use	1.00E+01	low	0	78	277	0.00E+00	7.80E-04	2.77E-03
Arsenic [a]	Seds	Commercial/Residential	Mixed Use	1.40E+01	midpoint	0	78	277	0.00E+00	1.09E-03	3.88E-03
Arsenic [a]	Seds	Commercial/Residential	Mixed Use	1.80E+01	high	0	78	277	0.00E+00	1.40E-03	4.99E-03
Arsenic [a]	Seds	Undeveloped	Parks/Open	2.00E+00	low	0	58	194	0.00E+00	1.16E-04	3.88E-04
Arsenic [a]	Seds	Undeveloped	Parks/Open	4.00E+00	midpoint	0	58	194	0.00E+00	2.32E-04	7.76E-04
Arsenic [a]	Seds	Undeveloped	Parks/Open	5.00E+00	high	0	58	194	0.00E+00	2.90E-04	9.70E-04
Arsenic [a]	Seds	Residential	Residential	4.00E+00	low	0	64	225	0.00E+00	2.56E-04	9.00E-04
Arsenic [a]	Seds	Residential	Residential	7.00E+00	midpoint	0	64	225	0.00E+00	4.48E-04	1.58E-03
Arsenic [a]	Seds	Residential	Residential	1.10E+01	high	0	64	225	0.00E+00	7.04E-04	2.48E-03
Copper [a]	Seds	Commercial	Commercial	2.00E+01	low	0	92	215	0.00E+00	1.84E-03	4.30E-03
Copper [a]	Seds	Commercial	Commercial	3.00E+01	midpoint	0	92	215	0.00E+00	2.76E-03	6.45E-03
Copper [a]	Seds	Commercial	Commercial	5.00E+01	high	0	92	215	0.00E+00	4.60E-03	1.08E-02
Copper [b]	Seds	Industrial	Industrial	1.24E+01	low	0	148	340	0.00E+00	1.84E-03	4.22E-03
Copper [a]	Seds	Industrial	Industrial	2.00E+01	low	0	148	340	0.00E+00	2.96E-03	6.80E-03
Copper [a]	Seds	Industrial	Industrial	6.50E+01	midpoint	0	148	340	0.00E+00	9.62E-03	2.21E-02
Copper [a]	Seds	Industrial	Industrial	1.10E+02	high	0	148	340	0.00E+00	1.63E-02	3.74E-02
Copper [b]	Seds	Industrial	Industrial	1.04E+03	midpoint	0	148	340	0.00E+00	1.54E-01	3.53E-01
Copper [b]	Seds	Industrial	Industrial	1.32E+04	high	0	148	340	0.00E+00	1.95E+00	4.49E+00

Table D3-7. Stormwater Sediment Trap Data for Organic Chemicals and Extrapolated Water Concentrations Based on NSQD (Table D3-4) Database and ACWA (Table D3-5) TSS Values.

		Data Sources and Values				Extrapolation to Water Concentration (mg/L)					
						TSS (mg/L) (NSQD+ACWA)			Water Conc. (mg/L)		
Analyte	Method	Actual Landuse	Categorized Landuse	Conc. (mg/kg)	Type	Low	Med	High	Low	Med	High
Copper [a]	Seds	Commercial/Residential	Mixed Use	3.00E+01	low	0	78	277	0.00E+00	2.34E-03	8.31E-03
Copper [a]	Seds	Commercial/Residential	Mixed Use	3.50E+01	midpoint	0	78	277	0.00E+00	2.73E-03	9.70E-03
Copper [a]	Seds	Commercial/Residential	Mixed Use	4.00E+01	high	0	78	277	0.00E+00	3.12E-03	1.11E-02
Copper [a]	Seds	Undeveloped	Parks/Open	2.00E+01	low	0	58	194	0.00E+00	1.16E-03	3.88E-03
Copper [a]	Seds	Undeveloped	Parks/Open	2.50E+01	midpoint	0	58	194	0.00E+00	1.45E-03	4.85E-03
Copper [a]	Seds	Undeveloped	Parks/Open	3.00E+01	high	0	58	194	0.00E+00	1.74E-03	5.82E-03
Copper [a]	Seds	Residential	Residential	2.00E+01	low	0	64	225	0.00E+00	1.28E-03	4.50E-03
Copper [a]	Seds	Residential	Residential	4.00E+01	midpoint	0	64	225	0.00E+00	2.56E-03	9.00E-03
Copper [a]	Seds	Residential	Residential	5.00E+01	high	0	64	225	0.00E+00	3.20E-03	1.13E-02
Lead [a]	Seds	Commercial	Commercial	1.00E+01	low	0	92	215	0.00E+00	9.20E-04	2.15E-03
Lead [a]	Seds	Commercial	Commercial	4.00E+01	midpoint	0	92	215	0.00E+00	3.68E-03	8.60E-03
Lead [c]	Seds	High Density Commercial	Commercial	7.70E+01	single	0	92	215	0.00E+00	7.08E-03	1.66E-02
Lead [a]	Seds	Commercial	Commercial	1.50E+02	high	0	92	215	0.00E+00	1.38E-02	3.23E-02
Lead [c]	Seds	Industrial	Industrial	1.90E+00	single	0	148	340	0.00E+00	2.81E-04	6.46E-04
Lead [b]	Seds	Industrial	Industrial	2.36E+00	low	0	148	340	0.00E+00	3.49E-04	8.02E-04
Lead [a]	Seds	Industrial	Industrial	2.00E+01	low	0	148	340	0.00E+00	2.96E-03	6.80E-03
Lead [a]	Seds	Industrial	Industrial	6.00E+01	midpoint	0	148	340	0.00E+00	8.88E-03	2.04E-02
Lead [c]	Seds	Mixed Industrial Commerical	Industrial	1.10E+02	low	0	148	340	0.00E+00	1.63E-02	3.74E-02
Lead [c]	Seds	Mixed Industrial Commerical	Industrial	1.40E+02	high	0	148	340	0.00E+00	2.07E-02	4.76E-02
Lead [b]	Seds	Industrial	Industrial	1.41E+02	midpoint	0	148	340	0.00E+00	2.09E-02	4.79E-02
Lead [c]	Seds	Industrial	Industrial	1.90E+02	single	0	148	340	0.00E+00	2.81E-02	6.46E-02
Lead [a]	Seds	Industrial	Industrial	2.20E+02	high	0	148	340	0.00E+00	3.26E-02	7.48E-02
Lead [b]	Seds	Industrial	Industrial	6.70E+02	high	0	148	340	0.00E+00	9.92E-02	2.28E-01
Lead [a]	Seds	Commercial/Residential	Mixed Use	2.00E+01	low	0	78	277	0.00E+00	1.56E-03	5.54E-03
Lead [a]	Seds	Commercial/Residential	Mixed Use	4.00E+01	midpoint	0	78	277	0.00E+00	3.12E-03	1.11E-02
Lead [a]	Seds	Commercial/Residential	Mixed Use	7.00E+01	high	0	78	277	0.00E+00	5.46E-03	1.94E-02
Lead [a]	Seds	Undeveloped	Parks/Open	1.00E+01	low	0	58	194	0.00E+00	5.80E-04	1.94E-03
Lead [a]	Seds	Undeveloped	Parks/Open	3.00E+01	midpoint	0	58	194	0.00E+00	1.74E-03	5.82E-03

Table D3-7. Stormwater Sediment Trap Data for Organic Chemicals and Extrapolated Water Concentrations Based on NSQD (Table D3-4) Database and ACWA (Table D3-5) TSS Values.

		Data Sources and Values				Extrapolation to Water Concentration (mg/L)					
						TSS (mg/L) (NSQD+ACWA)			Water Conc. (mg/L)		
Analyte	Method	Actual Landuse	Categorized Landuse	Conc. (mg/kg)	Type	Low	Med	High	Low	Med	High
Lead [a]	Seds	Undeveloped	Parks/Open	3.50E+01	high	0	58	194	0.00E+00	2.03E-03	6.79E-03
Lead [a]	Seds	Residential	Residential	1.00E+01	low	0	64	225	0.00E+00	6.40E-04	2.25E-03
Lead [a]	Seds	Residential	Residential	4.00E+01	midpoint	0	64	225	0.00E+00	2.56E-03	9.00E-03
Lead [a]	Seds	Residential	Residential	8.00E+01	high	0	64	225	0.00E+00	5.12E-03	1.80E-02
Mercury [c]	Seds	High Density Commercial	Commercial	2.10E-02	low	0	92	215	0.00E+00	1.93E-06	4.52E-06
Mercury [a]	Seds	Commercial	Commercial	4.00E-02	low	0	92	215	0.00E+00	3.68E-06	8.60E-06
Mercury [a]	Seds	Commercial	Commercial	5.00E-02	midpoint	0	92	215	0.00E+00	4.60E-06	1.08E-05
Mercury [c]	Seds	High Density Commercial	Commercial	1.90E-01	high	0	92	215	0.00E+00	1.75E-05	4.09E-05
Mercury [a]	Seds	Commercial	Commercial	2.50E-01	high	0	92	215	0.00E+00	2.30E-05	5.38E-05
Mercury [b]	Seds	Industrial	Industrial	1.00E-02	low	0	148	340	0.00E+00	1.48E-06	3.40E-06
Mercury [a]	Seds	Industrial	Industrial	4.00E-02	low	0	148	340	0.00E+00	5.92E-06	1.36E-05
Mercury [a]	Seds	Industrial	Industrial	5.00E-02	midpoint	0	148	340	0.00E+00	7.40E-06	1.70E-05
Mercury [c]	Seds	Mixed Industrial Commerical	Industrial	1.10E-01	low	0	148	340	0.00E+00	1.63E-05	3.74E-05
Mercury [b]	Seds	Industrial	Industrial	1.30E-01	midpoint	0	148	340	0.00E+00	1.92E-05	4.42E-05
Mercury [c]	Seds	Mixed Industrial Commerical	Industrial	1.50E-01	high	0	148	340	0.00E+00	2.22E-05	5.10E-05
Mercury [b]	Seds	Industrial	Industrial	3.40E-01	high	0	148	340	0.00E+00	5.03E-05	1.16E-04
Mercury [a]	Seds	Industrial	Industrial	4.00E-01	high	0	148	340	0.00E+00	5.92E-05	1.36E-04
Mercury [a]	Seds	Commercial/Residential	Mixed Use	4.00E-02	low	0	78	277	0.00E+00	3.12E-06	1.11E-05
Mercury [a]	Seds	Commercial/Residential	Mixed Use	5.00E-02	midpoint	0	78	277	0.00E+00	3.90E-06	1.39E-05
Mercury [a]	Seds	Commercial/Residential	Mixed Use	5.00E-02	high	0	78	277	0.00E+00	3.90E-06	1.39E-05
Mercury [a]	Seds	Undeveloped	Parks/Open	4.00E-02	low	0	58	194	0.00E+00	2.32E-06	7.76E-06
Mercury [a]	Seds	Undeveloped	Parks/Open	5.00E-02	midpoint	0	58	194	0.00E+00	2.90E-06	9.70E-06
Mercury [a]	Seds	Undeveloped	Parks/Open	5.00E-02	high	0	58	194	0.00E+00	2.90E-06	9.70E-06
Mercury [a]	Seds	Residential	Residential	4.00E-02	low	0	64	225	0.00E+00	2.56E-06	9.00E-06
Mercury [a]	Seds	Residential	Residential	5.00E-02	midpoint	0	64	225	0.00E+00	3.20E-06	1.13E-05
Mercury [a]	Seds	Residential	Residential	5.00E-02	high	0	64	225	0.00E+00	3.20E-06	1.13E-05
Zinc [a]	Seds	Commercial	Commercial	4.00E+01	low	0	92	215	0.00E+00	3.68E-03	8.60E-03
Zinc [a]	Seds	Commercial	Commercial	7.00E+01	midpoint	0	92	215	0.00E+00	6.44E-03	1.51E-02

Table D3-7. Stormwater Sediment Trap Data for Organic Chemicals and Extrapolated Water Concentrations Based on NSQD (Table D3-4) Database and ACWA (Table D3-5) TSS Values.

		Data Sources and Values				Extrapolation to Water Concentration (mg/L)					
						TSS (mg/L) (NSQD+ACWA)			Water Conc. (mg/L)		
Analyte	Method	Actual Landuse	Categorized Landuse	Conc. (mg/kg)	Type	Low	Med	High	Low	Med	High
Zinc [c]	Seds	High Density Commercial	Commercial	9.90E+01	low	0	92	215	0.00E+00	9.11E-03	2.13E-02
Zinc [c]	Seds	High Density Commercial	Commercial	4.20E+02	high	0	92	215	0.00E+00	3.86E-02	9.03E-02
Zinc [a]	Seds	Commercial	Commercial	5.50E+02	high	0	92	215	0.00E+00	5.06E-02	1.18E-01
Zinc [b]	Seds	Industrial	Industrial	1.21E+01	low	0	148	340	0.00E+00	1.79E-03	4.11E-03
Zinc [a]	Seds	Industrial	Industrial	5.00E+01	low	0	148	340	0.00E+00	7.40E-03	1.70E-02
Zinc [a]	Seds	Industrial	Industrial	2.20E+02	midpoint	0	148	340	0.00E+00	3.26E-02	7.48E-02
Zinc [c]	Seds	Mixed Industrial Commerical	Industrial	2.60E+02	low	0	148	340	0.00E+00	3.85E-02	8.84E-02
Zinc [c]	Seds	Mixed Industrial Commerical	Industrial	3.40E+02	high	0	148	340	0.00E+00	5.03E-02	1.16E-01
Zinc [a]	Seds	Industrial	Industrial	4.40E+02	high	0	148	340	0.00E+00	6.51E-02	1.50E-01
Zinc [c]	Seds	Industrial	Industrial	7.40E+02	single	0	148	340	0.00E+00	1.10E-01	2.52E-01
Zinc [b]	Seds	Industrial	Industrial	1.71E+03	midpoint	0	148	340	0.00E+00	2.53E-01	5.81E-01
Zinc [b]	Seds	Industrial	Industrial	1.73E+04	high	0	148	340	0.00E+00	2.56E+00	5.88E+00
Zinc [a]	Seds	Commercial/Residential	Mixed Use	1.00E+02	low	0	78	277	0.00E+00	7.80E-03	2.77E-02
Zinc [a]	Seds	Commercial/Residential	Mixed Use	1.30E+02	midpoint	0	78	277	0.00E+00	1.01E-02	3.60E-02
Zinc [a]	Seds	Commercial/Residential	Mixed Use	2.50E+02	high	0	78	277	0.00E+00	1.95E-02	6.93E-02
Zinc [a]	Seds	Undeveloped	Parks/Open	4.50E+01	low	0	58	194	0.00E+00	2.61E-03	8.73E-03
Zinc [a]	Seds	Undeveloped	Parks/Open	5.00E+01	midpoint	0	58	194	0.00E+00	2.90E-03	9.70E-03
Zinc [a]	Seds	Undeveloped	Parks/Open	5.50E+01	high	0	58	194	0.00E+00	3.19E-03	1.07E-02
Zinc [a]	Seds	Residential	Residential	5.00E+01	low	0	64	225	0.00E+00	3.20E-03	1.13E-02
Zinc [a]	Seds	Residential	Residential	1.00E+02	midpoint	0	64	225	0.00E+00	6.40E-03	2.25E-02
Zinc [a]	Seds	Residential	Residential	3.00E+02	high	0	64	225	0.00E+00	1.92E-02	6.75E-02
PCBs											
PCBs [a]	Seds	Commercial	Commercial	1.00E-02	low	0	92	215	0.00E+00	9.20E-07	2.15E-06
PCBs [a]	Seds	Commercial	Commercial	1.00E-02	midpoint	0	92	215	0.00E+00	9.20E-07	2.15E-06
PCBs [a]	Seds	Commercial	Commercial	1.00E-01	high	0	92	215	0.00E+00	9.20E-06	2.15E-05
PCBs [b]	Seds	Industrial	Industrial	9.90E-03	low	0	148	340	0.00E+00	1.47E-06	3.37E-06
PCBs [a]	Seds	Industrial	Industrial	1.00E-02	low	0	148	340	0.00E+00	1.48E-06	3.40E-06
PCBs [a]	Seds	Industrial	Industrial	1.00E-02	midpoint	0	148	340	0.00E+00	1.48E-06	3.40E-06

Table D3-7. Stormwater Sediment Trap Data for Organic Chemicals and Extrapolated Water Concentrations Based on NSQD (Table D3-4) Database and ACWA (Table D3-5) TSS Values.

		Data Sources and Values				Extrapolation to Water Concentration (mg/L)					
						TSS (mg/L) (NSQD+ACWA)			Water Conc. (mg/L)		
Analyte	Method	Actual Landuse	Categorized Landuse	Conc. (mg/kg)	Type	Low	Med	High	Low	Med	High
PCBs [a]	Seds	Industrial	Industrial	3.00E-01	high	0	148	340	0.00E+00	4.44E-05	1.02E-04
PCBs [b]	Seds	Industrial	Industrial	4.24E-01	midpoint	0	148	340	0.00E+00	6.28E-05	1.44E-04
PCBs [b]	Seds	Industrial	Industrial	2.49E+00	high	0	148	340	0.00E+00	3.69E-04	8.47E-04
PCBs [a]	Seds	Commercial/Residential	Mixed Use	1.00E-02	low	0	78	277	0.00E+00	7.80E-07	2.77E-06
PCBs [a]	Seds	Commercial/Residential	Mixed Use	1.00E-02	midpoint	0	78	277	0.00E+00	7.80E-07	2.77E-06
PCBs [a]	Seds	Commercial/Residential	Mixed Use	1.00E-02	high	0	78	277	0.00E+00	7.80E-07	2.77E-06
PCBs [a]	Seds	Undeveloped	Parks/Open	1.00E-02	low	0	58	194	0.00E+00	5.80E-07	1.94E-06
PCBs [a]	Seds	Undeveloped	Parks/Open	1.00E-02	midpoint	0	58	194	0.00E+00	5.80E-07	1.94E-06
PCBs [a]	Seds	Undeveloped	Parks/Open	1.00E-02	high	0	58	194	0.00E+00	5.80E-07	1.94E-06
PCBs [a]	Seds	Residential	Residential	1.00E-02	low	0	64	225	0.00E+00	6.40E-07	2.25E-06
PCBs [a]	Seds	Residential	Residential	1.00E-02	midpoint	0	64	225	0.00E+00	6.40E-07	2.25E-06
PCBs [a]	Seds	Residential	Residential	2.00E+00	high	0	64	225	0.00E+00	1.28E-04	4.50E-04
Pesticides											
DDTs [c]	Seds	High Density Commercial	Commercial	4.00E-03	low	0	92	215	0.00E+00	3.68E-07	8.60E-07
DDTs [a]	Seds	Commercial	Commercial	1.00E-02	low	0	92	215	0.00E+00	9.20E-07	2.15E-06
DDTs [a]	Seds	Commercial	Commercial	1.00E-02	midpoint	0	92	215	0.00E+00	9.20E-07	2.15E-06
DDTs [a]	Seds	Commercial	Commercial	3.00E-02	high	0	92	215	0.00E+00	2.76E-06	6.45E-06
DDTs [c]	Seds	High Density Commercial	Commercial	3.20E-01	high	0	92	215	0.00E+00	2.94E-05	6.88E-05
DDTs [c]	Seds	Mixed Industrial Commerical	Industrial	4.00E-03	mean	0	148	340	0.00E+00	5.92E-07	1.36E-06
DDTs [a]	Seds	Industrial	Industrial	1.00E-02	low	0	148	340	0.00E+00	1.48E-06	3.40E-06
DDTs [a]	Seds	Industrial	Industrial	1.00E-02	midpoint	0	148	340	0.00E+00	1.48E-06	3.40E-06
DDTs [a]	Seds	Industrial	Industrial	4.00E-02	high	0	148	340	0.00E+00	5.92E-06	1.36E-05
DDTs [a]	Seds	Commercial/Residential	Mixed Use	1.00E-02	low	0	78	277	0.00E+00	7.80E-07	2.77E-06
DDTs [a]	Seds	Commercial/Residential	Mixed Use	1.00E-02	midpoint	0	78	277	0.00E+00	7.80E-07	2.77E-06
DDTs [a]	Seds	Commercial/Residential	Mixed Use	3.00E-01	high	0	78	277	0.00E+00	2.34E-05	8.31E-05
DDTs [a]	Seds	Undeveloped	Parks/Open	1.00E-02	low	0	58	194	0.00E+00	5.80E-07	1.94E-06
DDTs [a]	Seds	Undeveloped	Parks/Open	1.00E-02	midpoint	0	58	194	0.00E+00	5.80E-07	1.94E-06
DDTs [a]	Seds	Undeveloped	Parks/Open	1.00E-02	high	0	58	194	0.00E+00	5.80E-07	1.94E-06

Table D3-7. Stormwater Sediment Trap Data for Organic Chemicals and Extrapolated Water Concentrations Based on NSQD (Table D3-4) Database and ACWA (Table D3-5) TSS Values.

		Data Sources and Values				Extrapolation to Water Concentration (mg/L)					
						TSS (mg/L) (NSQD+ACWA)			Water Conc. (mg/L)		
Analyte	Method	Actual Landuse	Categorized Landuse	Conc. (mg/kg)	Type	Low	Med	High	Low	Med	High
DDTs [a]	Seds	Residential	Residential	1.00E-02	low	0	64	225	0.00E+00	6.40E-07	2.25E-06
DDTs [a]	Seds	Residential	Residential	1.00E-02	midpoint	0	64	225	0.00E+00	6.40E-07	2.25E-06
DDTs [a]	Seds	Residential	Residential	1.00E-02	high	0	64	225	0.00E+00	6.40E-07	2.25E-06
PAHs											
PAHs [c]	Seds	High Density Commercial	Commercial	4.41E+00	low	0	92	215	0.00E+00	4.06E-04	9.48E-04
PAHs [c]	Seds	High Density Commercial	Commercial	1.57E+02	high	0	92	215	0.00E+00	1.44E-02	3.38E-02
PAHs [b]	Seds	Industrial	Industrial	7.30E-02	low	0	148	340	0.00E+00	1.08E-05	2.48E-05
PAHs [b]	Seds	Industrial	Industrial	1.51E+01	midpoint	0	148	340	0.00E+00	2.24E-03	5.15E-03
PAHs [c]	Seds	Mixed Industrial Commerical	Industrial	3.72E+01	low	0	148	340	0.00E+00	5.51E-03	1.26E-02
PAHs [c]	Seds	Mixed Industrial Commerical	Industrial	6.44E+01	high	0	148	340	0.00E+00	9.53E-03	2.19E-02
PAHs [b]	Seds	Industrial	Industrial	3.00E+02	high	0	148	340	0.00E+00	4.43E-02	1.02E-01
PAHs [c]	Seds	Industrial	Industrial	2.06E+04	single	0	148	340	0.00E+00	3.05E+00	7.00E+00
Phthalates											
B2EHP [c]	Seds	High Density Commercial	Commercial	9.30E-01	low	0	92	215	0.00E+00	8.56E-05	2.00E-04
B2EHP [c]	Seds	High Density Commercial	Commercial	9.60E+01	high	0	92	215	0.00E+00	8.83E-03	2.06E-02
B2EHP [c]	Seds	Mixed Industrial Commerical	Industrial	6.70E+00	low	0	148	340	0.00E+00	9.92E-04	2.28E-03
B2EHP [b]	Seds	Industrial	Industrial	1.06E+01	low	0	148	340	0.00E+00	1.57E-03	3.60E-03
B2EHP [c]	Seds	Industrial	Industrial	1.70E+01	single	0	148	340	0.00E+00	2.52E-03	5.78E-03
B2EHP [c]	Seds	Mixed Industrial Commerical	Industrial	2.70E+01	high	0	148	340	0.00E+00	4.00E-03	9.18E-03
B2EHP [b]	Seds	Industrial	Industrial	4.84E+01	midpoint	0	148	340	0.00E+00	7.17E-03	1.65E-02
B2EHP [b]	Seds	Industrial	Industrial	1.72E+02	high	0	148	340	0.00E+00	2.55E-02	5.85E-02
BBP [c]	Seds	High Density Commercial	Commercial	5.20E-02	low	0	92	215	0.00E+00	4.78E-06	1.12E-05
BBP [c]	Seds	High Density Commercial	Commercial	8.80E+00	high	0	92	215	0.00E+00	8.10E-04	1.89E-03
BBP [c]	Seds	Mixed Industrial Commerical	Industrial	1.00E+00	low	0	148	340	0.00E+00	1.48E-04	3.40E-04
BBP [c]	Seds	Mixed Industrial Commerical	Industrial	3.00E+00	high	0	148	340	0.00E+00	4.44E-04	1.02E-03
BBP [c]	Seds	Industrial	Industrial	3.40E+00	single	0	148	340	0.00E+00	5.03E-04	1.16E-03
DNBP [c]	Seds	High Density Commercial	Commercial	9.60E-02	low	0	92	215	0.00E+00	8.83E-06	2.06E-05
DNBP [c]	Seds	High Density Commercial	Commercial	6.90E+00	high	0	92	215	0.00E+00	6.35E-04	1.48E-03

Table D3-7. Stormwater Sediment Trap Data for Organic Chemicals and Extrapolated Water Concentrations Based on NSQD (Table D3-4) Database and ACWA (Table D3-5) TSS Values.

		Data Sources and Values				Extrapolation to Water Concentration (mg/L)					
						TSS (mg/L) (NSQD+ACWA)			Water Conc. (mg/L)		
Analyte	Method	Actual Landuse	Categorized Landuse	Conc. (mg/kg)	Type	Low	Med	High	Low	Med	High
DNBP [c]	Seds	Mixed Industrial Commerical	Industrial	2.70E-01	low	0	148	340	0.00E+00	4.00E-05	9.18E-05
DNBP [c]	Seds	Industrial	Industrial	4.40E+00	single	0	148	340	0.00E+00	6.51E-04	1.50E-03
DNBP [c]	Seds	Mixed Industrial Commerical	Industrial	5.40E+00	high	0	148	340	0.00E+00	7.99E-04	1.84E-03
DNBP [b]	Seds	Industrial	Industrial	2.36E+01	low	0	148	340	0.00E+00	3.49E-03	8.02E-03
DNBP [b]	Seds	Industrial	Industrial	3.48E+01	midpoint	0	148	340	0.00E+00	5.15E-03	1.18E-02
DNBP [b]	Seds	Industrial	Industrial	5.59E+01	high	0	148	340	0.00E+00	8.27E-03	1.90E-02

Notes:

[a]Parker, J.T.C., K.D. Fossum, and T.L. Ingersoll. 2000. Chemical Characteristics of Urban Stormwater Sediments and Implications for Environmental Management, Maricopa County, Arizona. Environmental Management 26(1):99-115.

[b]City of Portland. 2005. 2000-2004 Catch Basin Solids Data Summary Memorandum. Prepared for Dawn Sanders, City of Portland. Prepared by David Lacey, Jennifer Sellers, and Lyndsey Maxwell, CH2MHill. City of Portland Bureau of Environmental Services, Portland, OR.

[c]Norton, D. 1998. 1998 Sediment Trap Monitoring of Suspended Particulates in Stormwater Discharges to Thea Foss Waterway. Washington State Department of Ecology Report #98-336. Olympia, Washington

Table D4-1. Groundwater Flow Zone Areas and Estimated Flow Rates.

Site Name	Flow Zone ID	Flow Zone Type	Mean Measured Seepage Rate (q_{mean}, cm/d)[a]	Max Measured Seepage Rate (q_{max}, cm/d)	Flow Zone Subdivision ID	TZW Sample Location	Flow Zone Subdivision Area (A, ft^2)	Mean Calculated Flow (Q_{mean}, ft^3/yr)[b]	Max Calculated Flow (Q_{max}, ft^3/yr)[b]
ARCO	ARCO1	Groundwater Discharge Zone	5.3	5.3	ARCO1-A	AR01A	6557	416157	416157
					ARCO1-B	AR02A	6804	431834	431834
	ARCO2	Low-To-No Groundwater Discharge Zone	0.5	0.6	ARCO2-A	AR04B	51876	310622	372747
					ARCO2-B	R2AR01	34173	204624	245549
					ARCO2-C	R2AR02	34684	207680	249216
					ARCO2-D	ARC03B-PS	11408	68311	81973
					ARCO2-E	ARC06B-PS	12129	72627	87153
					ARCO2-F	R2AR03	18368	109986	131983
					ARCO2-G	R2AR04	3222	19290	23148
					ARCO2-H	ARC02B-PS	39419	236034	283240
	ARCO3	Groundwater Discharge Zone	14.20	14.20	ARCO3-A	ns[c]	1894	322113	322113
Arkema	ARK1	Low-To-No Groundwater Discharge Zone	0.1[d]	0.1[d]	ARK1-A	AP04D-PS	52402	62755	62755
					ARK1-B	CP08D-PS	25499	30537	30537
					ARK1-C	CP09D	13982	16744	16744
	ARK2	Nearshore Groundwater Discharge Zone	3.13	7	ARK2-A	AP02A	6410	240258	537317
					ARK2-B	AP03A	16046	601477	1345155
					ARK2-C	CP06A	10002	374913	838463
					ARK2-D	CP07A	4797	179823	402160
					ARK2-E	CP07B	2190	82072	183548
					ARK2-F	CP08B	6222	233242	521627
					ARK2-G	CP09A	2210	82827	185237
	ARK3	Variable Groundwater Discharge Zone (Lower Rate)	1.27	3.1	ARK3-B	AP02D	16928	256782	628441
					ARK3-C	AP03D-p	4931	74793	183047
					ARK3-D	AP03D-t	2022	30667	75053
					ARK3-E	AP03B-PS	3410	51731	126604
					ARK3-F	R2AP01	6810	103297	252806
					ARK3-G	AP04B-PS	1918	29092	71199
					ARK3-H	AP04C	5671	86022	210527
					ARK3-I	R2AP02	12300	186579	456627
					ARK3-J	CP06C-PS	7960	120741	295499
					ARK3-K	R2CP01	3474	52698	128972
					ARK3-L	CP07B-PS	3436	52118	127552
					ARK3-M	CP07D	5816	88228	215927
ExxonMobil	EM1	Groundwater Discharge Zone (Lower Flow Rate)	1.2	1.2	EM1-A	EM02C	12821	184246	184246
					EM1-B	EM04C	10917	156890	156890
					EM1-C	EM06B	19978	287092	287092
	EM2	Interpreted Groundwater Discharge Zone	6.2	9.8	EM2-A	EM01A	2268	168381	266151
					EM2-B	EM02A	1990	147768	233569
					EM2-C	EM03A	2291	170141	268932
					EM2-D	EM04A	2182	162040	256128
					EM2-E	EM05A	4310	319990	505790
	EM3	Low-To-No Groundwater Discharge Zone	0.1[d]	0.1[d]	EM3-A	R2EM01	107259	128450	128450
	EM4	Interpreted Groundwater Discharge Zone	6.2[e]	9.8[e]	EM4-A	EM08A	2316	171930	271760

Table D4-1. Groundwater Flow Zone Areas and Estimated Flow Rates.

Site Name	Flow Zone ID	Flow Zone Type	Mean Measured Seepage Rate (q_{mean}, cm/d)[a]	Max Measured Seepage Rate (q_{max}, cm/d)	Flow Zone Subdivision ID	TZW Sample Location	Flow Zone Subdivision Area (A, ft^2)	Mean Calculated Flow (Q_{mean}, ft^3/yr)[b]	Max Calculated Flow (Q_{max}, ft^3/yr)[b]
Gasco	GS1	Intermedate Indeterminate Zone	0.6[f]	1[f]	GS1-A	GS01B	37041	266153	443588
					GS1-B	GS02A	76066	546561	910935
					GS1-C	GS07D	55064	395660	659433
					GS1-D	GS08A	13057	93819	156365
	GS2	Possible Offshore Groundwater Discharge Zone	0.65[f]	1[f]	GS2-A	GS08D	320492	2494762	3838096
					GS2-B	GP41	29300	228073	350882
					GS2-C	GP54	7153	55681	85663
					GS2-D	GP73	4966	38654	59468
	GS3	Variable Nearshore Groundwater Discharge Zone	4.7	5.7	GS3-A	GS07B	53384	3004769	3644082
Gunderson	GN1	Groundwater Discharge Zone	1.3	1.3	GN1-A	GN04A	17344	270016	270016
					GN1-B	GN05A	22210	345765	345765
	GN2	Low-To-No Groundwater Discharge Zone	0.3	0.7	GN2-A	GN01E	69840	250914	585467
					GN2-B	R2GN01	62621	224977	524947
					GN2-C	GN02E	306359	1100656	2568196
					GN2-D	GN03A	86271	309945	723206
					GN2-E	GN04B	324220	1164823	2717920
Kinder Morgan	KM1	Groundwater Discharge Zone	4.8	4.8	KM1-A	R2KM01	2326	133721	133721
					KM1-B	KM08A	5408	310859	310859
	KM2	Low-To-No Groundwater Discharge Zone	0.27	0.8	KM2-A	KM06A	130515	416800	1250399
					KM2-B	R2KM02-p	9355	29877	89630
					KM2-C	R2KM02-t	17090	54578	163733
					KM2-D	KM10A	12541	40050	120149
					KM2-E	KM11B	49095	156785	470356
Rhone Poulenc	RP1	Groundwater Discharge Zone	7.6	14	RP1-A	RP02E	8839	804460	1481900
					RP1-B	R2RP01	14108	1284012	2365285
					RP1-C	RP03C	15366	1398572	2576316
					RP1-D	RP03E	9486	863381	1590439
	RP2	Inferred Groundwater Discharge Zone Extension	0.7[h]	1.5[h]	RP2-A	ns[g]	55236	463043	992234
	RP3	Inferred Nearshore Groundwater Discharge Zone	4.4	4.4	RP3-A	R2RP02	53444	2816106	2816106
					RP3-B	R2RP03	55481	2923473	2923473
	RP4	Low-To-No Groundwater Discharge Zone	0.7	1.5	RP4-A	RP07E	287671	2411532	5167569
	RP5	Groundwater Discharge Zone	4.8	4.8	RP5-A	RP07B	28351	1629729	1629729

Table D4-1. Groundwater Flow Zone Areas and Estimated Flow Rates.

Site Name	Flow Zone ID	Flow Zone Type	Mean Measured Seepage Rate (q_{mean}, cm/d)[a]	Max Measured Seepage Rate (q_{max}, cm/d)	Flow Zone Subdivision ID	TZW Sample Location	Flow Zone Subdivision Area (A, ft^2)	Mean Calculated Flow (Q_{mean}, ft^3/yr)[b]	Max Calculated Flow (Q_{max}, ft^3/yr)[b]
Siltronic	SL1	Low-To-No Groundwater Discharge Zone	0.25	0.3	SL1-A	SL01A	9351	27996	33596
					SL1-B	GP47	9523	28510	34212
					SL1-C	SL02A	7256	21725	26070
					SL1-D	SL03A	5783	17312	20775
					SL1-E	SL05A	21499	64366	77240
	SL2	Nearshore Groundwater Discharge Zone	10.5	10.5	SL2-A	GP46	21368	2686899	2686899
					SL2-B	SL04A	16268	2045651	2045651
	SL3	Offshore Groundwater Discharge Zone	4.25	5	SL3-A	SL01E	1003	51039	60046
					SL3-AA	SL02C	3573	181848	213939
					SL3-AB	SL02E	5226	265960	312895
					SL3-AC	SL03C	3888	197895	232818
					SL3-AD	SL03F	2333	118748	139703
					SL3-AE	GP42	3823	194600	228941
					SL3-AF	GP43	38530	1961036	2307101
					SL3-AG	GP44	16395	834426	981677
					SL3-AH	GP45	5741	292191	343755
					SL3-AI	GP48	4587	233450	274647
					SL3-AJ	GP56	2941	149668	176079
					SL3-AK	GP58	2308	117476	138207
					SL3-AL	SL04F	2756	140273	165027
					SL3-B	GP38	4506	229355	269829
					SL3-C	GP39	3358	170918	201080
					SL3-D	GP40	6303	320808	377421
					SL3-E	GP50	3635	184987	217631
					SL3-F	GP51	4101	208745	245583
					SL3-G	GP52	4066	206930	243447
					SL3-H	GP53	6623	337063	396544
					SL3-I	GP55	1963	99888	117515
					SL3-J	GP57	4698	239110	281306
					SL3-K	GP61	5566	283303	333297
					SL3-L	GP62	3266	166230	195565
					SL3-M	GP63	3014	153419	180493
					SL3-N	GP64	919	46794	55052
					SL3-O	GP66	828	42138	49574
					SL3-P	GP67	1783	90739	106752
					SL3-Q	GP68	1397	71107	83655
					SL3-R	GP69	3479	177071	208319
					SL3-S	GP70	3825	194675	229029
					SL3-T	GP71	6264	318834	375099
					SL3-U	GP75	5302	269858	317480
					SL3-V	GP76	1997	101652	119591
					SL3-W	GP80	2637	134211	157895
					SL3-X	GP81	1430	72775	85618
					SL3-Y	GP82	1834	93348	109821
					SL3-Z	GP84	3712	188911	222249

Table D4-1. Groundwater Flow Zone Areas and Estimated Flow Rates.

Site Name	Flow Zone ID	Flow Zone Type	Mean Measured Seepage Rate (q_{mean}, cm/d)[a]	Max Measured Seepage Rate (q_{max}, cm/d)	Flow Zone Subdivision ID	TZW Sample Location	Flow Zone Subdivision Area (A, ft^2)	Mean Calculated Flow (Q_{mean}, ft^3/yr)[b]	Max Calculated Flow (Q_{max}, ft^3/yr)[b]
Willbridge	W1	Groundwater Discharge Zone (Higher Flow Rate)	10.35	13.6	W1-A	W09A	13352	1654898	2174552
					W1-B	R2W02	22349	2770068	3639896
					W1-C	W12A	62749	7777621	10219870
	W2	Groundwater Discharge Zone (Lower Flow Rate)	3.13	3.9	W2-A	W04C	204730	7682236	9561932
					W2-B	W06A	8996	337545	420136
					W2-C	W07C	10159	381198	474470
					W2-D	W09C	71156	2670045	3323353
	W3	Low-To-No Groundwater Discharge Zone	0.4	0.4	W3-A	ns[i]	781726	3744669	3744669

Notes:

PS - Indicates location sampled during Round 2 GWPA Pilot Study (Integral 2004)

ns - Indicates no TZW samples were located in the zone identified by discharge mapping and other lines of evidence.

[a] Positive mean seepage rates measured with seepage meters in the GWPA Pilot Study (Integral 2004) and Round 2 SCSR (Integral 2006) were averaged.

[b] Calculated according to the following equation: Q (ft^3/yr) = q (cm/d) x A (ft^2) x 0.03281(ft/cm) x 365 (d/yr).

[c] TZW chemical data not available for this flow zone. Concentrations from sample location R2AR02 used.

[d] Seepage meter seepage rate not available for this flow zone. Lines of evidence suggest that very low-to-no flow occurs in these zones (see TZW SCSR, Integral 2006). Value of 0.1 cm/d assumed.

[e] Seepage meter seepage rate not available for this flow zone. Applied flow measurements for ExxonMobil nearshore flow zone EM2.

[f] Seepage meter GSC4E is located on the border between flow zones GS1 and GS2. GSC4E seepage rates used in mean and max flow rate estimates for both GS1 and GS2.

[g] TZW chemical data not available for this flow zone. Average of all Rhone Poulenc < 38 cm TZW concentrations applied for all analytes.

[h] Seepage meter seepage rate not available for this flow zone. Applied flow measurements for adjacent flow zone RP4 based on similar sediment texture.

[i] TZW chemical data not available for this flow zone. Average of all Willbridge flow zone W2 < 38 cm TZW concentrations applied for all analytes.

Table D4-2. Estimated Upland Groundwater Plume Loading to the Water Column.

Analyte	Peepers and Unfiltered Push Probe[a]		Peepers and Filtered Trident[b]	
	Load, Maximum Flow (kg/yr)	Load, Mean Flow (kg/yr)	Load, Maximum Flow (kg/yr)	Load, Mean Flow (kg/yr)
Conventionals				
Cyanide	629	383	n/a	n/a
Perchlorate	4.75E+03	2.09E+03	n/a	n/a
Metals				
Aluminum	9.81E+03	7.24E+03	2.78E+03	1.77E+03
Arsenic	35.1	25.8	34.8	25.5
Barium	483	307	383	237
Cadmium	0.509	0.311	0.372	0.211
Copper	20.8	16.1	6.06	4.42
Iron	3.36E+04	2.70E+04	2.81E+04	2.19E+04
Lead	15.2	11.4	3.46	2.46
Manganese	1.08E+04	7.15E+03	1.05E+04	6.92E+03
Mercury	0.0437	0.0231	0.0561	0.0334
Silver	0.154	0.107	0.0601	0.0383
Sodium	1.09E+06	5.27E+05	1.12E+06	5.36E+05
Zinc	71.9	53.7	35.1	26.0
Pesticides				
2,4'-DDD	0.0509	0.0232	0.0324	0.0148
2,4'-DDT	4.53E-03	2.10E-03	6.00E-04	3.24E-04
4,4'-DDD	0.0572	0.0247	0.0236	9.67E-03
4,4'-DDE	6.99E-03	3.21E-03	6.93E-06	6.93E-06
4,4'-DDT	0.0913	0.0406	1.71E-05	1.71E-05
Total of 2,4' and 4,4'-DDD	0.108	0.0479	0.0560	0.0245
Total of 2,4' and 4,4'-DDE	6.99E-03	3.21E-03	6.93E-06	6.93E-06
Total of 2,4' and 4,4'-DDT	9.59E-02	4.27E-02	6.17E-04	3.41E-04
Total of 2,4' and 4,4'-DDD, -DDE, -DDT	0.211	0.0938	5.67E-02	2.48E-02
Polycyclic Aromatic Hydrocarbons				
2-Methylnaphthalene	11.1	8.68	10.7	8.48
Acenaphthene	32.5	25.7	27.4	21.9
Anthracene	2.32	1.85	1.93	1.57
Benzo(a)anthracene	0.663	0.520	0.310	0.251
Benzo(a)pyrene	0.726	0.576	0.630	0.515
Benzo(b)fluoranthene	0.526	0.417	0.464	0.379
Benzo(g,h,i)perylene	0.568	0.447	0.469	0.384
Benzo(k)fluoranthene	0.309	0.241	0.249	0.204
Chrysene	0.815	0.642	0.705	0.576
Dibenzo(a,h)anthracene	0.396	0.303	0.0341	0.0277
Fluoranthene	4.26	3.35	3.31	2.69
Fluorene	9.98	8.07	7.90	6.39
Indeno(1,2,3-cd)pyrene	0.449	0.353	0.366	0.301
Naphthalene	727	595	726	595
Phenanthrene	18.9	14.8	15.4	12.3
Pyrene	6.04	4.79	5.14	4.19
Total PAHs	817	666	801	655
Semivolatile Organic Compounds				
1,2-Dichlorobenzene	64.2	35.0	n/a	n/a
1,4-Dichlorobenzene	23.1	12.5	n/a	n/a

Table D4-2. Estimated Upland Groundwater Plume Loading to the Water Column.

Analyte	Peepers and Unfiltered Push Probe[a]		Peepers and Filtered Trident[b]	
	Load, Maximum Flow (kg/yr)	Load, Mean Flow (kg/yr)	Load, Maximum Flow (kg/yr)	Load, Mean Flow (kg/yr)
Volatile Organic Compounds				
1,1,2-Trichloroethane	1.31	0.547	n/a	n/a
1,2-Dichloroethane	2.81	1.16	n/a	n/a
Benzene	87.0	70.3	n/a	n/a
Bromodichloromethane	1.04	0.426	n/a	n/a
Carbon disulfide	11.4	6.86	n/a	n/a
Chlorobenzene	76.9	47.9	n/a	n/a
Chloroform	2.77E+03	3.54 [c]	n/a	n/a
cis-1,2-Dichloroethene	258	219	n/a	n/a
Ethylbenzene	15.0	12.1	n/a	n/a
Methylene chloride	1.86E+03	762	n/a	n/a
o-Xylene	7.54	6.05	n/a	n/a
Tetrachloroethene	5.18	2.12	n/a	n/a
Toluene	4.10	2.95	n/a	n/a
Total Xylenes	16.6	13.3	n/a	n/a
Trichloroethene	276	3.71 [c]	n/a	n/a
Vinyl chloride	39.2	32.7	n/a	n/a

Notes:

n/a Indicates that filtered Trident samples were not collected. Per sampling protocols filtered samples were not collected for VOCs. Additionally, filtered samples were not collected for ionic analytes cyanide and perchlorate.

[a] Push probe refers to samples collected by either Trident or GeoProbe samplers.

[b] Due to sample volume limitations, filtered Trident samples were not collected at all sample locations. To calculate loading rate estimates at these sample locations, the corresponding unfiltered Trident chemical concentrations were used.

[c] In recognition of significant uncertainty associated with the loading estimate for chloroform, the approach to estimation of the lower end of the loading rate estimate was modified. Note: No modifications were made to the approach for estimation of the upper range of the loading rate. The resulting larger range for the loading estimate better represents the associated uncertainty. Detailed discussion of this modification is provided in Appendix D.4.1.2.1.

Table D4-3. Summary of Hydrogeologic Information Gathered from the CSMs.

Site	Number of Wells	Aquifer Units Present	Groundwater Flow Direction	Depth to Groundwater (ft bgs)	Depth of Aquifer (ft bgs)	Saturated Thickness (ft)	Horizontal Gradient (avg - linear ft/ft)	Downward Vertical Gradient (potential)	Hydraulic Conductivity K (ft/day)	Transmissivity T (ft^2/day)	Average Linear Groundwater Velocity (ft/day)
ACF Industries #794	5	Fill and Alluvium	Northeast toward the Willamette River	5-10	-	1-13	0.04	-	-	-	-
Alder Creek #2446	-	-	-	-	-	-	-	-	-	-	-
Anderson Brothers #970	-	-	-	-	-	-	-	-	-	-	-
ARCO #1528	49[a]	Channel Deposit	East toward the Willamette River	-	-	-	0.01	-	33 - 100	1,800 - 3,200	-
		Fine-grained Alluvium	-	-	-	-	0.05	-	~0.5 - 2	-	-
		Sandy Alluvial Deposits	-	-	-	-	0.05	-	~1 - 2	-	-
Arkema #398	>50	Shallow Unconfined Alluvial	East-northeast in Acid Plant Area; East-southeast in Chlorate Plant Area	-	ground surface to 32	~20 (West); 10-15 (adjacent to the Willamette River)	0.0024 - 0.0069	-	1.2 - 34 (17 average)	-	-
	11	Intermediate Confined Alluvial	East-northeast in Acid Plant Area; East-southeast in Chlorate Plant Area	-	36 - 46	5 - 10	0.0038 - 0.0069	-	0.04 - 21 (5.8 average)	-	-
	1	Deep Confined Alluvial	East-northeast	-	40 - 45	-	-	-	0.3	-	-
	1	Columbia River Basalt Bedrock	Northeast	-	45 - >70	-	-	-	-	-	-
Babcock #2361	-	-	-	~25 (from adjacent site)	-	-	-	-	-	-	-
BES #2452	5 (40-42 ft bgs)	-	-	23-27	-	-	-	-	-	-	-
BNSF	-	-	Expected to flow North toward the Willamette River	-	-	-	-	-	-	-	-
Boydstun #2362	2 (1 MW and 1 temp well point)	-	-	26-28	15-20 (perched Groundwater zones)	-	low and variable	-	-	-	-
Burgard, Noncontiguous #none	-	Shallow Unconfined Dredge Fill and Alluvium	West toward the Willamette River	-	-	-	-	-	-	-	-
Calbag #2454	-	-	-	-	-	-	-	-	-	-	-
Cascade General #271	50 (push probe)	Fill and Upper Alluvial Deposit	Radially outward toward the Willamette River and Swan Island Lagoon	18-31	-	-	-	-	-	-	-
Chase Bag #2424	-	-	-	-	-	-	-	-	-	-	-
Chevron Asphalt	26	Upper Fill and Alluvial	North and northeast toward the Willamette River	4-17	-	-	-	-	-	-	-
	1 (Industrial water supply well, MULT 991)	Columbia River Basalt	-	27	70 to unknown	-	-	-	-	-	-
Christenson Oil #2426	-	-	-	-	-	-	-	-	-	-	-
Columbia American Plating #29	38 (Geoprobe to 15 ft.)	-	-	8-14	-	-	-	-	-	-	-

Table D4-3. Summary of Hydrogeologic Information Gathered from the CSMs.

Site	Number of Wells	Aquifer Units Present	Groundwater Flow Direction	Depth to Groundwater (ft bgs)	Depth of Aquifer (ft bgs)	Saturated Thickness (ft)	Horizontal Gradient (avg - linear ft/ft)	Downward Vertical Gradient (potential)	Hydraulic Conductivity K (ft/day)	Transmissivity T (ft^2/day)	Average Linear Groundwater Velocity (ft/day)
Consolidated Metco #3295	-	Sandy Alluvium/Sandy Dredge Fill	-	6-20	5-10 (thin elevated perched aquifers)	-	-	-	-	-	-
Crawford Street #2363	3	Recent Fill and Alluvium	-	29	-	-	-	-	-	-	-
Equilon #169	-	Upper Sand	North and East toward the Willamette River	8-12	ground surface to 20	-	Southwest: 0.02; near the Willamette River 0.002	-	-	-	-
Exxon #137	>55	Shallow Alluvial	Northeast toward the Willamette River, deflected by slurry wall to the North or South ends of property	-	-	-	0.03 - 0.04	-	~4	~43	0.56
	0[c]	Deep Alluvial[b]	-	-	-	-	-	-	-	-	-
Foss Brix #2364	7 (and a river staff gauge)	Shallow (Fill/Sand)	Northeast towards the Willamette River	-	-	-	Between upland and edge of Willamette River: 0.2; Upland: 0.014	-	-	-	-
Fred Devine # 2365	-	-	-	-	-	-	-	-	-	-	-
Freightliner TMP II #115	5 (screened 10-20 ft bgs)	Uppermost Waterbearing Zone (Fill Sand)	Westerly	7-14	20-25	-	0.009-0.01	-	-	-	-
	-	Alluvium (flood deposit)	-	-	up to 112	-	-	-	-	-	-
	?	Deeper Waterbearing Zone (water wells screened in this unit)	-	-	below 100	-	-	-	-	-	-
Freightliner #2366	?	Uppermost Waterbearing Zone - Fill below 10 ft	South to Southwest	10-17	-	-	-	-	-	-	-
Front Ave #1239	temporary well points only	Shallow Dredge Fill and Alluvial	-	18-35	ground surface to 40	-	-	-	-	-	-
	10	Surficial Fill Deposits	Northeasterly towards the Willamette River	-	2 - 30	2 -20	0.017	0.04 - 0.4	0.0067- 26 (3.9 average)	-	0.0007 - 2.6

Table D4-3. Summary of Hydrogeologic Information Gathered from the CSMs.

Site	Number of Wells	Aquifer Units Present	Groundwater Flow Direction	Depth to Groundwater (ft bgs)	Depth of Aquifer (ft bgs)	Saturated Thickness (ft)	Horizontal Gradient (avg - linear ft/ft)	Downward Vertical Gradient (potential)	Hydraulic Conductivity K (ft/day)	Transmissivity T (ft^2/day)	Average Linear Groundwater Velocity (ft/day)
Gasco #84	14	Alluvial	Northeast towards the Willamette River	-	30 - 200	-	0.016, 0.020 and 0.030 (toward the river) are typical for the central portion of the site, while gradients ranging from 0.001 (toward the river) to 0.0030 (to the south-southwest, away from the river)	–0.002 to -0.02 (upward) and between 0.002 and 0.008 (downward) between intermediate-depth Alluvial Waterbearing Zone well and deep Alluvial. A slight upward hydraulic gradient ranging from -0.0005 to –0.002 is typical between deep Alluvial Waterbearing Zone wells	0.79	-	0.07
	-	Combined Columbia River Basalt	-	-	258 (between two basalt layers)	-	-	-	-	-	-
GE Decommissioning #	6	Fill	North toward the Willamette River	10-13	-	-	0.003	-	-	-	-
Goldendale Aluminum #2440	8 (Geoprobe)	-	West toward the Willamette River	20-22	-	-	-	-	-	-	-
Gould #49	32	Shallow Dredge Fill and Alluvial	-	-	-	-	-	-	-	-	-
Georgia Pacific Linnton #2370	-	-	-	-	-	-	-	-	-	-	-
GS Roofing #117	14	-	East toward the Willamette River	8-22	-	-	-	-	-	-	-
Gunderson #1155	65	Shallow Sand/Silt Unit (Unconsolidated Sedimentary Aquifer)	North toward the Willamette River	-	Area 1: 30 to 40 ft. thick; Area 2: up to 160 ft. thick	-	-	-	1	-	-
	-	Detrital Gravel Zone	Northeast toward the Willamette River	-	Area 1: 35 ft; Area 2: 70 to 110 ft	-	0.025 (in Southeast) to 0.003 (in Northwest)	-0.011 (in vicinity of MW-50 (shallow) and MW-43 (deep)	100	-	-
	-	Gravelly Fractured Columbia River Basalt Zone	-	-	-	-	-	-	50	-	-
	-	Fractured Columbia River Basalt Zone	-	-	-	-	-	-	10	-	-
	-	Massive Columbia River Basalt Zone	-	-	-	-	-	-	0.1	-	-
	-	Vantage Horizon	-	-	92 (near the Willamette River)	-	-	-	5	-	-

Table D4-3. Summary of Hydrogeologic Information Gathered from the CSMs.

Site	Number of Wells	Aquifer Units Present	Groundwater Flow Direction	Depth to Groundwater (ft bgs)	Depth of Aquifer (ft bgs)	Saturated Thickness (ft)	Horizontal Gradient (avg - linear ft/ft)	Downward Vertical Gradient (potential)	Hydraulic Conductivity K (ft/day)	Transmissivity T (ft^2/day)	Average Linear Groundwater Velocity (ft/day)
Jefferson Smurfitt #2371	-	Dredge Fill overlaying Alluvium	On-site flow: West toward the Willamette River or South towards Slip; Regional flow: Northeast toward confuence of the Willamette River and Columbia River	7-18	-	-	-	-	-	-	-
Kinder Morgan #1096	32	Single Shallow Aquifer (screened at ~25 ft bgs)	-	-	-	-	-	-	19.4	-	-
Lakeside Industries #2372	5 (Gunderson wells)	-	Northeast toward the Willamette River	21-34	-	-	-	0.12 (based on shallow and deep wells)	-	-	-
Linnton Oil and Fire #1189	12 (Shallow)	-	Northeast towards the Willamette River (Spring); East (Fall)	1-5	-	-	-	-	horizontal: 0.004-0.01	-	-
Linnton Plywood #2373	13 (Deep)	Fill overlaying Alluvium	Towards the Willamette River	23-33	-	-	-	-	-	-	-
MarCom #2350	13	Shallow Fill	Expected toward the Willamette River	6-16	-	-	-	-	-	-	-
Marine Finance #2352	6 (7 temp well points)	Single unconfined (Fill and Quaternary Alluvial deposits)	Northeast toward the Willamette River	7 - 20	-	-	0.045	-	-	-	-
McCall Oil #134	20 shallow (2 piezometers; max depth 28 ft bgs)	Single unit in Dredge Fill and/or Alluvium	North toward the Willamette River	12 - 25	max ~75	-	-	-	0.0034-0.16	-	-
McCormick and Baxter #74	14	Shallow unconfined Sand Fill	South-Southwest toward the Willamette River	20 - 25	-	up to 30	0.006-0.005	-	-	-	-
McWhorter #135	-	-	-	10-17	-	-	-	-	-	-	-
NW Pipe #138	9	Shallow Unconfined Lower Dredge Fill and Alluvium	Northeast: West to Northwest; Southeast: South to Southwest; overall towards the Willamette River	-	30	-	0.001-0.0014	-	-	-	-
Olympic Pipeline #2374	-	Shallow Waterbearing Zone	Northeast to ExxonMobil and to the Willamette River	-	-	-		-	-	-	-
Oregon Steel Mills #141	23 (16 Upland, 7 Beach)	Upper - Dredge Fill and Native Alluvium	Eastern site: West-Southwest; Western site: West-Northwest	-	-	30-70	East: 0.002-0.009; West: 0.02-0.06	-	vertical: 0.0074 - 0.00019	-	-
Owens Corning #1036	6 (Shallow)	-	Northeast toward the Willamette River	8-21	-	-	-	-	-	-	-

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Site	Number of Wells	Aquifer Units Present	Groundwater Flow Direction	Depth to Groundwater (ft bgs)	Depth of Aquifer (ft bgs)	Saturated Thickness (ft)	Horizontal Gradient (avg - linear ft/ft)	Downward Vertical Gradient (potential)	Hydraulic Conductivity K (ft/day)	Transmissivity T (ft^2/day)	Average Linear Groundwater Velocity (ft/day)
Port Terminal 1 North	-	Four units: Fill and fine grained Pleistocene flood and Recent Alluvial Facies; the Lower Troutdale/Sandy River Mudstone; and Columbia River Basalt	East to Northeast toward the Willamette River and Slip 2	-	-	-	-	-	-	-	-
Port Terminal 1 South #2642	112 (push probes to max of 80 ft.), 7 MW (for GW analysis)	Three zones: Shallow unconfined Fill/Alluvial deposits; Generally confined Troutdale; Columbia River Basalt	Northeast toward the Willamette River	23	-	-	-	-	-	-	-
Port Terminal 2 #2769	9 (Geoprobe)	Sand and Silty Sand	-	21-22 (1998); 29-36 (2000)	-	-	-	-	-	-	-
Port Terminal 4, Auto Storage	53 (borings, probes, monitoring wells)	Sand Fill overlying Alluvial deposits	Toward the Willamette River	-	-	-	-	-	-	-	-
Port Terminal 4, Slip 1	Soil borings and monitoring wells <40 ft and well clusters	Fill Unit (10-35 ft thick) Alluvial unit (65-125 ft thick)	Toward the Willamette River, Slip 1, or Slip 3	8-30 (Fill and upper alluvial units)	-	-	0.01, decreasing to 0.001 in Eastern portion of facility	-	-	-	-
	-	Troutdale formation	-	-	85-150	-	-	-	-	-	-
Port of Portland, Terminal 4, Slip 3 #272	50	-	West portion of site: toward the Willamette River; Eastern portion of site: Variable, flows away from the Willamette River to North or to South	12-23	-	-	0.01 (at head of Slip 3)	-	Sandy Fill: 28.4; Silt: 0.57	-	2
Portland Container #2375	-	Perched Zones	-	-	15-20	-	Low and variable	-	-	-	-
Premier Edible Oils #2013	14	Shallow Fill	Southwest toward the Willamette River and International Slip	-	21-25	-	-	Between 2 zones, changes seasonally (downward in dry season, upward in wet season)	-	-	-
	3	Deep - native Pleistocene and Recent Alluvial deposits		-	35-44	-	-		-	-	-
PGE Harborton #2353	-	Shallow Groundwater within sand	-	3-9	-	-	0.001-0.003	-	-	-	-
	53	Fill/Shallow Alluvium Zone	Generally towards the Willamette river	-	ground surface to 30	-	0.00882 (between W-18 and RP-01)	0.25 feet/foot (at W-11) to a minimum of 0.013 feet/foot (at AL-05) - Between Fill and Alluvial zones	-	-	-

Table D4-3. Summary of Hydrogeologic Information Gathered from the CSMs.

Site	Number of Wells	Aquifer Units Present	Groundwater Flow Direction	Depth to Groundwater (ft bgs)	Depth of Aquifer (ft bgs)	Saturated Thickness (ft)	Horizontal Gradient (avg - linear ft/ft)	Downward Vertical Gradient (potential)	Hydraulic Conductivity K (ft/day)	Transmissivity T (ft^2/day)	Average Linear Groundwater Velocity (ft/day)
Rhone Poulenc #0155	188	Alluvium Zone	Southwest to Northeast toward the Willamette River	-	25 - 175	-	-	-	Sandy Silt/Silty Sand: 2.38 (range of 0.01 to 10.7);Clays: 0.06 (range of 0.03 to 0.09)	-	0.15 (assuming an effective porosity of 0.14)
	26	Columbia River Basalt	Southwest to Northeast towards the Willamette River	-	60 - 215	-	-	0.087 feet/foot (at W-06) to a minimum of 0.0003 feet/foot (at BTB-4) - Between alluvial and basalt zones	-	-	-
RK Storage #2376	-	-	North toward the Willamette River	25	-	-	0.04	-	-	-	-
Romar #2437	-	-	-	-	-	-	-	-	-	-	-
Ryerson #2441	-	-	-	-	-	-	-	-	-	-	-
Sante Fe Pacific #2104	-	Alluvial	East to Northeast	21-28	-	-	-	-	-	-	-
Schnitzer Calbag-Steel #2355		Alluvial Groundwater Zones (Perched)	-	12-20	15-20	-	-	-	-	-	-
Schnitzer Doane #395	3	3 units: Fill, alluvial, Columbia River Basalt	-	-	-	-	-	-	-	-	-
Schnitzer-Kittridge #2442	5 (temp wells to 15 ft.)	-	North toward the Willamette River	10-15	-	-	-	-	-	-	-
Shaver #2377	-	-	-		-	-	-	-	-	-	-
Siltronic #183	8	Surficial Fill Unit	Generally North to Northeast toward the Willamette River	-	ground surface to 70	-	0.02	-	-	-	-
	19	Alluvial Water Bearing Zone	Generally North to Northeast, increasingly North with increasing depth	-	104 - 124	up to 170 ft	0.003 - 0.005	-	-	-	-
South Rivergate Industrial #2980	-	-	-	-	-	-	-	-	-	-	-
ST Services #1989	-	Fill and Alluvial	Northeast towards the Willamette River	15-23	-	-	0.018-0.026	-	-	-	-
Sulzer Bingham #1235	-	-	-	18-28	-	-	-	-	-	-	-
Time Oil #170	45	Upper Unconfined Alluvial	West-Southwest toward the Willamette River	-	10-20	<1 to <15 (seasonal)	0.007-0.012	-	40-160	180-520	0.9-6.4 (at an effective porosity of 0.3)
	32	Lower Zone - Alluvial		-	-	15-20	0.0002-0.004	-	25-130	2,100-7,000	0.02-1.7 (at an effective porosity of 0.3)
Transloader #2367	-	-	-	-	-	-	-	-	-	-	-
Triangle Park #277	7	Uppermost Waterbearing Zone (Fill and Recent Alluvial)	Southwesterly toward the Willamette River	9-25	-	-	-	-	-	-	-
Trumbull Asphalt #1160	8	Alluvium	South to Southeast	7-9	-	-	0.001-0.003	-	-	-	-

Table D4-3. Summary of Hydrogeologic Information Gathered from the CSMs.

Site	Number of Wells	Aquifer Units Present	Groundwater Flow Direction	Depth to Groundwater (ft bgs)	Depth of Aquifer (ft bgs)	Saturated Thickness (ft)	Horizontal Gradient (avg - linear ft/ft)	Downward Vertical Gradient (potential)	Hydraulic Conductivity K (ft/day)	Transmissivity T (ft^2/day)	Average Linear Groundwater Velocity (ft/day)
UPRR #178	11 (and 2 piezometers)	Shallow - Unconfined Fill and Alluvium	West toward the Willamette River	7-25	40	Fill: 10-20; Alluvium: 100	-	-	-	-	-
US Moorings #1641	-	Discontinuous interbedded Sand and Silty Sand overlaying Columbia River Basalt	-	-	20-80	-	-	-	-	-	-
USGS Marine Safety # 1338	-	Shallow unit in Fill and Alluvium	South toward Swan Island Lagoon	7-15	-	-	-	-	-	-	-
Van Water Rogers #330	-	Shallow, Dredge Fill	West then splits South and North (due to high elevation of aquitard)	6-13	-	<5	West: 0.002; North and South: 0.006	-	horizontal: 150-300	-	-
	-	Aquitard	-	-	-	-	-	-0.1	vertical: 0.0043	-	vertical: 0.0012
	-	Deep - Gravel and Sand (Troutdale)	North to Northeast	7-14	-	-	<0.001	-	-	-	-
Willamette Cove #2066	-	-	-	-	-	-	-	-	-	-	-
Willbridge #1549	143	Holocene Alluvial Deposits	-	-	ground surface to 30	-	-	-	-	-	-
	-	Columbia River Basalt	-	-	20 - 50	-	0.02	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-

Notes:

? - Indicates unspecified number of wells

[a] CSM does not indicate the depth of the wells.

[b] *Deep aquifer investigation conducted by Kleinfelder in 1997 (no hydrogeologic information in CSM).*

[c] An unknown number of historic wells that were used to determine vertical gradients have been abandoned.

Table D4-4. Literature Koc Values for Advective Loading Estimates.

	EPA Soil Screening Guidance log K_{oc} (L/kg)	ORNL Risk Assess Info System log K_{oc} (L/kg)	ASTDR log K_{oc}[a] (L/kg)	Other log K_{oc} Value (L/kg)	Minimum log K_{oc} (L/kg)	Maximum log K_{oc} (L/kg)
Metals						
Arsenic[b]	--	--	--	--	--	--
PCBs	--	--	--	--	--	--
PCB TEQ (birds)	5.49	--	6.17	--	5.49	6.17
Total PCBs	5.49	--	6.17	--	5.49	6.17
Dioxins/Furans	--	--	--	--	--	--
Dioxin TEQ (birds)	--	--	6.30	7.59[c]	6.30	7.59
Pesticides	--	--	--	--	--	--
2,4'- and 4,4'-DDD	4.66	5.18	5.13	--	4.66	5.18
2,4'- and 4,4'-DDE	4.94	5.18	5.13	6.60	4.94	6.60
2,4'- and 4,4'-DDT	5.83	5.34	5.13	--	5.13	5.83
Aldrin	4.69	5.03	7.67	--	4.69	7.67
alpha-Hexachlorocyclohexane	3.25	3.53	3.57	--	3.25	3.57
beta-Hexachlorocyclohexane	3.33	3.53	3.57	--	3.33	3.57
Dieldrin	4.41	4.03	6.67	--	4.03	6.67
gamma-Hexachlorocyclohexane	3.13	3.53	3.00	--	3.00	3.53
Heptachlor	3.98	4.72	4.34	--	3.98	4.72
Total Chlordanes	--	--	--	--	4.02[d]	4.71[d]
Benzo(a)pyrene	5.99	5.90	6.74	6.00[e]	5.90	6.74
Polycyclic Aromatic Hydrocarbons	--	--	--	--	--	--
Total PAHs	--	--	--	--	4.94[f]	5.12[f]
Phthalate	--	--	--	--	--	--
Bis(2-ethylhexyl) phthalate	5.05	5.22	--	--	5.05	5.22
Semivolatile Organic Compounds	--	--	--	--	--	--
Hexachlorobenzene	4.90	3.53	4.84	--	3.53	4.90

-- Indicates that a Koc value was not available.

[a] Compiled by Windward Consulting.

[b] Because arsenic is not expected to behave according to organic matter partitioning theory, K_{oc} equilibrium estimation of the TZW concentrations is not appropriate for this analyte. A detailed analysis of arsenic geochemistry in TZW is presented in Appendix E.7. Based on the results of this analysis, the median observed TZW concentration for arsenic was applied uniformly to all polygons.

[c] Lodge K.B. and P.M. Cook, 1989.

[d] A K_{oc} value for total chlordanes was not available. Available ATSDR (compiled by Windward Consulting) and EPA Soil Screening Guidance minimum and maxium values for individual chlordanes (cis-, trans-, and gamma-chlordane) were used.

[e] Calculated K_{oc} (EPA 2003; Hilal et al. 1994; Di Toro et al. 1991), where K_{oc}=10^[0.00028 + (0.983)log10K_{ow}].

[f] A K_{oc} value for total PAHs was not available. The minimum and maximum of the geometric means of ATSDR (compiled by Windward Consulting), EPA Soil Screening Guidance, ORNL RAIS, and calculated (see footnote c) K_{oc} values for 17 individual PAHs were used

Table D4-5. Advective Groundwater Loading Estimate Results.

Analyte	*Estimated Advective Loading to the Water Column (kg / year)*			
	lower K_{oc} value used		*upper K_{oc} value used*	
	Entire Study Area[b]	**Limited Discharge Area[c]**	**Entire Study Area[b]**	**Limited Discharge Area[c]**
Metals				
Arsenic[a]	38.6	39.4	38.6	39.4
PCBs				
Total PCB	0.141	0.209	2.94E-02	4.36E-02
Pesticides				
4,4'-DDD	9.34E-02	0.149	2.80E-02	4.45E-02
4,4'-DDT	7.90E-02	0.149	1.57E-02	2.97E-02
Aldrin	3.88E-03	5.56E-03	4.04E-06	5.80E-06
alpha-Hexachlorocyclohexane	5.98E-02	6.22E-02	3.17E-02	3.30E-02
beta-Hexachlorocyclohexane	0.572	0.647	0.367	0.414
Dieldrin	8.66E-03	1.12E-02	1.97E-05	2.54E-05
gamma-Hexachlorocyclohexane	0.519	0.450	0.163	0.140
Heptachlor	1.81E-03	1.90E-03	3.30E-04	3.47E-04
Total Chlordane	0.114	0.113	2.39E-02	2.36E-02
Total of 2,4' and 4,4'-DDD	0.130	0.205	3.89E-02	6.15E-02
Total of 2,4' and 4,4'-DDE	3.43E-02	5.40E-02	7.51E-04	1.18E-03
Total of 2,4' and 4,4'-DDT	9.40E-02	0.178	1.87E-02	3.54E-02
Total of 2,4' and 4,4'-DDD, -DDE, -DDT	2.58E-01	0.258	2.58E-01	2.58E-01
Polycyclic Aromatic Hydrocarbons				
Benzo(a)pyrene	0.867	0.485	0.124	6.95E-02
Total PAHs	1.00E+02	52.9	67.3	35.5
Phthalate				
Bis (2-ethylhexyl) phthalate	1.86	2.45	1.25	1.65
Semivolatile Organic Compounds				
Hexachlorobenzene	0.108	0.102	4.68E-03	4.41E-03

[a] Because arsenic is not expected to behave according to organic matter partitioning theory, Koc equilibrium estimation of the TZW concentrations is not appropriate for this analyte. A detailed analysis of arsenic geochemistry in TZW is presented in Appendix E.7. Based on the results of this analysis, the median observed TZW concentration for arsenic was applied uniformly to all polygons.

[b] Groundwater discharge distributed through sediments from the entire Study Area.

[c] Groundwater discharge distributed through sediments from the area between the navigational channel boundary and the shoreline.

Table D5-1. Compilation of Estimates of Dry Deposition Velocity.

Analyte	Dry Deposition Velocity (cm/s)	Min/Max	Surface Type for Dry Deposition Velocity Estimation	Location	Reference
Metals					
Arsenic	0.1	Min	Land	not reported	Schnoor et al. 2002 [a]
Arsenic	0.3	Median	Land	not reported	Schnoor et al. 2002 [a]
Arsenic	1	Max	Land	not reported	Schnoor et al. 2002 [a]
Cadmium	0.1	Min	Land	not reported	Schnoor et al. 2002 [a]
Cadmium	0.3	Median	Land	not reported	Schnoor et al. 2002 [a]
Cadmium	1	Max	Land	not reported	Schnoor et al. 2002 [a]
Copper	0.1	Min	Land	not reported	Schnoor et al. 2002 [a]
Copper	0.3	Median	Land	not reported	Schnoor et al. 2002 [a]
Copper	1	Max	Land	not reported	Schnoor et al. 2002 [a]
Mercury (Elemental)	0.06	Min	not reported	not reported	EPA 2005 [b]
Mercury Compounds	1	Central Tendency	not reported	not reported	n/a [c]
Mercury Compounds	3	Max	not reported	not reported	
Metals	0.1	Min	not reported	not reported	n/a [c]
Metals	1	Central Tendency	not reported	not reported	
Metals	3	Max	not reported	not reported	
PCBs					
PCBs	1.75	Central Tendency	not reported	not reported	Slater and Spedding 1981 [d]
PCBs	0.5	Max	Land	Chicago	SFEI 2005
PCBs	0.2	Min	Water	Great Lakes - Chicago	SFEI 2005
Dioxin/Furan Congeners					
Dioxin/Furan Congeners	0.02	Min	Water	Japan	Ogura et al. 2001 [e]
Dioxin/Furan Congeners	0.2	Central Tendency	Water	Japan	Ogura et al. 2001 [e]
Dioxin/Furan Congeners	4.2	Max	Water	Japan	Ogura et al. 2001 [e]

Table D5-1. Compilation of Estimates of Dry Deposition Velocity.

Analyte		Dry Deposition Velocity (cm/s)	Min/Max	Surface Type for Dry Deposition Velocity Estimation	Location	Reference
Pesticides						
	Dieldrin	2.105	Central Tendency	not reported	not reported	Slater and Spedding 1981 [d]
	Dieldrin	0.009	Min	Water	New Zealand	Slater and Spedding 1981
	Dieldrin	0.05	Max	Water	New Zealand	Slater and Spedding 1981
	Pesticides	0.5	Central Tendency	not reported	not reported	n/a [c]
	Pesticides	0.01	Min	not reported	not reported	EPA 2005 [f]
	Pesticides	1.1	Max	not reported	not reported	EPA 2005 [f]
Polycyclic Aromatic Hydrocarbons						
	PAHs	0.1	Min	Water	not reported	AHI 1987
	PAHs	0.2	Mean	Water	Great Lakes - Chicago	SFEI 2005
	PAHs	0.6	Max	Water	not reported	AHI 1987
Organics						
	Organic Pollutants	0.5	Default	not reported	not reported	EPA 2005 [f]

Notes

[a]Fine particles less than 1 um in mean mass diameter.

[b]Value used in report to Congress (EPA 1997).

[c]Estimated based on scientific judgement.

[d]Average of Min and Max values

[e]Water was in stainless steel vats on top of skyscraper in Yokohama.

[f]Default value recommended by EPA.

Table D5-2. Compilation of Estimates of Air Concentrations.

Analyte	Sample/Modeled Location	Sample Year(s)	Concentration	Units	Qualifier	Type of Estimate	N	Monitored/ Modeled/ Calculated	Source
Metals									
Arsenic Compounds	Multnomah County	1999	0.00002	ug/m^3		Min		Modeled [a]	EPA 1999
Arsenic Compounds	Multnomah County	1999	0.00009	ug/m^3		Mean	170	Modeled [a]	EPA 1999
Arsenic Compounds	Multnomah County	1999	0.00050	ug/m^3		Max		Modeled [a]	EPA 1999
Cadmium Compounds	Multnomah County	1999	0.00003	ug/m^3		Min		Modeled [a]	EPA 1999
Cadmium Compounds	Multnomah County	1999	0.00025	ug/m^3		Mean	170	Modeled [a]	EPA 1999
Cadmium Compounds	Multnomah County	1999	0.00192	ug/m^3		Max		Modeled [a]	EPA 1999
Copper	Linn County	1992 - 1999	0.00010	ug/m^3		Min		Monitored [b]	EPA 1996a
Copper	Synthetic	1992 - 1999	0.00051	ug/m^3		Mean	16	Calculated [b]	EPA 1996a
Copper	Klamath County	1992 - 1999	0.00160	ug/m^3		Max		Monitored [b]	EPA 1996a
Mercury Compounds	Multnomah County	1999	0.00174	ug/m^3		Min		Modeled [a]	EPA 1999
Mercury Compounds	Multnomah County	1999	0.00393	ug/m^3		Mean	170	Modeled [a]	EPA 1999
Mercury Compounds	Multnomah County	1999	0.02508	ug/m^3		Max		Modeled [a]	EPA 1999
Zinc	Linn County	1992 - 1999	0.00130	ug/m^3		Min		Monitored [b]	EPA 1996a
Zinc	Synthetic	1992 - 1999	0.00232	ug/m^3		Min	16	Calculated [b]	EPA 1996a
Zinc	Klamath County	1992 - 1999	0.00490	ug/m^3		Max		Monitored [b]	EPA 1996a
PCB Aroclors									
PCB Aroclors	Multnomah	1999	0.00041	ug/m^3		Min		Modeled [a]	EPA 1999
PCB Aroclors	Multnomah	1999	0.00052	ug/m^3		Mean	170	Modeled [a]	EPA 1999
PCB Aroclors	Multnomah	1999	0.00059	ug/m^3		Max		Modeled [a]	EPA 1999
PCB TEQ	Livermore	2004	0.00000	ng/m3		Min	10	Monitored [c]	CARB 2004
PCB TEQ	Boyle Heights	2004	0.00001	ng/m3		Max		Monitored [c]	CARB 2004
Dioxins/Furans									
Dioxin TEQ	Crockett, CA	2004	0.00001	ng/m3		Min		Monitored [c]	CARB 2004
Dioxin TEQ	Synthetic	2004	0.00002	ng/m3		Mean	10	Calculated [d]	CARB 2004
Dioxin TEQ	Wilmington, CA	2004	0.00003	ng/m3		Max		Monitored [c]	CARB 2004
Pesticides									
Chlordane	Multnomah County	1999	0.00001	ug/m^3		Mean	170	Modeled [a]	EPA 1999
Chlordane	Multnomah County	1999	0.00001	ug/m^3		Max		Modeled [a]	EPA 1999
Chlordane	Multnomah County	1999	0.00001	ug/m^3		Min		Modeled [a]	EPA 1999
DDE	Saginaw, MI	1991	0.06300	ug/m^3		Min		Monitored [e]	ATSDR 2002b
DDE	Synthetic	1991	0.09133	ug/m^3		Mean	4	Calculated [e]	ATSDR 2002b
DDE	Sault Ste. Marie, MI	1991	0.11900	ug/m^3		Max		Monitored [e]	ATSDR 2002b
DDT	Traverse City, MI	1991	0.02100	ug/m^3		Min		Monitored [e]	ATSDR 2002b
DDT	Synthetic	1991	0.02900	ug/m^3		Mean	3	Calculated [e]	ATSDR 2002b
DDT	Saginaw, MI	1991	0.03500	ug/m^3		Max		Monitored [e]	ATSDR 2002b
Dieldrin	Lake Michigan	1990 - 1992	0.00190	ug/m^3		Mean		Monitored [f]	ATSDR 2002a

Table D5-2. Compilation of Estimates of Air Concentrations.

Analyte	Sample/Modeled Location	Sample Year(s)	Concentration	Units	Qualifier	Type of Estimate	N	Monitored/ Modeled/ Calculated	Source
Heptachlor	Multnomah County	1999	0.00000	ug/m^3		Min		Modeled [a]	EPA 1999
Heptachlor	Multnomah County	1999	0.00000	ug/m^3		Mean	170	Modeled [a]	EPA 1999
Heptachlor	Multnomah County	1999	0.00000	ug/m^3		Max		Modeled [a]	EPA 1999
Polycyclic Aromatic Hydrocarbons									
Benzo(a)anthracene	Portland	1999 - 2004	0.00090	ug/m^3		Min	2	Monitored [g]	DEQ 2006
Benzo(a)anthracene	Portland	1999 - 2004	0.00100	ug/m^3		Max		Monitored [g]	DEQ 2006
Benzo(a)pyrene	Portland	1999 - 2004	0.00030	ug/m^3	DL	~Min	3	Monitored	DEQ 2006
Benzo(a)pyrene	Beaverton	1999 - 2004	0.00064	ug/m^3		Max		Monitored [h]	DEQ 2006
Benzo(g,h,i)perylene	Portland	1999 - 2004	0.00040	ug/m^3		Min	2	Monitored [g]	DEQ 2006
Benzo(g,h,i)perylene	Portland	1999 - 2004	0.00060	ug/m^3		Max		Monitored [g]	DEQ 2006
Benzo(k)fluoranthene	Portland	1999 - 2004	0.00030	ug/m^3	DL	~Min	3	Monitored	DEQ 2006
Benzo(k)fluoranthene	Beaverton	1999 - 2004	0.00088	ug/m^3		Max		Monitored [h]	DEQ 2006
Dibenzo(a,h)anthracene	Portland	1999 - 2004	0.00030	ug/m^3	DL	Max	3	Monitored	DEQ 2006
Indeno(1,2,3-cd)pyrene	Portland	1999 - 2004	0.00030	ug/m^3	DL	~Min	3	Monitored	DEQ 2006
Indeno(1,2,3-cd)pyrene	Beaverton	1999 - 2004	0.00194	ug/m^3		Max		Monitored [h]	DEQ 2006
Phthalates									
Bis(2-ethylhexyl) phthalate	Multnomah County	1999	1.60000	ug/m^3		Min		Modeled [a]	EPA 1999
Bis(2-ethylhexyl) phthalate	Multnomah County	1999	1.60005	ug/m^3		Mean	170	Modeled [a]	EPA 1999
Bis(2-ethylhexyl) phthalate	Multnomah County	1999	1.60051	ug/m^3		Max		Modeled [a]	EPA 1999
Dibutyl phthalate	Multnomah County	1999	0.08212	ug/m^3		Min		Modeled [a]	EPA 1999
Dibutyl phthalate	Multnomah County	1999	1.20642	ug/m^3		Mean	170	Modeled [a]	EPA 1999
Dibutyl phthalate	Multnomah County	1999	11.05000	ug/m^3		Max		Modeled [a]	EPA 1999
Semivolatile Organic Compounds									
Hexachlorobenzene	Multnomah County	1999	0.00000	ug/m^3		Min		Modeled [a]	EPA 1999
Hexachlorobenzene	Multnomah County	1999	0.00000	ug/m^3		Mean	170	Modeled [a]	EPA 1999
Hexachlorobenzene	Multnomah County	1999	0.00000	ug/m^3		Max		Modeled [a]	EPA 1999

Notes
DL = All values reported were below the laboratory detection limit.
~Min = minimum value defined by the detection limit, which is likely higher than the true minimum concentration

[a]Modeled annual mean for all census tracts in Multnomah County.
[b]Annual mean. Value selected from detected Klamath and Linn County values.
[c]10 California sites each of which reports the annual mean of 13 samples; WHO-97 TEFs define the TEQ.
[d]Mean of all values from California.
[e]Value derived from data set of maximum values at 6 Michigan stations.
[f]Annual mean of particulate dieldrin concentration over Lake Michigan. The number of measurements used to calcuate the mean shown was not reported.
[g]Only two measurements were available for this species.
[h]10 California sites each of which reports the annual mean of 13 samples; WHO-97 TEFs define the TEQ.

Table D5-3. Estimates of Dry Deposition Loading Rates to the Study Area.

Analyte	Load (kg/yr) Minimum	Central	Maximum
Metals			
Arsenic Compounds	0.004	0.075	1.34
Cadmium Compounds	0.008	0.201	5.16
Copper	0.027	0.407	4.29
Mercury Compounds	0.280	10.5	202
Zinc	0.349	1.87	13.1
PCB Aroclors			
PCB Aroclors [a]	0.220	0.488	0.797
PCB TEQ [a]	1.07E-06		1.38E-05
Dioxin/Furans			
Dioxin TEQ [b]	6.76E-07	1.24E-05	3.72E-04
Pesticides			
Chlordane [c]	2.65E-04	0.0133	0.0292
Dieldrin	4.58E-05	1.50E-04	2.55E-04
DDE [c]	1.69E-03	0.122	0.351
DDT [c]	5.63E-04	0.039	0.103
Heptachlor [c]	2.29E-09	1.25E-06	2.07E-05
Polycyclic Aromatic Hydrocarbons			
Benzo(a)anthracene [d]	0.241		1.61
Benzo(a)pyrene [d,e]	0.080		1.03
Benzo(g,h,i)perylene [d]	0.107		0.965
Benzo(k)fluoranthene [d,e]	0.080		1.42
Dibenzo(a,h)anthracene [d,e]	0.080	0.161	0.483
Indeno(1,2,3-cd)pyrene [d,e]	0.080		3.12
Phthalates			
Bis(2-ethylhexyl) phthalate [f]	2.14E+03	2.15E+03	2.15E+03
Dibutyl phthalate [f]	110	1.62E+03	1.48E+04
Semivolatile Organic Compounds			
Hexachlorobenzene [f]	3.58E-04	1.71E-03	2.57E-03

Notes

[a]A standard range of deposition velocity for PCBs was used here (see Table D5-1).

[b]A standard range of deposition velocity for dioxins was used here (see Table D5-1).

[c]A standard range of deposition velocity for pesticides was used here (see Table D5-1).

[d]A standard range of deposition velocity for PAHs was used here (see Table D5-1).

[e]All measured concentrations of this pollutant were non-detect. The concentration used in this estimate is the detection limit. As such, this is expected to be conservatively high.

[f]The depositon velocity used for this estimate is an EPA-recommended default for all organic pollutants (see Table D5-1).

Table D6-1. Summary of Available Bank Chemistry Data.

Site	Chemicals Detected - 2004 CSM	Chemicals Detected - 2006 LWG or DEQ Data	Erodable Bank (per Figure 5-4)	Metals	Butyltins	Hydrocarbons	PAHs	PCBs	Pesticides	Other SVOCs	VOCs	Other
AAC/Marine Finance	No	Yes	No - riprap	X	X		X				X	
Alder Creek	No	Yes	Maybe - beach (human health RA)	X			X					sloughing wood waste
ARCO	Yes	Yes	No - seawall	X		X	X				X	
Arkema	Yes	Yes	Maybe - beach				X		X	X	X	
Burgard	No	Yes	No - riprap	X		X	X	X				
Crawford Street Corp.	No	Yes	Maybe - some beach	X		X	X	X			X	phthalates
ExxonMobil	Yes	Yes	No - riprap & apron			X						
Front Ave.	No	Yes	Maybe - beach	X		X		X				
Gasco	Yes	Yes	Yes - some unclassified fill & beach	X			X				X	
Gunderson	No	Yes	Maybe - some beach	X	X	X	X	X		X	X	
Kinder Morgan	Yes	?	No - riprap									
MarCom	No	Yes	Yes - unclassified fill	X	X	X	X				X	
Oregon Steel Mills	Yes	Yes	Maybe - beach	X				X				
Premier Edible Oil	Yes		Maybe - beach and natural bank			X	X				X	
Siltronic	Yes	Yes	No - riprap	X		X	X					potentially others
Sulzer Bingham Pumps	No	Yes	No - structures	X		X	X					
T4 Slip 1	No	Yes	Yes - unclassified fill at head	X			X		X			
T4 Slip 3	No	Yes	Yes - unclassified fill at head and some beach			X	X					
Triangle Park	No	Yes	No - riprap	X		X	X	X		X	X	
Willbridge Terminal	Yes	Yes	Maybe - beach	X			X		X			

Table D7-1. Concentrations of Arsenic, Barium, Manganese, and Major Ions in TZW Samples.

Location	Arsenic ug/L	Barium ug/L	Manganese ug/L	Alkalinity mg/L (as CaCO3)	Chloride mg/L	ORP mV	pH su	Sulfate mg/L	Calcium mg/L	Iron ug/L	Magnesium mg/L	Potassium mg/L	potassium ug/L	Sodium mg/L
ARCO														
AR01A	4.7	78.4	2210	148	4.2	-37	6.39	3.4	51.4	2.66E+04	11.7	3.6	3600	11
AR02A	14.7	58.2	2440	--	--	--	6.67	--	40.1	4.59E+04	22.4	3.65	3650	12.5
AR04B	2.96	95.3	2730	--	--	--	--	--	76.6	3.16E+04	25.5	2.97	2970	12.6
ARC02B	23.3	--	4250	375	6	--	6.94	0.4	89.5	--	26.2	4.84	4840	23.2
ARC03B	8	--	2330	502	5.7	--	7.32	4.5	111	--	34.3	5.42	5420	20.9
ARC06B-1	10.9	--	4340	434	4.7	--	7.25	2.9	84.7	--	38.5	4.56	4560	19.6
R2AR01	32.3	172	2450	357	4.2	-98	6.41	0.12	83.1	7.34E+04	17.1	4.51	4510	15
R2AR02	15.6	123	5110	308	8	-90	6.67	0.5	73.5	3.12E+04	20.9	4.57	4570	18.5
R2AR03	0.76	38.5	397	60	5 5	-20	7.21	0.4	13.2	3580	5.46	1.57	1570	5.71
R2AR04	15.1	49.2	1110	164	6 4	-90	6.98	3.2	32.4	1.49E+04	11.2	3.38	3380	13 7
Arkema Acid Plant														
AP02A	27	120	9840	334	62.7	-120	6.63	0.7	104	7.13E+04	28	3.85	3850	20.8
AP02D	--	--	--	480	913	-105	6 36	0.3	135	--	48.2	7.42	7420	590
AP03A	7.93	679	5080	584	1740	-120	6.48	1.2	161	8.60E+04	520	11.8	1.18E+04	393
AP03B-1	--	--	1.86E+04	132	3040	--	6.3	27.4	125	--	743	7.71	7710	179
AP03D	--	--	--	34	1000	--	5.99	942	--	--	--	--	10	--
AP04B	--	--	1.73E+04	1300	2370	--	7.79	70.1	281	--	382	6.14	6140	590
AP04C	0.91	13.6	710	124	1.6	--	7.42	0.4	8.85	4730	3.97	0.54	540	3.36
AP04D	--	--	11800	585	1150	--	7.34	0.9	242	--	76.1	6.47	6470	612
R2AP01	0.73	58.2	146	658	11.1	--	8.1	0.5	9.61	660	91.6	1.76	1760	8.22
R2AP02	5.22	2120	4800	1430	1.45E+04	-112	7.13	264	342	1.08E+04	599	22.4	2.24E+04	9880
Arkema Chlorate Plant														
CP06A	0.21	39.8	717	486	1220	-96	7.27	26.6	7.63	3980	2.96	7.33	7330	1290
CP06C	--	--	1.08E+04	259	3.46E+04	--	6.075	9	690	--	280.5	65.2	6.52E+04	1.83E+04
CP07A	6.5	119	146	810	9280	30	7.26	278	14 8	169	6.43	16.4	1.64E+04	8250
CP07B	0.43	785	6740	922	1.27E+04	5	7.24	292	97.1	289	23.7	28.1	2.81E+04	1.09E+04
CP07D	0.46	570	5360	289	5.17E+04	--	6.76	485	119	385	75.2	92.2	9.22E+04	3.75E+04
CP08B	0.55	52	125	502	9910	61	7	268	11	145	7.75	12.3	1.23E+04	8810
CP08D-1	--	--	3.35E+04	540	8.97E+04	--	6.44	45	384	--	139	90.9	9.09E+04	5.87E+04
CP09A	0.69	1430	617	359	8660	38	7.19	124	46.6	30.8	11.1	12.2	1.22E+04	6920
CP09D	10.7	2230	2.29E+04	492	2.91E+04	--	6.96	47	164	2.52E+05	75.9	47.8	4.78E+04	2.50E+04
CP10A	--	--	1940	374	3.56E+04	--	7.04	18	77.9	--	50.3	27.1	2.71E+04	2.95E+04
R2CP01	4.09	2670	6.62E+04	548	1.96E+04	--	7.07	238	787	1.45E+05	312	197	1.97E+05	1.50E+04

Table D7-1. Concentrations of Arsenic, Barium, Manganese, and Major Ions in TZW Samples.

Location	Arsenic ug/L	Barium ug/L	Manganese ug/L	Alkalinity mg/L (as CaCO3)	Chloride mg/L	ORP mV	pH su	Sulfate mg/L	Calcium mg/L	Iron ug/L	Magnesium mg/L	Potassium mg/L	potassium ug/L	Sodium mg/L
Exxon Mobil														
EM01A	2.73	50.3	2810	80	4.6	-45	6.99	2	20.2	5020	5.49	2.06	2060	7.11
EM02A	6.35	34.8	2270	145	6.3	-66	7.34	2.3	32.5	1.12E+04	11.7	2.09	2090	11.2
EM02C	16	43.8	2180	188	4.4	-86	6.8	0.3	47.5	2.35E+04	20.9	4.68	4680	19.9
EM03A	26.4	42.3	1690	178	4.6	--	6.99	5	40.7	1.78E+04	15.7	2.78	2780	14.8
EM04A	9.63	84.6	1650	292	5.2	--	6.86	1.6	48.2	2.63E+04	15	4.22	4220	38.2
EM04C	23.8	233	2.03E+04	680	6.4	--	6.7	0.1	170	1.09E+05	52	6.63	6630	18.4
EM05A	6.52	143	1230	418	6	--	6.69	0.1	75.1	4.20E+04	26.1	6.14	6140	16.3
EM06B	30.9	64.1	2030	187	4.7	--	6.85	0.3	39.2	4.06E+04	16.1	2.95	2950	11.2
EM08A	23.9	77.5	3990	219	6.45	--	6.92	1.3	51.7	3.36E+04	16	3.36	3360	13.2
R2EM01	11.3	95.5	4050	331	5.3	--	6.74	0.1	62.4	5.05E+04	27.2	4.86	4860	14.3
Gunderson														
GN01E	5.9	240	835	750	7.4	--	6.81	0.6	137	6.41E+04	49.5	8.0	8000	24
GN02E	6.87	215	5100	519	7.5	--	6.9	0.19	121	7.46E+04	38.7	5.32	5320	16.5
GN03A	0.89	10.9	317	40	2	--	6.46	0.14	5.91	6250	1.85	0.445	445	2.4
GN04A	9.42	68.6	3330	306	10.9	-91	6.61	0.12	70.3	4.07E+04	20.5	3.87	3870	18.2
GN04B	0.4	4.06	133	60	0.7	--	6.85	0.06	2.91	1870	1.02	0.199	199	1.39
GN05A	1.53	70.8	1010	157	15.9	-49	6.47	0.6	34.9	2.70E+04	17.5	3.47	3470	15.6
R2GN01	14.3	270	5070	756	8.2	--	6.73	0.3	178	9.23E+04	62.7	7.56	7560	18.6
Gasco														
GS01B	0.55	54.9	3540	--	--	--	--	--	88.7	4.42E+04	39.2	5.21	5210	23.6
GS02A	1.2	66.6	74.1	66	2.8	-152	5.6	15.9	11.5	6920	5.84	1.36	1360	48.3
GS07B	--	--	--	168	5.7	-52	6.5	1.1	45.4	--	14.7	3.58	3580	13.8
GS07D	7.59	102	6040	337	4.2	--	6.97	0.2	68.8	4.79E+04	22.1	2.94	2940	12.2
GS08A	16.8	307	1.43E+04	676	5.55	-106	6.58	0.1	163	1.22E+05	50.9	5.64	5640	23.2
GS08D	1.9	91.7	2530	223	6.3	-88	6.56	0.1	50.5	4.36E+04	20.5	3.7	3700	14.2
Kinder Morgan														
KM06A	0.74	22.2	455	114	1.5	--	7.24	0.9	19.9	1610	11.1	1.34	1340	9.97
KM08A	8.31	36.9	2990	280	9.9	-47	7.26	3.1	41.4	9840	25.5	3.11	3110	44.6
KM10A	2.38	20.9	1420	85	3.7	--	7.72	1.4	19.4	1700	6.69	1.69	1690	8.85
KM11B	4.04	26.5	1560	162	1.6	--	6.88	0.13	18.9	1.42E+04	5.33	1.04	1040	3.39
R2KM01	6.8	34.5	6150	240	4.6	-47	6.94	2.6	61.4	3920	31.8	3.41	3410	18.8
R2KM02	11.6	125	7150	321	30.5	-104	7.36	0.17	65.8	4.91E+04	18.7	3.33	3330	13.2

Table D7-1. Concentrations of Arsenic, Barium, Manganese, and Major Ions in TZW Samples.

Location	Arsenic ug/L	Barium ug/L	Manganese ug/L	Alkalinity mg/L (as CaCO3)	Chloride mg/L	ORP mV	pH su	Sulfate mg/L	Calcium mg/L	Iron ug/L	Magnesium mg/L	Potassium mg/L	potassium ug/L	Sodium mg/L
Rhone Poulenc														
RP02E	11	250	1.52E+04	272	638	-50	6.8	2.8	262	2.82E+04	119	7.8	7800	35
RP03C	22.4	391	9510	--	--	--	--	73.5	456	1.65E+04	145	13.3	1.33E+04	73.2
RP03E	--	--	--	358	780	-12	6.76	51.8	332	--	180	13	1.30E+04	43.1
RP07B	4.33	155	1920	463	476	-74	6.92	7.7	94.6	4420	42.9	8.91	8910	344
RP07E	7.09	110	3050	330	134	--	7.42	0.16	63.4	2.92E+04	29.7	3.56	3560	95.4
R2RP01	11.2	198	1.37E+04	487	234	-99	6.55	0.1	167	9.11E+04	69.3	8.18	8180	40.7
R2RP02	5.91	296	705	347	5.05	-90	6.73	0.1	54.1	4.88E+04	22	4.93	4930	48.5
R2RP03	3.83	5.39	297	57	11.3	2	7.28	5.2	6.35	1310	2.95	1.77	1770	29
Siltronic														
SL01A	14.3	205	9020	492	10.5	-108	6.47	0.1	105	8.91E+04	34	5.12	5120	21.8
SL01E	11	151	1.01E+04	426	14.3	--	7.77	0.1	105	7.72E+04	31.2	3.26	3260	14
SL02A	14.9	65.6	3590	153	8	-89	6.67	2.5	36.7	2.88E+04	11.2	2.29	2290	12.7
SL02C	12.5	122	8140	330	5	--	7	0.2	81.7	5.94E+04	25.5	2.96	2960	13.2
SL02E	4.67	112	5430	350	27.9	--	6.96	0.2	87	5.66E+04	32.5	3.85	3850	14.6
SL03A	5.25	41.6	2480	109	6.7	-49	6.75	2.8	34.4	1.24E+04	11.2	2.13	2130	11.4
SL03C	10	111	6400	317	0.04	--	6.93	0.1	70.1	5.28E+04	22.1	3.37	3370	12.2
SL03F	11.1	137	6430	390	25.5	--	6.82	0.4	88.8	7.52E+04	38.7	4.08	4080	17.9
SL04A	4.56	68	2040	111	5.5	-89	6.69	3.6	31.9	2.10E+04	10.5	2.75	2750	12.7
SL04F	5.76	128	5570	352	14.7	--	6.79	0.2	85.1	8.01E+04	30.3	2.93	2930	12.9
SL05A	14.8	119	7260	324	7.5	-104	6.69	0.3	76.9	5.16E+04	22.8	3.79	3790	17.2
Willbridge														
W04C	14.7	67.5	3080	263	24.7	--	7.63	0.19	50	2.53E+04	13.9	3.33	3330	43.9
W06A	0.56	10.3	88.8	34	8.3	138	7.33	4.8	8.23	116	3.42	1.51	1510	9.99
W07C	1.92	17.6	184	44	11.4	75	7.12	4.4	17.4	392	12.5	3.32	3320	13
W09A	0.55	8.5	43.6	31	8.1	128	7.35	4.8	7.83	91.1	2.97	1.3	1300	9.6
W09C	7.22	58.3	3710	232	1.65	--	6.74	0.4	53.9	3.28E+04	16.6	2.37	2370	7.36
W12A	51.8	48.5	2560	213	9.95	-64	6.75	0.1	35.7	3.51E+04	13.9	3.06	3060	39.9
R2W02	27	246	1.25E+04	922	13	-105	6.62	0.1	229	1.13E+05	69.9	7.15	7150	26.9

-- Indicates that no data are available.

Table D7-2. Kruskal-Wallis Test Results.

	p-value (All Sites)	p-value (Arkema Chlorate Plant Excluded)
Arsenic	0.0579 / 0.044 / 0.0414[a]	0.324
Barium	0.0274	0.075
Manganese	0.1812	0.0828

[a] p-Values assuming arsenic concentration in samples with arsenic below the detection were detection limit, 1/2 detection limit, and 0, respectively.

Table D7-3. Summary Values for Available Arsenic, Barium, Manganese, and Major Ion Data for Upland Groundwater.

	Arsenic (mg/L)	Barium (mg/L)	Manganese (mg/L)	Iron (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	pH (s.u.)	Potassium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Alkalinity (mg/L as CaCO3)
All Sites												
# of Data Points	933	509	130	60	87	146	124	111	87	114	109	67
% Detected	82%	100%	100%	95%	100%	99%	99%	100%	100%	95%	100%	97%
Min	0	0	2.73E-04	0	1.39	0	0	5.76	0.488	0	0	0
Max	0.897	6.84	87	457	1550	1.64E+05	484	11.6	78.4	7650	3500	7230
Average	0.0221	0.183	5.55	48.3	198	2730	73.3	6.76	15	312	272	642
Kinder Morgan												
# of Data Points	16	16	--	--	--	--	--	--	--	--	--	--
% Detected	94%	100%	--	--	--	--	--	--	--	--	--	--
Min	0	9.07E-03	--	--	--	--	--	--	--	--	--	--
Max	0.0896	0.182	--	--	--	--	--	--	--	--	--	--
Average	0.0213	0.0791	--	--	--	--	--	--	--	--	--	--
ARCO												
# of Data Points	90	16	--	--	--	--	--	--	--	--	--	--
% Detected	76%	88%	--	--	--	--	--	--	--	--	--	--
Min	0	0.0151	--	--	--	--	--	--	--	--	--	--
Max	0.0574	0.441	--	--	--	--	--	--	--	--	--	--
Average	6.69E-03	0.102	--	--	--	--	--	--	--	--	--	--
ExxonMobil												
# of Data Points	135	--	--	--	--	--	--	--	--	--	--	--
% Detected	65%	--	--	--	--	--	--	--	--	--	--	--
Min	0	--	--	--	--	--	--	--	--	--	--	--
Max	0.067	--	--	--	--	--	--	--	--	--	--	--
Average	8.63E-03	--	--	--	--	--	--	--	--	--	--	--
Arkema Acid Plant and Chlorate Plant												
# of Data Points	26	--	39	13	27	66	27	17	27	27	38	38
% Detected	19%	--	100%	77%	100%	100%	100%	100%	100%	100%	100%	95%
Min	0	--	0.0633	0	2.81	5.36	2.28	6.04	1.15	18.7	0	0
Max	0.0296	--	87	12.7	1140	1.64E+05	484	10.4	78.4	3960	3500	7230
Average	3.23E-03	--	9.11	4.18	239	5520	148	7.42	24.4	706	531	850
Rhone Poulenc												
# of Data Points	118	--	30	--	30	27	30	37	30	30	27	27
% Detected	85%	--	100%	--	100%	100%	100%	100%	100%	100%	100%	100%
Min	0	--	2.73E-04	--	1.39	3.6	0.0171	5.76	0.488	10	0.37	87
Max	0.295	--	31.2	--	1550	1.55E+04	426	11.6	73.7	7650	232	1480
Average	0.0155	--	5.03	--	214	1080	70.6	6.66	10.5	472	63.2	373
Siltronic												
# of Data Points	52	26	61	47	15	38	52	57	15	42	29	2
% Detected	40%	100%	100%	100%	100%	97%	98%	100%	100%	86%	100%	100%
Min	0	0.0348	0.14	4.36	50.6	0	0	6.21	1.34	0	0.26	330
Max	0.0607	1.08	28.9	457	282	1000	152	7.85	30.3	110	399	334
Average	7.67E-03	0.234	3.54	60.5	141	72.8	47.2	6.62	9.32	26.2	261	332
Gasco												
# of Data Points	45	--	--	--	--	--	--	--	--	--	--	--
% Detected	60%	--	--	--	--	--	--	--	--	--	--	--
Min	0	--	--	--	--	--	--	--	--	--	--	--
Max	0.052	--	--	--	--	--	--	--	--	--	--	--
Average	9.04E-03	--	--	--	--	--	--	--	--	--	--	--

Table D7-3. Summary Values for Available Arsenic, Barium, Manganese, and Major Ion Data for Upland Groundwater.

	Arsenic (mg/L)	Barium (mg/L)	Manganese (mg/L)	Iron (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	pH (s.u.)	Potassium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Alkalinity (mg/L as CaCO3)
Willbridge												
# of Data Points	451	451	--	--	--	--	--	--	--	--	--	--
% Detected	98%	100%	--	--	--	--	--	--	--	--	--	--
Min	0	0	--	--	--	--	--	--	--	--	--	--
Max	0.897	6.84	--	--	--	--	--	--	--	--	--	--
Average	0.0350	0.187	--	--	--	--	--	--	--	--	--	--
Gunderson												
# of Data Points	--	--	--	--	15	15	15	--	15	15	15	--
% Detected	--	--	--	--	100%	100%	100%	--	100%	100%	100%	--
Min	--	--	--	--	18.4	13.1	6.28	--	3.19	10.9	7.66	--
Max	--	--	--	--	612	825	91.4	--	42.3	554	22.1	--
Average	--	--	--	--	148	182	34.3	--	13.0	86.8	13.0	--

Notes:
-- Indicates that no data are available.

Dissolved data for arsenic, barium, and manganese presented; total concentrations shown for all other analytes.
Exceptions:
Rhone Poulenc total manganese data (n = 30) used instead of dissolved data (n = 3) due to small dissolved sample count.
Siltronic magnesium data compiled from the R2 SAP (Integral 2005) is dissolved, not total.
Arkema iron data compiled from the R2 SAP (Integral 2005) is dissolved, not total.
Willbridge dissolved arsenic and barium data was not avaialble; total data used.

Table D7-4. Calculated Solubility Indices for Important Minerals Affecting Arsenic, Barium, Manganese, and Iron Solubility in TZW.

	Arsenic Minerals			Barium Minerals		Manganese Minerals		Iron Minerals	
Location	Realgar	Orpiment	Ba3(AsO4)3	Witherite	Barite	Rhodochrosite	Mn(OH)2	Fe(OH)3	Siderite
ARCO									
AR01A	-13.2	-36.2	-4.30	0.617	-0.783	-0.652	-7.97	-7.26	-3.14
AR02A	-6.41	-18.7	-5.31	0.599	-1.45	-0.494	-7.36	-7.51	-3.02
AR04B	-25.1	-68.3	3.45	1.10	-1.33	-0.159	-6.68	-1.47	0.763
ARC02B	-23.9	-65.9	-13.3	-4.38	-7.73	0.503	-6.65	-5.21	-2.29
ARC03B	-27.8	-75.7	-11.1	-3.91	-6.73	0.709	-6.18	-4.11	-1.83
ARC06B-1	-27.0	-73.6	-11.2	-4.03	-6.89	0.866	-6.03	-4.30	-1.94
R2AR01	-4.34	-13.6	-5.84	1.32	-1.98	-0.268	-7.93	-8.35	-2.81
R2AR02	-8.18	-23.5	-3.74	1.37	-1.50	0.253	-7.09	-7.42	-2.61
R2AR03	-26.7	-72.2	2.65	0.801	-1.88	-0.901	-7.02	-4.43	-2.64
R2AR04	-10.7	-30.2	-1.74	1.06	-0.977	-0.310	-7.08	-6.43	-2.50
Arkema Acid Plant									
AP02A	-2.59	-8.74	-5.90	1.32	-1.43	0.5	-6.91	-8.09	-2.65
AP02D	-7.94	-19.4	-37.0	-5.02	-8.12	-7.75	-15.6	-8.75	-2.91
AP03A	-1.58	-5.62	-6.84	1.88	-1.00	0.0387	-7.69	-8.75	-2.83
AP03B-1	-20.8	-53.1	-31.2	-5.82	-6.58	-0.240	-7.49	-7.32	-3.66
AP03D	-15.5	-38.0	-34.9	-6.83	-4.81	-9.34	-16.4	-8.25	-4.49
AP04B	-38.8	-100	-20.3	-3.35	-6.08	2.12	-4.61	-2.99	-1.33
AP04C	-30.9	-83.4	3.46	0.8655	-2.34	-0.141	-6.36	-0.976	0.534
AP04D	-33.9	-88.9	-21.3	-4.01	-7.74	1.33	-5.55	-4.17	-1.91
R2AP01	-41.1	-109	6.48	2.75	-1.90	0.341	-5.88	-0.0699	0.763
R2AP02	-8.09	-22.6	0.508	2.97	1.29	0.634	-6.67	-6.93	-2.22
Arkema Chlorate Plant									
CP06A	-14.1	-38.0	-3.91	1.44	-0.585	-0.0268	-6.90	-5.90	-2.05
CP06C	-19.1	-48.6	-34.5	-6.23	-7.73	-0.887	-8.55	-8.37	-4.06
CP07A	-33.6	-89.6	5.42	1.70	0.251	-0.889	-7.86	-3.93	-2.22
CP07B	-29.7	-79.2	5.09	2.48	0.972	0.734	-6.28	-4.48	-2.26
CP07D	-21.3	-57.0	-0.324	0.993	0.532	-0.760	-7.61	-4.83	-2.02
CP08B	-36.9	-97.5	1.57	0.865	-0.1476	-1.42	-8.44	-4.15	-2.68
CP08D-1	-22.5	-57.8	-31.3	-5.92	-7.45	-0.280	-7.71	-7.55	-3.82
CP09A	-35.4	-93.8	6.69	2.41	1.04	-0.631	-7.33	-3.95	-2.58
CP09D	-23.2	-63.2	6.36	2.15	0.300	0.483	-6.43	-1.30	1.38
CP10A	-29.6	-77.1	-25.1	-5.29	-7.53	-0.694	-7.38	-5.50	-3.12
R2CP01	-24.1	-65.2	6.89	2.50	1.22	1.23	-5.68	-1.14	1.41
Exxon Mobil									
EM01A	-18.9	-51.7	0.187	0.804	-1.10	-0.164	-6.62	-5.55	-2.75
EM02A	-19.1	-52.5	2.36	1.22	-1.27	0.309	-6.05	-4.92	-2.20
EM02C	-10.4	-29.7	-3.41	0.865	-2.12	-0.164	-7.17	-6.92	-2.65
EM03A	-23.3	-63.7	4.27	1.02	-0.883	-0.0976	-6.89	-4.99	-2.47
EM04A	-22.8	-62.2	2.98	1.39	-1.11	-0.0548	-7.19	-5.41	-2.43
EM04C	-22.0	-60.7	3.27	1.93	-2.11	1.12	-6.51	-6.01	-2.36
EM05A	-22.3	-61.2	1.57	1.58	-2.16	-0.235	-7.69	-5.96	-2.49
EM06B	-22.9	-63.0	3.59	1.09	-1.92	-0.134	-7.09	-5.41	-2.59
EM08A	-23.1	-63.5	4.27	1.30	-1.23	0.280	-6.67	-5.21	-2.47
R2EM01	-22.6	-62.2	2.05	1.36	-2.31	0.251	-7.05	-5.79	-2.51
Gunderson									
GN01E	-23.0	-62.9	3.18	2.10	-1.31	-0.128	-7.69	-1.88	1.58
GN02E	-24.4	-66.9	4.11	2.00	-1.83	0.623	-6.69	-1.50	1.62
GN03A	-20.3	-55.0	-5.49	-0.650	-2.84	-1.90	-8.59	-3.69	-0.74
GN04A	-8.22	-23.7	-5.64	1.04	-2.41	-0.0122	-7.40	-3.88	1.06
GN04B	-25.3	-68.5	-3.56	-0.501	-3.61	-1.70	-8.19	-5.31	-2.97
GN05A	-13.4	-36.7	-5.49	0.665	-1.61	-0.902	-8.16	-3.72	0.475
R2GN01	-22.1	-60.7	3.26	2.05	-1.62	0.558	-7.08	-1.97	1.65

Table D7-4. Calculated Solubility Indices for Important Minerals Affecting Arsenic, Barium, Manganese, and Iron Solubility in TZW.

	Arsenic Minerals			Barium Minerals		Manganese Minerals		Iron Minerals	
Location	**Realgar**	**Orpiment**	**Ba3(AsO4)3**	**Witherite**	**Barite**	**Rhodochrosite**	**Mn(OH)2**	**Fe(OH)3**	**Siderite**
Gasco									
GS01B	-25.8	-69.8	1.25	0.851	-1.59	-0.0533	-6.57	-4.97	-2.74
GS02A	5.75	13.7	-23.4	-0.609	-7.54	-3.28	-11.0	-8.58	-1.23
GS07B	-17.2	-44.0	-31.4	-5.14	-7.23	-7.86	-15.1	-3.41	0.799
GS07D	-25.0	-68.6	4.06	1.63	-1.98	0.660	-6.42	-5.10	-2.28
GS08A	-5.44	-16.5	-4.75	1.91	-2.04	0.821	-6.92	-3.98	1.60
GS08D	-8.90	-25.0	-6.89	0.994	-2.33	-0.293	-7.60	-3.97	0.884
Kinder Morgan									
KM06A	-28.4	-76.7	2.67	0.839	-1.83	-0.570	-6.93	-1.99	-0.166
KM08A	-21.0	-57.7	3.10	1.40	-1.20	0.575	-6.13	-4.88	-2.06
KM10A	-34.2	-92.0	5.85	1.18	-1.64	0.287	-5.46	-0.523	0.218
KM11B	-24.4	-66.6	1.03	0.705	-2.60	-0.251	-7.12	-2.14	0.561
R2KM01	-17.7	-48.6	-0.351	0.979	-1.34	0.502	-6.46	-5.83	-2.44
R2KM02	-14.1	-40.0	1.90	2.06	-1.99	1.08	-5.57	-1.92	1.76
Rhone Poulenc									
R2RP01	-6.43	-19.0	-5.51	1.53	-2.25	0.633	-6.99	-4.04	1.19
R2RP02	-9.97	-28.3	-2.87	1.84	-1.85	-0.517	-7.84	-3.54	0.476
R2RP03	-29.5	-79.7	3.05	-0.0251	-1.64	-0.994	-7.01	-0.760	1.33
RP02E	-15.7	-43.3	0.653	1.58	-0.8053	0.645	-6.46	-2.87	0.858
RP03C	-22.7	-61.8	6.57	1.49	0.701	0.187	-6.26	-1.58	0.578
RP03E	-25.1	-64.8	-26.5	-4.80	-6.04	-7.51	-14.8	-1.96	1.28
RP07B	-13.0	-35.7	-1.21	1.77	-0.4195	0.125	-7.11	-3.79	0.380
RP07E	-30.6	-83.5	7.52	2.05	-2.11	0.757	-5.85	-0.319	1.58
Siltronic									
SL01A	-3.88	-12.2	-6.52	1.56	-2.06	0.452	-7.28	-8.39	-2.67
SL01E	-35.8	-96.8	9.36	2.63	-2.23	1.70	-4.65	1.11	2.40
SL02A	-7.59	-21.7	-4.41	0.843	-0.967	-0.140	-7.19	-7.34	-2.84
SL02C	-25.2	-69.2	4.95	1.69	-1.97	0.781	-6.25	-1.25	1.49
SL02E	-26.8	-73.2	4.24	1.63	-2.03	0.580	-6.51	-1.22	1.44
SL03A	-15.3	-41.9	-2.24	0.587	-1.10	-0.355	-7.18	-6.37	-2.89
SL03C	-24.8	-68.1	3.98	1.58	-2.28	0.603	-6.48	-1.50	1.36
SL03F	-23.0	-63.0	3.18	1.61	-1.67	0.546	-6.73	-1.71	1.46
SL04A	-8.15	-22.8	-5.17	0.750	-0.772	-0.489	-7.38	-7.26	-2.94
SL04F	-23.2	-63.6	2.25	1.52	-1.98	0.422	-6.84	-1.76	1.42
SL05A	-6.41	-18.9	-4.63	1.39	-1.75	0.441	-6.90	-7.61	-2.58
Willbridge									
W04C	-33.1	-90.1	8.43	2.00	-2.16	0.920	-5.39	0.284	1.67
W06A	-57.4	-151	2.91	0.108	-1.35	-1.66	-7.42	-1.26	-2.76
W07C	-41.6	-111	4.03	0.210	-1.23	-1.48	-7.54	-3.03	-2.88
W09A	-55.8	-146	2.70	0.008	-1.43	-1.99	-7.68	-1.37	-2.77
W09C	-22.2	-60.7	1.05	1.00	-1.90	0.079	-7.07	-2.25	0.88
W12A	-13.3	-37.9	-1.18	0.920	-2.52	-0.086	-7.20	-6.68	-2.64
R2W02	-5.85	-17.7	-4.19	1.98	-2.16	0.911	-6.92	-7.98	-2.37

Appendix E

LWG
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PORTLAND HARBOR RI/FS

COMPREHENSIVE ROUND 2 SITE CHARACTERIZATION SUMMARY AND DATA GAPS ANALYSIS REPORT

APPENDIX E

FOOD WEB MODEL AND BIOTA-SEDIMENT ACCUMULATION FACTOR (BSAF) DEVELOPMENT

February 21, 2007

LWG
LOWER WILLAMETTE GROUP

PORTLAND HARBOR SUPERFUND SITE
COMPREHENSIVE ROUND 2 SITE CHARACTERIZATION
SUMMARY AND DATA GAPS ANALYSIS REPORT
APPENDIX E: BSAFS AND FOOD WEB MODELING

February 21, 2007

Prepared For:
The Lower Willamette Group

Prepared By:
Windward Environmental LLC

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LIST OF ACRONYMS

AOPC	area of potential concern
BEHP	bis(2-ethylhexyl) phthalate
BIC	benthic invertebrate consumer
BIF	benthic invertebrate filter feeder
BSAF	biota-sediment accumulation factor
COI	chemical of interest
COPC	chemical of potential concern
dw	dry weight
EIC	epibenthic invertebrate consumer
EPA	US Environmental Protection Agency
ERA	ecological risk assessment
FWM	food web model
GIS	geographic information system
HCH	hexachlorocyclohexane
HHRA	human health risk assessment
iAOPC	initial area of potential concern
iCOC	initial chemical of concern
Integral	Integral Consulting, Inc.
iPRG	initial preliminary remediation goal
J-qualifier	estimated concentration
K_{OW}	octanol-water partition coefficient
LIDAR	light detection and ranging
LN	lipid normalized
LOE	line of evidence
LWG	Lower Willamette Group
LWR	Lower Willamette River
N-qualifier	presumptive evidence of a compound
NLOM	non-lipid organic matter
OC	organic carbon
ODEQ	Oregon Department of Environmental Quality
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PRG	preliminary remediation goal
RI/FS	remedial investigation/feasibility study
RL	reporting limit

RM	river mile
SCRA	site characterization and risk assessment
SD	standard deviation
SMA	sediment management area
SPAF	species predictive accuracy factor
SWAC	spatially weighted average concentration
TEQ	toxic equivalent
TRV	toxicity reference value
TSS	total suspended solids
U-qualifier	not detected at a given concentration
UCL	upper confidence limit
VBA	Visual Basic for Applications®
ww	wet weight
XAD	Infiltrex system with XAD resin column

1.0 EXPOSURE MODELING APPROACH

Exposure modeling includes the prediction of tissue concentration from sediment or sediment and water concentrations. For the *Portland Harbor Superfund Site Comprehensive Round 2 Site Characterization Summary and Data Gaps Analysis Report*, hereafter referred to as the Comprehensive Round 2 Report, exposure modeling was used for evaluation of chemicals of interest (COIs) and chemicals of potential concern (COPCs) in the ecological risk assessment (ERA) and for development of initial preliminary remediation goals (iPRGs) for Round 2 initial chemicals of concern (iCOCs) for human health and ecological (i.e., fish and wildlife) receptors. In order to evaluate COIs for some receptors, biota-sediment accumulation factors or functions (BSAFs) were developed to ensure that predicted tissue concentrations did not identify potential risk that empirical tissue data had not identified. The process for this is detailed in Section 2.0, and the list of COIs by receptor is presented in Appendix G. The overall approach for exposure modeling for iPRG development and in application in the ERA for COPCs is discussed below.

One of the goals of the Comprehensive Round 2 Report is to develop iPRGs for iCOCs for each human health and ecological (i.e., fish and wildlife) receptor. The development of final PRGs requires the completion of the baseline risk assessment. Sediment thresholds for benthos based on the ERA and human health risk assessment (HHRA) iPRGs for direct contact sediment exposures were developed based on the risk evaluations for these receptors (see Appendix G and Section 9 of the Comprehensive Round 2 Report, respectively). In order to develop sediment iPRGs for tissue-based (ecological) or tissue exposure-based (ecological and human health) risks, it was first necessary to develop a predictive relationship between chemical concentrations in sediment and tissue. A mechanistic approach such as a food web model (FWM) is preferred because it describes chemical retention and movement between organisms and abiotic media and across trophic levels. However, the FWM (Windward 2005c) selected for application to the Lower Willamette River (LWR) is the Arnot and Gobas (2004) model, which was designed for hydrophobic organic chemicals. If chemicals are highly metabolized, a metabolism rate is needed for model development as well. Appropriate estimates of metabolism are often lacking for the chemicals and organisms of concern in the LWR. In addition, it is important that the chemical be detected consistently in water, sediment, and tissue so that the model can be accurately calibrated and model performance evaluated. Developing and calibrating FWMs for numerous chemicals is also time consuming. For these reasons, FWM development was focused on the chemicals and chemical groups (hereafter referred to as chemicals) that were consistently detected in all media and expected to be risk drivers.

At a June 6, 2006, meeting between the US Environmental Protection Agency (EPA), its partners and the Lower Willamette Group (LWG), it was agreed that the FWM (specifically the Arnot and Gobas model [2004]) would be applied for iPRG development for the following chemicals: polychlorinated biphenyls (PCBs), DDTs,

and dioxin-like chemicals. For other iCOCs, a biota-sediment relationship would be explored. This latter approach is less rigorous and involves the statistical evaluation of sediment and tissue chemical concentration data so that a predictive relationship can be developed. This approach, unlike the FWM, does not consider exposure from water explicitly. Instead all chemical exposure is assumed to come ultimately from sediment. Table 1-1 presents all iCOCs from the HHRA and Round 2 ERA (see Appendices F and G, respectively) and identifies which chemicals were evaluated using the FWM and/or evaluated for a biota-sediment relationship. The exploration and application of biota-sediment relationships are presented in Section 2.0. FWM development and application are presented in Section 3.0.

In addition, the FWM or a biota-sediment relationship (site-specific regression) was used in the ERA to predict tissue concentrations when data were lacking. Specifically, some sandpiper prey items were modeled if there were no empirical data for a particular beach area. The chemicals that were modeled and the modeling approach for ecological risk application are presented in Table 1-2. If the chemical was modeled for iPRG development with the FWM (Table 1-1), the FWM was also used for this ERA application. In addition, aldrin was modeled with the FWM because it was consistently detected in all media of concern and is not significantly metabolized. For all other chemicals, a site-specific regression was used.

2.0 BIOTA-SEDIMENT RELATIONSHIP DEVELOPMENT

BSAFs are relationships used to describe the accumulation of sediment-associated organic compounds or metals in tissues of ecological receptors (Burkhard 2006). BSAFs are calculated from paired sets of chemical concentrations in sediment and tissue. BSAFs can be calculated in two ways: 1) from the slope of the line that results from plotting paired sediment and tissue concentrations, or 2) as the average of BSAF values calculated for each paired dataset. In theory, the calculation of BSAFs should be very straightforward; if the relationship between sediment and tissue is proportional, then both methods should result in the same value (although in practice, the two methods will not have the same uncertainty distribution even if the data are suitable for calculating a BSAF by averaging individual ratios). In practice, the relationship between sediment and tissue can be difficult to discern, non-proportional, and/or even non-existent. Draft EPA guidance (Burkhard 2006) was followed to the extent possible in developing BSAFs; however, the guidance does not cover all the issues that arise when the BSAFs are developed.

Section 2.1 describes how BSAFs were estimated for receptors with small exposure areas (i.e., worms, clams, crayfish, and sculpin). Section 2.2 describes how BSAFs were estimated for fish with larger exposure areas (i.e., black crappie, juvenile chinook salmon, peamouth, brown bullhead, largescale sucker, northern pikeminnow, smallmouth bass, and carp).

2.1 BENTHIC INVERTEBRATE/SCULPIN BSAFS

Field-collected tissue samples for clams (*Corbicula* spp.), crayfish (indeterminate genus), and sculpin (*Cottus* spp.) were collected with co-located sediment samples from locations throughout the Study Area. In addition, laboratory bioaccumulation tests were conducted with worms (*Lumbriculus variegatus*) and clams (*Corbicula fluminea*) using sediment collected in the field (Windward 2005a).

The co-located empirical sediment and tissue concentration data from the ERA dataset were used to estimate BSAFs. Sediment and tissue concentrations of organic COIs were organic carbon- (OC-) and lipid-normalized (LN), respectively. Only when the chemical was detected in both co-located sediment and tissue samples were the sediment and tissue pairs used to estimate BSAFs. The co-located tissue and sediment concentration datasets for the laboratory worms, field clams, laboratory clams, crayfish, and sculpin and scatterplots of tissue concentrations versus sediment concentrations and paired BSAFs versus sediment concentrations are provided on a CD in Microsoft® Excel® format for all COIs that were not modeled with the FWM.

Visual inspection of the ERA dataset was the first step in estimating BSAFs. Tissue concentrations and pair-wise BSAFs (i.e., the ratios of co-located tissue and sediment concentrations) were plotted against sediment concentrations. The purpose of graphing the data was to identify trends that would help determine whether the

averaging approach or a regression model should be used for BSAF estimation (Burkhard 2006).

The relationship between the paired BSAFs for hydrophobic organic COIs and organic carbon-normalized sediment chemical concentrations are illustrated in Figure 2-1 for laboratory-exposed worms, Figure 2-2 for field-collected clams, Figure 2-3 for laboratory-exposed clams, Figure 2-4 for field-collected crayfish and Figure 2-5 for field-collected sculpin. Note that for all these species and a range of organic chemicals that included total PCBs, DDTs, and total polycyclic aromatic hydrocarbons (PAHs), the calculated BSAF values decrease with increasing sediment concentrations. Potential explanations for this trend include:

- Relatively constant waterborne exposure (due to water column mixing or, in the case of laboratory bioaccumulation tests, water exchanges) over a range of sediment concentrations
- Physiological constraints on bioaccumulation at higher sediment concentrations

Using an average paired BSAF to predict tissue concentrations when this trend occurs would underestimate tissue concentrations at lower sediment concentrations and overestimate bioaccumulation at higher sediment concentrations.

If upon visual and statistical inspection the BSAF was found to be independent of the sediment concentration, the averaging approach was used per the draft EPA guidance (i.e., the average of the BSAFs calculated for each co-located sediment and tissue concentration pair was selected).

The relationships between chemical concentrations in tissue and co-located sediment, and between pair-wise BSAFs and sediment were examined for each COI to determine whether statistically significant linear or log-linear regressions existed. The term "significant" used here means that there was sufficient statistical evidence to conclude that the slope of the true regression line was not zero. Significance was determined by calculating the probability (p-value) of obtaining an F-ratio greater than or equal to the observed F-ratio if the true slope of the regression line was zero. The regression was deemed significant if the p-value was less than 0.05.

If upon visual and statistical inspection the BSAF was found to be independent of sediment concentration, the averaging approach (i.e., the average of the pair-wise BSAFs) was used per the draft EPA guidance. If inspection revealed no relationship between sediment and tissue concentrations (e.g., for several metals) or an inverse relationship (i.e., statistically significant decrease in tissue concentrations as sediment concentration increased), then a BSAF was not estimated.

In cases where the averaging approach was inappropriate, the linear and log-linear regressions were evaluated for suitability as BSAFs. Factors considered in selecting the linear or log-linear BSAF included the R^2 value, distribution of residuals, and

distribution of the sediment concentration data on linear and log scales. If the BSAF was decreasing as sediment concentration increased but the tissue concentrations at higher sediment concentrations were non-detects, a BSAF was not calculated.

2.2 DEMERSAL/PELAGIC FISH BSAFS

Site-specific fish BSAFs were derived for ERA and HHRA fish species that live in the water column for all iCOCs that were not modeled using the FWM (Table 1-1). The BSAF expresses the steady-state relationship between the concentration of a bioaccumulating chemical in sediment and that measured in the tissue of an organism.

BSAFs for organic iCOCs were derived using Equation 1:

$$BSAF = \frac{(C_{tiss,LN})}{(C_{sed,OC})} \qquad \textbf{Equation 1}$$

Where:

BSAF = site-specific fish BSAF
$C_{tiss,LN}$ = fish tissue concentration, LN (mg/kg lipid dry weight [dw])
$C_{sed,OC}$ = surface sediment concentration, OC-normalized (mg/kg OC dw)

BSAFs for mercury were derived using Equation 2:

$$BSAF = \frac{(C_{tiss,dw})}{(C_{sed,dw})} \qquad \textbf{Equation 2}$$

Where:

BSAF = site-specific fish BSAF
$C_{tiss,dw}$ = fish tissue concentration (mg/kg dw)
$C_{sed,dw}$ = surface sediment concentration (mg/kg dw)

2.2.1 Dataset Definition

BSAFs were derived using surface sediment and fish tissue data. Tissue data consisted of all Round 1 and Round 2 whole-body fish tissue collected by LWG included in the LWG ERA dataset (described in detail Appendix G). Geographic information system (GIS)-generated spatially weighted average concentrations (SWACs) were calculated to represent surface sediment concentrations to estimate fish BSAFs. The sediment data used to generate SWACs were also based on the ERA dataset, which included a subset of data from the site characterization and risk assessment (SCRA) database. Only those data included in the SCRA database of acceptable data quality for risk evaluation (Category 1/QA2) were included in the ERA dataset, as agreed to between LWG, EPA, and EPA's partners in the Programmatic Work Plan (Integral et al. 2004). Surface sediment in the ERA dataset included all data collected from within the top 30.5 cm of the sediment horizon and located within the Study Area, excluding Round 1 human health beach sediment.

Sediment natural attenuation cores collected by LWG for nature and extent were not included in the ERA dataset because multiple depth intervals in small increments (as small as 4 cm) were collected within the 0 to 30.5 cm surface sediment depth horizon, and these cores were collected to support the nature and extent evaluation.

For GIS mapping, surface sediment results qualified as non-detected were treated as one-half the reporting limit (RL) value. Only those stations with reported results were included in the set of points for generating Thiessen polygons for the SWAC calculation. The ratio of each Thiessen polygon's area to the total area was multiplied by the analyte value at each station, and the sum of these area-weighted values was the SWAC. The GIS boundary layer was based on the current draft Study Area boundary from Integral Consulting, Inc. (Integral), defined as just above River Mile (RM) 2.0 to RM 11. The upland boundary of the analysis was the Oregon Department of Environmental Quality (ODEQ) definition that divides the in-water Study Area from upland areas (+13 ft NAVD88 contour line). Integral meshed LWG's light detection and ranging (LIDAR) and precision bathymetry dataset to produce this river edge. Field replicates were treated as discrete samples during data analysis. However, those replicates with coordinates identical to the parent sample were excluded from GIS exports to prevent mapping errors.

2.2.2 BSAF Derivation for Site-Wide Receptors

For site-wide receptors (i.e., black crappie, brown bullhead, carp, largescale sucker, peamouth, and juvenile chinook salmon), BSAFs were calculated using the following methodology:

- Sediment concentrations were represented using site-wide GIS-generated SWACs (Table 2-1).
- Tissue concentrations were represented using all detected whole-body tissue composite concentrations for all site-wide receptors. Non-detected tissue concentrations were not used to derive fish BSAFs.
- BSAFs were derived using Equations 1 and 2 for all detected tissue concentrations for each species. A BSAF was calculated for each composite tissue sample compared to the SWAC. An average BSAF was derived for each trophic guild when data were available (Table 2-1). Minimum and maximum BSAFs are presented for all site-wide fish receptors.

2.2.3 BSAF Derivation for Fish with Small Home Ranges

For smallmouth bass and northern pikeminnow,[1] BSAFs were calculated using the following methodology:

- Sediment concentrations were represented using SWACs over a 1-mile-long stretch (for smallmouth bass) and 2-mile-long stretch (for northern pikeminnow). These areas represented the areas over which fish were collected for composite tissue analyses.
- Tissue concentrations were represented using detected whole-body tissue composite concentrations only. Non-detected tissue concentrations were not used to derive fish BSAFs.
- BSAFs were derived using Equations 1 and 2 for all detected tissue concentrations to their respective 1- or 2-mile SWACs. A BSAF was calculated for each composite sample from a given 1-mile (for bass) or 2-mile (for pikeminnow) reach. The average BSAF for each reach was then calculated for the sample/sediment pairs.
- An average BSAF was derived for smallmouth bass and northern pikeminnow when data were available (Table 2-1, listed as "piscivores"). BSAFs were derived for organic iCOCs and mercury only (not for other metals iCOCs).

2.3 BSAF UNCERTAINTIES

2.3.1 Uncertainties in the Benthic Invertebrate/Sculpin BSAF Approach

The BSAFs that were developed for benthic invertebrates and sculpin are based on co-located empirical data. Some of the BSAFs are highly uncertain because they were based on one or a few co-located data pairs due to low detection frequencies (e.g., some BSAFs were based on a single co-located sediment-tissue concentration pair). In the BSAF models developed for beta-hexachlorocyclohexane (HCH) and endrin, the majority of the higher concentrations were either NJ-qualified concentrations or non-detected concentrations (non-detected concentrations were included has one-half the detection limit in the models), and the 95th percentile site-wide sediment concentration was much higher (approximately 500 times) than the maximum co-located sediment concentration.

In the case of metals, often there was no relationship between sediment and tissue concentrations. This was not unexpected because organisms are adapted to bioregulate metals concentrations over natural ranges of exposure concentrations. In a few cases (e.g., copper in laboratory-exposed clams), a linear BSAF was accepted, but the data were more consistent with a threshold (e.g., piece-wise linear or "hockey stick" regression) model in which bioaccumulation only increases above background

[1] Sculpin BSAFs are presented with benthic invertebrate BSAFs based on co-located sediment and tissue data.

at elevated concentrations. In these cases, further analysis would be required if the BSAF were to be used to extrapolate below the apparent bioaccumulation threshold because there was no evidence in the empirical data that reducing sediment below that level would reduce tissue concentrations. The effect of using linear regression models instead of log-linear was conservative because the Study Area-wide 95th percentile was less than the maximum co-located sediment concentration. The linear regression model had a lower slope than would have been expected from a hockey stick regression model.

In the case of individual PAHs, it was often difficult to discern whether there was a relationship between the BSAF and the sediment concentration; however, visual inspection of the data across the individual PAHs suggested that BSAF was a declining function of the sediment concentration so regression models were used instead of the averaging approach. The resultant BSAFs were generally more conservative than those that would have been generated if the averaging approach had been used.

2.3.2 Uncertainties in the Fish BSAF Approach

The greatest source of uncertainty in developing fish BSAF values was in the definition of the home ranges for the different species. The calculation of SWACs did not take into account the ecological exposure of the fish that may have habitat preferences that result in an exposure that is greater or less than exposure to the site-wide SWAC concentration for a given chemical.

BSAFs for site-wide fish were based on detected tissue concentrations. Many organic contaminants were rarely detected. The exclusion of the non-detected values resulted in a BSAF that was based on very few samples. Similarly, the SWACs were calculated using one-half RLs for non-detected concentrations in sediment. The site-wide detection frequency in sediment was low for many organic COPCs (< 50% for most chemicals). Further work with statistical techniques that support the use of non-detected results, such as regression-on-order statistics, may be warranted for some chemicals.

BSAFs were not developed for inorganic iCOCs with the exception of mercury. Most metals are bioregulated by fish and are not considered to be bioaccumulative. Therefore, there was no theoretical basis for the development of BSAFs. Regional and background concentrations of metals in fish tissue and sediment may be developed to provide a basis for the identification of areas with elevated concentrations.

Organochlorine pesticides (other than the DDT isomers) were rarely detected in tissue or sediment. When these chemicals were detected, they were frequently NJ-qualified, which indicates that the laboratory believed that the identification and quantification of the compound was uncertain because of analytical interference. Most commonly, the presence of PCB congeners results in high bias in the pesticide results. Further

investigation of the influence of NJ-qualified results on the BSAF results for these chemicals may be warranted.

3.0 FOOD WEB MODEL

3.1 MODELING GOAL AND APPLICATIONS

The overall goal of food web modeling for the Portland Harbor remedial investigation/feasibility study (RI/FS) is to characterize predictive relationships between the chemical concentrations present in sediment, water, and tissue. The specific goal of the Comprehensive Round 2 Report was to use the FWM to derive iPRGs for PCBs, DDTs, and dioxin-like compounds. The iPRGs are SWACs at which chemical concentrations present in fish tissue are predicted to be below concentrations associated with unacceptable risk. The iPRGs are used to identify iAOPCs in Section 10 of the Comprehensive Round 2 Report. In future applications, the FWM will be used to set final PRGs for the identification of AOPCs and the definition of sediment management areas (SMAs) and, in conjunction with fate and transport models, to evaluate different remedial options.

Section 3.2 presents the processes for model development and calibration, followed by the plan for using the model to develop iPRGs and approaches to evaluate model sensitivity and uncertainty. Sections 3.3 to 3.5 present model performance results, sensitivity analysis, and uncertainty analysis, respectively. The mechanical details (e.g., the number of model runs and values used) for human health and ecological iPRG calculation are also presented in Section 3.3. The resulting iPRGs are presented in Section 10 of the Comprehensive Round 2 Report. Section 3.6 presents a summary and future direction, particularly as these relate to data needs for future model applications.

3.2 MODEL DEVELOPMENT AND METHODOLOGY

The Arnot and Gobas model (Arnot and Gobas 2004; EPA 2006) was selected after an evaluation of several different FWMs (Windward 2005c, 2004). The Arnot and Gobas FWM (2004) includes several advances over previous Gobas-type models; these were discussed in the 2005 FWM report (Windward 2005c). This model is most appropriate for hydrophobic organics. Some general underlying assumptions include:

- The aquatic system is in steady state with respect to bioaccumulation of hydrophobic organic chemicals.
- The flux of chemicals between water and organisms, between ingested media (i.e., sediment and other organisms) and organism tissue, and between different tissue types (e.g., lipid and non-lipid organic matter) are governed by fugacity relationships (Arnot and Gobas 2004).

The above assumptions are generally made for applications of Gobas-type models, which have been used for a variety of sites including rivers, lakes, and estuaries. The

model structure and additional model assumptions are discussed in the following subsections.

3.2.1 Species to be Modeled

The use of an overly detailed FWM with numerous species categories would have exceeded both the availability of site-specific and literature-derived physiological data (ODEQ 2006). The LWR FWM working group, which consists of LWG members and EPA and its partners, had several discussions to agree on the species to be modeled. EPA and its partners stated, "as the model's primary purpose is to inform remediation decisions and not to precisely predict tissue residues, a simplified food web, encompassing pelagic and benthic species, should be sufficient at this time" (EPA 2006). Based on this premise, certain representative pelagic and benthic species were selected for modeling through negotiations within the LWR FWM working group. The trophic groups modeled, and the representative species for which LWG data are available (listed in parentheses), are as follows:

- Phytoplankton
- Zooplankton
- Benthic infaunal invertebrate filter feeders (clams, *Corbicula* spp.)
- Benthic infaunal invertebrate consumers[2]
- Epibenthic invertebrate consumers (crayfish [crayfish samples were not identified by species])
- Foraging fish (sculpin, *Cottus* spp.)[3]
- Benthivorous fish (largescale sucker, *Catostomus macrocheilus*)[4]
- Omnivorous fish (common carp, *Cyprinus carpio*)
- Small piscivorous fish (smallmouth bass, *Micropterus dolomieui*)
- Large piscivorous fish (northern pikeminnow, *Ptychocheilus oregonensis*)

3.2.2 Development of Visual Basic for Applications® Model

The LWG was provided with a Visual Basic for Applications® (VBA) version of the Arnot and Gobas (2004) model by Dr. Bruce Hope, a senior environmental toxicologist with ODEQ (ODEQ 2006). In this version of the model, an Excel® workbook uses imbedded VBA macros to perform calculations. This version of the model was evaluated and adjusted in collaboration with Dr. Hope to ensure that it functioned in the same manner as the original Arnot and Gobas version of the model. The equations used in the modified model and general model assumptions are the

[2] A generalized category designed to represent oligochaetes, insect larvae, and amphipods.
[3] This trophic group was also used to represent black crappie for iPRG development.
[4] This trophic group was also used to represent brown bullhead for iPRG development.

same as those in the Arnot and Gobas model (2004). These equations along with the actual VBA code are described in a detail in Attachment E1.

3.2.3 Selection of Chemicals to be Modeled

The FWM was applied to several hydrophobic organic chemicals. The following subsections describe the chemicals that were used to calibrate the model and the chemicals to which the model was applied for iPRG development. Other applications of the model for the ERA also are described.

3.2.3.1 Chemicals Used for Initial Model Calibration

There are numerous parameters used in the FWM that are not chemical-specific (e.g., lipid content of zooplankton). Accurate values for parameters common to all chemicals (hereafter referred to as non-chemical-specific parameters) must be selected so that the model can perform well for a range of chemicals. Six individual chemicals and one chemical group were selected for the development of optimal values for non-chemical-specific input parameters. Three of these chemicals used to initially calibrate the model were not among the chemicals for which iPRGs were developed (Table 1-1).

For model calibration, it was desirable to have individual chemicals with a range of octanol-water partition coefficient (K_{OW}) values. Although the chemicals to be modeled for iPRG development (Table 1-1) have a range of K_{OW}s, many are mixtures. PCB congener data was available for water, sediment, and tissue, and PCB congeners are commonly modeled with Gobas-type models. Three PCB congeners were selected for initial calibration based on four criteria. First, chemicals for calibration that represented a range of K_{OW} values were chosen so that model performance could be evaluated across the spectrum of K_{OW} values. It was important to select chemicals with a range of K_{OW}s because the model is highly sensitive to K_{OW}, which is involved in numerous model equations (see Attachment E1) (Arnot and Gobas 2004). Second, congeners with a high frequency of detection in sediment, water, and tissue were chosen. Third, congeners that did not co-elute during chemical analysis were chosen because co-elution makes concentration data difficult to interpret. Finally, congeners that made up a relatively high percentage of the total PCB concentration were chosen. The congeners chosen for use during the calibration process were PCB 17 (K_{OW} = 5.25), PCB 170 (K_{OW} = 7.27) and PCB 206 (K_{OW} = 8.09) (Hawker and Connell 1988). Attachment E2 provides details on the frequency of detection and the concentrations of these three congeners in water, sediment, and tissue samples. In addition to these three chemicals, four other chemicals for iPRG development (4,4′-DDD; 4,4′-DDE; and 4,4′-DDT; total PCBs) were used in the non-chemical-specific calibration. Model calibration is described in detail in Section 3.2.5.

3.2.3.2 Chemicals and Chemical Groups for iPRG Development

After initial model calibration (for non-chemical-specific parameters), the chemical-specific parameters of the model were calibrated for each chemical for which an

iPRG was needed (see Table 1-1). These included total PCBs (as a sum of Aroclors), PCB toxic equivalents (TEQs [birds and mammals]), dioxin/furan TEQs (birds and mammals), and DDT compounds. For the purpose of this appendix, chemical-specific parameters refer to those parameters used for the modeling of a specific chemical. Some of these parameters, such as chemical concentration in water and sediment are also site-specific parameters. K_{OW} and chemical concentration in water were calibrated for each chemical for a specific sediment concentration. Details on the calibration and iPRG development process are presented in Section 3.2.5.

3.2.3.3 Chemicals Modeled for Ecological Risk Assessment Applications

For the ERA, the FWM was used to predict benthic tissue chemical concentrations when data were lacking. This was done for several chemicals listed in Table 1-2. In addition, the model was applied for aldrin to predict benthic tissue concentrations for risk estimates. The details of these FWM applications are presented in the ERA (Appendix H and Section 8 of the Comprehensive Round 2 Report).

3.2.4 Model Performance Metrics

One model performance metric was used to characterize the ability of the model to predict tissue chemical concentrations at specified sediment and water chemical concentrations. The primary model evaluation metric used was the species predictive accuracy factor (SPAF). The SPAF can be calculated in one of two ways: 1) if the model is overpredicting, such that the predicted value is greater than the empirical value, then the SPAF is calculated by dividing the predicted value by the empirical value, or 2) if the model is underpredicting, the SPAF is calculated by dividing the empirical value by the predicted value. Thus the SPAF is always a positive value greater than 1.

$$\text{SPAF} = \text{predicted/empirical or SPAF} = \text{empirical/predicted} \qquad \textbf{Equation 3}$$

The LWR FWM working group established a performance goal of predictive capability within a factor of 10 (average of all modeled groups). For the purpose of this report, a factor of 10 (average of all trophic groups) was considered the minimum model performance and an average factor of 3 was identified as a target. By definition, a SPAF of 1 demonstrates that the model is exactly predicting the empirical data.

3.2.5 Modeling Approach

Model calibration was performed through probabilistic analysis. An overview of the calibration process is presented here, and details are presented in Section 3.2.5.2. Briefly, the model for one of the PCB congeners selected for initial calibration (Section 3.2.3.1) was run thousands of times using Monte Carlo simulation (performed using Crystal Ball® software) with different combinations of plausible values for model input parameters. The best performing model run (i.e., the one with the lowest SPAF) was identified. The values for non-chemical-specific parameters

(i.e., all parameters except K_{OW}, chemical concentration in sediment, and chemical concentration in water) were applied to the model for another example PCB congener. After confirming that these parameters performed well for other chemicals with a range of K_{OW}s (Section 3.2.3.1) and some other example chemicals, these calibrated parameter values were applied to the models for all other modeled chemicals (Section 3.2.3.2). Probabilistic analysis was again used to select the values for chemical-specific parameters (K_{OW} and chemical concentration in water) associated with the best model performance (i.e., lowest SPAF) at a specific sediment concentration.

3.2.5.1 Selection of Model Parameter Values and Distributions Used for Calibration

This section presents an overview of the selection of initial input values used in the probabilistic model. The input parameters required by the adaptation of the Arnot and Gobas bioaccumulation model (Arnot and Gobas 2004) used in this report were derived from site-specific data whenever possible. The main sources of site-specific data were the Round 1 and Round 2 data collected for the Portland Harbor RI/FS. When an input parameter could not be defined using this data, literature values and best professional judgment were used.

Parameter distributions were defined based on the assigned shape (i.e., normal or triangular) and descriptive statistics (i.e., mean and standard deviation or mode, maximum, and minimum). The distributions were intended to reflect the uncertainty in estimates of central tendency. For example, according to the Central Limit Theorem, estimates of the mean (with sufficient sample size) approach a normal distribution. The standard deviation of the distribution of estimates of the mean is defined by the standard error of the original data. The process for the selection of a distribution shape is described in Attachment 3. Attachment 3 also presents the distributions and values selected for all model parameters, including dietary assumptions. Distributions were developed for over 100 model parameters. The distributions used for model calibration for water and sediment chemical concentrations are summarized here because these parameters are of particular relevance to the task of developing a predictive relationship between sediment, water, and tissue chemical concentrations.

3.2.5.1.1 Chemical Concentrations in Water

Chemical concentrations in the water column were calculated from nine integrated river transect XAD (Infiltrex system with XAD resin column) samples collected at three locations. Data were collected once at each location during each of the three sampling events that took place in November 2004, March 2005, and July 2005 (n = 9) (Integral 2004). Table 3-1 presents the distribution type, mean value, and standard deviation calculated for each modeled chemical, including the three PCB congeners that were used for model calibration but not iPRG development (i.e., PCB 17, PCB 170, and PCB 206). As described in Attachment 3, normal distributions were assigned when site-specific data were available and were sufficient to define a mean and standard error.

3.2.5.1.2 Chemical Concentrations in Sediment

Sediment chemistry data were available from LWG and non-LWG sources for locations throughout the Study Area (RM 2 to RM 11). In order to minimize any spatial bias that may be present in the data, a SWAC was calculated for the modeled chemicals using Thiessen polygons (Table 3-2). The process for developing Thiessen polygons and generating SWACs is described in Section 10 of the Comprehensive Round 2 Report. SWACs were based on site-wide chemical concentrations in sediment.

For the FWM application for developing iPRGs, sediment chemical concentration was defined as a decision variable, consistent with Morgan and Henrion (1990):

> "Decision variables are quantities over which the decision maker exercises direct control. They are sometimes also referred to as control variables or policy variables. For example, in a risk assessment model designed to help an EPA decision maker set a standard for a particular air pollutant, the permitted maximum ambient level or total quantity of pollutant emitted might be a decision variable. ...One may very well be uncertain about the 'best' value for a decision variable – otherwise why would we be constructing a policy model in the first place? But it does not make sense to be uncertain about its 'true' value. If it is a decision variable, then by definition it has no true value. It is up to the decision maker to select its value."

According to Morgan and Henrion (1990), sediment chemical concentrations should be treated parametrically because they are decision variables. "Treated parametrically" means that the analysis should be repeated with a range of possible SWAC values (point estimates) until the model produces the desired outcome (target tissue concentration). The resulting SWAC is the iPRG.

In order to calibrate the model, it was necessary to define current conditions (Table 3-2). Uncertainties surrounding estimates of the baseline (current conditions) SWAC would also apply to alternative conditions (such as iPRGs or estimates of post-remediation SWACs) provided they all are calculated consistently (i.e., based on the same Thiessen polygons). This does not mean that sediment concentration uncertainty can be ignored, but it reduces the importance of this uncertainty in the FWM. Uncertainty associated with this assumption was explored through the model sensitivity and uncertainty analysis but was not included in the model calibration (unlike water chemical concentrations, which had distributions used for model calibration).

3.2.5.2 Probabilistic Approach to Model Calibration

In order to calculate iPRGs, it was necessary to develop a calibrated FWM. Calibration was performed by selecting the input parameter values from initial parameter distributions that produced the best estimate of the empirical tissue

concentration (i.e., model prediction with the lowest average SPAF). Empirical tissue concentrations for modeled chemicals that were used to calculate SPAFs are presented in Attachment 4.

This process was performed in two steps. First, the model was calibrated for the parameters applicable to all chemicals, and then the model for each chemical was further calibrated for those parameters that were chemical-specific (i.e., K_{OW}, chemical concentration in water). The SWAC was used as a point estimate for the sediment chemical concentration. Because the uncertainty surrounding current sediment chemical concentrations would also apply to alternative conditions (iPRGs), a distribution describing many of the uncertainties surrounding the SWAC was not included in the model calibration. In addition, uncertainty related to the relationship between sediment chemical concentrations and other parameters, such as water chemical concentration, were not evaluated through the inclusion of distributions. The uncertainties related to sediment chemical concentrations and the relationship between chemical concentrations in water and sediment were evaluated in the uncertainty analysis. The calibration process is shown in Figure 3-1 and described in detail in the subsections that follow.

3.2.5.2.1 Calibration of Non-Chemical-Specific Parameters

The calibration of the model for non-chemical-specific parameters was performed first. In this case, the congener with the lowest K_{OW} (PCB 17) was selected for the initial calibration (see Section 3.2.3.1). The model was run probabilistically 50,000 times using the parameter distributions that were derived from site-specific data and literature values (see Attachment 3). Both chemical-specific and non-chemical-specific parameters were allowed to vary to ensure that the calibrated parameters were not overly constrained. The only exception was that sediment concentration was held as a point estimate, as explained previously.

The 50,000 model output runs were sorted based on an average SPAF, and the best run based on lowest average SPAF was selected. A screening step was performed to confirm that no parameters fell outside of the acceptable range (i.e., the ranges defined as distributions of mean estimates for parameters in Attachment 3). This was important for the dietary parameters because it was necessary to normalize these values to ensure that each modeled trophic group was achieving the correct total food intake. Dietary intake for each trophic group was defined by ranges of fractional consumption of sediment and other organisms. For each model iteration, the total of the randomly selected fractions was normalized to equal 1. During the normalization process, it is possible to generate dietary fractions outside the initial specified ranges (see Attachments 1 and 3 for details on diet). Model runs with diet fractions outside the initial specified ranges were discarded.

The non-chemical-specific parameter values from the best run (SPAF = 2.2) were entered into templates for the two other PCB congeners: PCB 170 and PCB 206. The models were then run deterministically using the calibrated values from the PCB 17

model for non-chemical-specific parameters and mean values for chemical-specific parameters (i.e., K_{OW}, chemical concentration in sediment, and chemical concentration in water). The models for the three PCB congeners were also run using the mean or mode values from the original distributions (uncalibrated values). The results from the calibrated and uncalibrated models were compared to ensure that calibration had improved model performance (i.e., reduced the average SPAF). This assessment also served to confirm that model met the minimum performance specification (mean SPAF < 10).

The calibrated non-chemical-specific values were also tested for total PCBs; 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT. As with the PCB congeners, model performance with calibrated values was compared to performance with uncalibrated values and overall model performance goals. After the calibrated values passed these tests (i.e., the model performance was acceptable for all chemicals using the originally determined distributions for all non-chemical-specific parameters), the parameter values were accepted as final calibrated values for non-chemical-specific parameters.

3.2.5.2.2 Calibration of Chemical-Specific Parameters

Once the non-chemical-specific parameters had been calibrated, the next step was to calibrate the model for each chemical to be modeled. The non-chemical-specific calibrated values were entered into the model, and distributions were included only for the chemical's K_{OW} and concentration in water. The normal distribution for the K_{OW} was define by a mean (the selected literature K_{OW} value) and a standard deviation equal to 1% of the K_{OW} selected from the literature. The range defined by these distributions generally included all the available literature values for K_{OW} for chemicals with multiple values. The normal distribution for the water chemical concentration was defined by the mean concentration of the site-specific data and a standard deviation equal to the standard error of mean of the site-specific data(see Attachment E3 for details on distribution selection). Again, the SWAC was used for sediment chemical concentration.

For each chemical, the model was run probabilistically 1,000 times, and the resulting output for the model runs was sorted by the average SPAF. For each chemical, the best average SPAF was identified, and the associated K_{OW} and water concentration values were selected as the calibrated chemical-specific values. Inherent in this calibration process is the assumption that the basic model structure is correct (i.e., the process included in the model, the trophic groups included, and the relative relationships of the trophic groups are defined appropriately). With all parameters calibrated, the minimum acceptable model performance was an average SPAF of 10 or less , and the target model performance was an average SPAF of 3.

3.2.5.3 Approach for iPRG Calculation

The HHRA and ERA identified chemicals for which iPRGs needed to be developed. For some of these chemicals (see Table 1-1), the FWM was applied to derive a relationship between water, sediment, and tissue chemical concentrations. After the chemical-specific versions of the model were calibrated with point estimates for all

parameter values except sediment chemical concentration, the FWM was used to calculate iPRGs.

Some assumptions needed to be made before application of the FWM for iPRG development. Tissue chemical concentration predictions are dependent on both sediment and water chemical concentrations. Because the relationship between chemical concentrations in water and sediment has not been well characterized, the assumption was made that the water concentration would not change with sediment concentration. This assumption was conservative in that water chemical concentrations were assumed to be reduced as sediment chemical concentrations were reduced. Thus, in the iPRG development, as sediment concentration was lowered to achieve target tissue concentrations (provided by the HHRA and ERA), water concentration was held constant. Because the FWM is a forward calculation (i.e., tissue concentration is calculated based on specified water and sediment concentrations), the model had to be run numerous times with a range of sediment concentrations until a target tissue concentration was achieved. This process was automated using Crystal Ball® software and a sediment chemical concentration distribution with a range sufficient to yield a range of tissue concentration predictions that would bound target tissue concentrations (i.e., exceed the maximum and fall below the minimum target tissue concentration).

The model's predictive capability is limited (generally an average SPAF of 10 or better), so some imprecision in the predicted tissue concentrations was acceptable in the iPRG calculations. In addition, empirical tissue chemistry data were not available for all modeled trophic groups, so model performance could only be assessed for those groups with available data. Therefore, tissue concentration predictions within 10% but not exceeding the target tissue concentrations were considered sufficiently precise. For example, if the target tissue concentration was 100 µg/kg, the closest model predicted tissue concentration between 90 and 100 µg/kg was identified, and the sediment concentration associated with this tissue concentration was then selected as the iPRG. If no predicted tissue concentrations fell between 90 and 100 µg/kg, the model was rerun with additional sediment concentrations until a predicted tissue concentration within the target range was achieved.

Some human health and ecological risk exposure scenarios involved consumption of multiple fish and shellfish species. The following equation illustrates how output from the FWM was compared to target tissue concentrations for human health or ecological consumption scenarios involving multiple species diets:

$$C_{tiss} = \frac{[(G_A + C_A) \times (G_B + C_B) + \ldots]}{Total\ G}$$ **Equation 4**

Where:

C_{tiss}	=	average chemical concentration in tissue consumed (µg/g)
G_A	=	consumption of species A (g)
C_A	=	chemical concentration of species A (µg/g)
G_B	=	consumption of species B (g)
C_B	=	chemical concentration of species B (µg/g)
Total G	=	total fish and/or shellfish consumption (g)

The model was run numerous times with different assumptions of sediment chemical concentration until the average chemical concentration in tissue consumed (calculated using the equation above with the FWM providing the chemical concentrations for the different species) was equal to or very close to the target chemical concentration. The corresponding sediment concentration was then selected as the iPRG.

The FWM included representative trophic groups. When data were available, the model was calibrated using tissue chemistry data from samples from the LWR. Section 3.2.1 provides a list of the model trophic-level groupings followed by the sampled species in the LWR, if available. In some cases, the species of interest for iPRG development were not the same as the species used for model calibration for a particular trophic group. However, the trophic group was still assumed to represent the species of interest. Specifically, the forage fish category was modeled after and calibrated with sculpin data, but for human health and ecological iPRG development, this category was assumed to also represent black crappie. Similarly, the benthic fish category was modeled and calibrated with largescale sucker data but was assumed to also represent brown bullhead for iPRG development. As discussed in Section 3.2.1, the trophic groups modeled and the species they were intended to represent were negotiated and agreed upon by the LWR FWM working group.

3.2.5.4 Model Sensitivity

The sensitivity of the model to different parameters was evaluated through a correlation approach. There are many approaches to evaluate the sensitivity of models to different parameters. The approach used this evaluation relied on the Crystal Ball® software's sensitivity analysis function, which includes consideration of both the uncertainty of a particularly input parameter value and the effect that a change in that parameter value has on model predictions (as determined solely by the mathematical formulas of the model). The model was run with distributions for all parameters for which distributions were developed (both non-chemical-specific and chemical-specific parameters). Crystal Ball® calculates "sensitivity" by computing rank correlation coefficients between each input parameter and model output value (i.e., predicted chemical concentration in tissue). The rank correlation coefficients are squared and normalized to 100%. The result can be interpreted as an estimate of the percentage of variance or uncertainty in the predicted tissue concentration due to a particular input parameter. This percent contribution estimate is useful in identifying the parameters that have the greatest influence on model prediction. This analysis was

performed using several example chemicals and chemical groups with a range of K_{OW}s: total PCBs, total DDTs, 4,4'-DDD, and dioxin TEQ (mammals).

The analysis was performed first by applying distributions to all parameters for which distributions were established in Attachment E3. Model simulations were performed with 10,000 runs for each chemical. Next, additional model simulations (n = 10,000 model runs) were performed using distributions for sediment chemical concentrations along with the distributions described in Attachment E3. It was important to evaluate model response to changes in values for different parameters with and without sediment chemical concentration uncertainty. In evaluating overall model response to changes values for different parameters, uncertainty in sediment chemical concentrations is important but this uncertainty was not considered in developing iPRG estimates.

Table 3-3 presents the average SWAC, as well as the minimum and maximum concentrations that were used to define triangular distributions for each sediment chemical concentration. These ranges were selected to extend 40% below and above the calculated SWAC value. Because much of the sediment chemical concentration uncertainty relates to the number and location of samples, the SWAC standard errors on the means were not considered sufficient to bound this uncertainty. Therefore, the distributions assigned to represent the range of chemical concentrations present in sediment relied on best professional judgment. These same distributions were also used for the uncertainty analysis.

3.2.5.5 Uncertainty Assessment

Several approaches were used to evaluate model uncertainty. First, results of the probabilistic model runs (including all parameter distributions developed) were evaluated to determine what percentage of the runs fell within the acceptable performance criteria (i.e., minimum average SPAF < 10, target average SPAF < 3). This approach used the same model output as the sensitivity analysis (Section 3.2.5.4), which included and excluded distributions for sediment chemical concentrations. It was important to evaluate uncertainty without sediment chemical concentration uncertainty because iPRG estimates did not include consideration of uncertainty related to sediment chemical concentrations. Model predictions were also compared to empirical data on a species-by-species basis, including the mean empirical values and calibrated model predictions as well as the full range of empirical values and full range of model predictions. The comparisons to empirical means provide information on the model's predictive capability, both before and after calibration. In addition, although the model was intended to predict average tissue concentrations, comparisons of model output to the full range of empirical data provide information about how the model predictions relate to the variability in the empirical data.

The FWM was also applied at several smaller spatial scales. This application was intended to address uncertainty related to the model's predictive capability for organisms with smaller home ranges. Specifically, the model was run for several

example chemicals for Swan Island Lagoon, focusing on species that might have home ranges confined to that area (i.e., plankton, invertebrates, sculpin, and smallmouth bass). The model was also applied to 1-mile catch areas (excluding the channel as supported by Pribyl et al. (2005)) for smallmouth bass. For sculpin, clams, and crayfish, the model was applied on a sample-by-sample basis using individual co-located sediment and tissue samples for these species with smaller home ranges. The data used to run the model for Swan Island Lagoon, as well as the data used to evaluate model performance (i.e., tissue chemistry data), are presented in Attachment E5.

Finally, some tissue chemistry data available from multiplate samples (Windward 2005b) and laboratory worms (*Lumbriculus variegatus*) (Windward and Integral 2005) were not used in the FWM calibration or performance evaluation. The multiplate data are not directly comparable to any FWM trophic level because the species living on the multiplates were generally benthic infaunal species, although the multiplates had been intended to reflect water column exposure. The multiplate data were considered somewhat informative because empirical data for some modeled trophic groups were lacking. Multiplate tissue chemistry data were compared to FWM predictions for zooplankton, epibenthic invertebrates, and benthic invertebrate consumers for reference. The laboratory worm data were not directly comparable to FWM predictions for benthic invertebrate filter feeders because the laboratory worms were exposed to LWR sediment but not LWR water. So the FWM was run assuming all chemical exposure was from sediment (i.e., the water chemical concentration was assumed to be equal to zero). In addition, the benthic invertebrate filter feeder compartment was intended to represent insect larvae and amphipods in addition to worms (oligochaetes). This affected the selection of values for parameters such as weight and lipid fraction (see Attachment E3). Again, for reference and in the absence of better data for comparison, FWM predictions for benthic invertebrate filter feeders were compared to empirical laboratory worm tissue chemistry data.

3.3 PREDICTIVE MODEL RESULTS

This section presents the model calibration results for non-chemical-specific and chemical-specific parameters, calibrated model performance results, and results for human health and ecological iPRG development.

3.3.1 Calibration for Non-Chemical-Specific Parameters

As discussed in Section 3.2.5, the model was first calibrated for non-chemical-specific parameters using example chemicals with a range of K_{OW}s. The non-chemical-specific parameter values for the best performing model run for PCB 17 were confirmed to improve model performance for PCB 170, PCB 206, 4,4′-DDD, 4,4′-DDE, 4,4′-DDT, and total PCBs. Table 3-4 presents the SPAF for each of the three PCB congeners, three DDT isomers, and total PCBs using the initial uncalibrated parameter values (i.e., the mean or mode of the distributions) and the calibrated parameter values from the best run for PCB 17. For the PCB 17 calibrated model run, the water chemical

concentration and K_{OW} were calibrated, but for the other chemicals, the original mean (uncalibrated) estimates for the water chemical concentration and K_{OW} were used. For all tested chemicals, the SWAC was used for the sediment chemical concentration. The average SPAFs for all trophic groups with available empirical data are presented in Table 3-4. In most cases, the use of the calibrated parameters from the PCB 17 best run reduced the average SPAF. The greatest reduction in average SPAF was for 4,4′-DDD. The calibration did increase the average SPAFs for 4,4′-DDE and 4,4′-DDT, though these changes were small compared to the improvement in the 4,4'-DDD average SPAF. The greatest reduction in trophic group SPAF was for small piscivorous fish for 4,4′-DDD. The SPAFs for some other trophic groups increased but to a much smaller degree. Overall, the calibration, reduced both over and underprediction for most chemical-trophic group combinations.

Tables 3-5 through 3-8 provide the original distributions as well as the selected calibrated values (from the best run for PCB 17) for non-chemical-specific parameters. Table 3-5 shows the environmental parameters, Table 3-6 shows the general biological parameters, Table 3-7 shows the species-specific biological parameters, and Table 3-8 shows the dietary parameters that were used in the FWM. Information concerning the selection of the initial distributions can be found in Attachment 3.

3.3.2 Calibration for Chemical-Specific Parameters

After calibration for non-chemical-specific parameters, the chemical concentration in water and the K_{OW} for each chemical were calibrated through probabilistic model runs (by selecting the values for non-chemical-specific parameters associated with the lowest average SPAF) as described in 3.2.5.2.2. Table 3-9 provides the calibrated values for K_{OW} and water chemical concentration along with the initial distributions for these parameters for all chemicals for which the FWM was used for iPRG development. The table also provides the average SPAF when all calibrated values were used in the model. In addition, the model was calibrated for aldrin. The aldrin model was used for the ERA to predict tissue concentrations in sandpiper prey when empirical data were lacking (see Appendix H for details).

3.3.3 Calibrated Model Performance

All chemicals and chemicals groups had an average SPAF below 5 with one exception (Table 3-10). Concentrations of some chemicals were either under or overpredicted The average SPAF for PCB TEQ (birds) slightly exceeded the minimum performance target of a SPAF of 10. Because the calibration worked well for all other chemicals, this slightly sub par level performance was accepted for PCB TEQ (birds). This was accepted because iPRGs for PCB TEQ (birds) were only developed for shorebirds (Section 10 of the Comprehensive Round 2 Report), which eat only lower trophic group organisms (i.e., benthic invertebrate consumers and benthic invertebrate filter feeders). The SPAF for PCB TEQ (birds) for benthic invertebrate filter feeders was 1.3, and no empirical tissue data were available for benthic invertebrate consumers. The high average SPAF for PCB TEQ (birds) was

driven largely by the poor model performance for small piscivorous fish and omnivorous fish, but the model was not applied for iPRG development using either of those trophic groups.

As demonstrated by the example of PCB TEQ (birds) iPRG application for shorebirds, the performance of the model for individual trophic groups was especially important because many iPRGs were developed based on target tissue concentrations for only one or two species (as represented by a trophic group). Compared to available empirical data, the model predicted within a SPAF of 5 or less for all but six combinations of trophic group and chemical. Three predictions exceeded empirical values and had SPAFs greater than 10: PCB TEQ (birds) in omnivorous and small piscivorous fish and 4,4′-DDT in epibenthic invertebrate consumers (crayfish) (Table 3-10). In general, predictive performance was worst for smallmouth bass and crayfish. The model overpredicted smallmouth bass and crayfish concentrations for many chemicals. Application of the model for crayfish and small piscivorous fish for smaller spatial scales was explored in the uncertainty analysis.

3.3.4 Human Health iPRG Development

Several thousand models runs were required to generate estimates of iPRGs for the human health target tissue concentrations. Table 3-11 provides the target tissue range (for all species based on back calculations from acceptable risk levels, see Section 10 of the Comprehensive Round 2 Report for details), sediment range used in the FWM, and number of the model runs needed to estimate iPRGs for each chemical. The target tissue concentrations were for individual species (represented by a single FWM trophic group) or multiple species (represented by an average of several trophic groups) for a multiple species human diet scenario.

The species represented by each trophic group are explained in Sections 3.2.1 and 3.2.5.3. The dietary assumptions for the calculation of iPRGs and target tissue concentrations are discussed in Section 10 of the Comprehensive Round 2 Report. The range of sediment concentrations needed was determined by running the model with a series of sediment concentrations until the maximum and minimum target tissue concentrations were achieved. The sediment concentration range was defined in Crystal Ball® as a uniform distribution. The number of model runs was selected to provide estimates within, but not exceeding, 10% of the target tissue concentrations (i.e., more model runs results in higher precision). The model was run using Latin hypercube sampling because it is expected to provide a more even sampling distribution than Monte Carlo sampling. Generally the model predictions used for iPRG selection were within a few percent of target tissue concentrations. The estimated human health iPRGs and the uncertainties associated with them are presented in Section 10 of the Comprehensive Round 2 Report. For many chemical exposure scenario combinations, it was not possible to develop sediment iPRGs due to contributions from water. Even assuming no contribution from sediment exposure (sediment chemical concentration = 0), predicted tissue concentrations exceeded target tissue concentrations based on chemical exposure from water alone. As

discussed previously, water chemical concentrations were held constant and assumed not to change with sediment chemical concentrations.

3.3.5 Ecological iPRG Development

Numerous model runs were also needed to generate ecological iPRGs. Section 10 of the Comprehensive Round 2 Report provides information on target tissue levels and dietary assumptions for ecological iPRG development. Table 3-12 provides the ecological target tissue concentrations, sediment concentrations evaluated, and number of model runs. The methodology for determining the range of sediment concentrations and number of models runs was the same as for the estimation of human health iPRGs. All estimated ecological iPRGs fell within the target tissue concentration range (90 to 100% of the target tissue value). Calculated ecological iPRGs are presented in Section 10 of the Comprehensive Round 2 Report. For a few receptor chemical pairs, iPRGs could not be developed. Again, this occurred when exposure from water alone resulted in predicted tissue concentrations in excess of target tissue concentrations.

3.4 SENSITIVITY ANALYSIS

The model sensitivity analysis results are based on correlations between changes in input parameters and changes in predicted tissue concentrations. The results are presented as the percent contribution of individual parameter variations to total variation in predicted tissue concentrations. Differences in model output values are influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. As discussed in the methods section, the model was run 10,000 times for each chemical with and without a distribution for sediment chemical concentration. Because of the large number of parameters with distributions (over 100), even this large number of model runs does not completely capture all possible combinations of parameter values. Replicate 10,000-run iterations of the model indicated slight differences in estimates of percent contribution; however, the top five parameters identified as contributing the most to differences in model output were very consistent across runs.

Tables 3-13 through 3-22 show the percent contribution of each parameter to differences in the model predictions for each species for several example chemicals (total PCBs, PCB TEQ (birds), dioxin TEQ (mammals), total DDTs, and 4,4′-DDD). For brevity, only parameters contributing at least 5% to differences in predictions for at least one trophic group are presented in these tables. Therefore, the totals for each species do not equal 100%. The complete results are provided in Attachment E6. In Tables 3-13 to 3-22, many of the trophic groups modeled are identified by the representative species that the trophic group was modeled after (see notes on Tables 3-13 to 3-22). The percent contribution values for all dietary parameters for each trophic group were summed; the sum presented is the sum of absolute values for all relevant dietary parameters (i.e., items with a fractional consumption assigned for that trophic group). For all other parameters, positive values indicate changes in the

parameter were proportional to changes in tissue concentration predictions, while negative numbers indicate parameter changes were inversely proportional to changes in tissue concentration predictions. The model was run with and without inclusion of a distribution for sediment chemical concentrations.

Crystal Ball® calculates model correlations between input and output parameters (an estimate of sensitivity) directly; therefore, it was not possible to screen model runs prior to running the Crystal Ball® sensitivity analysis. The result was that some runs with dietary assumptions outside specified ranges were included in the analysis (see Section 3.2.5.2.1 for details on diet). Details on the dietary assumptions and normalization of dietary constituents are included in Attachment E1, Section 6.7, and Attachment E1, Section 2.3.1. However, only about one third of the runs had one or more dietary assumptions that were outside the initial specified range. When these runs were removed for the uncertainty analysis, there was minimal impact on the distribution of the predicted concentration data (mean, 10th, 50th, and 90th percentiles for each species for all chemicals were altered by less than 1.5 %). This indicates the model output distributions were not significantly reduced or biased when the runs were excluded. Thus, inclusion of these runs was expected to have little or no effect on the correlations used for the sensitivity analysis.

The results in these tables were condensed to show only parameters that contributed 5% or more to differences in values for the model output for at least one species (shown in bold in Tables 3-13 to 3-22). In the following paragraphs, important parameters are defined as contributing 5% or more to differences in model predictions. A value of 10% or more was considered significant given the predictive capability of the model (average SPAF ranging from 1.3 to 11.2 across all chemicals, Table 3-10). However, the 5% cutoff was selected to conservatively include all parameters with model percent contributions of 10% or more. This was intended to include any parameters for which the percent contribution may have been reduced due to the inclusion of model runs with diets outside the original specified fractions. The inclusion of these runs might slightly overestimate the influence of dietary composition and underestimate the influence of other parameters on model predictions. The complete results of the sensitivity analysis can be found in Attachment E6.

The most consistently important parameter (across species and chemicals, with and without sediment variability) was K_{OW}. Generally, K_{OW} was more important with increasing trophic level and with increasing K_{OW}. Dioxin TEQ (mammals) has the highest K_{OW} values and 4,4'-DDD has the lowest (see Table 3-9 or Attachment E3). When sediment chemical concentration was allowed to vary, the importance of K_{OW} was generally reduced. Sediment chemical concentration, when allowed to vary, was very important for all trophic groups other than plankton. Chemical concentration in filtered water was consistently important for plankton. Water temperature was shown to be consistently important (often over 5%), particularly for fish groups.

Benthic invertebrate consumer lipid fraction was also important for benthic invertebrate consumers and many fish groups consuming them. This may be due in part to the large range included for lipid fraction for this species (0.008 to 0.042). This range was much broader than the lipid fraction range for most other trophic groups, due largely to the fact that benthic invertebrate consumers were intended to reflect a large and diverse group of organisms (benthic worms, insect larvae, and amphipods).

Several other parameters were less consistently important across species and chemicals. Despite the fact that very broad ranges were included for dietary consumptions parameters (often spanning 50% or more of total diet; see Attachment E3), these were only important for a few groups (i.e., northern pikeminnow, largescale sucker, and benthic invertebrate filter feeders) and only for some chemicals. Only northern pikeminnow and largescale sucker dietary consumption parameters consumption contributed more than 10% to their predicted chemical concentration differences for some chemicals. Dietary consumption parameters for most other species and chemicals contributed well below 5%. Concentration of suspended solids was important for benthic invertebrate filter feeders for PCB TEQ (birds) only. Lipid fraction and water content fraction were sometimes important for their associated modeled group (i.e., common carp lipid content to common carp predicted tissue concentration) for some chemicals. Porewater ventilation was sometimes important for benthic invertebrate filter feeders and sculpin, which consume large amounts of benthic invertebrates. Dietary absorption efficiency of lipids was sometimes important for epibenthic invertebrate consumers and, less frequently, also important for largescale sucker, which may consume large quantities of epibenthic invertebrate consumers. The non-lipid organic matter (NLOM) (octanol) proportionality constant was important for epibenthic invertebrate consumers only for a few chemicals (for 4,4′-DDD with and without sediment varying and for total DDTs without sediment varying only). Phytoplankton growth rate was important for PCB TEQ (birds and dioxin TEQ (mammals). Resistance to chemical uptake through aqueous phase (for phytoplankton) was important for phytoplankton for dioxin TEQ (mammal) only.

3.5 UNCERTAINTY ASSESSMENT

Model uncertainty was evaluated using probabilistic analysis and application of the model to smaller spatial scales. The results of these efforts are presented in Sections 3.5.1 and 3.5.2.

3.5.1 Uncertainty Evaluation Using Probabilistic Modeling

The model was run probabilistically using the full range of parameter values from the original parameter distributions (see Attachment E3 for details). These model results and results for calibrated model runs were compared to empirical data (Sections 3.5.1.1 and 3.5.1.2).

3.5.1.1 Percentage of Model Runs Falling in Acceptable Range Based on Prior Distributions

The FWM was run probabilistically (10,000 runs) with distributions for all parameters for which distributions were developed and using either a distribution for sediment (variable) or the SWAC only (constant) for several example chemicals (same model runs as for the sensitivity analysis). About 37% of the model runs for each chemical had values for at least one dietary parameter that were outside the original specified ranges (due to normalization of diets, see Attachment E3). Those model runs were excluded from the uncertainty results presented here. The results of the "filtered" model runs characterize the contribution of uncalibrated parameter uncertainty to overall model uncertainty. The inclusion of a distribution for sediment concentration did not dramatically change the range of model predictions as indicated by the average SPAF (Table 3-23). For PCB TEQ (birds) the model predictions were within a SPAF of 10 for only a small percentage of runs, whether or not sediment was allowed to vary. For all other chemicals evaluated, the majority of model runs produced average SPAFs less than 3, and at least 98% percent of the model runs were within an average SPAF of 5. For model runs except PCB TEQ (birds), all average SPAFs were less than the minimum target SPAF of 10.

3.5.1.2 Distributions of Modeled Data Compared to Empirical Data

In order to evaluate the uncertainty associated with the FWM, calibrated model values were compared to the empirical data from the Study Area. The same 10,000-run simulations used for the sensitivity analysis were also used for the uncertainty analysis. However, about 37% of the model results for each chemical were excluded because the values for at least one dietary parameter were outside the original specified ranges (due to normalization of diets, see Attachment E3). The calculated mean, 10th, 50th, and 90th percentiles including and excluding the runs with dietary parameter values outside original specified ranges differed by less than 1.5 %.

Figures 3-2 through 3-6 show a comparison of descriptive statistics for the model results (excluding runs with dietary parameters outside of original specified ranges) and empirical tissue chemistry data for total PCBs, PCB TEQ (birds), dioxin TEQ (mammals), total DDTs, and 4,4-DDD. Since the inclusion or exclusion of sediment distributions did not significantly affect the range of model predictions (see Table 3-23), the mean, 10th, 50th, and 90th percentile values for only the runs with sediment distributions were graphed. The calibrated values in the figures used the SWAC; the models were not calibrated for sediment chemical concentration. The species codes from the sensitivity analysis were used as identifiers in these figures.

The calibrated model predictions exceeded the 50th percentile of the uncalibrated model for all species for total PCBs, indicating the calibration tended to reduce predicted values. For PCB TEQ (birds), dioxin TEQ (mammals), total DDTs, and 4,4′-DDD, calibrated values generally exceeded the 50th percentile of uncalibrated values. Because calibration was performed separately for non-chemical specific

parameters and then for chemical-specific parameters, under- and overprediction for different chemicals could be addressed in part in the calibration process.

For total PCBs and dioxin TEQ (mammals), the average empirical concentration of four of the five fish groups fell within the 10th to 90th percentile range of model output. Mean empirical concentrations for largescale sucker and sculpin fell within the model's predicted range (10th to 90th percentile) for all chemicals except PCB TEQ (birds). In contrast, empirical average concentrations for smallmouth bass were outside the model's predicted 10th to 90th percentile range for four of the five chemicals evaluated. For benthic invertebrate filter feeders and epibenthic invertebrate consumers, the mean empirical concentrations fell outside the model's 10th and 90th percentiles of predictions for all chemicals. These small home range species also had some of the largest ranges of empirical data. This indicates localized conditions might be important for these species, and smaller-spatial-scale models might provide more accurate predictions of tissue concentrations. The results of smaller-spatial-scale models for these two species, as well as smallmouth bass, are presented in following sections.

The model was set up and calibrated for the prediction of mean tissue concentrations at the site. However, the uncalibrated models generally overlapped with empirical tissue concentrations for individual samples. The 10th to 90th percentiles of model predictions encompassed at least one sample's empirical tissue concentration (as indicated by the error bars) for all species for all chemicals except total DDTs and PCB TEQ (birds) in smallmouth bass, and PCB TEQ (birds) in carp and sculpin.

3.5.2 Application of the Model at Smaller Spatial Scales

For species with home ranges smaller than the Study Area, localized conditions might be important, and smaller spatial scale models might provide more accurate predictions of tissue concentrations than site wide models. The model was applied for predicting tissue chemical concentrations for species with smaller home ranges for Swan Island Lagoon (Section 3.5.2.1), and for predicting tissue concentrations for species with tissue samples that had sediment and/or water data collected in close proximity (Sections 3.5.2.2 to 3.5.2.5).

3.5.2.1 Swan Island Lagoon

The model was also applied to Swan Island Lagoon for three example chemicals using location specific data when appropriate (see Attachment E5 for details). All modeled species were predicted with SPAFs less than 5 (Table 3-24). The model performance was well within minimum target performance (maximum average SPAF of 10) but slightly worse than model performance at larger spatial scales. Tissue concentrations were overpredicted in all trophic groups except benthic invertebrate filter feeders, which was consistently underpredicted. The sample size for Swan Island Lagoon was also much smaller than for the site-wide model (n = 2 or 3 composite samples for modeled species compared to at least 6 composite samples). Thus, there may be greater uncertainty and bias for estimates of mean tissue

concentration for this smaller area. Overall, although the model tended to overpredict, the results indicate that the model also performs well on a smaller spatial scale, such as Swan Island Lagoon.

3.5.2.2 Smaller-Scale Model Applications for Benthic Invertebrate Filter Feeders (Clams)

The model was applied for benthic invertebrate filter feeders on smaller spatial scales and compared to clam tissue data. The sensitivity analysis indicated sediment chemical concentration and water chemical concentration were important for benthic invertebrate filter feeders. Therefore, the model was set up for an example chemical (total PCBs) for locations with clam tissue chemistry data, co-located sediment data and nearby water chemistry data. There were only 4 locations with near bottom XAD samples and the nearest clam composite sample to each of those was selected. Total suspended solids (TSS) data from the peristaltic pump samples co-located with the XAD samplers were also used in the model. TSS was also identified in the sensitivity analysis as important for benthic invertebrate filter feeders for one chemical (PCB TEQ [birds]). All sediment samples from which chemical concentrations were derived were intended to reflect the sediment used by the clams included in the composite samples. All other parameters were based on calibrated model values. Table 3-25 provides information about the data used in the model as well as model performance results. Model predictions using the localized site-specific data for these samples were better than the model predictions for average clam tissue concentrations at the site (SPAF = 5.2, see Table 3-4). Just as it had for the site-wide application, the model tended to underpredict for the small spatial scale.

3.5.2.3 Smaller-Scale Model Applications for Epibenthic Invertebrate Consumers (Crayfish)

The model was applied for epibenthic invertebrate consumers (crayfish) for total PCBs for smaller spatial scales (Table 3-26). Sediment chemical concentration was the only location-specific parameter in the sensitivity analysis identified as being important. Sediment samples intended to reflect the sediment where crayfish were collected were available for each crayfish composite sample (n = 26). Most localized model predictions were worse than the site-wide prediction (SPAF = 3.5, Table 3-4). As with the site-wide prediction for total PCBs, most smaller-scale model predictions exceeded empirical data even though many of the crayfish samples had undetected tissue concentrations. Many sediment concentrations were also non-detected values, some with very high RLs; two sediment RLs exceeded 1,000 µg/kg. Possible reasons for the difficulties of the FWM to predict crayfish included large numbers of undetected sediment and tissue concentration values, the highly opportunistic feeding style of crayfish, and the potential for greater chemical elimination by this species compared to other modeled species.

3.5.2.4 Smaller-Scale Model Applications for Foraging Fish (Sculpin)

The FWM was also applied for total PCBs in sculpin (foraging fish) for smaller spatial scale. Again, sediment was the only site-specific parameter identified in the

sensitivity analysis as important for this group. Sediment samples intended to reflect the sediment where sculpin were collected were available for each tissue composite tissue sample (n=26). The model predicted well for sculpin site-wide (SPAF=1.4, see Table 3-4) and for most samples when the model was applied for smaller spatial scales. All but 6 samples had a SPAF less than 5, and over half had SPAFs less than 3 (Table 3-27).

3.5.2.5 Small-Scale Application for Small Piscivorous Fish (Smallmouth Bass)

The model was also applied for the prediction of total PCBs in individual smallmouth bass composite samples (n = 14 from eight locations). These samples were collected from 1-mile river areas. SWACs were developed for a circular area, excluding the channel, with a 1-mile diameter centered on each composite sample location. The channel was excluded based on information about bass behavior (Pribyl et al. 2005) (for further discussion see Appendix C on exposure area for smallmouth bass). Most of the small-scale models performed worse than the site-wide model (SPAF = 3.7, Table 3-28), but only one prediction was off by more than a SPAF of 10, the minimum performance goal for the model when applied site-wide. Possible reasons for the poorer performance of the model for the smaller spatial scales include uncertainties about the size of smallmouth bass home range and uncertainties about the specific locations of the home ranges for individuals in the composited samples.

3.5.3 Application of the Model for Other Tissue Data

3.5.3.1 Laboratory Worm

As discussed previously (Section 3.2.5.5), data for worms (*Lumbriculus variegatus*) exposed in the laboratory to LWR sediment were available (Windward and Integral 2005). The FWM was run using the sediment PCB concentrations to which the worms were exposed (n = 35 paired sediment and tissue samples). The laboratory-exposed worms had only sediment chemical exposure, so the FWM was run with zero for the PCB concentration in water. Overall, the model predicted the laboratory data fairly well with an average SPAF of 6.3 across the samples (Table 3-29). The model underpredicted in all cases. It is not known whether steady-state was reached in the laboratory worms, which might confer higher or lower tissue concentrations than were measured. Differences in lipid content may have been the most important contributors to the underpredictions. The benthic invertebrate consumer compartment of the FWM was intended to represent other species besides worms, including insect larvae and amphipods, which have much lower lipid fractions. Thus, the assumed lipid fraction for benthic invertebrate consumers was lower than the lipid fraction for the laboratory worms. This is supported by the sensitivity analysis (Section 3.3), which showed benthic invertebrate consumer tissue concentration predictions were highly sensitive to benthic invertebrate consumer lipids (which were highly uncertain) and barely affected by chemical water concentration.

3.5.3.2 Multiplates

Similar to the laboratory worms, the multiplates provided data that are not directly comparable to an FWM modeled group but did provide some perspective. The

multiplates were unusual in that they represented water column exposure for benthic organisms (with no sediment exposure) (Windward 2005b). Mean multiplate tissue chemical concentrations were compared to FWM predicted concentrations for three trophic groups representing water column and benthic organisms (benthic invertebrate consumers, zooplankton, and epibenthic invertebrate consumers) (Table 3-30). Calibrated model parameters were used for all parameters for all model runs (see Section 3.3.1).

The model-predicted concentrations for benthic invertebrate consumers and epibenthic invertebrate consumers were generally higher than the empirical multiplate data, while the model-predicted zooplankton were all lower than empirical data. Only two modeled concentrations were off by more than a SPAF of 10. Overprediction for benthic invertebrate consumers and epibenthic invertebrate consumers was expected as these groups were modeled with more benthic (sediment) exposure than the multiplates received. Since the organisms on the multiplates were primarily epibenthic invertebrates with higher lipid contents than zooplankton, it was also expected that the model would underpredict this trophic group (as compared to the multiplate data).

3.5.4 Uncertainty Associated with Application of FWM for Development of iPRGs

When the FWM was applied for development of iPRGs, these calculations carried several uncertainties. Some of these are discussed in Section 10 of the Comprehensive Round 2 Report. One of the difficulties was the fact that trophic groups may have been modeled after one species but expected to represent another species for iPRG development. For example, largescale sucker was used as the basis for the benthivorous fish trophic group in the model, but the group was also assumed to represent brown bullhead in iPRG development. Similarly, the foraging fish group was based on sculpin but assumed to also represent peamouth and black crappie. These assumptions could lead to both over and underestimation of iPRGs. Table 3-31 presents the empirical data for whole-body brown bullhead, black crappie, and peamouth and compares them with the relevant calibrated model predictions. With three exceptions (i.e., sum DDT for peamouth and PCB TEQ [birds] for black crappie and brown bullhead), the surrogate species provided predictions with a SPAF of 10 or less. For most chemical/species pairs, SPAFs were below 5 and similar to the SPAFs for the explicitly modeled species.

The FWM focused on one size for each trophic group. Smallmouth bass consumed by people may be larger or smaller than the size assumed for the small piscivorous fish category (based on empirical smallmouth bass data). This is also an issue for wildlife iPRGs. Wildlife might be expected to consume fish smaller than the adult fish modeled. The uncertainties associated with this assumption would apply to both the risk assessments using the empirical tissue data and the iPRGs (developed from the FWM calibrated with the same empirical tissue data).

The predictive capability of the FWM must also be considered in interpretation of iPRGs derived from the FWM. For all modeled chemicals (except dioxin TEQ for birds) the FWM performed better than minimum performance criteria. However, the uncertainty in the FWM predictions is still significant and should be considered in iPRG interpretation. The relationship between the model's tissue prediction errors at baseline and errors in sediment concentrations selected as iPRGs is not known but would likely vary across chemicals and trophic groups. It is not known whether a SPAF of 3 (overprediction) for model performance could be interpreted precisely as a factor of 3 or 4 overprediction in iPRG estimation; the latter may be greater or less than the former. However, the model SPAFs do provide information about the relative magnitude of expected errors in iPRG estimates.

Finally, in estimation of iPRGs it was assumed that all parameters except sediment chemical concentration would be the same as for the current model calibration. Thus, no relationship between water and sediment chemicals concentrations was assumed, and it was assumed that water chemical concentrations would not change. Similarly, no assumptions were made about changes in sediment parameters that might be related to changes in chemical concentration such as organic carbon content. Under future condition other parameters may change as well, such as organism feeding rates or lipid fraction. All these factors contribute to uncertainty and bias regarding iPRGs, which should be interpreted cautiously.

3.6 CONCLUSIONS AND FUTURE DIRECTIONS

The calibrated FWM met the minimum performance criteria (SPAFs within a factor of 10) for all of the chemicals modeled except one and was generally with a factor of 5 or better. The single exception was PCB TEQ (birds), which was within a factor of 11. The model was applied to estimate iPRGs for a subset of the human health and ecological iCOCs when a reduction in sediment chemical concentration alone (i.e., no change in water chemical concentrations was assumed) was sufficient to achieve target tissue concentrations. For some chemicals, sediment iPRGs could not be determined because chemical exposure from water alone (i.e., sediment chemical concentration = 0) was sufficient to yield tissue chemical concentrations that exceeded target tissue concentrations. If a relationship is developed between sediment and water concentrations, it may be possible to determine PRGs for these chemicals in future model iterations. The use of parameter distributions and probabilistic modeling facilitated model calibration as well as model sensitivity and uncertainty analyses.

In future applications, the FWM will be used to set final PRGs for the identification of AOPCs and the definition of SMAs and, in conjunction with fate and transport models, to evaluate different remedial options. The model performed better than minimum performance criteria (average SPAF of 10 across samples) when applied at smaller spatial scales for all species but crayfish, which provides confidence in the appropriateness of the model structure and parameter values for the trophic groups

modeled. The uncertainty analysis indicated that even uncalibrated model predictions (i.e., those made using the full range of plausible mean parameter values) were better than minimum performance criteria for the majority of model runs, for all chemicals except PCB TEQ (birds). Again, this helps to confirm the model structure and parameter distributions.

Evaluation of the model in the context of its applications in the RI/FS is useful for assessing data needs related to the FWM. In future applications, the list of chemicals to be modeled may be refined, allowing for more focused model calibration and, therefore, further improvements to model performance. The sensitivity analysis also provided information useful for future model improvements by identifying the parameters with the greatest influence on model predictions.

The sensitivity analysis indicated that chemical K_{OW} and sediment SWACs were the most important parameters influencing the FWM's predictions. By comparison, species-specific biological parameters, such as diet, weight, and lipid content, were of very little importance for model predictions. Therefore, additional species-specific input parameter data (e.g., organism weights, lipids, and diet) would be expected to have little influence on model performance. Tissue chemistry data were used for FWM calibration as well as for the evaluation of human health and ecological risks. Tissue chemistry data sufficient to characterize risks should also be sufficient to define the tissue chemical concentrations used to calibrate the FWM. The model performed better than the target goal of an average SPAF of 10 across species for all chemicals and spatial scales except one, indicating available tissue chemistry data are adequate for calibration.

The model was very sensitive to K_{OW} values, which are highly uncertain. Improved K_{OW} estimates might be very useful for improving model performance. These are unlikely to become available for use in the RI/FS, but they will be incorporated if they are developed. The model was also sensitive to SWACs. As with tissue chemical concentrations, uncertainty related to baseline SWACs is best evaluated from a risk assessment perspective (i.e., sediment concentration estimates needs to be reliable enough to characterize risks from direct exposure to sediments).

4.0 REFERENCES

Arnot JA, Gobas FAPC. 2004. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. Environ Toxicol Chem 23:2343-2355.

Burkhard LP. 2006. Estimation of biota sediment accumulation factor (BSAF) from paired observations of chemical concentrations in biota and sediment. EPA/600/R-06/045. Ecological Risk Assessment Support Center, US Environmental Protection Agency, Cincinnati, OH.

EPA. 2004. ProUCL Version 3.0 user guide. Technical Support Center for Monitoring and Site Characterization, US Environmental Protection Agency.

EPA. 2006. EPA comments on food web modeling report: evaluating TrophicTrace and the Arnot and Gobas Models for application to the Portland Harbor Superfund Site (November 2005 draft). March 10, 2006. US Environmental Protection Agency, Region 10, Portland, OR.

Hawker DW, Connell DW. 1988. Octanol-water partition coefficients of polychlorinated biphenyl congeners. Environ Sci Tech 22:382-387.

Integral. 2004. Portland Harbor RI/FS round 2a field sampling plan: surface water sampling. Prepared for Lower Willamette Group. Integral Consulting, Inc., Mercer Island, WA.

Integral, Windward, Kennedy/Jenks, Anchor, Groundwater Solutions. 2004. Portland Harbor remedial investigation/feasibility study programmatic work plan. Prepared for Lower Willamette Group. Integral Consulting, Inc., Mercer Island, WA; Windward Environmental LLC, Seattle, WA; Kennedy/Jenks Consultants, Portland, OR; Anchor Environmental, LLC, Seattle, WA; Groundwater Solutions, Inc., Portland, OR.

Morgan MG, Henrion M. 1990. Uncertainty: a guide to dealing with uncertainty in quantitative risk and policy analysis. Cambridge University Press, Cambridge, UK.

ODEQ. 2006. Portland Harbor Superfund Site: Models for estimation of chemical distribution and fate in response to remedial alternatives in the Lower Willamette River. Revised working draft, 21 April 2006. Oregon Department of Environmental Quality, Portland, OR.

Pribyl AL, Vile JS, Friesen TA. 2005. Population structure, movement, habitat use, and diet of resident piscivorous fishes in the Lower Willamette River. In: Friesen TA, ed, Biology, behavior, and resources of resident and anadromous fish in the Lower Willamette River. Final report of research, 2000-2004. Prepared for City of Portland. Oregon Department of Fish and Wildlife, Clackamas, OR, pp 139-183.

Windward. 2004. Portland Harbor RI/FS. Technical memorandum: evaluating steady-state aquatic food web models for the Portland Harbor Superfund site. WE-04-0002. Draft. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Windward. 2005a. Portland Harbor RI/FS. Ecological risk assessment: Estimating risks to benthic organisms using sediment toxicity tests. WE-05-0003. Draft. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Windward. 2005b. Portland Harbor RI/FS. Field sampling plan: Round 2 sampling of invertebrates using multiplate samplers. WE-05-0006. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Windward. 2005c. Portland Harbor RI/FS. Food web modeling report: evaluating TrophicTrace and the Arnot and Gobas models for application to the Portland Harbor Superfund Site. WE-05-0009. Draft. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Windward, Integral. 2005. Portland Harbor RI/FS. Field sampling plan: Round 2 sampling of benthic invertebrate tissue. WE-05-0008. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA; Integral Consulting, Inc., Mercer Island, WA.

TABLES

Table 1-1. iPRG Development Approaches for Human Health and Ecological iCOCs

Chemical	iCOC Type		iPRG Approach[c]	
	Human Health[a]	Ecological[b]	FWM	Biota-Sediment Relationship[d]
Arsenic	X			X
Mercury	X			X
PCB TEQ	X	X[e]	X	
Total PCBs	X	X	X	
Dioxin TEQ	X	X[e]	X	
Total chlordane	X			X
Aldrin	X			X
Dieldrin	X			X
alpha-Hexachlorocyclohexane	X			X
beta-Hexachlorocyclohexane	X			X
gamma-Hexachlorocyclohexane	X			X
Benzo(a)anthracene	X			X
Benzo(a)pyrene	X			X
Benzo(b)fluoranthene	X			X
Benzo(k)fluoranthene	X			X
Dibenzo(a,h)anthracene	X			X
Indeno(1,2,3-cd)pyrene	X			X
Hexachlorobenzene	X			X
Pentachlorophenol	X			X
BEHP	X	X		X
Sum DDD (2,4′-DDD and 4,4′-DDD)	X	X	X	
Sum DDE (2,4′-DDE and 4,4′-DDE)	X	X	X	
Sum DDT (2,4′-DDT and 4,4′-DDT)	X		X	
Total DDTs		X	X	

[a] Human health iCOCs are those chemicals that result in a cancer risk greater than 1×10^{-6} or a hazard quotient greater than 1 for any of the exposure scenarios and exposure point concentrations evaluated in the Round 2 HHRA for consumption of fish or shellfish (see Appendix B).

[b] Ecological iCOCs for the development of iPRGs are limited to fish and wildlife receptors (see the Round 2 ERA, Appendix H). iPRGs for benthic invertebrates were not developed using the FWM or biota-sediment relationships.

[c] Initial PRGs (iPRGs) are intended to be used for exploratory spatial data analyses. The development of final PRGs requires the completion of the baseline risk assessment.

[d] Site-specific regressions were developed for worms, clams, sculpin, and crayfish based on co-located tissue and sediment data, when data were available and a statistical relationship was found. For fish species other than sculpin, tissue concentrations and spatially averaged sediment concentrations were used to develop, site-specific BSAFs.

[e] Both bird and mammal dioxin TEQ and PCB TEQ iPRGs were developed.

BEHP – bis(2-ethylhexyl) phthalate
FWM – food web model
iCOC – initial chemical of concern
iPRG – initial preliminary remediation goal
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

Table 1-2. Chemicals Modeled for ERA Application

Chemical	Modeling Method[a]	
	FWM	Site-Specific Regression
Cadmium		X
Lead		X
Zinc		X
PCB TEQ (birds)	X	
Total PCBs	X	
Dioxin TEQ (birds)	X	
Aldrin	X	
Benzo(a)pyrene		X
Total PAHs		X
Sum DDD (2,4′-DDD and 4,4′-DDD)	X	
Sum DDE (2,4′-DDE and 4,4′-DDE)	X	
Sum DDT (2,4′-DDT and 4,4′-DDT)	X	
Total DDTs	X	

[a] The FWM or a site-specific regression model was used to estimate benthic prey tissue concentrations in the risk assessment for shorebirds feeding in distinct beach sediment areas (see Appendix C).

ERA – ecological risk assessment
FWM – food web model
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

Table 2-1. BSAFs for Fish COPCs Calculated for Each Trophic Guild

COPC	SWAC	SWAC Unit (dw)	BSAF[a]							
			Forage Fish[b]		Benthivores[c]		Piscivores[d]		Omnivores[e]	
			n	Avg	n	Avg	n	Avg	n	Avg
Mercury	0.0813	mg/kg	23	1.1	12	2.4	20	5.9	7	1.7
BEHP	34.2	mg/kg OC		ND	3	1.6	2	24		ND
Dibutyl phthalate	1.28	mg/kg OC	2	2.0		ND		ND		ND
Hexachlorobenzene	0.271	mg/kg OC	14	0.23[f]		ND		ND		ND
Total chlordane	0.175	mg/kg OC	18	1.5[f]	6	4.5[f]	2	2.6[f]	3	1.3[f]
Dieldrin	0.0398	mg/kg OC	7	1.8[f]	2	2.1[f]	1	3.6[f]		ND
Endrin	0.0550	mg/kg OC		ND		ND		ND		ND
Heptachlor	0.0225	mg/kg OC	4	2.0[f]		ND		ND		ND
alpha-HCH	0.0315	mg/kg OC	1	0.68[f]		ND		ND		ND
beta-HCH[g]	0.151	mg/kg OC		ND		ND		ND		ND
gamma-HCH	0.0823	mg/kg OC		ND	4	0.76[f]		ND		ND

[a] Based on the ERA dataset.
[b] Forage fish = black crappie, juvenile chinook salmon, and peamouth.
[c] Benthivores = brown bullhead, largescale sucker.
[d] Piscivores = northern pikeminnow, smallmouth bass (calculated as described in Section 2.2.3).
[e] Omnivores = carp.
[f] BSAF based on N- or NJ-qualified (detected) tissue concentration(s).
[g] iCOC not detected in whole body tissue.

BEHP – bis(2-ethylhexyl) phthalate
BSAF –biota sediment accumulation factor
COPC – chemical of potential concern
dw – dry weight
ERA – ecological risk assessment
HCH – hexachlorocyclohexane
HHRA – human health risk assessment
ND – iCOC not detected in tissue for given trophic level; no BSAF derived
OC – organic carbon
SWAC – spatially weighted average concentration

Table 3-1. Chemical Concentrations in the Water Column

Chemical	Distribution	Mean (ng/L)	Standard Deviation (ng/L)[a]
PCB 17	normal	3.93×10^{-3}	5.95×10^{-4}
PCB 170	normal	5.17×10^{-4}	9.83×10^{-5}
PCB 206	normal	5.95×10^{-5}	1.21×10^{-5}
Total PCBs (sum of congeners)[b]	normal	1.95×10^{-1}	2.79×10^{-2}
PCB TEQ (mammals)	normal	2.16×10^{-6}	2.54×10^{-7}
PCB TEQ (birds)	normal	1.38×10^{-5}	1.72×10^{-6}
Dioxin TEQ (mammals)	normal	7.29×10^{-6}	1.28×10^{-6}
Dioxin TEQ (birds)	normal	1.04×10^{-5}	1.82×10^{-6}
4,4'-DDD	normal	3.44×10^{-2}	8.69×10^{-3}
4,4'-DDE	normal	1.95×10^{-2}	3.10×10^{-3}
4,4'-DDT	normal	4.96×10^{-3}	8.95×10^{-4}
Sum DDD	normal	5.02×10^{-2}	1.24×10^{-2}
Sum DDE	normal	2.06×10^{-2}	3.32×10^{-3}
Sum DDT	normal	7.18×10^{-3}	1.34×10^{-3}
Total DDTs	normal	7.79×10^{-2}	1.61×10^{-2}

[a] The standard error of the data was used to describe the standard deviation of estimates of the mean.

[b] PCB Aroclor data were not available for water samples so total PCBs were calculated as sum of congeners.

PCB – polychlorinated biphenyl

TEQ – toxic equivalent

Table 3-2. Spatially Weighted Average Concentrations for Chemicals in Sediment

Chemical	Number of Samples	Polygon-Generated SWAC (ng/g)
PCB 17	146	1.59
PCB 170	229	2.30
PCB 206	146	0.950
Total PCBs (sum of Aroclors)	869	72.1
PCB TEQ (mammals)	158	0.00347
PCB TEQ (birds)	158	0.0213
Dioxin TEQ (mammals)	152	0.0274
Dioxin TEQ (birds)	152	0.0557
4,4′-DDD	895	7.87
4,4′-DDE	892	3.85
4,4′-DDT	880	15.3
Sum DDD	895	10.6
Sum DDE	892	4.63
Sum DDT	894	17.4
Total DDTs	895	32.6

PCB – polychlorinated biphenyl
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

Table 3-3. Sediment Distribution Values for Sensitivity and Uncertainty Analyses

Chemical	Concentration (ng/g)		
	Average (SWAC)	Minimum	Maximum
Total PCBs (sum of Aroclors)	72.1	43.3	101
PCB TEQ (birds)	0.0213	0.0128	0.0298
Dioxin TEQ (mammals)	0.0274	0.0164	0.0384
4,4′-DDD	7.87	4.72	11.0
Total DDTs	32.6	19.6	45.6

Note: A triangular distribution was assigned for all sediment distributions with the model equal to the SWAC and the specified minimums and maximums.
PCB – polychlorinated biphenyl
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

Table 3-4. Comparison of SPAFs by Species Before and After the Calibration of Non-Chemical-Specific Parameters

Chemical	Calibration[c]	SPAF by Trophic Group[a]								Average SPAF[b]
		BIF (clams)	BIC	EIC (crayfish)	Foraging Fish (sculpin)	Benthivorous Fish (largescale sucker)	Omnivorous Fish (carp)	Small Piscivorous Fish (smallmouth bass)	Large Piscivorous Fish (northern pikeminnow)	
PCB 17	pre-calibration	4.6	NA	**4.7**	2.3	NA	2.1	**2.0**	NA	3.1
	post-calibration[d]	2.6	NA	**2.7**	2.2	NA	1.6	**1.7**	NA	2.2
PCB 170	pre-calibration	2.0	NA	**4.3**	1.2	NA	3.1	**2.9**	NA	2.7
	post-calibration[d]	1.5	NA	**2.8**	1.1	NA	2.5	**2.8**	NA	2.1
PCB 206	pre-calibration	2.3	NA	**7.6**	1.2	NA	4.6	**1.2**	NA	3.4
	post-calibration[d]	1.7	NA	**5.9**	1.1	NA	3.6	**1.2**	NA	2.7
4,4'-DDD	pre-calibration	3.8	NA	**17.4**	**4.0**	**2.5**	**2.5**	**16.2**	**9.7**	8.0
	post-calibration[d]	4.8	NA	**3.1**	**1.0**	1.4	**1.1**	**3.2**	**2.0**	2.4
4,4'-DDE	pre-calibration	8.1	NA	**1.5**	1.6	2.4	2.9	**1.6**	2.3	2.9
	post-calibration[d]	7.1	NA	**3.8**	1.4	1.2	**1.2**	**5.4**	**3.0**	3.3
4,4'-DDT[c]	pre-calibration	1.7	NA	**5.2**	5.0	5.7	**1.2**	**1.1**	**1.8**	3.1
	post-calibration[d]	**1.0**	NA	**12.6**	2.3	4.7	**2.1**	**1.5**	**2.7**	3.9
Total PCBs	pre-calibration	8.7	NA	**2.9**	1.5	1.5	3.2	**1.9**	**1.4**	3.0
	post-calibration[d]	5.2	NA	**3.5**	**1.4**	1.1	1.7	**3.7**	**2.4**	2.7

[a] **Bolded** text indicates that the model was over-predicting for this chemical-species combination. All unbolded values represent underpredictions.

[b] Average SPAF for all trophic groups with empirical data available for a given chemical. For the three PCB congeners, data were available for five trophic groups. For all other chemicals, data were available for seven trophic groups. Under or overprediction is not indicted for average SPAF values.

[c] The SWAC was used as the sediment chemical concentration for all modeled chemicals, both pre and post-calibration (see Section 3.2.5).

[d] Calibrated values from PCB 17 model runs ware used for non-chemical-specific parameters. Best estimates of the mean were used to define the water concentration and K_{OW}.

BIC – benthic invertebrate consumer
BIF – benthic invertebrate filter feeder
EIC – epibenthic invertebrate consumers
PCB – polychlorinated biphenyl
NA – not available
SPAF – species predictive accuracy factor
SWAC – spatially weighted average concentration

Table 3-5. Calibrated Values for Environmental Parameters

Model Component	Unit	Initial Distribution[a]	Calibrated Value
Water temperature	°C	13.56 (SD = 1.60)	14.99
Concentration of TSS	kg/L	5.9×10^{-6} (SD = 5.1×10^{-7})	5.9×10^{-6}
Dissolved organic carbon concentration in water	kg/L	1.30×10^{-6} (SD = 3.0×10^{-8})	1.29×10^{-6}
Organic carbon content of sediment	fraction	0.0188 (SD = 0.00054)	0.0183

[a] A normal distribution was assigned with the first value as the mean and the indicated standard deviation.
SD – standard deviation
TSS – total suspended solids

Table 3-6. Calibrated Values for General Biological Parameters

Model Component	Initial Distribution (unitless)[a]	Calibrated Value (unitless)
Resistance to chemical uptake through aqueous phase for phytoplankton/algae (UA)	6.0×10^{-5} ($4.0 \times 10^{-5} - 8.0 \times 10^{-5}$)	7.3×10^{-5}
Resistance to chemical uptake through organic phase for phytoplankton/algae (UB)	5.5 (1.80 – 9.20)	4.5
Dietary transfer efficiency constant A (EDA)	3.0×10^{-7}	3.0×10^{-7}
Dietary transfer efficiency constant B (EDB)	2.0	2.0
NLOM-octanol proportionality constant (BETA)	0.035 (SD = 0.005)	0.040
NLOC-octanol proportionality constant (GAMMA)	0.35	0.35

[a] A normal distribution was assigned with the first value as the mean and the indicated standard deviation.
NLOM – non-lipid organic matter
SD – standard deviation

Table 3-7. Calibrated Values for Species-Specific Biological Parameters

Model Component	Unit	Initial Distribution[a]	Calibrated Value
Phytoplankton			
Lipid content	fraction	0.00123 (0.0008 – 0.002)	0.00168
Moisture content	fraction	0.955 (0.935 – 0.993)	0.965
Fraction of porewater ventilated	fraction	0	0
Growth rate constant	1/day	0.08 (0.03 – 0.13)	0.07
Zooplankton			
Weight	kg	1.4×10^{-7} (3.3×10^{-8} – 2.3×10^{-7})	2.1×10^{-7}
Lipid content	fraction	0.01 (0.009 – 0.011)	0.01
Moisture content	fraction	0.90 (0.80 – 0.98)	0.84
Dietary absorption efficiency of lipid	fraction	0.72 (0.55 – 0.85)	0.81
Dietary absorption efficiency of NLOM	fraction	0.72 (0.55 – 0.85)	0.75
Dietary absorption efficiency of water	fraction	0.25	0.25
Fraction of porewater ventilated	unitless	0	0
Benthic Invertebrate Filter Feeders (clams)			
Weight	kg	0.00103 (SD = 1.9×10^{-5})	0.00103
Lipid content	fraction	0.0228 (SD = 0.0013)	0.0231
Moisture content	fraction	0.864 (SD = 0.0033)	0.862
Dietary absorption efficiency of lipid	fraction	0.75 (0.15 – 0.96)	0.61
Dietary absorption efficiency of NLOM	fraction	0.75 (0.15 – 0.96)	0.78
Dietary absorption efficiency of water	fraction	0.25	0.25
Fraction of porewater ventilated	unitless	0.05 (0.01 – 0.10)	0.09
Filter feeder scavenging efficiency	unitless	1.0	1.0
Benthic Invertebrate Consumers			
Weight	kg	5.33×10^{-6} (1.4×10^{-6} – 6.0×10^{-6})	5.05×10^{-6}
Lipid content	fraction	0.015 (0.008 – 0.042)	0.017
Moisture content	fraction	0.80 (0.72 – 0.88)	0.88
Dietary absorption efficiency of lipid	fraction	0.75 (0.15 – 0.96)	0.72
Dietary absorption efficiency of NLOM	fraction	0.75 (0.15 – 0.96)	0.75
Dietary absorption efficiency of water	fraction	0.25	0.25
Fraction of porewater ventilated	unitless	0.05 (0.01 – 0.10)	0.05
Epibenthic Invertebrate Consumers (crayfish)			
Weight	kg	0.0424 (SD = 0.00070)	0.0435
Lipid content	fraction	0.00781 (SD = 0.00052)	0.00725
Moisture content	fraction	0.736 (SD = 0.0035)	0.738
Dietary absorption efficiency of lipid	fraction	0.75 (0.15 – 0.96)	0.57
Dietary absorption efficiency of NLOM	fraction	0.75 (0.15 – 0.96)	0.51
Dietary absorption efficiency of water	fraction	0.25	0.25
Fraction of porewater ventilated	unitless	0.05 (0.01 – 0.10)	0.01

Table 3-7. Calibrated Values for Species-Specific Biological Parameters

Model Component	Unit	Initial Distribution[a]	Calibrated Value
Sculpin			
Weight	kg	0.0189 (SD = 0.0004)	0.0180
Lipid content	fraction	0.0417 (SD = 0.0020)	0.0395
Moisture content	fraction	0.748 (SD = 0.0025)	0.752
Dietary absorption efficiency of lipid	fraction	0.92 (0.90 – 0.95)	0.94
Dietary absorption efficiency of NLOM	fraction	0.60 (0.50 – 0.65)	0.58
Dietary absorption efficiency of water	fraction	0.25	0.25
Fraction of porewater ventilated	fraction	0.05 (0.01 – 0.10)	0.05
Largescale Sucker			
Weight	kg	0.794 (SD = 0.011)	0.802
Lipid content	fraction	0.0756 (SD = 0.0052)	0.0793
Moisture content	fraction	0.712 (SD = 0.0054)	0.708
Dietary absorption efficiency of lipid	fraction	0.92 (0.90 – 0.95)	0.95
Dietary absorption efficiency of NLOM	fraction	0.60 (0.50 – 0.65)	0.60
Dietary absorption efficiency of water	fraction	0.25	0.25
Fraction of porewater ventilated	unitless	0	0
Common Carp			
Weight	kg	2.33 (SD = 0.088)	2.48
Lipid content	fraction	0.0788 (SD = 0.011)	0.0792
Moisture content	fraction	0.705 (SD = 0.0083)	0.703
Dietary absorption efficiency of lipid	fraction	0.92 (0.90 – 0.95)	0.93
Dietary absorption efficiency of NLOM	fraction	0.60 (0.50 – 0.65)	0.53
Dietary absorption efficiency of water	fraction	0.25	0.25
Fraction of porewater ventilated	unitless	0	0
Smallmouth Bass			
Weight	kg	0.372 (SD = 0.024)	0.319
Lipid content	fraction	0.0544 (SD = 0.0044)	0.0515
Moisture content	fraction	0.702 (SD = 0.0066)	0.711
Dietary absorption efficiency of lipid	fraction	0.92 (0.90 – 0.95)	0.94
Dietary absorption efficiency of NLOM	fraction	0.60 (0.50 – 0.65)	0.61
Dietary absorption efficiency of water	fraction	0.25	0.25
Fraction of porewater ventilated	unitless	0	0
Northern Pikeminnow			
Weight	kg	0.558 (SD = 0.048)	0.570
Lipid content	fraction	0.0525 (SD = 0.0080)	0.0604
Moisture content	fraction	0.719 (SD = 0.0088)	0.720
Dietary absorption efficiency of lipid	fraction	0.92 (0.90 – 0.95)	0.94
Dietary absorption efficiency of NLOM	fraction	0.60 (0.50 – 0.65)	0.57
Dietary absorption efficiency of water	fraction	0.25	0.25

Table 3-7. Calibrated Values for Species-Specific Biological Parameters

Model Component	Unit	Initial Distribution[a]	Calibrated Value
Fraction of porewater ventilated	fraction	0	0

[a] If a range is provided, a triangular distribution was selected with the first value as the mode and the range defining the minimum and maximum values. If a standard deviation (SD) is provided, a normal distribution was selected with the mean defined by the first number and the given SD. Details of the parameters distribution selections are provided in Attachment E3.

NLOM – non-lipid organic matter

SD – standard deviation

Table 3-8. Calibrated values for Species-Specific Dietary Parameters

Species	Prey Item	Initial Distribution (%)[a]	Calibrated Value (%)
Zooplankton	phytoplankton	100	100
Benthic invertebrate filter feeders (clams)	sediment solids	70 (50 – 80)	53
	phytoplankton	30 (20 – 50)	47
Benthic invertebrate consumers	sediment solids	95 (85 – 100)	93
	phytoplankton	5 (0 – 15)	7
Epibenthic invertebrate consumers (crayfish)	sediment solids	2 (0 – 4)	2
	phytoplankton	10 (0 – 20)	12
	zooplankton	10 (0 – 20)	19
	benthic invertebrates (filter feeders)	18 (0 – 35)	15
	benthic invertebrates (consumers)	60 (25 – 75)	52
Sculpin	sediment solids	0 (0 – 5)	0.2
	zooplankton	0 (0 – 5)	0.5
	benthic invertebrates (filter feeders)	5 (0 – 10)	8
	benthic invertebrates (consumers)	90 (25 – 95)	86
	epibenthic invertebrates (consumers)	5 (0 – 10)	6
Largescale sucker	sediment solids	5 (1 – 15)	9
	phytoplankton	25 (0 – 60)	37
	zooplankton	15 (5 – 25)	10
	benthic invertebrates (filter feeders)	10 (5 – 15)	12
	benthic invertebrates (consumers)	25 (15 – 35)	15
	epibenthic invertebrates (consumers)	20 (0 – 40)	18
Common carp	sediment solids	5 (0 – 10)	6
	phytoplankton	45 (30 – 60)	36
	benthic invertebrates (filter feeders)	10 (5 – 15)	13
	benthic invertebrates (consumers)	40 (25 – 55)	45
Smallmouth bass	sediment solids	0	0
	benthic invertebrates (consumers)	5 (0 – 30)	5
	epibenthic invertebrates (consumers)	5 (0 – 30)	24
	sculpin	90 (50 – 100)	72
Northern pikeminnow	sediment solids	0	0
	phytoplankton	4 (0 – 10)	2
	benthic invertebrates (filter feeders)	5 (0 – 10)	8
	benthic invertebrates (consumers)	26 (15 – 45)	23
	epibenthic invertebrates (consumers)	40 (25 – 65)	49
	sculpin	25 (0 – 60)	17

[a] For all values in which a range is provided, a triangular distribution was assigned with the first number as the mode and the minimum and maximum defined by the range.

Table 3-9. Calibrated K_{OW} and Water Concentration Values

Chemical	K_{OW}		Water Concentration (ng/L)		Best Average SPAF[c]
	Initial Distribution[a]	Calibrated Value	Initial Distribution[b]	Calibrated Value	
4,4'-DDD	6.02 (SD = 0.0602)	5.87	3.44×10^{-2} (SD = 8.69×10^{-3})	5.12×10^{-2}	2.2
Sum DDD	5.99 (SD = 0.0599)	5.79	5.02×10^{-2} (SD = 1.24×10^{-2})	7.44×10^{-2}	2.2
Sum DDE	6.48 (SD = 0.0648)	6.61	2.06×10^{-2} (SD = 3.32×10^{-3})	2.88×10^{-2}	2.2
4,4'-DDT	6.91 (SD = 0.0691)	7.15	4.96×10^{-3} (SD = 8.95×10^{-4})	4.41×10^{-3}	4.1
Sum DDT	6.87 (SD = 0.0687)	6.64	7.18×10^{-3} (SD = 1.34×10^{-3})	7.48×10^{-3}	3.0
Total DDTs	6.47 (SD = 0.0647)	6.28	7.79×10^{-2} (SD = 1.61×10^{-2})	4.93×10^{-2}	2.2
Total PCBs	6.67 (SD = 0.0667)	6.46	1.95×10^{-1} (SD = 2.79×10^{-2})	1.89×10^{-1}	2.5
PCB TEQ (birds)	6.81 (SD = 0.0681)	6.59	1.38×10^{-5} (SD = 1.72×10^{-6})	1.45×10^{-5}	11.2
PCB TEQ (mammals)	6.81 (SD = 0.0681)	6.59	2.16×10^{-6} (SD = 2.54×10^{-7})	1.72×10^{-6}	4.2
Dioxin TEQ (birds)	8.47 (SD = 0.0847)	8.59	1.04×10^{-5} (SD = 1.82×10^{-6})	1.57×10^{-5}	1.7
Dioxin TEQ (mammals)	8.47 (SD = 0.0847)	8.59	7.29×10^{-6} (SD = 1.28×10^{-6})	6.80×10^{-6}	1.3

[a] Initial distributions were defined using a normal distribution using the mean value given and the standard deviation (based on 1% of the literature value of the K_{OW}).

[b] Initial distributions were defined using a normal distribution using the mean value given and the standard deviation (based on the standard error of the water data).

[c] Based on an average of SPAFs for all trophic groups for which empirical data were available for a given chemical. For PCB TEQs and dioxin TEQs, data were available for five trophic groups. For all other chemicals, data were available for seven trophic groups.

K_{OW} –.octanol-water partition coefficient

PCB – polychlorinated biphenyl

SD – standard deviation

SPAF – species predictive accuracy factor

TEQ – toxic equivalent

Table 3-10. SPAF Values by Species for Food-Web-Modeled Chemicals

Chemical	SPAF for Model Runs with Best Input Values[a]								Average SPAF[b]
	BIF (clams)	BIC	EIC (crayfish)	Foraging Fish (sculpin)	Benthivorous Fish (largescale sucker)	Omnivorous Fish (carp)	Small Piscivorous Fish (smallmouth bass)	Large Piscivorous Fish (northern pikeminnow)	
4,4'-DDD	4.7	NA	**2.6**	1.2	1.6	1.1	**2.3**	**1.5**	2.2
Sum DDD	5.0	NA	**2.5**	1.4	1.8	1.4	**1.9**	**1.2**	2.2
Sum DDE	4.9	NA	**1.3**	1.1	1.9	1.8	**2.2**	**1.8**	2.2
4,4'-DDT	1.1	NA	**13.5**	3.1	6.7	**1.5**	1.2	**1.8**	4.1
Sum DDT	1.1	NA	**5.4**	1.7	2.5	**3.0**	**4.3**	**2.7**	3.0
Total DDT	3.4	NA	**2.2**	1.1	1.1	**1.4**	**4.5**	**1.5**	2.2
Total PCBs	5.6	NA	**2.8**	**1.1**	1.3	2.0	**2.8**	**1.9**	2.5
PCB TEQ (birds)	1.3	NA	**2.6**	**6.1**	NA	**12.7**	**33.6**	NA	11.2
PCB TEQ (mammals)	1.7	NA	**2.7**	**2.2**	NA	**3.3**	**11.2**	NA	4.2
Dioxin TEQ (birds)	2.0	NA	1.6	1.6	NA	**1.8**	**1.4**	NA	1.7
Dioxin TEQ (mammals)	1.4	NA	**1.2**	**1.1**	NA	**1.3**	**1.3**	NA	1.3

[a] Bolded text indicates that the model was over-predicting for this chemical-species combination. All unbolded values represent underpredictions.

[b] Average SPAF based on an average of SPAFs for all trophic groups for which empirical data were available for a given chemical. For PCB TEQs and dioxin TEQs, data were available for five trophic groups. For all other chemicals, data were available for seven trophic groups. Average SPAF provides no indication of overall model under or overprediction.

BIC – benthic invertebrate consumers
BIF – benthic invertebrate filter feeders
EIC – epibenthic invertebrate consumers
NA – no data available for this species
PCB – polychlorinated biphenyl
SPAF – species predictive accuracy factor
TEQ – toxic equivalent

Table 3-11. Details of Human Health iPRG Development Model Runs

Chemical	Target Tissue Range (µg/kg)[a]	Sediment Range (ng/g)	Number of Crystal Ball® Runs
Sum DDD	4.79 – 20,623	0 – 65,000	53,000
Sum DDE	3.38 – 14,557	0 – 32,000	30,000
Sum DDT	3.38 – 14,558	1 – 32,000	50,000
Total PCBs	0.575 – 2,475	0 – 5,300	10,000
PCB TEQ (mammals)	$7x10^{-6}$ to $3.3x10^{-2}$	0 – 0.5	5,000
Dioxin TEQ (mammals)	$7x10^{-6}$ to $3.3x10^{-2}$	0 – 3	10,000

[a] Approximate target tissue concentrations based on back calculation using human health risk equations for fish and shellfish consumption from acceptable risk levels to tissue concentrations (see Section 10 of the Comprehensive Round 2 Report for details). Range includes all consumption scenarios and target risk ranges.

iPRG –initial preliminary remediation goal

PCB – polychlorinated biphenyl

TEQ – toxic equivalent

Table 3-12. Details of Ecological iPRG Development Model Runs

Chemical	Target Tissue Value or Range (µg/kg)[a]	Sediment Range (ng/g)	Number of Crystal Ball® Runs
4,4'-DDD	54	0 – 150	5,000
Sum DDD	900	1,400 – 1,800	5,000
Sum DDE	40	0 – 5	5,000
4,4'-DDT	470	100 – 1,225	10,000
Sum DDT	150	100 – 200	5,000
Total DDT's	1,800	0 – 700	7,000
Total PCBs	0.28 – 4020	0 – 1,600	10,000
PCB TEQ (birds)	0.0032 – 0.14	0 – 0.5	5,000
Dioxin TEQ (birds)	0.0032 – 0.14	0 – 4	5,000
PCB TEQ (mammals)	0.00224	0 – 0.05	5,000
Dioxin TEQ (mammals)	0.00224	0 – 1	6,000

[a] Approximate target tissue concentrations based on TRVs for fish or back-calculations using risk equations for wildlife (see Section 10 of the Comprehensive Round 2 Report for details). Range includes target tissue concentrations for all receptors.

iPRG –initial preliminary remediation goal

PCB – polychlorinated biphenyl

TEQ – toxic equivalent

Table 3-13. Results of Sensitivity Analysis for Total PCBs with Concentration in Sediment Held Constant

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**9.3%**	**8.6%**	2.2%	0.1%	0.1%	0.1%	0.2%	0.2%	0.0%	0.1%
K_{OW}	**50.5%**	**83.3%**	**39.6%**	**48.8%**	**55.5%**	**75.0%**	**68.4%**	**59.6%**	**75.9%**	**66.3%**
Water temperature	0.0%	0.2%	0.1%	1.7%	1.8%	4.1%	5.6%	5.9%	5.7%	4.7%
PHY water content fraction	**-38.5%**	-1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**46.6%**	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%
BIC lipid fraction	0.0%	0.0%	0.0%	**43.6%**	3.3%	**16.3%**	**9.8%**	**19.7%**	**11.2%**	**8.5%**
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**28.1%**	0.1%	3.8%	0.0%	0.2%	1.4%
Dietary consumption parameters[b]	NA	NA	1.5%	0.5%	2.2%	0.1%	**6.4%**	2.5%	1.5%	**10.2%**

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanlol water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NPM – Northern pikeminnow (representing large piscivorous fish)
PCB – polychlorinated biphenyl
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
ZOO – zooplankton

Bold identifies contribution of 5% or more to differences in model predictions.

Table 3-14. Results of Sensitivity Analysis for Total PCBs with Concentration in Sediment Allowed to Vary

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**10.3%**	**8.6%**	1.7%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%
Concentration in sediment	0.0%	0.0%	**22.6%**	**14.2%**	**9.7%**	**10.3%**	**11.2%**	**12.6%**	**7.8%**	**7.3%**
K_{OW}	**49.8%**	**83.6%**	**30.1%**	**42.1%**	**49.1%**	**67.3%**	**59.6%**	**52.8%**	**70.8%**	**61.0%**
Water temperature	0.0%	0.1%	0.1%	1.5%	1.6%	3.7%	5.2%	5.2%	5.2%	4.9%
PHY water content fraction	**-38.1%**	-1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**35.8%**	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%
BIC lipid fraction	0.0%	0.0%	0.0%	**36.1%**	3.1%	**14.0%**	**8.7%**	**16.5%**	**10.0%**	**7.4%**
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**26.0%**	0.1%	3.5%	0.0%	0.1%	1.2%
Dietary consumption parameters[b]	NA	NA	1.3%	0.4%	1.7%	0.2%	**6.0%**	2.0%	1.3%	**10.0%**

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanlol water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NPM – Northern pikeminnow (representing large piscivorous fish)
PCB – polychlorinated biphenyl
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-15. Results of Sensitivity Analysis for PCB TEQ (Birds) with Concentration in Sediment Held Constant

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**21.5%**	**39.8%**	0.7%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
Concentration of suspended solids	0.0%	0.0%	**11.5%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	2.2%	**19.8%**	0.1%	3.4%	2.5%	4.0%	0.5%	0.3%	1.4%	0.9%
Water temperature	0.0%	1.0%	0.3%	5.0%	3.3%	**21.0%**	**18.8%**	**20.3%**	**28.6%**	**16.5%**
PHY growth rate constant	**-9.0%**	-1.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	**-63.9%**	**-9.1%**	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%
ZOO moisture	0.0%	**-22.1%**	0.0%	-0.1%	0.0%	-0.1%	0.1%	-0.1%	-0.1%	0.0%
BIF lipids[b]	0.0%	0.0%	**6.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**66.8%**	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	**82.8%**	4.0%	**58.9%**	**25.8%**	**51.7%**	**40.4%**	**18.9%**
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**70.1%**	0.8%	**18.1%**	0.0%	1.0%	5.0%
CAR lipids[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**5.7%**	0.0%	0.0%
CAR moisture[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-5.2%**	0.0%	0.0%
NPM lipids[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.1%**
Dietary consumption parameters[c]	NA	NA	**9.2%**	1.2%	**6.7%**	1.6%	**24.1%**	**9.9%**	**6.2%**	**35.9%**

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, percent contribution for this parameter may be overstated and should be interpreted with caution.

[c] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanol-water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NPM – Northern pikeminnow (representing large piscivorous fish)
PCB – polychlorinated biphenyl
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
TEQ – toxic equivalent
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-16. Results of Sensitivity Analysis for PCB TEQ (Birds) with Concentration in Sediment Allowed to Vary

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**20.9%**	**41.4%**	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Concentration in sediment	0.0%	0.0%	**47.4%**	**30.2%**	**17.8%**	**38.8%**	**29.7%**	**32.1%**	**31.5%**	**22.3%**
Concentration of suspended solids	0.0%	0.0%	**6.4%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	2.1%	**19.3%**	0.1%	2.0%	1.4%	1.9%	0.3%	0.2%	0.8%	0.7%
Water temperature	0.0%	0.5%	0.1%	3.4%	3.3%	**12.7%**	**14.2%**	**13.5%**	**19.3%**	**12.0%**
PHY growth rate constant	**-8.0%**	-0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	**-65.5%**	**-9.4%**	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.0%	0.0%
ZOO moisture	0.0%	**-22.4%**	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.1%	0.0%
BIF porewater ventilation	0.0%	0.0%	**35.1%**	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	**57.4%**	2.8%	**36.2%**	**16.7%**	**34.3%**	**27.7%**	**14.4%**
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**56.6%**	0.7%	**13.0%**	0.0%	1.0%	4.8%
NPM lipids[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**7.2%**
Dietary consumption parameters[c]	NA	NA	4.7%	1.0%	**6.0%**	0.6%	**15.2%**	**6.7%**	4.3%	**27.5%**

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, percent contribution for this parameter may be overstated and should be interpreted with caution.

[c] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanol-water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NPM – Northern pikeminnow (representing large piscivorous fish)
PHY – phytoplankton
PCB – polychlorinated biphenyl
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
TEQ – toxic equivalent
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-17. Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Concentration in Sediment Held Constant

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**21.5%**	**58.5%**	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Concentration of suspended solids	0.0%	0.0%	**10.5%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**-20.7%**	**-34.4%**	**-64.8%**	**-75.2%**	**-63.1%**	**-79.0%**	**-67.0%**	**-73.6%**	**-79.7%**	**-78.6%**
Resistance to chemical uptake through aqueous phase (PHY)	**-10.9%**	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	1.2%	1.7%	**18.3%**	**14.6%**	**18.3%**	**14.9%**	**17.1%**	**18.4%**	**18.2%**
PHY growth rate constant	**-45.7%**	-0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**13.8%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**9.9%**	0.0%	0.2%	0.0%	0.0%	0.3%
Dietary consumption parameters[b]	NA	NA	**7.9%**	2.7%	**9.2%**	1.1%	**16.6%**	**7.9%**	0.3%	1.2%

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanol-water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NPM – Northern pikeminnow (representing large piscivorous fish)
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
TEQ – toxic equivalent
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-18. Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Concentration in Sediment Allowed to Vary

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**21.4%**	**58.0%**	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Concentration in sediment	0.0%	0.0%	**32.3%**	**41.6%**	**17.3%**	**15.4%**	**14.2%**	**15.8%**	**8.2%**	**10.1%**
Concentration of suspended solids	0.0%	0.0%	**7.3%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**-20.9%**	**-35.1%**	**-44.2%**	**-43.2%**	**-53.1%**	**-66.3%**	**-56.4%**	**-61.9%**	**-72.6%**	**-70.5%**
Resistance to chemical uptake through aqueous phase (PHY)	**-11.7%**	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	1.2%	1.4%	**10.7%**	**12.3%**	**15.9%**	**13.1%**	**14.4%**	**17.5%**	**16.8%**
PHY growth rate constant	**-44.4%**	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**8.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**7.2%**	0.0%	0.1%	0.0%	0.0%	0.2%
Dietary consumption parameters[b]	NA	NA	**5.5%**	1.3%	**7.2%**	0.7%	**14.9%**	**6.4%**	0.3%	0.9%

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanol-water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NPM – Northern pikeminnow (representing large piscivorous fish)
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
TEQ – toxic equivalent
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-19. Results of Sensitivity Analysis for Total DDTs with Concentration in Sediment Held Constant

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**36.8%**	**59.1%**	**10.7%**	0.7%	1.0%	1.3%	2.3%	1.7%	1.1%	0.8%
K_{OW}	**6.5%**	**21.4%**	**6.9%**	**7.7%**	**7.4%**	**18.1%**	**11.8%**	**8.5%**	**17.7%**	**11.7%**
NLOM prop constant	0.0%	1.4%	1.1%	1.0%	**5.3%**	0.1%	0.2%	0.0%	-0.6%	-0.2%
Water temperature	0.0%	0.4%	0.2%	3.0%	3.3%	**12.6%**	**14.7%**	**13.4%**	**18.3%**	**11.5%**
PHY water content fraction	**-53.8%**	-4.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO water content fraction	0.0%	**-11.2%**	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
BIF lipid fraction[b]	0.0%	0.0%	**6.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	63.8%	0.0%	0.2%	0.0%	0.4%	0.2%	0.0%	0.1%
BIC lipid fraction	0.0%	0.0%	0.0%	**80.2%**	**5.6%**	**55.2%**	**26.1%**	**46.6%**	**39.6%**	**20.3%**
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**63.8%**	0.6%	**14.0%**	0.0%	0.9%	4.1%
CAR lipid fraction[b]	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	**8.6%**	0.0%	0.0%
CAR water content fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-8.1%**	0.0%	0.0%
NPM lipid fraction[b]	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.8%**
NPM water content fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-5.3%**
Dietary consumption parameters[c]	NA	NA	3.7%	1.0%	4.7%	1.1%	**18.4%**	**7.2%**	4.3%	**29.0%**

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, percent contribution for this parameter may be overstated and should be interpreted with caution.

[c] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanol-water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NLOM – Non-lipid organic matter
NPM – Northern pikeminnow (representing large piscivorous fish)
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-20. Results of Sensitivity Analysis for Total DDTs with Concentration in Sediment Allowed to Vary

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**36.1%**	**58.5%**	**6.1%**	0.4%	0.3%	0.6%	1.1%	1.1%	0.5%	0.4%
Concentration in sediment	0.0%	0.0%	**35.8%**	**22.8%**	**15.2%**	**28.4%**	**26.3%**	**25.3%**	**24.2%**	**17.9%**
K_{OW}	**6.3%**	**21.7%**	**5.0%**	**6.3%**	**7.0%**	**13.5%**	**9.9%**	**7.1%**	**13.6%**	**9.8%**
Water temperature	0.0%	0.4%	0.1%	2.5%	2.5%	**9.5%**	**11.4%**	**10.9%**	**14.0%**	**9.7%**
PHY water content fraction	**-54.3%**	-3.9%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO water content fraction	0.0%	**-11.4%**	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**40.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC lipid fraction	0.0%	0.0%	0.0%	**60.4%**	4.7%	**38.9%**	**20.2%**	**34.5%**	**30.3%**	**16.6%**
EIC dietary absorption efficiency of lipids	0.0%	0.0%	-0.1%	0.0%	**51.8%**	0.2%	**8.5%**	0.0%	0.3%	2.7%
CAR lipid fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**6.1%**	0.0%	0.0%
CAR water content fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-5.5%**	0.0%	0.0%
NPM lipid fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**8.5%**
Dietary consumption parameters[c]	NA	NA	2.9%	0.9%	4.5%	0.5%	**11.5%**	4.7%	3.6%	**24.0%**

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, percent contribution for this parameter may be overstated and should be interpreted with caution.

[c] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanol-water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NPM – Northern pikeminnow (representing large piscivorous fish)
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-21. Results of Sensitivity Analysis for 4,4′-DDD with Concentration in Sediment Held Constant

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**41.7%**	**68.6%**	**8.5%**	0.9%	1.8%	1.8%	3.6%	2.9%	1.5%	1.4%
K_{OW}	**6.4%**	**17.7%**	**5.6%**	**7.7%**	**15.2%**	**27.4%**	**25.7%**	**18.4%**	**33.5%**	**23.6%**
NLOM proportionality constant	0.0%	1.1%	0.9%	1.5%	**8.7%**	1.0%	0.6%	0.1%	0.0%	0.1%
Water temperature	0.0%	0.1%	0.0%	1.6%	2.2%	**7.7%**	**9.8%**	**8.4%**	**11.9%**	**8.0%**
PHY water content fraction	**-50.9%**	-1.8%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO water content fraction	0.0%	**-9.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**75.0%**	0.0%	0.3%	0.0%	0.5%	0.3%	0.0%	0.0%
BIC lipid fraction	0.0%	0.0%	0.0%	**77.1%**	**9.2%**	**49.1%**	**24.7%**	**36.4%**	**33.7%**	**19.4%**
BIC porewater ventilation	0.0%	0.0%	0.0%	**7.1%**	2.8%	**6.2%**	3.5%	4.4%	4.7%	3.2%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**47.5%**	0.1%	4.5%	0.0%	0.2%	2.2%
CAR lipid fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**11.1%**	0.0%	0.0%
CAR water content fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-10.3%**	0.0%	0.0%
NPM lipid fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**11.5%**
NPM water content fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-6.1%**
Dietary consumption parameters[c]	NA	NA	0.8%	0.2%	4.2%	0.7%	**15.0%**	**5.3%**	3.2%	**21.1%**

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, percent contribution for this parameter may be overstated and should be interpreted with caution.

[c] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanol-water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NLOM – Non-lipid organic matter
NPM – Northern pikeminnow (representing large piscivorous fish)
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-22. Results of Sensitivity Analysis for 4,4′-DDD with Concentration in Sediment Allowed to Vary

Parameter	Percent Contribution to Differences in Model Predictions[a]									
	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**40.4%**	**67.8%**	**7.5%**	0.7%	1.4%	1.3%	2.5%	2.0%	1.1%	1.0%
Concentration in sediment	0.0%	0.0%	**24.0%**	**20.1%**	**18.4%**	**23.7%**	**23.4%**	**20.8%**	**18.6%**	**14.8%**
K_{OW}	**7.6%**	**18.3%**	4.8%	**6.6%**	**12.7%**	**21.5%**	**20.6%**	**15.3%**	**27.7%**	**20.0%**
NLOM proportionality constant	0.0%	1.3%	0.5%	0.7%	6.1%	0.4%	0.2%	0.0%	0.0%	0.0%
Water temperature	0.0%	0.0%	0.0%	1.5%	2.2%	**6.5%**	**7.9%**	**6.7%**	**10.6%**	**7.3%**
PHY water content fraction	**-50.9%**	-1.5%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	0.0%	0.0%
ZOO water content fraction	0.0%	**-9.4%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**55.2%**	0.0%	0.4%	0.0%	0.6%	0.3%	0.1%	0.1%
BIC lipid fraction	0.0%	0.0%	0.0%	**61.0%**	**7.5%**	**35.3%**	**17.8%**	**27.2%**	**26.1%**	**17.0%**
BIC porewater ventilation	0.0%	0.0%	0.0%	**5.7%**	3.1%	**5.1%**	3.6%	4.0%	4.0%	3.2%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**39.3%**	0.2%	4.2%	0.0%	0.2%	1.9%
CAR lipid fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.3%**	0.0%	0.0%
CAR water content fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-8.5%**	0.0%	0.0%
NPM lipid fraction[b]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.2%**
Dietary consumption parameters[c]	NA	NA	0.6%	0.4%	3.2%	0.5%	**11.7%**	3.7%	2.8%	**17.4%**

[a] Differences in model output influenced by the model sensitivity to parameters as a result of mathematical formulas in the model and by uncertainty in parameter values. Negative values indicate an increase in the input parameter value is associated with a decrease in the output value, and vice versa. Positive values indicate that the parameter values and output change together (both or decrease together).

[b] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, percent contribution for this parameter may be overstated and should be interpreted with caution.

[c] The percentage of dietary consumption refers to the total consumption for all prey items for each species. For example, the total dietary consumption percentage for clam represents clam consumption of sediment and phytoplankton. The reported sum is the sum of the absolute values of the dietary constituents. A breakdown of the importance of each prey item is provided in Attachment E6.

BIF – benthic invertebrate filter feeders (clams)
BIC – benthic invertebrate consumers
CAR – common carp (representing omnivorous fish)
EIC – epibenthic invertebrate consumers (crayfish)
K_{OW} – octanol-water partition coefficient
LSS – largescale sucker (representing benthivorous fish)
NA – not applicable
NLOM – Non-lipid organic matter
NPM – Northern pikeminnow (representing large piscivorous fish)
PHY – phytoplankton
SCL – sculpin (representing foraging fish)
SMB – smallmouth bass (representing small piscivorous fish)
ZOO – zooplankton

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 3-23. Percentage of Runs Meeting Average SPAF Criteria

Chemical	Concentration in Sediment	Average SPAF Criteria[a]		
		SPAF < 3	SPAF < 5	SPAF < 10
Total PCBs	constant	55.2%	99.0%	100%
	variable	52.6%	98.5%	100%
PCB TEQ (birds)	constant	0%	0%	9.6%
	variable	0%	0%	16.1%
Dioxin TEQ (mammals)	constant	92.8%	99.7%	100%
	variable	91.1%	99.6%	100%
Total DDTs	constant	52.2%	99.7%	100%
	variable	54.4%	99.2%	100%
4,4'-DDD	constant	63.2%	99.98%	100%
	variable	60.8%	99.9%	100%

[a] Average SPAF for all trophic groups with empirical data available for a given chemical. For dioxin TEQ data were available for five trophic groups. For all other chemicals, data were available for seven trophic groups.

PCB – polychlorinated biphenyl

SPAF – species predictive accuracy factor

TEQ – toxic equivalent

Table 3-24. Food Web Model Results for Swan Island Lagoon

Chemical	SPAF[a]								
	BIF (Clams) n = 3	**BIC**	**EIC (Crayfish) n = 3**	**Foraging Fish (Sculpin) n = 2**	**Benthivorous Fish (Largescale Sucker)**	**Omnivorous Fish (Carp)**	**Small Piscivorous Fish (Smallmouth Bass) n = 3**	**Small Piscivorous Fish (Northern Pikeminnow)**	**Average SPAF[b]**
4,4'-DDD	3.5	NA	**3.9**	**3.8**	NM	NM	**2.4**	NM	3.4
Total DDTs	2.7	NA	**2.6**	**2.2**	NM	NM	**4.4**	NM	3.0
Total PCBs	2.4	NA	**6.9**	**4.1**	NM	NM	**4.1**	NM	4.4

[a] Model was run using calibrated values identified in Section 3.3 and Swan Island Lagoon-specific values from Attachment E5. Empirical tissue chemistry data are also in Attachment E5. Bolded text indicates that the model was over-predicting for this chemical-species combination. All unbolded values represent underpredictions. Average SPAF does not reflect over or underprediction.

[b] Average SPAF based on an average of SPAFs for all trophic groups for which empirical data were available for a given chemical. For PCB TEQs and dioxin TEQs, data were available for five trophic groups. For all other chemicals, data were available for seven trophic groups. Average SPAF provides no indication of overall model under- or overprediction.

BIC – Benthic invertebrate consumer

BIF – Benthic invertebrate filter feeder

EIC – Epibenthic invertebrate consumer

NM – not modeled for Swan Island Lagoon; home range is larger than Swan Island Lagoon

NA – no data available for this species

PCB – polychlorinated biphenyl

SPAF – species predictive accuracy factor

Table 3-25. FWM Results for Clams Using Co-Located Water and Sediment Samples

Clam Sampling Location	Corresponding Water XAD Sample	Concentration of Total PCBs		TSS	Concentration of Total PCBs in Clam Tissue (µg/kg)		SPAF[a]
		Sediment (ng/g)	Water (ng/L)		Empirical	Predicted	
BT017	W015	85.0	0.434	5.17×10^{-6}	111	61.2	1.8
BT018	W016-1	40.0	0.323	4.67×10^{-6}	91.0	34.5	2.6
BT026	W018	219	0.406	3.00×10^{-6}	386	108.1	3.6
BT016	W013-1	1038	1.731	4.67×10^{-6}	2,655	546	4.9

[a] Model underpredicted for all samples

FWM – food web model

SPAF– species predictive accuracy factor

TSS – total suspended solids

XAD – Infiltrex system with XAD resin column

Table 3-26. FWM Results for Crayfish Using Co-Located Sediment Samples

Crayfish Sampling Location	Concentration of Total PCBs in Sediment (µg/kg)	Concentrations of Total PCBs in Crayfish Tissue (µg/kg)		SPAF[a]
		Empirical	Predicted	
08R003	47	51.5	71.1	**1.4**
08R001	36.7	82.8	58.7	1.4
09R002	147	125	191	**1.5**
09R001	16 U	54.2	33.9	1.6
09R001	16 U	59.7	33.9	1.8
08R002	33.7	24.8	55.1	**2.2**
03R001	4 U	2.9 U	19.4	**6.7**
03R005	2,060	335	2490	**7.4**
03R003	19.6	4.3 U	38.2	**8.9**
05R001	4 U	2 U	19.4	**9.7**
03R002	13 U	2.6 U	30.3	**12**
05R003	411	29.7	509	**17**
07R006	1,100 U	70.7 J	1,337	**19**
06R004	50 U	2.9 U	74.7	**26**
03R032	37.8	2.3 U	60.1	**26**
07R004	27.3	1.8 U	47.5	**26**
07R003	1,300 U	57	1,577	**28**
04R003	48.4	2 U	72.8	**36**
06R001	36.8 J	1.3 U	58.9	**45**
02R015	1,430	36.9 J	1,733	**47**
04R002	88.5	2.5 U	121	**48**
02R001	1,220	29.7 J	1,481	**50**
04R004	31.9	1 U	53.0	**53**
06R004	50 U	1.3 U	74.7	**57**
04R004	31.9	0.85 U	53.0	**62**
03R004	385	3.5 U	477	**140**

[a] Bold values indicate overpredictions. Unbolded values indicate underpredictions.
FWM – food web model
J – estimated concentration
U – undetected (value based on reporting limit)
PCB – polychlorinated biphenyl
SPAF – species predictive accuracy factor

Table 3-27. FWM Results for Sculpin Using Co-Located Sediment Samples

Sculpin Sampling Location	Concentration of Total PCBs in Sediment (µg/kg)	Concentration of Total PCBs in Sculpin Tissue (µg/kg)		SPAF[a]
		Empirical	Predicted	
05R020	7.5 U	134 J	127	1.1
06R004	50 U	588 J	467	1.3
08R003	47.0	583 J	443	1.3
03R002	13 U	123 J	171	**1.4**
03R001	3.95 U	146 J	98	1.5
09R002	147	823	1,245	**1.5**
06R002	37.5 U	691 J	367	1.9
08R001	36.7	189	361	**1.9**
05R001	3.95 U	198 J	98	2.0
03R032	37.8	176	370	**2.1**
08R002	33.7	159	337	**2.1**
03R034	22.1	538	243	2.2
04R003	48.4	198J	454	**2.3**
04R004	31.9	125 J	322	**2.6**
02R015	1428	3,398	11,501	**3.4**
09R001	15.5 U	651 J	191	3.4
06R001	36.8 J	100 J	362	**3.6**
02R001	1,223	2,368 J	9,863	**4.2**
04R002	88.5	166 J	776	**4.7**
06R002	37.5 U	2,447	367	6.7
03R004	385	334	3,151	**9.4**
03R004	385	315	3,151	**10**
07R006	1,100 U	440 J	8,878	**20**
07R003	1,300 U	236 J	10,479	**44**
03R005	2,060	370	16,563	**45**

[a] Bold values indicate overpredictions. Unbolded values indicate underpredictions.
FWM – food web model
J – estimated concentration
U – undetected (value based on reporting limit)
SPAF – species predictive accuracy factor

Table 3-28. FWM Results for Smallmouth Bass Using SWACs for Local Sediment

SMB Sampling Location	Number of Composite Samples[b]	Concentration of Total PCBs in Sediment (µg/kg)[c]	Concentration of Total PCBs in Smallmouth Bass Tissue (µg/kg)		SPAF[a]
			Empirical	Predicted	
03R014	1	15.2	788	1,010	**1.3**
04R023	3	134	798	6,024	**7.5**
05R006	1	25.5	400	1,444	**3.6**
06R024	1	53	278	2,611	**9.4**
07R009	3	87.5	490[d]	4,070	**8.3**
08R010[e]	3	307	3,221[d]	13,369	**4.2**
08R032	1	73.2	918	3,465	**3.8**
09R006	1	233	878	10,234	**11.7**

[a] Bold values indicate model overpredictions. Model overpredicted for all samples.

[b] Counts are the number of composite smallmouth bass samples taken within a given river mile.

[c] Sediment concentrations are based on SWACs calculated using a 1-RM segment centered on the smallmouth bass composite sample location.

[d] Mean of three composite samples

[e] This river segment corresponds to Swan Island Lagoon.

FWM – food web model

PCB – polychlorinated biphenyl

SMB – smallmouth bass

SPAF – species predictive accuracy factor

SWAC – spatially weighted average concentration

Table 3-29. FWM Predictions for Laboratory Worms Using Corresponding Sediment Samples

Sampling Location	Concentration of Total PCBs in Sediment (µg/kg)	Concentration of Total PCBs in Laboratory Worm Tissue (µg/kg)		SPAF[a]
		Empirical	BIC Predicted	
BT027-1	63.5	117	82.8	1.4
BT015	39.3	73.8	51.2	1.4
BT008	75	147	97.8	1.5
BT020	39.3	91.4	51.2	1.8
BT002	1170	2970	1525	1.9
BT031	25.6	67.6	33.4	2.0
BT029	59	168	76.9	2.2
BT026	219	730	285	2.6
BT028	1270	4310	1655	2.6
BT030	50.3	171	65.6	2.6
BT016	1040	3910	1356	2.9
BT033	19.1	73.7	24.9	3.0
BT022	115	449	150	3.0
BT019	20.2	82.1	26.3	3.1
BT021	39.5	166	51.5	3.2
BT023	112	475	146	3.3
BT027-2	21.7	101	28.3	3.6
BT032	309	1450	403	3.6
BT009	27.8	131	36.2	3.6
BT001	78	402	102	4.0
BT018	40	208	52.1	4.0
BT003	9.4	48.9	12.3	4.0
BT024	77	488	100	4.9
BT025	25.4	161	33.1	4.9
BT014	12	76.8	15.6	4.9
BT0062	96.8	656	126	5.2
BT010	16	112	20.9	5.4
BT013	34.4	282	44.8	6.3
BT005	33.8	302	44.1	6.9
BT006-1	58.3	527	76.0	6.9
BT012	35.5	331	46.3	7.2
BT011	5.5	108	7.17	15.1
BT017	85	1890	111	17.1
BT007	2	85	2.61	32.6

Table 3-29. FWM Predictions for Laboratory Worms Using Corresponding Sediment Samples

Sampling Location	Concentration of Total PCBs in Sediment (µg/kg)	Concentration of Total PCBs in Laboratory Worm Tissue (µg/kg)		SPAF[a]
		Empirical	BIC Predicted	
BT004	0.85	44.8	1.11	40.4
Average				6.3

[a] Model underpredicted for all samples

BIC – benthic invertebrate consumer

FWM – food web model

PCB – polychlorinated biphenyl

SPAF – species predictive accuracy factor

Table 3-30. Comparison of Multiplate Data to Selected FWM Trophic Group Predictions

Chemical	Unit	Mean Multiplate Conc.[a]	Comparison to BIC		Comparison to ZOO		Comparison to EIC	
			Predicted Conc.	SPAF[b]	Predicted Conc.	SPAF[b]	Predicted Conc.	SPAF[b]
4,4'-DDD	µg/kg	5.44	5.21	1.0	0.668	8.1	4.4	1.2
4,4'-DDT	µg/kg	1.90	32.6	**17.2**	0.508	3.7	30.3	**16.0**
Sum DDD	µg/kg	7.88	6.0	1.3	0.751	10.5	4.8	1.6
Sum DDE	µg/kg	7.45	8.3	**1.1**	1.70	4.4	9.0	**1.2**
Sum DDT	µg/kg	3.06	25.9	**8.4**	0.44	6.9	24.5	**8.0**
Total DDTs	µg/kg	18.40	34.3	**1.9**	1.6	11.5	31.5	**1.7**
Total PCBs	µg/kg	111.60	102.7	1.1	9.3	12.1	101.3	1.1
PCB TEQ (birds)	µg/kg	0.003033	0.032	**10.4**	0.00085	3.6	0.0301	**9.9**
PCB TEQ (mammals)	µg/kg	0.000808	0.005	**6.4**	0.00010	8.0	0.0049	**6.1**
Dioxin TEQ (birds)	µg/kg	0.003017	0.024	**7.9**	0.00049	6.1	0.0080	**2.7**
Dioxin TEQ (mammals)	µg/kg	0.001201	0.012	**9.6**	0.00021	5.7	0.0038	**3.2**
Average SPAF across all chemicals				**6.0**		**7.3**		**4.8**

[a] n = 7 composite samples.

[b] Bolded text indicates that the model was over-predicting for this chemical-species combination. All unbolded values represent underpredictions.

BIC – benthic invertebrate consumers

EIC – epibenthic invertebrate consumers (crayfish)

FWM – food web model

PCB – polychlorinated biphenyl

SPAF – species predictive accuracy factor

TEQ – toxic equivalent

ZOO – zooplankton

Table 3-31. Comparison of Empirical and Calibrated Model Data for Species Not Explicitly Modeled

Chemical	Peamouth			Black Crappie			Brown Bullhead		
	Empirical data (µg/kg ww)	Model Prediction[a] (µg/kg ww)	SPAF[b]	Empirical data (µg/kg ww)	Model Prediction[a] (µg/kg ww)	SPAF[b]	Empirical data (µg/kg ww)	Model Prediction[c] (µg/kg ww)	SPAF[b]
4,4'-DDD	22.5	21.6	1.0	12.1	21.6	**1.8**	9.38	34.0	**3.6**
4,4'-DDT	4.93	33.3	**6.8**	9.2	33.3	**3.6**	19.7	8.83	2.2
Sum DDD	25.4	22.6	1.1	13.6	22.6	**1.7**	12.9	36.5	**2.8**
Sum DDE	133	55.2	2.4	56.2	55.2	1.0	48.8	63.9	**1.3**
Sum DDT	7.36	75.4	**10.2**	13.3	75.4	**5.7**	27.4	28.8	**1.1**
Total DDTs	167	192	**1.1**	83.9	192	**2.3**	89.5	232	**2.6**
Total PCBs	193	644	**3.3**	137	644	**4.7**	428	720	**1.7**
PCB TEQ (birds)	na	na	na	0.0188	0.201	**10.7**	0.00725	0.202	**27.9**
PCB TEQ (mammals)	na	na	na	0.00338	0.0330	**9.8**	0.00682	0.0327	**4.8**
Dioxin TEQ (birds)	na	na	na	0.00254	0.0153	**6.0**	0.00253	0.00902	**3.6**
Dioxin TEQ (mammals)	na	na	na	0.00124	0.00720	**5.8**	0.00176	0.00427	**2.4**

[a] Model predictions for foraging fish (as represented by sculpin for the calibration of the FWM).

[b] **Bolded** SPAF values indicate that the model was over-predicting for this chemical-species combination.

[c] Model predictions for benthivorous fish (as represented by largescale sucker for the calibration of the FWM).

na – not available; no data for this species-chemical combination

PCB – polychlorinated biphenyl

SPAF – species predictive accuracy factor

TEQ – toxic equivalent

ww – wet weight

FIGURES

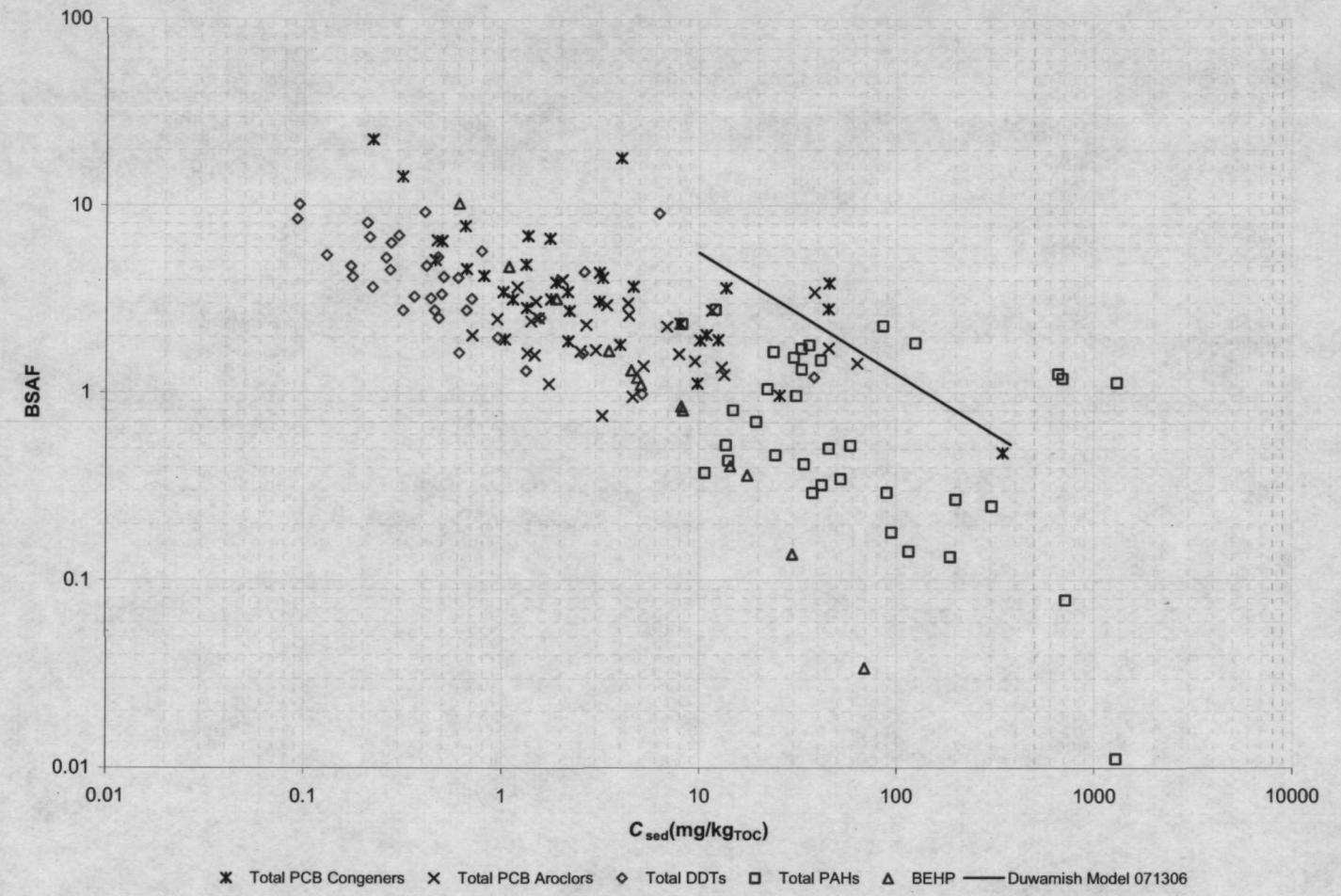


Figure 2-1
BSAF Versus Organic Carbon-Normalized Sediment Concentration, Laboratory Worms

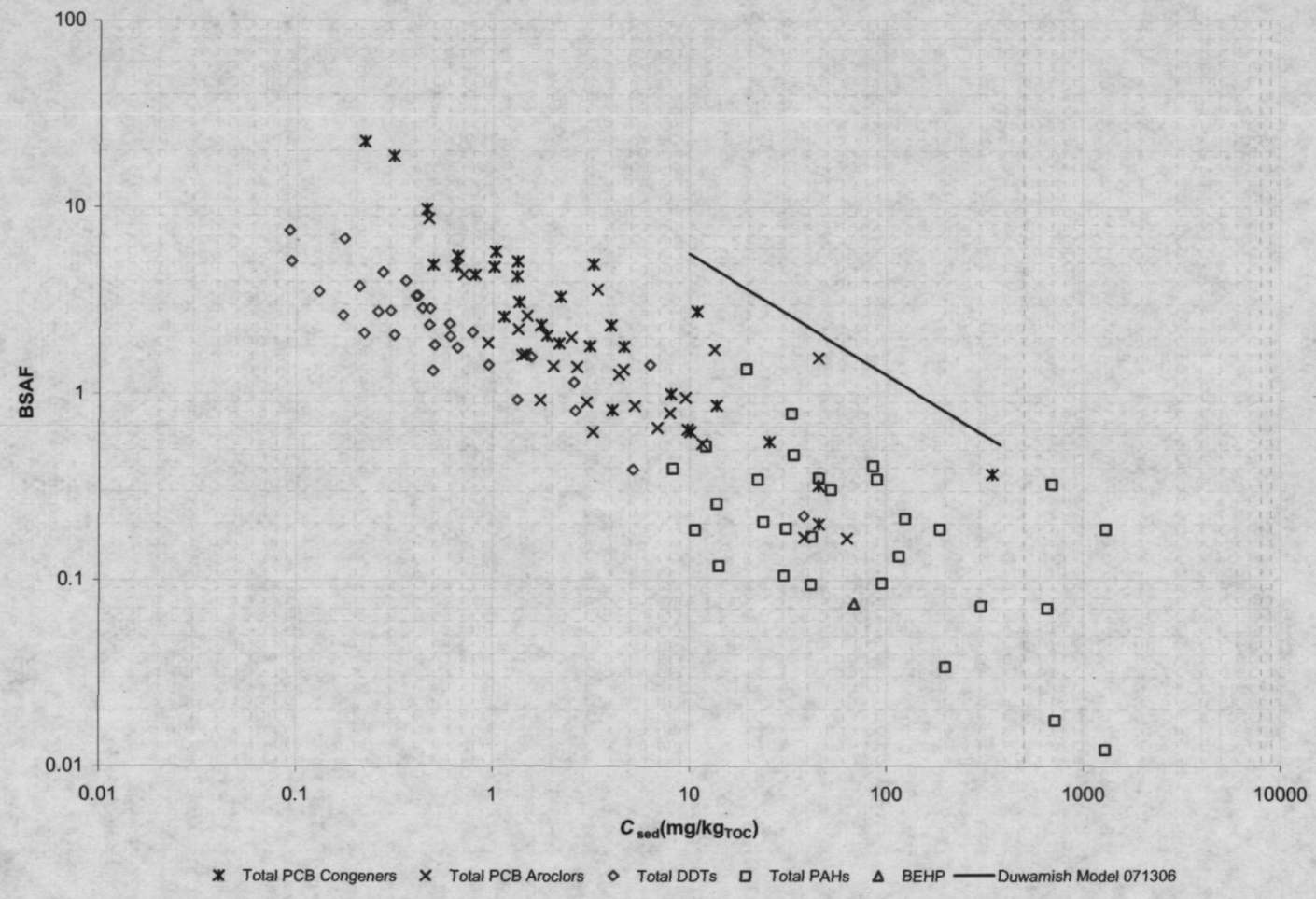


Figure 2-2
BSAF Versus Organic Carbon-Normalized Sediment Concentration, Field Clams

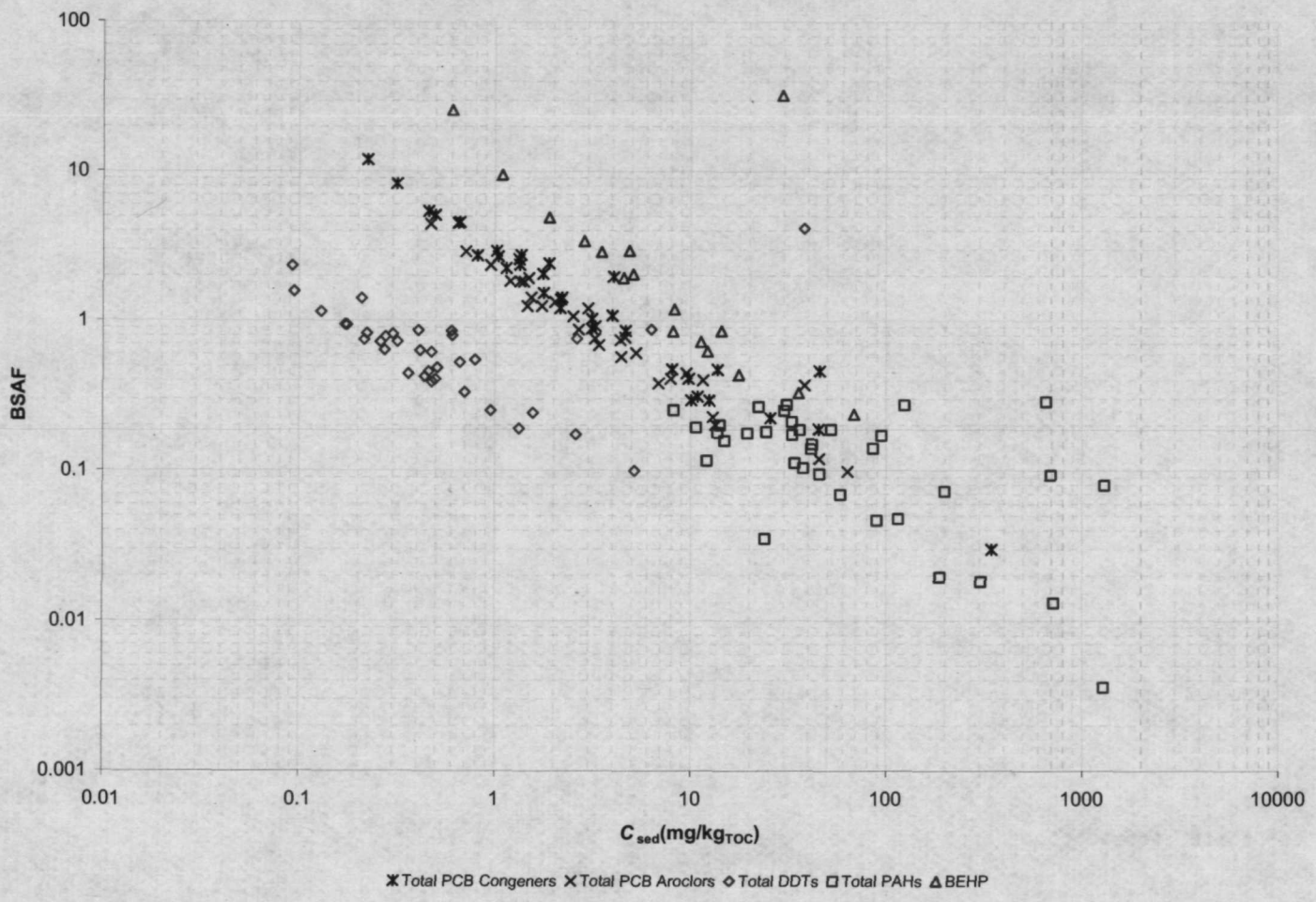


Figure 2-3
BSAF Versus Organic Carbon-Normalized Sediment Concentration, Laboratory Clams

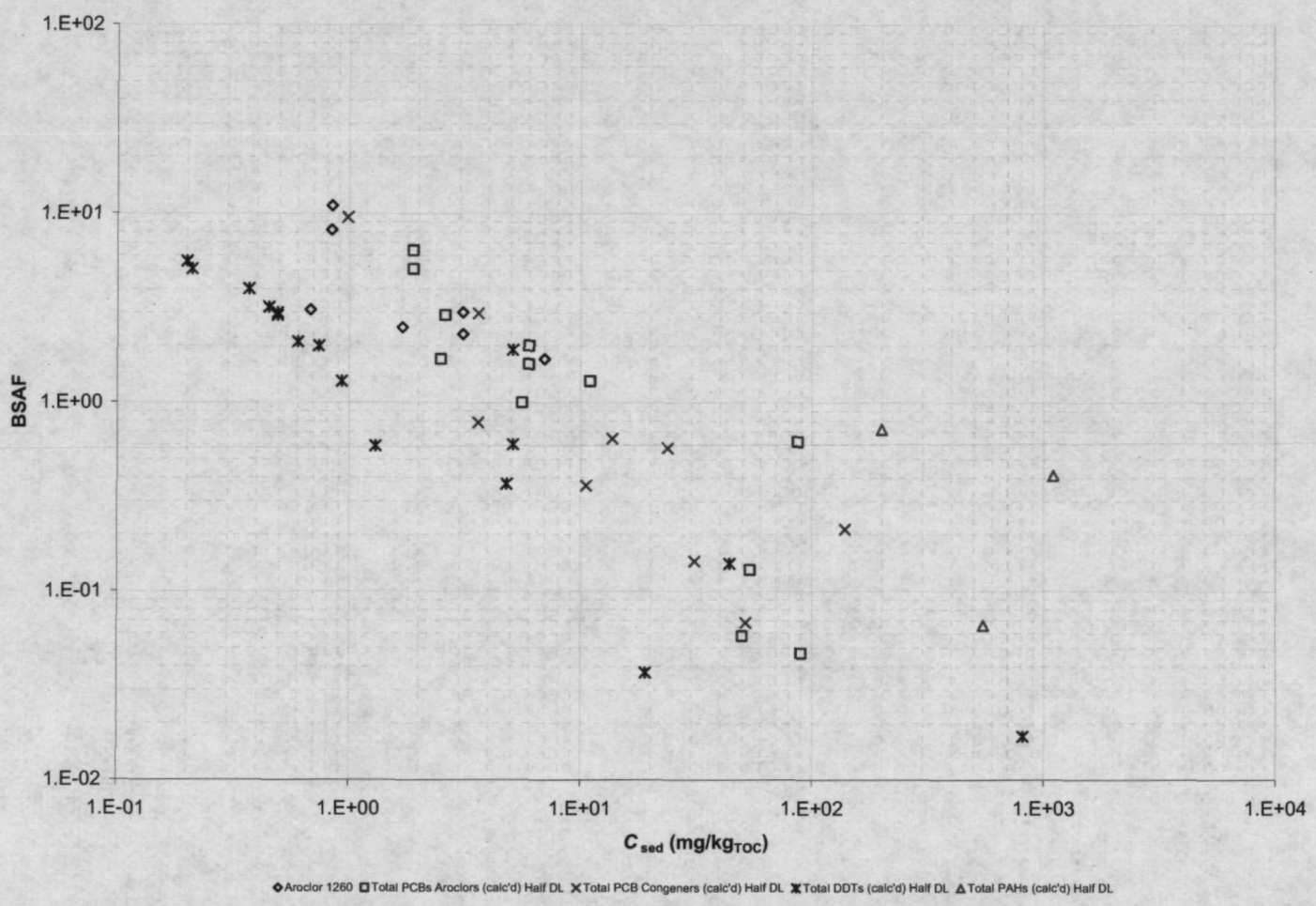


Figure 2-4
Crayfish BSAF Versus Organic Carbon-Normalized Sediment Concentration

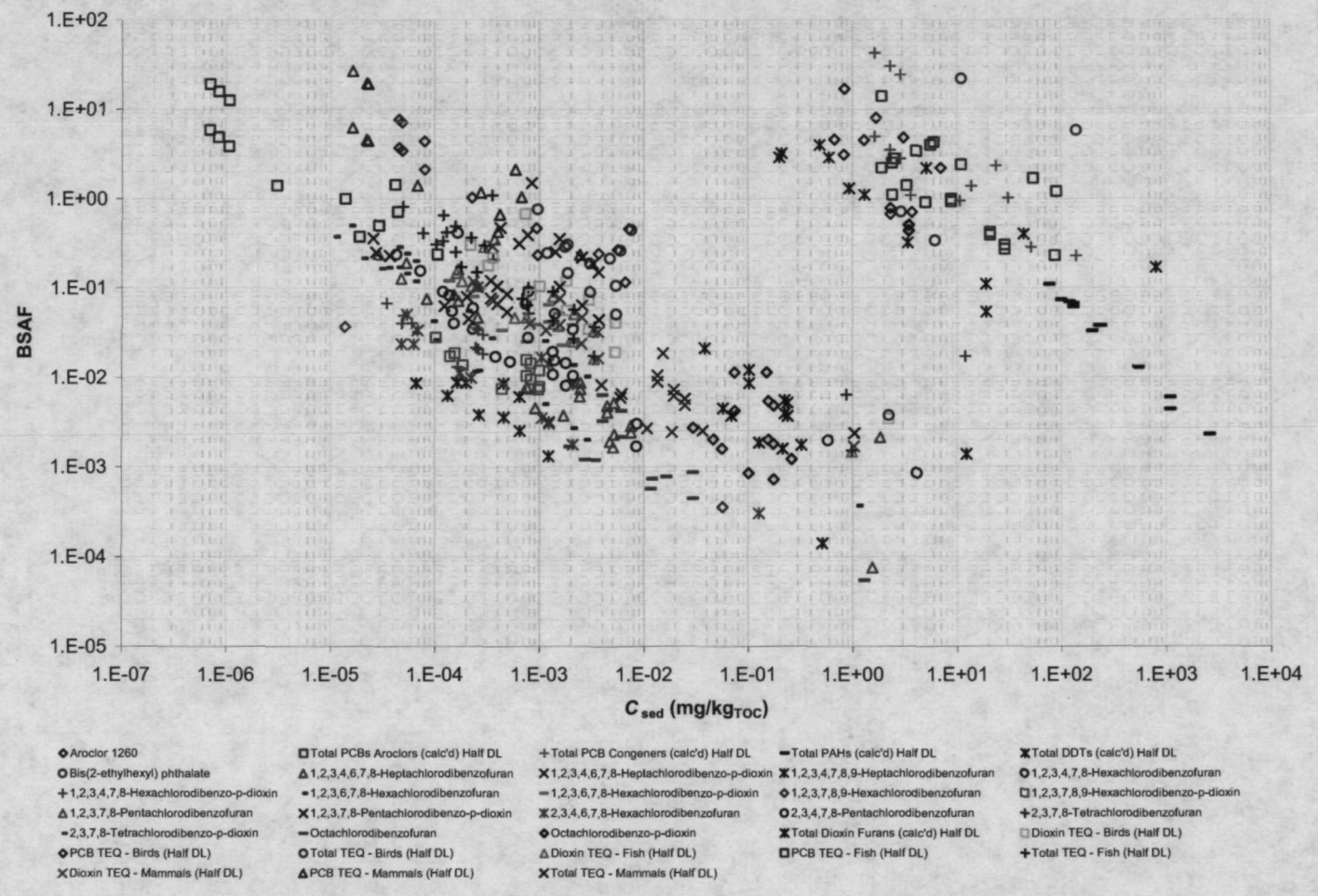
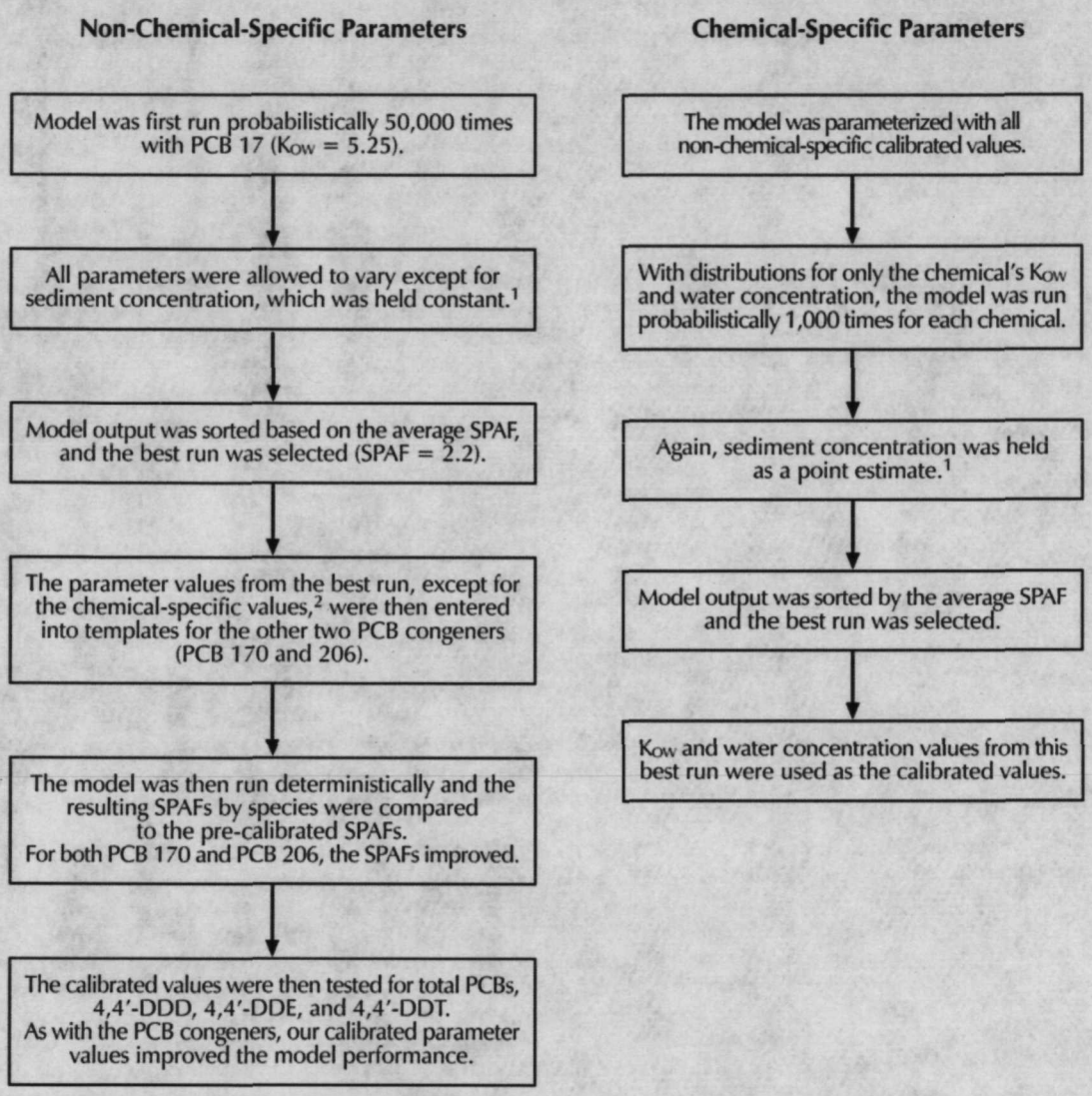


Figure 2-5
Sculpin BSAF Versus Organic Carbon-Normalized Sediment Concentration



[1] *When iPRGs were calculated, a series of sediment values were used in the model. The actual sediment concentration was thus not calibrated.*

[2] *Chemical-specific parameters include the K_{OW} and the chemical water concentration. Best estimates of the mean values were used for these parameters to check the non-chemical-specific calibration.*

Figure 3-1
Food Web Model Calibration Process

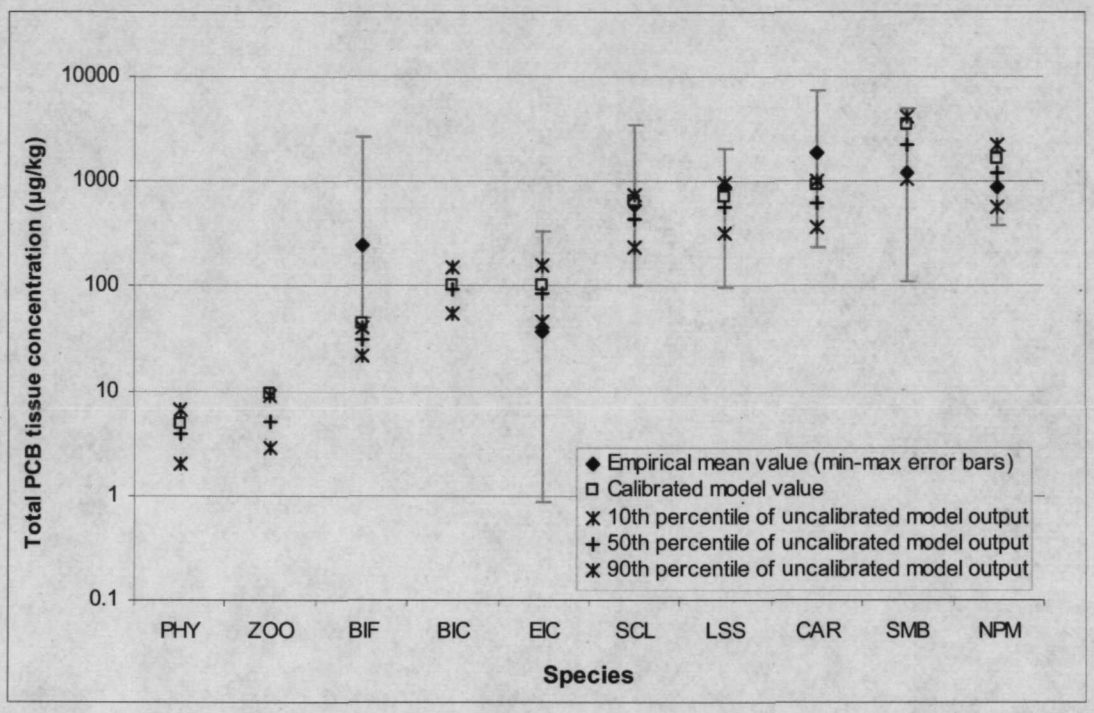


Figure 3-2
Predicted and Empirical Tissue Concentrations for Total PCBs

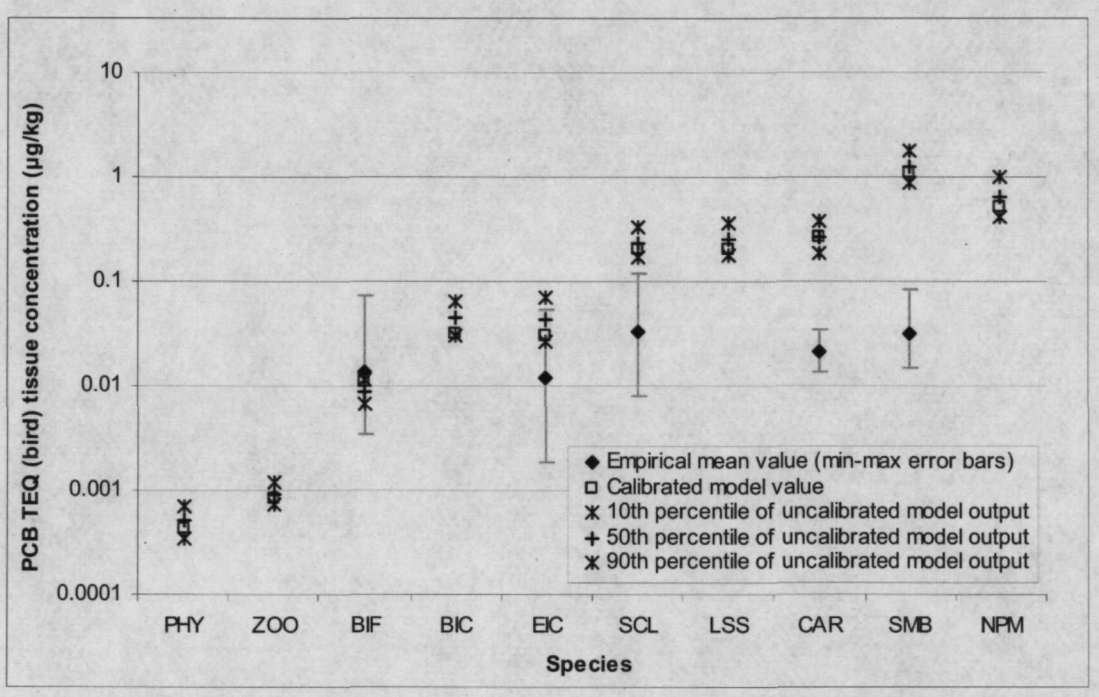


Figure 3-3
Predicted and Empirical Tissue Concentrations for PCB TEQ (Birds)

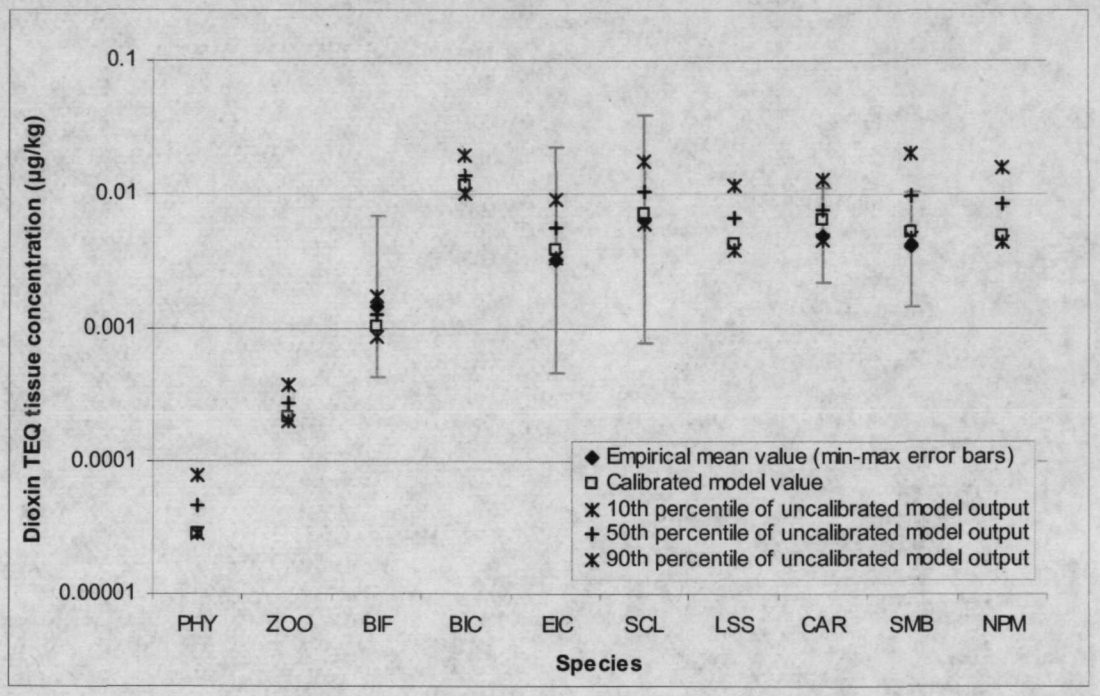


Figure 3-4
Predicted and Empirical Tissue Concentrations for Dioxin TEQ (Mammals)

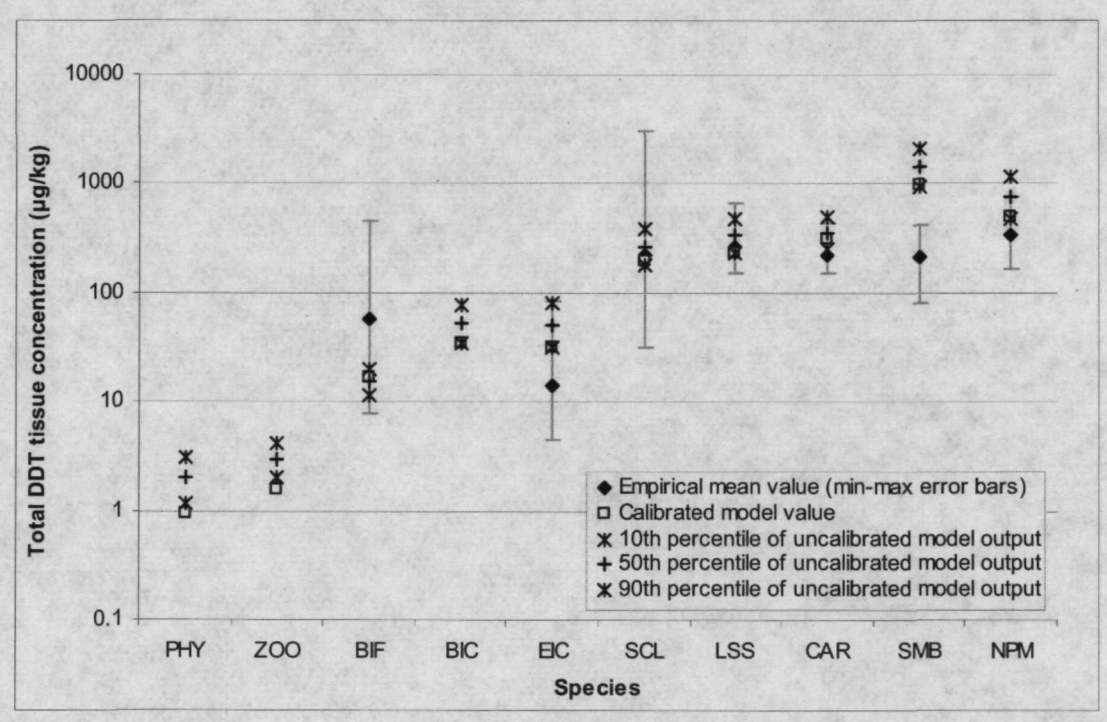


Figure 3-5
Predicted and Empirical Tissue Concentrations for Total DDTs

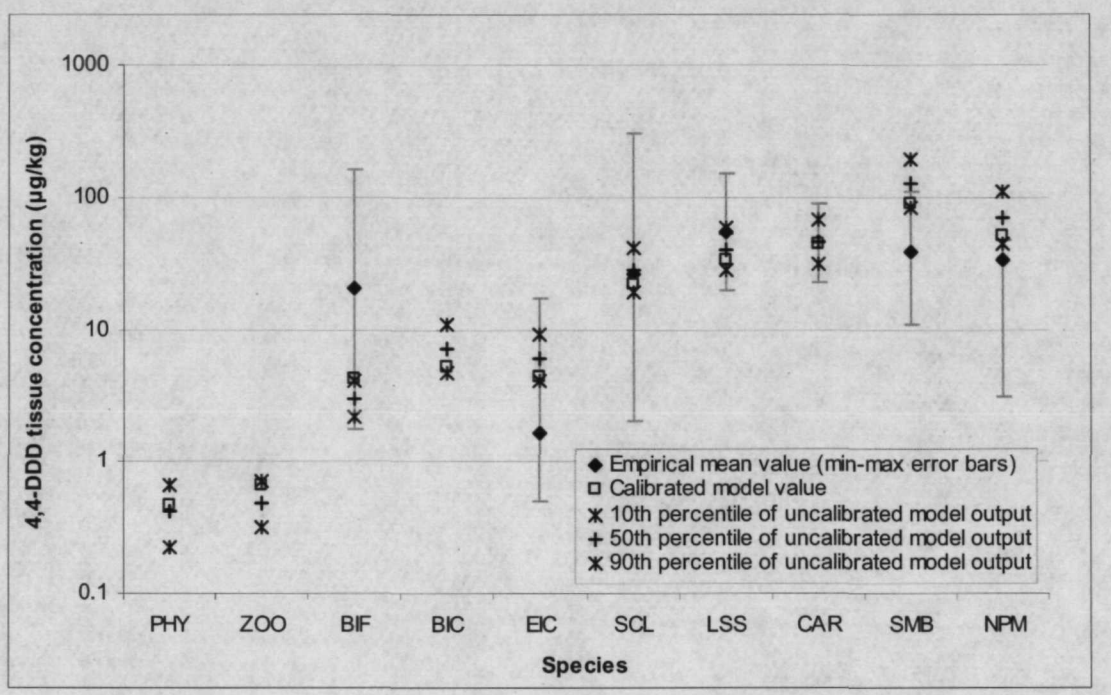
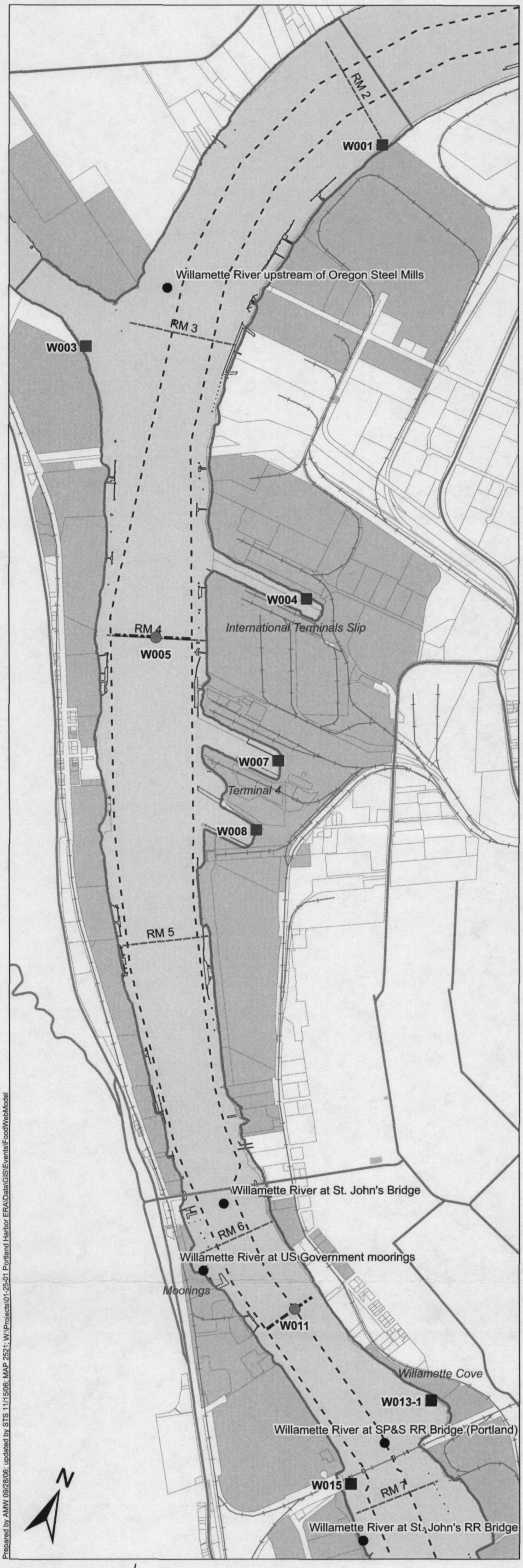
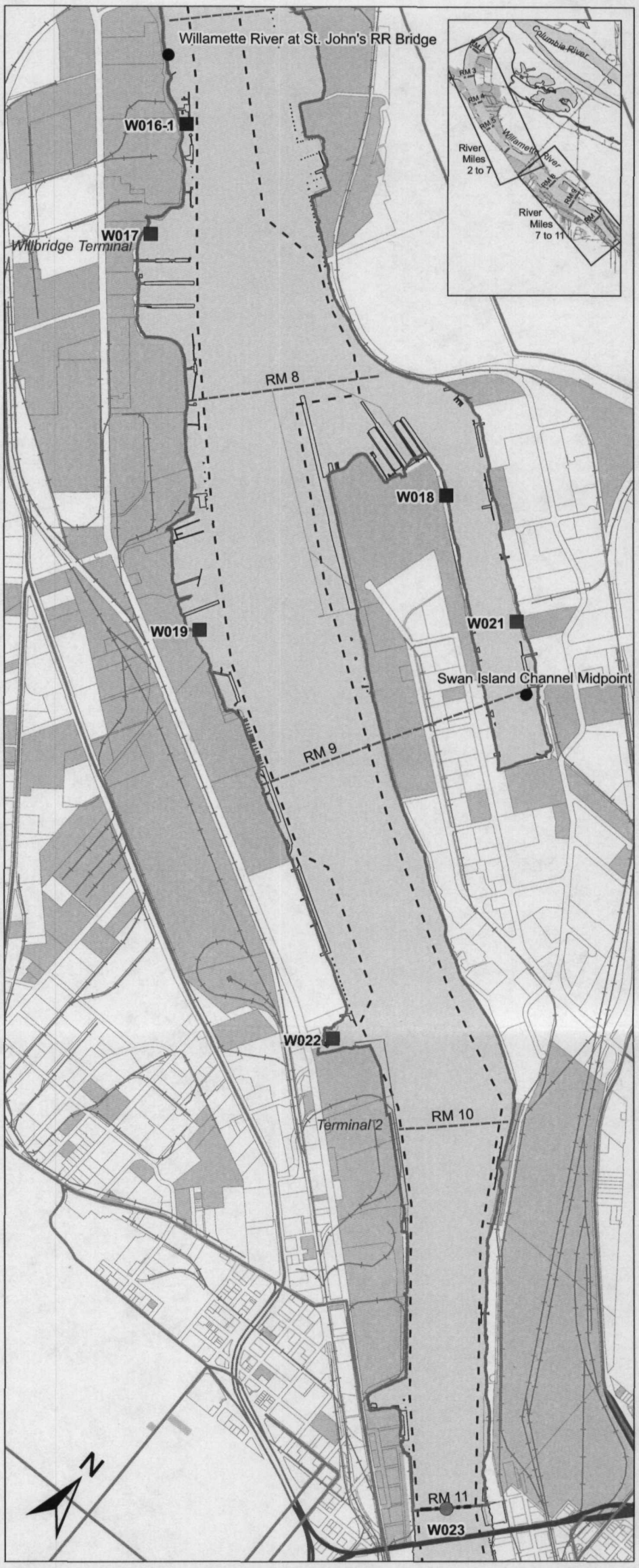


Figure 3-6
Predicted and Empirical Tissue Concentrations for 4,4'-DDD





Water sample location for site-wide water data

- ODEQ temperature station
- Total suspended solids - LWG
- Total suspended solids and water chemistry - LWG
- Dissolved organic carbon - LWG
- Transect water chemistry - LWG
- Upland site
- Waterfront tax lot
- Arterial
- Highway
- Freeway
- Railroad
- Dock or structure
- River mile
- Navigation channel
- 13-foot contour (in-river analysis elev.)
- River or slough

FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS.
Channel & River miles: US Army Corps of Engineers.

Prepared by AMW 09/28/06; updated by STS 11/15/06; MAP 2521; W:\Projects\01-25-01 Portland Harbor ERA\Data\GIS\Events\FoodWebModel

Wind Ward environmental LLC

LWG LOWER WILLAMETTE GROUP

0 500 1,000 1,500 2,000 2,500 Feet

Figure 4-1
Water Sampling Locations on the Willamette River
River Miles 2 to 11

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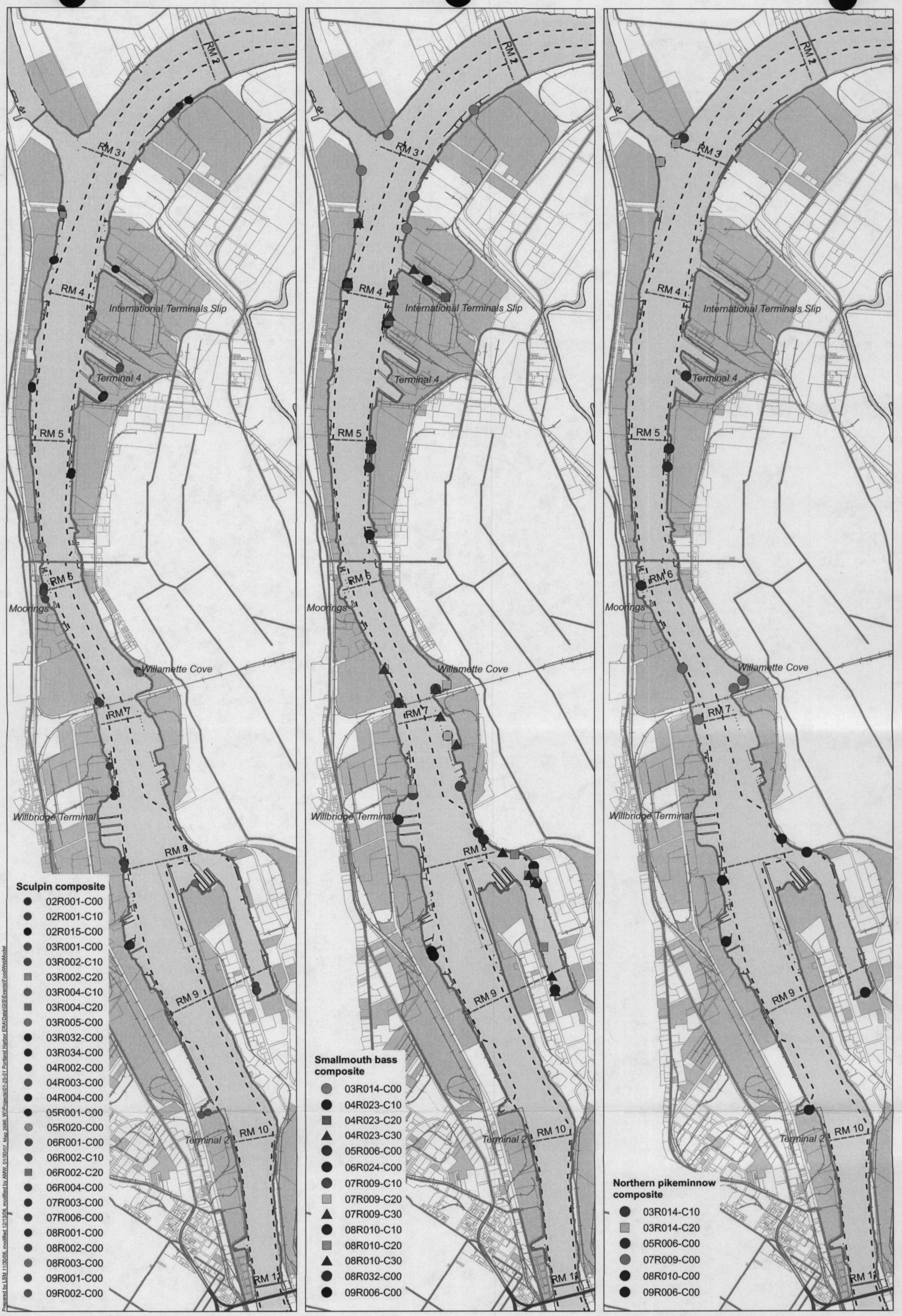
Attachment E3



Prepared by LSM 11/30/06, modified 12/13/06, modified by AMW, 01/30/07, Map 2686, W:\Projects\01-25-01 Portland Harbor ERA\Data\GIS\Events\FoodWebModel

Wind Ward environmental LLC

LWG Lower Willamette Group

0 1,000 2,000 3,000 4,000 Feet

Upland site
Waterfront tax lot
Arterial
Highway
Freeway
Railroad
Dock or structure
River mile
Navigation channel
13-foot contour (in-river analysis elevation)
River or slough

FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS.
Channel & River miles: US Army Corps of Engineers.

Figure 6-1
Sculpin, Smallmouth Bass and Northern Pikeminnow Sampling Locations on the Willamette River River Miles 2 to 11

Portland Harbor RI/FS
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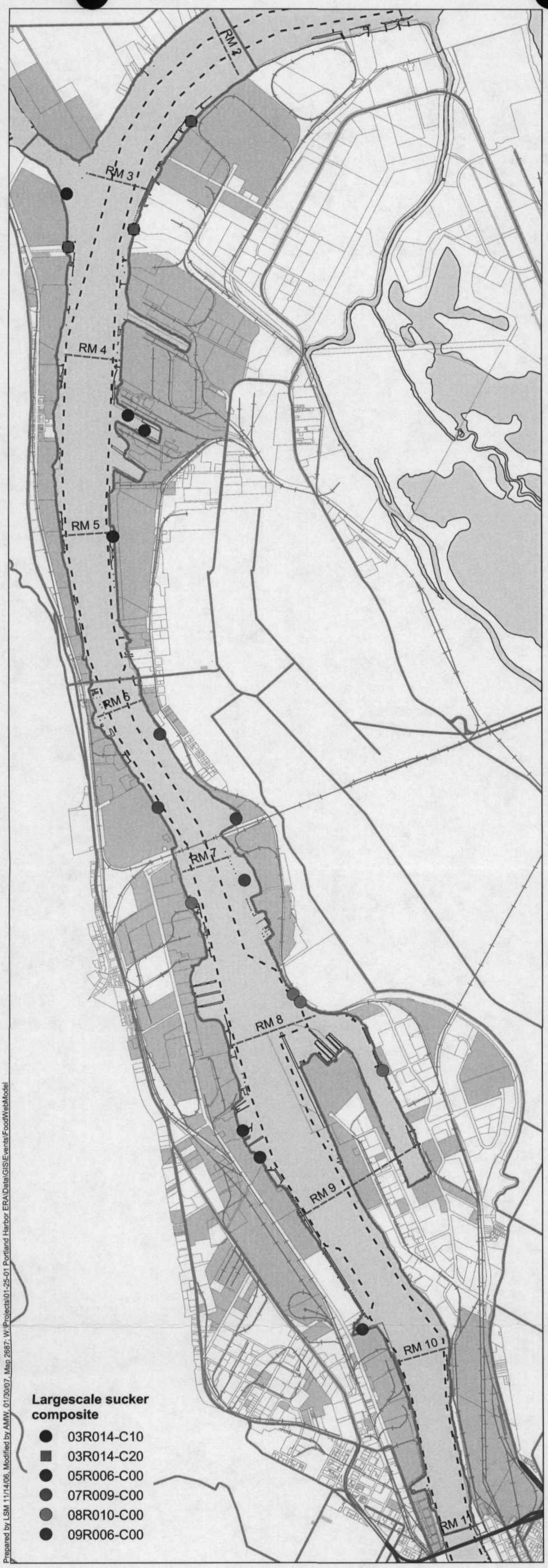
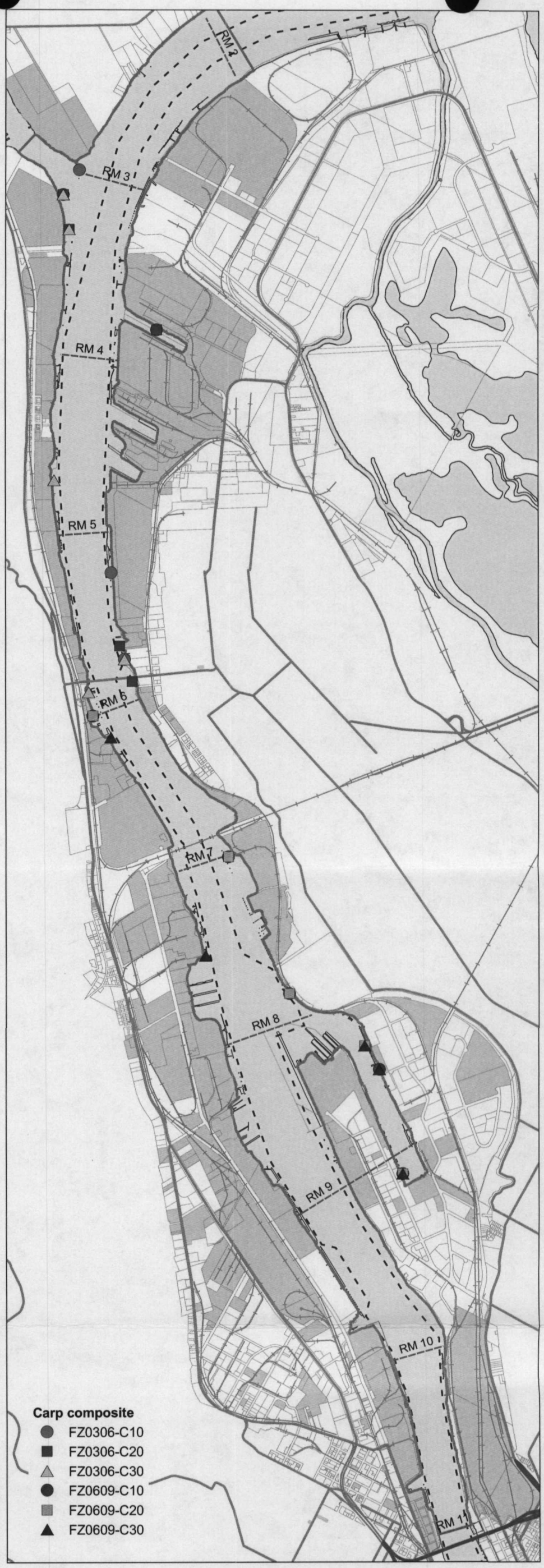
Attachment E3





Prepared by LSM 11/14/06, Modified by AMW, 01/30/07, Map 2687, W:\Projects\01-25-01 Portland Harbor ERA\Data\GIS\Events\FoodWebModel

Wind Ward environmental LLC

LWG Lower Willamette Group

N

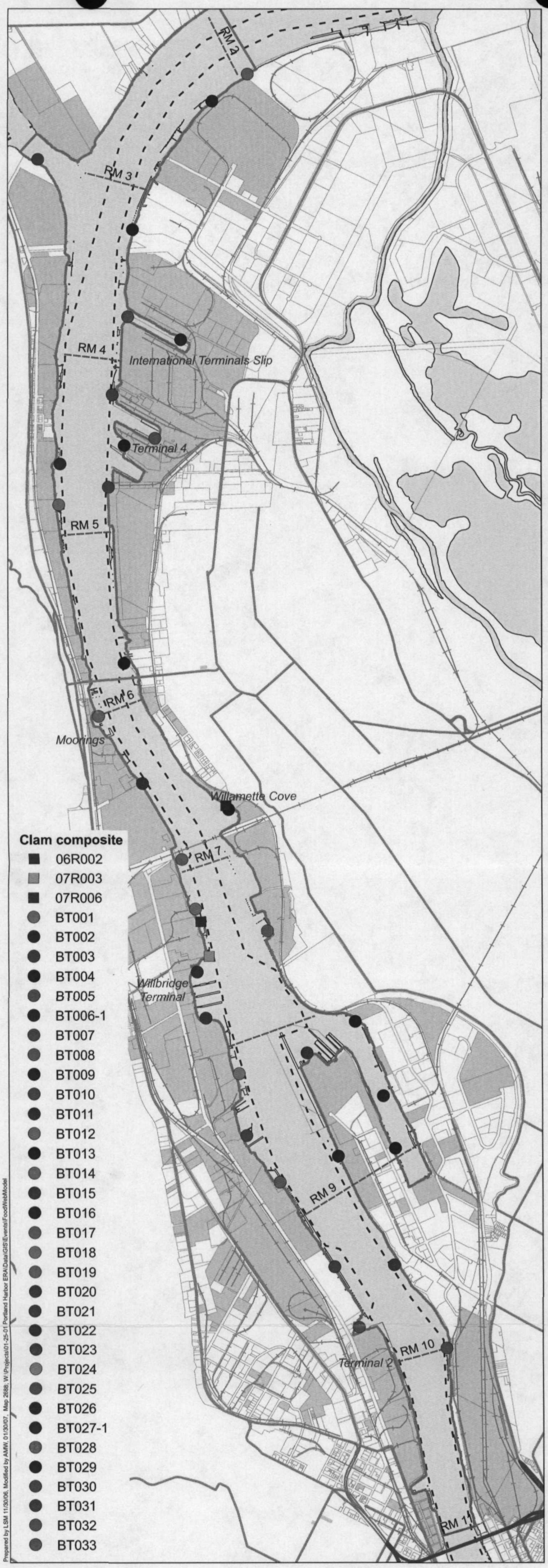
0 1,000 2,000 3,000 4,000 Feet

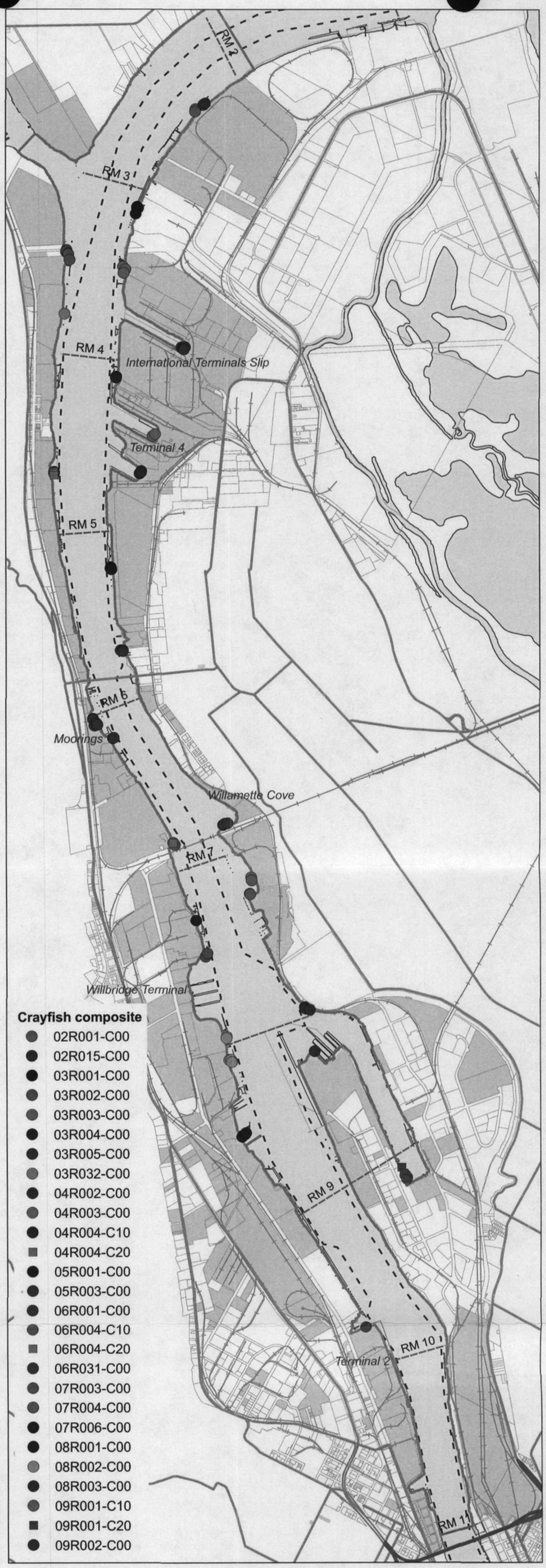
Upland site
Waterfront tax lot
Arterial
Highway
Freeway
Railroad
Dock or structure
River mile
Navigation channel
13-foot contour (in-river analysis elevation)
River or slough

FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS.
Channel & River miles: US Army Corps of Engineers.

Figure 6-2
Largescale Sucker and Carp Sampling Locations on the Willamette River River Miles 2 to 11

Portland Harbor RI/FS
Comprehensive Round 2 Report
Attachment E3





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Wind Ward LLC environmental

LWG Lower Willamette Group

N

0 1,000 2,000 3,000 4,000 Feet

Upland site
Waterfront tax lot
Arterial
Highway
Freeway
Railroad
Dock or structure
River mile
Navigation channel
13-foot contour (in-river analysis elevation)
River or slough

FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS.
Channel & River miles: US Army Corps of Engineers.

Figure 6-3
Clam and Crayfish Sampling Locations on the Willamette River River Miles 2 to 11

Portland Harbor RI/FS
Comprehensive Round 2 Report
Attachment E3

APPENDIX E: FOOD WEB MODEL

Attachment E1
Model Documentation

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4.0 REFERENCES **38**

1.0 MODEL AND RATIONALE FOR CONVERSION TO VISUAL BASIC FOR APPLICATIONS

The primary goal of food web modeling for the remedial investigation/feasibility study is to develop a predictive relationship between chemical concentrations in sediment, water, and tissue that can be used to derive preliminary sediment remediation goals and compare remedial alternatives for chemicals that are present in fish tissue, water, and sediment at concentrations associated with unacceptable risk. The food web model (FWM) used to calculate initial preliminary remediation goals (iPRGs) in this report is based on algorithms and equations initially established by Gobas (1993). This model has been used as the basis for many subsequent updates and iterations of Gobas-type models, including refinements and simplifications (Arnot and Gobas 2004; Morrison et al. 1996, 1997). The driving force of these fugacity-based models is phase partitioning. The first type of partitioning occurs between water and the organism, and the second occurs during the digestion process between prey items or ingested sediment and the organism within the gastrointestinal tract.

Models based on the original Gobas (1993) approach have been used in a broad range of environments (i.e., lakes, rivers, and estuaries) as described in the 2004 technical memorandum on evaluating steady-state aquatic FWMs for the Portland Harbor Superfund site (Windward 2004). The model used for development of iPRGs was adapted from the Arnot-Gobas (2004) model but was transferred into Visual Basic for Applications® (VBA) code. This conversion was primarily the work of Bruce Hope (senior environmental toxicologist with ODEQ) and was intended to increase the transparency of the model's function (EPA 2006; ODEQ 2006). The conversion to VBA code also served to reduce the effort required to enter parameters into the model. Section 3 provides a full presentation of the VBA code. The following description of the model is largely adapted from the VBA model description provided to LWG by Bruce Hope (ODEQ 2006).

Inputs and outputs for the VBA version of the FWM are accomplished through the use of Microsoft® Excel® spreadsheets. An effort was made to avoid complicated (although perhaps more efficient) coding in order to preserve the transparency of the way the model functions (ODEQ 2006). Use of Excel® for the biotic model interface facilitates the concurrent use of Monte Carlo software (in this case, Crystal Ball®) for enhanced uncertainty and sensitivity analyses. This combination of software makes it possible to run multiple iterations of the FWM. This attachment describes the components of the model and then presents the VBA code used to run the model. The acronyms provided in the model and sub-model explanations (inputs and outputs) are the same as those used in the VBA code, unless otherwise indicated.

2.0 GENERAL PROCESSES AND STRUCTURE OF THE FOOD WEB MODEL

The use of an overly detailed food web with numerous species categories would have exceeded both the availability of site-specific and literature-derived physiological data. The Lower Willamette River (LWR) FWM working group, consisting of Lower Willamette Group (LWG) members and the US Environmental Protection Agency (EPA) and its partners, had several meetings and discussions to agree on the species to be modeled. Because the model's primary purpose is to inform remediation decisions and not to precisely predict tissue residues, a simplified food web was deemed sufficient (EPA 2006). Based on this premise, certain representative pelagic and benthic species were selected for modeling. The species groups that were modeled, and the representative species for which LWG data are available, are as follows:

- Phytoplankton
- Zooplankton
- Benthic invertebrate filter feeders (clams, *Corbicula* spp.)
- Benthic invertebrate consumers[1]
- Epibenthic invertebrate consumers (crayfish, unidentified species)
- Foraging fish (sculpin, *Cottus* spp.)
- Benthivore fish (largescale sucker, *Catostomus macrocheilus*)
- Omnivore fish (common carp, *Cyprinus carpio*)
- Small piscivorous fish (smallmouth bass, *Micropterus dolomieui*)
- Large piscivorous fish (northern pikeminnow, *Ptychocheilus oregonensis*)

[1] A generalized category designed to represent oligochaetes, insect larvae, and amphipods.

2.1 MODEL SET-UP AND ASSUMPTIONS

The Arnot and Gobas FWM that is the basis for this FWM was designed around the premise that a single equation may be used to represent the exchange of non-ionic organic chemicals between an organism and its environment (Arnot and Gobas 2004). The conceptual equation, which underlies the model and describes the net flux of a parent chemical being absorbed or deposited (dM_B) by an organism at any time (dt), is:

$$\frac{dM_B}{dt} = \left\{ W_B \cdot \left(k_1 \cdot \left[m_O \cdot C_{WD,O} + m_P C_{WD,P} \right] + k_D \cdot \sum_i \left(P_i \cdot C_{D,i} \right) \right) \right\} - \left(k_2 + k_E + k_M \right) \cdot M_B \qquad \textbf{Equation 1}$$

Acronym	Definition	Unit
M_B	mass of chemical in organism	g
W_B	wet weight of organism	kg
K_1	clearance constant	L/kg×day
m_O	fraction of respiratory ventilation involving overlying water	unitless
m_P	fraction of respiratory ventilation involving porewater	unitless
$C_{WD,O}$	total freely dissolved chemical concentration in overlying water	g/L
$C_{WD,P}$	freely dissolved chemical concentration in porewater	g/L
k_D	clearance rate constant	kg/kg×day
P_i	fraction of the diet composed of prey item i	unitless
$C_{D,i}$	chemical concentration in prey item i	g/kg
k_2	gill and skin elimination rate constant	1/day
k_E	fecal egestion rate constant	1/day
k_m	metabolic transformation rate constant	1/day

Because of a lack of adequate time-dependent data, the model has been simplified to assume steady-state conditions for the purposes of this application. Therefore, per Arnot and Gobas (2004), the equation used to assess biomagnification and bioaccumulation up the food chain (and actually applied in the model) becomes:

$$C_B = \frac{k_1 \times \left(m_O \times C_{WD,O} + m_P \times C_{WD,P} \right) + k_D \times \sum P_i \times C_{D,i}}{k_2 + k_E + k_G + k_M} \qquad \textbf{Equation 2}$$

Where:

Acronym	Definition	Unit
C_B	chemical concentration in biota tissue	g/kg ww
k_1	gill uptake rate constant	L/kg×day
m_o	fraction of respiratory ventilation that involves overlying water	unitless

Acronym	Definition	Unit
$C_{WD,O}$	total freely dissolved chemical concentration in the water column above the sediment	g/L
m_p	fraction of respiratory ventilation that involves sediment-associated porewater	unitless
$C_{WD,P}$	total freely dissolved chemical concentration in the sediment associated porewater	g/L
k_d	dietary uptake rate constant	kg/kg × day
P_i	fraction of the diet consisting of the prey item i	unitless
$C_{D,i}$	concentration of a chemical in a prey item	g/kg
k_2	gill elimination rate constant	1/day
k_E	fecal egestion rate constant	1/day
k_G	growth rate constant	1/day
k_M	metabolic transformation rate constant	1/day

A number of specific sub-models are used to define the rate coefficients and dissolved water concentrations in the steady-state equation. These sub-models can be broken down into three categories: physical, chemical, and biological processes. Additional variables are required to parameterize the sub-models and are defined as below as the sub-models are presented.

2.2 PHYSICAL AND CHEMICAL PROCESSES

Inputs from physical site-specific data and literature were used to describe various physical processes required in the model to predict chemical flux through the environment. The following parameters were calculated by the model.

$$Z_{water} = \frac{1}{HT}$$ **Equation 3**

$$Z_{lipid} = Z_{water} \times K_{ow}$$ **Equation 4**

$$C_{ox} = (-0.24\ T_w + 14.04) \times 0.9$$ **Equation 5**

Where:

Acronym	Definition	Unit
Z_{water}	water fugacity	mol m^{-3}/Pa
Z_{lipid}	lipid fugacity	mol m^{-3}/Pa
HT	temperature-compensated Henry's Law constant	Pa m^{-3}/mol
K_{OW}	chemical-specific octanol-water partition coefficient	kg/L
T_w	mean water temperature	°C
C_{ox}	dissolved oxygen content at 90% saturation	mg/L

Z_{lipid} is used in the calculation of chemical uptake from lipid and non- lipid organic matter (NLOM) in the gut during digestion. Z_{water} is used in the calculation of

chemical uptake from water in the gut (see Section 2.3.3). C_{ox} is used to calculate the gill ventilation rate (Section 2.3.2).

Some of chemical and physical parameters were used to calculate bioavailable chemical concentrations in surface water ($C_{WD,O}$) and in porewater ($C_{WD,P}$). $C_{WD,O}$ and $C_{WD,P}$ were used to describe organism exposure through respiration.

In the Arnot and Gobas model (2004), the model calculates the fraction of dissolved and freely available chemical in the water column in the case that there is no available empirical data. The previous version of the model applied to the LWR (Windward 2005) estimated dissolved concentration from total water concentration. EPA and its partners recommended that the site-specific filtered surface water data (XAD column data) be used in future model iterations (EPA 2006). A new equation was required to convert the site-specific filtered surface water data (XAD column data) to the dissolved concentration ($C_{WD,O}$) used in the model. The dissolved water concentration for chemicals was estimated using the following equation from Morrison et. al. (1997).

$$C_{WD,O} = \frac{\text{filtered water concentration}}{1 + (K_{OW} \times 0.08 \times DOC)} \qquad \textbf{Equation 6}$$

In Morrison et al. (1997), an adjustment was made (multiplying 0.5 × dissolved organic carbon [DOC] in the denominator, not shown in the above equation) because the filter pore size used in the measurements for that study (0.2 μm) was smaller than the diameter of DOC particles (0.45 μm). The filter size for LWG DOC water sampling was 0.5 μm, so this adjustment was not necessary.

Because the model was modified to use XAD sample information, which directly estimates freely dissolved water concentration, no overlying water information (identified as previous versions on the model as ϕ or $C_{WT,O)}$) (Arnot and Gobas 2004) was needed.

The concentration of a chemical freely dissolved in porewater (g/L), $C_{WD,P,}$ can be estimated from the concentration of the chemical in sediment using the following equation.

$$C_{WD,P} = \frac{C_{S,OC}}{K_{OC}} \qquad \textbf{Equation 7}$$

In this equation, $C_{S,OC}$ (g/kg organic carbon) represents the concentration of the chemical in sediment after it has been normalized for organic carbon content. K_{OC} is the organic carbon-water partition coefficient (L/kg organic carbon).

2.3 GENERAL BIOLOGICAL PROCESSES

The general biological processes included in the model are described below. In some cases, the acronyms used by Arnot and Gobas (2004) and described below vary slightly from the acronyms used in the VBA model provided by Bruce Hope (ODEQ

2006). For example, the clearance rate via respiration is described below as K_1 and is included in the model code as K1, and the dietary absorption efficiency of lipid ε_L is included in the model code as eL.

2.3.1 Species Modeled and Dietary Apportionment

Aquatic food webs may be large and rather complex. At the recommendation of EPA and its partners (EPA 2006), the number of species included in the FWM were reduced from the previous LWR FWM (Windward 2005). Through the LWR FWM working group, a reduced the number of trophic groups to be modeled and representative species for each group were agreed upon. For example, the "benthic invertebrate consumer" category was designed to represent oligochaetes, amphipods, and insect larvae. The dietary menu selected for the benthic invertebrate consumers trophic group was therefore designed to reflect the dietary preferences of all three of those species. Diets for each trophic group were then assigned by Windward Environmental LLC (Windward), incorporating comments from EPA and its partners (EPA 2006) and with consideration of all species that the trophic groups were intended to represent.

The selection of dietary prey items is fully discussed in Attachment E3, which describes the selection of all parameters included in the model. Briefly, dietary compositions for fish and invertebrates were compiled primarily from studies in the LWR (ODFW 2005) and general qualitative observations of fish stomach contents collected during Round 1 sampling, as reported in Attachment B8 of Appendix B of the RI/FS Programmatic Work Plan (Integral et al. 2004). These stomach content analysis results were augmented with data from the general literature, including a study of dietary habits of Lower Columbia River fish (Zimmerman 1999).

Diets of fish and invertebrates are likely to be variable because of opportunistic feeding behavior and seasonal and spatial variations in prey availability. The presence of natural fluctuations in dietary preferences was addressed by normalizing dietary fractions across a "menu" of possible food items (as described in EPA 2006). This normalization was accomplished using a matrix spreadsheet provided by Bruce Hope (ODEQ 2006). When the model is run deterministically (a single iteration using point estimates), each trophic group is assigned one best estimate of dietary items and portion of each dietary item. When the model is run probabilistically (multiple model iterations using distributions), the portion of each dietary item consumed varies with each model iteration. The matrix ensures that the selected portions are normalized so the sum of dietary portion equals 1.

Dietary exposure to ingested prey tissue and ingested sediment affects the consumer during the digestion process. Phase partitioning occurs across the gut wall, and chemicals may be absorbed into the tissues or expelled from the tissues into the gut contents. This exchange of chemicals during the digestive process is discussed in greater detail in Section 2.3.3.

2.3.2 Direct Contact Through Water Exposure – Phase Partitioning

Organic chemicals are thought to partition between lipid, protein, and carbohydrate (collectively known as non-lipid organic matter [NLOM]), and water. The sorption and storage of chemicals may occur to a certain extent in each of these media for each organism modeled. Therefore, an organism-water partitioning coefficient (k_{BW}), which results from direct contact with water during respiration, is determined for each organism according to the following equation.

$$k_{BW} = \frac{k_1}{k_2} = VLB_{org} \times K_{OW} + VNB_{org} \times \beta \times K_{OW} + VWB_{org} \qquad \textbf{Equation 8}$$

Where:

Acronym	Definition	Unit
k_1	gill uptake rate constant	L/kg×day
k_2	gill elimination rate constant	d^{-1}
VLB_{org}	lipid fraction of the organism	unitless
VNB_{org}	NLOM fraction of the organism	unitless
VWB_{org}	water fraction of the organism	unitless
β (BETA)	NLOM-octanol proportionality constant	unitless
GAMMA	NLOC-octanol proportionality constant	unitless

The constant GAMMA affects partitioning between water and non-lipid organic carbon (NLOC) and is used only for phytoplankton (see Section 2.4.3).

In order to estimate the parameters k_1 and k_2, Arnot and Gobas rely on the following set of sub-models (Arnot and Gobas 2004).

The gill uptake rate constant, k_1, describes the rate at which chemicals are absorbed from water across the membranes of the gills and skin. It is considered a function of the ventilation rate (G_v, in units of L/day) and the diffusion rate across the surface, such that:

$$K_1 = \frac{E_W \times G_v}{W_B} \qquad \textbf{Equation 9}$$

Where:

E_W = the chemical uptake efficiency across the gills as a percentage (%)
W_B = the weight of the organism in kg

G_v is calculated as:

$$G_V = \frac{1{,}400 \times W_B^{0.65}}{C_{OX}} \qquad \textbf{Equation 10}$$

Arnot and Gobas (2004) propose a different method of calculating k_1 for algae and macrophytes. Instead of the equation presented above, the following relationship is recommended.

$$k_1 = [A + (B/K_{ow})]^{-1}$$ **Equation 11**

In this equation, A and B are constants that represent the resistance of the algae or macrophytes to the uptake of the chemical through aqueous and organic phases, respectively. Based on empirical data described more fully in Arnot and Gobas (2004), default values of 6.0×10^{-5} and 5.5 were selected for constants A and B, respectively.

The gill elimination rate constant, k_2, describes the rate at which chemicals are removed from the organism across the gill membrane. Closely related to k_1, inasmuch as both constants are sensitive to ventilation rate and permeability across the surface of the gill membrane, k_2 is defined such that $k_2 = k_1/K_{BW}$.

Because bioaccumulation is defined by the ratio of k_1 to k_2, any errors that may occur in the selection of appropriate G_V and E_W values will be canceled out in the model. Therefore, the model is relatively insensitive to parameterization errors in G_V and E_W, which makes it possible to represent the ventilation rate and chemical uptake efficiency across the gill membrane with a single equation for a variety of species.

2.3.3 Direct Contact Through Dietary Exposure – Phase Partitioning

In addition to direct exposure to chemicals in the water, organisms may be exposed to chemicals present in ingested prey items.

The dietary uptake rate constant, k_D, defines the rate at which chemicals are removed from the gastrointestinal tract of an organism and absorbed into tissue. The dietary uptake rate constant is defined as $k_D = E_D \times G_D/W_B$, where E_D is the dietary chemical transfer efficiency, G_D is the feeding rate, and W_B is the weight of the organism. E_D has been shown to rely heavily on the K_{OW} value of the chemical being absorbed and therefore was defined by Arnot and Gobas (2004) based on a two-phase lipid-water resistance model. Thus, $E_D = (3.0 \times 10^{-7} \times K_{OW} + 2.0)^{-1}$. The first and last terms in this equation are defined as dietary uptake constants A and B, respectively (EDA and EDB). Feeding rates are best defined using site-specific empirical data, if such data are available. However, if such information does not exist for a particular site being modeled, feeding rate G_D may be defined as $G_D = 0.022 \times W_B^{0.85} \times \exp(0.06 \times T)$ for fish, zooplankton, and aquatic invertebrate species. In the absence of empirical data, the feeding rate of aquatic filter feeders is best defined as $G_D = G_V \times C_{SS} \times \sigma$, such that the feeding rate is a product of the gill ventilation rate (G_V), the concentration of suspended solids (C_{SS} in units of kg/L), and the scavenging efficiency of particles removed from water (σ as a percentage, called in SCV in VBA model).

Chemicals may also be eliminated from an organism across the wall of the gastrointestinal tract. Such fecal egestion is defined by the fecal elimination rate constant k_E. This rate constant $k_E = G_F \times E_D \times K_{GB}/W_B$, where G_F is the fecal egestion rate, E_D is the dietary chemical transfer rate (described above), K_{GB} is the partitioning coefficient between the gut contents of the organism and its tissue, and W_B is the organism's weight. The fecal egestion rate G_F is a function of how digestible the various components of the diet are.

$$GF = \{[(1-\varepsilon_L) \times v_{LD}] + [(1-\varepsilon_N) \times v_{ND}] + [(1-\varepsilon_W) \times v_{WD}]\} \times G_D. \qquad \textbf{Equation 12}$$

Where:

Acronym	Definition	Unit
ε_L	dietary assimilation efficiencies of lipid	unitless
ε_N	dietary assimilation efficiencies of NLOM	unitless
ε_W	dietary assimilation efficiencies of water	unitless
V_{LD}	lipid fraction of the diet	unitless
V_{ND}	NLOM fraction of the diet	unitless
V_{WD}	water fraction of the diet	unitless

It is estimated as $K_{GB} = (V_{LG} \times K_{OW} + V_{NG} \times \beta \times K_{OW} + V_{WG}) / (V_{LB} \times K_{OW} + V_{NB} \times \beta \times K_{OW} + V_{WB})$, where V_{LG}, V_{NG}, and V_{WG} are the lipid, water, and NLOM contents of the gut. These gut fractions are estimated as shown below; they collectively add up to a number approaching 1 and are dependent upon the assimilation efficiency fraction for each component. (Arnot and Gobas 2004) The fractions of lipid, water, and NLOM present in the tissue of the organism are described as V_{LB}, V_{NB}, and V_{WB}, respectively, and are based on organism-specific information.

$$V_{LG} = \frac{([1-\varepsilon L] \times V_{LD})}{(1-\varepsilon L \times V_{LD}) + (1-\varepsilon N \times V_{ND}) + ([1-\varepsilon W] \times V_{WD})} \qquad \textbf{Equation 13}$$

$$V_{NG} = \frac{([1-\varepsilon N] \times V_{LD})}{([1-\varepsilon L] \times V_{LD}) + ([1-\varepsilon N] \times V_{ND}) + ([1-\varepsilon W] \times V_{WD})} \qquad \textbf{Equation 14}$$

$$V_{WG} = \frac{([1-\varepsilon L] \times V_{WD})}{([1-\varepsilon L] \times V_{LD}) + ([1-\varepsilon N] \times V_{ND}) + ([1-\varepsilon W] \times V_{WD})} \qquad \textbf{Equation 15}$$

In the model, Z_{water} is used to determine chemical uptake from water in the gut (V_{WG}), and Z_{lipid} is used to determine chemical uptake from both lipid matter in the gut (V_{LG}) and non-lipid organic matter in gut (V_{NG}). These parameters are used in conjunction with the above equations to describe the chemical flux between an organism's tissue and the material in its gut (see Section 2.4.4 for full equation).

2.3.4 Growth

Growth rate information is available for a wide range of species. However, growth rates may vary between and within species according to a number of factors, including, but not limited to, the organism size and age, the environmental temperature, and the availability and quality of food (Arnot and Gobas 2004). The recommended approximation for growth rate in the absence of empirical data is $k_G = 0.0005 \times W_B^{-0.2}$ for temperatures around 10°C (Arnot and Gobas 2004; Thomann et al. 1992).

2.3.5 Metabolism

Chemical compounds may be eliminated from an organism through metabolic transformation, in which the parent compound undergoes structural changes to become a chemical derivative or metabolite of the original compound. The metabolic process is species- and chemical-specific. Few data exist regarding metabolic transfer rate constants. For 4,4'-DDT and sum DDT, a metabolic rate was developed according to Konwick et al. (2006) and applied in the two models for those chemicals. See Attachment E3 for specific information regarding the parameterization of the model and inclusion of metabolism.

2.4 SPECIES-SPECIFIC CALCULATIONS

2.4.1 Overview

Many of the equations presented in Arnot Gobas (2004) were included in the version of the model used in this food web modeling effort. Excerpts of the VBA code used to run the model for the LWR FWM are presented below with explanations of each input parameter used and examples of how those parameters fit into the equations required to run the model. The parameter abbreviations used by Arnot and Gobas in the 2004 model were altered slightly for convenience in the version presented here (ODEQ 2006). However, the functionality of the model was preserved.

The entire VBA code is presented at the end of this section; but because of the iterative nature of the model, a representative organism from each of the three main types of organisms modeled (i.e., one plankton, one benthic invertebrate, and one fish) has been selected for a more detailed description in this section. Section 3, the complete VBA code, presents the exact coding information used for the other organisms.

2.4.2 Identifying Numbers for Species Used in Equations

The identifying numbers used to represent species in the FWM are presented in Table 1.

Table 1. Identifying Numbers for Species

Identifying Number	Species
2	phytoplankton
3	zooplankton
4	clam
5	worm (benthic invertebrate consumer)
6	crayfish
7	largescale sucker
8	sculpin
9	carp

Table 1. Identifying Numbers for Species

Identifying Number	Species
10	smallmouth bass
11	northern pikeminnow

This numbering methodology allowed for the identification of species-specific values within the code without having to write out the entire species name as it accompanied each of the individual parameters.

2.4.3 Phytoplankton

VLB_2 = empirical value defined by model user
VWB_2 = empirical value defined by model user
$VNB_2 = 1-(VLB_2 + VWB_2)$
$K1_2 = 1/(UA + (UB/KOW))$
KM_2 = empirical data defined by user
$KPW_2 = (VLB_2 * KOW) +(VNB_2 * (GAMMA * 10) * KOW) + VWB_2$
$K2_2 = K1_2/KPW_2$
FPW_2 = empirical data defined by user
$CB_2 = CWB * K1_2 * (1-FPW_2)/(K2_2 + KG_2 + KM_2)$

Acronym	Definition
VLB_2	lipid fraction of organism (unitless)
VNB_2	non-lipid organic matter fraction of organism (unitless)
VWB_2	water fraction of organism (unitless)
GAMMA	non-lipid organic carbon (NLOC) proportionality constant (unitless)
$K1_2$	gill uptake rate constant (d^{-1})
UA	uptake constant A (unitless)
UB	uptake constant B (unitless)
KOW	chemical-specific octanol-water partition coefficient (kg/L)
KPW_2	organism-water partition coefficient (unitless)
$K2_2$	gill elimination rate constant (d^{-1})
KG_2	growth rate constant (d^{-1})
KM_2	metabolic rate constant (d^{-1})
FPW_2	fraction of sediment porewater ventilated by organism (unitless)
CWB	biologically available concentration of chemical in water (ng/g)
CB_2	predicted tissue concentration in organism (ng/g)

2.4.4 Benthic Invertebrate Filter Feeder (Clam)

WB_4 = empirical value defined by user
VLB_4 = empirical value defined by model user
VLBsed = empirical value defined by model user

VWB_4 = empirical value defined by model user
VWBsed = empirical value defined by model user
$VNB_4 = 1-(VLB_4 + VWB_4)$
VNBsed = empirical value defined by model user
$WBL_4 = WB_4 * VLB_4$
KM_4 = empirical data defined by user
$QW_4 = 88.3 * WB_4^{0.06}$
$QL_4 = QW_4 * 0.01$
$KG_4 = 0.000502 * WB_4^{-0.2}$
$GV_4 = (1400 * (WB_4^{0.065}))/COX$
SCV_4 = empirical value defined by model user
$GD_4 = GV_4 * CPW * SCV_4$
DF4,1 = dietary fraction of prey item 1 (sediment) for organism 4 (clam)
DF4,2 = dietary fraction of prey item 2 (phytoplankton) for organism 4 (clam)
eL_4 = empirical value defined by model user
eN_4 = empirical value defined by model user
eW_4 = empirical value defined by model user
FPW_4 = empirical value defined by model user
Food 4A = DF4,2 * VLB2 + DF4,1 * VLBsed
Food 4B = DF4,2 * VNB2 + DF4,1 * VNBsed
Food 4C = DF4,2 * VWB2 + DF4,1 * VWBsed
Food 4D = DF4,2 * CB2 +DF4,1 * CST
$GF_4 = (((1 - eL_4) * Food4A) + ((1 - eN_4) * Food4B) + ((1 - eW_4) * Food4C))) * GD_4$
$VLG_4 = ((1 - eL_4) * Food4A) / (((1 - eL_4) * Food4A) + ((1 - eN_4) * Food4B) + ((1 - eW_4) * Food4C))$
$VNG_4 = ((1 - eN_4) * Food4B) / (((1 - eL_4) * Food4A) + ((1 - eN_4) * Food4B) + ((1 - eW_4) * Food4C))$
$VWG_4 = ((1 - eW_4) * Food4C) / (((1 - eL_4) * Food4A) + ((1 - eN_4) * Food4B) + ((1 - eW_4) * Food4C))$
$ED_4 = 1 / (EDA * KOW + EDB)$
$KD_4 = ED4 * GD4 / WB_4$
$EWW_4 = 1 / (1.89 + (155 / KOW))$
$K1_4 = 1/((UA + (UB/KOW))$
$KPW_4 = (VLB_4 * KOW) +(VNB_4 * (BETA * KOW) * KOW) + VWB_4$
$K2_4 = K1_4/KPW_4$
FPW_4 = empirical data defined by model user
$Zorg_4 = (VLB_4 * Zlipid) + (VNB_4 * BETA * Zlipid) + (VWB_4 * Zwater)$
$Zgut_4 = VLG_4 * Zlipid + VNG_4 * BETA * Zlipid + VWG_4 * Zwater$
$KGB_4 = Zgut_4 / Zorg_4$
$KE_4 = KGB_4 / WB_4 * ED_4 * GF_4$
$CB4 = (CWB * K1_4 * (1 - FPW_4) + K1_4 * FPW_4 * CSD + ((GV_4 / WB_4) * CPW * ED_4 * Food4D)) / (K2_4 + KE_4 + KG_4 + KM_4)$

Acronym	Definition
VLB_4	lipid fraction of organism (unitless)
VNB_4	non-lipid organic matter fraction of organism (unitless)
VWB_4	water fraction of organism (unitless)
WB_4	organism body weight (kg)
WBL_4	organism lipid weight (kg)
QW_4	aqueous transport parameter for organism (d^{-1})
QL_4	lipid transport parameter for organism (d^{-1})
GD_4	food ingestion rate (kg food/day)
TW	mean water temperature (°C)
KG_4	growth rate constant (d^{-1})
GV_4	gill ventilation rate (L d^{-1})
COX	dissolved oxygen content at 90% saturation (mg/L)
DF_{42}	fraction of phytoplankton in invertebrate diet (unitless)
DF_{43}	fraction of zooplankton in invertebrate diet (unitless)
DF_{41}	fraction of sediment in invertebrate diet (unitless)
$FoodA_4$	intermediate calculation term (unitless)
$FoodB_4$	intermediate calculation term (unitless)
$FoodC_4$	intermediate calculation term (unitless)
$FoodD_4$	intermediate calculation term (unitless)
GF_4	fecal egestion rate (kg food/day)
eL_4	lipid dietary absorption efficiency for organism (unitless)
eN_4	NLOM dietary absorption efficiency for organism (unitless)
eW_4	water dietary absorption efficiency for organism (unitless)
VLG_4	lipid fraction in organism gut (unitless)
VNG_4	NLOM fraction in organism gut (unitless)
VWG_4	water fraction in organism gut (unitless)
ED_4	intestinal tract chemical transfer efficiency (unitless)
EDA	dietary chemical transfer constant A
EDB	dietary chemical transfer constant B
KD_4	dietary uptake rate constant (d^{-1})
$K1_4$	gill uptake rate constant (d^{-1})
EWW_4	gill chemical transfer efficiency (unitless)
KOW	chemical-specific octanol-water partition coefficient (kg/L)
KPW_4	organism-water partition coefficient (unitless)
$K2_4$	gill elimination rate constant (d^{-1})
BETA	NLOM proportionality constant (unitless)
Z_{org4}	organism fugacity (mol m^{-3} Pa^{-1})
Z_{gut4}	organism intestinal tract fugacity (mol m^{-3} Pa^{-1})
KGB_4	gut-organism partition coefficient (unitless)
KE_4	fecal egestion rate constant (d^{-1})
KM_4	metabolic rate constant (d^{-1})
FPW_4	fraction of sediment porewater ventilated (unitless)
CWD_s	biologically available concentration of chemical in water (ng/g)

Acronym	Definition
CST_s	total concentration of chemical in sediment (ng/g)
CSD_s	concentration of chemical in sediment porewater (ng/g)
CB_4	tissue concentration in organism (ng/g)

2.4.5 Fish (Sculpin)

WB_7 = empirical value defined by model user
VLB7 = empirical value defined by model user
VWB_7 = empirical value defined by model user
VNB7 = 1 - (VLB_7 + VWB_7)
WBL_7 = WB_7 * VLB_7
KM_7 = empirical value defined by model user
$QW_7 = 88.3 * WB_7^{0.6}$
$QL_7 = QW_7 * 0.01$
$KG_7 = 0.000502 * WB_7^{-0.2}$
$GV_7 = (1400 * (WB_7^{0.65})) / COX$
$GD_7 = 0.022 * WB_7^{0.85} * Exp(0.06 * T_W)$
DF71 = dietary fraction of prey item 1 (sediment) for organism 7 (sculpin)
DF72 = dietary fraction of prey item 2 (phytoplankton) for organism 7 (sculpin)
DF73 = dietary fraction of prey item 3 (zooplankton for) organism 7 (sculpin)
DF74 = dietary fraction of prey item 4 (clam) for organism 7 (sculpin)
DF75 = dietary fraction of prey item 5 (worm) for organism 7 (sculpin)
DF76 = dietary fraction of prey item 6 (crayfish) for organism 7 (sculpin)
eL_7 = empirical value defined by model user
eN_7 = empirical value defined by model user
eW_7 = empirical value defined by model user
FPW_7 = empirical value defined by model user
Food7A = DF71 * VLBsed + DF72 * VLB_2 + DF73 * VLB_3 + DF74 * VLB_4 + DF75 * VLB_5 + DF76 * VLB_6
Food7B = DF71 * VNBsed + DF72 * VNB_2 + DF73 * VNB_3 + DF74 * VNB_4 + DF75 * VNB_5 + DF76 * VNB_6
Food7C = DF71 * VWBsed + DF72 * VWB_2 + DF73 * VWB_3 + DF74 * VWB_4 + DF75 * VWB_5 + DF76 * VWB_6
Food7D = DF71 * CST + DF72 * CB_2 + DF73 * CB_3 + DF74 * CB_4 + DF75 * CB_5 + DF76 * CB_6
GF_7 = (((1 - eL_7) * Food7A) + ((1 - eN_7) * Food7B) + ((1 - eW_7) * Food7C)) * GD_7
VLG_7 = ((1 - eL_7) * Food7A) / (((1 - eL_7) * Food7A) + ((1 - eN_7) * Food7B) + ((1 - eW_7) * Food7C))
VNG_7 = ((1 - eN_7) * Food7B) / (((1 - eL_7) * Food7A) + ((1 - eN_7) * Food7B) + ((1 - eW_7) * Food7C))
VWG_7 = ((1 - eW_7) * Food7C) / (((1 - eL_7) * Food7A) + ((1 - eN_7) * Food7B) + ((1 - eW_7) * Food7C))
ED_7 = 1 / (EDA * KOW + EDB)

$KD_7 = ED_7 * GD_7 / WB_7$
$EWW_7 = 1 / (1.89 + (155 / KOW))$
$K1_7 = EWW_7 * GV_7 / WB_7$
$KPW_7 = (VLB_7 * KOW) + (VNB_7 * BETA * KOW) + VWB_7$
$K2_7 = K1_7 / KPW_7$
$Zorg_7 = (VLB_7 * Zlipid) + (VNB_7 * BETA * Zlipid) + (VWB_7 * Zwater)$
$Zgut_7 = VLG_7 * Zlipid + VNG_7 * BETA * Zlipid + VWG_7 * Zwater$
$KGB_7 = Zgut_7 / Zorg_7$
$KE_7 = KGB_7 / WB_7 * ED_7 * GF_7$
$CB_7 = (CWB * K1_7 * (1 - FPW7) + CSD * K1_7 * FPW_7 + KD_7 * Food7D) / (K2_7 + KE_7 + KG_7 + KM_7)$

Acronym	Definition
VLB_8	lipid fraction of organism (unitless)
VNB_7	non-lipid organic matter fraction of organism (unitless)
VWB_7	water fraction of organism (unitless)
WB_7	organism body weight (kg)
WBL_7	organism lipid weight (kg)
QW_7	aqueous transport parameter for organism (d^{-1})
QL_7	lipid transport parameter for organism (d^{-1})
GD_7	food ingestion rate (kg food/day)
TW	mean water temperature (°C)
KG_7	growth rate constant (d^{-1})
GV_7	gill ventilation rate (L/day)
COX	dissolved oxygen content at 90% saturation (mg/L)
DF	fraction of other organism in fish diet (unitless).
$FoodA_7$	intermediate calculation term (unitless)
$FoodB_7$	intermediate calculation term (unitless)
$FoodC_7$	intermediate calculation term (unitless)
$FoodD_7$	intermediate calculation term (unitless)
GF_7	fecal egestion rate (kg food/day)
eL_7	lipid dietary absorption efficiency for organism (unitless)
eN_7	NLOM dietary absorption efficiency for organism (unitless)
eW_7	water dietary absorption efficiency for organism (unitless)
VLG_7	lipid fraction in organism gut (unitless)
VNG_7	NLOM fraction in organism gut (unitless)
VWG_7	water fraction in organism gut (unitless)
ED_7	intestinal tract chemical transfer efficiency (unitless)
KD_7	dietary uptake rate constant (d^{-1})
EDA	dietary chemical transfer constant A
EDB	dietary chemical transfer constant B
$K1_7$	gill uptake rate constant (d^{-1})
EWW_7	gill chemical transfer efficiency (unitless)
KOW	chemical-specific octanol-water partition coefficient (kg/L)

Acronym	Definition
KPW_7	organism-water partition coefficient (unitless)
$K2_7$	gill elimination rate constant (d^{-1})
BETA	NLOM proportionality constant (unitless)
Z_{orgg}	organism fugacity (mol m^{-3} Pa^{-1})
Z_{gutg}	organism intestinal tract fugacity (mol m^{-3} Pa^{-1})
KGB_7	gut-organism partition coefficient (unitless)
KE_7	fecal egestion rate constant (d^{-1})
KM_7	metabolic rate constant (d^{-1})
FPW_7	fraction of sediment porewater ventilated (unitless)
CWB	biologically available concentration of chemical in water (ng/g)
CST	total concentration of chemical in sediment (ng/g)
CSD	concentration of chemical in sediment porewater (ng/g)
CB_7	tissue concentration in 7th organism (ng/g)

3.0 COMPLETE VBA CODE

Option Base 1

```
'---
Dim DT As Single
Dim KOW As Single
Dim BETA As Single
Dim GAMMA As Single
Dim EDA As Single
Dim EDB As Single
Dim HT As Single
Dim TW As Single
Dim CPW As Single
Dim CWB As Single
Dim CST As Single
Dim CSD As Single
Dim FPW2 As Single
Dim FPW3 As Single
Dim FPW4 As Single
Dim FPW5 As Single
Dim FPW6 As Single
Dim FPW7 As Single
Dim FPW8 As Single
Dim FPW9 As Single
Dim Zwater As Single
Dim Zlipid As Single
Dim VLBsed As Single
Dim VNBsed As Single
Dim VWBsed As Single
Dim COX As Single
Dim H As Single
Dim CWT As Single
Dim XPOC As Single
Dim APOC As Single
Dim DPOC As Single
Dim ADOC As Single
Dim BSF As Single
'----
Dim WB2 As Single
Dim VLB2 As Single
Dim VNB2 As Single
Dim VWB2 As Single
Dim UA As Single
Dim UB As Single
```

```
Dim K12 As Single
Dim K22 As Single
Dim KPW2 As Single
Dim KG2 As Single
Dim CB2 As Single
'----
Dim WB3 As Single
Dim VLB3 As Single
Dim VNB3 As Single
Dim VWB3 As Single
Dim WBL3 As Single
Dim KM3 As Single
Dim QW3 As Single
Dim QL3 As Single
Dim GD3 As Single
Dim KG3 As Single
Dim GV3 As Single
Dim DF32 As Single
Dim eL3 As Single
Dim eN3 As Single
Dim eW3 As Single
Dim GF3 As Single
Dim VLG3 As Single
Dim VNG3 As Single
Dim VWG3 As Single
Dim ED3 As Single
Dim KD3 As Single
Dim EWW3 As Single
Dim K13 As Single
Dim KPW3 As Single
Dim K23 As Single
Dim KE3 As Single
Dim Food3A As Single
Dim Food3B As Single
Dim Food3C As Single
Dim Zorg3 As Single
Dim Zgut3 As Single
Dim KGB3 As Single
Dim CB3 As Single
'----
Dim WB4 As Single
Dim VLB4 As Single
Dim VNB4 As Single
Dim VWB4 As Single
Dim WBL4 As Single
```

```
Dim KM4 As Single
Dim QW4 As Single
Dim QL4 As Single
Dim GD4 As Single
Dim KG4 As Single
Dim GV4 As Single
Dim DF41 As Single
Dim DF42 As Single
Dim DF43 As Single
Dim eL4 As Single
Dim eN4 As Single
Dim eW4 As Single
Dim GF4 As Single
Dim VLG4 As Single
Dim VNG4 As Single
Dim VWG4 As Single
Dim ED4 As Single
Dim KD4 As Single
Dim EWW4 As Single
Dim K14 As Single
Dim KPW4 As Single
Dim K24 As Single
Dim KE4 As Single
Dim SCV4 As Single
Dim Food4A As Single
Dim Food4B As Single
Dim Food4C As Single
Dim Food4D As Single
Dim Zorg4 As Single
Dim Zgut4 As Single
Dim KGB4 As Single
Dim CB4 As Single
'----
Dim WB5 As Single
Dim VLB5 As Single
Dim VNB5 As Single
Dim VWB5 As Single
Dim WBL5 As Single
Dim KM5 As Single
Dim QW5 As Single
Dim QL5 As Single
Dim GD5 As Single
Dim KG5 As Single
Dim GV5 As Single
Dim DF51 As Single
```

```
Dim DF52 As Single
Dim DF53 As Single
Dim DF54 As Single
Dim eL5 As Single
Dim eN5 As Single
Dim eW5 As Single
Dim GF5 As Single
Dim VLG5 As Single
Dim VNG5 As Single
Dim VWG5 As Single
Dim ED5 As Single
Dim KD5 As Single
Dim EWW5 As Single
Dim K15 As Single
Dim KPW5 As Single
Dim K25 As Single
Dim KE5 As Single
Dim Food5A As Single
Dim Food5B As Single
Dim Food5C As Single
Dim Food5D As Single
Dim Zorg5 As Single
Dim Zgut5 As Single
Dim KGB5 As Single
Dim CB5 As Single
'----
Dim WB6 As Single
Dim VLB6 As Single
Dim VNB6 As Single
Dim VWB6 As Single
Dim WBL6 As Single
Dim KM6 As Single
Dim QW6 As Single
Dim QL6 As Single
Dim GD6 As Single
Dim KG6 As Single
Dim GV6 As Single
Dim DF61 As Single
Dim DF62 As Single
Dim DF63 As Single
Dim DF64 As Single
Dim DF65 As Single
Dim eL6 As Single
Dim eN6 As Single
Dim eW6 As Single
```

```
Dim GF6 As Single
Dim VLG6 As Single
Dim VNG6 As Single
Dim VWG6 As Single
Dim ED6 As Single
Dim KD6 As Single
Dim EWW6 As Single
Dim K16 As Single
Dim KPW6 As Single
Dim K26 As Single
Dim KE6 As Single
Dim Food6A As Single
Dim Food6B As Single
Dim Food6C As Single
Dim Food6D As Single
Dim Zorg6 As Single
Dim Zgut6 As Single
Dim KGB6 As Single
Dim CB6 As Single
'----
Dim WB7 As Single
Dim VLB7 As Single
Dim VNB7 As Single
Dim VWB7 As Single
Dim WBL7 As Single
Dim KM7 As Single
Dim QW7 As Single
Dim QL7 As Single
Dim GD7 As Single
Dim KG7 As Single
Dim GV7 As Single
Dim DF71 As Single
Dim DF72 As Single
Dim DF73 As Single
Dim DF74 As Single
Dim DF75 As Single
Dim DF76 As Single
Dim eL7 As Single
Dim eN7 As Single
Dim eW7 As Single
Dim GF7 As Single
Dim VLG7 As Single
Dim VNG7 As Single
Dim VWG7 As Single
Dim ED7 As Single
```

```
Dim KD7 As Single
Dim EWW7 As Single
Dim K17 As Single
Dim KPW7 As Single
Dim K27 As Single
Dim KE7 As Single
Dim Food7A As Single
Dim Food7B As Single
Dim Food7C As Single
Dim Food7D As Single
Dim Zorg7 As Single
Dim Zgut7 As Single
Dim KGB7 As Single
Dim CB7 As Single
'----
Dim WB8 As Single
Dim VLB8 As Single
Dim VNB8 As Single
Dim VWB8 As Single
Dim WBL8 As Single
Dim KM8 As Single
Dim QW8 As Single
Dim QL8 As Single
Dim GD8 As Single
Dim KG8 As Single
Dim GV8 As Single
Dim DF81 As Single
Dim DF82 As Single
Dim DF83 As Single
Dim DF84 As Single
Dim DF85 As Single
Dim DF86 As Single
Dim DF87 As Single
Dim eL8 As Single
Dim eN8 As Single
Dim eW8 As Single
Dim GF8 As Single
Dim VLG8 As Single
Dim VNG8 As Single
Dim VWG8 As Single
Dim ED8 As Single
Dim KD8 As Single
Dim EWW8 As Single
Dim K18 As Single
Dim KPW8 As Single
```

```
Dim K28 As Single
Dim KE8 As Single
Dim Food8A As Single
Dim Food8B As Single
Dim Food8C As Single
Dim Food8D As Single
Dim Zorg8 As Single
Dim Zgut8 As Single
Dim KGB8 As Single
Dim CB8 As Single
'----
Dim WB9 As Single
Dim VLB9 As Single
Dim VNB9 As Single
Dim VWB9 As Single
Dim WBL9 As Single
Dim KM9 As Single
Dim QW9 As Single
Dim QL9 As Single
Dim GD9 As Single
Dim KG9 As Single
Dim GV9 As Single
Dim DF91 As Single
Dim DF92 As Single
Dim DF93 As Single
Dim DF94 As Single
Dim DF95 As Single
Dim DF96 As Single
Dim DF97 As Single
Dim DF98 As Single
Dim eL9 As Single
Dim eN9 As Single
Dim eW9 As Single
Dim GF9 As Single
Dim VLG9 As Single
Dim VNG9 As Single
Dim VWG9 As Single
Dim ED9 As Single
Dim KD9 As Single
Dim EWW9 As Single
Dim K19 As Single
Dim KPW9 As Single
Dim K29 As Single
Dim KE9 As Single
Dim Food9A As Single
```

```
Dim Food9B As Single
Dim Food9C As Single
Dim Food9D As Single
Dim Zorg9 As Single
Dim Zgut9 As Single
Dim KGB9 As Single
Dim CB9 As Single
'----
Dim WB10 As Single
Dim VLB10 As Single
Dim VNB10 As Single
Dim VWB10 As Single
Dim WBL10 As Single
Dim KM10 As Single
Dim QW10 As Single
Dim QL10 As Single
Dim GD10 As Single
Dim KG10 As Single
Dim GV10 As Single
Dim DF101 As Single
Dim DF102 As Single
Dim DF103 As Single
Dim DF104 As Single
Dim DF105 As Single
Dim DF106 As Single
Dim DF107 As Single
Dim DF108 As Single
Dim DF109 As Single
Dim eL10 As Single
Dim eN10 As Single
Dim eW10 As Single
Dim GF10 As Single
Dim VLG10 As Single
Dim VNG10 As Single
Dim VWG10 As Single
Dim ED10 As Single
Dim KD10 As Single
Dim EWW10 As Single
Dim K110 As Single
Dim KPW10 As Single
Dim K210 As Single
Dim KE10 As Single
Dim FPW10 As Single
Dim Food10A As Single
Dim Food10B As Single
```

```
Dim Food10C As Single
Dim Food10D As Single
Dim Zorg10 As Single
Dim Zgut10 As Single
Dim KGB10 As Single
Dim CB10 As Single
'----
Dim WB11 As Single
Dim VLB11 As Single
Dim VNB11 As Single
Dim VWB11 As Single
Dim WBL11 As Single
Dim KM11 As Single
Dim QW11 As Single
Dim QL11 As Single
Dim GD11 As Single
Dim KG11 As Single
Dim GV11 As Single
Dim DF111 As Single
Dim DF112 As Single
Dim DF113 As Single
Dim DF114 As Single
Dim DF115 As Single
Dim DF116 As Single
Dim DF117 As Single
Dim DF118 As Single
Dim DF119 As Single
Dim DF1110 As Single
Dim eL11 As Single
Dim eN11 As Single
Dim eW11 As Single
Dim GF11 As Single
Dim VLG11 As Single
Dim VNG11 As Single
Dim VWG11 As Single
Dim ED11 As Single
Dim KD11 As Single
Dim EWW11 As Single
Dim K111 As Single
Dim KPW11 As Single
Dim K211 As Single
Dim KE11 As Single
Dim FPW11 As Single
Dim Food11A As Single
Dim Food11B As Single
```

```
Dim Food11C As Single
Dim Food11D As Single
Dim Zorg11 As Single
Dim Zgut11 As Single
Dim KGB11 As Single
Dim CB11 As Single

Private dic As Scripting.Dictionary
'Private Const PHYTOPLANKTON As String = "phytoplankton"
Private Const ZOOPLANKTON As String = "zooplankton"
Private Const BI_FILTER_FEEDER As String = "benthic filter feeder"
Private Const BI_CONSUMER As String = "benthic consumer"
Private Const EBI_CONSUMER As String = "epibenthic consumer"
Private Const SCULPIN As String = "sculpin"
Private Const LARGESCALE_SUCKER As String = "largescale sucker"
Private Const CARP As String = "carp"
Private Const SMALLMOUTH_BASS As String = "smallmouth bass"
Private Const NORTHERN_PIKEMINNOW As String = "northern pikeminnow"
Public Function TissueConcentration(species As String, r As Range) As Single
  PHFWPRG5
TissueConcentration = CSng(dic.Item(species))
End Function
Sub PHFWPRG5()
  Set dic = New Scripting.Dictionary

'INPUT COMMON BIOLOGICAL PARAMETERS
KOW = 10 ^ Worksheets("inputs").Cells(4, 4)
VLBsed = 0
VNBsed = Worksheets("inputs").Cells(5, 4) 'same as OCSS
VWBsed = 1 - VNBsed
EDA = Worksheets("inputs").Cells(25, 4)
EDB = Worksheets("inputs").Cells(26, 4)
BETA = Worksheets("inputs").Cells(27, 4)
GAMMA = Worksheets("inputs").Cells(28, 4)

'INPUT PHYSICOCHEMICAL & CONCENTRATION PARAMETERS
H = Worksheets("inputs").Cells(6, 4)
TW = Worksheets("inputs").Cells(7, 4)
Zwater = 1 / HT
Zlipid = Zwater * KOW
COX = (-0.24 * TW + 14.04) * 0.9
CPW = Worksheets("inputs").Cells(8, 4)
CWT = Worksheets("inputs").Cells(9, 4)
XPOC = Worksheets("inputs").Cells(16, 4)
APOC = Worksheets("inputs").Cells(17, 4)
```

```
DPOC = Worksheets("inputs").Cells(18, 4)
ADOC = Worksheets("inputs").Cells(19, 4)
BSF = 1 / (1 + (XPOC * APOC * KOW + DPOC * ADOC * KOW))
CWB = Worksheets("inputs").Cells(10, 4)
CST = Worksheets("inputs").Cells(11, 4)
CSD = Worksheets("inputs").Cells(12, 4)
'PHYTOPLANKTON (2)
VLB2 = Worksheets("inputs").Cells(32, 5)
VWB2 = Worksheets("inputs").Cells(33, 5)
VNB2 = 1 - (VLB2 + VWB2)
UA = Worksheets("inputs").Cells(23, 4)
UB = Worksheets("inputs").Cells(24, 4)
K12 = 1 / (UA + (UB / KOW))
KPW2 = (VLB2 * KOW) + (VNB2 * GAMMA * KOW) + VWB2
K22 = K12 / KPW2
KG2 = Worksheets("inputs").Cells(41, 5)
FPW2 = Worksheets("inputs").Cells(37, 5)
CB2 = (CWB * K12 * (1 - FPW2)) / (K22 + KG2)
dic.Add PHYTOPLANKTON, CB2
'ZOOPLANKTON (3)
WB3 = Worksheets("inputs").Cells(31, 6)
VLB3 = Worksheets("inputs").Cells(32, 6)
VWB3 = Worksheets("inputs").Cells(33, 6)
VNB3 = 1 - (VLB3 + VWB3)
WBL3 = WB3 * VLB3
KM3 = Worksheets("inputs").Cells(42, 6)
QW3 = 88.3 * WB3 ^ 0.6
QL3 = QW3 * 0.01
GD3 = 0.022 * WB3 ^ 0.85 * Exp(0.06 * TW)
KG3 = 0.000502 * WB3 ^ -0.2
GV3 = (1400 * (WB3 ^ 0.65)) / COX
DF32 = Worksheets("DF").Cells(4, 3)
eL3 = Worksheets("inputs").Cells(34, 6)
eN3 = Worksheets("inputs").Cells(35, 6)
eW3 = Worksheets("inputs").Cells(36, 6)
Food3A = DF32 * VLB2
Food3B = DF32 * VNB2
Food3C = DF32 * VWB2
GF3 = (((1 - eL3) * Food3A) + ((1 - eN3) * Food3B) + ((1 - eW3) * Food3C)) * GD3
VLG3 = ((1 - eL3) * Food3A) / (((1 - eL3) * Food3A) + ((1 - eN3) * Food3B) + ((1 - eW3) *
Food3C))
VNG3 = ((1 - eN3) * Food3B) / (((1 - eL3) * Food3A) + ((1 - eN3) * Food3B) + ((1 - eW3)
* Food3C))
VWG3 = ((1 - eW3) * Food3C) / (((1 - eL3) * Food3A) + ((1 - eN3) * Food3B) + ((1 - eW3)
* Food3C))
```

```
ED3 = 1 / (EDA * KOW + EDB)
KD3 = ED3 * GD3 / WB3
EWW3 = 1 / (1.89 + (155 / KOW))
K13 = EWW3 * GV3 / WB3
KPW3 = (VLB3 * KOW) + (VNB3 * BETA * KOW) + VWB3
K23 = K13 / KPW3
Zorg3 = (VLB3 * Zlipid) + (VNB3 * BETA * Zlipid) + (VWB3 * Zwater)
Zgut3 = VLG3 * Zlipid + VNG3 * BETA * Zlipid + VWG3 * Zwater
KGB3 = Zgut3 / Zorg3
KE3 = KGB3 / WB3 * ED3 * GF3
FPW3 = Worksheets("inputs").Cells(37, 6)
CB3 = (CWB * K13 * (1 - FPW3) + CB2 * KD3 * DF32) / (K23 + KE3 + KG3 + KM3)
dic.Add ZOOPLANKTON, CB3
'BENTHIC INVERTEBRATE - FILTER FEEDER (4)
  WB4 = Worksheets("inputs").Cells(31, 7)
  VLB4 = Worksheets("inputs").Cells(32, 7)
  VWB4 = Worksheets("inputs").Cells(33, 7)
  VNB4 = 1 - (VLB4 + VWB4)
  WBL4 = WB4 * VLB4
  KM4 = Worksheets("inputs").Cells(42, 7)
  QW4 = 88.3 * WB4 ^ 0.6
  QL4 = QW4 * 0.01
  KG4 = 0.000502 * WB4 ^ -0.2
  GV4 = (1400 * (WB4 ^ 0.65)) / COX
  SCV4 = Worksheets("inputs").Cells(38, 7)
  GD4 = GV4 * CPW * SCV4
  DF41 = Worksheets("DF").Cells(5, 2)
  DF42 = Worksheets("DF").Cells(5, 3)
  eL4 = Worksheets("inputs").Cells(34, 7)
  eN4 = Worksheets("inputs").Cells(35, 7)
  eW4 = Worksheets("inputs").Cells(36, 7)
  FPW4 = Worksheets("inputs").Cells(37, 7)
  Food4A = DF42 * VLB2 + DF41 * VLBsed
  Food4B = DF42 * VNB2 + DF41 * VNBsed
  Food4C = DF42 * VWB2 + DF41 * VWBsed
  Food4D = DF42 * CB2 + DF41 * CST
  GF4 = (((1 - eL4) * Food4A) + ((1 - eN4) * Food4B) + ((1 - eW4) * Food4C)) * GD4
  VLG4 = ((1 - eL4) * Food4A) / (((1 - eL4) * Food4A) + ((1 - eN4) * Food4B) + ((1 -
eW4) * Food4C))
  VNG4 = ((1 - eN4) * Food4B) / (((1 - eL4) * Food4A) + ((1 - eN4) * Food4B) + ((1 -
eW4) * Food4C))
  VWG4 = ((1 - eW4) * Food4C) / (((1 - eL4) * Food4A) + ((1 - eN4) * Food4B) + ((1 -
eW4) * Food4C))
  ED4 = 1 / (EDA * KOW + EDB)
  KD4 = ED4 * GD4 / WB4
```

```
EWW4 = 1 / (1.89 + (155 / KOW))
K14 = EWW4 * GV4 / WB4
KPW4 = (VLB4 * KOW) + (VNB4 * BETA * KOW) + VWB4
K24 = K14 / KPW4
Zorg4 = (VLB4 * Zlipid) + (VNB4 * BETA * Zlipid) + (VWB4 * Zwater)
Zgut4 = VLG4 * Zlipid + VNG4 * BETA * Zlipid + VWG4 * Zwater
KGB4 = Zgut4 / Zorg4
KE4 = KGB4 / WB4 * ED4 * GF4
CB4 = (CWB * K14 * (1 - FPW4) + K14 * FPW4 * CSD + ((GV4 / WB4) * CPW * ED4
* Food4D)) / (K24 + KE4 + KG4 + KM4)
dic.Add BI_FILTER_FEEDER, CB4
'BENTHIC INVERTEBRATE (CONSUMER) (5)
WB5 = Worksheets("inputs").Cells(31, 8)
VLB5 = Worksheets("inputs").Cells(32, 8)
VWB5 = Worksheets("inputs").Cells(33, 8)
VNB5 = 1 - (VLB5 + VWB5)
WBL5 = WB5 * VLB5
KM5 = Worksheets("inputs").Cells(42, 8)
QW5 = 88.3 * WB5 ^ 0.6
QL5 = QW5 * 0.01
KG5 = 0.000502 * WB5 ^ -0.2
GV5 = (1400 * (WB5 ^ 0.65)) / COX
GD5 = 0.022 * WB5 ^ 0.85 * Exp(0.06 * TW)
DF51 = Worksheets("DF").Cells(6, 2)
DF52 = Worksheets("DF").Cells(6, 3)
DF53 = Worksheets("DF").Cells(6, 4)
DF54 = Worksheets("DF").Cells(6, 5)
eL5 = Worksheets("inputs").Cells(34, 8)
eN5 = Worksheets("inputs").Cells(35, 8)
eW5 = Worksheets("inputs").Cells(36, 8)
FPW5 = Worksheets("inputs").Cells(37, 8)
Food5A = DF51 * VLBsed + DF52 * VLB2 + DF53 * VLB3 + DF54 * VLB4
Food5B = DF51 * VNBsed + DF52 * VNB2 + DF53 * VNB3 + DF54 * VNB4
Food5C = DF51 * VWBsed + DF52 * VWB2 + DF53 * VWB3 + DF54 * VWB4
Food5D = DF51 * CST + DF52 * CB2 + DF53 * CB3 + DF54 * CB4
GF5 = (((1 - eL5) * Food5A) + ((1 - eN5) * Food5B) + ((1 - eW5) * Food5C)) * GD5
VLG5 = ((1 - eL5) * Food5A) / (((1 - eL5) * Food5A) + ((1 - eN5) * Food5B) + ((1 -
eW5) * Food5C))
VNG5 = ((1 - eN5) * Food5B) / (((1 - eL5) * Food5A) + ((1 - eN5) * Food5B) + ((1 -
eW5) * Food5C))
VWG5 = ((1 - eW5) * Food5C) / (((1 - eL5) * Food5A) + ((1 - eN5) * Food5B) + ((1 -
eW5) * Food5C))
ED5 = 1 / (EDA * KOW + EDB)
KD5 = ED5 * GD5 / WB5
EWW5 = 1 / (1.89 + (155 / KOW))
```

```
K15 = EWW5 * GV5 / WB5
KPW5 = (VLB5 * KOW) + (VNB5 * BETA * KOW) + VWB5
K25 = K15 / KPW5
Zorg5 = (VLB5 * Zlipid) + (VNB5 * BETA * Zlipid) + (VWB5 * Zwater)
Zgut5 = VLG5 * Zlipid + VNG5 * BETA * Zlipid + VWG5 * Zwater
KGB5 = Zgut5 / Zorg5
KE5 = KGB5 / WB5 * ED5 * GF5
CB5 = (CWB * K15 * (1 - FPW5) + CSD * K15 * FPW5 + KD5 * Food5D) / (K25 + KE5
+ KG5 + KM5)
dic.Add BI_CONSUMER, CB5
'EPIBENTHIC INVERTEBRATE (CONSUMER) (6)
WB6 = Worksheets("inputs").Cells(31, 9)
VLB6 = Worksheets("inputs").Cells(32, 9)
VWB6 = Worksheets("inputs").Cells(33, 9)
VNB6 = 1 - (VLB6 + VWB6)
WBL6 = WB6 * VLB6
KM6 = Worksheets("inputs").Cells(42, 9)
QW6 = 88.3 * WB6 ^ 0.6
QL6 = QW6 * 0.01
KG6 = 0.000502 * WB6 ^ -0.2
GV6 = (1400 * (WB6 ^ 0.65)) / COX
GD6 = 0.022 * WB6 ^ 0.85 * Exp(0.06 * TW)
DF61 = Worksheets("DF").Cells(7, 2)
DF62 = Worksheets("DF").Cells(7, 3)
DF63 = Worksheets("DF").Cells(7, 4)
DF64 = Worksheets("DF").Cells(7, 5)
DF65 = Worksheets("DF").Cells(7, 6)
eL6 = Worksheets("inputs").Cells(34, 9)
eN6 = Worksheets("inputs").Cells(35, 9)
eW6 = Worksheets("inputs").Cells(36, 9)
FPW6 = Worksheets("inputs").Cells(37, 9)
Food6A = DF61 * VLBsed + DF62 * VLB2 + DF63 * VLB3 + DF64 * VLB4 + DF65 *
VLB5
Food6B = DF61 * VNBsed + DF62 * VNB2 + DF63 * VNB3 + DF64 * VNB4 + DF65 *
VNB5
Food6C = DF61 * VWBsed + DF62 * VWB2 + DF63 * VWB3 + DF64 * VWB4 + DF65
* VWB5
Food6D = DF61 * CST + DF62 * CB2 + DF63 * CB3 + DF64 * CB4 + DF65 * CB5
GF6 = (((1 - eL6) * Food6A) + ((1 - eN6) * Food6B) + ((1 - eW6) * Food6C)) * GD6
VLG6 = ((1 - eL6) * Food6A) / (((1 - eL6) * Food6A) + ((1 - eN6) * Food6B) + ((1 -
eW6) * Food6C))
VNG6 = ((1 - eN6) * Food6B) / (((1 - eL6) * Food6A) + ((1 - eN6) * Food6B) + ((1 -
eW6) * Food6C))
VWG6 = ((1 - eW6) * Food6C) / (((1 - eL6) * Food6A) + ((1 - eN6) * Food6B) + ((1 -
eW6) * Food6C))
```

```
ED6 = 1 / (EDA * KOW + EDB)
KD6 = ED6 * GD6 / WB6
EWW6 = 1 / (1.89 + (155 / KOW))
K16 = EWW6 * GV6 / WB6
KPW6 = (VLB6 * KOW) + (VNB6 * BETA * KOW) + VWB6
K26 = K16 / KPW6
Zorg6 = (VLB6 * Zlipid) + (VNB6 * BETA * Zlipid) + (VWB6 * Zwater)
Zgut6 = VLG6 * Zlipid + VNG6 * BETA * Zlipid + VWG6 * Zwater
KGB6 = Zgut6 / Zorg6
KE6 = KGB6 / WB6 * ED6 * GF6
CB6 = (CWB * K16 * (1 - FPW6) + CSD * K16 * FPW6 + KD6 * Food6D) / (K26 + KE6
+ KG6 + KM6)
dic.Add EBI_CONSUMER, CB6
'SCULPIN - FORAGE (7)
WB7 = Worksheets("inputs").Cells(31, 10)
VLB7 = Worksheets("inputs").Cells(32, 10)
VWB7 = Worksheets("inputs").Cells(33, 10)
VNB7 = 1 - (VLB7 + VWB7)
WBL7 = WB7 * VLB7
KM7 = Worksheets("inputs").Cells(42, 10)
QW7 = 88.3 * WB7 ^ 0.6
QL7 = QW7 * 0.01
KG7 = 0.000502 * WB7 ^ -0.2
GV7 = (1400 * (WB7 ^ 0.65)) / COX
GD7 = 0.022 * WB7 ^ 0.85 * Exp(0.06 * TW)
DF71 = Worksheets("DF").Cells(8, 2)
DF72 = Worksheets("DF").Cells(8, 3)
DF73 = Worksheets("DF").Cells(8, 4)
DF74 = Worksheets("DF").Cells(8, 5)
DF75 = Worksheets("DF").Cells(8, 6)
DF76 = Worksheets("DF").Cells(8, 7)
eL7 = Worksheets("inputs").Cells(34, 10)
eN7 = Worksheets("inputs").Cells(35, 10)
eW7 = Worksheets("inputs").Cells(36, 10)
FPW7 = Worksheets("inputs").Cells(37, 10)
Food7A = DF71 * VLBsed + DF72 * VLB2 + DF73 * VLB3 + DF74 * VLB4 + DF75 *
VLB5 + DF76 * VLB6
Food7B = DF71 * VNBsed + DF72 * VNB2 + DF73 * VNB3 + DF74 * VNB4 + DF75 *
VNB5 + DF76 * VNB6
Food7C = DF71 * VWBsed + DF72 * VWB2 + DF73 * VWB3 + DF74 * VWB4 + DF75
* VWB5 + DF76 * VWB6
Food7D = DF71 * CST + DF72 * CB2 + DF73 * CB3 + DF74 * CB4 + DF75 * CB5 +
DF76 * CB6
GF7 = (((1 - eL7) * Food7A) + ((1 - eN7) * Food7B) + ((1 - eW7) * Food7C)) * GD7
```

```
VLG7 = ((1 - eL7) * Food7A) / (((1 - eL7) * Food7A) + ((1 - eN7) * Food7B) + ((1 -
eW7) * Food7C))
VNG7 = ((1 - eN7) * Food7B) / (((1 - eL7) * Food7A) + ((1 - eN7) * Food7B) + ((1 -
eW7) * Food7C))
VWG7 = ((1 - eW7) * Food7C) / (((1 - eL7) * Food7A) + ((1 - eN7) * Food7B) + ((1 -
eW7) * Food7C))
ED7 = 1 / (EDA * KOW + EDB)
KD7 = ED7 * GD7 / WB7
EWW7 = 1 / (1.89 + (155 / KOW))
K17 = EWW7 * GV7 / WB7
KPW7 = (VLB7 * KOW) + (VNB7 * BETA * KOW) + VWB7
K27 = K17 / KPW7
Zorg7 = (VLB7 * Zlipid) + (VNB7 * BETA * Zlipid) + (VWB7 * Zwater)
Zgut7 = VLG7 * Zlipid + VNG7 * BETA * Zlipid + VWG7 * Zwater
KGB7 = Zgut7 / Zorg7
KE7 = KGB7 / WB7 * ED7 * GF7
CB7 = (CWB * K17 * (1 - FPW7) + CSD * K17 * FPW7 + KD7 * Food7D) / (K27 + KE7
+ KG7 + KM7)
dic.Add SCULPIN, CB7
'LARGESCALE SUCKER - BENTHIVORE (8)
WB8 = Worksheets("inputs").Cells(31, 11)
VLB8 = Worksheets("inputs").Cells(32, 11)
VWB8 = Worksheets("inputs").Cells(33, 11)
VNB8 = 1 - (VLB8 + VWB8)
WBL8 = WB8 * VLB8
KM8 = Worksheets("inputs").Cells(42, 11)
QW8 = 88.3 * WB8 ^ 0.6
QL8 = QW8 * 0.01
KG8 = 0.000502 * WB8 ^ -0.2
GV8 = (1400 * (WB8 ^ 0.65)) / COX
GD8 = 0.022 * WB8 ^ 0.85 * Exp(0.06 * TW)
'DF81 = Worksheets("DF").Cells(8, 2)
'DF82 = Worksheets("DF").Cells(8, 3)
'DF83 = Worksheets("DF").Cells(8, 4)
'DF84 = Worksheets("DF").Cells(8, 5)
'DF85 = Worksheets("DF").Cells(8, 6)
DF81 = Worksheets("DF").Cells(9, 2)
DF82 = Worksheets("DF").Cells(9, 3)
DF83 = Worksheets("DF").Cells(9, 4)
DF84 = Worksheets("DF").Cells(9, 5)
DF85 = Worksheets("DF").Cells(9, 6)
DF86 = Worksheets("DF").Cells(9, 7)
DF87 = Worksheets("DF").Cells(9, 8)
eL8 = Worksheets("inputs").Cells(34, 11)
eN8 = Worksheets("inputs").Cells(35, 11)
```

```
eW8 = Worksheets("inputs").Cells(36, 11)
FPW8 = Worksheets("inputs").Cells(37, 11)
Food8A = DF81 * VLBsed + DF82 * VLB2 + DF83 * VLB3 + DF84 * VLB4 + DF85 *
VLB5 + DF86 * VLB6 + DF87 * VLB7
Food8B = DF81 * VNBsed + DF82 * VNB2 + DF83 * VNB3 + DF84 * VNB4 + DF85 *
VNB5 + DF86 * VNB6 + DF87 * VNB7
Food8C = DF81 * VWBsed + DF82 * VWB2 + DF83 * VWB3 + DF84 * VWB4 + DF85
* VWB5 + DF86 * VWB6 + DF87 * VWB7
Food8D = DF81 * CST + DF82 * CB2 + DF83 * CB3 + DF84 * CB4 + DF85 * CB5 +
DF86 * CB6 + DF87 * CB7
GF8 = (((1 - eL8) * Food8A) + ((1 - eN8) * Food8B) + ((1 - eW8) * Food8C)) * GD8
VLG8 = ((1 - eL8) * Food8A) / (((1 - eL8) * Food8A) + ((1 - eN8) * Food8B) + ((1 -
eW8) * Food8C))
VNG8 = ((1 - eN8) * Food8B) / (((1 - eL8) * Food8A) + ((1 - eN8) * Food8B) + ((1 -
eW8) * Food8C))
VWG8 = ((1 - eW8) * Food8C) / (((1 - eL8) * Food8A) + ((1 - eN8) * Food8B) + ((1 -
eW8) * Food8C))
ED8 = 1 / (EDA * KOW + EDB)
KD8 = ED8 * GD8 / WB8
EWW8 = 1 / (1.89 + (155 / KOW))
K18 = EWW8 * GV8 / WB8
KPW8 = (VLB8 * KOW) + (VNB8 * BETA * KOW) + VWB8
K28 = K18 / KPW8
Zorg8 = (VLB8 * Zlipid) + (VNB8 * BETA * Zlipid) + (VWB8 * Zwater)
Zgut8 = VLG8 * Zlipid + VNG8 * BETA * Zlipid + VWG8 * Zwater
KGB8 = Zgut8 / Zorg8
KE8 = KGB8 / WB8 * ED8 * GF8
CB8 = (CWB * K18 * (1 - FPW8) + CSD * K18 * FPW8 + KD8 * Food8D) / (K28 + KE8
+ KG8 + KM8)
dic.Add LARGESCALE_SUCKER, CB8
'CARP - OMNIVORE (9)
WB9 = Worksheets("inputs").Cells(31, 12)
VLB9 = Worksheets("inputs").Cells(32, 12)
VWB9 = Worksheets("inputs").Cells(33, 12)
VNB9 = 1 - (VLB9 + VWB9)
WBL9 = WB9 * VLB9
KM9 = Worksheets("inputs").Cells(42, 12)
QW9 = 88.3 * WB9 ^ 0.6
QL9 = QW9 * 0.01
KG9 = 0.000502 * WB9 ^ -0.2
GV9 = (1400 * (WB9 ^ 0.65)) / COX
GD9 = 0.022 * WB9 ^ 0.85 * Exp(0.06 * TW)
DF91 = Worksheets("DF").Cells(10, 2)
DF92 = Worksheets("DF").Cells(10, 3)
DF93 = Worksheets("DF").Cells(10, 4)
```

```
DF94 = Worksheets("DF").Cells(10, 5)
DF95 = Worksheets("DF").Cells(10, 6)
DF96 = Worksheets("DF").Cells(10, 7)
DF97 = Worksheets("DF").Cells(10, 8)
DF98 = Worksheets("DF").Cells(10, 9)
eL9 = Worksheets("inputs").Cells(34, 12)
eN9 = Worksheets("inputs").Cells(35, 12)
eW9 = Worksheets("inputs").Cells(36, 12)
FPW9 = Worksheets("inputs").Cells(37, 12)
Food9A = DF91 * VLBsed + DF92 * VLB2 + DF93 * VLB3 + DF94 * VLB4 + DF95 *
VLB5 + DF96 * VLB6 + DF97 * VLB7 + DF98 * VLB8
Food9B = DF91 * VNBsed + DF92 * VNB2 + DF93 * VNB3 + DF94 * VNB4 + DF95 *
VNB5 + DF96 * VNB6 + DF97 * VNB7 + DF98 * VNB8
Food9C = DF91 * VWBsed + DF92 * VWB2 + DF93 * VWB3 + DF94 * VWB4 + DF95
* VWB5 + DF96 * VWB6 + DF97 * VWB7 + DF98 * VWB8
Food9D = DF91 * CST + DF92 * CB2 + DF93 * CB3 + DF94 * CB4 + DF95 * CB5 +
DF96 * CB6 + DF97 * CB7 + DF98 * CB8
GF9 = (((1 - eL9) * Food9A) + ((1 - eN9) * Food9B) + ((1 - eW9) * Food9C)) * GD9
VLG9 = ((1 - eL9) * Food9A) / (((1 - eL9) * Food9A) + ((1 - eN9) * Food9B) + ((1 -
eW9) * Food9C))
VNG9 = ((1 - eN9) * Food9B) / (((1 - eL9) * Food9A) + ((1 - eN9) * Food9B) + ((1 -
eW9) * Food9C))
VWG9 = ((1 - eW9) * Food9C) / (((1 - eL9) * Food9A) + ((1 - eN9) * Food9B) + ((1 -
eW9) * Food9C))
ED9 = 1 / (EDA * KOW + EDB)
KD9 = ED9 * GD9 / WB9
EWW9 = 1 / (1.89 + (155 / KOW))
K19 = EWW9 * GV9 / WB9
KPW9 = (VLB9 * KOW) + (VNB9 * BETA * KOW) + VWB9
K29 = K19 / KPW9
Zorg9 = (VLB9 * Zlipid) + (VNB9 * BETA * Zlipid) + (VWB9 * Zwater)
Zgut9 = VLG9 * Zlipid + VNG9 * BETA * Zlipid + VWG9 * Zwater
KGB9 = Zgut9 / Zorg9
KE9 = KGB9 / WB9 * ED9 * GF9
  'CB9 = (CWB * K19 * (1 - FPW9) + CSD * WB9 * K19 * FPW9 + KD9 * Food9D) /
(K29 + KE9 + KG9 + KM9)
CB9 = (CWB * K19 * (1 - FPW9) + CSD * K19 * FPW9 + KD9 * Food9D) / (K29 + KE9
+ KG9 + KM9)
dic.Add CARP, CB9
'SMALLMOUTH BASS - SMALL PISCIVORE (10)
WB10 = Worksheets("inputs").Cells(31, 13)
VLB10 = Worksheets("inputs").Cells(32, 13)
VWB10 = Worksheets("inputs").Cells(33, 13)
VNB10 = 1 - (VLB10 + VWB10)
WBL10 = WB10 * VLB10
```

```
KM10 = Worksheets("inputs").Cells(42, 13)
QW10 = 88.3 * WB10 ^ 0.6
QL10 = QW10 * 0.01
KG10 = 0.000502 * WB10 ^ -0.2
GV10 = (1400 * (WB10 ^ 0.65)) / COX
GD10 = 0.022 * WB10 ^ 0.85 * Exp(0.06 * TW)
DF101 = Worksheets("DF").Cells(11, 2)
DF102 = Worksheets("DF").Cells(11, 3)
DF103 = Worksheets("DF").Cells(11, 4)
DF104 = Worksheets("DF").Cells(11, 5)
DF105 = Worksheets("DF").Cells(11, 6)
DF106 = Worksheets("DF").Cells(11, 7)
DF107 = Worksheets("DF").Cells(11, 8)
DF108 = Worksheets("DF").Cells(11, 9)
DF109 = Worksheets("DF").Cells(11, 10)
eL10 = Worksheets("inputs").Cells(34, 13)
eN10 = Worksheets("inputs").Cells(35, 13)
eW10 = Worksheets("inputs").Cells(36, 13)
FPW10 = Worksheets("inputs").Cells(37, 13)
Food10A = DF101 * VLBsed + DF102 * VLB2 + DF103 * VLB3 + DF104 * VLB4 +
DF105 * VLB5 + DF106 * VLB6 + DF107 * VLB7 + DF108 * VLB8 + DF109 * VLB9
Food10B = DF101 * VNBsed + DF102 * VNB2 + DF103 * VNB3 + DF104 * VNB4 +
DF105 * VNB5 + DF106 * VNB6 + DF107 * VNB7 + DF108 * VNB8 + DF109 * VNB9
Food10C = DF101 * VWBsed + DF102 * VWB2 + DF103 * VWB3 + DF104 * VWB4 +
DF105 * VWB5 + DF106 * VWB6 + DF107 * VWB7 + DF108 * VWB8 + DF109 * VWB9
Food10D = DF101 * CST + DF102 * CB2 + DF103 * CB3 + DF104 * CB4 + DF105 *
CB5 + DF106 * CB6 + DF107 * CB7 + DF108 * CB8 + DF109 * CB9
GF10 = (((1 - eL10) * Food10A) + ((1 - eN10) * Food10B) + ((1 - eW10) * Food10C)) *
GD10
VLG10 = ((1 - eL10) * Food10A) / (((1 - eL10) * Food10A) + ((1 - eN10) * Food10B) +
((1 - eW10) * Food10C))
VNG10 = ((1 - eN10) * Food10B) / (((1 - eL10) * Food10A) + ((1 - eN10) * Food10B) +
((1 - eW10) * Food10C))
VWG10 = ((1 - eW10) * Food10C) / (((1 - eL10) * Food10A) + ((1 - eN10) * Food10B) +
((1 - eW10) * Food10C))
ED10 = 1 / (EDA * KOW + EDB)
KD10 = ED10 * GD10 / WB10
EWW10 = 1 / (1.89 + (155 / KOW))
K110 = EWW10 * GV10 / WB10
KPW10 = (VLB10 * KOW) + (VNB10 * BETA * KOW) + VWB10
K210 = K110 / KPW10
Zorg10 = (VLB10 * Zlipid) + (VNB10 * BETA * Zlipid) + (VWB10 * Zwater)
Zgut10 = VLG10 * Zlipid + VNG10 * BETA * Zlipid + VWG10 * Zwater
KGB10 = Zgut10 / Zorg10
KE10 = KGB10 / WB10 * ED10 * GF10
```

```
  CB10 = (CWB * K110 * (1 - FPW10) + CSD * K110 * FPW10 + KD10 * Food10D) /
(K210 + KE10 + KG10 + KM10)
  dic.Add SMALLMOUTH_BASS, CB10
'NORTHERN PIKEMINNOW - LARGE PISCIVORE (11)
  WB11 = Worksheets("inputs").Cells(31, 14)
  VLB11 = Worksheets("inputs").Cells(32, 14)
  VWB11 = Worksheets("inputs").Cells(33, 14)
  VNB11 = 1 - (VLB11 + VWB11)
  WBL11 = WB11 * VLB11
  KM11 = Worksheets("inputs").Cells(42, 14)
  QW11 = 88.3 * WB11 ^ 0.6
  QL11 = QW11 * 0.01
  KG11 = 0.000502 * WB11 ^ -0.2
  GV11 = (1400 * (WB11 ^ 0.65)) / COX
  GD11 = 0.022 * WB11 ^ 0.85 * Exp(0.06 * TW)
  DF111 = Worksheets("DF").Cells(12, 2)
  DF112 = Worksheets("DF").Cells(12, 3)
  DF114 = Worksheets("DF").Cells(12, 5)
  DF115 = Worksheets("DF").Cells(12, 6)
  DF116 = Worksheets("DF").Cells(12, 7)
  DF117 = Worksheets("DF").Cells(12, 8)
  DF118 = Worksheets("DF").Cells(12, 9)
  DF119 = Worksheets("DF").Cells(12, 10)
  DF1110 = Worksheets("DF").Cells(12, 11)
  eL11 = Worksheets("inputs").Cells(34, 14)
  eN11 = Worksheets("inputs").Cells(35, 14)
  eW11 = Worksheets("inputs").Cells(36, 14)
  FPW11 = Worksheets("inputs").Cells(37, 14)
  Food11A = DF111 * VLBsed + DF112 * VLB2 + DF113 * VLB3 + DF114 * VLB4 +
DF115 * VLB5 + DF116 * VLB6 + DF117 * VLB7 + DF118 * VLB8 + DF119 * VLB9 +
DF1110 * VLB10
  Food11B = DF111 * VNBsed + DF112 * VNB2 + DF113 * VNB3 + DF114 * VNB4 +
DF115 * VNB5 + DF116 * VNB6 + DF117 * VNB7 + DF118 * VNB8 + DF119 * VNB9 +
DF1110 * VNB10
  Food11C = DF111 * VWBsed + DF112 * VWB2 + DF113 * VWB3 + DF114 * VWB4 +
DF115 * VWB5 + DF116 * VWB6 + DF117 * VWB7 + DF118 * VWB8 + DF119 * VWB9
+ DF1110 * VWB10
  Food11D = DF111 * CST + DF112 * CB2 + DF113 * CB3 + DF114 * CB4 + DF115 *
CB5 + DF116 * CB6 + DF117 * CB7 + DF118 * CB8 + DF119 * CB9 + DF1110 * CB10
GF11 = (((1 - eL11) * Food11A) + ((1 - eN11) * Food11B) + ((1 - eW11) * Food11C)) *
GD11
VLG11 = ((1 - eL11) * Food11A) / (((1 - eL11) * Food11A) + ((1 - eN11) * Food11B) + ((1
- eW11) * Food11C))
VNG11 = ((1 - eN11) * Food11B) / (((1 - eL11) * Food11A) + ((1 - eN11) * Food11B) + ((1
- eW11) * Food11C))
```

```
VWG11 = ((1 - eW11) * Food11C) / (((1 - eL11) * Food11A) + ((1 - eN11) * Food11B) +
((1 - eW11) * Food11C))
ED11 = 1 / (EDA * KOW + EDB)
KD11 = ED11 * GD11 / WB11
EWW11 = 1 / (1.89 + (155 / KOW))
K111 = EWW11 * GV11 / WB11
KPW11 = (VLB11 * KOW) + (VNB11 * BETA * KOW) + VWB11
K211 = K111 / KPW11
Zorg11 = (VLB11 * Zlipid) + (VNB11 * BETA * Zlipid) + (VWB11 * Zwater)
Zgut11 = VLG11 * Zlipid + VNG11 * BETA * Zlipid + VWG11 * Zwater
KGB11 = Zgut11 / Zorg11
KE11 = KGB11 / WB11 * ED11 * GF11
CB11 = (CWB * K111 * (1 - FPW11) + CSD * K111 * FPW11 + KD11 * Food11D) /
(K211 + KE11 + KG11 + KM11)
dic.Add NORTHERN_PIKEMINNOW, CB11
End Sub
```

4.0 REFERENCES

Arnot JA, Gobas FAPC. 2004. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. Environ Toxicol Chem 23:2343-2355.

EPA. 2006. EPA comments on food web modeling report: evaluating TrophicTrace and the Arnot and Gobas Models for application to the Portland Harbor Superfund Site (November 2005 draft). March 10, 2006. US Environmental Protection Agency, Region 10, Portland, OR.

Gobas FAPC. 1993. A model for predicting the bioaccumulation of hydrophobic organic chemicals in aquatic food-webs: application to Lake Ontario. Ecol Model 69:1-17.

Integral, Windward, Kennedy/Jenks, Anchor, Groundwater Solutions. 2004. Portland Harbor RI/FS programmatic work plan. Appendix B: ecological risk assessment. Prepared for Lower Willamette Group. Integral Consulting, Inc., Mercer Island, WA; Windward Environmental LLC, Seattle, WA; Kennedy/Jenks Consultants, Portland, OR; Anchor Environmental, LLC, Seattle, WA; Groundwater Solutions, Inc., Portland, OR.

Konwick BJ, Garrison AW, Black MC, Avants JK, Fisk AT. 2006. Bioaccumulation, biotransformation, and metabolite formation of fipronil and chiral legacy pesticides in rainbow trout. Environ Sci Tech 40:2930-2936.

Morrison HA, Gobas FAPC, Lazar R, Haffner GD. 1996. Development and verification of a bioaccumulation model for organic contaminants in benthic invertebrates. Environ Sci Technol 30:3377-3384.

Morrison HA, Gobas FAPC, Lazar R, Whittle DM, Haffner GD. 1997. Development and verification of a benthic/pelagic food web bioaccumulation model for PCB congeners in Western Lake Erie. Environ Sci Technol 31:3267-73.

ODEQ. 2006. Portland Harbor Superfund Site: Models for estimation of chemical distribution and fate in response to remedial alternatives in the Lower Willamette River. Revised working draft, 21 April 2006. Oregon Department of Environmental Quality, Portland, OR.

ODFW. 2005. Biology, behavior, and resources of resident and anadromous fish in the Lower Willamette River. Final report of research, 2000-2004. Prepared for City of Portland. Oregon Department of Fish and Wildlife, Clackamas, OR.

Thomann RV, Connolly JP, Parkerton T. 1992. Modeling accumulation of organic chemicals in aquatic food webs. In: Gobas FAPC, McCorquodale JA, eds, Chemical dynamics in fresh water ecosystems. Lewis Publishers, Boca Raton, FL, pp 153-183.

Windward. 2004. Portland Harbor RI/FS. Technical memorandum: evaluating steady-state aquatic food web models for the Portland Harbor Superfund site. WE-04-0002. Draft. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Windward. 2005. Portland Harbor RI/FS. Food web modeling report: evaluating TrophicTrace and the Arnot and Gobas models for application to the Portland Harbor Superfund Site. WE-05-0009. Draft. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Zimmerman MP. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the Lower Columbia River basin during outmigration of juvenile anadromous salmonids. Trans Am Fish Soc 128:1036-1054.

APPENDIX E: FOOD WEB MODEL

Attachment E2
PCB Congener Selection

PCB CONGENER SELECTION

SELECTED PCB CONGENERS FOR MODEL CALIBRATION

Three polychlorinated biphenyl (PCB) congeners were selected for model calibration based on their detection frequency and percent contribution to the total PCB concentration in tissue, sediment, and water. In addition, consideration was given to selecting congeners with a range of log octanol-water partition coefficients (K_{OW}s). The congeners selected for use in model calibration were PCB 17 (K_{OW} = 5.25), PCB 170 (K_{OW} = 7.27), and PCB 206 (K_{OW} = 8.09) (Hawker and Connell 1988).

CONGENER CONCENTRATIONS IN TISSUE

Comparing model output to empirical tissue concentrations allows model performance to be evaluated and is useful for model calibration. Table 1 presents the site-specific tissue concentrations for PCB 17, PCB 170, and PCB 206. The detection frequency for these chemicals was 100% in all tissue types for which they were analyzed except one (i.e., PCB 17 in crayfish).

CONGENER CONCENTRATIONS IN SEDIMENT

Sediment chemistry data are needed as inputs to the model. Spatially weighted average concentrations (SWACs) were calculated using Thiessen polygons for PCB 17, PCB 170, and PCB 206. Again, detection frequency was high (> 80%) for all three congeners (Table 2).

CONGENER CONCENTRATIONS IN WATER

Water chemistry data were also needed to run the model. Concentrations of PCB 17, PCB 170, and PCB 206 in water were based on data from XAD water column samples from the three integrated transect sampling locations used in Round 2 surface water sampling (Integral 2004). Mean concentrations and detection frequency are presented in Table 3.

REFERENCES

Hawker DW, Connell DW. 1988. Octanol-water partition coefficients of polychlorinated biphenyl congeners. Environ Sci Tech 22:382-387.

Integral. 2004. Portland Harbor remedial investigation/feasibility study round 2a field sampling plan: surface water sampling. Prepared for Lower Willamette Group. Integral Consulting, Inc., Mercer Island, WA.

TABLES

Table 1. Tissue Concentrations for PCB Congeners

Congener	Species	Number of Samples	Detection Frequency	Mean Concentration (µg/kg)
PCB 17	clams	31	100%	1.64
	crayfish	10	70%	0.0716
	carp	6	100%	2.93
	largescale sucker	NA	NA	NA
	northern pikeminnow	NA	NA	NA
	sculpin	9	100%	2.33
	smallmouth bass	14	100%	1.07
PCB 170	clams	31	100%	1.31
	crayfish	10	100%	1.60
	carp	6	100%	63.3
	largescale sucker	NA	NA	NA
	northern pikeminnow	NA	NA	NA
	sculpin	9	100%	28.2
	smallmouth bass	14	100%	40.9
PCB 206	clams	31	100%	0.169
	crayfish	10	100%	0.101
	carp	6	100%	4.98
	largescale sucker	NA	NA	NA
	northern pikeminnow	NA	NA	NA
	sculpin	9	100%	1.83
	smallmouth bass	14	100%	2.41

NA – no data available for this species
PCB – polychlorinated biphenyl

Table 2. Sediment Concentrations for PCB Congeners

Congener	Number of Samples	Detection Frequency	SWAC (ng/g)
PCB 17	146	99%	1.59
PCB 170	229	82%	2.30
PCB 206	146	100%	0.950

PCB – polychlorinated biphenyl
SWAC – spatially weighted average concentration

Table 3. PCB Congener Concentrations in Water

Congener	Number of Samples	Detection Frequency	Distribution	Mean Concentration (ng/L)	Standard Error (ng/L)[a]
PCB 17	9	100%	normal	3.93×10^{-3}	5.95×10^{-4}
PCB 170	9	100%	normal	5.17×10^{-4}	9.83×10^{-5}
PCB 206	9	100%	normal	5.95×10^{-5}	1.21×10^{-5}

[a] When assigning distributions to the food web model for calibration, the standard error of the data was used to represent the standard deviation of the mean value.

APPENDIX E: FOOD WEB MODEL

Attachment E3
Parameterization

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LIST OF ACRONYMS

ATSDR	Agency for Toxic Substances and Disease Registry
BIC	benthic invertebrate consumer
BIF	benthic invertebrate filter feeder
EIC	epibenthic invertebrate consumer
DOC	dissolved organic carbon
EDA	dietary chemical transfer constant A
EDB	dietary chemical transfer constant B
EPA	US Environmental Protection Agency
iPRG	initial preliminary remediation goal
FWM	food web model
K_{OW}	octanol-water partition coefficient
LASAR	Laboratory Analytical Storage and Retrieval
LWR	Lower Willamette River
NLOC	non-lipid organic carbon
NLOM	non-lipid organic matter
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
PCB	polychlorinated biphenyl
RI/FS	risk investigation/feasibility study
RM	river mile
SWAC	spatially weighted average concentration
TEQ	toxic equivalent
TOC	total organic carbon
TSS	total suspended solids

1.0 SUMMARY OF APPROACH TO PARAMETER VALUES AND DISTRIBUTIONS

The input parameters required by the adaptation of the Arnot and Gobas bioaccumulation model (Arnot and Gobas 2004) used in this report were derived from site-specific data whenever possible. The main sources of site-specific data were the Round 1 and Round 2 data collected and analyzed for the Portland Harbor remedial investigation/feasibility study (RI/FS) prior to June 2006. Literature values were used when an input parameter could not be defined using these data.

In order to reflect the uncertainty regarding the values of parameters based on site-specific or literature-derived information, statistical distributions were defined for most parameters. Once distributions had been assigned to the input parameters, the model could be run either probabilistically, using distributions, or deterministically, using point estimates. The results of probabilistic model runs were distributions for predicted tissue concentrations (i.e., model output) based on random selection of input parameter values from the defined input distributions. Because the focus of the model was on prediction of average tissue concentrations, the input parameter distributions were intended to bound uncertainty on estimates of the central tendency of parameter values. Parameter values from within these distributions were selected for the calibrated version of the model and used in the development of initial preliminary remediation goals (iPRGs). The statistical distributions were also used in the model sensitivity analysis to identify parameters with the greatest influence on model predictions and in the uncertainty analysis to quantitatively characterize the uncertainty of model predictions. This attachment discusses the parameter distributions in detail and the sources used to develop each distribution.

2.0 RULES FOR ASSIGNING DISTRIBUTIONS

For input into the model, parameter distributions were defined based on shape (i.e., normal or triangular) and descriptive statistics (i.e., mean and standard deviation or mode, maximum, and minimum). The selected distributions were based on empirical data whenever possible and were intended to reflect the uncertainty surrounding estimates of central tendency. For example, in the central limit theorem, estimates of the mean (with sufficient sample size) approach a normal distribution. The standard deviation of the distribution of estimates of the mean is defined by the standard error of the original data. The following standardized approach was used to develop parameter distributions.

1. When site-specific data were available, estimates of the mean were defined by a normal distribution with a mean equal to the mean of the empirical data and a standard deviation equal to the standard error of the empirical data.
2. If there were no site-specific data, but literature values for the mean and standard deviation were available, the literature mean and standard deviation were used to define a normal distribution that would provide a conservative bounding of the distribution of mean estimates.
3. For all chemicals or chemical groups modeled, a normal distribution was assigned for the log of the octanol-water partition coefficient (log K_{OW}, hereafter referred to as the K_{OW}) for a given chemical group. The mean was defined as the most appropriate K_{OW} based on the literature reviewed and in consideration of site-specific data for chemical mixtures (e.g., for polychlorinated biphenyl [PCB] toxic equivalent [TEQ], the concentrations of different PCB congeners in tissue were considered). The standard deviation was defined as one one-hundredth of the K_{OW}. This was based on best professional judgment and generally bounded the range of other published estimates of K_{OW}.
4. For all other parameters with insufficient data to define a distribution (i.e., mean and standard deviation or standard error), a triangle distribution was assigned (MacIntosh et al. 1994). The mode of the triangle was defined as the mean of the data if the data were considered sufficiently relevant and comprehensive. For more uncertain data, the mode was based on the consideration of published selections for parameter values used in other food web models (FWMs) (Gobas and Arnot 2005; Arnot and Gobas 2004) and best professional judgment. The minimum and maximum values (tails of the triangle) were defined by the literature values if they were considered sufficient to bound a plausible range.

In addition to developing distributions for parameters, available data were also evaluated for correlations between parameters. Crystal Ball® allows for inclusion of correlations between parameters. Many of the parameters included in the model are likely correlated, so including these correlations in the probabilistic model prevents unrealistic combinations of values for different parameters. Unfortunately, for most parameters including many expected to be related, paired data needed to develop correlations were lacking. Paired data were available for lipid fraction and water content from tissue samples from the LWR. So for these two species-specific parameters, correlations were developed and included in the probabilistic model. Details of the development of species are presented in section 6.5.3.

3.0 CHEMICAL DATA

Two chemical-specific parameters are required for the adaptation of the Arnot and Gobas model used in this report: the K_{OW} and the Henry's Law constant. Because the Henry's Law constant cancels itself out in the model calculations, no values were entered for this parameter. Thus, the only chemical-specific parameter that was required for this model was the K_{OW}. The same K_{OW} value is used throughout the model, regardless of media.

A literature K_{OW} value was found for each chemical that was modeled. For those chemicals that were modeled individually (e.g., 4,4′-DDD and 4,4′-DDT), the most appropriate literature K_{OW} value was used directly. These values are reported in Table 3-1. For the remaining mixtures of chemicals (i.e., sum DDD, sum DDE, sum DDT, total DDTs, total PCBs, PCB TEQ, and dioxin TEQ), a weighted K_{OW} was calculated (Table 3-2). Literature values for individual chemical constituents (Table 3-3) and the site-specific empirical concentration data for tissue were used to develop a weighted K_{OW} such that the summed group K_{OW} reflected the relative proportions of the group constituents based on Study Area data. The mean weighted K_{OW} across tissue samples for which the group of chemicals was measured (i.e., all tissue data except epibenthic invertebrate, laboratory-exposed worm, and laboratory-exposed clam samples) was used as the mean value of a normal distribution. For PCB TEQ and dioxin TEQ, the weighted K_{OW}s were calculated based on chemical mass (but not the toxic equivalency factor). In order to account for the uncertainty of K_{OW} values, a standard deviation of 1% was used to define the distribution. The range of this distribution generally included the range of K_{OW} values found in the literature for chemicals with multiple estimates available (e.g., 4,4′-DDE, 4,4′-DDT, total PCBs).

4.0 ENVIRONMENTAL DATA

The environmental input parameters needed for the Arnot and Gobas model used in this report are based on the surface water and sediment chemistry for the Lower Willamette River (LWR). All parameters were calculated using site-specific data from the project database or the Oregon Department of Environmental Quality (ODEQ) Web site (2006).

4.1 WATER DATA

The water input parameters required for the Arnot and Gobas model are temperature, total suspended solids (TSS), dissolved organic carbon (DOC), and dissolved chemical concentrations in the water column. Water sample locations in the LWR are shown on Figure 4-1.

4.1.1 Temperature Data

Sampling events for the Portland Harbor RI/FS at the conclusion of Round 2 were limited to three events over 1 year. Therefore, water temperature data for the site were taken from the Laboratory Analytical Storage and Retrieval (LASAR) database provided online by ODEQ (2006). A map of the river on the ODEQ Web site was used to choose stations that were located within the Study Area (River Mile [RM] 2 to RM 11). Thirteen stations were identified, but water temperature data were available for only seven of these stations from January 11, 1995, though February 1, 2006, n = 6612. These seven stations are listed below, along with their station identification numbers from the LASAR database and their approximate location.

- Willamette River upstream of Oregon Steel Mills, City of Portland site (No. 29746) – between RM 2 and RM 3
- Willamette River at US Government moorings (No. 30755) – RM 6
- Willamette River at St. John's Bridge (No. 10821) – RM 6
- Willamette River at SP&S RR Bridge, Portland (No. 10332) – RM 7
- Willamette River at St. John's RR Bridge, City of Portland site (No. 28765) – between RM 7 and RM 8
- Swan Island Channel Midpoint (No. 10801) – RM 8.5 in the Swan Island Lagoon
- Swan Island Channel Boat Ramp (No. 10802) – RM 9 in the Swan Island Lagoon

The number of samples taken per year per location was variable during the period from January 11, 1995 to February 1, 2006. An average was calculated for each month across all years between 1995 and 2006 (e.g., mean January temperature included all samples collected at all locations for all years during the month of January). The 12 monthly averages were used to calculate a yearly average. The mean temperature was 13.6°C, with a standard error of 1.6°C over a 12-month period. To describe uncertainty about this estimate of the mean, a normal distribution was assigned with a standard deviation of the distribution equal to the standard error of the data.

4.1.2 Total Suspended Solids Data

The concentration of TSS was calculated using data collected for the Portland Harbor remedial investigation/feasibility study (RI/FS). Because the TSS parameter affects only the feeding rate for benthic invertebrate filter feeders (clams), it was determined that near-bottom TSS data would be the most appropriate. Each of the 17 near-bottom sample locations in the study area was sampled once during the three sampling events that took place in November 2004, March 2005, and July 2005. The mean TSS value calculated for this model was 5.9×10^{-6} kg/L, and a normal distribution with a standard deviation (defined by the standard error of the empirical data) of 5.1×10^{-7} kg/L was used to for the model distribution.

4.1.3 Dissolved Organic Carbon Data

The average DOC value used in the FWM was calculated from nine integrated river transect samples collected at three locations (project database). As with the data used for TSS, each location was sampled once during each of the three sampling events that took place in November 2004, March 2005, and July 2005. A normal distribution was used to define the DOC parameter distribution, with a mean value of 1.31×10^{-6} kg/L and a standard deviation (defined by the standard error of the empirical data) of 3.0×10^{-8} kg/L.

4.1.4 Water Chemistry Data

Chemical concentrations in the water column were calculated from XAD water column samples collected during the three sampling events at the three integrated transect locations (same as described for DOC). Table 4-1 presents the mean value, standard deviation (the standard error of the empirical data), and distribution type that were calculated for each modeled chemical or chemical mixture.

4.2 SEDIMENT DATA

The sediment input parameters required for the Arnot and Gobas model include the total organic carbon (TOC) concentration and the chemical concentration in the sediment. In order to reduce spatial bias in the available sediment chemistry data for the site, a spatially weighted average concentration (SWAC) was calculated for these parameters using Thiessen polygons. The approach for developing Thiessen polygons and their application to estimate sediment TOC and chemicals concentrations in the surface sediment are described in the subsections that follow.

4.2.1 Thiessen Polygon Approach

Thiessen polygons associate each point in a plane with the closest sampling location for which a measurement is available (Burmaster and Thompson 1997). This in effect assumes that the concentration at any point where measurements have not been made is the same as the concentration in the sample closest to that point. The borders of a Thiessen polygon are thus the line segments bisecting the distance between the sampling point inside the polygon and its neighbors. In practice, the process of drawing the boundaries of Thiessen polygons is automated using built-in geographic information system (GIS) functionality.

The sizes of Thiessen polygons are used to calculate SWACs. A SWAC is simply the weighted average of all measurements within an exposure area (in this case, RM 2 to RM 11), with each measurement assigned a weight equal to the area of its polygon (Scott et al. 2000), as shown below:

$$\text{SWAC} = \frac{\sum_{\text{exposure area}} a_i x_i}{\sum_{\text{exposure area}} a_i} \qquad \textbf{Equation 1}$$

where:

a_i = area of the polygon associated with the ith sample
x_i = concentration of the ith sample

4.2.2 Total Organic Carbon in Sediment

Using the approach for creating Thiessen polygons described above in Section 4.2.1, a spatially weighted value for the percent of TOC in the sediment was obtained based on 1,108 sediment samples. For the model, a normal distribution was used with a mean concentration of 1.88% and a standard deviation of 0.05%.

4.2.3 Chemical Concentrations in Sediment

For each modeled chemical, a SWAC was calculated using the Thiessen polygon approach (Section 4.2.1). Table 4-2 presents the average concentrations and standard deviation (defined by standard error of the SWAC). Distributions were not included

for this parameter in calibration. Because the primary purpose of model development for this report was generation of iPRGs, the uncertainty surrounding estimates of sediment concentration was not a primary concern of model calibration. To develop iPRGs there must be an assumed change in sediment chemical concentrations from current conditions. Therefore, it was necessary to define current conditions. The SWAC was assumed to represent current conditions, and uncertainties surrounding estimates of the SWAC would also apply to alternative conditions (such as the iPRGs). Uncertainty associated with this assumption was explored through the model sensitivity and uncertainty analysis but was not included in model calibration.

5.0 BIOAVAILABLE FRACTION AND NON-SPECIES-SPECIFIC BIOLOGICAL PARAMETERS

Site-specific data for the bioavailable fractions and many general biological parameters in the Arnot and Gobas FWM were not available. Thus, literature values were assigned to these parameters, and distributions were created when appropriate.

5.1 UPTAKE CONSTANTS

The value used in the model for uptake constant A (UA) was 6.0×10^{-5} (Gobas and Arnot 2005; Arnot and Gobas 2004). A triangular distribution was assigned to this value, using a minimum of 4.0×10^{-5} and a maximum of 8.0×10^{-5} based on a range provided in Gobas and Arnot (2005).

A triangle distribution was used to characterize uncertainty for uptake constant B (UB). The best estimate (mode) was 5.50, with a minimum value of 1.80 and a maximum of 9.20 (Gobas and Arnot 2005; Arnot and Gobas 2004).

5.2 DIETARY CHEMICAL TRANSFER EFFICIENCY

Dietary chemical transfer efficiency (E_D) is described by K_{OW} and two dietary chemical transfer constants (EDA and EDB). Both EDA and EDB were taken from Arnot and Gobas (2004). The value used for constant EDA was 3×10^{-7}, and a value of 2.0 was used for constant EDB. No distributions were applied to these values because of a lack of information on parameter value uncertainty.

5.3 PROPORTIONALITY CONSTANTS

The value used for the non-lipid organic matter (NLOM)-octanol proportionality constant (BETA) was 0.035 (unitless) (Arnot and Gobas 2004). A standard deviation of 0.005 was used to define the normal distribution based on the recommendation of Jon Arnot (Arnot 2005).

For the non-lipid organic carbon (NLOC)-octanol proportionality constant (GAMMA), a value of 0.350 (unitless) was obtained from Arnot and Gobas (2004). No distribution was used for this parameter.

5.4 METABOLISM

Metabolism (K_M) was not included for most chemicals because they are not thought to be heavily metabolized and/or metabolism data were lacking. The exceptions were

for 4,4′-DDT and sum DDT (sum of 2,4′-DDT and 4,4′-DDT). The application of metabolism rates on a chemical and species-specific basis is discussed in detail in Section 6.6.

6.0 SPECIES-SPECIFIC BIOLOGICAL DATA

The trophic groups modeled, and the representative species for which LWG data are available (listed in parentheses), are as follows:

- Phytoplankton
- Zooplankton
- Benthic invertebrate filter feeders (clams, *Corbicula* spp.)
- Benthic invertebrate consumers[1]
- Epibenthic invertebrate consumers (crayfish, unidentified species)
- Foraging fish (sculpin, *Cottus* spp.)[2]
- Benthivorous fish (largescale sucker, *Catostomus macrocheilus*)[3]
- Omnivorous fish (common carp, *Cyprinus carpio*)
- Small piscivorous fish (smallmouth bass, *Micropterus dolomieui*)
- Large piscivorous fish (northern pikeminnow, *Ptychocheilus oregonensis*)

Site-specific data was available for clams, crayfish, sculpin, largescale suckers, common carp, smallmouth bass, and northern pikeminnow. Figures 6-1, 6-2, and 6-3 provide information retarding the sample locations for these species. Circled locations indicate samples that were composited.

6.1 WEIGHTS, LIPID FRACTION, AND WATER CONTENT

Weight, lipid fraction, and water content data were derived from site-specific data for most organisms. These data were not available for phytoplankton, zooplankton, and worms, so literature values were identified for these parameters. As discussed in Section 2, correlations were developed and included in the model for the relationship between lipid fraction and water content when possible.

[1] A generalized category designed to represent oligochaetes, insect larvae, and amphipods.
[2] This trophic group was also used to represent black crappie for iPRG development.
[3] This trophic group was also used to represent brown bullhead for iPRG development.

6.1.1 Phytoplankton

Weight data for phytoplankton were not required by the model. The lipid fraction and water content fraction values for phytoplankton were calculated from Mackintosh et al. (2004). The values presented in this study are an aggregate of brown algae, green algae, and phytoplankton collected from a tow net. A triangle distribution was assigned for the lipid fraction with a mode of 0.00123 and minimum and maximum of 0.0008 and 0.002, respectively. The water content fraction was calculated by subtracting the reported NLOC fraction (mode of 0.0433 and minimum and maximum of 0.006 and 0.063, respectively) and lipid fractions from 1. This estimate of water content does not include consideration of other constituents besides lipids, carbon, and moisture because these were not available. A triangle distribution was also assigned for water content fraction with a mode of 0.955 and a minimum and maximum of 0.935 and 0.993, respectively.

6.1.2 Zooplankton

The average weight of zooplankton was estimated from Giles and Cordell (1998). Assuming 90% moisture content, the best estimate value for zooplankton was 1.4×10^{-7} kg. A triangle distribution was assigned with the best estimate as the mode and minimum and maximum of 3.3×10^{-8} and 2.3×10^{-7}, reflecting the range presented in Giles and Cordell (1998). The lipid fraction was calculated from Evjemo and Olsen (1997), again assuming a moisture content of 90%. A triangle distribution was assigned with the best estimate of 0.01 as the mode and minimum and maximum of 0.009 and 0.011, respectively, reflecting the range from Evjemo and Olsen (1997). The moisture content fraction used for zooplankton was 0.9 (Kuroshima et al. 1987) [as cited in Delbare et al. (1996)]. A triangle distribution was assigned with a mean of 0.9 and a minimum and maximum of 0.80 and 0.98, respectively, as determined using best professional judgment.

6.1.3 Invertebrates

Site-specific data were available for benthic invertebrate filter feeders (clams) and epibenthic invertebrate consumers (crayfish). For these two taxa, distributions for weight, lipid fraction, and water content (Table 6-1) were assigned based on the criteria described in Section 2.0. Correlations were also developed for lipid fraction and water content when paired data for these parameters were available (Table 6-1).

For benthic invertebrate consumers (worms, amphipods, midges, etc), values were assigned based on literature and best professional judgment. Weight data for three detrital/deposit feeding species (*Chironomus riparius, Limnodrilus hoffmeisteri,* and *Corophium voluntator*) were examined (Kraaij et al. 2001; Millward et al. 2001; Bervoets et al. 2003) and used to define a triangle distribution. The lipid fraction for this trophic group was also evaluated using literature data on several different species (*Corphium* spp., *Nereis vexillosa,* and *Chironomus* spp.) (Weston et al. 2002; Kraaij

et al. 2001; Lyytikäinen et al. 2003). In addition, information on lipid content collected prior to exposure for LWG bioaccumulation tests was considered. These studies used worm species found in the LWR (*Lumbriculus* spp.)(Windward and Integral 2005). Table 6-1 summarizes distribution selections for weight, lipid content, and water content fraction for benthic invertebrate consumers.

6.1.4 Fish Species

Site-specific data were available for all modeled fish species, which included sculpin, largescale sucker, carp, smallmouth bass, and northern pikeminnow. Weight, lipid fraction, and water content fraction data were calculated using data from the project database. Before use, the data were examined to ensure that all samples were taken within the study area (RM 2 to RM 11). Table 6-2 presents the values and distributions that were used for the parameters for each species. Again, correlations between lipid fraction and water content were developed when paired data for these parameters were available.

6.2 DIETARY ABSORPTION EFFICIENCIES

Dietary absorption efficiencies of lipids, NLOM, and water were generally taken from Arnot and Gobas (2004) because site-specific data were not available for these parameters. Table 6-3 presents the values and distributions that were assigned to each of these parameters. No distribution was assigned to dietary absorption of water inasmuch as the model is not sensitive to this parameter because water is not a significant reservoir for hydrophobic organics compared to lipid and NLOM. (Arnot and Gobas 2004) These parameters were not required for phytoplankton, but all other modeled species are represented in the table.

6.3 POREWATER VENTILATION

The fraction of porewater ventilated by each species was determined by best professional judgment. In addition, porewater ventilation fractions were altered from the previous FWM based on agency comments that suggested eliminating porewater ventilation for all fish except sculpin (EPA 2006). Table 6-4 presents the values used for each species in this model.

6.4 GROWTH RATE CONSTANT

The growth rate for most modeled species is approximated by the model using an equation that is based on the weight parameter and is specialized for aquatic organisms. However, no weight data were required for phytoplankton, so a growth rate constant was required. A triangular distribution was assigned with a mode of 0.08

per day, a minimum of 0.03 per day, and maximum of 0.13 per day (Arnot and Gobas 2004).

6.5 SCAVENGING EFFICIENCY (FILTER FEEDERS ONLY)

Scavenging efficiency is only required for benthic invertebrate filter feeders (clams). A value of 1.0 was derived from Morrison et al. (1996, as cited in Arnot and Gobas 2004), Reeders et al. (1989), and Ten Winkel and Davids (1982).

6.6 CHEMICAL-SPECIFIC METABOLISM

The metabolic rate constant for each species was assumed to be zero for all chemicals except 4,4′-DDT and sum DDTs. In a study on the metabolism of DDT isomers in rainbow trout, Konwick et al. (2006) found that 4,4′-DDT is biotransformed at a rate of 0.011 per day. No positive biotransformation rate was identified for any other DDT isomers the study. Therefore, 0.011 was used for the metabolism rate in the 4,4′-DDT model for all modeled fish (i.e., sculpin, largescale suckers, carp, smallmouth bass, and northern pikeminnow). For the sum DDT model (both 2,4′-DDT and 4,4′-DDT), it was assumed that only half of this mixture was metabolized, and a metabolism rate of 0.0055 per day was used for the modeled fish. This was a conservative assumption because 4,4′-DDT constituted the majority of the sum DDT in tissue (Table 3-3).

6.7 DIETARY ASSUMPTIONS

The diets of each modeled species were developed by conducting literature reviews, interviewing fish biologists, and reviewing agency comments (EPA 2006) in order to best reflect the diets of each species. However, because of the limited number of species that were modeled, dietary consumption described in the literature of species (i.e., prey) not included in the model had to be reassigned to other species using best professional judgment. The species included in the current model were based on discussions with and comments from the US Environmental Protection Agency (EPA) and its partners (EPA 2006), and this list is smaller than the one in the previous version of the model (Windward 2005). Thus, most diets are necessarily different from the previous version of the model. For example, sculpin are known to eat juvenile fish, but this category was not included in this version of the FWM. For other fish species, sculpin were used to represent juvenile fish. Because cannibalism and eating fish designated as higher up in the food web are not possible in the model, sculpin cannibalism and sculpin consumption of juvenile fish were represented by benthic invertebrate consumer and benthic invertebrate filter feeder consumption categories. These surrogate selections were based primarily on a consideration of life history and lipid content in the previously modeled juvenile fish (Windward 2005) and the three invertebrates.

Table 6-5 presents the diet percentages and distributions that were used in the model and notes the rationales that were used to create these diets. Sediment and tissue consumption was determined as a percentage of the species' overall diet. The design of the dietary portion of the FWM is described in Attachment E1. This design normalized the total of different randomly selected dietary constituents to 100%. Model results in which normalized diets containing values for consumption that were below the minimums or in excess of maximums specified in Table 6-5 were rejected.

7.0 REFERENCES

Arnot J. 2005. Personal communication (e-mail to Fiona McNair, Windward Environmental, LLC, Seattle, WA, regarding sensitivity and uncertainty analyses). Canadian Environmental Modeling Center, Peterborough, Ontario, Canada. July 26.

Arnot JA, Gobas FAPC. 2004. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. Environ Toxicol Chem 23:2343-2355.

ATSDR. 2002. Toxological profile for DDT, DDE, DDD [online]. Agency for Toxic Substances and Disease Registry, Atlanta, GA. [Cited 9/7/06]. Available from: http://www.atsdr.cdc.gov/toxprofiles/tp35.html.

Bervoets L, De Bruyn L, Van Ginneken L, Lusta R. 2003. Accumulation of 137Cs by larvae of the midge Chironomus riparius from sediment: effect of potassium. Environ Toxicol Chem 22(7):1589-1596.

Brown LR, Matern SA, Moyle PB. 1995. Comparative ecology of prickly sculpin, Cottus asper, and coastrange sculpin, C. aleuticus, in the Eel River, California. Environ Biol Fish 42:329-343.

Buchanan DV, Hooton RM, Moring JR. 1981. Northern squawfish (Ptychocheilus oregonensis) predation on juvenile salmonids in sections of the Willamette River basin, Oregon. Can J Fish Aquat Sci 38:360-364.

Burmaster DE, Thompson KM. 1997. Estimating exposure point concentrations for surface soils for use in deterministic and probabilistic risk assessments. Hum Ecolog Risk Assess 3(3):363-384.

Delbare D, Dhert P, Lavens P. 1996. Chapter 5: Zooplankton. In: Lavens P, Sorgeloos P, eds, Manual on the production and use of live food for aquaculture. FAO Fisheries technical paper 361. Food and Agriculture Organization of the United Nations, Rome, Italy.

EPA. 2003. EPI (Estimation Programs Interface) SuiteTM. Version 3.11. [online]. Office of Pollution Prevention Toxics, US Environmental Protection Agency, Washington, DC. [Cited 5/4/05]. Available from: http://www.epa.gov/opptintr/exposure/docs/episuite.htm.

EPA. 2006. EPA comments on food web modeling report: evaluating TrophicTrace and the Arnot and Gobas Models for application to the Portland Harbor Superfund Site (November 2005 draft). March 10, 2006. US Environmental Protection Agency, Region 10, Portland, OR.

Evans-White M, Dodds WK, Gray LJ, Fritz KM. 2001. A comparison of trophic ecology of the crayfishes (Orconectes nais [Faxon] and Orconectes neglectus [Faxon]) and the central stoneroller minnow (Campostoma anomalum [Rafinesque]): omnivory in a tallgrass prairie stream. Hydrobiologia 462:131-144.

Evjemo JO, Olsen Y. 1997. Lipid and fatty acid content in cultivated live feed organisms compared to marine copepods. Hydrobiologia 358:159-162.

FishBase. 2004. FishBase relational database. A global information system on fishes [online]. WorldFish Center, Penang, Malaysia. [Cited April 2004]. Available from: http://www.fishbase.org/home.htm.

Giles SL, Cordell JR. 1998. Zooplankton composition and abundance in Budd Inlet, Washington. Puget Sound Research 1998, March 12-13, 1998, Seattle, WA.

Gobas FAPC, Arnot J. 2005. San Francisco Bay PCB food web bioaccumulation model: final technical report. Prepared for the Clean Estuary Partnership, San Francisco, CA.

Gobas FAPC, Wilcockson JB, Russell RW, Haffner GD. 1999. Mechanism of biomagnification in fish under laboratory and field conditions. Environ Sci Technol 33:133-141.

Gray RH, Dauble DD. 2001. Some life history characteristics of cyprinids in the Hanford Reach, mid-Columbia River. Northwest Sci 75(2):122-133.

Hawker DW, Connell DW. 1988. Octanol-water partition coefficients of polychlorinated biphenyl congeners. Environ Sci Tech 22:382-387.

Howard P, Meylan W, eds. 1997. Handbook of physical properties of organic chemicals. Lewis Publishers, Boca Raton, FL.

Integral, Windward, Kennedy/Jenks, Anchor, Groundwater Solutions. 2004. Portland Harbor RI/FS programmatic work plan. Appendix B: ecological risk assessment. Prepared for Lower Willamette Group. Integral Consulting, Inc., Mercer Island, WA; Windward Environmental LLC, Seattle, WA; Kennedy/Jenks Consultants, Portland, OR; Anchor Environmental, LLC, Seattle, WA; Groundwater Solutions, Inc., Portland, OR.

Jorgensen SE, ed. 1979. Handbook of environmental data and ecological parameters. Part A, tables A208-A434. International Society for Ecological Modeling. Pergamon Press, New York, NY.

Konwick BJ, Garrison AW, Black MC, Avants JK, Fisk AT. 2006. Bioaccumulation, biotransformation, and metabolite formation of fipronil and chiral legacy pesticides in rainbow trout. Environ Sci Tech 40:2930-2936.

Kraaij RH, Ciarelli S, Tolls J, Kater BJ, Belfroid A. 2001. Bioavailability of lab-contaminated and native polycyclic aromatic hydrocarbons to the amphipod Corophium volutator relates to chemical desorption. Environ Toxicol Chem 20(8):1716-1724.

Kuroshima R, Sato M, Yoshinaka R, Ikeda S. 1987. Nutritional quality of the wild zooplankton as a living feed for fish larvae. Suisanzoshoku 35(2):113-117.

Lee C. 2006. Personal communication (telephone conversation with Matt Luxon, Windward Environmental, regarding sediment ingestion by large scale sucker and northern pikeminnow). Fish biologist, Department of Natural Resources, Spokane Tribe, Wellpinit, WA. August 9, 2006.

Lyytikäinen M, Rantalainen A, Mikkelson P, Hämäläinen H, Paasivirta J, Kukkonen JVK. 2003. Similarities in bioaccumulation patterns of polychlorinated dibenzo-p-dioxins and furans and polychlorinated diphenyl ethers in laboratory-exposed oligochaetes and semipermeable membrane devices and in field-collected chironomids. Environ Toxicol Chem 22(10):2405-2415.

MacIntosh DL, Suter GW, II, Hoffman FO. 1994. Use of probabilistic exposure models in ecological risk assessments of contaminated sites. Risk Anal 14:405-19.

Mackintosh CE, Maldonado J, Hongwu J, Hoover N, Chong A, Ikonomou MG, Gobas FAPC. 2004. Distribution of phthalate esters in a marine aquatic food web: comparison to polychlorinated biphenyls. Environ Sci Tech 38:2011-2020.

Millward RN, Fleeger JW, Reible DD, Keteles KA, Cunningham BP, Zhang L. 2001. Pyrene bioaccumulation, effects of pyrene exposure on particle-size selection, and fecal pyrene content in the oligochaete Limnodrilus hoffmeisteri (Tubificidae, Oligochaeta). Environ Toxicol Chem 20:1359-1366.

Morrison HA, Gobas FAPC, Lazar R, Haffner GD. 1996. Development and verification of a bioaccumulation model for organic contaminants in benthic invertebrates. Environ Sci Technol 30:3377-3384.

Northcote TG. 1954. Observations on the comparative ecology of two species of fish, Cottus asper and Cottus rhotheus, in British Columbia. Copeia 1954(1):25-28.

ODEQ. 2006. Laboratory analytical storage and retrieval (LASAR) database [online]. DEQ Online, Oregon Department of Environmental Quality, Portland, OR. [Cited August 24, 2006]. Available from: <http://www.deq.state.or.us/wq/lasar/lasarhome.htm>.

ODFW. 2005. Biology, behavior, and resources of resident and anadromous fish in the Lower Willamette River. Final report of research, 2000-2004. Prepared for City of Portland. Oregon Department of Fish and Wildlife, Clackamas, OR.

Pechenik JA. 1991. Biology of the invertebrates. 2nd ed. Wm. C. Brown Publishers, Dubuque, IA.

Reeders HH, de Vaate AB, Slim FJ. 1989. The filtration rate of Dreissena polymorpha (Bivalvia) in three Dutch lakes with reference to biological water quality management. Freshwat Biol 22:133-141.

Scott PK, Rabbe DE, Liebig EW, Finley BL. 2000. Evaluation of three measures of exposure concentration: a case study of surface sediment concentrations in the Passaic River. Hum Ecol Risk Assess 6(3):511-528.

Ten Winkel EH, Davids C. 1982. Food selection by Dreissena polymorpha Pallas (mollusca: bivalvia). Freshwat Biol 12:553-558.

Weston DP, Jarman WM, Cabana G, Bacon CE, Jacobson LA. 2002. An evaluation of the success of dredging as remediation at a DDT-contaminated site in San Francisco Bay, California, USA. Environ Toxicol Chem 21(10):2216-2224.

Windward. 2005. Portland Harbor RI/FS. Food web modeling report: evaluating TrophicTrace and the Arnot and Gobas models for application to the Portland Harbor Superfund Site. WE-05-0009. Draft. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Windward, Integral. 2005. Portland Harbor RI/FS. Field sampling plan: Round 2 sampling of benthic invertebrate tissue. WE-05-0008. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA; Integral Consulting, Inc., Mercer Island, WA.

Zaranko DT, Griffiths RW, Kaushik NK. 1997. Biomagnification of polychlorinated biphenyls through a riverine food web. Environ Toxicol Chem 16(7):1463-1471.

Zimmerman MP. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the Lower Columbia River basin during outmigration of juvenile anadromous salmonids. Trans Am Fish Soc 128:1036-1054.

TABLES

Table 3-1. Octanol-Water Partition Coefficients for Individual Chemicals

Chemical	Distribution	Mean	Standard Deviation	Source
PCB 17	normal	5.25	0.0525	Hawker and Connell (1988)
PCB 170	normal	7.27	0.0727	Hawker and Connell (1988)
PCB 206	normal	8.09	0.0809	Hawker and Connell (1988)
4,4′-DDD	normal	6.02	0.0602	Howard and Meylan (1997), as cited in ATSDR (2002)
4,4′-DDE	normal	6.51	0.0651	Howard and Meylan (1997), as cited in ATSDR (2002)
4,4′-DDT	normal	6.91	0.0691	Howard and Meylan (1997), as cited in ATSDR (2002)

ATSDR – Agency for Toxic Substances and Disease Registry
PCB – polychlorinated biphenyl

Table 3-2. Calculated Octanol-Water Partition Coefficients for Chemical Mixtures

Chemical	Distribution	Calculated Mean	Standard Deviation	Source
PCB TEQ	normal	6.81	0.0681	Calculated from project database based on percentage of components in all tissue except multiplate, laboratory clam, and laboratory worm samples.
Total PCBs	normal	6.67	0.0667	
Dioxin TEQ	normal	8.47	0.0847	
Sum DDD	normal	5.99	0.0599	
Sum DDE	normal	6.48	0.0648	
Sum DDT	normal	6.87	0.0687	
Total DDT	normal	6.47	0.0647	

PCB – polychlorinated biphenyl
TEQ – toxic equivalent

Table 3-3. Octanol-Water Partition Coefficients for Components of Calculated Chemical Mixtures

Chemical	Fraction of Total (by tissue mass)[a]	K_{OW}	Source
PCB TEQ			
PCB 077	0.0152	6.36	Hawker and Connell (1988)
PCB 081	0.000714	6.36	Hawker and Connell (1988)
PCB 105	0.170	6.65	Hawker and Connell (1988)
PCB 114	0.0126	6.65	Hawker and Connell (1988)
PCB 118	0.603	6.74	Hawker and Connell (1988)
PCB 123	0.0110	6.74	Hawker and Connell (1988)
PCB 126	0.00146	6.89	Hawker and Connell (1988)
PCB 156	0.0659	7.18	Hawker and Connell (1988)
PCB 156, 157	0.0347	7.18[b]	Hawker and Connell (1988)
PCB 157	0.00827	7.18	Hawker and Connell (1988)
PCB 167	0.0617	7.27	Hawker and Connell (1988)
PCB 169	0.000373	7.42	Hawker and Connell (1988)
PCB 189	0.0152	7.71	Hawker and Connell (1988)
Total PCBs			
PCB 001	2.39×10^{-3}	4.46	Hawker and Connell (1988)
PCB 002	1.48×10^{-5}	4.69	Hawker and Connell (1988)
PCB 003	2.10×10^{-4}	4.69	Hawker and Connell (1988)
PCB 004	5.71×10^{-3}	4.65	Hawker and Connell (1988)
PCB 005	2.19×10^{-5}	4.97	Hawker and Connell (1988)
PCB 006	4.40×10^{-4}	5.06	Hawker and Connell (1988)
PCB 007	3.93×10^{-5}	5.07	Hawker and Connell (1988)
PCB 008	1.69×10^{-3}	5.07	Hawker and Connell (1988)
PCB 009	7.11×10^{-5}	5.06	Hawker and Connell (1988)
PCB 010	1.54×10^{-4}	4.84	Hawker and Connell (1988)
PCB 011	1.37×10^{-3}	5.28	Hawker and Connell (1988)
PCB 012, 013	9.65×10^{-5}	5.23[b]	Hawker and Connell (1988)
PCB 014	9.33×10^{-6}	5.28	Hawker and Connell (1988)
PCB 015	7.71×10^{-4}	5.30	Hawker and Connell (1988)
PCB 016	1.66×10^{-3}	5.16	Hawker and Connell (1988)
PCB 017	3.31×10^{-3}	5.25	Hawker and Connell (1988)
PCB 018, 030	4.20×10^{-3}	5.34[b]	Hawker and Connell (1988)
PCB 019	2.87×10^{-3}	5.02	Hawker and Connell (1988)
PCB 020, 028	1.06×10^{-2}	5.62[b]	Hawker and Connell (1988)
PCB 021, 033	2.48×10^{-3}	5.56[b]	Hawker and Connell (1988)
PCB 022	2.52×10^{-3}	5.58	Hawker and Connell (1988)
PCB 023	1.69×10^{-5}	5.57	Hawker and Connell (1988)

Table 3-3. Octanol-Water Partition Coefficients for Components of Calculated Chemical Mixtures

Chemical	Fraction of Total (by tissue mass)[a]	K_{OW}	Source
PCB 024	4.74×10^{-5}	5.35	Hawker and Connell (1988)
PCB 025	6.76×10^{-4}	5.67	Hawker and Connell (1988)
PCB 026, 029	1.52×10^{-3}	5.63[b]	Hawker and Connell (1988)
PCB 027	1.15×10^{-3}	5.44	Hawker and Connell (1988)
PCB 031	5.33×10^{-3}	5.67	Hawker and Connell (1988)
PCB 032	1.57×10^{-3}	5.44	Hawker and Connell (1988)
PCB 034	4.04×10^{-5}	5.66	Hawker and Connell (1988)
PCB 035	6.53×10^{-5}	5.82	Hawker and Connell (1988)
PCB 036	6.78×10^{-5}	5.88	Hawker and Connell (1988)
PCB 037	1.83×10^{-3}	5.83	Hawker and Connell (1988)
PCB 038	2.20×10^{-5}	5.76	Hawker and Connell (1988)
PCB 039	8.53×10^{-5}	5.89	Hawker and Connell (1988)
PCB 040, 041, 071	6.50×10^{-3}	5.78[a]	Hawker and Connell (1988)
PCB 042	4.79×10^{-3}	5.76	Hawker and Connell (1988)
PCB 043	5.15×10^{-4}	5.75	Hawker and Connell (1988)
PCB 044, 047, 065	2.38×10^{-2}	5.82[b]	Hawker and Connell (1988)
PCB 045, 051	3.09×10^{-3}	5.58[b]	Hawker and Connell (1988)
PCB 046	3.53×10^{-4}	5.53	Hawker and Connell (1988)
PCB 048	2.61×10^{-3}	5.78	Hawker and Connell (1988)
PCB 049, 069	1.24×10^{-2}	5.95[b]	Hawker and Connell (1988)
PCB 050, 053	3.95×10^{-3}	5.63[b]	Hawker and Connell (1988)
PCB 052	1.91×10^{-2}	5.84	Hawker and Connell (1988)
PCB 054	4.48×10^{-4}	5.21	Hawker and Connell (1988)
PCB 055	9.10×10^{-5}	6.11	Hawker and Connell (1988)
PCB 056	3.94×10^{-3}	6.11	Hawker and Connell (1988)
PCB 057	9.55×10^{-5}	6.17	Hawker and Connell (1988)
PCB 058	9.76×10^{-5}	6.17	Hawker and Connell (1988)
PCB 059, 062, 075	1.57×10^{-3}	5.96[b]	Hawker and Connell (1988)
PCB 060	4.08×10^{-3}	6.11	Hawker and Connell (1988)
PCB 061, 070, 074, 076	2.56×10^{-2}	6.14[b]	Hawker and Connell (1988)
PCB 063	1.06×10^{-3}	6.17	Hawker and Connell (1988)
PCB 064	5.95×10^{-3}	5.95	Hawker and Connell (1988)
PCB 066	2.15×10^{-2}	6.20	Hawker and Connell (1988)
PCB 067	4.31×10^{-4}	6.20	Hawker and Connell (1988)
PCB 068	2.42×10^{-4}	6.26	Hawker and Connell (1988)
PCB 072	2.66×10^{-4}	6.26	Hawker and Connell (1988)
PCB 073	1.30×10^{-4}	6.04	Hawker and Connell (1988)

Table 3-3. Octanol-Water Partition Coefficients for Components of Calculated Chemical Mixtures

Chemical	Fraction of Total (by tissue mass)[a]	K_{OW}	Source
PCB 077	1.23×10^{-3}	6.36	Hawker and Connell (1988)
PCB 078	2.43×10^{-5}	6.35	Hawker and Connell (1988)
PCB 079	3.78×10^{-4}	6.42	Hawker and Connell (1988)
PCB 080	1.90×10^{-5}	6.48	Hawker and Connell (1988)
PCB 081	5.70×10^{-5}	6.36	Hawker and Connell (1988)
PCB 082	1.76×10^{-3}	6.20	Hawker and Connell (1988)
PCB 083, 099	2.60×10^{-2}	6.33[b]	Hawker and Connell (1988)
PCB 084	3.56×10^{-3}	6.04	Hawker and Connell (1988)
PCB 085, 116, 117	6.14×10^{-3}	6.36[b]	Hawker and Connell (1988)
PCB 086, 087, 097, 108, 119, 125	1.80×10^{-2}	6.44[b]	Hawker and Connell (1988)
PCB 088, 091	4.33×10^{-3}	6.10[b]	Hawker and Connell (1988)
PCB 089	1.88×10^{-4}	6.07	Hawker and Connell (1988)
PCB 090, 101, 113	3.62×10^{-2}	6.43[b]	Hawker and Connell (1988)
PCB 092	7.49×10^{-3}	6.35	Hawker and Connell (1988)
PCB 093, 095, 098, 100, 102	2.47×10^{-2}	6.14[b]	Hawker and Connell (1988)
PCB 094	3.43×10^{-4}	6.13	Hawker and Connell (1988)
PCB 096	2.60×10^{-4}	5.71	Hawker and Connell (1988)
PCB 103	8.97×10^{-4}	6.22	Hawker and Connell (1988)
PCB 104	1.11×10^{-4}	5.81	Hawker and Connell (1988)
PCB 105	1.20×10^{-2}	6.65	Hawker and Connell (1988)
PCB 106	3.58×10^{-5}	6.64	Hawker and Connell (1988)
PCB 107, 124	8.68×10^{-4}	6.72[b]	Hawker and Connell (1988)
PCB 109	3.22×10^{-3}	6.48	Hawker and Connell (1988)
PCB 110, 115	2.68×10^{-2}	6.49[b]	Hawker and Connell (1988)
PCB 111	8.35×10^{-5}	6.76	Hawker and Connell (1988)
PCB 112	7.69×10^{-5}	6.45	Hawker and Connell (1988)
PCB 114	9.63×10^{-4}	6.65	Hawker and Connell (1988)
PCB 118	4.15×10^{-2}	6.74	Hawker and Connell (1988)
PCB 120	3.28×10^{-4}	6.79	Hawker and Connell (1988)
PCB 121	9.55×10^{-5}	6.64	Hawker and Connell (1988)
PCB 122	2.45×10^{-4}	6.64	Hawker and Connell (1988)
PCB 123	8.11×10^{-4}	6.74	Hawker and Connell (1988)
PCB 126	9.85×10^{-5}	6.89	Hawker and Connell (1988)
PCB 127	2.03×10^{-4}	6.95	Hawker and Connell (1988)
PCB 128, 166	6.37×10^{-3}	6.84[b]	Hawker and Connell (1988)
PCB 129, 138, 160, 163	7.96×10^{-2}	6.87[b]	Hawker and Connell (1988)
PCB 130	3.26×10^{-3}	6.80	Hawker and Connell (1988)

Table 3-3. Octanol-Water Partition Coefficients for Components of Calculated Chemical Mixtures

Chemical	Fraction of Total (by tissue mass)[a]	K_{OW}	Source
PCB 131	3.79×10^{-4}	6.58	Hawker and Connell (1988)
PCB 132	1.01×10^{-2}	6.58	Hawker and Connell (1988)
PCB 133	1.81×10^{-3}	6.86	Hawker and Connell (1988)
PCB 134, 143	2.01×10^{-3}	6.58[b]	Hawker and Connell (1988)
PCB 135, 151, 154	2.42×10^{-2}	6.68[b]	Hawker and Connell (1988)
PCB 136	4.92×10^{-3}	6.22	Hawker and Connell (1988)
PCB 137	2.37×10^{-3}	6.83	Hawker and Connell (1988)
PCB 139, 140	8.72×10^{-4}	6.67[b]	Hawker and Connell (1988)
PCB 141	8.59×10^{-3}	6.82	Hawker and Connell (1988)
PCB 142	2.75×10^{-5}	6.51	Hawker and Connell (1988)
PCB 144	2.45×10^{-3}	6.67	Hawker and Connell (1988)
PCB 145	1.45×10^{-5}	6.25	Hawker and Connell (1988)
PCB 146	1.82×10^{-2}	6.89	Hawker and Connell (1988)
PCB 147, 149	4.09×10^{-2}	6.66[b]	Hawker and Connell (1988)
PCB 148	3.28×10^{-4}	6.73	Hawker and Connell (1988)
PCB 150	2.12×10^{-4}	6.32	Hawker and Connell (1988)
PCB 152	1.12×10^{-4}	6.22	Hawker and Connell (1988)
PCB 153, 168	1.18×10^{-1}	7.02[b]	Hawker and Connell (1988)
PCB 155	5.06×10^{-5}	6.41	Hawker and Connell (1988)
PCB 156	4.06×10^{-3}	7.18	Hawker and Connell (1988)
PCB 156, 157	1.84×10^{-3}	7.18[b]	Hawker and Connell (1988)
PCB 157	5.95×10^{-4}	7.18	Hawker and Connell (1988)
PCB 158	6.21×10^{-3}	7.02	Hawker and Connell (1988)
PCB 159	3.86×10^{-4}	7.24	Hawker and Connell (1988)
PCB 161	$0.00 \times 10^{+0}$	7.08	Hawker and Connell (1988)
PCB 162	1.96×10^{-4}	7.24	Hawker and Connell (1988)
PCB 164	3.21×10^{-3}	7.02	Hawker and Connell (1988)
PCB 165	1.13×10^{-4}	7.05	Hawker and Connell (1988)
PCB 167	3.60×10^{-3}	7.27	Hawker and Connell (1988)
PCB 169	1.85×10^{-5}	7.42	Hawker and Connell (1988)
PCB 170	1.86×10^{-2}	7.27	Hawker and Connell (1988)
PCB 171, 173	6.19×10^{-3}	7.07[b]	Hawker and Connell (1988)
PCB 172	3.17×10^{-3}	7.33	Hawker and Connell (1988)
PCB 174	9.37×10^{-3}	7.11	Hawker and Connell (1988)
PCB 175	9.33×10^{-4}	7.17	Hawker and Connell (1988)
PCB 176	1.77×10^{-3}	6.76	Hawker and Connell (1988)
PCB 177	1.16×10^{-2}	7.08	Hawker and Connell (1988)

Table 3-3. Octanol-Water Partition Coefficients for Components of Calculated Chemical Mixtures

Chemical	Fraction of Total (by tissue mass)[a]	K_{OW}	Source
PCB 178	6.01×10^{-3}	7.14	Hawker and Connell (1988)
PCB 179	6.66×10^{-3}	6.73	Hawker and Connell (1988)
PCB 180, 193	6.74×10^{-2}	7.44[b]	Hawker and Connell (1988)
PCB 181	2.40×10^{-4}	7.11	Hawker and Connell (1988)
PCB 182	1.30×10^{-4}	7.20	Hawker and Connell (1988)
PCB 183, 185	1.78×10^{-2}	7.16[b]	Hawker and Connell (1988)
PCB 184	4.00×10^{-5}	6.85	Hawker and Connell (1988)
PCB 186	1.46×10^{-5}	6.69	Hawker and Connell (1988)
PCB 187	4.40×10^{-2}	7.17	Hawker and Connell (1988)
PCB 188	9.31×10^{-5}	6.82	Hawker and Connell (1988)
PCB 189	7.58×10^{-4}	7.71	Hawker and Connell (1988)
PCB 190	4.98×10^{-3}	7.46	Hawker and Connell (1988)
PCB 191	1.09×10^{-3}	7.55	Hawker and Connell (1988)
PCB 192	0.00×10^{0}	7.52	Hawker and Connell (1988)
PCB 194	7.57×10^{-3}	7.80	Hawker and Connell (1988)
PCB 195	3.69×10^{-3}	7.56	Hawker and Connell (1988)
PCB 196	4.88×10^{-3}	7.65	Hawker and Connell (1988)
PCB 197, 200	9.16×10^{-4}	7.29[b]	Hawker and Connell (1988)
PCB 198, 199	8.92×10^{-3}	7.41[b]	Hawker and Connell (1988)
PCB 201	1.36×10^{-3}	7.62	Hawker and Connell (1988)
PCB 202	2.32×10^{-3}	7.24	Hawker and Connell (1988)
PCB 203	6.19×10^{-3}	7.65	Hawker and Connell (1988)
PCB 204	3.38×10^{-5}	7.30	Hawker and Connell (1988)
PCB 205	4.14×10^{-4}	8.00	Hawker and Connell (1988)
PCB 206	1.79×10^{-3}	8.09	Hawker and Connell (1988)
PCB 207	3.45×10^{-4}	7.74	Hawker and Connell (1988)
PCB 208	6.47×10^{-4}	7.71	Hawker and Connell (1988)
PCB 209	6.61×10^{-4}	8.18	Hawker and Connell (1988)
Dioxin TEQ			
1,2,3,4,6,7,8-Heptachlorodibenzofuran	0.0190	8.22	KowWin Estimation Software (EPA 2003)
1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin	0.124	8.80	KowWin Estimation Software (EPA 2003)
1,2,3,4,7,8,9-Heptachlorodibenzofuran	0.00235	8.22	KowWin Estimation Software (EPA 2003)
1,2,3,4,7,8-Hexachlorodibenzofuran	0.0249	7.58	KowWin Estimation Software (EPA 2003)
1,2,3,4,7,8-Hexachlorodibenzo-*p*-dioxin	0.0104	8.20	KowWin Estimation Software (EPA 2003)
1,2,3,6,7,8-Hexachlorodibenzofuran	0.00821	7.58	KowWin Estimation Software (EPA 2003)
1,2,3,6,7,8-Hexachlorodibenzo-*p*-dioxin	0.0648	8.20	KowWin Estimation Software (EPA 2003)
1,2,3,7,8,9-Hexachlorodibenzofuran	0.00138	7.58	KowWin Estimation Software (EPA 2003)
1,2,3,7,8,9-Hexachlorodibenzo-*p*-dioxin	0.00955	8.20	KowWin Estimation Software (EPA 2003)

Table 3-3. Octanol-Water Partition Coefficients for Components of Calculated Chemical Mixtures

Chemical	Fraction of Total (by tissue mass)[a]	K_{OW}	Source
1,2,3,7,8-Pentachlorodibenzofuran	0.0341	6.94	KowWin Estimation Software (EPA 2003)
1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin	0.0356	7.56	KowWin Estimation Software (EPA 2003)
2,3,4,6,7,8-Hexachlorodibenzofuran	0.00489	7.58	KowWin Estimation Software (EPA 2003)
2,3,4,7,8-Pentachlorodibenzofuran	0.0558	6.94	KowWin Estimation Software (EPA 2003)
2,3,7,8-Tetrachlorodibenzofuran	0.113	6.29	KowWin Estimation Software (EPA 2003)
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin	0.0215	6.92	KowWin Estimation Software (EPA 2003)
Octachlorodibenzofuran	0.0247	8.87	KowWin Estimation Software (EPA 2003)
Octachlorodibenzo-*p*-dioxin	0.446	9.50	KowWin Estimation Software (EPA 2003)
Sum DDD			
2,4′-DDD	0.201	5.87	Howard and Meylan (1997), as cited in ATSDR (2002)
4,4′-DDD	0.799	6.02	Howard and Meylan (1997), as cited in ATSDR (2002)
Sum DDE			
2,4′-DDE	0.0564	6.00	Howard and Meylan (1997), as cited in ATSDR (2002)
4,4′-DDE	0.944	6.51	Howard and Meylan (1997), as cited in ATSDR (2002)
Sum DDT			
2,4′-DDT	0.330	6.79	Howard and Meylan (1997), as cited in ATSDR (2002)
4,4′-DDT	0.670	6.91	Howard and Meylan (1997), as cited in ATSDR (2002)
Total DDT			
2,4′-DDD	0.0533	5.87	Howard and Meylan (1997), as cited in ATSDR (2002)
2,4′-DDE	0.0264	6.00	Howard and Meylan (1997), as cited in ATSDR (2002)
2,4′-DDT	0.0954	6.79	Howard and Meylan (1997), as cited in ATSDR (2002)
4,4′-DDD	0.175	6.02	Howard and Meylan (1997), as cited in ATSDR (2002)
4,4′-DDE	0.487	6.51	Howard and Meylan (1997), as cited in ATSDR (2002)
4,4′-DDT	0.164	6.91	Howard and Meylan (1997), as cited in ATSDR (2002)

[a] Calculated from project database based on percentage of components in all tissue except multiplate, laboratory clam, and laboratory worm samples.

[b] For co-eluting PCB congeners, an average K_{OW} was calculated based on individual congener K_{OW}s in Hawker and Connell (1988).

ATSDR – Agency for Toxic Substances and Disease Registry
EPA – US Environmental Protection Agency
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

Table 4-1. Chemical Concentrations in the Water Column

Chemical	Distribution	Mean (ng/L)	Standard Deviation (ng/L) [a]
PCB 17	normal	3.93×10^{-3}	5.95×10^{-4}
PCB 170	normal	5.17×10^{-4}	9.83×10^{-5}
PCB 206	normal	5.95×10^{-5}	1.21×10^{-5}
Total PCBs	normal	1.95×10^{-1}	2.79×10^{-2}
PCB TEQ (mammals)	normal	2.16×10^{-6}	2.54×10^{-7}
PCB TEQ (birds)	normal	1.38×10^{-5}	1.72×10^{-6}
Dioxin TEQ (mammals)	normal	7.29×10^{-6}	1.28×10^{-6}
Dioxin TEQ (birds)	normal	1.04×10^{-5}	1.82×10^{-6}
4,4'-DDD	normal	3.44×10^{-2}	8.69×10^{-3}
4,4'-DDE	normal	1.95×10^{-2}	3.10×10^{-3}
4,4'-DDT	normal	4.96×10^{-3}	8.95×10^{-4}
Sum DDD	normal	5.02×10^{-2}	1.24×10^{-2}
Sum DDE	normal	2.06×10^{-2}	3.32×10^{-3}
Sum DDT	normal	7.18×10^{-3}	1.34×10^{-3}
Total DDTs	normal	7.79×10^{-2}	1.61×10^{-2}

[a] The standard error of the data was used to describe the standard deviation of estimates of the mean.
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

Table 4-2. Spatially Weighted Chemical Concentrations in Sediment

Chemical	Number of Samples	SWAC (ng/g)
PCB 17	146	1.59
PCB 170	229	2.30
PCB 206	146	0.950
Total PCBs	869	72.1
PCB TEQ (mammals)	158	0.00347
PCB TEQ (birds)	158	0.0213
Dioxin TEQ (mammals)	152	0.0274
Dioxin TEQ (birds)	152	0.0557
4,4'-DDD	895	7.87
4,4'-DDE	892	3.85
4,4'-DDT	880	15.3
Sum DDD	895	10.6
Sum DDE	892	4.63
Sum DDT	894	17.4
Total DDTs	895	32.6

PCB – polychlorinated biphenyl
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

Table 6-1. Weight, Lipid Fraction, and Water Content for Invertebrate Species

Species	Parameter	Count[a]	Distribution Type	Mean or Mode	SD or Min and Max[b]	Source
Benthic invertebrate filter feeders (clams)	weight (g)	1885	normal	0.00103	SD = 1.94×10^{-5}	project database
	lipid fraction	35	normal	0.02276	SD = 0.001319	project database
	water content fraction	30	normal	0.863	SD = 0.003278	project database
	lipid:moisture correlation[c]	30	NA	-0.652	NA	project database
Benthic invertebrate consumers	weight (g)	NA	triangle	5.33×10^{-6}	min = 1.4×10^{-6} max = 6.0×10^{-6}	Kraaij et al. (2001); Millward et al. (2001); Beroets et al. (2003)
	lipid fraction	NA	triangle	0.015	min = 0.008 max = 0.042	Weston et al. (2002); Kraaij et al. (2001); Lyytikainen et al. (2003); project database
	water content fraction	NA	triangle	0.80	min = 0.72 max = 0.88	best professional judgment
Epibenthic invertebrate consumers (crayfish)	weight (g)	232	normal	0.042	SD = 0.000704	project database
	lipid fraction	27	normal	0.00781	SD = 0.000517	project database
	water content fraction	27	normal	0.736	SD = 0.00345	project database
	lipid:moisture correlation[c]	27	NA	-0.414	NA	project database

[a] Count represents the number of individuals for weight data and the number of composite samples for all other parameters.

[b] The standard error of the data was used to describe the standard deviation of estimates of the mean.

[c] The lipid:moisture correlation coefficient was calculated on a sample-by-sample basis for species for which site-specific data were available.

NA – not applicable

SD – standard deviation

Table 6-2. Weight, Lipid Fraction, and Water Content for Fish Species

Species	Parameter	Count[a]	Distribution Type	Mean	Standard Deviation[b]
Sculpin	weight (kg)	489	normal	0.0189	0.00386
	lipid fraction	26	normal	0.0417	0.00197
	water content fraction	26	normal	0.748	0.00248
	lipid: moisture correlation[c]	26	NA	-0.583	NA
Largescale sucker	weight (kg)	34	normal	0.794	0.0122
	lipid fraction	6	normal	0.0756	0.00515
	water content fraction	6	normal	0.712	0.00542
	lipid: moisture correlation[c]	6	NA	-0.892	NA
Carp	weight (kg)	30	normal	2.33	0.0879
	lipid fraction	6	normal	0.0788	0.0107
	water content fraction	6	normal	0.705	0.00826
	lipid: moisture correlation[c]	6	NA	-0.956	NA
Smallmouth bass	weight (kg)	62	normal	0.372	0.0241
	lipid fraction	14	normal	0.0544	0.00442
	water content fraction	14	normal	0.702	0.00660
	lipid: moisture correlation[c]	14	NA	-0.617	NA
Northern pikeminnow	weight (kg)	27	normal	0.558	0.0483
	lipid fraction	6	normal	0.0525	0.00804
	water content fraction	6	normal	0.719	0.00879
	lipid: moisture correlation[c]	6	NA	-0.704	NA

[a] Count represents the number of individual fish for weight data and the number of composite samples for all other parameters.

[b] The standard error of the data was used to describe the standard deviation of estimates of the mean.

[c] The lipid:moisture correlation coefficient was calculated on a sample-by-sample basis for species for which site-specific data were available.

NA – not applicable

Table 6-3. Dietary Absorption Efficiency Fractions

Species	Dietary Absorption Efficiency[a]	Distribution Type	Mean or Mode	Minimum and Maximum	Source
Zooplankton	lipid (eL)	triangle	0.72	min = 0.55 max = 0.85	Arnot and Gobas (2004)
	NLOM (eN)	triangle	0.72	min = 0.55 max = 0.85	Arnot and Gobas (2004)
	water (eW)	point estimate	0.25	NA	Arnot and Gobas (2004)
Invertebrates[b]	lipid (eL)	triangle	0.75	min = 0.15 max = 0.96	Arnot and Gobas (2004)
	NLOM (eN)	triangle	0.75	min = 0.15 max = 0.96	Arnot and Gobas (2004)
	water (eW)	point estimate	0.25	NA	Arnot and Gobas (2004)
Fish species[c]	lipid (eL)	triangle	0.92	min = 0.90 max = 0.95	Arnot and Gobas (2004), Gobas and Arnot (2005), and Gobas (1999)
	NLOM (eN)	triangle	0.60	min = 0.50 max = 0.65	Arnot and Gobas (2004), Gobas and Arnot (2005), and Gobas (1999)
	water (eW)	point estimate	0.25	NA	Arnot and Gobas (2004)

[a] Abbreviations for dietary absorption efficiencies used in the model are provided in parentheses for reference.

[b] Invertebrates include benthic invertebrate filter feeders (clams), benthic invertebrate consumers, and epibenthic invertebrate consumers (crayfish).

[c] Fish species include sculpin, largescale suckers, carp, smallmouth bass, and northern pikeminnow.

NA – not applicable

Table 6-4. Fraction of Porewater Ventilated

Species	Distribution Type	Mean or Mode	Minimum and Maximum	Rationale
Phytoplankton	point estimate	0	NA	Live in water column and are not exposed to porewater.
Zooplankton	point estimate	0	NA	Live in water column and are not exposed to porewater.
Benthic invertebrate filter feeders (clams)	triangle	0.05	min = 0.01 max = 0.10	Live in the sediment and use short siphon to ventilate water from just above the sediment surface.
Benthic invertebrate detrital/deposit feeders)	triangle	0.05	min = 0.01 max = 0.10	Primarily dwell beneath sediment.
Epibenthic invertebrate consumers (crayfish)	triangle	0.05	min = 0.01 max = 0.10	Crayfish live in burrows in the sediment and forage on the sediment,
Sculpin	triangle	0.05	min = 0.01 max = 0.10	Some sediment surface feeding. Agency comments suggested eliminating FPW for all fish except sculpin (EPA 2006).
Largescale suckers	point estimate	0	NA	Limited contact with sediment. Agency comments suggested eliminating FPW for all fish except sculpin (EPA 2006).
Carp	point estimate	0	NA	Some bottom feeding, but primarily lives in water column. Agency comments suggested eliminating FPW for all fish except sculpin (EPA 2006).
Smallmouth bass	point estimate	0	NA	Primarily swim and feed in water column.
Northern pikeminnow	point estimate	0	NA	Primarily swim and feed in water column.

EPA – US Environmental Protection Agency
FPW – fraction of porewater ventilated
NA – not applicable

Table 6-5. Diets for Modeled Species

Prey Item	Distribution Type	Value or Mode (%)	Min and Max (%)	Rationale and Source
Zooplankton diet				
Phytoplankton	point estimate	100	NA	Using best professional judgment, it was assumed that the portion of carnivorous zooplankton in the LWR is insignificant as compared to planktivores.
Benthic invertebrate filter feeder (BIF) diet based on clams				
Sediment solids	triangle	70	min = 50 max = 80	Diet was based on Pechenick (1991), Kraaij et al. (2001), and Zaranko et al. (1997).
Phytoplankton	triangle	30	min = 20 max = 50	
Benthic invertebrate consumer (BIC) diet based on worms, amphipods, insect larvae, etc.				
Sediment solids	triangle	95	min = 85 max = 100	Diet was developed based on a combination of insect larvae, oligochaete, and amphipod diets from the previous FWM (Windward 2005), as well as Pechenick (1991) and Zaranko et al. (1997).
Phytoplankton	triangle	5	min = 0 max = 15	
Epibenthic invertebrate consumer (EIC) diet based on crayfish				
Sediment solids	triangle	2	min = 0 max = 4	Crayfish diets and distributions are highly uncertain because they are thought to feed non-selectively. Best professional judgment was used to resolve these differences in available studies (Pechenik 1991; Evans-White et al. 2001).
Phytoplankton	triangle	10	min = 0 max = 20	
Zooplankton	triangle	10	min = 0 max = 20	
BIF (clams)	triangle	18	min = 0 max = 35	
BIC	triangle	60	min = 25 max = 75	
Sculpin diet				
Sediment solids	triangle	0	min = 0 max = 5	Fish consumption, cannibalism, and worm consumption likely occupy the highest percentages of sculpin diets. The fish consumption portion of the diet was transferred to clams, worms, and crayfish. Studies do not indicate specific consumption of sediment (although sculpin likely ingest some), zooplankton, clams or crayfish. Sources included Northcote (1954) and Brown et al. (1995).
Zooplankton	triangle	0	min = 0 max = 5	
BIF (clams)	triangle	5	min = 0 max = 10	
BIC	triangle	90	min = 25 max = 95	
EIC (crayfish)	triangle	5	min = 0 max = 10	
Largescale sucker diet				
Sediment solids	triangle	5	min = 1 max = 15	Personal communication with Charles Lee (2006) indicated that sucker diet consisted of 50% clams and 50% worms. Best professional judgment was used to
Phytoplankton	triangle	25	min = 0 max = 60	

Table 6-5. Diets for Modeled Species

Prey Item	Distribution Type	Value or Mode (%)	Min and Max (%)	Rationale and Source
Zooplankton	triangle	15	min = 5 max = 25	reconcile differences between the information provided above and information from Jorgensen (1979) and stomach content analysis (Integral et al. 2004)
BIF (clams)	triangle	10	min = 5 max = 15	
BIC	triangle	25	min = 15 max = 35	
EIC (crayfish)	triangle	20	min = 0 max = 40	
Carp diet				
Sediment solids	triangle	5	min = 0 max = 10	The carp diet was based on the diet used in the previous FWM (Windward 2005) from studies conducted in the Hanford Reach of the Mid-Columbia River. Best professional judgment was used to resolve differences between Gray and Daubble (2001) and Fishbase (2004).
Phytoplankton	triangle	45	min = 30 max = 60	
BIF (clams)	triangle	10	min = 5 max = 15	
BIC	triangle	40	min = 25 max = 55	
Smallmouth bass diet				
Sediment solids	point estimate	0	NA	Based on the diet used in the previous FWM, but replaced peamouth and juvenile fish consumption with sculpin. Best professional judgment was used to resolve difference between ODFW (2005), Zimmerman (1999), and LWR gut content survey (Integral et al. 2004)
BIC	triangle	5	min = 0 max = 30	
EIC (crayfish)	triangle	5	min = 0 max = 30	
Sculpin	triangle	90	min = 50 max = 100	
Northern pikeminnow diet				
Sediment solids	point estimate	0	NA	ODFW study conducted in the LWR indicated that juvenile salmon were a major part of the pikeminnow diet (2005). All fish consumption (juvenile fish, juvenile chinook, peamouth, and sculpin) was combined under the sculpin prey category. Best professional judgment was used to resolve difference between the ODFW (2005), Gray and Daubble (2001), Buchanan et al. (1981), and Zimmerman (1999).
Phytoplankton	triangle	4	min = 0 max = 10	
BIF (clams)	triangle	5	min = 0 max = 10	
BIC	triangle	26	min = 15 max = 45	
EIC (crayfish)	triangle	40	min = 25 max = 65	
Sculpin	triangle	25	min = 0 max = 60	

NA – not applicable
BIC – benthic invertebrate consumer
BIF – benthic invertebrate filter feeder
EIC – epibenthic invertebrate consumer
FWM – food web model
LWR – Lower Willamette River
ODFW – Oregon Department of Fish and Wildlife

APPENDIX E: FOOD WEB MODEL

Attachment E4
Site-Wide Empirical
Tissue Concentrations

SITE-WIDE EMPIRICAL TISSUE CONCENTRATIONS

Site-specific tissue concentrations for all modeled chemicals were obtained from the project database. Average empirical tissue concentrations were compared to model-predicted tissue concentrations and used to evaluate model performance.

All tissue chemistry data for samples collected between River Miles 2 and 11 in the database were used to calculate site-specific tissue concentrations. Table 1 provides mean empirical concentrations for invertebrates; Table 2 provides mean empirical concentrations for fish species. Total PCBs were calculated as the sum of Aroclors.

Table 1. Site-Wide Mean Empirical Tissue Concentrations for Field-Collected Invertebrates

Chemical	Clam (µg/kg)	Crayfish (µg/kg)
	n = 34	n = 27
PCB 17	1.64[a]	0.0716[b]
PCB 170	1.31[a]	1.60[b]
PCB 206	0.169[a]	0.101[b]
Total PCBs (calc'd)	245[c]	36.6[d]
PCB TEQ (birds)	0.0138[a]	0.0118[b]
PCB TEQ (mammals)	0.00289[a]	0.00179[b]
Dioxin TEQ (birds)	0.00428[c]	0.0129[b]
Dioxin TEQ (mammals)	0.00143[e]	0.00322[b]
4,4'-DDD	20.2	1.66
4,4'-DDT	6.96	2.24
Sum DDD (calc'd)	27.6	1.91
Sum DDE (calc'd)	19.4	6.95
Sum DDT (calc'd)	9.86	4.56
Total DDTs (calc'd)	56.9	14.1

[a] A subset of the clam samples (n = 31) were analyzed for this chemical.
[b] A subset of crayfish samples (n = 10) were analyzed for this chemical.
[c] Calculated as sum of PCB congeners (n=31) and sum of Aroclors (n=3).
[d] Calculated as sum of PCB Aroclors.
[e] A subset of clam samples (n = 29) were analyzed for this chemical.

Table 2. Site-Wide Mean Empirical Tissue Concentrations for Fish Species

Chemical	Sculpin (µg/kg) n = 26	Largescale Sucker (µg/kg) n = 6	Carp (µg/kg) n = 6	Smallmouth Bass (µg/kg) n = 14	Northern Pikeminnow (µg/kg) n = 6
PCB 17	2.33[a]	NA	2.93	1.07	NA
PCB 170	28.2[a]	NA	63.3	40.9	NA
PCB 206	1.83[a]	NA	4.98	2.41	NA
Total PCBs (calc'd)[a]	602	903	1,860	1,200	884
PCB TEQ (birds)	0.0332[b]	NA	0.0211	0.0320	NA
PCB TEQ (mammals)	0.0148[b]	NA	0.0132	0.0157	NA
Dioxin TEQ (birds)	0.0242[b]	NA	0.00760	0.00818	NA
Dioxin TEQ (mammals)	0.00631[b]	NA	0.00479	0.00407	NA
4,4'-DDD	26.5	54.4	46.4	37.9	32.9
4,4'-DDT	102	59.2	6.63	29	11.5
Sum DDD (calc'd)	32.3	66.6	68.8	44.5	40.4
Sum DDE (calc'd)	59.3	124	138	134	264
Sum DDT (calc'd)	128	72.6	10.7	34.2	28.6
Total DDTs (calc'd)	221	263	220	214	335

[a] Calculated as sum of PCB Aroclors.

[b] A subset of the sculpin data (n = 9) were analyzed for this chemical.

NA – not available

APPENDIX E: FOOD WEB MODEL

Attachment E5

FOOD WEB MODEL APPLICATION FOR SWAN ISLAND LAGOON

FOOD WEB MODEL APPLICATION FOR SWAN ISLAND LAGOON

Evaluations of the food web model (FWM) were done on smaller spatial scales to further evaluate the model's performance. In order to evaluate the performance of the food web model for a range of chemicals, the FWM was run for 4,4′-DDD, total DDTs, and total polychlorinated biphenyls (PCBs) for Swan Island Lagoon. The mean values for data below were used in the model. All parameter values not specified here were based on those for the calibrated site wide model (Appendix G, Section G.3.3.1). The model was not calibrated specifically for Swan Island Lagoon. Results for application of the model to Swan Island Lagoon are presented in Appendix G, Section G.3.4.

ENVIRONMENTAL WATER AND SEDIMENT DATA

Site-specific environmental data were assembled for Swan Island Lagoon. Table 1 shows the water temperature, total suspended solids, dissolved organic carbon, and total organic carbon in the sediment used for the Swan Island Lagoon food web model. Mean values were used in the model applications for Swan Island Lagoon.

CHEMICAL-SPECIFIC DATA

Site-specific water chemistry data for 4,4′-DDD, total DDTs, and total PCBs were averaged from Infiltrex system with XAD resin column (XAD) samples collected at one sampling location in Swan Island Lagoon (location 18, see Figure 3-1 from Attachment E3). Table 2 shows the values used in the Swan Island Lagoon food web model. The sediment concentrations used for the Swan Island Lagoon food web model were Thiessen polygon spatially weighted average concentrations (SWACs) calculated using only data from the lagoon. Table 3 shows the values used in the food web model. For the Swan Island Lagoon model, the model was not calibrated (the average empirical water and sediment chemistry data were used in the model).

EMPIRICAL TISSUE CONCENTRATIONS

Swan Island Lagoon was modeled for species with smaller home ranges only. Table 4 shows average tissue concentrations that were calculated for clams, crayfish, sculpin, and smallmouth bass using only samples collected in the lagoon.

REFERENCE

ODEQ. 2006. Laboratory analytical storage and retrieval (LASAR) database [online]. DEQ Online, Oregon Department of Environmental Quality, Portland, OR. [Cited August 24, 2006]. Available from: <http://www.deq.state.or.us/wq/lasar/lasarhome.htm>.

TABLES

Table 1. Site-Specific Water and Sediment Environmental Data for Swan Island Lagoon

Parameter	Mean Value	Standard Deviation	Standard Error	Data Source	Notes
Water temperature (°C)	14.57	6.57	2.19	ODEQ (2006)	Data from ODEQ Swan Island Channel midpoint (1995 – 2006)
Total suspended solids (TSS, kg/L)	2.75×10^{-6}	6.12×10^{-7}	2.50×10^{-7}	project database	Near-bottom location in Swan Island Lagoon (W018 and W021)
Dissolved organic carbon (kg/L)	1.52×10^{-6}	2.79×10^{-7}	1.14×10^{-7}	project database	Near-bottom locations in Swan Island Lagoon (W018 and W021)
Total organic carbon in the sediment (fraction)	0.0204	0.0094	0.00104	project database	SWAC calculated using Thiessen polygons

Table 2. Water Chemistry Data for Swan Island Lagoon

Chemical	Unit	Number of Samples	Average	Standard Deviation	Standard Error
4,4'-DDD	ng/L	3	0.0237	0.0110	0.00635
Total DDTs	ng/L	3	0.0535	0.0185	0.0107
Total PCBs[a]	ng/L	3	0.245	0.118	0.0683

[a] Calculated as sum of PCB congeners.

Table 3. Sediment SWACs for Swan Island Lagoon

Chemical	Unit	Number of Samples	Average
4,4'-DDD	ng/g	66	3.67
Total DDTs	ng/g	66	15.6
Total PCBs[a]	ng/g	82	317

[a] Calculated as sum of PCB Aroclors.

Table 4. Swan Island Lagoon Empirical Tissue Concentrations for Species with Small Home Ranges

Chemical	Unit	Clam (n = 3)	Crayfish (n = 3)	Sculpin (n = 2)	Smallmouth Bass (n = 3)
44-DDD	µg/kg	6.13	0.50	2.53	16.2
Total DDTs	µg/kg	20.8	6.0	42.1	108
Total PCBs	µg/kg	303[a]	55.1[b]	617[b]	3220[b]

[a] Calculated as sum of PCB congeners.
[b] Calculated as sum of PCB Aroclors.

APPENDIX E: FOOD WEB MODEL

Attachment E6
COMPLETE SENSITIVITY ANALYSIS RESULTS

COMPLETE SENSITIVITY ANALYSIS RESULTS

As described in the Round 2 ERA (Appendix G, Section 3.2.5.4), a sensitivity analysis was done in order to identify the parameters with the largest impact on the model-predicted tissue concentrations. This attachment provides the complete results from the sensitivity analysis for total PCBs, PCB TEQ (birds), dioxin TEQ (mammals), total DDTs, and 4,4-DDD. The model was run 10,000 times for each chemical using Crystal Ball®, both with and without a distribution defined for the sediment concentration. Table 1 shows the species codes used in the tables in this attachment to represent the 10 modeled species groups.

Table 2 provides an explanation of the shortened parameter names that were used in the sensitivity results tables. Tables 3 through 12 show the percent contribution of each parameter to the variance of the model-predicted tissue concentration for a given species. Percentages greater than 5% are shown in bold to help highlight the parameters with the largest impact on the model output.

TABLES

Table 1. Explanation of Species Codes

Code	Species
PHY	Phytoplankton
ZOO	Zooplankton
BIF	Benthic invertebrate filter feeders (clams)
BIC	Benthic invertebrate consumers (worms)
EIC	Epibenthic invertebrate consumers (crayfish)
SCL	Sculpin, representing forage fish
LSS	Largescale sucker, representing benthivore fish
CAR	Common carp, representing omnivorous fish
SMB	Smallmouth bass, representing small piscivorous fish
NPM	Northern pikeminnow, representing large piscivorous fish

Table 2. Explanation of Shortened Parameter Codes

Parameter	Explanation
Concentration in filtered water	Site-specific chemical concentration in the water (column only data)
Concentration in sediment	Site-specific chemical concentration in the sediment
Concentration of suspended solids	Site-specific concentration of suspended solids in the water
K_{OW}	Octanol-water partition coefficient
NLOM prop constant	Proportionality constant expressing the sorption capacity of non-lipid organic matter (NLOM) to that of octanol
Sediment organic carbon	Organic carbon content of the sediment
Uptake constant A	Resistance to chemical uptake through aqueous phases for phytoplankton
Uptake constant B	Resistance to chemical uptake through organic phases for phytoplankton
Water temperature	Site-specific average water temperature
XDOC	Site-specific concentration of dissolved organic carbon in water
XXX growth rate constant	Growth rate
XXX lipids	Species-specific lipid fraction[a]
XXX moisture	Species-specific water content fraction[a]
XXX dietary absorption efficiency of NLOM	Dietary absorption efficiency of non-lipid organic matter
XXX dietary absorption efficiency of lipids	Dietary absorption efficiency of lipid
XXX porewater ventilation	Porewater ventilation rate
XXX consumption of XXX	Dietary consumption parameters

[a] Species-specific data from the LWR were not available for PHY, ZOO or BIC, and thus literature values were used for these parameters.

XXX – represents species codes (see Table 1)

Table 3. Complete Results of Sensitivity Analysis for Total PCBs with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**9.3%**	**8.6%**	2.2%	0.1%	0.1%	0.1%	0.2%	0.2%	0.0%	0.1%
Concentration of suspended solids	0.0%	0.0%	1.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**50.5%**	**83.3%**	**39.6%**	**48.8%**	**55.5%**	**75.0%**	**68.4%**	**59.6%**	**75.9%**	**66.3%**
NLOM proportionality constant	0.0%	0.5%	0.6%	0.7%	3.0%	0.1%	0.1%	0.0%	0.0%	0.0%
Sediment organic carbon	0.0%	0.0%	-0.4%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	-0.1%	-0.1%
Uptake constant A	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	0.2%	0.1%	1.7%	1.8%	4.1%	**5.6%**	**5.9%**	**5.7%**	4.7%
XDOC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	-0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	**-38.5%**	-1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO lipids	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	-4.5%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zoo weight	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	4.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	-2.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation rate	0.0%	0.0%	**46.6%**	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	**43.6%**	3.3%	**16.3%**	**9.8%**	**19.7%**	**11.2%**	**8.5%**
BIC moisture	0.0%	0.0%	0.0%	-1.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%

Table 3. Complete Results of Sensitivity Analysis for Total PCBs with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC porewater ventilation rate	0.0%	0.0%	0.0%	1.8%	0.9%	0.9%	0.6%	1.0%	0.5%	0.6%
BIC weight	0.0%	0.0%	0.0%	1.1%	0.4%	0.6%	0.4%	0.7%	0.5%	0.4%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**28.1%**	0.1%	3.8%	0.0%	0.2%	1.4%
EIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.1%	2.7%	0.1%	0.7%	0.1%	0.2%	0.3%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.1%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.1%	0.0%
SCL dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.3%	0.2%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%	-0.1%	0.0%	-0.2%	-0.1%
SCL porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.0%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%
CAR dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.5%	0.0%	0.0%
CAR moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-4.1%	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB dietary absorption efficiency of NLOM	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
SMB dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%

Table 3. Complete Results of Sensitivity Analysis for Total PCBs with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
NPM dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
NPM lipids[a]	0.0%	-0.1%	0.0%	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	3.4%
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.0%
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF consumption of sediment	0.0%	0.0%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	0.5%	0.3%	0.3%	0.2%	0.4%	0.2%	0.2%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	-0.1%	0.0%	0.0%	0.0%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-0.8%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of BIC	0.0%	0.1%	0.0%	0.0%	1.0%	0.0%	0.2%	0.0%	0.0%	0.1%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.7%	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.6%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%
CAR consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.8%	0.0%	0.0%

Table 3. Complete Results of Sensitivity Analysis for Total PCBs with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%
SMB consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.6%	0.0%
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.2%	0.0%
NPM consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	-0.1%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.7%**

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 4. Complete Results of Sensitivity Analysis for Total PCBs with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**10.3%**	**8.6%**	1.7%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%
Concentration in sediment	0.0%	0.0%	**22.6%**	**14.2%**	**9.7%**	**10.3%**	**11.2%**	**12.6%**	**7.8%**	**7.3%**
Concentration of suspended solids	0.0%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**49.8%**	**83.6%**	**30.1%**	**42.1%**	**49.1%**	**67.3%**	**59.6%**	**52.8%**	**70.8%**	**61.0%**
NLOM proportionality constant	0.0%	0.9%	0.8%	0.9%	3.4%	0.3%	0.3%	0.1%	0.0%	0.0%
Sediment organic carbon	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant A	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	0.1%	0.1%	1.5%	1.6%	3.7%	**5.2%**	**5.2%**	**5.2%**	4.9%
XDOC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	-0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	**-38.1%**	-1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of NLOM	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO lipids	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	-4.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zoo weight	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	3.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	-1.6%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation rate	0.0%	0.0%	**35.8%**	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 4. Complete Results of Sensitivity Analysis for Total PCBs with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC lipids	0.0%	0.0%	0.0%	**36.1%**	3.1%	**14.0%**	**8.7%**	**16.5%**	**10.0%**	**7.4%**
BIC moisture	0.0%	0.0%	0.0%	-1.2%	-0.2%	0.0%	-0.1%	0.0%	0.0%	0.0%
BIC porewater ventilation rate	0.0%	0.0%	0.0%	1.8%	0.6%	1.0%	0.7%	1.0%	0.7%	0.7%
BIC weight	0.0%	0.0%	0.0%	0.8%	0.3%	0.5%	0.4%	0.5%	0.4%	0.3%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**26.0%**	0.1%	3.5%	0.0%	0.1%	1.2%
EIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	0.3%	0.0%	0.0%	0.2%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.1%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC porewater ventilation rate	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%	-0.2%	-0.1%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of lipids	-0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	-0.1%	0.0%	0.0%
SCL dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.2%	0.1%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.2%	0.2%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%	-0.1%	-0.1%
SCL porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.0%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
CAR dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.1%	0.0%	0.0%
CAR moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.7%	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%

Table 4. Complete Results of Sensitivity Analysis for Total PCBs with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
SMB dietary absorption efficiency of lipids	0.0%	-0.1%	0.0%	0.0%	-0.1%	0.0%	-0.1%	-0.1%	0.3%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
NPM dietary absorption efficiency of lipids	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%
NPM lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.6%
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.7%
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF consumption of sediment	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	0.4%	0.2%	0.3%	0.2%	0.3%	0.2%	0.3%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%	-0.1%	0.0%	0.0%	0.0%
EIC consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.1%	0.0%	0.0%	0.1%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%	0.0%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%	0.0%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.2%	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%

Table 4. Complete Results of Sensitivity Analysis for Total PCBs with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
CAR consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.9%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%	0.0%
SMB consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%
SMB consumption of EIC	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.8%	0.0%
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
NPM consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.5%**

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 5. Complete Results of Sensitivity Analysis for PCB TEQ (Birds) with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**21.5%**	**39.8%**	0.7%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
Concentration of suspended solids	0.0%	0.0%	**11.5%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
KOW	2.2%	**19.8%**	0.1%	3.4%	2.5%	4.0%	0.5%	0.3%	1.4%	0.9%
NLOM prop constant	0.0%	2.6%	1.0%	1.0%	4.5%	0.0%	0.1%	0.0%	-1.4%	-0.5%
Sediment organic carbon	0.0%	0.0%	-0.5%	-0.1%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Uptake constant A	-2.4%	-0.3%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	1.0%	0.3%	5.0%	3.3%	**21.0%**	**18.8%**	**20.3%**	**28.6%**	**16.5%**
XDOC	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	**-9.0%**	-1.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	-0.1%	0.0%
PHY moisture	**-63.9%**	**-9.1%**	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%
ZOO Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO lipids	0.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	**-22.1%**	0.0%	-0.1%	0.0%	-0.1%	0.1%	-0.1%	-0.1%	0.0%
Zoo weight	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	**6.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	-2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**66.8%**	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%
BIC lipids	0.0%	0.0%	0.0%	**82.8%**	4.0%	**58.9%**	**25.8%**	**51.7%**	**40.4%**	**18.9%**
BIC moisture	0.0%	0.0%	0.0%	-2.2%	-0.1%	0.3%	-0.1%	0.0%	0.3%	0.4%
BIC porewater ventilation	0.0%	0.0%	0.0%	1.5%	0.7%	2.2%	1.3%	1.3%	1.7%	1.1%

Table 5. Complete Results of Sensitivity Analysis for PCB TEQ (Birds) with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC weight	0.0%	0.0%	0.0%	1.9%	1.0%	2.5%	1.6%	1.6%	1.7%	1.0%
EIC Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**70.1%**	0.8%	**18.1%**	0.0%	1.0%	**5.0%**
EIC Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	4.7%	0.1%	1.3%	0.0%	0.1%	0.5%
EIC lipids[a]	0.0%	-0.1%	0.0%	0.0%	0.8%	0.1%	0.3%	0.1%	0.0%	0.1%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	-0.1%	0.0%	0.0%	0.0%
EIC porewater ventilation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	1.1%	0.4%
SCL Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%	0.0%	1.0%	0.3%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	0.0%	0.7%	0.4%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%	0.0%	-0.1%	-0.1%
SCL porewater ventilation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%
LSS Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.1%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.1%
CAR Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**5.7%**	0.0%	0.0%
CAR Moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-5.2%**	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%
SMB Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.6%	0.0%
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.6%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%

Table 5. Complete Results of Sensitivity Analysis for PCB TEQ (Birds) with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
NPM lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.1%**
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-4.9%
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF consumption of sediment	0.0%	-0.1%	**9.2%**	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	1.2%	0.6%	1.6%	1.1%	1.1%	1.2%	1.0%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-1.0%	-0.1%	-0.3%	0.0%	-0.1%	-0.1%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-3.1%	-0.1%	-1.0%	0.0%	-0.1%	-0.3%
EIC consumption of BIC	0.0%	0.0%	0.0%	0.0%	2.4%	0.0%	0.7%	0.0%	0.0%	0.2%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.1%	0.0%	-0.1%	0.0%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%	0.0%	-0.5%	-0.2%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.1%	0.0%	0.7%	0.0%	0.1%	0.5%	0.1%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-11.4%**	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.2%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	**7.9%**	0.0%	0.1%	0.0%
CAR consumption of sediment	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.2%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**6.1%**	0.0%	0.0%
SMB consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.5%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.0%	0.0%
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%

Table 5. Complete Results of Sensitivity Analysis for PCB TEQ (Birds) with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM consumption of PHY	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.9%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.4%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**33.4%**

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 6. Complete Results of Sensitivity Analysis for PCB TEQ (Birds) with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**20.9%**	**41.4%**	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Concentration in sediment	0.0%	0.0%	**47.4%**	**30.2%**	**17.8%**	**38.8%**	**29.7%**	**32.1%**	**31.5%**	**22.3%**
Concentration of suspended solids	0.0%	0.0%	**6.4%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
KOW	2.1%	**19.3%**	0.1%	2.0%	1.4%	1.9%	0.3%	0.2%	0.8%	0.7%
NLOM prop constant	0.0%	2.5%	0.3%	0.6%	3.6%	0.0%	0.1%	0.0%	-0.9%	-0.3%
Sediment organic carbon	0.0%	0.0%	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant A	-2.3%	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	0.5%	0.1%	3.4%	3.3%	**12.7%**	**14.2%**	**13.5%**	**19.3%**	**12.0%**
XDOC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	**-8.0%**	-0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%
PHY moisture	**-65.5%**	**-9.4%**	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.0%	0.0%
ZOO Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO lipids	0.0%	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	**-22.4%**	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.1%	0.0%
Zoo weight	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	-1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation	0.0%	0.0%	**35.1%**	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%
BIC lipids	0.0%	0.0%	0.0%	**57.4%**	2.8%	**36.2%**	**16.7%**	**34.3%**	**27.7%**	**14.4%**
BIC moisture	0.0%	0.0%	0.0%	-1.5%	-0.1%	0.2%	-0.1%	0.0%	0.2%	0.2%

Table 6. Complete Results of Sensitivity Analysis for PCB TEQ (Birds) with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC porewater ventilation	0.0%	0.0%	0.0%	1.0%	0.4%	1.1%	0.6%	0.8%	0.8%	0.7%
BIC weight	0.0%	0.0%	0.0%	1.8%	0.9%	1.8%	1.3%	1.2%	1.5%	1.1%
EIC Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**56.6%**	0.7%	**13.0%**	0.0%	1.0%	4.8%
EIC Dietary absorption efficiency of NLOM	-0.1%	0.0%	0.0%	0.0%	4.4%	0.2%	1.4%	0.0%	0.2%	0.6%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%	0.2%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%	-0.2%	0.0%	0.0%	-0.1%
EIC porewater ventilation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.7%	0.3%
SCL Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.6%	0.3%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.3%	0.2%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%	0.0%	-0.1%	0.0%
SCL porewater ventilation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	-0.1%
LSS Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.1%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.4%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%
CAR Dietary absorption efficiency of lipids	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.6%	0.0%	0.0%
CAR Moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-4.3%	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%
SMB Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.9%	0.0%
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.4%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%

Table 6. Complete Results of Sensitivity Analysis for PCB TEQ (Birds) with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM Dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
NPM Dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%
NPM lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**7.2%**
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-4.1%
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF consumption of sediment	0.0%	0.0%	4.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	1.0%	0.6%	1.2%	0.8%	0.7%	1.0%	0.7%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%	-0.1%	0.0%	0.0%	-0.1%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-0.6%	0.0%	-0.1%	0.0%	0.0%	0.0%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-3.0%	0.0%	-0.6%	0.0%	0.0%	-0.1%
EIC consumption of BIC	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	0.6%	0.0%	0.0%	0.2%
SCL consumption of sediment	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%	0.0%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	0.0%	-0.3%	-0.1%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-7.8%**	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.4%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.8%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.9%	0.0%	0.0%	0.0%
CAR consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.1%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%	0.0%
SMB consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.0%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.8%	0.0%

Table 6. Complete Results of Sensitivity Analysis for PCB TEQ (Birds) with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%
NPM consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.6%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.5%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**25.2%**

Table 7. Complete Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**21.5%**	**58.5%**	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Concentration of suspended solids	0.0%	0.0%	**10.5%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**-20.7%**	**-34.4%**	**-64.8%**	**-75.2%**	**-63.1%**	**-79.0%**	**-67.0%**	**-73.6%**	**-79.7%**	**-78.6%**
NLOM proportionality constant	0.0%	0.2%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
Sediment organic carbon	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant A	**-10.9%**	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	1.2%	1.7%	**18.3%**	**14.6%**	**18.3%**	**14.9%**	**17.1%**	**18.4%**	**18.2%**
XDOC	-0.3%	-0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	**-45.7%**	-0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
PHY moisture	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO lipids	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	-1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zoo weight	0.0%	-1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation rate	0.0%	0.0%	**13.8%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	2.0%	-0.8%	0.2%	0.0%	0.2%	0.0%	0.0%
BIC moisture	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC porewater ventilation rate	0.0%	0.0%	0.0%	0.5%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%

Table 7. Complete Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC weight	0.0%	0.0%	0.0%	0.4%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**9.9%**	0.0%	0.2%	0.0%	0.0%	0.3%
EIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of NLOM	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
LSS dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 7. Complete Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF consumption of sediment	0.0%	0.0%	**7.9%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	2.7%	0.5%	0.6%	0.3%	0.4%	0.3%	0.3%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of BIF	0.0%	0.0%	0.0%	-0.1%	-4.7%	-0.1%	-0.3%	-0.1%	-0.1%	-0.4%
EIC consumption of BIC	0.0%	-0.1%	0.0%	0.0%	2.5%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.1%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	0.0%	-0.1%	0.0%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.1%	0.0%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**5.5%**	0.0%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-8.5%**	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.9%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%
CAR consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.5%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%
SMB consumption of BIC	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 7. Complete Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM consumption of PHY	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of BIF	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 8. Complete Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**21.4%**	**58.0%**	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Concentration in sediment	0.0%	0.0%	**32.3%**	**41.6%**	**17.3%**	**15.4%**	**14.2%**	**15.8%**	**8.2%**	**10.1%**
Concentration of suspended solids	0.0%	0.0%	**7.3%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**-20.9%**	**-35.1%**	**-44.2%**	**-43.2%**	**-53.1%**	**-66.3%**	**-56.4%**	**-61.9%**	**-72.6%**	**-70.5%**
NLOM proportionality constant	0.0%	0.1%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
Sediment organic carbon	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant A	**-11.7%**	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	1.2%	1.4%	**10.7%**	**12.3%**	**15.9%**	**13.1%**	**14.4%**	**17.5%**	**16.8%**
XDOC	-0.5%	-1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	**-44.4%**	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of NLOM	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO lipids	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	-1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zoo weight	0.0%	-1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation rate	0.0%	0.0%	**8.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF weight	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	1.6%	-0.4%	0.3%	0.1%	0.4%	0.2%	0.1%
BIC moisture	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 8. Complete Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC porewater ventilation rate	0.0%	0.0%	0.0%	0.4%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
BIC weight	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**7.2%**	0.0%	0.1%	0.0%	0.0%	0.2%
EIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
SMB dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%
SMB dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 8. Complete Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF consumption of sediment	0.0%	0.0%	**5.5%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	1.3%	0.4%	0.4%	0.2%	0.3%	0.2%	0.3%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-3.1%	0.0%	-0.1%	0.0%	0.0%	-0.1%
EIC consumption of BIC	0.0%	0.0%	0.0%	0.0%	2.6%	0.0%	0.1%	0.0%	0.0%	0.1%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.1%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%
SCL consumption of BIF	-0.1%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	-0.1%	0.0%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.1%	0.0%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**5.2%**	0.0%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	**-7.6%**	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.8%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.4%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.8%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%
SMB consumption of BIC	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%

Table 8. Complete Results of Sensitivity Analysis for Dioxin TEQ (Mammals) with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
SMB consumption of SCL	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 9. Complete Results of Sensitivity Analysis for Total DDTs with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**36.8%**	**59.1%**	**10.7%**	0.7%	1.0%	1.3%	2.3%	1.7%	1.1%	0.8%
Concentration of suspended solids	0.0%	0.0%	3.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**6.5%**	**21.4%**	**6.9%**	**7.7%**	**7.4%**	**18.1%**	**11.8%**	**8.5%**	**17.7%**	**11.7%**
NLOM proportionality constant	0.0%	1.4%	1.1%	1.0%	**5.3%**	0.1%	0.2%	0.0%	-0.6%	-0.2%
Sediment organic carbon	0.0%	0.0%	-0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant A	-0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	0.4%	0.2%	3.0%	3.3%	**12.6%**	**14.7%**	**13.4%**	**18.3%**	**11.5%**
XDOC	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	-1.5%	-0.2%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	**-53.8%**	-4.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
ZOO lipids	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	**-11.2%**	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
Zoo weight	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of NLOM	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	**6.1%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	-3.1%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
BIF porewater ventilation rate	0.0%	0.0%	**63.8%**	0.0%	0.2%	0.0%	0.4%	0.2%	0.0%	0.1%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	**80.2%**	**5.6%**	**55.2%**	**26.1%**	**46.6%**	**39.6%**	**20.3%**

Table 9. Complete Results of Sensitivity Analysis for Total DDTs with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC moisture	0.0%	0.0%	0.0%	-1.8%	-0.2%	0.2%	-0.1%	0.0%	0.2%	0.1%
BIC porewater ventilation rate	0.0%	0.0%	0.0%	2.2%	1.1%	2.5%	1.8%	1.9%	2.1%	1.5%
BIC weight	0.0%	0.0%	0.0%	1.7%	0.8%	2.1%	1.2%	1.3%	1.6%	1.2%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**63.8%**	0.6%	**14.0%**	0.0%	0.9%	4.1%
EIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	4.4%	0.0%	0.8%	0.0%	0.0%	0.4%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.1%	0.0%	0.1%	0.0%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.5%	0.2%
SCL dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.7%	0.3%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%	0.6%	0.5%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%	0.0%	-0.1%	-0.1%
SCL porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.9%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%
CAR dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	**8.6%**	0.0%	0.0%
CAR moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-8.1%**	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%
SMB dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.3%	0.0%

Table 9. Complete Results of Sensitivity Analysis for Total DDTs with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.1%	0.0%
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.7%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
NPM dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
NPM dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
NPM lipids[a]	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.8%**
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-5.3%**
NPM weight	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF consumption of sediment	0.0%	0.0%	3.7%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	1.0%	0.4%	1.1%	0.8%	0.7%	0.9%	0.6%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-0.6%	0.0%	-0.1%	0.0%	0.0%	-0.1%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-2.2%	-0.1%	-0.7%	0.0%	-0.1%	-0.1%
EIC consumption of BIC	0.0%	0.0%	0.0%	0.0%	1.7%	0.0%	0.4%	0.0%	0.0%	0.2%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	0.0%	-0.3%	-0.1%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%	0.0%	-0.3%	-0.1%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.2%	0.0%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.9%	0.1%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	**-9.2%**	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.0%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.8%	0.0%	0.0%	0.0%
CAR consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%

Table 9. Complete Results of Sensitivity Analysis for Total DDTs with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.2%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	4.3%	0.0%	0.1%
SMB consumption of BIC	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.0%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.8%	0.0%
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%
NPM consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%
NPM consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.1%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**27.0%**

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 10. Complete Results of Sensitivity Analysis for Total DDTs with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**36.1%**	**58.5%**	**6.1%**	0.4%	0.3%	0.6%	1.1%	1.1%	0.5%	0.4%
Concentration in sediment	0.0%	0.0%	**35.8%**	**22.8%**	**15.2%**	**28.4%**	**26.3%**	**25.3%**	**24.2%**	**17.9%**
Concentration of suspended solids	0.0%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**6.3%**	**21.7%**	**5.0%**	**6.3%**	**7.0%**	**13.5%**	**9.9%**	**7.1%**	**13.6%**	**9.8%**
NLOM proportionality constant	0.0%	1.3%	0.7%	1.0%	4.9%	0.2%	0.2%	0.0%	-0.2%	0.0%
Sediment organic carbon	0.0%	0.0%	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant A	-0.7%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	0.4%	0.1%	2.5%	2.5%	**9.5%**	**11.4%**	**10.9%**	**14.0%**	**9.7%**
XDOC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	-1.6%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	**-54.3%**	-3.9%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	0.0%	-0.1%	0.0%
ZOO lipids	0.0%	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	**-11.4%**	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
Zoo weight	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	4.2%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	-2.2%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation rate	0.0%	0.0%	**40.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	**60.4%**	4.7%	**38.9%**	**20.2%**	**34.5%**	**30.3%**	**16.6%**
BIC moisture	0.0%	0.0%	0.0%	-1.8%	-0.1%	0.0%	0.0%	0.0%	0.1%	0.0%

Table 10. Complete Results of Sensitivity Analysis for Total DDTs with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC porewater ventilation rate	0.0%	0.0%	0.0%	1.9%	1.0%	2.0%	1.4%	1.4%	1.8%	1.3%
BIC weight	0.0%	0.0%	0.0%	1.2%	0.7%	1.4%	0.9%	1.1%	1.1%	0.8%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	-0.1%	0.0%	**51.8%**	0.2%	**8.5%**	0.0%	0.3%	2.7%
EIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	4.6%	0.0%	0.9%	0.0%	0.1%	0.3%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.1%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of lipids	0.0%	-0.1%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.6%	0.4%
SCL dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.3%	0.1%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.4%	0.3%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%	0.0%	-0.2%	-0.1%
SCL porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of lipids	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.3%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.8%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
CAR dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**6.1%**	0.0%	0.0%
CAR moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-5.5%**	0.0%	0.0%
CAR weight	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%
SMB dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	0.0%
SMB moisture[a]	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.7%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 10. Complete Results of Sensitivity Analysis for Total DDTs with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
NPM dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
NPM lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**8.5%**
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-4.1%
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF consumption of sediment	0.0%	0.0%	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	0.9%	0.4%	0.9%	0.7%	0.7%	0.8%	0.6%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	-0.1%	0.0%	0.0%	0.0%	-0.4%	0.0%	-0.2%	0.0%	0.0%	0.0%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-0.5%	0.0%	-0.1%	0.0%	0.0%	0.0%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-2.1%	0.0%	-0.3%	0.0%	0.0%	-0.1%
EIC consumption of BIC	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%	0.3%	0.0%	0.0%	0.1%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL consumption of ZOO	0.1%	0.1%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%	0.0%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	0.0%	-0.2%	0.0%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-5.9%**	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	-1.0%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	0.0%	0.0%	0.0%
CAR consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.7%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.4%	0.0%	0.0%
SMB consumption of BIC	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.4%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.8%	0.0%

Table 10. Complete Results of Sensitivity Analysis for Total DDTs with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%
NPM consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	-0.3%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	-0.5%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**23.1%**

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 11. Complete Results of Sensitivity Analysis for 4,4′-DDD with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**41.7%**	**68.6%**	**8.5%**	0.9%	1.8%	1.8%	3.6%	2.9%	1.5%	1.4%
Concentration of suspended solids	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**6.4%**	**17.7%**	**5.6%**	**7.7%**	**15.2%**	**27.4%**	**25.7%**	**18.4%**	**33.5%**	**23.6%**
NLOM proportionality constant	0.0%	1.1%	0.9%	1.5%	**8.7%**	1.0%	0.6%	0.1%	0.0%	0.1%
Sediment organic carbon	0.0%	0.0%	-0.5%	0.0%	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%
Uptake constant A	-0.1%	0.0%	-0.1%	0.0%	-0.1%	0.0%	-0.1%	0.0%	0.0%	0.0%
Uptake constant B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%
Water temperature	0.0%	0.1%	0.0%	1.6%	2.2%	**7.7%**	**9.8%**	**8.4%**	**11.9%**	**8.0%**
XDOC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	**-50.9%**	-1.8%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO lipids	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	**-9.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%
Zoo weight	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF lipids[a]	0.0%	0.0%	4.5%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	0.0%	-2.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation rate	0.0%	0.0%	**75.0%**	0.0%	0.3%	0.0%	0.5%	0.3%	0.0%	0.0%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	**77.1%**	**9.2%**	**49.1%**	**24.7%**	**36.4%**	**33.7%**	**19.4%**
BIC moisture	0.0%	0.0%	0.0%	-2.0%	-0.3%	0.0%	-0.1%	0.0%	0.0%	0.0%
BIC porewater ventilation rate	0.0%	0.0%	0.0%	**7.1%**	2.8%	**6.2%**	3.5%	4.4%	4.7%	3.2%

Table 11. Complete Results of Sensitivity Analysis for 4,4'-DDD with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC weight	0.0%	0.0%	0.0%	1.1%	0.7%	1.1%	0.9%	1.0%	0.8%	0.7%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**47.5%**	0.1%	4.5%	0.0%	0.2%	2.2%
EIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	3.8%	0.0%	0.5%	0.0%	0.0%	0.1%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.2%	0.0%	0.0%	0.1%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.2%	0.0%
SCL dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.2%	0.2%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	0.0%	0.0%	0.5%	0.2%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	-0.6%	0.0%	0.0%	-0.1%	0.0%
SCL porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.6%	0.2%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	-3.8%	0.0%	-0.1%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
CAR dietary absorption efficiency of lipids	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**11.1%**	0.0%	0.0%
CAR moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-10.3%**	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%
SMB dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.8%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NPM dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%

Table 11. Complete Results of Sensitivity Analysis for 4,4′-DDD with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
NPM lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**11.5%**
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-6.1%**
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%	0.1%
BIF consumption of sediment	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	0.0%	0.0%	0.2%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%
EIC consumption of sediment	0.0%	0.1%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	-0.1%	0.0%	0.0%	-0.1%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-0.8%	0.0%	-0.1%	0.0%	0.0%	0.0%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-1.6%	0.0%	-0.1%	0.0%	0.0%	-0.1%
EIC consumption of BIC	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.1%	0.0%	0.0%	0.1%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.0%	0.0%	0.1%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%	0.0%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	0.0%	-0.2%	-0.1%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.1%	0.0%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%	0.0%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-8.5%**	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.7%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.0%
CAR consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.7%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.4%	0.0%	0.0%
SMB consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.5%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.3%	0.0%
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%

Table 11. Complete Results of Sensitivity Analysis for 4,4′-DDD with Sediment Held Constant

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%
NPM consumption of BIF	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.2%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**19.3%**

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold values indicate contribution of 5% or more to differences in model predictions.

Table 12. Complete Results of Sensitivity Analysis for 4,4′-DDD with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
Concentration in filtered water	**40.4%**	**67.8%**	**7.5%**	0.7%	1.4%	1.3%	2.5%	2.0%	1.1%	1.0%
Concentration in sediment	0.0%	0.0%	**24.0%**	**20.1%**	**18.4%**	**23.7%**	**23.4%**	**20.8%**	**18.6%**	**14.8%**
Concentration of suspended solids	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K_{OW}	**7.6%**	**18.3%**	4.8%	**6.6%**	**12.7%**	**21.5%**	**20.6%**	**15.3%**	**27.7%**	**20.0%**
NLOM proportionality constant	0.0%	1.3%	0.5%	0.7%	**6.1%**	0.4%	0.2%	0.0%	0.0%	0.0%
Sediment organic carbon	0.0%	0.0%	-0.7%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%
Uptake constant A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Uptake constant B	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water temperature	0.0%	0.0%	0.0%	1.5%	2.2%	**6.5%**	**7.9%**	**6.7%**	**10.6%**	**7.3%**
XDOC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY growth rate constant	-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHY moisture	**-50.9%**	-1.5%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	0.0%	0.0%
ZOO dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO lipids	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ZOO moisture	0.0%	**-9.4%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zoo weight	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	-0.1%	0.0%	-0.1%	-0.1%	0.0%	-0.1%	-0.1%
BIF lipids[a]	0.0%	0.0%	3.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF moisture[a]	0.0%	-0.1%	-1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIF porewater ventilation rate	0.0%	0.0%	**55.2%**	0.0%	0.4%	0.0%	0.6%	0.3%	0.1%	0.1%
BIF weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of lipds	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC lipids	0.0%	0.0%	0.0%	**61.0%**	**7.5%**	**35.3%**	**17.8%**	**27.2%**	**26.1%**	**17.0%**
BIC moisture	0.0%	0.0%	0.0%	-1.6%	-0.1%	0.0%	-0.1%	0.0%	0.0%	0.0%

Table 12. Complete Results of Sensitivity Analysis for 4,4′-DDD with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
BIC porewater ventilation rate	0.0%	0.0%	0.0%	**5.7%**	3.1%	**5.1%**	3.6%	4.0%	4.0%	3.2%
BIC weight	0.0%	0.0%	0.0%	0.7%	0.2%	0.6%	0.4%	0.5%	0.5%	0.4%
EIC dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	**39.3%**	0.2%	4.2%	0.0%	0.2%	1.9%
EIC dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	2.9%	0.0%	0.4%	0.0%	0.0%	0.2%
EIC lipids[a]	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.1%	0.0%	0.0%	0.0%
EIC moisture[a]	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SCL dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.2%	0.0%
SCL dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.2%	0.1%
SCL lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	0.0%	0.0%	0.6%	0.3%
SCL moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%	0.0%	-0.3%	-0.1%
SCL porewater ventilation rate	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.3%	0.1%
SCL weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS dietary absorption efficiency of NLOM	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.6%	0.1%	0.1%	0.1%
LSS dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
LSS lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%	0.0%	0.0%	0.0%
LSS moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-2.1%	0.0%	0.0%	0.0%
LSS weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
CAR dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
CAR lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.3%**	0.0%	0.0%
CAR moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-8.5%**	0.0%	0.0%
CAR weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SMB dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
SMB dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%
SMB lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.1%	0.0%
SMB moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.4%	0.0%
SMB weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 12. Complete Results of Sensitivity Analysis for 4,4'-DDD with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
NPM dietary absorption efficiency of NLOM	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.7%
NPM dietary absorption efficiency of lipids	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
NPM lipids[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**9.2%**
NPM moisture[a]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-4.9%
NPM weight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
BIF consumption of sediment	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BIC consumption of sediment	0.0%	-0.1%	-0.1%	0.4%	0.1%	0.3%	0.1%	0.2%	0.2%	0.1%
EIC consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
EIC consumption of PHY	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%	0.0%	-0.1%	0.0%
EIC consumption of ZOO	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%	0.1%	0.0%	0.0%
EIC consumption of BIF	0.0%	0.0%	0.0%	0.0%	-1.3%	0.0%	-0.1%	0.0%	0.0%	-0.1%
EIC consumption of BIC	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.1%	-0.1%	0.0%	0.0%
SCL consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
SCL consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%	0.0%
SCL consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	-0.2%	0.0%
SCL consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%
SCL consumption of EIC	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
LSS consumption of sediment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%	0.1%	0.0%	0.0%
LSS consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**-6.5%**	0.0%	0.0%	0.0%
LSS consumption of ZOO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.2%	0.0%	0.0%	0.0%
LSS consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
LSS consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%
LSS consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%
CAR consumption of sediment	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%
CAR consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.6%	0.0%	0.0%
CAR consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CAR consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%	0.0%
SMB consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.9%	0.0%
SMB consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.8%	0.0%

Table 12. Complete Results of Sensitivity Analysis for 4,4′-DDD with Sediment Allowed to Vary

Parameter	PHY	ZOO	BIF	BIC	EIC	SCL	LSS	CAR	SMB	NPM
SMB consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
NPM consumption of PHY	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
NPM consumption of BIF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%
NPM consumption of BIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%
NPM consumption of EIC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.5%
NPM consumption of SCL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**16.4%**

[a] This parameter was defined to be correlated with another parameter (see Attachment E3). Therefore, sensitivity information for this parameter may be overstated and should be interpreted with caution.

Bold *values indicate contribution of 5% or more to differences in model predictions.*

Appendix F

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PORTLAND HARBOR RI/FS

COMPREHENSIVE ROUND 2 SITE CHARACTERIZATION SUMMARY AND DATA GAPS ANALYSIS REPORT

APPENDIX F
ROUND 2 HUMAN HEALTH RISK ASSESSMENT

February 21, 2007

LWG
LOWER WILLAMETTE GROUP

PORTLAND HARBOR RI/FS

COMPREHENSIVE ROUND 2 SITE CHARACTERIZATION SUMMARY AND DATA GAPS REPORT

APPENDIX F:
ROUND 2 HUMAN HEALTH RISK ASSESSMENT

Prepared for:
The Lower Willamette Group

Prepared by:
Kennedy/Jenks Consultants

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ACG	analytical concentration goal
ALM	Adult Lead Methodology
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
BCF	bioconcentration factor
Cal EPA	California Environmental Protection Agency
CDC	Centers for Disease Control
CDI	chronic daily intake
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
COC	chemical of concern
COI	chemical of interest
COPC	chemical of potential concern
CRITFC	Columbia River Inter-tribal Fish Commission
CSM	conceptual site model
CT	central tendency
DA_{event}	absorbed dose per event
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
delta-HCH	delta-hexachlorocyclohexane
DEQ	Oregon Department of Environmental Quality
DL	detection limit
DQO	data quality objective
E	east
EPA	United States Environmental Protection Agency
EPC	exposure point concentration
EqP	equilibrium partitioning
g/day	grams per day
GI	gastrointestinal
HEAST	Health Effects Assessment Summary Table
HHRA	human health risk assessment
HI	hazard index
HQ	hazard quotient
iAOPC	initial area of potential concern
iCOC	initial chemical of concern
IEUBK	Integrated Exposure Uptake Biokinetic
iPRG	initial preliminary remediation goal
IRIS	Integrated Risk Information System
ISA	initial study area
LADI	lifetime average daily intake
L/kg	liter per kilogram

LWG	Lower Willamette Group
LWR	Lower Willamette River
µg/day	microgram per day
µg/dl	microgram per deciliter
µg/kg	microgram per kilogram
µg/l	microgram per liter
MCL	Maximum Concentration Level
mg/kg	milligram per kilogram
mL/day	milliliter per day
MRL	method reporting limit
ODFW	Oregon Department of Fish and Wildlife
ODHS	Oregon Department of Human Services
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PPRTV	Provisional Peer Reviewed Toxicity Value
PRG	preliminary remediation goal
RfD	reference dose
RI/FS	remedial investigation/feasibility study
RM	river mile
RME	reasonable maximum exposure
SCRA	site characterization and risk assessment
SF	slope factor
STSC	Superfund Health Risk Technical Support Center
SVOC	semivolatile organic compound
TCDD	tetrachlorodibenzo-p-dioxin
TEF	toxic equivalency factor
TEQ	toxic equivalent
TM	Technical Memo
TZW	transition zone water
UCL	upper confidence limit
UCL/max	95UCL or maximum
VOC	volatile organic compound
W	west
WHO	World Health Organization
XAD	XAD-2 Infiltrex™ 300 system

1.0 INTRODUCTION

This Round 2 Human Health Risk Evaluation (HHRA) presents the Lower Willamette Group's (LWG's) initial evaluation of risks to human health for the Portland Harbor Superfund Site (Site) in Portland, Oregon. This Round 2 HHRA is intended to present preliminary human health risk estimates based on the data that are available at this time and to identify any data needs required to complete the baseline HHRA.

The remedial investigation/feasibility study (RI/FS) being completed for the Site is designed to be an iterative process that addresses the relationships among the factors that may affect chemical distribution, risk estimates, and remedy selection. Currently, two rounds of field investigations have been completed as part of the RI/FS. Round 1 was conducted in 2002 and focused primarily on chemical concentrations in fish and shellfish tissue and in beach sediments. Round 2 was conducted in 2004 and 2005 and focused on chemical concentrations in sediment core samples, in-water surface sediments, surface water, transition zone water, and additional shellfish tissue and beach sediment. These Round 1 and Round 2 sampling efforts, while focused on river mile (RM) 3.5 to 9.2, the Administrative Order on Consent-defined initial study area (ISA), extended well beyond the ISA to RM 2 downstream and to RM 11 upstream. This 9-mile portion of Portland Harbor, RM 2 to 11, is referred to as the Study Area. Because the Site has not yet been defined, this Round 2 HHRA focused on the Study Area.

This Round 2 HHRA is being conducted as part of the Comprehensive Round 2 Site Characterization Summary and Data Gaps Report (Round 2 Report) to begin focusing on those chemicals and exposure pathways that are predicted to have the highest contribution to the estimated risk at the Site and for purposes of identifying the RI/FS data needs for Round 3. A baseline HHRA will be conducted after the completion of Round 3 field investigations. The results of the baseline HHRA will be used in developing remedial action objectives and to assist in risk management decisions.

1.1 OBJECTIVES

The general objective of an HHRA is to characterize the potential risks to human health that may be posed by chemicals present in or entering into environmental media (i.e., water, air, or soil) or bioaccumulating in the food chain. The overall objective of this Round 2 HHRA for the Site is to determine whether exposure to chemicals in sediment, surface water, or biota results in unacceptable risks to human health. To achieve the overall objective, the following are specific objectives of this Round 2 HHRA:

- Identify and select chemicals of potential concern (COPCs) for human health

- Identify potential exposure pathways to populations who may contact COPCs
- Characterize potentially exposed populations and estimate the extent of their exposure to COPCs
- Quantitatively characterize the noncarcinogenic and carcinogenic risks to the populations resulting from potential exposure to COPCs and identify initial chemicals of concern (iCOCs) that will be considered in developing initial preliminary remediation goals (iPRGs).
- Characterize uncertainties associated with the initial risk assessment and identify data needs critical for completion of baseline HHRA.

For those chemicals with unacceptable preliminary risk estimates, iPRGs were developed. A discussion of the development of iPRGs is presented in Section 10 of the Round 2 Report.

1.2 APPROACH

This Round 2 HHRA follows the approach that was documented in the Programmatic Work Plan (Integral et al. 2004) and subsequent interim deliverables. It also incorporates the results of numerous discussions on appropriate risk assessment techniques for the Site among interested parties: United States Environmental Protection Agency (EPA), Oregon Department of Environmental Quality (DEQ), Oregon Department of Human Services (ODHS), and Native American Tribes. The approach of this Round 2 HHRA is based on EPA (1986, 1989, 1991, 2001a, 2004a) and Region 10 EPA (2000a) guidance. The approach is also consistent with DEQ guidance for HHRA (DEQ 2000a).

1.3 ORGANIZATION

In accordance with guidance from EPA (1989), which is consistent with DEQ guidance (2000a), the Round 2 HHRA incorporates the four steps of the baseline risk assessment process: data collection and evaluation, exposure assessment, toxicity assessment, and risk characterization, which includes an uncertainty assessment.

This Round 2 HHRA is organized as follows:

- Section 2, Data Evaluation – This section evaluates the available data for the Study Area and identifies the COPCs for further evaluation in the Round 2 HHRA.
- Section 3, Exposure Analysis – This section presents potentially complete routes of exposure and potential receptor populations

for further evaluation in the Round 2 HHRA, which are summarized in the conceptual site model (CSM).

- Section 4, Toxicity Analysis – This section evaluates the potential hazard and toxicity of the COPCs selected for quantitative evaluation in this Round 2 HHRA.
- Section 5, Risk Characterization – This section presents the cancer risks and noncancer hazards and describes how potential health hazards and risks were characterized in this Round 2 HHRA.
- Section 6, Screening of Surface and Transition Zone Water Data – This section presents an evaluation of surface water and transition zone water (TZW) with respect to human health based screening levels that were specified by EPA.
- Section 7, Uncertainty Analysis – This section discusses the uncertainties that are inherent in performing an HHRA and evaluates potential data needs for completion of the baseline HHRA
- Section 8, Summary and Conclusions – This section summarizes the findings of this Round 2 HHRA and identifies iCOCs.
- Section 9, References – This section lists the references used in this Round 2 HHRA.

2.0 DATA EVALUATION

Data collection and evaluation included the gathering and analysis of data relevant to human exposures and the identification of those chemicals that are the focus of this Round 2 HHRA. Initial data needs for the Round 2 HHRA were identified through the data quality objective (DQO) process described in Section 7 of the Programmatic Work Plan (Integral et al. 2004).

This section presents the data that were used in this Round 2 HHRA and the results of the selection of COPCs in sediment, water, and tissue. The LWG sampling events and non-LWG sampling events included in the site characterization and risk assessment (SCRA) dataset are described in detail in Section 2.0 of the Round 2 Report. The Round 2 HHRA dataset used in this risk analysis and described in this section is a subset of the sampling events that comprise the SCRA dataset as of September 2006.

2.1 AVAILABLE DATA

The dataset includes only those matrices relevant for direct human heath exposure pathways that were quantitatively evaluated in the Round 2 HHRA: surface sediment (0 to 30.5 centimeter (cm) in depth), clam and crayfish tissue, fish tissue, surface water and seep water. TZW data were compared with screening levels, as presented in Section 6, but not included in the risk characterization because there are no complete direct exposure pathways for humans. Other matrices included in the SCRA dataset (e.g., subsurface sediment) were not evaluated in the Round 2 HHRA because they were not relevant to the exposure pathways evaluated (see Section 3).. The Round 2 HHRA dataset is summarized, by matrix, in Table 2-1 and briefly described in the following subsections. Detailed information on these sampling events is presented in Section 2.0 of the Round 2 Report.

2.1.1 Beach Sediment

Areas where potential exposure to beach sediment could occur were identified and designated as human use areas in the Programmatic Work Plan. Beach composite sediment samples were collected from designated human use areas within the ISA during Round 1. Additional human use areas within the Study Area but downstream of the ISA were sampled during Round 2 as part of the sampling of shorebird habitat. All of the Round 1 beach samples and the six Round 2 beach samples that were collected from human use areas located downstream of the ISA were included in the Round 2 HHRA dataset. The designated potential human use areas and associated beach sediment samples are shown in Figure 2-1. Table 2-2 presents a summary of the beach composite sediment samples included in the Round 2 HHRA dataset.

2.1.2 In-Water Sediment

In-water surface sediment chemistry data in the Round 2 HHRA dataset includes LWG collected data (from Rounds 1 and 2) and non-LWG collected data. Table 2-2 presents a summary of the surface sediment samples included in the Round 2 HHRA dataset. All non-LWG data included in the SCRA database (see Section 2.0 of the Round 2 Report) met the data quality requirements for risk evaluation (Category 1/QA2), as agreed to between LWG, EPA, and EPA's partners in the Programmatic Work Plan (Integral et al. 2004).

All in-water surface sediment data included in the Round 2 HHRA dataset were collected from the top 30.5 cm in depth, outside of the navigation channel of the river, and located throughout the entire length of the Study Area (RM 2 to RM 11)[1]. Surface sediment samples that were collected from areas that have since been dredged were not included in the SCRA and HHRA datasets because these samples are no longer representative of the current conditions in the Study Area.

2.1.3 Surface Water

Surface water data were collected by the LWG during Round 2. All Round 2 surface water data were included in the Round 2 HHRA dataset. Surface water sampling was performed in three separate events in 2004 and 2005 to capture the seasonal water flow levels on the Lower Willamette River (LWR). Table 2-3 presents a summary of the surface water samples included in the Round 2 HHRA dataset.

Twenty-three surface water locations were sampled within the Study Area (between RM 2.0 and RM 11) during each sampling event. Data from all three sampling events were included in the Round 2 HHRA dataset. Surface water samples were collected from 14 amphibian habitat locations, 3 beach locations, 3 human-use areas, and 3 transect locations (at RM 4.0, RM 6.3, and RM 11). Surface water samples were collected with either a peristaltic pump or an XAD-2 Infiltrex™ 300 system (XAD). Several types of surface water samples were collected, including single-point near-bottom samples, single-point water column samples, and cross-sectional river transect water column samples.

2.1.4 Seep Water

A seep reconnaissance survey was conducted during Round 1 to document readily identifiable groundwater seeps along approximately 17 miles of riverbank from RM 2 to 10.5 (GSI 2003). Twelve potential seeps were observed at or near a designated human use beach area. Of these, only three sites were identified where it was likely for upland chemicals of interest (COIs) to reach seeps or other surface expressions of groundwater discharging to human use beaches (GSI 2003): City of Portland storm sewer Outfall 22B, Willbridge, and McCormick and Baxter (at Willamette Cove).

[1] The Study Area is defined as RM 2 to 11. For purposes of the Round 2 HHRA dataset, samples collected between RM 1.91 and 11.3 were considered part of the Study Area.

Of the three potential seep areas, only the Outfall 22B discharge was evaluated in this Round 2 HHRA. The beach where Outfall 22B discharges is designated a transient use area, so exposure to the groundwater seep in that beach by transients is considered a potentially complete pathway. The seep identified at Willbridge is in a beach restricted to industrial use, and exposure to groundwater seeps is considered an incomplete pathway for workers. The seep identified during the seep survey (GSI 2003) in Willamette Cove, downgradient of the McCormick and Baxter Superfund Site, was capped during remedial activities in 2004.

The storm water pipeline that discharges at Outfall 22B provides a conduit for surface discharge of groundwater containing COIs that infiltrates into the pipe upland of the beach. Samples of the discharge at Outfall 22B have periodically been collected for analysis. The data from Outfall 22B met the data quality requirements for risk evaluation (Category 1/QA2), and the results of this sampling were included in the SCRA database. Table 2-3 presents a summary of the samples from Outfall 22B that were included in the Round 2 HHRA dataset.

2.1.5 Fish Tissue

Target fish species for human consumption were identified in the Programmatic Work Plan (Integral et al. 2004). Resident fish samples were collected during Round 1 by the LWG. In addition, sturgeon, adult spring chinook, and adult Pacific lamprey were collected in the summer of 2003 through a cooperative effort of the ODHS, Agency for Toxic Substances and Disease Registry (ATSDR), Oregon Department of Fish and Wildlife (ODFW), the City of Portland and EPA Region 10. (This sampling effort is referred to as the "ODHS Study" in the rest of this Round 2 HHRA). Table 2-4 presents a summary of the fish tissue samples included in the Round 2 HHRA dataset.

2.1.5.1 Resident Fish Tissue

Smallmouth bass, black crappie, common carp, and brown bullhead were the resident fish species collected and analyzed to support the Round 2 HHRA. The sampling design was based on the reported home ranges of the target fish, so the sampling approach differed based on species. The tissue compositing scheme for each sample was reviewed and approved by EPA in November and December 2002 prior to laboratory analysis.

For smallmouth bass, samples were collected from eight locations, each corresponding to approximately one river mile. Smallmouth bass were collected and composited based on river mile locations due to their small home range relative to the other fish collected during Round 1. Three whole body replicate composite samples were collected at three of the eight river mile locations. At each of the remaining five river mile locations, one whole body composite sample and one fillet composite sample was collected.

For black crappie, carp, and brown bullhead, samples were collected and composited for two fishing zones, each approximately three river miles in length. Three whole body and three fillet replicate composite samples were collected at each of the two fishing zones for carp and brown bullhead. Two whole body and two fillet replicate composite samples were collected within each of the fishing zones for black crappie.

2.1.5.2 Salmon, Lamprey, and Sturgeon

The tissue data collected during the ODHS Study were the only non-LWG fish tissue of acceptable data quality for risk evaluation (Category 1/QA2). Although these data were not collected as part of the RI, they were evaluated by the LWG and used in this Round 2 HHRA.

The salmon samples were collected at the Clackamas fish hatchery. Whole body, fillet with skin, and fillet without skin composite samples were analyzed. Each composite sample included three individual fish. Five whole body composite samples, including one split, and three fillet with skin and three fillet without skin composite samples were analyzed. The fillet without skin composite samples were only analyzed for dioxin, furan, and polychlorinated biphenyl (PCB) congeners and mercury.

The lamprey samples were collected at the Willamette Falls. Only whole body composite samples were analyzed. Each composite sample included 30 individual fish. Four whole body composite samples were analyzed.

The sturgeon samples were collected between RM 3.5 and 9.2. Only fillet without skin samples were analyzed. Each sample was an individual fish. Six fillet samples, including one split, were analyzed.

2.1.6 Shellfish Tissue

Shellfish tissue in the Round 2 HHRA dataset included field-collected samples for crayfish and clam (*Corbicula* sp.) tissue. Crayfish samples were collected during Round 1 and clam samples were collected during Rounds 1 and 2. Although data from laboratory bioaccumulation samples were also available from Round 2, these data were not used because field-collected tissue samples provide for a more direct evaluation of potential human exposure than laboratory bioaccumulation samples. No field-collected non-LWG shellfish tissue data of acceptable data quality for risk evaluation (Category 1/QA2) were identified.

For crayfish, samples were collected from 24 stations during Round 1. The crayfish stations were selected based on habitat areas. Crayfish were collected and composited from individual stations commensurate with their limited home ranges. Only whole body composite samples were collected for crayfish. Two replicate composite samples were collected at three of the 24 stations. At each of the remaining stations, a single composite sample was collected.

For clams, samples were collected from 3 stations during Round 1 and 33 stations during Round 2. The clam stations were selected based on habitat areas and biomass availability. Clams were collected and composited from individual stations commensurate with their limited home ranges. A single composite sample was collected at each station. Depuration is a common method for cleansing shellfish that is typically done prior to human consumption to eliminate the sediment present in the gastrointestinal (GI) tract of the shellfish. The field-collected clams were not depurated prior to analysis, and the data are therefore biased towards over predicting human health risks from this exposure pathway.

2.1.7 Transition Zone Water

TZW data were collected by the LWG during Round 2. All shallow (0 to 38 cm) TZW data were included in the Round 2 HHRA dataset for purposes of a screening evaluation. TZW sampling was performed between October 3 and December 2, 2005, to capture the relatively higher groundwater discharge to the LWR. Table 2-5 presents a summary of the shallow TZW samples included in the Round 2 HHRA dataset.

The TZW sampling locations were selected to focus primarily on the zones of possible groundwater plume discharge, based on the Round 2 groundwater pathway assessment pilot study discharge mapping effort conducted from August 1 to September 9, 2005 (Integral 2006). Nine high-priority Category A sites, defined as sites with a confirmed or reasonable likelihood for discharge of upland groundwater COIs to Portland Harbor, were selected as TZW locations and sampled within the Study Area. TZW samples were collected from the following nine sites: Kinder Morgan Linnton Terminal, ARCO Terminal 22T, ExxonMobil Oil Terminal, Gasco, Siltronic, Rhone-Poulenc, Arkema (acid plant and chlorate plant areas), Willbridge Bulk Fuels Terminal, and Gunderson. TZW samples were collected with either a Trident® probe or small-volume peeper.

2.2 USE OF DATA

Prior to using the data in the Round 2 HHRA, data reduction was conducted consistent with the *Guidelines for Data Reporting, Data Averaging, and Treatment of Non-Detected Values for the Round 1 Database* (Kennedy/Jenks Consultants et al. 2004) and the *Exposure Point Concentration Calculation Approach and Summary of Exposure Factors* (Exposure Point Concentration (EPC) Approach and Exposure Factors Technical Memo (TM)) (Kennedy/Jenks Consultants 2006).

2.2.1 XAD Surface Water Samples

For the surface water samples collected using the high volume XAD sampling method, a concentration is reported for both the filter and XAD-2 resin beads for

each chemical. The following rules were used to combine the two concentrations measured in either the filter or XAD-2 resin beads:

- If a chemical was detected in both the filter and the XAD-2 resin beads, the detected concentrations were summed and the sum was used.
- If a chemical was detected in either the filter or the XAD-2 resin beads but not in the other portion of the sample, only the detected concentration was used.
- If a chemical was not detected in the filter and the XAD-2 resin beads, one-half of the highest detection limit reported for either the filter or the XAD-2 resin beads was used.

2.2.2 Non-Detects

Chemicals that were not detected at concentrations above the detection limit were designated as non-detects. Non-detects may represent concentrations that are zero or may represent concentrations greater than zero, but less than the detection limit. For use of the Round 2 HHRA dataset, proxy values were assigned to non-detects in accordance with the following rules, which were previously presented in Appendix C of the Programmatic Work Plan and the EPC Approach and Exposure Factors TM:

- If a chemical was not detected in any sample for a given medium in a given exposure area, it was assumed to not be present.
- If a chemical was detected at least once in samples for a given medium and exposure area, it was assumed to potentially be present. In such cases, one-half the detection limit was used as a proxy value for that chemical.

For surface water and sediment, the entire Study Area was considered the exposure area for purposes of applying the non-detect rules. As a result, if a chemical was detected in a given medium anywhere within the Study Area, it was assumed to potentially be present in that medium when designated a non-detect.

2.2.3 Summed Concentrations

Some toxicity values used in the Round 2 HHRA are based on exposure to chemical mixtures that are congeners, isomers, or closely related degradation products of a parent compound and not to individual chemicals. As a result, risks were evaluated in the Round 2 HHRA for the combined exposure to the chemicals and not on an individual chemical basis. The concentrations of the individual isomers or congeners that comprise the mixtures were summed according to the following rules:

- If an individual chemical was detected in the sample, the detected concentration was used for that chemical in the sum.

- If an individual chemical was not detected in the sample but was determined to potentially be present using the rules for non-detects, one-half the detection limit was used for that chemical in the sum.

- If an individual chemical was not detected in the sample and was determined not to be present using the rules for non-detects, zero was used for that chemical in the sum.

Summed concentrations were calculated for the following chemicals:

- Total dichlorodiphenyldichloroethane (DDD). Total DDD was calculated by summing 2,4'-DDD and 4,4'-DDD.

- Total dichlorodiphenyldichloroethylene (DDE). Total DDE was calculated by summing 2,4'-DDE and 4,4'-DDE.

- Total dichlorodiphenyltrichloroethane (DDT). Total DDT was calculated by summing 2,4'-DDT and 4,4'-DDT.

- Total chlordane. Total chlordane was calculated by summing alpha-chlordane, trans-chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane.

- Total endosulfan. Total endosulfan was calculated by summing alpha-endosulfan, beta-endosulfan and endosulfan sulfate.

- Total PCBs. Total PCBs were calculated for both Aroclors and congeners by summing the individual Aroclors or congeners.

- Adjusted total PCBs. Adjusted total PCBs were calculated by subtracting the total coplanar PCB concentration from the total PCB congener concentration.

- Total dioxin toxic equivalent (TEQ). Total dioxin TEQ was calculated by multiplying dioxin and furan congeners by their Toxic Equivalency Factors (TEFs) and summing the resulting concentrations. The World Health Organization (WHO) TEFs, which are shown in Table 2-6, were used to calculate the total dioxin TEQ.

- Total PCB TEQ. Total PCB TEQ was calculated by multiplying coplanar PCB congeners by their TEFs and summing the resulting concentrations. The WHO TEFs, which are shown in Table 2-6, were used to calculate the total PCB TEQ.

2.3 CHEMICAL SCREENING CRITERIA

EPA guidance (1989) recommends considering criteria to limit the number of chemicals that are included in a quantitative risk assessment while also ensuring

that all chemicals that may contribute significantly to the overall risk are addressed. According to EPA guidance, the screening procedure is used to focus quantitative risk assessment efforts on chemicals that could be of concern under health-protective exposure assumptions. For purposes of the Round 2 HHRA, the only screening criterion used to select COPCs was a comparison with risk-based concentrations, as described in the Programmatic Work Plan (Integral et al. 2004). The risk-based concentrations used to select COPCs are described for the respective media.

2.3.1 Sediment

Sediment data were quantitatively evaluated in the Round 2 HHRA for direct exposure scenarios. As a health-protective initial approach, the current EPA Region 9 preliminary remediation goals (PRGs) for soil (EPA 2004b) were used as the basis for screening values for sediment. For chemicals that do not have Region 9 PRGs, Region 9 PRGs for surrogate chemicals with similar chemical structures were used if available (e.g., naphthalene for 1- and 2-methylnaphthalene and pyrene for phenanthrene). For carcinogenic chemicals, the Region 9 PRGs were used as the screening values. For noncarcinogenic chemicals, the Region 9 PRGs were divided by 10 to account for potential cumulative effects from multiple chemicals, and these modified PRGs were used as the screening values, as required by EPA Region 10. For chemicals that exhibit both carcinogenic and noncarcinogenic effects, the more conservative screening value was used for selecting COPCs.

Region 9 PRGs have been developed for both residential and industrial exposure scenarios for soil. Residential soil Region 9 PRGs are based on exposure assumptions of 350 days per year. For cancer endpoints, the residential Region 9 PRGs are calculated using an age-adjusted soil ingestion factor that takes into account the difference in daily soil ingestion rates, body weight, and exposure duration for children from 1 to 6 years old and others from 7 to 31 years old (total exposure over 30 years). For noncancer endpoints, the residential Region 9 PRGs are calculated using exposure factors for children from 1 to 6 years old and chronic toxicity criteria. Industrial soil Region 9 PRGs are based on exposure assumptions of 250 days per year for 25 years. Both residential and industrial Region 9 PRGs are based on a target cancer risk of 1×10^{-6} for carcinogenic chemicals or a hazard quotient of 1 for noncarcinogenic chemicals. Dividing Region 9 PRGs for noncarcinogenic chemicals by 10 is equivalent to using a hazard quotient of 0.1. Because the potential exposure to sediments that may occur is anticipated to be less than the exposure that was assumed to occur with soil in developing the Region 9 PRGs, the soil PRGs represent conservative screening values for protection of human health. Because uses of Portland Harbor include both recreational and industrial activities, COPCs were selected using both residential and industrial Region 9 PRGs, as described in the Programmatic Work Plan.

For beach sediment, residential soil PRGs were used to select COPCs in areas where exposures could occur during recreational, transient, or fishing activities. In areas where occupational exposures could occur, COPCs were selected using industrial soil PRGs. The designated potential uses for beaches in the Study Area are presented in Figure 2-1.

The extent of direct contact with in-water sediment that could occur under site-specific exposure scenarios would be significantly less than with upland soil or beach sediment. Therefore, COPCs for in-water sediment were identified using only the EPA Region 9 industrial soil PRGs.

2.3.2 Surface Water and Groundwater Seep

Surface water and groundwater seep data were quantitatively evaluated in the Round 2 HHRA for direct exposure scenarios. As a health-protective initial approach, EPA Region 9 PRGs for tap water (EPA 2004b) were used as the screening values for surface water and groundwater seep to select COPCs for direct exposure scenarios. For chemicals that do not have Region 9 PRGs, Region 9 PRGs for surrogate chemicals with similar chemical structures were used if available (e.g., naphthalene for 1- and 2-methylnaphthalene and pyrene for phenanthrene). For carcinogenic chemicals, the Region 9 PRGs were used as the screening values. For noncarcinogenic chemicals, the Region 9 PRG was divided by 10 to account for potential cumulative effects from multiple chemicals, and this modified PRG was used as the screening value, as required by EPA Region 10.

Tap water Region 9 PRGs are based on domestic use of water, including ingestion, and on a target cancer risk of 1×10^{-6} for carcinogenic chemicals or a hazard quotient of 1 for noncarcinogenic chemicals. Dividing Region 9 PRGs for noncarcinogenic chemicals by 10 is equivalent to using a hazard quotient of 0.1. Because surface water and the groundwater seep at Outfall 22B are not currently used as a domestic water source, nor are there future plans for domestic water use at the Site, the Region 9 PRGs represent conservative screening values.

2.3.3 Tissue

EPA Region 10 has not accepted any criteria for screening tissue from Portland Harbor, therefore, risk-based concentrations were not used for screening the tissue data.

2.4 IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN

COPCs for human health were selected according to the approach described in the Programmatic Work Plan (Integral et al. 2004) and were quantitatively evaluated in this Round 2 HHRA. The process used to select the COPCs for quantitative evaluation in this Round 2 HHRA is described in the following subsections.

Also, surface water and transition zone water data were compared with additional screening criteria but were not quantitatively evaluated in this Round 2 HHRA for the scenarios associated with the screening criteria. The screening evaluation of surface water and transition zone water is described in Section 6.

2.4.1 Sediment

Humans can be exposed to both beach sediments and in-water sediment. Because the exposure scenarios for beach versus in-water sediment are different, COPCs were selected for both beach and in-water sediment exposures.

2.4.1.1 Beach Sediment

Beach sediment data were evaluated in the Round 2 HHRA for potential risks to human health through direct contact. The selection of COPCs for beach sediment evaluated sediment data from designated potential human use areas where direct contact with human receptors could occur (only reasonably accessible beach sediments, such as those with access from contiguous upland areas or by boat). The locations of the beach sediment data evaluated in the Round 2 HHRA are shown in Map 2-1.

For chemicals that were detected in beach sediment, the detected concentrations were compared to risk-based screening levels described in Section 2.3.1. The maximum detected concentration of each chemical from all samples collected in recreational, transient, or fishing beach areas was compared to the screening level based on the residential soil PRG. The maximum detected concentration of each chemical from all samples collected in industrial beach areas was compared to the screening level based on the industrial soil PRG. If the maximum detected concentration of a chemical was greater than the screening level, that chemical was selected as a COPC for beach sediment. The chemicals selected as COPCs for beach sediment and the rationale for selection are presented in Tables 2-7 and 2-8.

Chemicals selected as COPCs for beach sediment were quantitatively evaluated in this Round 2 HHRA. Chemicals with maximum detected concentrations less than the screening values were not selected as COPCs and were not evaluated further in this Round 2 HHRA for direct contact with beach sediment.

2.4.1.2 In-Water Sediment

In-water sediment data were evaluated in the Round 2 HHRA for potential risks to human health through direct contact and not based on the potential for bioaccumulation. The selection of COPCs for in-water sediment evaluated all surface sediment data between RM 2 and 11 that were not beach composite samples.

For chemicals that were detected in in-water sediment, the maximum detected concentration of each chemical from all surface sediment samples was compared to the screening level based on the industrial soil PRG, as described in Section 2.3.1. If the maximum detected concentration of a chemical was greater than the screening

level, that chemical was selected as a COPC for in-water sediment. The chemicals selected as COPCs for in-water sediment and the rationale for selection are presented in Table 2-9.

Chemicals selected as COPCs for in-water sediment were quantitatively evaluated in this Round 2 HHRA. Chemicals with maximum detected concentrations less than the PRGs were not selected as COPCs and were not evaluated further in this Round 2 HHRA for direct contact with in-water sediment.

2.4.2 Surface Water

Direct contact with surface water was evaluated in the Round 2 HHRA for potential risks to human health. The selection of COPCs for quantitative evaluation in the Round 2 HHRA in surface water was based only on potential for direct human contact and not based on the potential for bioaccumulation. Surface water data gathered during the RI were used to identify the COPCs in surface water for quantitative evaluation in the Round 2 HHRA.

For chemicals that were detected in surface water, the detected concentrations were compared to screening values based on the tap water PRGs. PCBs were analyzed as Aroclors in samples collected using a peristaltic pump and as congeners in high-volume samples collected using the XAD sampling method. The detection limits for the peristaltic pump samples were higher than the high-volume samples, so the results for PCBs from the high-volume samples were used. In the high-volume samples, PCB Aroclor concentrations were estimated using the PCB congener data. As a result, only PCB congener data were used in determining PCB COPCs. If the maximum detected concentration of a chemical in surface water was greater than the screening value, that chemical was selected as a COPC for surface water and was quantitatively evaluated in the Round 2 HHRA. Chemicals that were detected only at concentrations less than the PRGs were not selected as COPCs for quantitative evaluation. The chemicals selected as COPCs for surface water and the rationale for selection are presented in
Table 2-10.

2.4.3 Groundwater Seep

Direct contact with the groundwater seep at Outfall 22B was evaluated in the Round 2 HHRA for potential risks to human health. The selection of COPCs for quantitative evaluation in the Round 2 HHRA in the groundwater seep was based only on potential for direct human contact and not based on the potential for bioaccumulation.

For chemicals that were detected in the groundwater seep, the detected concentrations were compared to screening values based on the tap water PRGs. If the maximum detected concentration of a chemical in the groundwater seep was greater than the screening value, that chemical was selected as a COPC for the groundwater seep and was quantitatively evaluated in the Round 2 HHRA. Chemicals that were detected only at concentrations less than the PRGs were not selected as COPCs for

quantitative evaluation. The chemicals selected as COPCs for the groundwater seep and the rationale for selection are presented in Table 2-11.

2.4.4 Fish and Shellfish Tissue

Fish and shellfish tissue were evaluated in the baseline HHRA for potential risks to human health through ingestion. Because EPA Region 10 has not accepted any criteria for screening tissue from Portland Harbor, all chemicals detected in fish and shellfish tissue in the Round 2 HHRA dataset were considered to be COPCs. The chemicals detected in each individual species were selected as COPCs only for ingestion of that species. For the non-tribal and Native American multi-species diet scenarios (discussed in Section 3), analytes detected in any of the target resident fish species (see Section 2.1.5.1) were selected as COPCs. Since no screening took place to determine COPCs for tissue, the tissue COPCs are presented in the exposure point concentration summary tables, discussed in Section 3.

3.0 EXPOSURE ASSESSMENT

The objectives of the exposure assessment are to identify potential exposure pathways to individuals who may come in contact with COPCs at the Study Area, to characterize potentially exposed populations, and to estimate the extent of exposure.

The exposure assessment in this Round 2 HHRA followed EPA guidance and incorporated the reasonable maximum exposure (RME) methods recommended by EPA. As stated in EPA guidance (EPA 1989), the RME is a conservative exposure level that is still within the range of possible exposures. The exposure assessment also used central tendency (CT) values, which better represent average exposures. According to EPA (1989), an exposure assessment includes four primary tasks:

- Identify potentially exposed human populations that may come in contact with the COPC. This requires knowledge of (and/or making reasonable assumptions regarding) both current and future populations.
- Identify relevant exposure pathways for human populations by which potentially exposed populations may contact environmental media containing COPCs.
- Estimate EPCs at the points of potential human contact for all identified COPCs.
- Estimate daily intakes for exposure routes and potentially exposed populations. The daily intakes are derived using the EPCs and assumptions regarding such variables as exposure duration, consumption rates, skin absorption factors, and other various parameters that describe human activities.

The exposure assumptions and methods for each task included in the exposure assessment are discussed below.

3.1 IDENTIFICATION OF POTENTIALLY EXPOSED HUMAN POPULATIONS

Potentially exposed populations were identified based on consideration of current and future uses of the Study Area and EPA (1989) guidance. The potential human populations identified below represent those populations that are anticipated to be present within the Study Area under current and reasonably foreseeable future conditions. The evaluation performed for the selected populations is considered to be protective of other potentially exposed populations that are not evaluated quantitatively in this Round 2 HHRA. The populations for current and future uses of the Study Area include the following:

- Dockside worker
- In-water worker

- Transient
- Diver
- Recreational beach user
- Non-tribal fisher
- Native American fisher.

The above populations were identified based on human activities that are known to occur within the Study Area, as described in the Programmatic Work Plan. This Round 2 HHRA does not include an evaluation of the diver exposure scenario, as further discussion between the LWG and the EPA and its partners is required to finalize diver exposure factors. Within the fish consumption exposure scenario, pregnant and nursing women are a subgroup of potential concern due to potential exposures to fetuses and nursing infants. The breast milk exposure pathway was not evaluated in this Round 2 HHRA, but it will be incorporated in the baseline HHRA.

Potential risks were quantified for each of the receptor populations; however, certain individuals may participate in activities resulting in potential exposures under more than one category (e.g., recreational beach users may also be non-tribal fishers). Potentially overlapping exposures are discussed in Section 3.3.7 of this Round 2 HHRA.

This Round 2 HHRA focused on potential exposures occurring within the Study Area in quantifying potential risks to humans. However, certain individuals may also be exposed to media at upland sites adjacent to the Study Area. Potential risks associated with exposures at upland sites will be addressed by DEQ through upland investigation/evaluation activities.

3.2 IDENTIFICATION OF EXPOSURE PATHWAYS

Exposure pathways are defined as the physical ways in which chemicals may enter the human body (e.g., ingestion, inhalation, dermal absorption). A complete exposure pathway consists of the following four elements:

- A source of chemical release
- A retention or transport medium (or media in cases involving media transfer)
- An exposure point (a point of potential human contact with the contaminated medium)
- An exposure route (e.g., ingestion, dermal contact) at the exposure point.

If any of the above elements is missing, the pathway is considered incomplete and exposure does not occur.

As discussed in Sections 4, 5, and 6 of the Round 2 Report, the currently known affected media within the Study Area are sediment, water, and biota. Current and historical industrial activities and processes within, upstream and downstream of the Study Area may have led to either point or nonpoint chemical releases to the Study Area. In addition to these releases, discharges to the river from outfalls and groundwater may be potential chemical sources to the Study Area. Finally, releases that occur upstream and downstream of the Study Area and atmospheric deposition may be potential sources to the Study Area. Potential sources are discussed in greater detail in Section 5 of the Round 2 Report. In addition, chemicals in sediment may be accumulated by bottom-dwelling organisms. Fish and shellfish species feeding on these organisms and living within the Study Area may accumulate chemicals in their tissues through dietary exposures and direct exposure to sediment and water. The potential exposure pathways to human populations at the Study Area include:

- Ingestion of and dermal contact with beach sediment
- Ingestion of and dermal contact with in-water sediment
- Ingestion of and dermal contact with surface water
- Ingestion of and dermal contact with groundwater seep
- Ingestion of fish and shellfish.

The following section provides a more detailed discussion of potential exposures at the Study Area under current and reasonably foreseeable future conditions, and presents the rationale for including or eliminating pathways from quantitative evaluation. The identified receptors, exposure routes, and exposure pathways, and the rationale for selection or exclusion are also summarized in Table 3-1.

3.2.1 Definition and Significance of Exposure Pathways

Exposure pathways are designated in one of the following four ways:

Potentially Complete: There is a source or release from a source, an exposure point where contact can occur, and an exposure route by which contact can occur. Pathways considered potentially complete are quantitatively evaluated in this Round 2 HHRA.

Potentially Complete and Insignificant: There is a source or release from a source, an exposure point where contact can occur, and an exposure route by which contact can occur; however, the pathway is considered a negligible contributor to the overall risk. Pathways considered complete and insignificant were not evaluated further in this Round 2 HHRA.

Incomplete: There is no source or release from a source, no exposure point where contact can occur, or no exposure route by which contact can occur for the given receptor. Pathways considered incomplete were not evaluated further in this Round 2 HHRA.

Potentially complete pathway, but evaluated under a different receptor category: These pathways may be complete for individuals in this receptor category due to overlapping exposure scenarios (e.g., some in-water workers may also be non-tribal fishers), but are not evaluated for the identified receptor category because the pathways are not considered relevant for that receptor. These pathways are evaluated under different receptor categories where the pathways are considered potentially complete and significant. Overlapping exposures that may occur for the different receptor categories are discussed further in Section 3.3.7 of this Round 2 HHRA.

3.2.2 Conceptual Site Model

The CSM for human exposures based on the current understanding of the Study Area is presented in Figure 3-1. The CSM graphically depicts possible sources of COPCs based on current information, possible COPC-affected media, mechanisms of COPC transfer between media, and the processes through which human receptors may be exposed to chemicals. Additional information on potential sources of COPCs is provided in Section 5 of the Round 2 Report. Only those pathways that are theoretically complete and may result in significant exposure or for which significance is unknown were evaluated quantitatively in this Round 2 HHRA.

3.3 EXPOSURE SCENARIOS

The following sections provide a detailed discussion of the exposure scenarios that are quantitatively evaluated in this Round 2 HHRA. The following exposure scenarios were identified based on exposures that may generically occur throughout the Study Area and do not consider site-specific conditions that may limit exposure at a given location.

3.3.1 Direct Exposure to Beach Sediment

Ingestion of and dermal contact with beach sediment could occur within natural river beach areas used by human populations within the Study Area. These areas are designated as human use areas and were identified in the Programmatic Work Plan based on current and future uses of the Site. Human use areas were further classified based on the type of exposures that could occur at these beaches including recreational, transient, or dockside worker use areas. These classifications are described in greater detail below. The human use areas in the Study Area and their associated classifications are shown in Figure 2-1.

3.3.1.1 Dockside Workers

Dockside workers include industrial and commercial workers at facilities adjacent to the river who conduct specific activities within natural river beach areas, such as unloading ships or barges from the beach itself or conducting occasional maintenance activities from the water's edge. The actual activities that occur within natural river beach areas are site-specific and generally occur only very infrequently. Although exposure is anticipated to be infrequent to non-existent, workers conducting activities

within natural river beach areas may contact beach sediment within riverfront industrial and commercial sites at the Study Area. Exposure for a given worker would occur only within the defined dockside worker use area adjacent to the facility of that worker.

3.3.1.2 Transients

During past site tours, tents and makeshift dwellings were observed as evidence that individuals were occupying some riverbank areas. While the tents and makeshift dwellings were typically observed above the actual beach areas, transients may contact beach sediment within transient use areas, which are beach areas that are not active industrial sites and are not otherwise restricted from access. Exposure for a given transient would likely occur only within a single transient use area, although it is possible that transients move from one transient use areas to others within or outside the Study Area.

3.3.1.3 Recreational Beach Users

Both adults and children participate in recreational activities in beach areas within the Study Area. Areas currently used for recreational beach activities, as well as other areas in the Study Area where sporadic beach use may occur were designated recreational use areas. Recreational beach users may contact beach sediment within recreational use areas at the Study Area. Some recreational beach users may primarily use a specific recreation use area while other recreational beach users may use various recreational use areas throughout and outside the Study Area.

3.3.1.4 Fishers

Fishers who fish from the water's edge within natural river beach areas could have direct exposure to beach sediment. In theory, fishing could occur at any beach area without restricted access. Therefore, all non-dockside worker use areas (i.e., all transient and recreational use areas) were considered potential human use areas where fishers could be exposed to beach sediment. Some fishers may primarily use a specific beach area for fishing activities while other fishers may use beach areas throughout and outside the Study Area.

Native American Fishers

Six Native American Tribes (Yakama, Grande Ronde, Siletz, Umatilla, Nez Perce, and Warm Springs) have treaty-fishing rights to fish in the Willamette River within the Study Area. The extent to which Native Americans fish within the Study Area, as well as the extent to which that fishing occurs from beach areas and the degree of sediment exposure that might occur while fishing are unknown.

Non-tribal Fishers

For beach sediment exposure, two different non-tribal fisher scenarios were included in this Round 2 HHRA to evaluate differences in the frequency of fishing activities. Non-tribal recreational fishers were assumed to fish more frequently than the non-tribal non-recreational fisher. The extent to which fishing from beach areas actually

occurs is unknown, as is the degree of sediment exposure that might occur while fishing.

3.3.2 Direct Exposure to In-Water Sediment

Ingestion of and dermal contact with in-water sediment could occur through overwater activities (i.e., activities conducted from a boat or other vessel) that result in bringing sediment to the river's surface where exposure would be possible. Unlike the beach sediment exposure scenarios that are restricted to specific beach areas, potential exposure to in-water sediment could occur anywhere that overwater activities occur. As a result, direct exposure to in-water sediment was evaluated throughout the Study Area.

3.3.2.1 In-Water Workers

While this population is referred to as "in-water" workers, these workers are not actually in the water. Rather, in-water workers are those workers who conduct overwater activities such as maintenance dredging and repair of in-water structures. These activities generally occur infrequently. Exposure to in-water sediment could occur while performing these specific activities, although most maintenance dredging activities are mechanical and are unlikely to result in significant sediment contact.

3.3.2.2 Fishers

Fishers who fish from boats or piers could be theoretically exposed to in-water sediment on anchors, hooks, or crayfish pots.

Native American Fishers

Six Native American Tribes (Yakama, Grande Ronde, Siletz, Umatilla, Nez Perce, and Warm Springs) have treaty-fishing rights to fish in the Willamette River within the Study Area. The extent to which Native Americans fish within the Study Area, as well as the extent to which that fishing occurs from boats or piers and the degree of sediment exposure that might occur while fishing are unknown.

Non-tribal Fishers

For in-water sediment exposure, two different non-tribal fisher scenarios were included in this Round 2 HHRA to evaluate differences in the frequency of fishing activities. Non-tribal recreational fishers were assumed to fish more frequently than the non-tribal non-recreational fisher. The extent to which fishing actually occurs under these two scenarios is unknown, as is the degree of sediment exposure that might occur while fishing.

3.3.3 Direct Exposure to Surface Water

Direct exposure to surface water could potentially occur for many of the populations evaluated in this Round 2 HHRA. However, contact with surface water would generally be unintentional and infrequent with the possible exception of transients and recreational beach users.

3.3.3.1 Transients

Transients may have direct contact with surface water during swimming, bathing or other activities, such as washing of clothing or equipment. In theory, transients may also use river water as a drinking water source; however, there is no evidence that this actually occurs. Exposure to surface water by transients would likely occur within transient use areas.

3.3.3.2 Recreational Beach Users

The lower Willamette River is used by both adults and children for boating, water skiing, swimming, and other water activities that result in exposure to surface water. Of these activities, exposure to surface water would occur to the greatest extent while swimming in the river. Swimming would likely occur primarily within recreational beach areas.

3.3.4 Direct Exposure to Groundwater Seeps

Direct contact with groundwater would occur only within human use areas where groundwater comes to the surface (i.e., seeps) on the beach above the water line and is only considered a potentially complete exposure pathway for transients and recreational beach users. As described in Section 2.1.4, there was only one groundwater seep identified during the seep reconnaissance survey that has not been remediated and is located in a recreational or transient use area. That seep, which is the potential groundwater discharge from Outfall 22B, occurs within a transient use area, so only exposures to transients were evaluated for groundwater seeps in this Round 2 HHRA.

3.3.4.1 Transients

Transients may have direct contact with seep water within riverfront beach areas that have been identified as transient use areas. While contact with seep water would be unintentional, dermal contact with or incidental ingestion of seep water may occur.

3.3.5 Fish Consumption

Certain chemicals may accumulate in fish tissue. Populations that consume fish may be exposed to COPCs that accumulate in the fish tissue. Fish may be caught throughout the Study Area. While the populations are described as "fishers", the fish consumption evaluation in this Round 2 HHRA includes all people who consume fish caught within the Study Area, not just those who catch the fish.

3.3.5.1 Native American Fishers

Six Native American Tribes (Yakama, Grande Ronde, Siletz, Umatilla, Nez Perce, and Warm Springs) have treaty-fishing rights to fish in the Willamette River within the Study Area. Four of these Native American Tribes (Yakama, Umatilla, Nez Perce, and Warm Springs) participated in a fish consumption survey that was conducted on the reservations of the participating Tribes and completed in 1994 (Columbia River Inter-tribal Fish Commission (CRITFC) 1994). The results of the survey suggest that Native American tribal members have higher fish ingestion rates

than the general public. Fish species, especially salmon and Pacific lamprey, are an important food source as well as an integral part of the Native Americans' cultural, economic, and spiritual heritage. Ingestion of fish by both adult and child Native Americans was evaluated in this Round 2 HHRA.

3.3.5.2 Non-tribal Fishers

A year-round recreational fishery exists within the Study Area. Current information suggests that spring chinook, steelhead, coho, shad, crappie, bass, and white sturgeon are the fish species preferred by local recreational fishers (DEQ 2000b, Hartman 2002, and Steele 2002). In addition to recreational fishing, the investigation by the Oregonian newspaper and the limited surveys conducted on other portions of the Willamette River indicate that immigrants from Eastern Europe and Asia, African-Americans, and Hispanics are most likely to be catching and eating fish from the lower Willamette (ATSDR 2002). These preliminary surveys also indicate that the most commonly consumed species are carp, bullhead catfish, and smallmouth bass (ATSDR 2002). However, other species may also be consumed. Site-specific information is not available for non-tribal fish consumption, so a range of ingestion rates and various diets were evaluated in this Round 2 HHRA for both adult and child non-tribal fish consumers, which include non-tribal recreational and non-tribal non-recreational fishers.

3.3.6 Shellfish Consumption

Like fish, certain chemicals may accumulate in shellfish tissue. Populations that consume shellfish may be exposed to COPCs that accumulate in the shellfish tissue. In the Programmatic Work Plan, crayfish was identified as the species for which to evaluate shellfish consumption. Additionally, as required by EPA in its comments on the PRG TM dated June 30, 2006, consumption of clams is also evaluated in this Round 2 HHRA. In theory, shellfish consumption could occur throughout the Study Area wherever shellfish are found. However, the available shellfish biomass at locations where shellfish have been found and collected are not sufficient to support ongoing human consumption.

3.3.6.1 Non-tribal Fishers

There is no documentation of ongoing shellfish consumption by humans occurring in the Study Area. ODFW records crayfish collection in the Columbia and Willamette Rivers, but the records do not indicate whether the collection actually occurs within the Study Area. Even if collection does occur within the Study Area, it is not known whether those crayfish are consumed by humans or used as bait. Only anecdotal information regarding the consumption of clams has been provided by EPA. Site-specific information is not available for non-tribal shellfish consumption, so a range of ingestion rates was evaluated in this Round 2 HHRA for adult non-tribal shellfish consumers, which include non-tribal recreational and non-tribal non-recreational fishers.

3.3.7 Potentially Overlapping Exposure Scenarios

Exposure can potentially occur under more than one scenario for an individual. Examples of these overlapping scenarios include; an in-water worker who is also a non-tribal fisher and recreational beach user, a transient who is also a non-tribal fisher, a Native American fisher who is also a recreational beach user, and others. The potentially overlapping scenarios are indicated in Figure 3-1. The risks associated with multiple potentially overalapping scenarios are discussed in the risk characterization (Section 5). It is possible that one or more of the exposure scenarios potentially affecting an individual will pose a much higher level of risk than the other scenario(s), such that combining the effects of the scenarios will not influence risk management decisions for the Study Area. Risks from potentially overlapping scenarios are discussed in Section 5 of this Round 2 HHRA.

3.4 CALCULATION OF EXPOSURE POINT CONCENTRATIONS

EPCs were calculated for media and pathways that were evaluated quantitatively in this Round 2 HHRA. The process to estimate EPCs for tissue and beach sediment was previously described in the Programmatic Work Plan and the tissue EPCs were previously presented in *Round 1 Tissue Exposure Point Concentrations* (Kennedy/Jenks Consultants 2004a) and *Salmon, Lamprey, and Sturgeon Tissue Exposure Point Concentrations for Oregon Department of Human Services* (Kennedy/Jenks Consultants 2004b), both of which were approved by EPA. The process for deriving EPCs for in-water sediment, surface water, and groundwater seeps was previously described in *Exposure Point Concentration Calculation Approach and Summary of Exposure Factors* (Kennedy/Jenks Consultants 2006), which was approved by EPA.

Prior to calculating EPCs for sediment, surface water, tissue, and groundwater seeps, data were reduced, as needed, to address reporting of multiple results for the same constituent in the same sample and to reduce laboratory duplicates and field splits of samples to derive one value for use. Data reductions followed the rules described in *Guidelines for Data Reporting, Data Averaging, and Treatment of Non-Detected Values for the Round 1 Database Technical Memorandum* (Kennedy/Jenks Consultants et al. 2004).

Chemicals that are not detected at concentrations above the detection limit were designated as non-detects. Non-detects may represent concentrations that are zero, or may represent concentrations greater than zero but less than the detection limit. For purposes of calculating EPCs, proxy values were assigned to non-detects in accordance with the rules that were previously presented in the Programmatic Work Plan (Integral et al. 2004). The following rules were applied to tissue, sediment, surface water, and groundwater seep datasets for a given exposure area:

- If a chemical was not detected in any sample for a given medium in a given exposure area, it was assumed to not be present, so an EPC was not calculated for that chemical in that medium in that exposure area

- If a chemical was detected at least once in samples for a given medium and exposure area, a concentration equal to one-half the detection limit was used as a proxy for non-detects in calculating the EPC for that chemical.

In risk characterization, some toxicity values are based on exposure to chemical mixtures and not to individual chemicals. The risks from these chemicals, which were identified in *Human Health Toxicity Values Interim Deliverable* (Kennedy/Jenks Consultants 2004c), were evaluated for the combined exposure to the chemicals and not on an individual chemical basis. For chemicals that were evaluated as mixtures in the Round 2 HHRA, the concentrations of the individual isomers or congeners that comprise the mixtures were summed to calculate the EPCs for the mixtures. In calculating EPCs for mixtures, the summed concentration was calculated first on an individual sample basis. The following rules were then used to calculate the summed concentrations for a sample:

- If an individual chemical was detected in the sample, the detected concentration was used for that chemical in the sum.

- If an individual chemical was not detected in the sample but was determined to potentially be present using the rules for non-detects, one-half the detection limit was used for that chemical in the sum.

- If an individual chemical was not detected in the sample and was determined not to be present using the rules for non-detects, zero was used for that chemical in the sum.

After summing the concentrations on an individual sample basis, EPCs for summed concentrations were derived using the same process that was used for other chemicals, as described below.

3.4.1 In-Water Sediment

In-water sediment data of appropriate data quality collected within the Study Area was used to estimate EPCs for in-water sediment. Direct contact would only occur with surface sediment, so only surface sediment data (less than 30.5 centimeters in depth) was used in estimating the EPCs. Because the sediment sampling designs were not random, but rather were generally biased towards potential sources, the EPCs for in-water sediment likely represent conservative estimates of potential exposure.

For purposes of applying non-detect rules to in-water sediment, the entire Study Area was considered the exposure area to be consistent with the ecological risk assessment

and to facilitate the identification of initial areas of potential concern (iAOPCs) following this Round 2 HHRA. As a result, if a chemical was detected at least once in surface sediment, one-half the detection limit was used for non-detects in estimating the EPCs for that chemical. In-water sediment EPCs were estimated for in-water workers and fishers and are presented in Table 3-2.

3.4.1.1 In Water Workers

For in-water workers, exposure could occur anywhere within the Study Area that docks or pilings are being constructed or where other in-water activities are occurring (such as maintenance dredging of private slips or berths). While these activities would not necessarily be restricted to a given area, exposure would most likely be localized to in-water sediment adjacent to facilities where these activities occur. Most of these activities would be between the shore and the navigation channel. As a result, sediment samples in nearshore (i.e., excluding the central navigation channel) half-river mile segments along both sides of the river were used to develop in-water sediment EPCs.

In accordance with EPA guidance (1989), the 95% upper confidence limit (UCL) on the arithmetic mean was used for the EPC for the RME scenario for in-water workers. The arithmetic mean was used for the CT scenario. The 95% UCLs were calculated for each dataset following EPA guidance (EPA 2002a). ProUCL version 3.0 (EPA 2004c) was used to test datasets for normal, lognormal, or gamma distributions and to calculate the 95% UCLs. Data were tested first for normality, then for gamma distributions, and finally for lognormal distributions, as recommended by ProUCL guidance (EPA 2004c). If the data did not exhibit a discernable distribution, a non-parametric approach (e.g. Chebyshev) was used to generate a UCL. The 95% UCLs were calculated using the method recommended by ProUCL guidance (EPA 2004c) for the data distribution, sample size, and skewness. In-water sediment EPCs for exposures by in-water workers are presented in Table 3-2.

3.4.1.2 Fishers

Fishers include adult non-tribal and Native American fishers. The fisher scenario is based on long-term exposure. For repeated exposures over an entire lifetime, direct contact with in-water sediment would occur over a very wide area. Even though exposure would occur over a wide area, in-water sediment EPCs for the fisher were derived on a half-mile segment on each side of the river, as was done for the in-water workers, as requested by EPA in its comments on *Exposure Point Concentration Calculation Approach and Summary of Exposure Factors* dated February 24, 2005. Consistent with EPA (1989) guidance, the 95% UCL on the arithmetic mean was used for the EPC for the RME scenario and the arithmetic mean was used for the CT scenario. The arithmetic means and 95% UCLs were calculated as described for the in-water worker EPCs. In-water sediment EPCs for exposures by fishers are presented in Table 3-2.

3.4.2 Beach Sediment

Sediment data collected from designated human use areas during Round 1 and 2 were used to estimate the EPCs for beach sediment. Within the Study Area, EPCs were estimated for exposure areas based on the types of populations potentially exposed. Since potentially complete exposure pathways for sediment involve direct contact with beach sediments, only beach sediment data were used in estimating EPCs for direct exposure pathways.

One composite sample was collected from each beach area. Therefore, the results from the composite sample were used as the EPCs for both the RME and the CT scenarios for that beach. The process to estimate EPCs for each receptor population is described below.

3.4.2.1 Dockside Workers

Dockside workers could potentially be exposed to beach sediment in designated dockside worker use areas, which are shown in Figure 2-1. Beach sediment data from these areas were used to estimate the EPCs for dockside workers. For dockside workers, the exposure area is considered to be the industrial site where the worker is employed. Therefore, EPCs were estimated for each individual industrial site within the dockside worker use areas for beach sediment samples collected within the property boundaries. If the beach area extends across multiple facilities, the EPCs were estimated for the beach area and those EPCs were used to evaluate the dockside workers at each of the facilities. Beach sediment EPCs for exposures by dockside workers are presented in Table 3-3.

3.4.2.2 Transients

Transients could potentially be exposed to beach sediment in designated transient use areas, which are shown in Figure 2-1. Although transients are anticipated to move throughout the Study Area, some may spend a majority of their time at only one of the identified areas. Therefore, EPCs for transients were conservatively estimated for each beach area within the transient use areas. Beach sediment EPCs for exposures by transients are presented in Table 3-4.

3.4.2.3 Recreational Beach Users

Recreational beach users could potentially be exposed to beach sediment in recreational use areas, which are shown in Figure 2-1. Beach sediment data from these areas were used to estimate the EPCs for recreational beach users. For recreational beach users, the exposure area is considered to be one river beach area, which represents a conservative assumption for the Round 2 HHRA. Therefore, EPCs were estimated for individual beaches within the recreational beach use areas. Beach sediment EPCs for exposures by recreational beach users are presented in Table 3-4.

3.4.2.4 Fishers

Fishing could occur from beaches with unrestricted access, which are the designated transient and recreational use areas. Beach sediment data from these areas were used

to estimate the EPCs for non-tribal and Native American fishers. For fishers, the exposure area is considered to be one river beach area, which represents a conservative assumption for the Round 2 HHRA. Therefore, EPCs were estimated for individual beaches within the recreational and transient use areas and are the same as the EPCs for transients and recreational beach users. Beach sediment EPCs for exposures by fishers are presented in Table 3-4.

3.4.3 Surface Water

Surface water data of appropriate data quality collected within the Study Area were used to estimate EPCs. Near-bottom and integrated water column surface water samples were collected at the Study Area during Round 2. The near-bottom samples are not representative of potential human exposures to surface water, which would occur mostly at the water surface and through the water column. As a result, only integrated water column data were used in estimating the surface water EPCs. Surface water EPCs were estimated for transient and recreational beach user exposure scenarios.

3.4.3.1 Transients

Transient exposures to surface water could occur throughout the year at transient use areas within the Study Area. As a result, data from all three of the completed seasonal sampling events were used in estimating the surface water EPCs for transients. Data from the three transect stations were used to estimate surface water EPCs for exposures at transient use areas throughout the Study Area. Surface water samples were also collected at Willamette Cove, which is a transient use area, because it is a quiescent area and may not be adequately characterized by the transect samples. Data from these surface water samples were used to estimate surface water EPCs for exposures in Willamette Cove. The other areas being sampled to support the Round 2 HHRA, Cathedral Park and Swan Island Lagoon, are not transient use areas, so were not used in estimating EPCs for transient exposures. Surface water EPCs for exposures by transients are presented in Table 3-5.

Given that transients can live in many parts of the river, EPCs were calculated for each transect, as well as for the combination of all three transects. For the RME scenario, the maximum contaminant level for each transect over all seasons was used, since only three transect samples were collected at each location. As a comparison, the 95% UCL on the arithmetic mean of all transects for all sampling events was also used. The 95% UCLs were calculated as described for in-water sediment. The arithmetic mean of all transects for each season was used for the CT scenario.

3.4.3.2 Recreational Beach Users

Recreational beach user exposures to surface water could occur during summer months at recreational use areas within the Study Area. As a result, only data from the low-water sampling event in July 2005 were used in estimating the surface water EPCs for recreational beach users. Data from the three transect stations were used to estimate surface water EPCs for exposures at non-quiescent recreational beach use

areas throughout the Study Area. Data from surface water samples collected at Cathedral Park, Willamette Cove, and Swan Island Lagoon were used to estimate EPCs for each of those respective recreational beach areas. Based on the current sampling design, only one sample was collected from each quiescent area during low-water periods, so the results for the sample were used as the EPCs for both the RME and CT scenarios for that area. Only three transect samples were collected in July 2005 during the low-water period, so the maximum concentrations were used as the EPCs for the RME scenarios and the arithmetic mean concentrations were used as the EPCs for the CT scenarios. Surface water EPCs for exposures by recreational beach users are presented in Table 3-6.

3.4.4 Groundwater Seeps

Direct contact with groundwater would occur only within human use areas where groundwater comes to the surface (i.e., seeps) on the beach above the water line. Each groundwater seep where direct contact could occur represents an exposure area for groundwater. The only groundwater seep where direct contact could occur within the Study Area is within the potential transient use area located on the west side of the river at RM 7 (Figure 2-1). Outfall 22B, which is a potential conduit of groundwater discharge and results in the water present on that beach, was sampled five times between 1993 and 2004. If only one result was reported for a chemical, that result was used as the EPC for both the RME and CT scenarios for that chemical. If more than one result is reported for a chemical, the 95% UCLs or maximum concentrations were used as the EPCs for the RME scenarios, depending on the number of reported concentrations. If an analyte was detected in at least five samples from the seep, the 95% UCLs were calculated as described for in-water sediment. The arithmetic mean concentrations were used as the EPCs for the CT scenarios. Groundwater seep EPCs are presented in Table 3-7.

3.4.5 Fish and Shellfish Tissue

Fish and crayfish tissue EPCs were derived from tissue sampling results of the LWG Round 1 investigation (Tables 3-8 through 3-17) and the ODHS study (Table 3-18 through 3-20). The Round 1 tissue EPCs were originally presented in *Round 1 Tissue Exposure Point Concentrations* (Kennedy/Jenks Consultants 2004a), which was approved by EPA. These EPCs were derived for fish species and crayfish that were evaluated for human consumption. The EPCs derived from the results of the ODHS study were originally presented in *Salmon, Lamprey, and Sturgeon Tissue Exposure Point Concentrations for Oregon Department of Human Services* (Kennedy/Jenks Consultants 2004b). These EPCs were derived for salmon whole body, fillet with skin, and fillet without skin composite samples, lamprey whole body composite samples, and sturgeon fillet without skin samples. EPCs for clams were calculated using data collected during Round 1 and 2 and are presented in Tables 3-21 and 3-22.

Crayfish and clams were collected and composited for a given sampling location. Even though the biomass available at a given location was generally not sufficient to support ongoing human consumption (Windward 2006), EPCs were calculated for crayfish and clams at individual locations, as required by EPA in its comments on the PRG TM dated June 30, 2006, as well as for the entire Study Area.

Smallmouth bass were collected and composited over a river mile. While it is unlikely that fish from only one river mile would be consumed over a lifetime, EPCs were calculated for smallmouth bass at each river mile as well as for the entire Study Area per the Programmatic Work Plan. EPCs were calculated for both whole body and fillet samples.

Carp, black crappie, and brown bullhead were collected and composited over a fishing zone, which includes three river miles. EPCs were calculated for carp, black crappie, and brown bullhead for each fishing zone as well as for the entire Study Area. EPCs were calculated for both whole body and fillet samples.

Adult salmon were collected at the Clackamas fish hatchery, adult lamprey were collected at Willamette Falls, and sturgeon were collected at locations throughout the Study Area. EPCs were calculated for adult salmon, adult lamprey, and sturgeon to be representative of the entire Study Area. EPCs were calculated for both whole body and fillet samples for adult salmon. Only whole body data were available for adult lamprey and only fillet data were available for sturgeon, so the EPCs for adult lamprey were calculated for whole body samples and the EPCs for sturgeon were calculated for fillet samples.

Tissue EPCs were calculated for both the 95% UCL or maximum (UCL/max) and mean concentrations for use in this Round 2 HHRA. In calculating the EPCs, if only one sample was collected at a given location or river mile that result was used as both the UCL/max and mean EPC for that chemical. If more than one sample was collected, either the 95% UCLs or maximum concentrations were used as the UCL/max EPCs, depending on the number of reported concentrations. If detected concentrations for at least five samples are available, the 95% UCLs were calculated as described for in-water sediment. The arithmetic mean concentrations were used as the mean EPCs.

3.5 PROCESS TO CALCULATE INTAKES

EPA (1989) defines exposure as "the contact with a chemical or physical agent" and defines the magnitude of exposure as "the amount of an agent available at human exchange boundaries (i.e., the lungs, gut, and skin) during a specified time period." Exposure assessments are designed to determine the degree of contact a person has with a chemical. Thus, estimating human exposure to a chemical requires information regarding the concentration of the chemical in the environmental media

(air, soil, water, tissue) with which a person will come into contact and the extent of contact the person will have with the media.

Chemical specific intake or dose was quantified in this Round 2 HHRA by estimating the chronic daily intake (CDI) for noncarcinogens or the lifetime average daily intake (LADI) for carcinogens. CDI and LADI, expressed in terms of the mass of substance taken into the body per unit body weight per unit time (mg/kg/day), were calculated using equations based on exposure parameters that represent the duration of exposure, frequency of exposure, and other factors that affect overall chemical dose. According to EPA guidance (1989), exposure assessments were based on the RME expected to occur under both current and future land use conditions. Exposure assessments using CT values, which are more representative of average exposures, were also conducted. Rationale and/or references for each of the RME and CT values for exposure pathways that were quantitatively assessed are provided in the exposure factor tables for each exposure scenario for different populations are presented in Tables 3-23 through 3-44 and discussed in the following sections.

Intakes were quantified using standard exposure equations (EPA 1989). These equations take the general form:

$$\text{CDI or LADI} = \frac{\text{EPC} * \text{IR} * \text{EF} * \text{ED}}{\text{BW} * \text{AT}}$$

Where:

- EPC = Exposure point concentration
- IR = Intake rate
- EF = Exposure frequency
- ED = Exposure duration
- BW = Body weight
- AT = Averaging time.

3.5.1 Population-Specific Assumptions

Assumptions about each population evaluated in this Round 2 HHRA were used to select exposure parameters to calculate the pathway-specific chemical intakes. Currently, site-specific values are not available for all populations and pathways. Therefore, default values were used where site-specific values are not available. Where default values are not available, best professional judgment based on knowledge of human uses of the Study Area was used.

Exposure parameters that were used in this Round 2 HHRA to calculate the CDIs and LADIs were previously included in *Exposure Point Concentration Calculation Approach and Summary of Exposure Factors* (Kennedy/Jenks Consultants 2006), which was approved by EPA. The exposure parameters are discussed below and

presented in Tables 3-23 to 3-44. These values represent potential exposures for application at appropriate areas and/or areas agreed upon with EPA and its partners within the Study Area. The actual exposure at a given location may be less than that assumed for the population and Study Area as a whole due to location-specific conditions.

3.5.1.1 Dockside Worker

Industrial land use was assumed only for portions of the Study Area that are zoned for industrial use and with river front areas that include natural river beach or bank areas. Activities at Portland Harbor industrial sites do not occur frequently in these areas, which are the only areas where direct exposure to beach sediment might occur. In fact, it is unlikely that workers are in direct contact with beach sediment through typical industrial activities on a daily basis.

Although it is unlikely that significant beach sediment exposure would occur for a dockside worker on a regular basis, exposure assumptions for the dockside worker were developed based on typical occupational assumptions. For the most part, default exposure values for an industrial worker from EPA were used. For beach sediment exposure frequency, it was assumed that a worker would only contact sediment one day per week while working at the industrial site. Therefore, the default exposure frequency of 250 days per year, which represents 5 days per week for 50 weeks, was changed to 50 days per year (i.e., 1 day per week for 50 weeks) for RME. Table 3-23 summarizes RME and CT exposure values for the dockside worker and the reference or rationale for each value.

3.5.1.2 In-water Worker

In-water workers could contact in-water sediment while performing specific activities such as replacement of fender piles or maintenance dredging. Exposure factors for in-water sediment were developed for Terminal 4 based on in-depth interviews with several workers who conduct or oversee activities that could result in contact with in-water sediment. According to the Army Corps of Engineers (Siipola 2004), the Port of Portland conducts the most frequent dredging at the Study Area, so the exposure factors for workers at Terminal 4 are considered protective of in-water workers throughout the Study Area for potential in-water sediment exposures. For the RME scenario, in-water workers are assumed to contact in-water sediment for 10 years during 25 years of employment at a given facility with 10 days of sediment contact per year. For the CT scenario, in-water workers are assumed to contact in-water sediment for 4 years during 9 years of employment at a given facility. Although most maintenance dredging activities are mechanical and are unlikely to result in significant sediment contact, the in-water worker exposure factor intake rates for in-water sediment are the same as the dockside worker for beach sediment, which in turn are the same as default exposure factors for soil for an industrial worker. Table 3-24 summarizes RME and CT exposure values for the in-water worker and the reference or rationale for each value.

3.5.1.3 Transients

Transient land use is assumed only for portions of the Study Area with riverfront access and that are not also active industrial sites. Transients may be exposed to beach sediment, surface water, and groundwater seeps while utilizing river beaches within transient use areas. EPA does not have recommended exposure parameters for transient scenarios, so the exposure frequency and duration for transients are based on best professional judgment. However, by definition, transient exposures are assumed to occur over a short duration of time. At the request of EPA, it was assumed that transients may remain at a single beach for up to two years. For intake rates, EPA required that values greater than those recommended for residential soil exposures be used for beach sediment and that residential, tap water ingestion rates be used for surface water. Tables 3-25, 3-26, and 3-27 summarize RME and CT exposure values for beach sediment, surface water, and groundwater seeps respectively, for the transient scenario, and the reference or rationale for each value.

3.5.1.4 Recreational Beach User

Recreational beach use is assumed only for portions of the Study Area where recreational exposures are reasonably likely to occur. Recreational beach users may have direct contact with beach sediment within river beach areas and with surface water while swimming or during other water activities. EPA does not have recommended exposure parameters for recreational beach use scenarios, so the exposure frequency and duration for recreational beach users are based on best professional judgment. Beach use was assumed to be more frequent (5 days per week) in the summer with less frequent use in the spring/fall (1 day per week) and even less use in the winter (1 day per month). The temperature of river water would limit swimming activities during much of the year. Therefore, exposure to surface water was only evaluated for the summer months when swimming might occur. For beach sediment intake, the recommended default values for residential soil were generally used but the adherence factor for children was more than 10 times greater than the value for residential soil. For surface water intake, the recommended default values for swimming scenarios were used. The recreational beach user includes both adults and children. Tables 3-28 and 3-29 summarize RME and CT exposure values for beach sediment and surface water, respectively, for adult recreational beach users. Tables 3-30 and 3-31 summarize child recreational beach user RME and CT values. A reference or rationale is included for each value.

3.5.1.5 Fishers

Exposure assessments for the fisher scenarios evaluated potential exposure to COPCs through direct contact with beach and in-water sediment and through consumption of fish and shellfish. Direct contact with beach sediments only occurs in river beach areas where fishing activities occur. Fishers could theoretically contact in-water sediment on anchors, hooks, or crayfish pots while fishing from boats or piers at the Study Area. For fish and shellfish consumption, it is assumed that exposure could occur throughout the Study Area and is continuous year-round as fishers may catch fish at the Study Area and then freeze them for later use.

This Round 2 HHRA evaluated two fisher scenarios: the non-tribal fisher, with two different sediment exposure scenarios (recreational and non-recreational) and three different fish ingestion rates; and the Native American fisher. Fish ingestion was evaluated for both adults and children while sediment exposure was evaluated for adults only, with the assumption that fishing is done primarily by adults but both adults and children may consume the fish that is caught.

Beach Sediment Exposure

Beach sediment exposure would only occur for fishers during bank fishing at natural river beach areas within the Study Area. EPA does not have recommended default exposure parameters for fishing scenarios, so the exposure frequency and duration for fishers are based on EPA's requirements or best professional judgment. EPA provided the exposure frequencies and durations for the Native American and non-tribal recreational fishers used in this Round 2 HHRA. Native American fishers were assumed to fish from the same beach area five days per week for the entire year (260 days/year) for an entire lifetime (70 years) for the RME. Non-tribal recreational fishers were assumed to fish from the same beach area three days per week for the entire year (156 days/year) for the default residential exposure duration (30 years) for the RME. Non-tribal non-recreational fishers were assumed to fish from the same beach area for two days per week for the entire year (104 days/year) for the default residential exposure duration (30 years) for the RME. Although it is not known how much sediment contact actually occurs during fishing activities, default intake values for residential soil were used. Exposure assumptions for beach sediment contact for fishers are presented in Tables 3-32 through 3-34.

In-water Sediment Exposure

At the request of EPA, the exposure frequencies and durations for beach sediment for each fisher scenario were assumed to represent the fishing frequency at the Study Area regardless of whether that fishing occurs from a beach or a boat. In contrast to beach sediment, a fisher is unlikely to have significant contact with in-water sediment in a given area at the Study Area every time fishing occurs, especially given the number of days and length of time over which exposures are assessed. A factor of 25 percent was used to represent the percent of time spent fishing in a single area within the Study Area.

Based on the exposure scenarios for in-water sediment (i.e., contact with sediment on anchors, hooks, or crayfish pots), the extent of contact with in-water sediment would be significantly less than what would occur with soil. Ingestion rates for soil are based on exposure to soil during yard work and to indoor dust (EPA 1997). These ingestion rates are not applicable to the in-water sediment exposure scenarios; however, incidental ingestion rates are not available for sediment. It is assumed that the incidental ingestion rate for in-water sediment is 50% of the ingestion rate for residential soil scenarios. For dermal contact, hands and forearms are the only body parts that could be exposed to in-water sediment on a regular basis. It is assumed that the entire surface area of both hands and forearms would be exposed to in-water

sediment. The adherence and absorption factors are assumed to be the same as those for beach sediment. Exposure assumptions for in-water sediment contact for fishers are presented in Tables 3-35 through 3-37.

Fish Consumption

This Round 2 HHRA evaluated two different fish consumption scenarios: non-tribal, which includes three different fish ingestion rates, and Native American. The non-tribal scenario included single species and multiple species diets of resident fish species. A multiple species diet that includes resident fish as well as salmonids, lamprey, and sturgeon was evaluated for the Native American scenario. The approaches that were used to evaluate these fish consumption scenarios are discussed below. Exposure assumptions for fish consumption are presented in Tables 3-38 through 3-43.

Non-Tribal Fish Consumption

Site-specific fish consumption information is not available for the non-tribal fisher scenarios. Therefore, to evaluate the potential range in consumption patterns that may exist, three ingestion rates were used to calculate intakes for adults and three were used for children. EPA specified the ingestion rates used in this Round 2 HHRA. For adults, the fish ingestion rates that were used in this Round 2 HHRA were 17.5 grams per day (g/day), 73 g/day, and 142 g/day. These rates correspond to approximately 2 meals per month, 10 meals per month, and 19 meals per month, based on an 8-ounce serving size, every month of the year consisting exclusively of fish caught within the Study Area. It should be noted that the current fish consumption advisory for the LWR recommends that children and expectant mothers do not eat resident fish from the Portland Harbor, and that healthy adults eat no more than one 8-ounce meal per month of resident fish from the Portland Harbor (DHS, 2007).

Two of these rates, 17.5 g/day and 142 g/day, represent the 90th and 99th percentile ingestion rates for uncooked freshwater and estuarine finfish and shellfish for individuals (consumers and non-consumers) of age 18 and over in the United States (EPA 2002b). Shellfish consumption is evaluated separately in this Round 2 HHRA, so using ingestion rates that include shellfish to evaluate fish consumption is overly conservative. In addition, Portland Harbor is a freshwater environment so including the consumption of estuarine fish and shellfish adds further conservatism to this assessment. The 99th percentile ingestion rate for uncooked, freshwater finfish from the same study is 43 g/day (EPA 2002b). Because these rates are from a national dietary study, they may not be representative of site-specific consumption patterns. The other ingestion rate used in this Round 2 HHRA, 73 g/day, is from a creel study conducted in the Columbia Slough and is the 95 percent upper confidence limit on the average for ingestion of fish where 75 percent of the mass of the total fish is consumed (Adolfson 1996). While this study may be more representative of consumption patterns for the Study Area, the study was limited in scope and the reported ingestion rates were estimated based on numerous assumptions. For all three

of the ingestion rates evaluated, the ingestion rates represent high end fish consumption relative to the average ingestion rates from these respective studies.

Limited information is available about child fish consumption. The child scenario evaluated in this Round 2 HHRA is for 0 to 6-year olds. The national dietary study does not include consumption information for this age range. However, this age range was evaluated in the CRITFC Fish Consumption study (CRITFC 1994). In that survey, the ratio of the child 95th percentile ingestion to the adult 95th percentile ingestion rate, which is the comparison specified by EPA, was 0.42. This ratio was applied to the three non-tribal adult ingestion rates to estimate the non-tribal child ingestion rates. The corresponding rates that were used for children were 7 g/day, 31 g/day, and 60 g/day.

For the non-tribal fisher scenarios, risks were evaluated for consumption of individual target resident fish species (bass, black crappie, bullhead, and carp) using the ingestion rates for this scenario with concentration data on each individual resident species (for both whole body and fillet tissue). EPCs were calculated for fishing zones (carp, crappie and bullhead) and mile reach (bass) as well as for the entire Study Area, as described in Section 3.5.5. In addition to the individual species diet, a multiple species diet was also evaluated by using the fish ingestion rates for the scenarios with the concentration data of all resident species (for whole body and fillet tissue) for the Study Area (i.e., a multiple species diet assuming that each of the 4 fish target species represents 1/4 of a person's diet). The following scenarios were evaluated for each of the above ingestion rates using both the UCL/max and mean EPCs described in Section 3.5.5 for both whole body and fillet samples:

	River Mile	Fishing Zone	Entire Study Area
Smallmouth bass	X		X
Black crappie		X	X
Carp		X	X
Brown bullhead		X	X
Multiple species			X

The uncertainties associated with the non-tribal fish consumption scenarios are discussed in Section 7 of this Round 2 HHRA..

Native American Fish Consumption

While site-specific fish consumption information is not available for the Native American fisher scenario, a fish consumption survey was conducted on the reservations of four of the participating Tribes (CRITFC 1994). The 95th percentile

fish ingestion rate for consumers only from the CRITFC Fish Consumption study, which is 175 g/day, was used to calculate intakes for adult Native American fish consumers. This rate corresponds to approximately 23 meals per month every month of the year of fish caught exclusively within the Study Area. The CRITFC study reported that none of the respondents fished the Willamette River for resident fish and at most, approximately 4 percent fished the Willamette River for anadromous fish. Therefore, the use of this parameter represents a very conservative assumption for this exposure pathway. The 95th percentile fish ingestion rate of 73 g/day for children from the CRITFC Fish Consumption study was used for child Native American fish consumers.

For the tribal scenario, a multiple species diet was evaluated using the fish consumption data from the CRITFC Fish Consumption study (CRITFC 1994) with concentration data from the target resident species as well as from sturgeon, salmon and lamprey caught as a part of the ODHS sampling effort. The fish consumption information from the CRITFC study was used to determine the ingestion rate for each fish species, as shown below:

Species	Grams per day[a]	Percent of diet
Salmon	67	38.4
Lamprey	12.3	7.0
Sturgeon	8.6	4.9
Smelt	12.5	7.2
Whitefish	23.2	13.3
Trout	25.1	14.3
Walleye	9.9	5.7
Northern Pikeminnow	3.7	2.1
Sucker	7.3	4.2
Shad	5.2	3.0
Total Ingestion Rate	175	100

(a) Grams per day are based on the weighted mean data in Table 18 of the CRITFC Fish Consumption study.

For adult Native American consumers, the ingestion rates for salmonids (67 g/day), lamprey (12.3 g/day), and sturgeon (8.6 g/day) were used with the respective UCL/max and mean EPCs for those species to calculate intakes. For the remaining species, each of the UCL/max and mean EPCs calculated for the entire Study Area for smallmouth bass, black crappie, carp, and brown bullhead were used with an

ingestion rate of 21.7 g/day (i.e., the ingestion rate for the sum of the species that are not salmonid, sturgeon or lamprey, 86.9 g/day, divided by 4). The combined intakes from salmonids, lamprey, sturgeon, and the remaining fish species in the above table were used to estimate risks from fish consumption. The intakes for child Native American consumers were calculated using the same dietary percentages as the adult Native American consumers, but with a total ingestion rate of 73 g/day.

Adult salmon, adult lamprey, and sturgeon have life histories such that significant exposure to contaminants can occur outside of the Study Area. The uncertainties in estimating the proportion of contaminants in sturgeon, salmon and lamprey and associated risks that result from contaminants at the Study Area are discussed in Section 7.

Shellfish Consumption

Site-specific shellfish consumption information is not available. For shellfish, only adult non-tribal consumption was evaluated. It should be noted that there is currently a fish consumption advisory for a portion of the Study Area recommending that crayfish not be eaten (DHS, 2007). Ingestion rates of 3.3 g/day and 18 g/day were used to calculate intakes from shellfish consumption. These values represent the average (3.3 g/day) and 95th percentile (18 g/day) ingestion rates for shellfish consumption from freshwater and estuarine systems for individuals of age 18 and older in the United States (EPA 2002b). Again, Portland Harbor is a freshwater environment. In the national dietary study, essentially no ingestion of shellfish occurs for an exclusively freshwater environment (mean of 0.01 g/day), so use of the combined freshwater and estuarine environment ingestion rates is overly conservative. These ingestion rates were used with UCL/max and mean EPCs for crayfish and clams. As required by EPA in its comments on the PRG TM dated June 30, 2006, the EPCs were calculated for each sample location, even though the available biomass at that location may not be sufficient to support human consumption and the location may not be accessible for shellfish harvesting, as well as for the entire Study Area. As described in Section 3.5.5, the shellfish EPCs included both the average and maximum concentrations of each chemical detected in any of the composites in the entire Study Area. Exposure assumptions for shellfish consumption are presented in Table 3-44. The uncertainties associated with shellfish consumption are discussed in Section 7 of this Round 2 HHRA.

3.5.2 Chemical Specific Exposure Factors and Assumptions

In calculating the intakes, certain assumptions were made that were specific to a given chemical or class of chemicals. These chemical-specific assumptions had an effect on both EPCs and intake calculations, and are described below.

3.5.2.1 Exposure Point Concentrations

In general, the EPC used in the intake calculation was directly based on the reported concentration for a chemical. However, for certain chemicals, the EPCs were derived from the reported concentrations.

Arsenic was analyzed as total arsenic, but the toxicity values for arsenic are only relevant for inorganic arsenic, which is most significant for tissue. In previous fish tissue studies in the lower Columbia and Willamette Rivers, the percent of inorganic arsenic relative to total arsenic ranged from 0.1% to 26.6% with an average percent inorganic arsenic of 5.3% in the resident fish samples from the Willamette River (Tetra Tech 1995, EVS 2000). The Columbia River Fish Contaminant Survey (EPA 2002b) concluded that a "value of 10% is expected to result in a health protective estimate of the potential health effects from arsenic in fish." Therefore, it was assumed that 10% of total arsenic in tissue was in the form of inorganic arsenic for purposes of this Round 2 HHRA. The total arsenic concentrations were multiplied by 10% and the resulting value was used in calculating the tissue EPCs for arsenic.

PCBs were analyzed as Aroclors and congeners in tissue. For PCBs analyzed as Aroclors, the summed concentration of individual Aroclors was used in calculating the EPCs, as described in Section 2.2.3. For PCBs analyzed as congeners, EPCs were calculated using both the total PCB value (sum of individual congeners) and an adjusted total PCB value. The adjusted total PCB value was calculated by subtracting the concentration of the coplanar PCB congeners from the total PCB concentration. This was done because the coplanar PCB congeners were evaluated separately (as PCB TEQs) for cancer risks.

3.5.2.2 Dermal Absorption Factors for Sediment

EPA's Supplemental Guidance for Dermal Risk Assessment (2004a) provides chemical specific values for dermal absorption from contaminated soil. These chemical specific dermal absorption factors were used in the intake equations for dermal contact with sediment and are presented in Table 3-45. However, as noted in EPA guidance (2004a), the amount of chemical absorbed from sediment may differ from that absorbed from soil due to differences in the relative importance of numerous chemical, physical, and biological factors. A default dermal absorption value was used for semivolatile organic compounds (SVOCs) that do not have chemical specific values. Per EPA guidance (2004a), only those compounds or classes of compounds for which dermal absorption factors exist were evaluated quantitatively for the dermal contact exposure pathway.

3.5.2.3 Dermal Absorption Factors for Surface Water and Groundwater Seeps

One of the parameters in the intake equations for dermal contact with surface water or groundwater seeps is the absorbed dose per event (DA_{event}). This parameter was derived per EPA guidance (2004a) using chemical specific factors, which are presented in Table 3-46. The chemical specific factors used in the calculation of DA_{event} were obtained from Appendix B (Screening Tables and Reference Values for the Water Pathway) of EPA's Supplemental Guidance for Dermal Risk Assessment (2004a).

4.0 TOXICITY ASSESSMENT

Toxicity values provide a quantitative estimate of the potential for adverse effects resulting from exposure to a chemical. Toxicity values are used in risk assessment to quantify the likelihood of adverse effects occurring at different levels of exposure to a chemical.

Toxicity values were identified for the COPCs that were selected in Section 2.4. The cancer and noncancer toxicity values are shown in Tables 4-1 and 4-2, respectively. The following sections discuss the toxicity values and describe how they were selected.

4.1 CARCINOGENIC TOXICITY VALUES

Slope factors (SFs) are used to quantify the response potency of potential carcinogens. SFs are derived from either human epidemiological or animal studies by applying a mathematical model to the data set to extrapolate from the high doses in studies to the lower exposure levels expected for human contact in the environment (EPA 1989). The SF is an upper-bound estimate or maximum likelihood estimate of the probability of a response over a lifetime.

Slope factors are available for oral and inhalation exposure pathways. The inhalation exposure pathway will not be quantitatively evaluated in the Round 2 HHRA, so inhalation SFs were not selected as toxicity values. Dermal SFs were derived from the oral SFs, as described in Section 4.7. The oral and dermal cancer slope factors are presented in Table 4-1. In accordance with EPA (2005) guidance, the weight of evidence for carcinogenicity for each COPC will be presented in the baseline HHRA.

4.2 NONCARCINOGENIC TOXICITY VALUES

A chemical that exhibits adverse effects other than cancer or mutation-based developmental effects is believed to have a threshold (i.e., a dose below which no adverse effect is expected to occur). Reference doses (RfDs) are typically used as toxicity values for chemicals with noncarcinogenic effects. A chronic RfD is defined as a daily dose to which humans, including sensitive subpopulations, may be exposed throughout their lifetimes without adverse health effects.

Reference doses are available for oral and inhalation exposure pathways. The inhalation exposure pathway will not be quantitatively evaluated in the Round 2 HHRA, so inhalation RfDs were not selected as toxicity values. Dermal reference doses were derived from oral reference doses, as described in Section 4.7. Reference doses for oral and dermal exposure pathways are presented in Table 4-2.

Chronic RfDs are specifically developed to be protective of long-term exposures to a chemical. Because the Round 2 HHRA will evaluate long-term exposures, chronic

RfDs were selected when available. If an RfD for a different duration was selected because a chronic RfD was not available, the exposure duration is noted in Table 4-2.

4.3 SOURCES OF TOXICITY VALUES

The following hierarchy of sources of toxicity values is currently recommended for use at Superfund sites (EPA 2003a):

- Tier 1 – EPA's Integrated Risk Information System (IRIS) database is the preferred source of information because it normally represents the official EPA scientific position regarding the toxicity of the chemicals based on the data available at the time of the review. IRIS contains RfDs and SFs that have gone through a peer review and EPA consensus review.
- Tier 2 - EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) are toxicity values derived for use in the Superfund Program when such values are not available in IRIS (EPA 2004d). PPRTVs are derived after a review of the relevant scientific literature using the methods, sources of data and guidance for value derivation used by the EPA IRIS Program. The PPRTV database includes RfDs and SFs that have undergone internal and external peer review. The Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk Technical Support Center (STSC) develops PPRTVs on a chemical-specific basis when requested by EPA's Superfund program.
- Tier 3 - Tier 3 includes additional EPA and non-EPA sources of toxicity information. Priority is given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer reviewed. Tier 3 sources may include, but need not be limited to, the following sources:
  - The California Environmental Protection Agency (Cal EPA) Toxicity Criteria Database (Cal EPA 2004) includes SFs that have been peer reviewed.
  - The ATSDR Minimal Risk Levels are similar to RfDs and are peer reviewed.
  - Health Effects Assessment Summary Table (HEAST) toxicity values are currently under review by the STSC to derive PPRTVs. The toxicity values remaining in HEAST are considered Tier 3 values.

In accordance with the above hierarchy, toxicity values from IRIS for both noncarcinogenic and carcinogenic effects were selected when available. If a toxicity value was not available from IRIS, toxicity values from the PPRTV database were selected, if available. In the absence of toxicity values from either IRIS or the PPRTV database, toxicity values from HEAST were selected, if available. The

sources of the cancer or noncancer toxicity value are indicated in Tables 4-1 and 4-2. The dates shown in Tables 4-1 and 4-2 indicate the date of the database search for IRIS toxicity values and PPRTVs. For HEAST, the date indicates the most recent version of published HEAST toxicity values.

4.4 CHEMICALS WITH SURROGATE TOXICITY VALUES

For some chemicals, if a toxicity value was not available from the above hierarchy, a structurally similar chemical was identified as a surrogate. The reference dose or slope factor for the surrogate chemical was selected as the toxicity value and the surrogate chemical was indicated in Tables 4-1 and 4-2. The following chemicals have toxicity values from surrogate chemicals:

- Butyltin ion. Toxicity values were identified from the recommended hierarchy for dibutyltin and tributyltin. Toxicity of alkyltin compounds depends on the number of alkyl side-chains, with monoalkyl tin being the least and trialkyl tin the most toxic (NLM 2004). Therefore, dibutyltin is thought to be more similar to butyltin than tributyltin in toxicity, and is more toxic than butyltin. As a health protective approach, the toxicity value for dibutyltin was selected as a surrogate for butyltin ion.

- Tetrabutyltin. As discussed for butyltin ion, toxicity values were identified for dibutyltin and tributyltin. Tetrabutyltin is less toxic than tributyltin, but more toxic than dibutyltin (NLM 2004). As a health protective approach, the toxicity value for tributyltin was selected as a surrogate for tetrabutyltin.

- Tributyltin ion. The available toxicity value for tributyltin is for tributyltin oxide. However, the Round 1 and Round 2 results were for tributyltin ion. The tributyltin oxide toxicity value was selected as a surrogate for tributyltin ion.

- Acenaphthylene. IRIS classifies acenaphthylene as a category D carcinogen (not classifiable as to human carcinogenicity), and therefore, is considered a noncarcinogenic polycyclic aromatic hydrocarbon (PAH). Acenaphthene is the noncarcinogenic PAH most similar in structure and carbon number to acenaphthylene. Therefore, the acenaphthene toxicity value was selected as a surrogate for acenaphthylene.

- Benzo(g,h,i)perylene. IRIS classifies benzo(g,h,i)perylene as a category D carcinogen (not classifiable as to human carcinogenicity), and therefore, is considered a noncarcinogenic PAH. Of the noncarcinogenic PAHs most similar in structure and carbon number to benzo(g,h,i)perylene, pyrene has the lowest toxicity value and is therefore, considered the most toxic. As a health protective approach, the pyrene toxicity value was selected as a surrogate for benzo(g,h,i)perylene.

- Phenanthrene. IRIS classifies phenanthrene as a category D carcinogen (not classifiable as to human carcinogenicity), and therefore, is considered a noncarcinogenic PAH. Of the noncarcinogenic PAHs similar in structure and carbon number to phenanthrene, pyrene has the lowest toxicity value and is therefore, considered the most toxic. As a health protective approach, the pyrene toxicity value was selected as a surrogate for phenanthrene.

- Endrin aldehyde. Endrin aldehyde can occur as an impurity of endrin or as a degradation product (ATSDR 1996). The toxicity value for endrin was selected as a surrogate for endrin aldehyde.

- Endrin ketone. Endrin ketone can occur as an impurity of endrin or as a degradation product (ATSDR 1996). The toxicity value for endrin was selected as a surrogate for endrin ketone.

- 4-Methylphenol. IRIS has toxicity values for 2-methylphenol and 3-methylphenol, but not 4-methylphenol. The toxicity values for 2-methylphenol and 3-methylphenol are the same. The toxicity value for 2-methylphenol was selected as a surrogate for 4-methylphenol.

- 4-Chloro-2-methylphenol and 4-Chlorophenol. Toxicity values were not available for 4-chloro-2-methylphenol or 4-chlorophenol. The chemical with the most similar chemical structure for which toxicity information was available is 2-chlorophenol. The toxicity value for 2-chlorophenol was selected as a surrogate for 4-chloro-2-methylphenol and 4-chlorophenol.

4.5 CHEMICALS LACKING TOXICITY VALUES

Only one COPC, delta-hexachlorocyclohexane (delta-HCH), did not have available toxicity values or appropriate surrogate chemicals from sources included in the hierarchy. An STSC review concluded that the other hexachlorocyclohexane isomers could not be used as surrogates for delta-HCH due to differences in toxicity (EPA 2002c). In this Round 2 HHRA, the potential risk from delta-HCH was discussed qualitatively in the uncertainty assessment of the Round 2 HHRA.

Toxicity values were not identified for lead because lead was evaluated through comparison with benchmark concentrations that are based on blood lead levels predicted by the Integrated Exposure Uptake Biokinetic (IEUBK) model.

4.6 TOXICITY VALUES FOR CHEMICAL MIXTURES

Some toxicity values are based on exposure to chemical mixtures and not to individual chemicals. As a result, the risks were evaluated for the combined exposure to the chemicals and not on an individual chemical basis. The chemicals that were evaluated as mixtures are indicated in Tables 4-1 and 4-2, and are discussed below.

- Chlordane. The chlordane toxicity values were derived for technical chlordane, which is composed of a mixture of chlordane isomers. The chlordane isomers analyzed in Round 1 and Round 2 samples were alpha-chlordane, trans-chlordane, cis-nonachlor, trans-nonachlor, and oxychlordane. These isomers were summed in a total chlordane concentration. The SF and RfD for technical chlordane were used to evaluate total chlordane.

- DDD, DDE, and DDT. Technical DDT includes 2,4'-DDT and 4,4'-DDT, as well as 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, and 4,4'-DDD. DDD, DDE, and DDT have separate SFs included in IRIS. While the SFs were derived for the 4,4' isomers, the SFs were used to evaluate the sum of the 2,4' and 4,4' isomers because toxicity values are not available for the 2,4' isomers. The DDT RfD was derived for a mixture of the 2,4' and 4,4' isomers and was used to evaluate the noncancer endpoint of DDT. An RfD is not available for the DDD or DDE isomers, so the DDT RfD was selected as a surrogate toxicity value and was used to evaluate the noncancer endpoint of DDD and DDE.

- Endosulfan. The toxicity value (RfD) for endosulfan was derived from studies using technical endosulfan, which includes alpha-endosulfan, beta-endosulfan and endosulfan sulfate. These compounds were summed in a total endosulfan concentration. The RfD for technical endosulfan was used to evaluate total endosulfan.

- PCBs. The PCB cancer SF was derived for PCB mixtures based on administered doses of Aroclors to rats. The cancer SF was applied to total PCBs, measured either as congeners or Aroclors. Dioxin-like PCB congener concentrations were evaluated separately using the 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) SF, as described below for dioxins and furans. The PCB SF was applied to the total PCB congener concentration after subtracting the total dioxin-like PCB congener concentration. The Aroclor 1254 RfD was used to evaluate the noncancer endpoint for total PCBs, measured either as congeners or Aroclors.

- Dioxins and furans. TEFs were used to evaluate carcinogenic effects of dioxin and furan congeners and dioxin-like PCB congeners (see Table 2-6). Concentrations of congeners are multiplied by their TEFs to estimate the toxicity of these congeners relative to 2,3,7,8-TCDD; the resulting concentrations are then summed into a total 2,3,7,8-TCDD TEQ. The 2,3,7,8-TCDD SF was used to evaluate the cancer endpoint of the TEQ for dioxin and furan congeners and for dioxin-like PCB congeners. The EPA guidance for assessing dioxins recommends not using the RfD approach to evaluate the noncancer endpoint (EPA 2000c), so an RfD was not selected for dioxins.

4.7 DERMAL TOXICITY ASSESSMENT

Most toxicity values are based on oral, not dermal, exposures. For oral exposures, toxicity values are often expressed as the amount of substance administered, whereas dermal exposures are expressed as absorbed dose. EPA has developed a simplified method for oral-to-dermal extrapolations (EPA 2004a). These extrapolations involve an adjustment to the oral toxicity value based on the GI absorption factor of the specific chemical in the same administration vehicle (e.g., corn oil, food) as used in the critical toxicity study to derive an estimated dermal dose.

As recommended by EPA guidance (EPA 2004a), an adjustment to the oral toxicity factor to account for the estimated absorbed dose was applied in this Round 2 HHRA when the following conditions are met:

- The toxicity value derived from the critical study is based on an administered dose (e.g., through diet or by gavage)
- A scientifically defensible database demonstrates the GI absorption of the chemical is less than 50% in a medium similar to the one used in the critical study.

If both of these conditions are met, the oral toxicity factor was adjusted to reflect the absorbed dose in this Round 2 HHRA. For carcinogenic effects, the oral slope factor was divided by the GI absorption factor to estimate the dermal slope factor. For noncarcinogenic effects, the oral reference dose was multiplied by the GI absorption factor to estimate the dermal reference dose.

If both conditions for adjustment are not met, the oral toxicity value was used as a surrogate for the dermal toxicity value in the baseline HHRA. Dermal toxicity factors are presented in Tables 4-1 and 4-2.

5.0 RISK CHARACTERIZATION

Risk characterization integrates the information from the exposure assessment and toxicity assessment, using a combination of qualitative and quantitative information. With this information, risk characterization estimates the potential health risk, based on the dose of a chemical, that a person may receive under certain site-specific exposure conditions and the toxicity of that chemical. Consistent with DEQ (DEQ 2000a) and EPA guidance(EPA 1989), noncarcinogenic and carcinogenic effects were evaluated separately. To characterize potential noncarcinogenic effects, comparisons were made between projected intakes of substances and toxicity values (Section 5.1.1). To characterize potential carcinogenic effects, projected intakes and chemical-specific, dose-response data were used to estimate the upper bound probability that an individual will develop cancer over a lifetime of exposure (Section 5.1.2).

5.1 RISK CHARACTERIZATION ESTIMATES

This section describes how estimates for noncancer and cancer health risks were estimated in this preliminary HHRA.

5.1.1 Noncancer Hazard Estimates

The potential for adverse effects resulting from exposure to chemicals with noncarcinogenic effects is generally addressed by comparing the CDI or absorbed dose for a specific COPC to its RfD. This comparison was made by calculating the ratio of the estimated CDI (or absorbed dose) to the corresponding RfD to yield a hazard quotient (HQ):

$$HQ = \frac{CDI}{RfD}$$

HQs for individual chemicals were summed to yield hazard indices (HIs) that provide a conservative estimate of total hazard. Per EPA guidance (1989), HQs should only be summed for chemicals with common toxicological endpoints. In this Round 2 HHRA, the HQs were summed regardless of the toxicological endpoint. In the baseline HHRA, endpoint specific HIs (e.g., neurological or immune system effects) will be calculated.

Estimated hazard indices were compared to a target HI of 1, below which remedial action at a Superfund site is generally not warranted (EPA 1991).

5.1.2 Cancer Risk Estimates

Potential cancer risks were assessed by multiplying the estimated LADI or absorbed dose of a carcinogen by its SF. This calculated risk is expressed as the probability of an individual developing cancer over a lifetime as a result of exposure to the potential

carcinogen, and is an estimated upper bound incremental probability of excess individual lifetime cancer risk.

$$Risk = LADI * SF$$

Initially, potential cancer risks were estimated separately for each chemical. The separate potential cancer risk estimates were summed across chemicals to obtain the cumulative excess lifetime cancer risk for the exposure scenario.

Estimated total cancer risks were compared to a 10^{-4} to 10^{-6} risk range, which is the "target range" within which the EPA strives to manage risk as a part of the Superfund program (EPA 1991). The DEQ acceptable risk levels are 1×10^{-6} for individual carcinogens and 1×10^{-5} for cumulative cancer risks.

5.1.3 Cumulative Risk Estimates

Noncancer HQs and cancer risks were calculated for all individual chemicals for which EPCs were available, as described above. In some cases, chemicals were analyzed by different methods, so there were multiple EPCs for that chemical. In calculating the cumulative risks, only the risk associated with the EPC for one method was included in the sum to avoid double-counting the risks from a given chemical.

PCBs were analyzed both as congeners and as Aroclors. In sediment, the Aroclor dataset was more robust, so the risk from PCBs as Aroclors was included in the cumulative risk estimate for sediment. For tissue, the congener analysis provides better detection limits. Therefore, the risk from PCBs as congeners was included in cumulative risk estimate for tissue, if congener data were available. If congener data were not available, the risk from PCBs as Aroclors was used.

PCBs were analyzed as Aroclors in surface water samples collected using a peristaltic pump and as congeners in high-volume samples collected using the XAD sampling method. The detection limits for the peristaltic pump samples were higher than the high-volume samples, so the results for PCBs from the high-volume samples were used. In the high-volume samples, PCB Aroclor concentrations were estimated using the PCB congener data. As a result, only PCB congener data, when available, were used in cumulative risk estimates for surface water.

In surface water and most of the groundwater seep samples, metals were analyzed as both total and dissolved. Because total concentrations are typically higher, the EPCs for total metals were included in the cumulative risk estimates as a conservative approach.

The individual risks from the EPCs for all of the analytical methods are presented in the risk characterization result tables (Tables 5-1 through 5-58).

5.2 RISK CHARACTERIZATION RESULTS

This section presents the results of the risk characterization for each of the scenarios described in Section 3.

5.2.1 Beach Sediment Risk Characterization Results

Potential risks from exposure to beach sediment through incidental ingestion and dermal absorption were estimated for the dockside worker, transients, recreational beach users, non-tribal fishers and Native American fishers. Cumulative risk exceedances for beach sediment scenarios are summarized by exposure point in Figure 5-1.

5.2.1.1 Dockside Worker

Risks for the dockside worker were estimated separately for each beach designated as a potential dockside worker use area, which are shown in Figure 2-1. The results of the risk evaluation for dockside worker exposure to beach sediment are presented in Tables 5-1 and 5-2.

The dockside worker RME scenario for beach sediment results in exceedances of a cumulative cancer risk of 10^{-6} at beaches 06B025 and B004. There are no exposure areas that result in an exceedance of 10^{-4} cancer risk for the dockside worker RME scenario. The maximum cumulative cancer risk for an individual exposure area occurs at 06B025 (9×10^{-5}) and is primarily due to incidental ingestion of beach sediment containing benzo(a)pyrene. In addition to benzo(a)pyrene, other chemicals contributing to the calculated cancer risk greater than 10^{-6} for at least one exposure area include: benzo(a)anthracene, benzo(b)flouranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene. The HIs for the dockside worker RME scenario do not exceed 1. In estimating risks for the RME scenario, it was assumed that exposure occurs at an individual beach one day per week for 50 weeks a year for 25 years, and the level of exposure is the same as for soil. If the actual exposure at a given beach is less than that predicted by these assumptions, the calculated risks would also decrease correspondingly.

The dockside worker CT scenario for beach sediment results in one exceedance of 10^{-6} cumulative cancer risk (at beach 06B025, 6×10^{-6} risk) due to the incidental ingestion of sediment containing benzo(a)pyrene. There are no exposure areas that result in an exceedance of 10^{-4} cancer risk for the dockside worker CT beach sediment scenario. The dockside worker CT scenario results in no exceedances of a hazard index of 1. In estimating risks for the CT scenario, it was assumed that exposure occurs at an individual beach one day per week for 44 weeks a year for 9 years, and the level of exposure is the same as for soil. If the actual exposure at a given beach is less than that predicted by these assumptions, the calculated risks would also decrease correspondingly.

5.2.1.2 Transients

Risks for the transients were estimated separately for each beach designated as a potential transient use area, which are shown in Figure 2-1. The results of the risk

evaluation for transient exposure to beach sediment are presented in Tables 5-3 and 5-4.

The transient RME scenario for beach sediment results in no exceedances of 10^{-6} cancer risk and no exceedances of a hazard index of 1. The transient CT scenario for beach sediment results in no exceedances of 10^{-6} cancer risk and no exceedances of a hazard index of 1.

5.2.1.3 Recreational Beach Users

Risks for the recreational beach users were estimated separately for each beach designated as a potential recreational use area, which are shown in Figure 2-1. Risks were evaluated for both adult and child recreational beach users. The results of the risk evaluation for adult recreational beach user exposure to beach sediment are presented in Tables 5-5 and 5-6. The results of the risk evaluation for child recreational beach user exposure to beach sediment are presented in Tables 5-7 and 5-8.

Adult Recreational Beach Users

The adult recreational beach user RME scenario for beach sediment results in cumulative risk exceedances of 10^{-6} at the following beaches: 04B024, 06B030, B003, and B005. There are no exceedances of 10^{-4} cancer risk for the adult recreational beach user RME scenario. The maximum cumulative cancer risk from RME occurs at Beach 06B030 (4×10^{-6}) and is primarily due to incidental ingestion of beach sediment containing arsenic. The adult recreational beach user RME scenario for beach sediment resulted in no hazard indices greater than 1.

Arsenic is a naturally occurring metal. The concentration for arsenic in soil recognized by DEQ to represent background levels in Oregon is 7 milligrams per kilogram (mg/kg) (State-wide 90th percentile from WDOE, 1994). At this background concentration, the calculated risk from arsenic would exceed 10^{-6} for the adult recreational beach user RME scenario.

The adult recreational beach user CT scenario for beach sediment results in no exceedances of 10^{-6} cumulative cancer risk and no exceedances of an HI of 1.

In estimating risks for the RME scenario, it was assumed that exposure occurs at an individual beach 5 days per week in the summer, 1 day per week in the spring and fall, and 1 day per month in the winter for 30 years, and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil. For the CT scenario, it was assumed that exposure occurs at an individual beach 2 days per week in the summer and 2 days per month in the spring and fall for 9 years, and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil. If the actual exposure at a given beach is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

Child Recreational Beach Users

The child recreational beach user RME scenario for beach sediment results in cumulative risk exceedances of 10^{-6} at 13 of the 15 exposure areas (beaches 09B024 and 09B028 do not exceed 10^{-6} cumulative cancer risk). There are no exceedances of 10^{-4} cancer risk for the child recreational beach user RME scenario. The maximum cumulative cancer risk from RME occurs at beaches 06B030 and 04B024 (1×10^{-5}) and is primarily due to dermal absorption of soil containing arsenic and benzo(a)pyrene. The child recreational beach user RME scenario resulted in no HIs greater than 1.

The cumulative risk exceedances were primarily due to arsenic, which is naturally occurring. At the DEQ background soil concentration of 7 mg/kg, the calculated risk from arsenic would exceed 10^{-6} for the child recreational beach user RME scenario.

The child recreational beach user CT scenario for beach sediment results in no exceedances of 10^{-6} cumulative cancer risk and no exceedances of a hazard index of 1.

In estimating risks for the RME scenario, it was assumed that exposure occurs at an individual beach 5 days per week in the summer, 1 day per week in the spring and fall, and 1 day per month in the winter for 6 years, and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil. For the CT scenario, it was assumed that exposure occurs at an individual beach 2 days per week in the summer and 2 days per month in the spring and fall for 6 years, and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil. If the actual exposure at a given beach is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

5.2.1.4 Native American Fishers

Risks for the Native American fishers were estimated separately for each beach designated as a potential transient or recreational use area, which are shown in Figure 2-1. The results of the risk evaluation for Native American fisher exposure to beach sediment are presented in tables 5-9 and 5-10.

The Native American fisher RME scenario for beach sediment results in exceedances of 10^{-6} cumulative cancer risk at 18 of 18 exposure areas. There are no exceedances of 10^{-4} cancer risk for the Native American fisher RME scenario. The maximum cumulative cancer risk occurs at beaches 06B030 and 04B024 (2×10^{-5}) and is primarily due to incidental ingestion of sediment containing arsenic. In addition to arsenic, benzo(a)pyrene also results in an individual cancer risk greater than 10^{-6} at some exposure areas. The Native American fisher RME scenario for beach sediment resulted in no HIs greater than 1.

The Native American fisher CT scenario for beach sediment results in exceedances of 10^{-6} cumulative cancer risk at one of the 18 exposure areas (beach 06B030) primarily

due to incidental ingestion of sediment containing arsenic. There are no exceedances of 10^{-4} cancer risk or HI of 1 for the Native American fisher CT scenario.

The cumulative risk exceedances of 10^{-6} were primarily due to arsenic, which is naturally occurring. At the DEQ background soil concentration of 7 mg/kg, the calculated risk from arsenic would exceed 10^{-6} for the Native American fisher RME and CT scenarios.

In estimating risks for the RME scenario, it was assumed that exposure occurs at an individual beach 5 days per week for the entire year for 70 years and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil. For the CT scenario, it was assumed that exposure occurs at an individual beach 2 days per week for the entire year for 30 years, and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil. If the actual exposure at a given beach is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

5.2.1.5 Non-Tribal Fishers

Risks for the non-tribal fishers were estimated separately for each beach designated as a potential transient or recreational use area, which are shown in Figure 2-1. To evaluate differences in fishing frequencies, risks were evaluated for both non-tribal recreational and non-tribal non-recreational fishers. The results of the risk evaluation for non-tribal recreational fisher exposure to beach sediment are presented in Tables 5-11 and 5-12. The results of the risk evaluation for non-tribal non-recreational fisher exposure to beach sediment are presented in Tables 5-13 and 5-14.

Non-Tribal Recreational Fishers

The non-tribal recreational fisher RME scenario for beach sediment results in exceedances of 10^{-6} cumulative cancer risk at 9 of 18 exposure areas (see Table 5-11). There are no exceedances of 10^{-4} cancer risk for the non-tribal recreational fisher RME scenario. The maximum cumulative cancer risk occurs at beach 06B030 (6 x 10^{-6}) and is primarily due to incidental ingestion of sediment containing arsenic. In addition to arsenic, benzo(a)pyrene is the only other individual analyte resulting in a cancer risk greater than 10^{-6} at some exposure areas. The non-tribal recreational fisher RME scenario for beach sediment resulted in no HIs greater than 1.

The non-tribal recreational fisher CT scenario for beach sediment results in no exceedances of 10^{-6} cumulative cancer risk and no exceedances of an HI of 1.

In estimating risks for the RME scenario, it was assumed that exposure occurs at an individual beach 3 days per week for the entire year for 30 years and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil (approximately 4 times higher). For the CT scenario, it was assumed that exposure occurs at an individual beach 1 day per

week for the entire year for 9 years, and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil. If the actual exposure at a given beach is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

Non-Tribal Non-Recreational Fishers

The non-tribal non-recreational fisher RME scenario for beach sediment results in exceedances of 10^{-6} cumulative cancer risk at 5 of 18 exposure areas (see Table 5-13). There are no exceedances of 10^{-4} cancer risk for the non-tribal non-recreational fisher RME scenario. The maximum cumulative cancer risk occurs at beach 06B030 (4 x 10^{-6}), and is primarily due to incidental ingestion of sediment containing arsenic. Besides arsenic, there are no individual analytes resulting in a cancer risk greater than 10^{-6}. The non-tribal non-recreational fisher RME scenario for beach sediment resulted in no HIs greater than 1.

The non-tribal non-recreational fisher CT scenario for beach sediment results in no exceedances of 10^{-6} cumulative cancer risk and no exceedances of an HI of 1.

In estimating risks for the RME scenario, it was assumed that exposure occurs at an individual beach 2 days per week for the entire year for 30 years and the level of exposure is the same as for residential soil, except the adherence factor is even greater than that recommended for residential soil. For the CT scenario, it was assumed that exposure occurs at an individual beach 1 day every other week for the entire year for 9 years, and the level of exposure is the same as for residential soil, except, as with the other fisher scenarios, the adherence factor is even greater than that recommended for residential soil. If the actual exposure at a given beach is less than either the RME or CT scenarios, the risks would also be lower. If the actual exposure at a given beach is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

5.2.2 In-water Sediment Risk Characterization Results

Potential risks from exposure to in-water sediment through incidental ingestion and dermal absorption were estimated for the in-water workers, non-tribal fishers and Native American fishers. Risks were estimated separately for in-water sediment for each of the ½-mile river segment exposure areas (east (E) and west (W)) and for site-wide exposure. Cumulative risk exceedances for in-water sediment scenarios are summarized by exposure point in Figures 5-2 and 5-3.

5.2.2.1 In-water Worker

The results of the risk evaluation for in-water worker exposure to in-water sediment are presented in Tables 5-15 and 5-16.

The in-water worker RME scenario for in-water sediment results in exceedances of a cumulative cancer risk of 10^{-6} at RM segments 4.5E, 6W, 7W, and from site wide exposure. There are no exceedances of 10^{-4} cancer risk for the in-water worker RME

scenario. The maximum cumulative cancer risk for an individual exposure area occurs at RM 7W (3×10^{-5}) and is primarily due to incidental ingestion of sediment containing dioxins/furans. The only other chemical resulting in a cancer risk greater than 10^{-6} within the Study Area is benzo(a)pyrene. The HIs for in-water worker RME scenario do not exceed 1.

The in-water worker CT scenario for in-water sediment results in no exceedances of 10^{-6} cancer risk and no exceedances of an HI of 1.

In estimating risks for the RME scenario, it was assumed that exposure occurs at one ½-mile river segment 10 days every year for 10 years, and the level of exposure is the same as for industrial soil. For the CT scenario, it was assumed that exposure occurs at one ½-mile river segment 10 days every year for 4 years, and the level of exposure is the same as for industrial soil. If the actual exposure to in-water sediment is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

5.2.2.2 Native American Fisher

The results of the risk evaluation for Native American fisher exposure to in-water sediment are presented in tables 5-17 and 5-18.

The Native American fisher RME scenario for in-water sediment results in exceedances of 10^{-6} cumulative cancer risk in 31 of 37 river mile segments and from site-wide exposure (see Table 5-17). The RME scenario for in-water sediment results in cumulative cancer risk greater than 10^{-4} at RM 4.5E and RM 7W. The maximum cumulative cancer risk occurs at RM 7W (4×10^{-4}) and is primarily due to incidental ingestion of sediment containing dioxins/furans. In addition to dioxins/furans, the following individual analytes also result in an individual cancer risk greater than 10^{-6} in at least one exposure area: arsenic, PCBs, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, benzo(a)anthracene, indeno(1,2,3-cd)pyrene. The Native American fisher RME scenario for in-water sediment resulted in no HIs greater than 1.

The Native American fisher CT scenario for in-water sediment results in exceedances of 10^{-6} cumulative cancer risk at three of the 37 river mile segments (RM 4.5E, RM 6W, and RM 7W). There are no exceedances of 10^{-4} cancer risk for the Native American fisher CT scenario. The maximum cumulative cancer risk occurs at RM 6W (5×10^{-6}) and is primarily due exposure to sediment containing benzo(a)pyrene. The Native American fisher CT scenario for in-water sediment resulted in no HIs greater than 1.

In estimating risks for the RME scenario, it was assumed that exposure occurs at one ½-mile river segment 5 days per week for the entire year for 70 years and that exposure resulting in ingestion of sediment and coverage of the hands and forearms occurs 25 percent of the time. For the CT scenario, it was assumed that exposure occurs at one ½-mile river segment 3 days per week for the entire year for 30 years

and that exposure resulting in ingestion of sediment and coverage of the hands and forearms occurs 25 percent of the time. If the actual exposure to in-water sediment from fishing is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

5.2.2.3 Non-Tribal Fisher

To evaluate differences in fishing frequencies, risks were evaluated for both non-tribal recreational and non-tribal non-recreational fishers. The results of the risk evaluation for non-tribal recreational fisher exposure to in-water sediment are presented in Tables 5-19 and 5-20. The results of the risk evaluation for non-tribal non-recreational fisher exposure to in-water sediment are presented in Tables 5-21 and 5-22.

Non-Tribal Recreational Fisher

The non-tribal recreational fisher RME scenario for in-water sediment results in exceedances of 10^{-6} cumulative cancer risk in 12 of 37 river mile segments and from site-wide exposure (see Table 5-19). There are no exceedances of 10^{-4} cancer risk for the non-tribal recreational fisher RME scenario. The maximum cumulative cancer risk occurs at RM 7W (1×10^{-4}) and is primarily due incidental ingestion of sediment containing dioxins/furans. In addition to dioxins/furans, the following individual analytes also result in a cancer risk greater than 10^{-6} in at least one exposure area: arsenic, PCBs, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, benzo(a)anthracene, indeno(1,2,3-cd)pyrene. The non-tribal recreational fisher RME scenario for in-water sediment resulted in no HIs greater than 1.

The non-tribal recreational fisher CT scenario for in-water sediment results in no exceedances of 10^{-6} cumulative cancer risk and no exceedances of an HI of 1.

In estimating risks for the RME scenario, it was assumed that exposure occurs at one ½-mile river segment 3 days per week for the entire year for 30 years and that exposure resulting in ingestion of sediment and coverage of the hands and forearms occurs 25 percent of the time. For the CT scenario, it was assumed that exposure occurs at one ½-mile river segment 1 day per week for the entire year for 9 years and that exposure resulting in ingestion of sediment and coverage of the hands and forearms occurs 25 percent of the time. If the actual exposure to in-water sediment from fishing is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

Non-Tribal Non-Recreational Fisher

The non-tribal non-recreational fisher RME scenario for in-water sediment results in exceedances of 10^{-6} cumulative cancer risk at 9 of 37 river mile segments and from site-wide exposure (see table 5-21). There are no exceedances of 10^{-4} cancer risk for the non-tribal non-recreational fisher RME scenario. The maximum cumulative cancer risk occurs at RM 7W (8×10^{-5}) and is primarily due to incidental ingestion of sediment containing dioxins/furans. In addition to dioxins/furans, the following individual analytes also result in a cancer risk greater than 10^{-6} in at least one

exposure area: arsenic, PCBs, benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(a)anthracene. The non-tribal non-recreational fisher RME scenario for in-water sediment resulted in no HIs greater than 1.

The non-tribal non-recreational fisher CT scenario for in-water sediment results in no exceedances of 10^{-6} cumulative cancer risk and no exceedances of an HI of 1.

In estimating risks for the RME scenario, it was assumed that exposure occurs at one ½-mile river segment 2 days per week for the entire year for 30 years and that exposure resulting in ingestion of sediment and coverage of the hands and forearms occurs 25 percent of the time. For the CT scenario, it was assumed that exposure occurs at one ½-mile river segment 1 day every other week for the entire year for 9 years and that exposure resulting in ingestion of sediment and coverage of the hands and forearms occurs 25 percent of the time. If the actual exposure to in-water sediment from fishing is less than that predicted by the RME or CT scenarios, the calculated risks would also decrease correspondingly.

5.2.3 Surface Water Risk Characterization Results

Potential risks from exposure to surface water through ingestion and dermal absorption were estimated for the transients and recreational beach users.

5.2.3.1 Transients

Risks to transients from surface water were evaluated for drinking water and bathing scenarios. The risks were evaluated for year-round exposure to three individual transect stations, to the three transects grouped together (to represent site-wide exposure), and to Willamette Cove. The results of the risk evaluation for transient exposure to surface water are presented in Tables 5-23 and 5-24.

The transient RME scenario for surface water results in no exceedances of 10^{-6} cancer risk and no exceedances of an HI of 1. The transient CT scenario for surface water results in no exceedances of 10^{-6} cancer risk and no exceedances of an HI of 1.

5.2.3.2 Recreational Beach Users

Risks to recreational beach users from surface water were evaluated for swimming scenarios, using data from summer months. Risks were evaluated for exposure to three transects grouped together (to represent site-wide exposure) and for exposure to three individual quiescent areas during summer months. Risks for both adults and children were evaluated. The results of the risk evaluation for adult recreational beach user exposure to surface water are presented in Tables 5-25 and 5-26. The results of the risk evaluation for child recreational beach user exposure to surface water are presented in tables 5-27 and 5-28.

The adult and child recreational beach user RME scenarios for surface water result in no exceedances of 10^{-6} cancer risk and no exceedances of an HI of 1. The adult and

child recreational beach user CT scenarios for surface water result in no exceedances of 10^{-6} cancer risk and no exceedances of an HI of 1.

5.2.4 Groundwater Seep Risk Characterization Results

Only one groundwater seep was identified in a transient or recreational use area where upland COIs were potentially discharging. The seep identified is actually the potential groundwater discharge that could occur from Outfall 22B, which discharges into a transient use area. As a result, risks to transients from potential exposure to groundwater seeps were evaluated at that beach (07B024).

5.2.4.1 Transients

Risks to transients from surface water were evaluated for drinking water and bathing scenarios. The risks were evaluated for year-round exposure to three individual transect stations, to the three transects grouped together (to represent site-wide exposure), and to Willamette Cove. The results of the risk evaluation for transient exposure to the groundwater seep are presented in tables 5-29 and 5-30.

The transient RME scenario for the groundwater seep results in no exceedances of 10^{-6} cancer risk and no exceedances of an HI of 1. The transient CT scenario for the groundwater seep results in no exceedances of 10^{-6} cancer risk and no exceedances of an HI of 1.

5.2.5 Fish Consumption Risk Characterization Results

Potential risks from fish consumption were estimated for non-tribal and Native American fisher scenarios.

5.2.5.1 Native American Fishers

Risks to Native Americans who consume fish caught within the Study Area were evaluated for a multi-species diet that includes salmon, lamprey, and sturgeon, in addition to resident fish species. A single ingestion rate for the multi-species diet was used to evaluate risks to the Native American fish consumer. Risks were evaluated using both UCL/max and mean site-wide tissue concentrations for both fillet and whole body tissue (see Section 3.3.5). Risks were higher for whole body tissue than for fillet tissue; however, fillet tissue was not analyzed for PCB or dioxin/furan congeners. The results of the risk evaluation for adult Native American fish consumption are presented in Tables 5-31 and 5-32. The results of the risk evaluation for child Native American fish consumption are presented in Tables 5-33 and 5-34.

Adult Consumption

The risks ranged from a cumulative cancer risk of 1×10^{-2} for the UCL/max EPCs of whole body tissue to a cumulative cancer risk of 1×10^{-3} for the mean EPCs of fillet tissue. For all scenarios, risks are above a 10^{-4} cumulative cancer risk and are primarily due to PCBs and dioxins/furans.

The HIs, which were not endpoint specific, ranged from 200 for the UCL/max EPCs of whole body tissue to 30 for the mean EPCs of fillet tissue. For the whole body tissue, 95UCL/max EPC diet scenario, the PCB HQ is approximately 30 times higher any other HQ.

The multiple species diet included resident fish as well as salmon, sturgeon, and lamprey. Because salmon, sturgeon, and lamprey spend time outside the Study Area, the risks from ingestion of salmon, sturgeon, and lamprey cannot be conclusively associated with sources within the Study Area. However, resident fish accounted for approximately 95 percent of the cumulative risk in the whole body diet.

The ingestion rate used for the adult Native American fish consumer (175 g/day) is the 95 percentile from the CRITFC Fish Consumption study. Fish consumption was assumed to occur at this level every day of every year for 70 years and consists entirely of fish caught within the Study Area. If the level of ingestion were lower or if a portion of the fish consumed includes store-bought fish or fish caught at other locations, the calculated risks from fish consumption at the Study Area would be lower. For participants of the CRITFC Fish Consumption study, none fished the Willamette River for resident fish and at most, approximately 4 percent fished the Willamette River for anadromous fish. The calculated risks do not account for any decrease in tissue concentrations of chemicals that may occur during preparation or cooking of the fish. Uncertainties associated with this scenario are discussed further in Section 7.0.

Child Consumption

The risks ranged from a cumulative cancer risk of 2×10^{-3} for the UCL/max EPCs of whole body tissue to a cumulative cancer risk of 2×10^{-4} for the mean EPCs of fillet tissue. For all scenarios, risks are above a 10^{-4} cumulative cancer risk and are primarily due to PCBs and dioxins/furans.

The HIs, which were not endpoint specific, ranged from 300 for the UCL/max EPCs of whole body tissue to 50 for the mean EPCs of fillet tissue. The PCB HQ for the whole body tissue diet is approximately 30 times higher than any other HQ.

The multi-species diet included resident fish as well as salmon, sturgeon, and lamprey. Because salmon, sturgeon, and lamprey spend time outside the Study Area, the calculated risks from ingestion of salmon, sturgeon, and lamprey cannot be conclusively associated with sources within the Study Area. However, resident fish accounted for approximately 95 percent of the cumulative risk.

The ingestion rate used for the child Native American fish consumer (73 g/day) is the 95 percentile from the CRITFC Fish Consumption study. Fish consumption was assumed to occur at this level every day of every year for 6 years and consists entirely of fish caught within the Study Area. If the level of ingestion were lower or if a portion of the fish consumed includes store-bought fish or fish caught at other locations, the risks from fish consumption at the Study Area would be lower. The calculated risks do not account for any decrease in tissue concentrations of chemicals

that may occur during preparation or cooking of the fish. Uncertainties associated with this scenario are discussed further in Section 7.0.

5.2.5.2 Non-Tribal Fishers

Risks for the non-tribal fish consumption scenarios were estimated for both single- and multi-species diets consisting only of resident fish species (smallmouth bass, black crappie, brown bullhead, and carp). Risks were estimated separately for each exposure area (based on species home range) and for site-wide exposure. Consumption of smallmouth bass was evaluated on a river mile basis, and consumption of carp, brown bullhead, and black crappie was evaluated on a fishing zone basis (fishing zones were designated from RM 3-6 and from RM 6-9). In addition to evaluating risks using mean and UCL/max tissue concentrations for both whole body and fillet tissue, each fish consumption scenario was evaluated using three different ingestion rates for adult and child non-tribal fish consumers. The results of the risk evaluation for non-tribal adult fish consumption are presented in tables 5-35 to 5-44. The results of the risk evaluation for non-tribal child fish consumption are presented in tables 5-45 to 5-54.

Adult Consumption

Risks to adult non-tribal fish consumers were evaluated for high (142 g/day), medium (73.5 g/day), and low (17.5 g/day) ingestion rates. These rates correspond to approximately 19 meals per month, 10 meals per month, and 2 meals per month, based on an 8-ounce serving size, every month of the year exclusively of fish caught within the Study Area.

The risks for all adult non-tribal fish consumer scenarios ranged from a cumulative cancer risk of 2×10^{-2} for the UCL/max EPC, high ingestion rate, carp tissue scenario to a cumulative cancer risk of 7×10^{-6} for the mean EPC, low ingestion rate, black crappie tissue scenario. For all tissue consumption scenarios, cumulative cancer risks are primarily driven by PCBs. Other analytes consistently resulting in greater than 10^{-6} individual cancer risk include dioxins/furans, inorganic arsenic, and total DDE.

The HIs, which were not endpoint specific, from fish tissue ranged from 700 for the UCL/max EPC, high ingestion rate, common carp tissue scenario to 0.5 for the mean EPC, low ingestion rate, black crappie tissue scenario. For the UCL/max EPC, multi-species, whole body tissue diet scenario, the PCB HQ is approximately 100 times higher than the HQ for any other chemical.

In general, risks from consuming whole body tissue were greater than risks from consuming fillet tissue; however, fillet tissue was not analyzed for PCB or dioxin/furan congeners, and therefore PCB TEQ and dioxin/furan TEQ risks could not be not evaluated in fillet tissue. Smallmouth bass and common carp diet scenarios generally resulted in higher risks than the other diets evaluated. Black crappie diet scenarios generally resulted in the lowest risks of the diets evaluated.

Tissue consumption was assumed to occur at the stated ingestion rate every day of every year for a 30-year duration and consists entirely of fish caught within the Study Area. If the ingestion rate were lower, or if a portion of the fish consumed included

store-bought fish or fish caught at other locations, the calculated risks from fish consumption at the Study Area would be lower. The risks do not account for any decrease in tissue concentrations of chemicals that may occur during preparation or cooking of the fish. Uncertainties associated with this scenario are discussed further in Section 7.0.

Child Consumption

Risks to child non-tribal fish consumers were evaluated for high (60 g/day), medium (31 g/day), and low (7 g/day) ingestion rates.

The risks for all child non-tribal fish consumer scenarios ranged from a cumulative cancer risk of 8×10^{-3} for the UCL/max EPC, high ingestion rate, carp tissue scenario to a cumulative cancer risk of 3×10^{-6} for the mean EPC, low ingestion rate, black crappie tissue scenario. For all tissue consumption scenarios, cumulative cancer risks are primarily driven by PCBs.

The HIs, which were not endpoint specific, from fish tissue ranged from 900 for the UCL/max EPC, high ingestion rate, bass tissue scenario to 1 for the mean EPC, low ingestion rate scenario for bass, bullhead, and black crappie tissue. For the UCL/max EPC, multi-species, whole body tissue diet scenario, the PCB HQ is approximately 100 times higher than the HQ for any other chemical.

In general, risks from whole body tissue were greater than risks from fillet tissue. Smallmouth bass and common carp diet scenarios generally resulted in higher risks than the other diets evaluated. Black crappie diet scenarios generally resulted in the lowest risks of the diets evaluated.

Tissue consumption was assumed to occur at the stated ingestion rate every day of every year for a 6-year duration, and consists entirely of fish caught within the Study Area. If the ingestion rate were lower, or if a portion of the fish consumed included store-bought fish or fish caught at other locations, the calculated risks from fish consumption at the Study Area would be lower. The calculated risks do not account for any decrease in tissue concentrations of chemicals that may occur during preparation or cooking of the fish. Uncertainties associated with this scenario are discussed further in Section 7.0.

5.2.5.3 Upstream Fish Consumption

Smallmouth bass and brown bullhead whole body tissue samples were collected and composited at RM 20 and 28 during Round 1, at the same time the resident fish species were collected and composited within the Study Area. A total of six smallmouth bass and three brown bullhead samples were collected. EPCs were calculated for these samples using the same approach as for the fish collected within the Study Area, which is described in Section 3.5.5. The EPCs for the upstream fish tissue and associated risk estimates are presented in Attachment F1.

Risks from consumption of the upstream fish tissue were evaluated using the same ingestion rates and exposure assumptions as the adult non-tribal fish consumer. The cumulative cancer risks ranged from 6×10^{-5} to 2×10^{-3}. The HIs, which were not

endpoint specific, ranged from 0.6 to 40. The cumulative cancer risks are primarily driven by PCBs and dioxins/furans. In the scenario with the highest HI, the PCB HQ is approximately 3 times higher than the next highest HQ, which is from mercury. PCBs and mercury are the only chemicals with HQs greater than 1 for any of the scenarios.

5.2.6 Shellfish Consumption Risk Characterization Results

Potential risks from shellfish consumption were estimated for the adult non-tribal scenarios. Risks to adult non-tribal shellfish consumers were evaluated for clam and crayfish diets. Risks were estimated separately for each sample station and for site-wide exposure, using both a high (18 g/day) and low (3.3 g/day) ingestion rate. Risks were evaluated using both UCL/max and mean tissue concentrations of shellfish tissue. The results of the risk evaluation for shellfish consumption are presented in tables 5-55 to 5-58. Cumulative risk exceedances for shellfish scenarios are summarized by exposure point in Figures 5-4 and 5-5.

The risks ranged from a cumulative cancer risk of 8×10^{-4} for the UCL/max high ingestion clam tissue scenario to a cumulative cancer risk of 1×10^{-6} for the mean EPC low ingestion crayfish tissue scenario. For all high ingestion rate scenarios, risks are above a 10^{-6} cumulative cancer risk and are primarily due to PCBs.

The HIs from shellfish tissue ranged from 4 for the UCL/max EPCs, high ingestion rate, crayfish tissue scenario to 0.05 for the mean EPCs, low ingestion rate clam tissue scenario. Noncancer risks above an HI of 1 are primarily due to PCBs.

Shellfish consumption was assumed to occur at the stated ingestion rate every day of every year for a 30-year duration, and consists entirely of shellfish collected at the same station within the Study Area. If the ingestion rate were lower, or if a portion of the shellfish consumed included store-bought shellfish or shellfish caught at other locations, the calculated risks from consuming shellfish collected from the Study Area might be lower. . In calculating the risk estimates it was assumed tha the whole organism was consumed, and there was no decrease in chemical concentrations in tissue during preparation, such as depuration for the clams or removal of crayfish heads, or cooking. Uncertainties associated with this scenario are discussed further inSection 7.0.

5.2.7 Evaluation of Cumulative and Overlapping Scenarios

As shown in the conceptual site model (Figure 3-1), multiple exposure scenarios may exist for a given population. For example, recreational beach users are potentially exposed to both beach sediment and surface water. The risks for each of the exposure scenarios that are considered potentially complete and significant for a given population were summed to estimate the cumulative risks for that population. The cumulative risks are presented in Table 5-59.

As discussed in Section 3, certain individuals may be exposed to COPCs within the Study Area through multiple exposure scenarios; for example, a recreational beach user might also be a non-tribal fisher. This Round 2 HHRA quantitatively estimated risks for the individual exposure scenarios. Due to multiple exposure locations over different scales for both RME and CT scenarios, as well as ranges of ingestion rates and multiple diets for fish consumption, there are numerous potential combinations of overlapping scenarios. As a result, this Round 2 HHRA did not quantitatively evaluate possible overlapping scenarios. However, risks from fish consumption are generally at least an order of magnitude higher than risks from other exposure scenarios, so if an individual consumes fish, the contribution from other exposure scenarios is not likely to contribute significantly to the overall risks for that individual. The uncertainties associated with overlapping scenarios are discussed further in Section 7.

5.2.8 Risk Characterization of Lead

A great deal of information on the health effects of lead has been obtained through decades of medical observation and scientific research. By comparison to most other environmental toxicants, the degree of uncertainty about the health effects of lead is quite low. Because age, health, nutritional state, body burden, and exposure duration influence the absorption, release, and excretion of lead, EPA has not established standard toxicity endpoints for lead. Instead, the concentration of lead in the blood is used as an index of the total dose of lead, regardless of the route of exposure (EPA 1994). As a result, blood lead levels, rather than intakes, are used to evaluate potential risks associated with exposure to lead. The Centers for Disease Control (CDC) has identified a blood lead level of 10 micrograms per deciliter (μg/dl) as the level of concern above which significant health risks may occur (CDC 1991). An acceptable risk for lead exposure typically equates to a predicted probability of no more than 5 percent greater than the 10 μg/dl level (EPA 1998).

Lead was identified as a COPC for in-water sediment, fish and shellfish, surface water, and groundwater seeps. The following discusses the evaluation of risks from lead for each of those media:

5.2.8.1 In-water sediment

Lead was identified as a COPC for in-water sediment because the maximum detected concentration exceeds the Region 9 PRG for industrial soil of 800 mg/kg. The Region 9 PRG was developed to be protective of the fetus of a pregnant woman exposed to lead. The only receptors for in-water sediment exposures are adults. Therefore, the fetus of a pregnant in-water worker or fisher is the most sensitive scenario for exposure to lead in in-water sediment, and the Region 9 PRG is protective of that scenario. While maximum detected concentrations were used in identifying COPCs, exposure point concentrations were used to calculate risks. The maximum exposure point concentration for lead is 690 mg/kg, which is less than the Region 9 PRG. Because the maximum exposure point concentration for lead is below

the Region 9 PRG, lead is not considered a chemical of concern for in-water sediment.

5.2.8.2 Fish

Lead was identified as a COPC for fish tissue because it was detected. The Columbia River Basin Fish Contaminant Survey (CRITFC 1994) determined fish tissue concentrations for lead that are unlikely to result in blood lead levels exceeding 10 µg/dl. These concentrations were developed using the IEUBK model and the Adult Lead Methodology (ALM) in combination with the fish ingestion rates from the CRITFC Fish Consumption Survey. The lead tissue concentrations of concern were determined to be 500 microgram per kilogram (µg/kg) for children and 700 µg/kg for fetuses. The concentrations of concern were developed using health protective exposure assumptions and were considered unlikely to underestimate risks from fish consumption. The maximum exposure point concentration of lead in fish in the Study Area was 300 µg/kg, which is below both of the tissue levels of concern. Therefore, lead is not considered a chemical of concern for fish tissue.

5.2.8.3 Shellfish

Lead was identified as a COPC for shellfish tissue because it was detected. Shellfish consumption was only evaluated for adult scenarios. Therefore the tissue concentration of concern for fetuses is the only tissue concentration relevant for shellfish consumption. The maximum detected concentration of lead in shellfish was 1320 µg/kg, which exceeds the CRITFC (1994) Fish Consumption Survey tissue concentration of concern of 700 µg/kg. However, that tissue concentration of concern was developed based on fish ingestion rates.

The CRITFC Fish Consumption Survey developed the tissue concentration of concern based on the ALM. The following equations were used:

$PbB_a = PbB_o + BKSF * (PbF * IR_F * AF_F * EF_F)/AT$
$PbBf = PbBa * 0.9$
Probability that fetal blood lead is greater or equal to 10 µg/dl using the z-value where: $z = \ln(10) - \ln(PbBf)/\ln(GSD)$

Where:
PbB_a = Central tendency of adult blood lead level
PbB_o = Adult baseline blood lead level (high end value of 2.2 µg/dl)
PbBf = Fetal blood lead level
GSD = Geometric standard deviation (high end value of 2.1)
BKSF = Biokinetic slope factor (0.4 µg/dl per microgram per day [µg/day])
PbF = Lead tissue concentration
IR_F = Tissue ingestion rate
AF_F = Absolute gastrointestinal ingestion factor for ingested lead in tissue (0.1)
EF_F = Exposure frequency of fish ingestion (365 days)
AT = Averaging time (365 days)

The evaluation of risks from lead is based on geometric mean levels and associated probabilities, so median values are generally used as inputs to the equations. If the median shellfish ingestion rate of 3.3 g/day is used with the maximum shellfish exposure point concentration of 1320 µg/kg, the ALM predicts that fetal blood lead levels will exceed 10 µg/dl less than 5 percent of the time. Therefore, lead is not considered a chemical of concern for shellfish tissue.

5.2.8.4 Surface water

Lead was identified as a COPC for surface water because it was detected and there is not a Region 9 tap water PRG for lead. The maximum detected concentration of lead in surface water is 0.277 microgram per liter (µg/l). The IEUBK model and ALM do not address the exposure scenarios evaluated in this preliminary HHRA. However, the action level for lead in drinking water is 15 µg/l. Because the maximum detected concentration is less than the action level for drinking water, lead is not considered a chemical of concern for surface water.

5.2.8.5 Groundwater Seep

Lead was identified as a COPC for the groundwater seep because it was detected and there is not a Region 9 tap water PRG for lead. The only exposure scenario for the groundwater seep is an adult transient. The maximum detected concentration of lead in the groundwater seep is 14 µg/l, which is less than the action level for drinking water. Because the maximum detected concentration is less than the action level for drinking water, lead is not considered a chemical of concern for groundwater seeps.

5.3 SUMMARY OF RISK CHARACTERIZATION

The ranges of estimated potential risks resulting from the different exposure scenarios evaluated in this Round 2 HHRA are summarized in Table 5-60. The ranges included in Table 5-60 for different scenarios reflect differences in CT vs. RME scenarios, differences in tissue EPCs (mean vs. UCL/max), level of fish consumption (high, medium, and low), location of sediment (for beach scenarios), tissue type (whole body vs. fillet), and species of fish consumed. In general, the risks from fish consumption are higher than any of the other exposure scenarios evaluated in this Round 2 HHRA. The range of cumulative risks from all fish consumption scenarios is 3×10^{-6} to 2×10^{-2}, and the HIs, without consideration of the toxicological endpoints, range from 0.5 to 1,000. Cumulative cancer risks from consumption of shellfish range from 1×10^{-6} to 8×10^{-4}, and the HIs, without consideration of the toxicological endpoints, range from 0.05 to 20. For beach sediment, cumulative cancer risks range from 8×10^{-9} to 9×10^{-5}, and the HIs range from 0.0005 to 0.4. For in-water sediment, cumulative cancer risks range from 5×10^{-9} to 4×10^{-4}, and the HIs range from 0.0001 to 0.3. For surface water, cumulative cancer risks range from 2×10^{-9} to 7×10^{-7}, and the HIs range from 0.00003 to 0.05. For groundwater seeps, cumulative cancer risks range from 6×10^{-10} to 5×10^{-9}, and the HIs range from 0.0007 to 0.003.

Chemicals were identified as iCOCs if they resulted in a cancer risk greater than 1×10^{-6} or an HQ greater than 1 under any of the exposure scenarios for any of the exposure point concentrations evaluated in this Round 2 HHRA, regardless of the uncertainties. As a result, the iCOCs include chemicals that were detected infrequently, that pose relatively low risks compared with other iCOCs, and that are associated with highly uncertain exposure scenarios. The iCOCs and the associated exposure scenarios are presented in Table 5-61.

6.0 SCREENING OF SURFACE AND TRANSITION ZONE WATER DATA

This Round 2 HHRA evaluated risks associated with the potentially complete and significant exposure pathways identified in the CSM. As agreed to by EPA, scenarios that were not evaluated in this Round 2 HHRA include: (1) surface water as a source of contamination for biota that are consumed by humans, (2) surface water as a drinking water source, (3) TZW as source of contamination for biota that are consumed by humans, and (4) TZW as a potential source to surface water. In its comments on the PRG TM dated June 30, 2006, EPA required that surface water and TZW be screened against specific criteria. This section presents the evaluation of TZW and surface water with respect to human health based screening levels that were specified by EPA. This evaluation was performed to assist with identifying data gaps with respect to human health exposure pathways. This screening evaluation does not indicate that these are potentially complete exposure pathways nor does it indicate that unacceptable risks exist for these exposure pathways.

6.1 SCREENING OF SURFACE WATER DATA

This section presents the results of screening the complete surface water data set (i.e., all of the Round 2 surface water samples from the SCRA dataset, including those not used in the Round 2 HHRA) against human health based screening levels for drinking water and for the consumption of organisms. This is a separate evaluation from the identification of COPCs presented in Section 2.

6.1.1 Screening of Surface Water Data for Biota Consumption Pathway

Risks from consumption of biota were evaluated in this Round 2 HHRA using empirical tissue data collected within the Study Area. The use of actual tissue data to assess risks provides for greater confidence in calculated risk estimates than attempting to model tissue data from sediment and/or water.

However, in the EPA's comments on the PRG TM (dated June 30, 2006), EPA requested that surface water data be screened, as a source of contaminants to biota consumed by humans, against Human Health Ambient Water Quality Criteria for the Consumption of Organisms (human health AWQC) (EPA 2006a). Human health AWQC are not site-specific but rather rely on default assumptions about bioconcentration.

To evaluate the biota consumption exposure pathway, the maximum concentration detected in surface water for each chemical was compared to the respective human health AWQC. If the human health AWQC was exceeded and the frequency of detection for that chemical was greater than 5 percent, the next consideration for the potential for bioconcentration was whether or not the chemical was detected in shellfish or fish tissue at concentrations that lead to unacceptable risk for the consumption of fish or shellfish. The evaluation of risk from consumption of fish or

shellfish based on tissue data was presented in Section 5 of the Round 2 HHRA. If the chemical was detected in tissue, though at concentrations not leading to unacceptable risk levels, it is likely that site specific factors are reducing the bioavailability of the chemical relative to the default assumptions used to derive the human health AWQC.

Table 6-1 presents the results for screening surface water against human health AWQC. All of the Round 2 surface water samples were included in the data set screened for this evaluation. Of the list of chemicals detected in surface water at concentrations exceeding human health AWQC, only chrysene was not identified as an iCOC for shellfish or fish tissue. The AWQC for chrysene was derived using the benzo(a)pyrene toxicity value; however, the cancer slope factor for chrysene is 1,000 times less than that of benzo(a)pyrene, so exceedance of the AWQC for chrysene is not an indication of unacceptable risk.

Chrysene was detected in clam and crayfish tissue at concentrations that do not lead to unacceptable risk levels. Chrysene was detected in only one of the 27 crayfish tissue samples analyzed. The detected concentration of 87 micrograms per kilogram (µg/kg) led to an estimated risk level of 7×10^{-8} (18 g/day ingestion rate). Chrysene was detected in 30 of the 32 clam samples in which it was analyzed. For consumption of clams, the maximum cancer risk level was 5×10^{-7} (18 g/day ingestion rate).

In summary, measured tissue concentrations are available for all chemicals that were detected in surface water at concentrations exceeding the human health AWQC, which allowed for the use of empirical data to calculate potential human health risks.

6.1.2 Screening of Surface Water Data for Drinking Water

The LWR is not currently used as a public drinking water source nor are there future plans to develop a source of public drinking water from the LWR. Nonetheless, a screening level evaluation was performed as required by EPA in its comments on the PRG TM (dated June 30, 2006) in order to identify which chemicals were detected in surface water at concentrations exceeding EPA Region 9 tap water PRGs (EPA 2004b) or EPA Maximum Concentration Levels (MCLs) for public water systems (EPA 2006b). Table 6-1 presents the results of this screening level evaluation.

Chemicals that were detected at a detection frequency greater than 5 percent and at a maximum concentration exceeding the EPA Region 9 tap water PRG include: arsenic, several PAHs and dioxin/furan compounds. No chemicals were detected at concentrations exceeding the respective MCL. Figure 6-1 displays the locations of surface water samples with measured results exceeding the respective EPA Region 9 tap water PRG.

6.2 SCREENING OF TRANSITION ZONE WATER DATA

There are no direct exposure pathways for human populations to TZW. However, in theory, chemicals present in TZW could accumulate in biota that are consumed by humans or could contribute to surface water concentrations. A framework was developed to provide a screening level evaluation of TZW data for human health endpoints (Figure 6-2). This section presents the results of the screening of TZW data for the biota consumption pathway and for contributions to surface water. It should be noted that TZW data were collected from targeted areas within the Site based on likelihood of contamination contribution from upland sources. The selective nature of the TZW data set represents the worst case scenario for human health risks from potential exposure to TZW.

6.2.1 Screening of TZW for Biota Consumption Pathway

As shown in the TZW evaluation framework, the first step in the screening process is comparison of the TZW data with human health AWQC. If chemicals that exceed AWQC were analyzed in tissue, risks from consumption of fish and shellfish were considered. If chemicals that exceed AWQC were not analyzed in tissue, the AWQC were evaluated further. The following describes the screening of TZW for the biota consumption pathway.

6.2.1.1 Screening of TZW Data Against Human Health AWQC

To evaluate TZW with respect to the biota consumption exposure pathway, for each chemical, the maximum concentration detected in TZW was compared to the respective human health AWQC. If the AWQC was exceeded and the frequency of detection was greater than 5 percent, then the next consideration for the potential for bioconcentration was whether or not the chemical was detected in shellfish or fish tissue at concentrations that resulted in unacceptable risk for the consumption of fish or shellfish.

Of the list of chemicals detected in TZW at concentrations exceeding AWQC and measured in shellfish or fish tissue, only thallium, manganese, and chrysene were not identified as iCOCs for shellfish or fish tissue:

- Chrysene was detected in clam and crayfish tissue at concentrations that do not lead to unacceptable risk levels. Chrysene was detected in one of the 27 crayfish tissue samples analyzed. The detected concentration of 87 µg/kg led to an estimated risk level of 7×10^{-8} (18 g/day ingestion rate). Chrysene was detected in 30 of the 32 clam samples in which it was analyzed. For consumption of clams, the maximum cancer risk level was 5×10^{-7} (18 g/day ingestion rate).
- Manganese was detected in all of the 27 samples crayfish tissue samples analyzed with a maximum concentration of 210 mg/kg. For consumption of crayfish, the highest HQ was 0.4 at the

highest ingestion rate of 18 g/day. Manganese was detected in all three of the clam tissue samples analyzed with a maximum concentration of 7.6 mg/kg. For consumption of clams, the highest HQ was 0.01 at the highest ingestion rate of 18 g/day.

- Thallium was detected in all of the 27 samples crayfish tissue samples analyzed with a maximum concentration of 0.008 mg/kg. For consumption of crayfish, the highest HQ was 0.03 at the highest ingestion rate of 18 g/day. Thallium was detected in all three of the clam tissue samples analyzed with a maximum concentration of 0.0007 mg/kg. For consumption of clams, the highest HQ was 0.003 at the highest ingestion rate of 18 g/day.

Because thallium, manganese, and chrysene were detected in tissue and empirically evaluated in this Round 2 HHRA for potential unacceptable risks due to fish or shellfish consumption, the results of the Round 2 HHRA should be used rather than relying on default AWQC that do not account for site-specific conditions. Therefore, thallium, manganese, and chrysene are not considered potential TZW iCOCs.

6.2.1.2 Derivation of Human Health AWQC

Based on the TZW evaluation framework for human health (Figure 6-2), several chemicals detected in TZW exceeded AWQC but were not analyzed for in surface water or tissue, including volatile organic compounds (VOCs) (VOCs are volatile and expected to be lost or greatly reduced during cooking of crayfish or clams). The proposed EPA (2003b) equilibrium partitioning (EqP) method to derive fish or shellfish tissue concentrations from sediments and TZW was determined to be inappropriate for this modeling exercise. According to EPA (2003b), the EqP method is applicable to nonionic organic chemicals with a log octanol-water partitioning coefficient (log K_{ow}) above 3.0. However, the VOCs that exceed the AWQC have log K_{ow}'s below 3.0. Therefore, background information on the AWQC for these six chemicals was researched to determine how they were derived.

Six chemicals (five VOCs and one conventional) that were not analyzed in tissue were retained as TZW COPCs for AWQC exceedances: benzene, chlorobenzene, chloroform, cyanide, trichloroethene, and vinyl chloride. The bioconcentration factors (BCFs) for these six chemicals were very low, ranging from a value of 1 liter per kilogram (L/kg) for cyanide to 10.6 L/kg for trichloroethene. As a basis of comparison, the BCF for Total PCBs is 23,000 L/kg. Based on the low BCFs, the bioconcentration potential for these six chemicals is assumed to be low.

The 2004 AWQC for these six chemicals were derived using BCFs retained from EPA's 1980 methodology documents. For benzene and chlorobenzene, a linear equation (Veith et al. 1979, as cited by EPA 1980a) was used to estimate the BCF for aquatic organisms containing approximately 7.6 percent lipids from the K_{ow} value:

$$\log BCF = (0.85 \log K_{ow}) - 0.70$$

The chemical-specific AWQC documents specify the average measured log K_{ow} value for the chemical and calculate a steady-state BCF. Based on a survey of fish and shellfish consumption in the United States (EPA 1980b as cited by EPA 1980a), a weighted average percent lipid value of 3.0 percent was derived for consumed freshwater and estuarine fish and shellfish. An adjustment factor was lastly applied to adjust the estimated BCF from the 7.6 percent lipids, on which the equation is based, to the 3.0 percent lipid value. The BCFs used to derive the human health AWQC for benzene and chlorobenzene were 5.2 L/kg and 10.3 L/kg, respectively. Based on the low BCFs, the bioconcentration potential for these chemicals is also assumed to be low.

For chloroform, a measured steady-state BCF of 6 L/kg was obtained using bluegills (EPA 1978 as cited by EPA 1980c). An adjustment factor was applied to adjust the average bluegill percent lipid content of 4.8 to the 3.0 percent weighted average lipid value for consumed fish and shellfish used to derive the chloroform BCF of 3.75 L/kg. For cyanide, the EPA concluded that "cyanide does penetrate aquatic organisms but bioaccumulation cannot be demonstrated because it is readily metabolized" (EPA 1985). Therefore, a BCF of 1 L/kg was used in deriving the human health AWQC for cyanide. Based on the low BCF, the bioconcentration potential for chloroform is assumed to be low.

Bioconcentration of trichloroethene in bluegill was studied, and after 14 days the BCF was 17 (EPA 1978 as cited by EPA 1980d). According to the EPA, "the half-life of this compound in tissue was less than one day" and "such bioconcentration and biological half-life data suggest no residue problem will occur at exposure concentrations that are not directly toxic to aquatic life" (EPA 1980d). The same adjustment factor used to derive the chloroform BCF was applied to derive the trichloroethene BCF of 10.6 L/kg. Based on the low BCF, the bioconcentration potential for trichloroethene is assumed to be low.

For vinyl chloride, the Veith et al. (1979) equation was also used to estimate the BCF. However, no measured log K_{ow} value was available for vinyl chloride. The EPA calculated a log K_{ow} value of 1.38 using the method described in Hansch and Leo (1979 as cited by EPA 1980e). Finally, an adjustment factor was applied to adjust the estimated BCF from the 7.6 percent lipids, on which the equation is based, to the 3.0 percent lipid value to obtain the vinyl chloride BCF of 1.17 L/kg. Based on the low BCF, the bioconcentration potential for vinyl chloride is also assumed to be low.

One limitation of the Veith et al. (1979) equation was that it was derived from a limited data set of 55 log BCF values, all for fathead minnows (Meylan et al. 1999). These fish BCFs were, in turn, used for the derivation of human health AWQC. The BCFs used in human health AWQC derivation were not updated with regard to lipid content adjustment and are still based on the 3.0 percent weighted average percent lipid for consumed freshwater and estuarine fish and shellfish. Although EPA has

updated the toxicity value and fish ingestion rate to derive the latest human health AWQC, it has not updated its BCF approach or values since the 1980s.

In summary, the AWQC for the five VOCs and one conventional mentioned above were derived using outdated BCF data and other parameters. The Veith et al. (1979) equation was used to estimate BCFs from log K_{ow} data, assuming 7.6 percent lipids. The BCFs were then adjusted using another assumed weighted average of 3.0 percent lipids for consumed freshwater and estuarine fish and shellfish, based on a 1980 national survey. These lipid assumptions add uncertainty to the BCFs derived for these chemicals, and thus, the AWQC derived from the BCFs. As a result, the AWQC for VOCs are considered highly uncertain for evaluating bioaccumulation and bioconcentration.

6.2.1.3 Applying Adjustment Factors to Screening of TZW Data Against Human Health AWQC

The direct comparison of TZW concentrations to human health AWQC for surface water is a very conservative evaluation that does not account for differences in uptake of chemicals from TZW versus surface water by shellfish organisms. In addition, the human health exposure assumptions and acceptable risks levels used to derive the human health AWQC differ from that used in the Round 2 HHRA. An adjustment factor of 5,000 was applied to the maximum detected TZW concentrations included the following assumptions:

- An adjustment factor of 10, for the maximum assumed TZW/surface water ventilation ratio for shellfish (see Appendix H);
- An adjustment factor of 100, for using an acceptable cancer risk level of 10^{-4} versus 10^{-6};
- An adjustment factor of 5, for the dietary fraction obtained from any single location (3.3 g/day versus 17.5 g/day).

Table 6-2 presents the comparison of the adjusted TZW concentrations to human health AWQC. With the adjustment factor applied, the chemicals identified as potential TZW iCOCs for biota consumption include total DDT and total DDD. Total DDT and total DDD were identified as iCOCs for consumption of fish and shellfish (Section 5).

6.2.2 Screening of TZW for Contributions to Surface Water

TZW data were also compared against the respective EPA Region 9 tap water PRG or the MCL, as required by EPA in its comments on the PRG TM (dated June 30, 2006). The results of this comparison are presented in Table 6-2.

However, EPA has not required screening of TZW as a potential source of drinking water, but rather for protection of surface water. Therefore, loading estimates and

models were used to estimate surface water concentrations based on the maximum discharge flow of groundwater to the Willamette River. In order to provide the most conservative estimate of surface water concentrations based on loading from groundwater discharge, these maximum loading estimates were used with the minimum average monthly flow rate (measured from 1973 through 2003) to calculate surface water concentrations. Further detail regarding the derivation of the surface water estimates is provided in Section 6.1.3 and Appendix D of the Round 2 Report. These estimates are considered conservatively high approximations of upland groundwater plume loading to surface water for several reasons that are discussed in detail in Appendix D.

Table 6-3 provides the comparison of the estimated surface water concentrations against EPA Region 9 PRGs and MCLs. Of the chemicals listed, only the surface water concentration estimates for chloroform and trichloroethylene exceed the respective Region 9 PRG for tap water. The magnitude of exceedance of the Region 9 PRG for tap water was 2.7 for chloroform and 1.7 for trichloroethene. As described in Appendix D, the loading estimates for chloroform and trichloroethene are dominated by TZW sample concentrations from a single location for each chemical. For chloroform, more than 99 percent of the estimated load is associated with a TZW sample concentration of 770,000 µg/L at location AP03D offshore of the Arkema Acid Plant. For trichloroethene, 97 percent of the load is associated with a TZW sample concentration of 88,500 ug/L at Siltronic location GP67. Given the conservatism in the approximations of upland groundwater plume loading to surface water, the uncertainty associated with loads that are dominated by individual TZW sample concentrations, and the small magnitude of the exceedances of the Region 9 PRGs for tap water, it is not likely the contribution from TZW to surface water leads to exceedances of human health based screening levels for drinking water. Also, these chemicals were not detected at concentrations that would result in exceedances of MCLs. Furthermore, the lower Willamette River is not currently used as a public drinking water source nor are there future plans to develop a source of public drinking water from the lower Willamette River.

6.3 SUMMARY AND CONCLUSIONS

TZW data were collected from specific stations within the Study Area based on likelihood of contribution to groundwater contamination from upland sources. Because TZW data were collected from specific locations, this data set represents the worst case scenario for potential risks to human health from potential TZW iCOCs. As required by EPA in its comments on the PRG TM (dated June 30, 2006), this evaluation included the screening of surface water and TZW against human health based screening levels. Based on this screening evaluation the chemicals retained as potential TZW iCOCs include total DDT and total DDE, based on the biota consumption pathway. Though trichloroethene and chloroform were retained as potential TZW iCOCs, based on slight exceedances of the EPA Region 9 tap water PRG, the assumptions used to model surface water concentrations from groundwater

loading estimates were extremely conservative. Lastly, the LWR is not currently used as a public drinking water source nor are there future plans to develop a source of public drinking water from the LWR.

In conclusion, the results of this evaluation do not lead to the identification of data needs with respect to TZW and human health exposure pathways.

7.0 UNCERTAINTY ANALYSIS

Uncertainty is associated with every step of a risk assessment, from the sampling and analysis of concentrations of chemicals in environmental media to the assessment of exposure and toxicity and the risk characterization. In general, the approach and methodologies used in a risk assessment are designed to err on the side of conservatism, i.e., protection of health. Uncertainty can have two components: 1) variability in data or information, and 2) lack of knowledge. An uncertainty analysis conducted as part of a risk assessment focuses on issues of variability and uncertainty associated with each of the inputs and models used to derive the risk estimates.

Variability arises from true heterogeneity in exposure variables or responses, such as dose-response differences within a population or differences in contaminant levels in the environment. The values of some variables used in an assessment change with time and space, or across the population whose exposure is being estimated. Although variability can be better understood, it cannot be reduced through further study. Use of RME and CT scenarios provide an estimate of high-end and average exposures that may reasonably occur. The difference between the RME and CT risk estimates provides an initial evaluation of the degree of variability in exposure between individuals.

The second factor that generates uncertainty is a lack of knowledge about factors such as adverse effects or chemical concentrations. Uncertainty may be reduced by increasing knowledge about a factor through additional study. A substantial amount of uncertainty is often inherent in environmental sampling as well as in the scientific models used in risk assessment.

This section includes a detailed analysis of uncertainties associated with each step of the Round 2 HHRA. The objective of the uncertainty analysis is to understand the overall degree of conservatism in the risk estimates for consideration when reviewing and applying the results of this Round 2 HHRA in identifying iAOPCs and additional data needs. The uncertainty analysis includes a discussion of variability and/or uncertainty in the inputs to the risk estimates, focusing on those inputs likely to have the greatest effects on the results of the risk analyses.

7.1 DATA EVALUATION

As discussed in Section 2, data collected during the RI, as well as data of confirmed quality that meet the DQOs for risk assessment, were used in this HHRA to estimate risks. Sediment, surface water, groundwater seep, and biota data were collected for use in this HHRA. Use of the EPA's DQO planning process (EPA 2000a) minimized the uncertainty associated with the data collected during the RI; however, a certain amount of uncertainty is inherent in environmental sampling. The following data evaluation uncertainties have been identified.

7.1.1 Use of target species to represent all types of biota consumed

Because it is not practical to collect samples of every resident species consumed by humans within the Study Area, target species were selected to represent the diet of all biota consumed by humans, as recommended by EPA guidance (2000b). Four target species were collected to represent resident fish tissue diet (smallmouth bass, black crappie, common carp, brown bullhead), and two species were collected to represent shellfish diet (crayfish, clam). The target species were selected to provide the most conservative estimate of risk to human health and are a source of uncertainty when used to represent the risk from consumption of all biota within the Study Area. Factors in selecting the target species included: consumption by humans, home range, potential for bioaccumulation, trophic level of species, and abundance.

While only the target species were included in this Round 2 HHRA, the number of species evaluated is three times more than that recommended by EPA guidance (2000b). The range of concentrations detected in the target species generally tracks the range of concentrations detected in other species that were collected. Furthermore, the concentrations of PCBs, which is the chemical with the greatest contribution to risk, are generally highest in smallmouth bass and carp, both of which were included in this Round 2 HHRA. Therefore, the use of target species to represent all biota consumed should not impact the conclusions of this Round 2 HHRA.

7.1.2 Source of chemicals for anadromous and wide-ranging fish species

For non-resident fish species, salmon, lamprey, and sturgeon were chosen as target species to represent a portion of the Native American fish tissue diet. Due to the life cycles of these species, these fish spend some portion of their lives outside of the Study Area. The time spent outside the Study Area may be significant for bioaccumulation of chemicals due to the growth, development, and feeding that occurs, as well as the relative amount of time spent within the Study Area versus outside of the Study Area. Therefore, there is a high degree of uncertainty as to the source of chemicals detected in non-resident fish species and whether those chemicals are actually due to exposures within the Study Area.

However, approximately 95 percent of the cumulative risk from fish consumption is due to resident fish even though resident fish only account for 50 percent of the fish consumed. Therefore, using the results of the Round 2 HHRA to focus on potential sources of chemicals of concern in resident fish species should address sources of chemicals of concern within the Study Area to non-resident fish species as well. As a result, the uncertainty associated with the source of chemicals to non-resident fish species should not impact the conclusions of this Round 2 HHRA.

7.1.3 Use of either whole body or fillet samples to represent all fish consumption

Chemicals bioaccumulate differently in different parts of an organism. Organic

compounds tend to accumulate more in the fatty tissues and heavy metals more in muscle tissues. The chemicals with the greatest contribution to the cumulative cancer risk and with the highest noncancer HQ are PCBs, which are organic compounds. Diets consisting of different fish parts result in varying levels of risk to the consumer. Using only whole body or fillet tissue with skin to evaluate risk from all types of fish tissue diets is a conservative representation of actual consumption of fish. Depending on the species, the difference in concentrations between fillet and whole body tissue can be minimal or more than a factor of 10. For example, in smallmouth bass, the average concentration of PCBs in fillet tissue is 62 µg/kg while the average concentration in whole body tissue is 914 µg/kg. In brown bullhead, the average concentration of PCBs in fillet tissue is 363 µg/kg and in whole body tissue is 415 µg/kg.

Based on the Columbia Slough consumption survey (Adolfson 1996), the majority of non-tribal fishers are most likely to consume only the fillet portion of the fish, which may not include skin. Based on the CRITFC Fish Consumption Survey (1994), Native Americans are also most likely to consume only the fillet portion of the fish, which may not include skin. However, some individuals may consume other portions of the fish, and the whole body diet is the most conservative estimate of potential risk from tissue consumption.

While it is not known to what extent consumption of non-fillet portions of fish occurs, this Round 2 HHRA evaluated risks associated with consumption of only fillet tissue or only whole body tissue. This approach provides the potential range of risks associated with the different diets, recognizing that the risks from consumption of fillet tissue without skin would likely be even lower than those presented in this Round 2 HHRA. If an individual consumes mostly fillets, but occasionally other portions of the fish, the risks to that individual should fall within the range of risks estimated in this Round 2 HHRA. Because it is unlikely that a diet consists entirely of whole body tissue, the evaluation of risks associated with consumption of only whole body tissue provides a health protective approach. Given this uncertainty, the risks from the whole body diet should be considered the theoretical maximum potential risks and are not necessarily representative of actual risks at the Study Area.

7.1.4 Detection limits that are above analytical concentration goals (ACGs)

Uncertainty exists in the evaluation of chemicals that were not detected for which the method detection limits (DLs) exceed the ACGs. Site-specific ACGs were established for each media. However, ACGs for some chemicals are exceptionally low, and in some instances, not attainable with present laboratory methods. DLs for chemicals that were analyzed but never detected were compared to the appropriate ACG for each media. For sediment, maximum DLs exceed both ACGs and method reporting limits (MRLs) for four analytes (see Table 7-1). In tissue, maximum DLs exceed ACGs for 12 analytes and MRLs for six (see Table 7-2). Seven chemicals were never detected but their DLs were below ACGs. In the groundwater seep,

maximum DLs exceed both ACGs and MRLs for two analytes (see Table 7-3). In surface water, four analytes plus PCB Aroclors exceed ACGs; two analytes plus PCB Aroclors exceed MRLs (see Table 7-4). However, for surface water PCB congener data were used instead of Aroclor data because the Aroclor data were derived from the congener data.

Chemicals that were not detected were not quantitatively evaluated further in this Round 2 HHRA. If chemicals were present at concentrations above the ACGs but below the DLs, those chemicals could contribute to unacceptable risks. However, given the number of chemicals that were detected at concentrations above their respective ACGs and the magnitude of difference between detected concentrations and ACGs, it is unlikely that exclusion of chemicals that were not detected would impact the conclusions of this Round 2 HHRA.

7.1.5 Chemicals that were not analyzed in certain samples

Per the sampling and analysis plan that was approved by EPA, certain fish tissue samples were analyzed for a subset of the analytes. For example, fillet tissue samples were not analyzed for PCB, dioxin, or furan congeners. In samples where congeners were analyzed, the risks from the congeners that are not included through other analytes (i.e., risks from total PCBs are included through PCBs as Aroclors) comprise approximately 42 percent of the cumulative risks. Therefore, the risks from consumption of fillet tissue likely underestimate the actual risks. However, a range of risks were calculated for fish consumption scenarios, so the lack of analysis of chemicals in certain samples should not impact the conclusions of this Round 2 HHRA.

7.1.6 Chemicals that were not included as analytes

It is not possible to analyze for every chemical, and thus chemicals and chemical groups were chosen for analysis based on an investigation of known or probable sources and pollutants. Because chemicals expected to have the potential for significant contributions to risk are included in the risk assessment, chemicals not included as analytes introduce a low level of uncertainty to overall risk. The list of chemicals for analysis was determined in collaboration with EPA and its partners and was included in the sampling and analysis plan that was approved by EPA. Since then, there has been interest in two groups of chemicals that were not included as analytes in this Round 2 HHRA: polybrominated diphenyl ethers (PBDEs) and VOCs in tissue.

PBDEs are flame retardants that leach from products with residential, commercial, and industrial uses. As a result, they are ubiquitous in the environment. The ODHS study used to represent salmon concentrations for the Study Area found PBDE concentrations within the range of those found in store-bought salmon in a 2005 study by the Washington State Department of Health. There are no known specific sources of PBDEs within the Study Area and the concentrations detected in tissue in the

ODHS study are similar to or lower than concentrations reported for fish tissue collected in other areas (non- Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA] sites) where PBDEs have been analyzed. A comparison of the tissue concentrations from the ODHS study with those from other studies that have analyzed for PBDEs is presented in Table 7-5. Based on the maximum detected concentration of PBDEs in the ODHS dataset and the lowest RfD (0.002 mg/kg-day) for PBDEs currently in IRIS (EPA 2006c), the maximum potential HQ associated with PBDEs is 0.05. The maximum HQs for PCBs and mercury in the ODHS dataset are 95 and 6, respectively. EPA is reviewing the toxicity data for PBDEs. The lowest RfD that is currently proposed is 0.0001 mg/kg-day. Even using this draft RfD that is still under review, the HQ associated with the maximum detected PBDE concentration does not exceed 1. Given the magnitude of concentrations and toxicities of other chemicals that were analyzed for and detected and the detected concentrations of PBDEs in the ODHS study, PBDEs are unlikely to contribute significantly to the overall risks.

VOCs were not analyzed in tissue and have not been analyzed to date in surface water. Because of the nature of VOCs, they are not expected to accumulate in tissue to a degree high enough to pose significant risk via tissue consumption, especially given the other chemicals detected in tissue that are clearly primary contributors to the calculated risk (e.g., PCBs).. Furthermore, if VOCs were present in tissue, VOCs would volatilize during cooking. However, even though it is unlikely VOCs could pose unacceptable risk through fish or shellfish consumption scenarios, VOCs were analyzed in transition zone water, and analytical results were evaluated in Section 6 to determine if there is a potential risk from loading to tissue either directly from transition zone water or through loading to surface water. Based on that evaluation, VOCs in transition zone water would not result in unacceptable risks for fish or shellfish consumption. Therefore, the lack of analysis for VOCs in tissue should not impact the conclusions of this Round 2 HHRA.

7.1.7 Compositing methods for biota and beach sediment sampling

Compositing methods for biota and beach sediment sampling were designed to provide a conservative estimate of risk.

Fish were composited based on an estimate of the average home range for each species. The home ranges for carp, crappie, and bullhead may be as large as the Study Area and possibly even larger, and the home range for bass may span from one to seven miles. Bass were composited on a river mile basis, and crappie, and bullhead were composited on a fishing zone basis (RM 3-6 and RM 6-9). Uncertainty exists in this compositing scheme because each species may span a home range much larger than that used for compositing, and the delineation of home range boundaries for the purposes of the risk evaluation are only an approximation of the home ranges of the fish samples actually collected. However, composite samples typically consisted of five individual fish, replicate composite samples were collected, and risks were evaluated both for individual sample locations as well as on a site-wide

basis. Therefore, the compositing method for biota is not expected to impact the conclusions of this Round 2 HHRA.

Beach sediment was composited on a beach by beach basis, resulting in one sample for each exposure area. Uncertainty exists in this compositing scheme because the results of the risk evaluation are dependent on a single sample. Composite samples are generally assumed to represent the area from which the individual samples of the composite were taken, but an unrepresentative individual sample (e.g., one representing extremely localized or ephemeral contamination) used in the composite could significantly bias the composite results. The compositing scheme for beaches results in risk evaluation based on a single sample at a single point in time. If a beach was found to pose an unacceptable risk, additional samples at that beach might be warranted. However, all of the beach sediment exposure scenarios were below or within the target risk range of 10^{-4} to 10^{-6}.

7.2 EXPOSURE ASSESSMENT

Uncertainties that arise during the exposure assessment typically have some of the greatest impacts on the risk estimates. The following subsections address uncertainties associated with exposure models, exposure factors, and EPCs used in the risk estimates.

7.2.1 Model Applicability

The standard exposure models used to estimate risks may result in uncertainty. The exposure models rely on identification of exposure scenarios and selection of appropriate exposure factors for those scenarios. Uncertainty in the applicability of the exposure scenarios will result in uncertainty in the risk estimates. Site-specific exposure scenarios were developed to provide a conservative estimate of risk within the Study Area, using conservative exposure factors to represent both reasonable maximum and central tendency exposures that could hypothetically occur within the Study Area. While uncertainties associated with the exposure models could impact the conclusions of this Round 2 HHRA, the models used are consistent with applicable risk assessment guidance and are a source of uncertainty in all risk assessments.

7.2.2 Exposure Factors

Assumptions about exposure factors typically result in a high degree of uncertainty in any risk assessment. Because many of the exposure scenarios that were evaluated in this HHRA are highly variable and do not have standard default exposure factors, uncertainties associated with the exposure factors are anticipated to have some of the greatest impacts on the risk estimates.

RME and CT values were used for some of the exposure scenarios to evaluate the overall impact that variability in each of the exposure assumptions has on the risk

estimates. As discussed previously, the RME scenarios represent the highest exposures that could occur at a site under current and future conditions. The CT exposure scenarios represent the expected average or mean exposure. The range of risk estimates between these two exposure scenarios provides a measure of the uncertainty surrounding these estimates.

For fish consumption, a range of ingestion rates representing possible high end consumption scenarios were used to evaluate the impact of variability on the risk estimates (see discussion of exposure parameters for tissue ingestion scenarios below).

In addition to the variability, there is also uncertainty associated with the exposure factors that were used in this Round 2 HHRA.

The following exposure factor uncertainties have been identified and analyzed further to determine the potential effects on the risk estimates:

7.2.2.1 Exposure parameters for sediment exposure scenarios

The beach and in-water sediment exposure parameters used in this Round 2 HHRA were extremely conservative estimates of potential uses for the Study Area.

Beach areas that are accessible to the general public were identified as potential human use areas, even though it is not known whether recreational beach use actually occurs at these locations. Even if beach use occurs, the extent to which the beach is used and the nature of the contact with sediments/beach is unknown. For in-water sediment, every ½ river mile segment on each side of the navigation channel was considered a potential exposure area for all in-water sediment exposure scenarios, regardless of the feasibility or practicality of use of the area.

The exposure duration, frequency, and intake parameters for both beach and in-water sediment also have associated uncertainties. The scenarios assume exposure to the same beach or ½-river segment for an entire childhood, or 25-70 years for adults, depending on receptor. Frequency of exposure ranges from 94 days/year to 250 days/year. Default intake parameters for soil exposure were generally used; however, the adherence factor (dermal contact with sediment) for recreational children was more than 10 times greater than the default for soil.

All of the uncertainties associated with the sediment exposure parameters are likely to overestimate the risks associated with direct exposure to sediment. However, all of the beach sediment exposure scenarios were below or within the target risk range of 10^{-4} to 10^{-6}, and with the exception of two segments specifically for the Native American fisher RME scenario, all of the in-water sediment exposure scenarios were also below or within the target risk range of 10^{-4} to 10^{-6}. For the Native American fisher RME scenario, the exposure parameters are especially conservative as it is highly unlikely an individual would fish the same ½-river mile river segment for 5 days every single week of every single year for 70 years.

7.2.2.2 Exposure parameters for surface water exposure scenarios

Transients were assumed to be exposed to surface water through ingestion and dermal contact. Tap water ingestion rates were used to represent exposure to surface water via ingestion for transients. However, tap water ingestion rates are an estimate of ingestion of a drinking water source, and the use of untreated water from the Lower Willamette as a source of drinking water by transients on an ongoing basis is highly unlikely. The tap water ingestion rate used in the risk evaluation is 2 L/day for the transient and assumes surface water will be ingested every day for 2 years. In addition, it was assumed that transients bathe directly in the Lower Willamette 2 days per week throughout the entire year for 2 years.

For the recreational beach users, exposure to surface water was assumed to occur through incidental ingestion and dermal contact while swimming in the Lower Willamette. The incidental ingestion rate of 50 milliliters per day (mL/day) used in this Round 2 HHRA is that recommended by EPA for a swimming scenario. The exposure scenario assumes that adults frequent the same quiescent water area 26 times per year for 30 years, and that children frequent the same area 94 times per year for 6 years.

All of the uncertainties associated with the surface water exposure parameters are likely to overestimate the risks associated with direct exposure to surface water. However, all of the surface water exposure scenarios were below the target risk range of 10^{-4} to 10^{-6}.

7.2.2.3 Exposure parameters for tissue ingestion scenarios

The exposure parameters for tissue ingestion were designed to provide a conservative estimate of risk and may not be representative of actual tissue consumption occurring within the Study Area.

Fish tissue ingestion rates were developed with variable exposure factors and environmental data that are not site-specific, or that are derived from limited consumption surveys or from anecdotal evidence.

Site-specific fish consumption information is not available for the nontribal scenarios. As a result, nationwide fish consumption data were used to calculate target fish tissue levels. A limited consumption study conducted for the Columbia Slough was also used. The 99th percentile rate from the nationwide survey was used as the high ingestion rate, the 95th UCL rate from the Columbia Slough study was used as the medium ingestion rate, and the 90th percentile rate from the nationwide survey was used as the low ingestion rate. All three of these rates represent high levels of fish consumption relative to average ingestion rates reported from the respective studies. Fish consumption was assumed to occur at the same ingestion rate every day of every year for 30 years for the nontribal scenarios. Furthermore, 100 percent of the fish consumed was assumed to be caught at the same location over 30 years, and no reduction in concentrations of contaminants during food preparation and cooking was assumed.

For the Native American fish consumption scenario, the 95th percentile rate from the CRITFC Study was used. Fish consumption was assumed to occur at the same rate every day of every year for 70 years. As with the nontribal scenarios, it was assumed that 100 percent of the fish consumed was caught at the same location for 70 years, and no reduction in concentration of contaminants occurred during food preparation or cooking. However, the same CRITFC Study that was used as the basis for the Native American fish ingestion rate also indicated that none of the respondents fished the Willamette River for resident fish and at most, approximately 4 percent fished the Willamette River for anadromous fish.

There is only anecdotal, unconfirmed information suggesting that shellfish consumption may occur at the Study Area; however, shellfish consumption was evaluated in this Round 2 HHRA as required by EPA in its comments on the PRG TM dated June 30, 2006. Because site-specific shellfish ingestion rates are not available, nationwide shellfish consumption data were used to calculate target tissue levels for clams and crayfish. The 95th percentile rate from the nationwide survey was used as the high ingestion rate and the mean rate from the nationwide survey was used as the low ingestion rate. In the nationwide survey, shrimp, which is not found within the Study Area, accounted for more than 80 percent of the shellfish consumed. Crayfish accounted for less than 1 percent of the shellfish consumed, and freshwater clams were not even included in the nationwide survey. Shellfish consumption was assumed to occur at the same rate every day of every year for 30 years. As with fish, 100 percent of the shellfish was assumed to be caught from the same location for the 30 years, and no losses in chemical concentration were assumed from food preparation or cooking. It is highly unlikely that the Study Area supports shellfish populations large enough to supply the quantity of tissue needed to satisfy these hypothetical ingestion rates. During the Round 2 sampling event, the maximum mass of clam tissue data collected at a given sampling location was only 217.57 grams. At 18 g/day, this location would be depleted of clam tissue within 13 days.

All of the uncertainties associated with the fish and shellfish exposure parameters are likely to result in overestimating the risks associated with fish and shellfish consumption. Because some of the fish and shellfish consumption scenarios exceeded the target risk range of 10^{-4} to 10^{-6}, the uncertainties associated with fish and shellfish consumption could impact the conclusions of this Round 2 HHRA.

7.2.2.4 Assumptions about a multiple species diet

Uncertainties exist in the assumptions about the multiple species diet composition. The non-tribal multiple species diet assumes equal proportions of all four resident fish species. The tribal multiple species diet consists of equal proportions of the four resident fish species, as well as dietary percentages of salmon, lamprey, and sturgeon that come from the CRITFC study. Variations from these compositions would result in different risk estimates. Because the risks from consumption of the individual species that make up the multiple species diet were evaluated separately, the range of risks from fish consumption scenarios encompasses the potential variations in the

multiple species diet.

7.2.3 Exposure Point Concentrations

The EPC is supposed to represent the arithmetic average of the concentration of a chemical that will be contacted over the exposure duration; however, as a protective approach, a UCL on the arithmetic average is recommended for use as the EPC (EPA 1989). Given the uncertainties and variability associated with environmental data, a high amount of uncertainty is associated with calculating a representative EPC. The following EPC uncertainties have been identified and were analyzed further in the Round 2 HHRA to determine the potential effects on the risk estimates.

7.2.3.1 Using one-half the detection limit for non-detect results.

When an analyte was determined to be present in a given medium according to the rules for non-detects discussed in Section 2, but was not detected for a specific exposure area, one-half of the DL was used for the EPC. This value is assumed to represent a conservative estimate for the concentrations below the DL, and introduces uncertainty into the EPC calculations.

In general, the DLs for non-detect results were low relative to detected concentrations. In addition, by only including those chemicals that were determined to be present in a given medium, the uncertainty associated with the use of non-detect results was minimized. However, in cases where the DLs were above ACGs and the chemical was detected infrequently, use of one-half the DL could impact the risk results. In these cases, additional evaluation of the method used to estimate non-detect results may be warranted.

7.2.3.2 Using the maximum concentration to represent exposure

In cases when there were less than 5 samples with detected concentrations for a given analyte for a given exposure area, the sample size was not sufficient to calculate a UCL for an EPC, and the maximum concentration was used. This includes EPCs calculated to represent site-wide exposure. Using maximum detected concentrations of infrequently detected chemicals to represent individual exposure areas, and especially site-wide exposure, results in an extremely conservative estimate of risk for the Study Area. In general, use of UCLs or maximum concentrations provided a protective approach and likely resulted in overestimates of the actual risks, especially for ongoing, repeated, long-term exposures.

Use of the maximum concentration to represent exposure occurred most frequently for the fish and shellfish consumption scenarios. In cases where use of the maximum concentration suggests the potential for unacceptable risks, additional evaluation of the concentration used to represent exposure may be warranted.

7.2.3.3 Possible effects of preparation and cooking methods.

Cooking and preparation methods of fish tissue can modify the amount of contaminant ingested by fish consumers. PCBs, which were found to have the

greatest contribution to the cumulative cancer risks and the highest noncancer HQs, tend to concentrate in fatty tissues. Therefore, trimming away fatty tissues, including the skin, will reduce the exposure to PCBs. The concentrations of PCBs in raw fillet tissue have been shown to decrease by approximately 50 percent by removing the skin (EPA 2000b). Cooking can also reduce the concentrations of PCBs from approximately 10 to 87 percent, depending on the method (Wilson et al. 1998). Dose modifications to account for cooking or tissue preparation were not used in determining EPCs for fish ingestion, resulting in conservative estimates of exposure from tissue. If included, the risk estimates may have been reduced by up to approximately 90 percent for some chemicals.

7.2.3.4 Assumptions about arsenic speciation

Arsenic in tissue was analyzed only as total arsenic. Toxicity data are only available for inorganic arsenic. The Columbia River Basin Fish Contaminant Survey (EPA 2002b) determined that a "value of 10% is expected to result in a health protective estimate of the potential health effects from arsenic in fish". Therefore, the EPC for inorganic arsenic in the initial evaluation was estimated as 10% of the total arsenic detected in tissue. In previous fish tissue studies in the lower Columbia and Willamette Rivers, the percent of inorganic arsenic relative to total arsenic ranged from 0.1% to 26.6% with an average percent inorganic arsenic of 5.3% in the resident fish samples from the Willamette River (Tetra Tech 1995, EVS 2000), so use of 10% for inorganic arsenic is likely overestimates the EPC for inorganic arsenic.

Although arsenic resulted in risks greater than 10^{-6} for some of the fish consumption scenarios, the contribution of arsenic to the cumulative risk was insignificant relative to that from PCBs. Therefore, the assumptions about inorganic arsenic are not likely to impact the conclusions of this Round 2 HHRA.

7.2.3.5 Polychlorinated biphenyls

PCBs were analyzed as Aroclors in some media and as individual PCB congeners in others. Congener analysis may provide a more accurate measure of PCBs in environmental samples than does the Aroclor analysis. Although most PCBs may have originally entered the environment as technical Aroclor mixtures, environmental processes, such as weathering and bioaccumulation, may have led to changes in the congener distributions in environmental media such that they no longer closely match the technical Aroclor mixtures used as standards in the laboratory analysis, leading to inaccuracies in quantitation.

When available, congener data were included in cumulative risk sums for tissue because differences in bioaccumulation, in addition to weathering, results in even greater uncertainty in the Aroclor analysis for tissue. Aroclor data were included in cumulative risk sums for sediment because the Aroclor dataset is more robust than the congener dataset. Congener data were included in the risk evaluation for surface water because the Aroclor data was derived from the results of the congener analysis. This introduces some uncertainty when comparing cumulative risk across media.

When congener data were used, the total PCB concentration was adjusted by subtracting the concentrations of coplanar PCBs from the total PCB concentration. This was done for purposes of estimating cancer risks because the coplanar PCBs were evaluated separately for the cancer endpoint. The uncertainties associated with applying toxicity factors to the PCB concentrations are discussed further in Section 7.3.6.

7.3 TOXICITY ASSESSMENT

The toxicity factors used in this risk evaluation, which are established by state and federal policy, are deliberate overestimates of the potential dose-response. In addition, the results of animal studies are often used to predict the potential human health effects of a chemical. Extrapolation of toxicological data from animal studies to humans is one of the largest sources of uncertainty in evaluating toxicity factors. Because of these uncertainties, toxicological data parameters are usually very conservative to be more protective of human health due to safety factors EPA uses when estimating toxicity values. The safety factors used by EPA typically range from two to three orders of magnitude (100 to 1,000 times), depending on various aspects of the animal study (EPA 2006c). As a result, actual risks at this site are likely to be lower than the potential risk estimates calculated in this HHRA. In addition to the uncertainty already included in the toxicity values, the following toxicity value uncertainties have been identified.

7.3.1 Toxicity equivalent factors for PCBs, dioxins, and furans.

TEFs were used to evaluate cancer risks from coplanar PCBs and dioxin and furan congeners. The TEFs used in this Round 2 HHRA were established by the WHO in 1997. In 2005, the WHO re-evaluated the TEFs and modified them for some of the individual congeners. In some cases, the TEFs increased and in other cases the TEFs decreased. For example, the TEFs for octachlorodibenzo-p-dioxin and octachlorodibenzofuran increased by a factor of 3 while the TEFs for 1,2,3,7,8- and 2,3,4,7,8-pentachlorodibenzofuran decreased by a factor of approximately 2. Overall the changes to the PCB TEFs were greater than the changes to the TEFs for dioxin and furans.

To consider the potential impact the new WHO TEFs would have on the results of this Round 2 HHRA, the average EPCs for whole body carp, which had the highest toxicity equivalent concentrations of the tissue samples, were compared for both sets of the TEF values. With the new WHO TEFs, the average EPC for the PCB TEQ in carp decreased by approximately a factor of 2 and the average EPC for the dioxin/furan TEQ in carp was unchanged. The overall impact on the site-wide cumulative risks was a decrease from 6×10^{-3} to 5×10^{-3} at the highest non-tribal adult ingestion rate and from 7×10^{-4} to 6×10^{-4} at the lowest non-tribal adult ingestion rate. Therefore, the selection of TEFs used in this Round 2 HHRA does not appear to have had a significant impact on the overall risk results.

7.3.2 Early life exposure to carcinogens.

In 2005, EPA finalized the Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens (EPA 2005). The guidance provides a process to evaluate risks from early-life exposure to carcinogens with a mutagenic mode of action. The only exposure scenarios with early-life exposures (i.e., child populations) are recreational beach users and fish consumption. Of these, the only scenario with potential exposure to chemicals with a mutagenic mode of action is the recreational beach user scenario for exposure to PAHs.

This Round 2 HHRA did not evaluate risks using the new EPA guidance as the exposure factors for the specific age classes have not been determined. However, the guidance applies a 10-fold weighting to exposures occurring under the age of 2 and a 3-fold weighting to exposures occurring between the age of 2 and the age of 16. Assuming that most beach use would likely occur above the age of 2, the risks for the child recreational beach user from carcinogenic PAHs would be approximately 3 times higher than those in this Round 2 HHRA. The highest risk for the child recreational beach user from exposure to benzo(a)pyrene in beach sediment is 5×10^{-6}. Even if this risk were 3 times higher, the risk would be within the target risk range of 10^{-6} to 10^{-4}. However, it should be noted that the exposure parameters for the frequency and duration of exposure were extremely conservative for this exposure scenario.

7.3.3 Lack of toxicity values for delta-hexachlorocyclohexane

Delta-HCH was detected in tissue and in-water sediment. A toxicity value could not be identified for delta-HCH according to the hierarchy of sources of toxicity values recommended for use at Superfund sites (EPA 2003a). Also, an STSC review concluded that the other hexachlorocyclohexane isomers could not be used as surrogates for delta-HCH due to differences in toxicity (EPA 2002c). Potential risk from delta-HCH was not quantitatively evaluated because of the lack of availability of toxicity data for the chemical.

7.3.4 Use of toxicity values from surrogate chemicals for some chemicals that lack toxicity values

For some chemicals, if a toxicity value was not available from the recommended hierarchy, a structurally similar chemical was identified as a surrogate. The RfD or SF for the surrogate was selected as the toxicity value and the surrogate chemical was indicated in Section 4. Uncertainty exists in using surrogate chemicals to represent the toxicity of chemicals for which toxicity values are not available. Using surrogate toxicity values could over- or under-estimate risk for a specific chemical.

Based on the results of the Round 2 HHRA, the chemicals that exceeded the minimum target cancer risks of 10^{-6} or hazard quotient of 1 did not rely on surrogate toxicity values. Therefore, the use of surrogate toxicity values should not impact the conclusions of this Round 2 HHRA.

7.3.5 Toxicity values for chromium

Chromium was analyzed as total chromium in all media. Toxicity values exist for trivalent and hexavalent chromium only. Hexavalent chromium is not considered carcinogenic for oral or dermal exposures. The reference dose for hexavalent chromium is 0.003 mg/kg-day versus 1.5 mg/kg-day for trivalent chromium. The toxicity values for trivalent chromium were used in the toxicity assessment for the Study Area because hexavalent chromium reduces to trivalent chromium in aerobic conditions, and thus trivalent chromium is more prevalent in the environment (ATSDR 2000). For fish consumption, the highest HQ from chromium was 0.004, so even if a portion of the chromium were present as hexavalent chromium, the HQ would likely still be less than 1. Therefore, use of toxicity values for trivalent chromium should not impact the conclusions of this Round 2 HHRA.

7.3.6 Toxicity values for polychlorinated biphenyls and applicability to environmental data.

The toxicity values for PCBs were applied to both PCB congeners (not including coplanar congeners) and Aroclors. The RfD for PCBs is based on an immunotoxicity endpoint for Aroclor 1254 (EPA 2006c). Several other Aroclors have been detected in media within the Study Area, indicating the mixture of PCBs differs from that used in the study used to develop the RfD. The cancer SF for PCBs was derived for PCB mixtures based on administered doses of Aroclors to rats. The PCB mixtures used in the studies included the coplanar congeners. These coplanar PCBs may have contributed significantly to the carcinogenicity observed in the study. The cancer risk from coplanar congeners was evaluated separately, so including both the total PCB and coplanar congener risks in the cumulative cancer risk results in an overestimate of the cancer risks. Although the potential double counting of PCB mass was corrected for in the PCB adjusted values (mass of dioxin-like PCB was subtracted), there was not correction for the potential double counting of toxicity of dioxin-like PCBs in the PCB TEQ cancer risk estimate and as part of the PCB adjusted value cancer risk estimate.

7.4 RISK CHARACTERIZATION

Uncertainties arise during risk characterization due to the methods used in calculating, summing, and presenting risks. The following subsections address uncertainties associated with the risk characterization of this Round 2 HHRA.

7.4.1 Hazard indices

Per EPA guidance (1989), HQs should only be summed for chemicals with common toxicological endpoints. In this Round 2 HHRA, the HQs were summed regardless of the toxicological endpoint, so the HIs presented in this Round 2 HHRA are not endpoint specific. The only exposure scenarios where the HIs exceeded 1 were the fish and shellfish consumption scenarios. In the shellfish consumption scenarios, PCBs are the only individual chemical with an HQ greater than 1. In the fish

consumption scenarios, PCBs, mercury, DDE, and bis(2-ethylhexylphthalate) were the only individual chemicals with an HQ greater than 1 under at least one of the scenarios evaluated in this Round 2 HHRA. In general, the HQ for PCBs was approximately 10 times or more greater than the next highest HQ, which was typically for mercury. Of the chemicals with individual HQs that exceed 1, DDE and bis(2-ethylhexylphthalate) have the same toxicological endpoint or target organ (liver) and should be summed together in calculating endpoint specific HIs. This is also true for PCBs and mercury. However, because all of these chemicals have individual HQs that exceed 1, the endpoint specific HIs would still exceed 1.

While the calculation of HIs that are not endpoint specific is not likely to impact the conclusions of this Round 2 HHRA, endpoint specific HIs will be calculated in the baseline HHRA.

7.4.2 Risks from cumulative or overlapping scenarios

Where multiple exposure scenarios exist for a given population (i.e., recreational beach users are potentially exposed to both beach sediment and surface water), the risks for each of the exposure scenarios that are considered potentially complete and significant for a given population were summed to estimate the cumulative risks for that population (see Table 5-59). In calculating the cumulative risks, the maximum cancer risk for each RME scenario was used. This provides a highly conservative approach, as the same individual may not have the maximum exposure under more than one exposure scenario. That being said, for exposure scenarios exceeding 10^{-6} risk, one exposure scenario was always at least an order of magnitude higher than the other exposure scenarios being summed. As a result, risks from potential cumulative scenarios should not impact the conclusions of this Round 2 HHRA.

In addition to cumulative exposure scenarios for a given population, an individual may be part of multiple populations (i.e., a dockside worker that is also a non-tribal fisher) and thus could have overlapping exposure scenarios. Because there are numerous possible combinations of overlapping scenarios due to variations in exposure points and exposure assumptions, a model was not developed to quantitatively evaluate overlapping scenarios in this Round 2 HHRA. However, because the risk from tissue ingestion is typically at least 10 times higher than other exposure pathways, if an individual consumes fish, the contribution from other exposure scenarios is not likely to contribute significantly to the overall risks for that individual. This Round 2 HHRA presents the risks for all of the exposure scenarios, so the risks for a given overlapping scenario could be calculated simply by summing the risks for each of the exposure scenarios that make up the overlapping scenario.

7.4.3 Risks from background

Arsenic and mercury were found to result in risks greater than 10^{-6} or an HQ of 1 for at least one of the exposure scenarios evaluated in this HHRA. Metals are naturally occurring chemicals and may be present in tissue, water or sediment due to

background concentrations. For example, the concentrations of arsenic and mercury in fish tissue samples collected within the Study Area were compared with concentrations in fish tissue samples collected at upstream locations and found to be similar. For beach sediment, the exposure point concentrations ranged from 0.7 to 9.9 mg/kg and are consistent with the default background soil concentration for arsenic of 7 mg/kg used by DEQ (WDOE 1994).

In addition to naturally occurring metals, anthropogenic background may contribute to the overall risks. Attachment F1 presents the evaluation of risks from consumption of upstream fish tissue. These risks were calculated using the same exposure assumptions as were used for calculating risks from consumption of fish tissue collected within the Study Area. The evaluation of risks from upstream tissue demonstrates that upstream contributions result in cumulative cancer risks that exceed the target risk of 10^{-4} and noncancer hazards that exceed the target HI of 1.

While risks were presented in this Round 2 HHRA without accounting for contributions from background, it is important to recognize that background concentrations may result in unacceptable risks based on the exposure assumptions used in this Round 2 HHRA. The contribution from background is also important to consider in establishing remedial goals, as it may not be possible to achieve EPA's target risk levels.

7.5 OVERALL ASSESSMENT OF UNCERTAINTY

A summary of the uncertainties and a qualitative classification of their magnitude, their impact on the health protectiveness of the assessment, and their significance to risk management decisions are presented in Table 7-6. For each of the uncertainties identified and discussed in this section, Table 7-6 provides a qualitative assessment (using High, Medium, and Low as descriptors) for each of these properties. While there are numerous uncertainties identified for this Round 2 HHRA, only a limited number of these uncertainties could impact the conclusions of the Round 2 HHRA and thus have any significance to risk management decisions. These are identified with a "High" descriptor under the "Significance to Risk Management" column in Table 7-6.

The cumulative effects of the numerous conservative assumptions made during this Round 2 HHRA are risk estimates that are likely higher, and potentially significantly higher, than actual risks that may exist within the Study Area. While they are conservative, the results of the Round 2 HHRA are used to identify data needs and also identify the most significant exposure scenarios and which chemicals are contributing the highest percentage of the calculated risks.

7.6 DATA NEEDS EVALUATION

The uncertainties described in the previous sections and summarized in Table 7-6 served as the basis for the evaluation of potential data needs required to complete the baseline HHRA to be included in the RI. For evaluating data needs that may be necessary to complete the baseline HHRA, the focus was on those uncertainties that were identified as having a potential significant impact to risk management decisions. Based on table 7-6, the only uncertainties that were identified as having a potentially "High" impact on risk management decisions were the following:

- Exposure parameters for the fish consumption exposure scenarios;
- Using the maximum concentration to represent exposure;
- Risks from background.

Each of these uncertainties is discussed in detail to determine whether they rise to the level of an actual data need for the completion of the baseline HHRA.

Exposure Parameters for the Fish Consumption Exposure Scenarios
The exposure parameters used in the Round 2 HHRA for fish consumption scenarios were selected to provide a protective estimation of risk. The ingestion rates that were used were based on nationwide fish consumption data and a limited fish consumption study conducted on the Columbia Slough (for non-tribal scenarios) and on a fish consumption study conducted on Native American reservations that are not located in the vicinity of the Study Area (for Native American scenarios). The ingestion parameters used were negotiated with EPA and its partners, and EPA and its partners have been clear that conducting additional regional fish consumption studies would not be considered as a mechanism to adjust these parameters. As these parameters already provide a high degree of protectiveness to the exposure scenarios being evaluated, it does not appear that this uncertainty can be resolved through additional data collection and is not considered a data need for the baseline HHRA.

Using the Maximum Concentration to Represent Exposure
In several instances in the Round 2 HHRA, EPCs were selected based on the maximum detected concentration of a chemical rather than based on an upper-bound estimate of the arithmetic average. The cases occurred when there were less than 5 samples with detected concentrations of a given chemical within an exposure area. The use of the maximum concentration to represent exposure occurred most frequently in the assessment of fish and shellfish tissue consumption scenarios.

The use of the maximum concentration to represent exposure is a highly health protective assumption; therefore, the concern that potential risks would be underestimated is not an issue. However, it is not certain that additional tissue collection would provide sufficient numbers of detected concentrations of a given chemical to allow for a calculation of an upper-bound estimate of the arithmetic

mean. Instead, it is proposed that alternative statistical procedures be evaluated to handle limited data sets and estimate an appropriate exposure concentration for these exposure areas and scenarios.

Risks from Background

Calculated risks were presented in this Round 2 HHRA without consideration of contributions from background or ambient regional concentrations of chemicals present upstream of the Study Area. As presented in Attachment F1, the calculated cumulative risks from consumption of fish tissue collected upstream of the Study Area exceed the target risk of 10^{-4} and a noncancer hazard index of 1. Understanding the contribution of background to calculated risks is important to place the risk estimates for the Study Area in perspective and also in establishing realistic or achievable remedial goals.

Additional upstream sediment data collection along with surface water and sediment trap data collection is currently underway or being proposed. The upstream sediment, surface water, and sediment trap data will be used to account for background when establishing remedial goals. There are upstream fish tissue data available of adequate data quality that can be used to provide context for Study Area risks for purposes of risk communication. Therefore, no additional data collection is recommended to address this uncertainty.

8.0 SUMMARY AND CONCLUSIONS

This Round 2 HHRA provides a preliminary evaluation of risks to human health for the Site based on the data available at the end of Round 2 of the RI/FS. The following are the populations and associated exposure scenarios that were quantitatively evaluated in this Round 2 HHRA:

- Dockside Worker – Direct exposure to beach sediment
- In-water Worker – Direct exposure to in-water sediment
- Adult and Child Recreational Beach User – Direct exposure to beach sediment and surface water
- Transient – Direct exposure to beach sediment, surface water, and groundwater seep
- Native American Fisher – Direct exposure to beach sediment or in-water sediment and fish consumption
- Non-tribal Fisher – Direct exposure to beach sediment or in-water sediment, fish consumption, and shellfish consumption

8.1 SUMMARY OF RISKS

The cancer risks and noncancer hazards are presented for each of the exposure scenarios in Section 5 of this Round 2 HHRA. As shown in Section 5, the magnitude of risk varies greatly across the different scenarios. The calculated risks were compared to better understand those scenarios and chemicals that are the most significant contributors to risks within the Study Area.

8.1.1 Summary by Exposure Scenario

This section summarizes the risks for each of the media evaluated in this Round 2 HHRA (beach sediment, in-water sediment, surface water, seeps, fish tissue, or shellfish tissue).

8.1.1.1 Fish Consumption

Fish consumption risks were calculated for the adult and child non-tribal consumers, based on three different ingestion rates representing a range of potential high end consumption scenarios; for both single species- and multi-species diet (crappie, bullhead, and smallmouth bass); and based on consumption of both whole body and fillet tissue. Fish consumption risks were also evaluated for adult and child Native American consumers for a multi-species diet consisting of resident fish species (carp, crappie, bullhead, and smallmouth bass) as well as sturgeon, lamprey, and salmon; and on consumption of both whole body and fillet tissue.

Consumption of individual species by the non-tribal consumer resulted in cumulative cancer risks ranging from 7×10^{-6} to 2×10^{-2} for the adult non-tribal consumer and from 3×10^{-6} to 8×10^{-3} for the child non-tribal consumer. HIs for cumulative noncarcinogenic risks, which are not endpoint specific, ranged from 0.5 to 700 for the adult non-tribal consumer and from 1 to 1,000 for the child non-tribal consumer.

Consumption of fish by the Native American resulted in cumulative cancer risks ranging from 4×10^{-4} to 1×10^{-2} for the Native American adult consumer and from 6×10^{-5} to 2×10^{-3} for the Native American child consumer. HIs for cumulative noncarcinogenic risks, which are not endpoint specific, ranged from 30 to 200 for the Native American adult consumer and from 50 to 300 for the Native American child consumer.

8.1.1.2 Shellfish Consumption

The consumption of shellfish was evaluated for adult non-tribal consumers based on two consumption rates representing a range of potential high end consumption scenarios, assuming shellfish collection/consumption actually occurs within the Study Area. The shellfish species evaluated for consumption risks were crayfish and clams. Cumulative cancer risks from consumption of shellfish ranged from 1×10^{-6} to 8×10^{-4}. HIs for cumulative noncarcinogenic risks, which are not endpoint specific, ranged from 0.05 to 20 for consumption of shellfish.

8.1.1.3 Direct Exposure to Beach Sediment

Beaches were identified as potential human use areas associated with industrial upland sites (dockside workers), recreation (recreational users or fishers), and/or trespassing or transient use (transients). Even if such beach use occurs, the extent to which the beach is used and the nature of the contact with sediments/beach is uncertain. However, conservative assumptions were included in the risk analysis of this exposure pathway to provide an estimate of potential risks.

The RME scenarios for exposure to beach sediment resulting in cumulative cancer risks above 10^{-6} include: dockside worker, adult and child recreational beach user, Native American fisher and non-tribal fisher. None of the RME scenarios resulted in risks greater than 10^{-4} or HIs exceeding 1. Only the dockside worker and Native American fisher had CT scenarios where the risks were above 10^{-6}. The cumulative cancer risks for all of the CT scenarios were below 10^{-4}. Risks above 10^{-6} resulting from exposures to beach sediment are due at least in part to arsenic, which is likely present at naturally occurring background concentrations.

8.1.1.4 Direct Exposure to In-water Sediment

Risks from in-water sediment exposure were estimated separately for each of the ½-mile river segment exposure areas (east (E) and west (W)), and for site-wide exposure. In-water sediments within the navigation channel were not included in the risk evaluation. Risks from in-water sediment exposure were evaluated for exposures by in-water workers, Native American fishers and non-tribal fishers.

Cumulative cancer risks were greater than 10^{-6} but were below 10^{-4}, with the exception exposures to in-water sediment by a Native American fisher at exposure areas RM 4.5 East (due primarily to PAHs) and RM 7 West (due primarily to dioxins). Only the Native American fisher CT scenario had cancer risks above 10^{-6}. The cumulative risks for all of the CT scenarios were below 10^{-4}. None of the scenarios resulted in a HI exceeding 1.

8.1.1.5 Direct Exposure to Surface Water

Risks were evaluated for surface water exposures to transients and adult and child recreational beach users. None of the evaluated scenarios resulted in cumulative cancer risks greater than 10^{-6} or HIs greater than 1.

8.1.1.6 Direct Exposure to Seeps

Risks from exposures to groundwater seeps were evaluated for the only seep identified in a human use area, which was designated for transient use only. The transient exposure scenario did not result in cumulative cancer risks greater than 10^{-6} or HIs greater than 1.

8.1.1.7 Comparison of Risks Across Exposure Scenarios

A comparison of risk ranges across media can help focus risk management decisions by identifying the media contributing most to risk. Figure 8-1 compares the ranges of estimated cumulative cancer risks by exposure scenario. Neither surface water nor the groundwater seep scenarios result in estimated risks above 10^{-6}, which is the lowest end of EPA's target risk range of 10^{-4} to 10^{-6}. Direct sediment exposure scenarios result in estimated cancer risks that fall below, within, or only slightly higher than EPA's target risk range (within the same order of magnitude and only for the RME scenario). Finally, maximum estimated cancer risks from tissue consumption scenarios are generally 2 to 3 orders of magnitude higher than those for the sediment scenarios, and up to 7 orders of magnitude higher than estimated cancer risks from water exposure. The fish consumption scenarios result in risks that range from 10^{-6} to 10^{-2}, which are within or higher than the EPA target range. Fish and shellfish consumption are the only scenarios that result in noncancer hazards that exceed a target HI of 1. As a result of this comparison, it is evident that fish and shellfish consumption result in the highest risks for the Study Area. Due to the uncertainties associated with the shellfish consumption scenario, fish consumption is considered the primary risk driver among the complete exposure scenarios for the Study Area.

8.1.2 Chemical Contributions to Risk

Because fish consumption is considered the primary risk driver for exposure scenarios within the Study Area, the relative contribution of individual chemicals to the cumulative risks from fish consumption was evaluated further.

Figure 8-2 presents the relative contribution of individual analytes to the cumulative cancer risk predicted from fish tissue consumption based on a multiple species diet

using the average tissue concentrations for the Study Area. For both Native American and non-tribal fish consumers, PCBs in fish tissue clearly contribute the most to the cumulative cancer risk, with approximately 85 percent of the total cancer risk due to PCBs in the non-tribal scenario. Dioxins/furans are the next highest contributor to the cumulative cancer risk. For noncancer hazards, PCBs result in an HQ that is approximately 80 times higher than any other HQ. The next highest HQ is due to mercury.

8.2 CONCLUSIONS

The following are the main conclusions that have been drawn from the analysis performed for the Round 2 HHRA:

- Risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment, surface water, or seeps. Risks from fish and shellfish consumption are within or above the EPA target cancer risk range of 10^{-6} to 10^{-4} and exceed the target noncancer HI of 1. With the exception of two ½-river segments for the Native American fisher scenario, which is a highly conservative scenario, direct contact with sediment, surface water, and seeps results in risks within or below the EPA target cancer risk range of 10^{-6} to 10^{-4} and below the target noncancer HI of 1. The evaluation of shellfish consumption was only done at the direction of EPA and there is no information documenting whether shellfish consumption actually occurs within the Study Area. Therefore, fish consumption is the exposure scenario that is considered the main risk driver for this site.

- The chemicals associated with the highest cancer and noncancer risk in fish tissue were PCBs. Approximately 85 percent of the cancer risk is due to PCBs. Dioxin TEQ is the next highest contributor to cancer risk in tissue but to a much smaller extent (approximately 10 percent). All other chemicals contribute to approximately 5 percent of the overall cancer risk. The noncancer HQ from PCBs is approximately 80 times higher than any other chemical.

- Human health risks from fish tissue collected upstream of the Study Area also exceed the EPA target cancer risk range and noncancer HI.

9.0 REFERENCES

Adolfson Associates, Inc. (Adolfson). 1996. Technical Memorandum on the Results of the 1995 Fish Consumption and Recreational Use Surveys, Amendment Number 1. 19 April 1996.

ATSDR. 1996. Toxicological Profile for Endrin.

ATSDR. 2000. Toxicological Profile for Chromium.

ATSDR. 2002. Public Health Assessment, Initial Release: Portland Harbor, Portland, Multnomah County, Oregon. 15 January 2002.

ATSDR. 2004. Agency for Toxic Substances and Disease Registry (ATSDR) Minimum Risk Levels (MRLs), December 2004. URL: http://www.atsdr.cdc.gov/mrls.html.

Cal EPA. 2004. Toxicity Criteria Database. Office of Environmental Health Hazard Assessment.

Centers for Disease Control (CDC). Preventing lead poisoning in young children: a statement by the Centers for Disease Control. Atlanta, Georgia: US Department of Health and Human Services, Public Health Service, 1991.

Columbia River Inter-Tribal Fish Commission (CRITFC). 1994. A Fish Consumption Survey of the Umatilla, Nez Perce, Yakama, and Warm Springs Tribes of the Columbia River Basin, Technical Report 94-3. Columbia River Inter-Tribal Fish Commission, Portland, OR. October 1994.

DEQ. 2000a. Guidance for Conduct of Deterministic Human Health Risk Assessments. Oregon Department of Environmental Quality. May 2000.

DEQ. 2000b. Portland Harbor RI/FS Work Plan, DRAFT. Oregon Department of Environmental Quality. 31 March 2000.

DEQ. 2003. Risk-Based Decision Making for the Remediation of Petroleum-Contaminated Sites. Land Quality Division, Environmental Tanks and Cleanup Program. Portland, OR. September 22, 2003.

Oregon Department of Human Services (DHS). 2007. Environmental Toxicology Program. Fish Advisories: Consumption Guidelines. Accessed January, 2007. http://oregon.gov/DHS/ph/envtox/fishconsumption.shtml#table.

EPA. 1978. In-depth studies on health and environmental impacts of selected water pollutants. Contract No. 68-01-4646.

EPA. 1980a. Ambient Water Quality Criteria for Benzene. Office of Water Regulations and Standards, Criteria and Standards Division, Washington DC. EPA 440/5-80-018. October 1980.

EPA. 1980b. Seafood consumption data analysis. Stanford Research Institute International, Menlo Park, CA. Final Report, Task 11, Contract No. 68-01-3887.

EPA. 1980c. Ambient Water Quality Criteria for Chloroform. Office of Water Regulations and Standards, Criteria and Standards Division, Washington DC. EPA 440/5-80-033. October 1980.

EPA. 1980d. Ambient Water Quality Criteria for Trichloroethylenes. Office of Water Regulations and Standards, Criteria and Standards Division, Washington DC. EPA 440/5-80-077. October 1980.

EPA. 1980e. Ambient Water Quality Criteria for Vinyl Chloride. Office of Water Regulations and Standards, Criteria and Standards Division, Washington DC. EPA 440/5-80-078. October 1980.

EPA. 1985. Ambient Water Quality Criteria for Cyanide - 1984. Office of Water Regulations and Standards, Criteria and Standards Division, Washington DC. EPA 440/5-84-028. January 1985.

EPA. 1986. Guidelines for Carcinogen Risk Assessment. Federal Register 51(185):33992-43003. 24 September 1986.

EPA. 1989. Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A), Interim Final. Office of Solid Waste and Emergency Response, EPA/540/1-89/002. December 1989.

EPA. 1991. Risk Assessment Guidance for Superfund, Volume I. Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors, Interim Final. Office of Emergency and Remedial Response: OSWER Directive: 9285.6-03.

EPA. 1993. Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons. Office of Health and Environmental Assessment, EPA/600/R-93/089. July 1993.

EPA. 1994. Memorandum: OSWER Directive: Revised Interim Soil Lead Guidance For CERCLA Sites and RECRA Corrective Action Facilities. Office of Solid Waste and Emergency Response. Washington, D.C.

EPA. 1997. Health Effects Assessment Summary Tables (HEAST), FY-1997 Annual Update. EPA/540/R-97/036. Office of Solid Waste and Emergency Response.

EPA. 1998. Memorandum: OSWER Directive: Clarification to the 1994 Revised Interim Soil Lead (Pb) Guidance for CERCLA Sites and RCRA Corrective Action Facilities (August 1998). EPA/540/F-98/030. Office of Solid Waste and Emergency Response.

EPA. 2000a. EPA Region 10 Supplemental Human Health Risk Assessment Guidance, Office of Environmental Assessment, Soil Ingestion Rates. 25 January 2000.

EPA. 2000b. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1, Fish Sampling and Analysis, Third Edition. Office of Water. EPA 823-B-00-007. November 2000.

EPA. 2000c. Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds, Preliminary Draft. Office of Research and Development, EPA/600/P-00/001Bg. September 2000.

EPA. 2001a. Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments), Final. Office of Emergency and Remedial Response, Publication 9285.7-47. December 2001.

EPA. 2001b. Trichloroethylene Health Risk Assessment: Synthesis and Characterization, External Review Draft. Office of Research and Development. EPA/600/P-01/002A.

EPA. 2002a. Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites. Office of Emergency and Remedial Response. OSWER 9285.6-10. December 2002.

EPA. 2002b. Estimated Per Capita Fish Consumption in the United States. EPA 821-C-02-003. August 2002.

EPA. 2002c. Feasibility for Derivation of Provisional Toxicity Values for delta-Hexachlorocyclohexane (CASRN 319-86-8). SRC SF 01-019a-c/10-17-02.

EPA. 2003a. OSWER Directive 9285.7-53. Human Health Toxicity Values in Superfund Risk Assessments. December 5, 2003.

EPA. 2003b. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. Office of Research and Development, Washington DC. EPA-600-R-02-0213.

EPA. 2004a. Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final. Office of Emergency and Remedial Response. EPA/540/R/99/005. July 2004.

EPA. 2004b. Region 9 Preliminary Remediation Goals (PRGs). U.S. Environmental Protection Agency. October 2004.

EPA. 2004c. ProUCL Version 3.0, User Guide. Office of Research and Development. April 2004.

EPA. 2004d. Provisional Peer Reviewed Toxicity Values for Superfund (PPRTV) database. Office of Superfund. Washington, D.C.

EPA. 2005. Guidelines for Carcinogen Risk Assessment. Risk Assessment Forum. Washington, D.C. EPA/630/P-03/001F. March 2005.

EPA. 2006a. National Recommended Water Quality Criteria. EPA Office of Water. Office of Science and Technology. U.S. Environmental Protection Agency.

EPA. 2006b. List of Contaminants & Their Maximum Contaminant Level (MCLs). Internet site: http://www.epa.gov/safewater/contaminants/index.html.

EPA. 2006c. Integrated Risk Information System (IRIS) database. Washington, D.C.

EVS Environment Consultants, Inc. (EVS). 2000. Human health risk assessment of chemical contaminants in four fish species from the Middle Willamette River, November 21, 2000. Salem, OR: Oregon Department of Environmental Quality. (Willamette River Basin Studies: Human Health Technical Study; EVS Project No. 2/839-01).

Groundwater Solutions, Inc. (GSI) 2003. Technical Memorandum: Results of Seep Reconnaissance Survey River Mile 2 – 10.5, Lower Willamette River. USEPA Docket No: CERCLA-10-2001-0240.

Hansch, C.E. and A.J. Leo. 1979. Substituent Constants for Correlation Analysis in Chemistry and Biology. Wiley-Interscience, New York.

Hartman, Bud (President of Pan Fish Association, Portland, OR). 2002. Personal communications, telephone call with Bill Williams, Senior Scientist, Kennedy/Jenks Consultants, Portland, OR. 19 March 2002.

Integral Consulting, Inc. and Windward Environmental, LLC (Integral and Windward). 2004. Portland Harbor RI/FS, Round 2 Quality Assurance Project Plan. Prepared for The Lower Willamette Group. June 24, 2004.

Integral Consulting, Inc., Windward Environmental, LLC, Kennedy/Jenks Consultants, Anchor Environmental, LLC, Groundwater Solutions, Inc. 2004. Portland Harbor RI/FS Programmatic Work Plan. Prepared for The Lower Willamette Group. Integral Consulting, Inc., Mercer Island, WA; Windward Environmental,

LLC, Seattle, WA; Kennedy/Jenks Consultants, Portland, OR; Anchor Environmental, LLC, Seattle, WA; Groundwater Solutions, Inc., Portland, OR.

Integral Consulting, inc. 2006. Portland Harbor RI/FS Round 2 Groundwater Pathway Assessment Transition Zone Water Site Characterization Summary Report. Prepared for The Lower Willamette Group. Integral Consulting, Inc.

Kennedy/Jenks Consultants. 2004a. Round I Tissue Exposure Point Concentrations. Interim Deliverable. Prepared for The Lower Willamette Group. Kennedy/Jenks Consultants, Portland, OR.

Kennedy/Jenks Consultants. 2004b. Salmon, Lamprey, and Sturgeon Tissue Exposure Point Concentrations for Oregon Department of Human Services. Prepared for The Lower Willamette Group. Kennedy/Jenks Consultants, Portland, OR.

Kennedy/Jenks Consultants. 2004c. Human Health Toxicity Values. Interim Deliverable. Prepared for The Lower Willamette Group. Kennedy/Jenks Consultants, Portland, OR.

Kennedy/Jenks Consultants, Integral Consulting, Inc., Windward Environmental, LLC. 2004. Portland Harbor RI/FS Technical Memorandum Guidelines for Data Reporting, Data Averaging, and Treatment of Non-detected Values for the Round I Database. Prepared for The Lower Willamette Group. Kennedy/Jenks Consultants, Portland, OR; Integral Consulting, Inc., Mercer Island, WA; Windward Environmental, LLC, Seattle, WA.

Kennedy/Jenks Consultants. 2006. Portland Harbor RI/FS Technical Memorandum Human Health Risk Assessment: Exposure Point Concentration Calculation Approach and Summary of Exposure Factors. Prepared for The Lower Willamette Group. Kennedy/Jenks Consultants, Portland, OR.

Meylan, W.M., P.H. Howard, R.S. Boethling, D. Aronson, H. Printup, and S. Gouchie. 1999. Improved method for estimating bioconcentration/bioaccumulation factor from octanol/water partition coefficient. Environmental Toxicology and Chemistry 18(4):664-672.

National Library of Medicine (NLM). 2004. Hazardous Substances Data Bank (HSDB).

Siipola, M. Personal communication (telephone conversation on November 9, 2004 with Laura Kennedy, Kennedy/Jenks Consultants). U.S. Army Corps of Engineers, Portland, OR.

Steele, Ralph (Owner of Lure-em Tackle Shop, Portland, OR). 2002. Personal communications, telephone call with Bill Williams, Senior Scientist, Kennedy/Jenks Consultants, Portland, OR. 8 April 2002.

Striplin Environmental Associates (Striplin). 2002. Portland Harbor RI/FS, Round 1 Quality Assurance Project Plan. Final Report. Prepared for The Lower Willamette Group. Olympia, WA. November 22, 2002.

Suter, G.W. II, and C.L. Tsao. 1996. Toxicological Benchmarks for Screening of Potential Contaminants of Concern for Effects on Aquatic Biota on Oak Ridge Reservation: 1996 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. 104 pp. ES/ER/TM-96/R2.

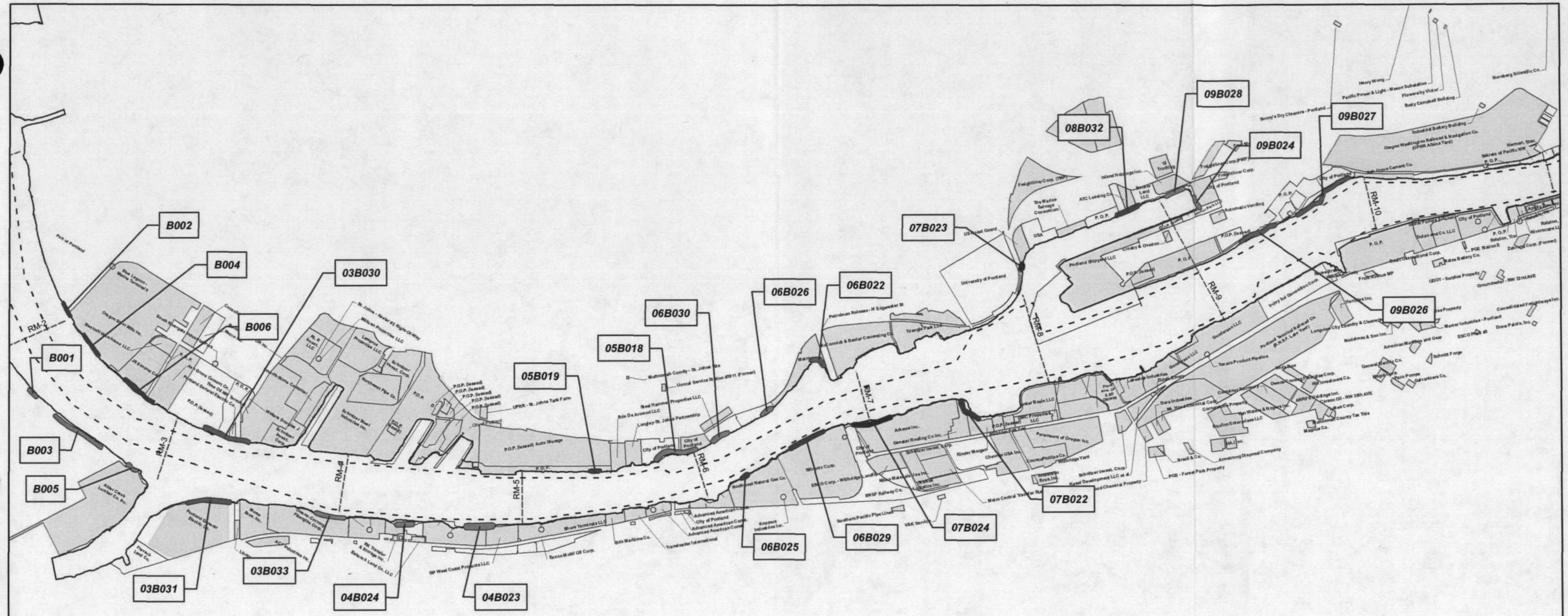
Tetra Tech. 1995. Willamette River Basin Water Quality Study. Summary and Synthesis of Study Findings. Final Report 97-094. Prepared for Oregon Department of Environmental Quality, Portland, OR. Tetra Tech, Inc., Redmond, WA. 119 pp.

Veith, G.D., D.L. DeFoe, and B.V. Bergstedt. 1979. Measuring and estimating the bioconcentration factor of chemicals in fish. J. Fish Res. Board Can. 36:1040-1048.

WDOE. 1994. Natural Background Soil Metal Concentration in Washington State. Publication #94-115. Washington department of Ecology, Olympia, WA (October, 1994).

Wilson et al. 1998. The effect of cooking practices on the concentration of DDT and PCB compounds in the edible tissue of fish. J Expo Anal Environ Epidemiol. Jul-Sep;8(3):423-40. javascript:PopUpMenu2_Set(Menu9679221);

Windward 2006. Portland Harbor RI/FS Round 2 Sampling of Benthic Invertebrate Tissue Field Sampling Report (DRAFT). Prepared for the Lower Willamette Group. Windward Environmental LLC, Integral Consulting Inc.



Legend

BeachandType

- Dockside
- Recreational
- Recreational and Transient
- Transient

Note:
All beaches classified as potential recreational and/or transient use areas are also potential Native American fisher and Non-tribal fisher use beaches for the purposes of the Round 2 HHRA

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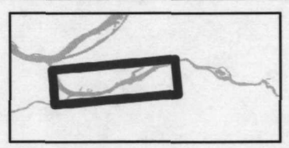
FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS .
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.

0 1,400 2,800 Feet



Ownership at Waterfront Sites
Navigation Channel
River miles

Figure 2-1
Portland Harbor RI/FS
Comprehensive Round 2 Report
Appendix F

Designated Potential Human Use Areas and Associated Beach Sediment Samples

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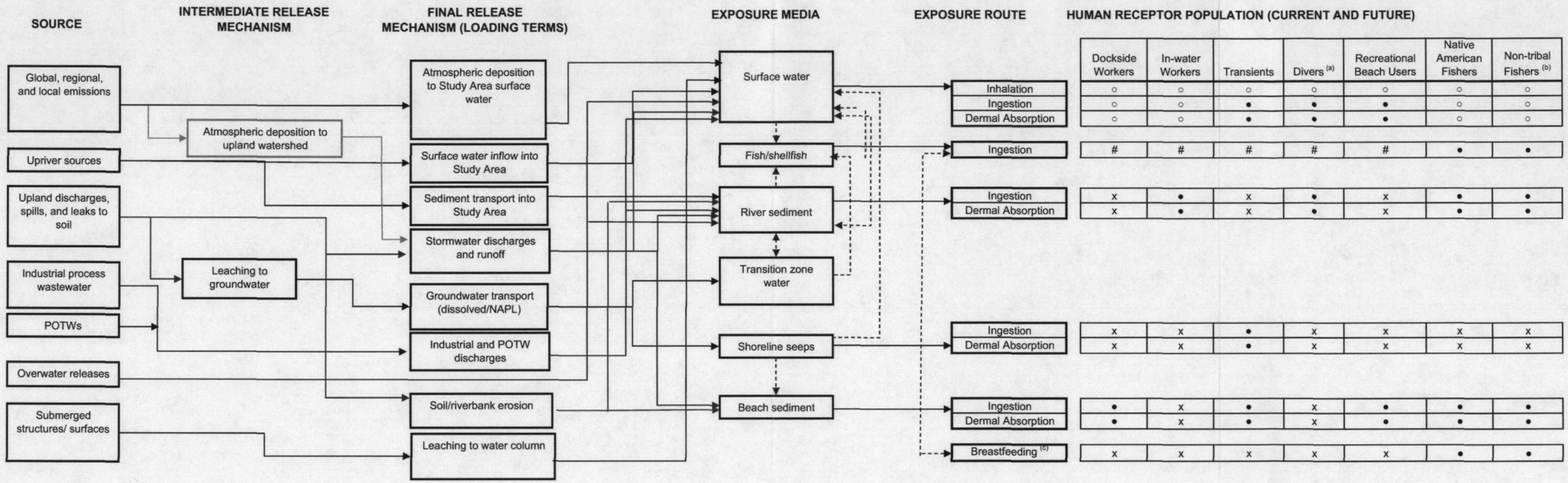
21/2007



Exposure Route	Dockside Workers	In-water Workers	Transients	Divers (a)	Recreational Beach Users	Native American Fishers	Non-tribal Fishers (b)
Inhalation	○	○	○	○	○	○	○
Ingestion	○	○	●	●	●	○	○
Dermal Absorption	○	○	●	●	●	○	○
Ingestion	#	#	#	#	#	●	●
Ingestion	x	●	x	●	x	●	●
Dermal Absorption	x	●	x	●	x	●	●
Ingestion	x	x	●	x	x	x	x
Dermal Absorption	x	x	●	x	x	x	x
Ingestion	●	x	●	x	●	●	●
Dermal Absorption	●	x	●	x	●	●	●
Breastfeeding (c)	x	x	x	x	x	●	●

Notes:
(a) The diver scenario is not quantitatively evaluated in the Round 2 HHRA.
(b) Nontribal fishers include three different fish ingestion rates and two different fishing frequencies.
(c) Breastfeeding is not quantitatively evaluated in the Round 2 HHRA.

Legend

● = Potentially complete pathway. Was evaluated in the Round 2 human health risk evaluation (HHRA).

x = Incomplete pathway

= Potentially complete pathway but evaluated under a different receptor category in the Round 2 HHRA.

○ = Potentially complete pathway but not evaluated in the Round 2 HHRA because exposure is expected to be insignificant.

——— Solid lines indicate potential pathways for iCOCs to the Study Area.

------ Dashed lines indicated potential transport pathways for iCOCs between exposure media within the Study Area

Acronyms

POTW (Publicly Owned Treatment Works)
NAPL (Non-Aqueous Phase Liquid)
iCOCs (Initial Chemicals of Concern)

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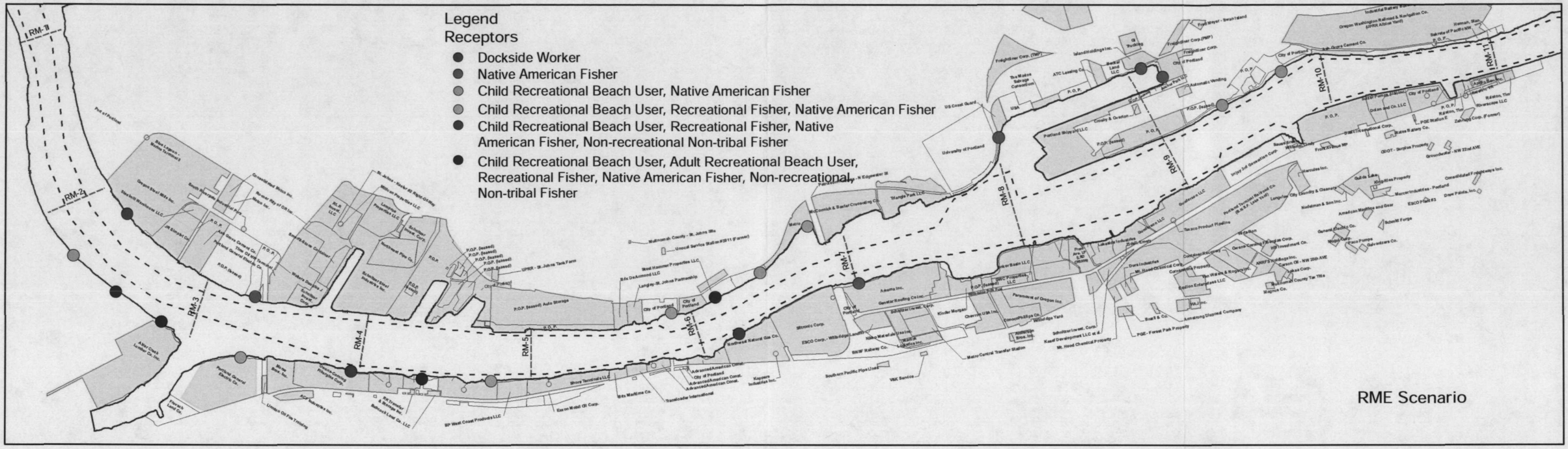
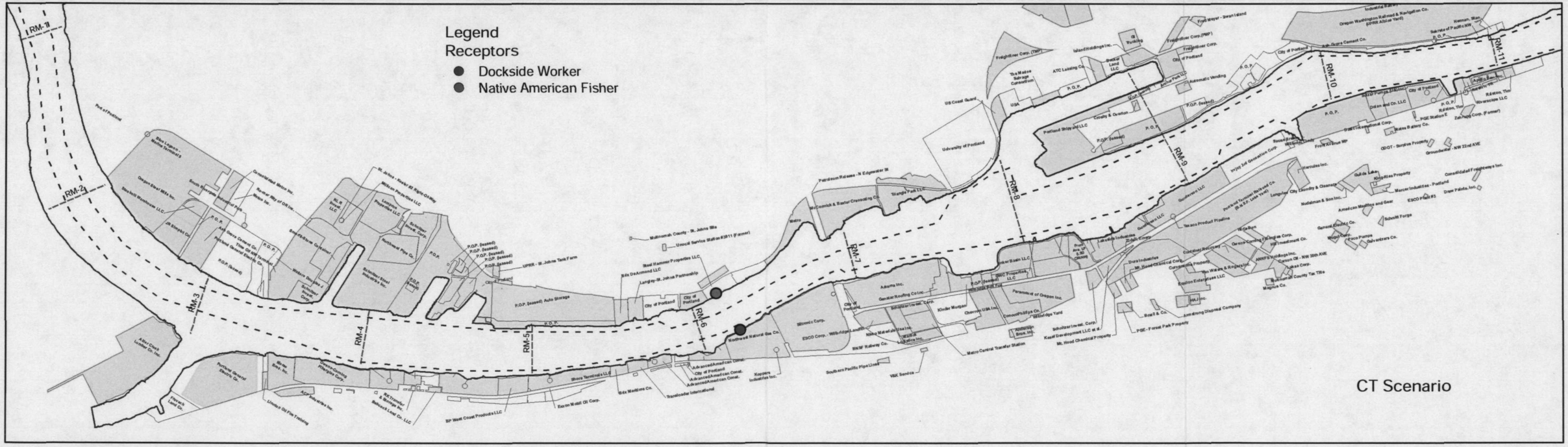
Figure 3.1
Human Health Risk Assessment Conceptual Site Model





Map Document: (Z:\Projects\LWG\Events\20070108_HHRA)
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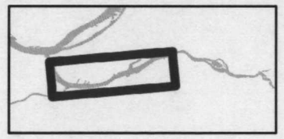
FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS .
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.

N

0 1,500 3,000 Feet



Navigation Channel
River miles
Assessors Tax Lot Owner Name
Upland Sites

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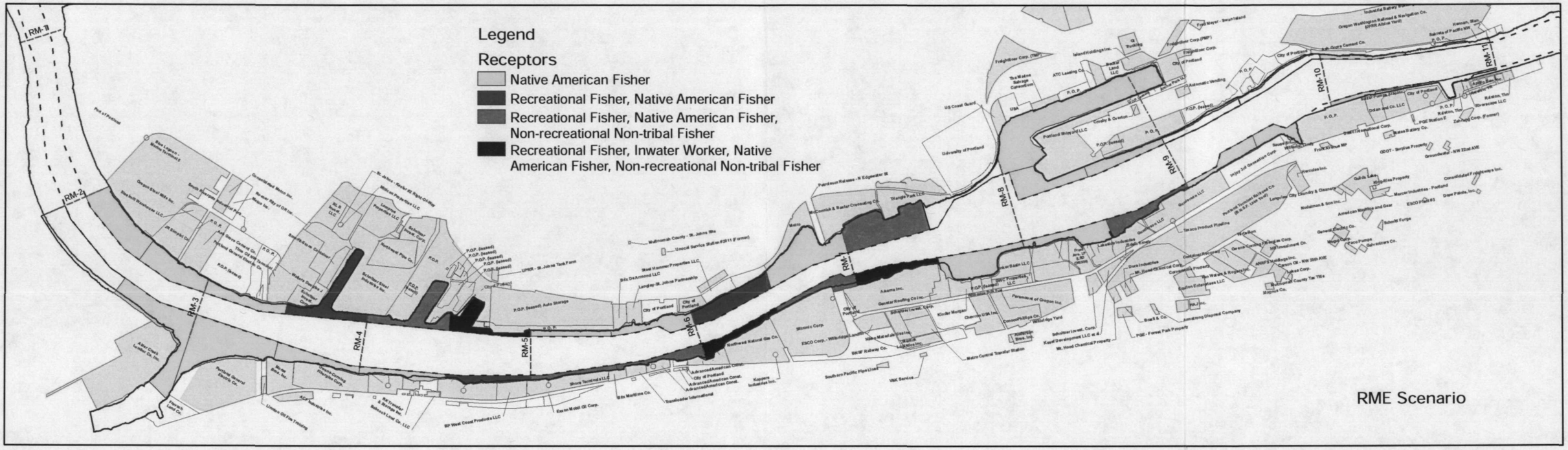
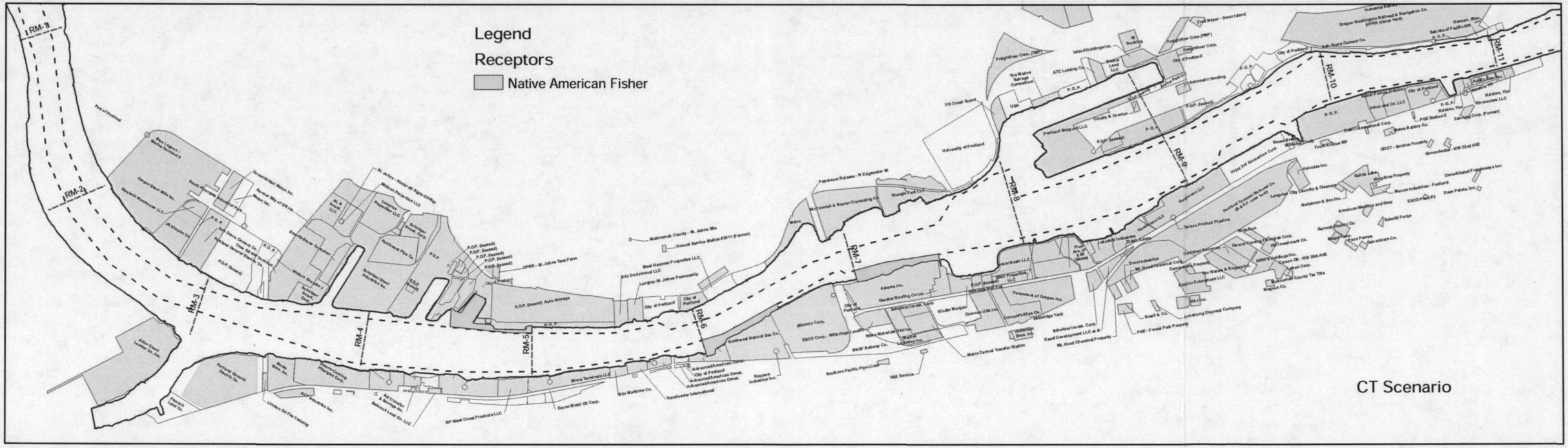
Figure 5-1
Portland Harbor RI/FS
Comprehensive Round 2 Report
Appendix F

Exposure Areas of Cumulative Risk >10-6 or Hazard Index >1
Direct Contact Beach Sediment, RME and CT Scenarios





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02/21/2007

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FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS .
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.

0 1,500 3,000 Feet

Navigation Channel
River miles
Assessors Tax Lot Owner Name
Upland Sites

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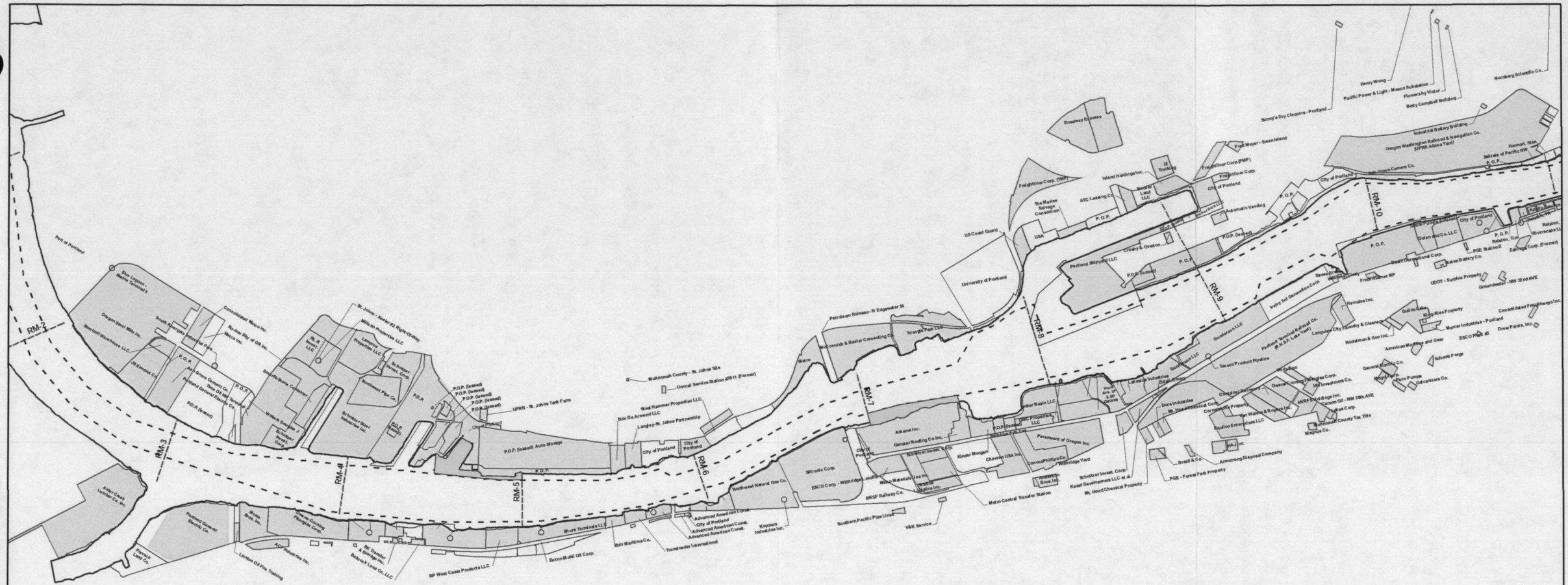
Figure 5-2
Portland Harbor RI/FS
Comprehensive Round 2 Report
Appendix F

Exposure Areas of Cumulative Risk >10-6 or Hazard Index >1
Direct Contact Inwater Sediment, RME and CT Scenarios



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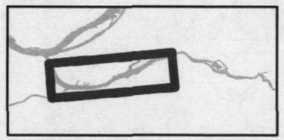
FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS .
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.

0 1,400 2,800 Feet



Ownership at Waterfront Sites
Navigation Channel
River miles

Figure 5-3
Portland Harbor RI/FS
Comprehensive Round 2 Report
Appendix F

Exposure Areas of Cumulative Risk >10-4 or Hazard Index >1
Direct Contact Inwater Sediment, RME Scenarios

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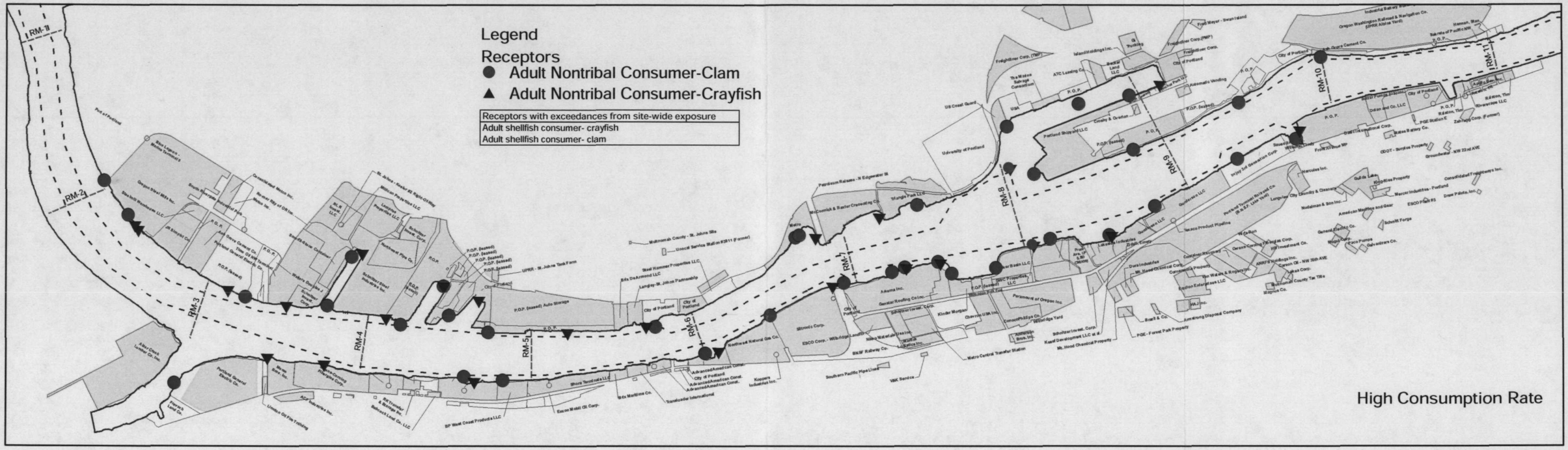

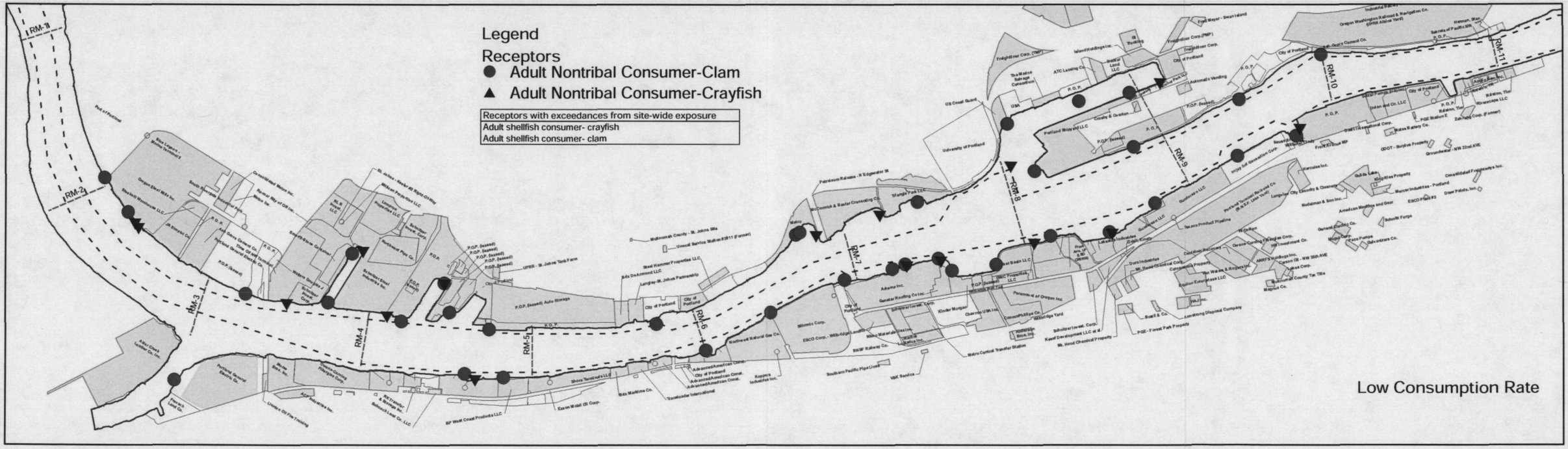

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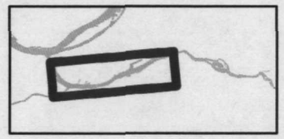
FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS .
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.

N

0 1,500 3,000 Feet



Navigation Channel
River miles
Assessors Tax Lot Owner Name
Upland Sites

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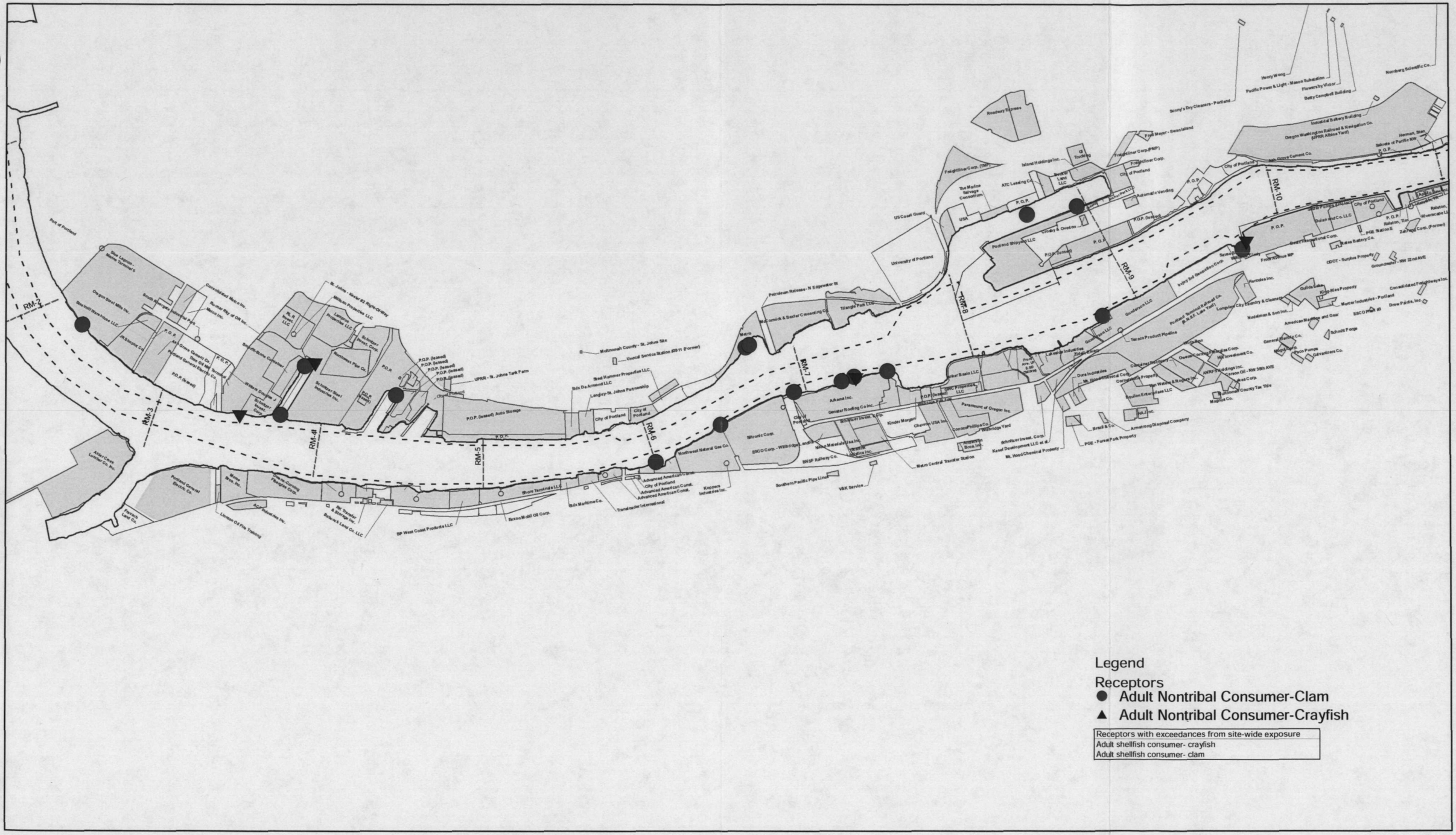
Figure 5-4
Portland Harbor RI/FS
Comprehensive Round 2 Report
Appendix F

Exposure Areas of Cumulative Risk >10-6 or Hazard Index >1
Shellfish Ingestion Scenarios, High and Low Consumption Rates



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FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS .
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.

0 1,400 2,800 Feet

Ownership at Waterfront Sites
Navigation Channel
River miles

Figure 5-5
Portland Harbor RI/FS
Comprehensive Round 2 Report
Appendix F

Exposure Areas of Cumulative Risk >10-4 or Hazard Index >1
Shellfish Ingestion Scenario, High Consumption Rate

p Document: (Z:\Projects\LWG\Events\20070108_HHRA)
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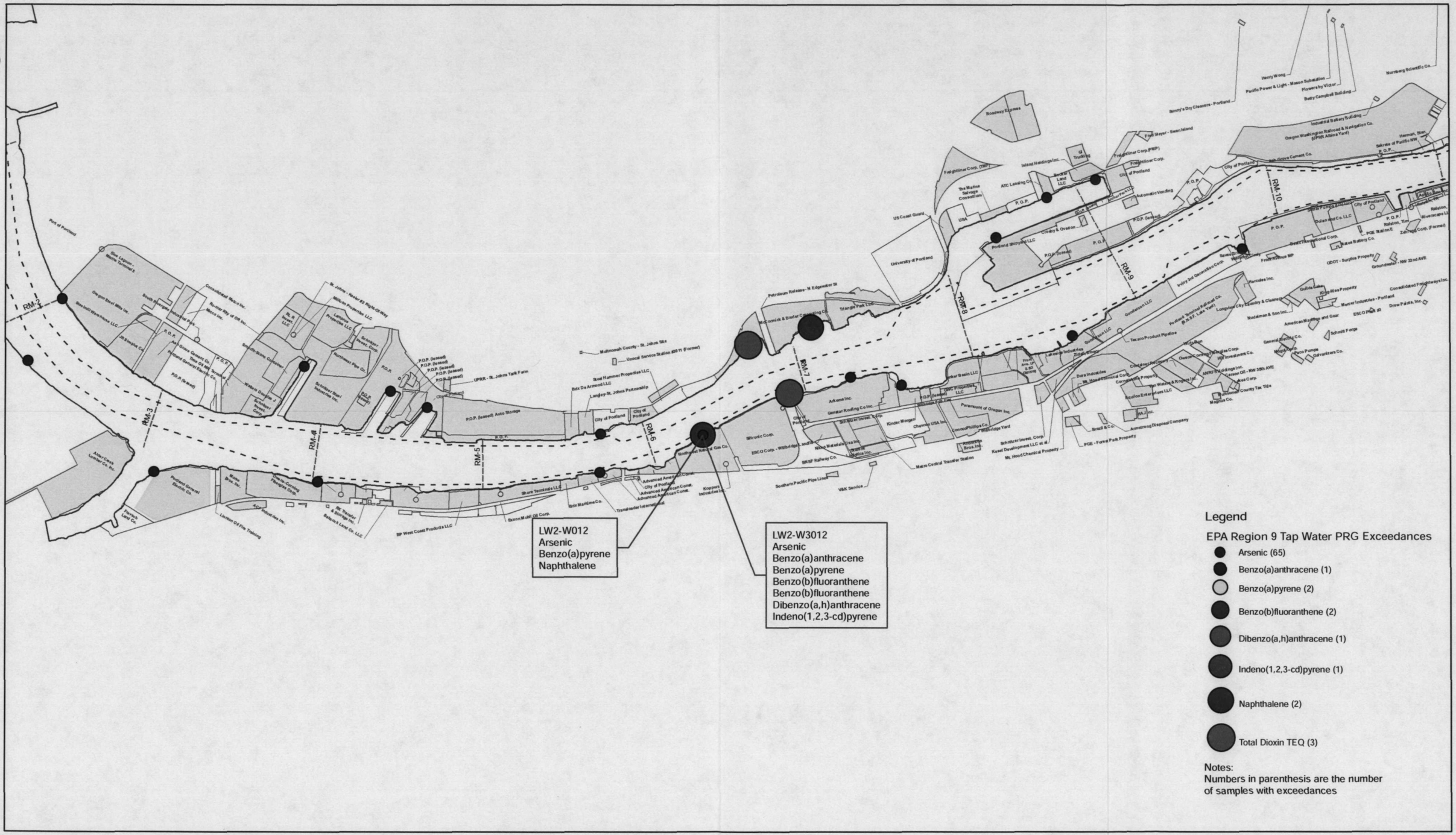

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FEATURE SOURCES:
Transportation, Property, or Boundaries: Metro RLIS .
Channel & River miles: US Army Corps of Engineers.
Bathymetric Information: David Evans and Associates, Inc.

0 1,400 2,800 Feet

Ownership at Waterfront Sites
Navigation Channel
River miles

Figure 6-1
Portland Harbor RI/FS
Comprehensive Round 2 Report
Appendix F

Surface Water Exceedances of EPA Region 9
Preliminary Remediation Goals for Tap Water

p Document: (Z:\Projects\LWG\Events\20070108_HHRA)
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Figure 6-2.

Transition Zone Water Evaluation Framework for Human Health

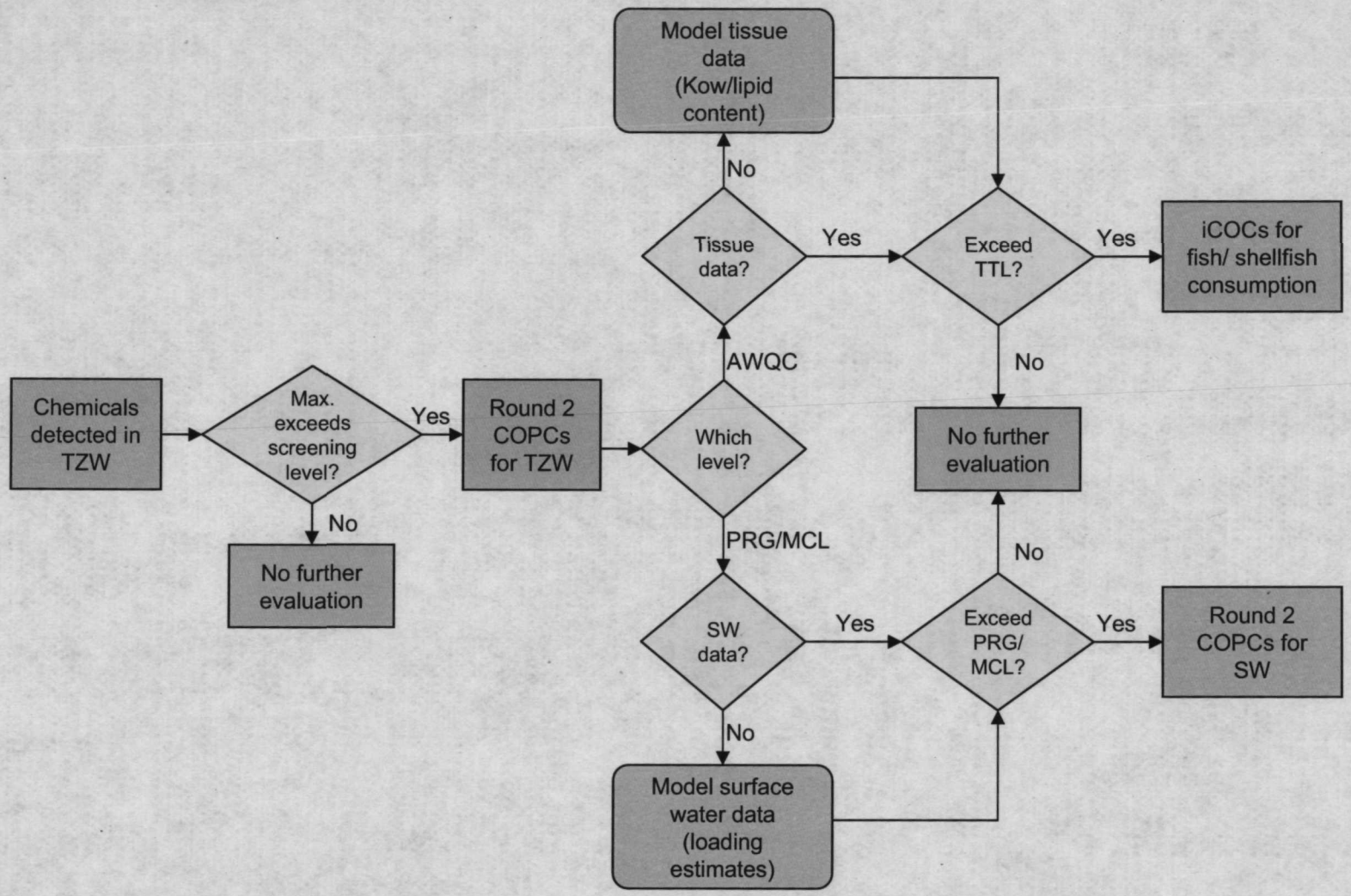


Figure 8-1. Ranges of Cumulative Cancer Risk from Reasonable Maximum Exposure Scenarios, by Medium

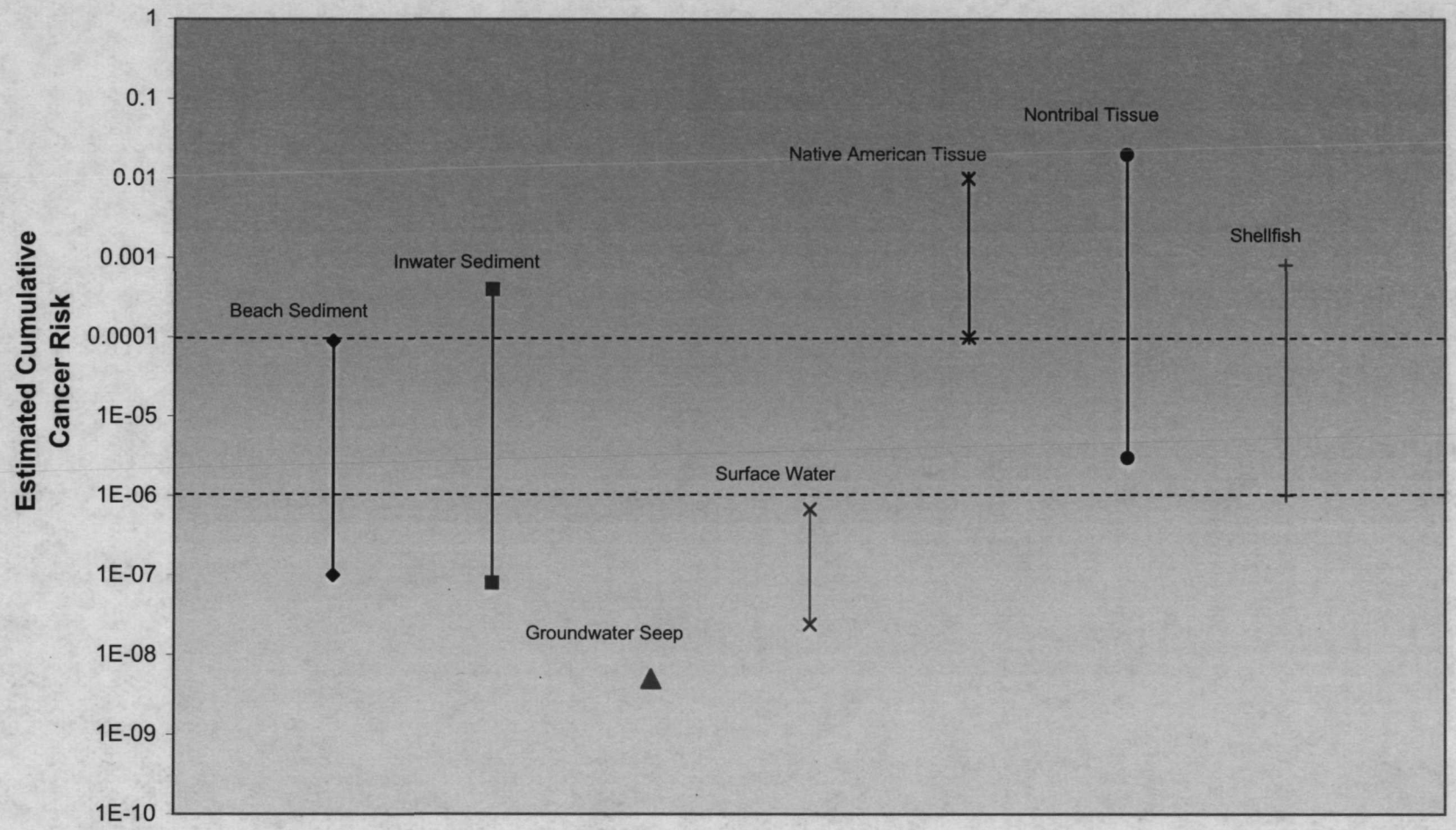
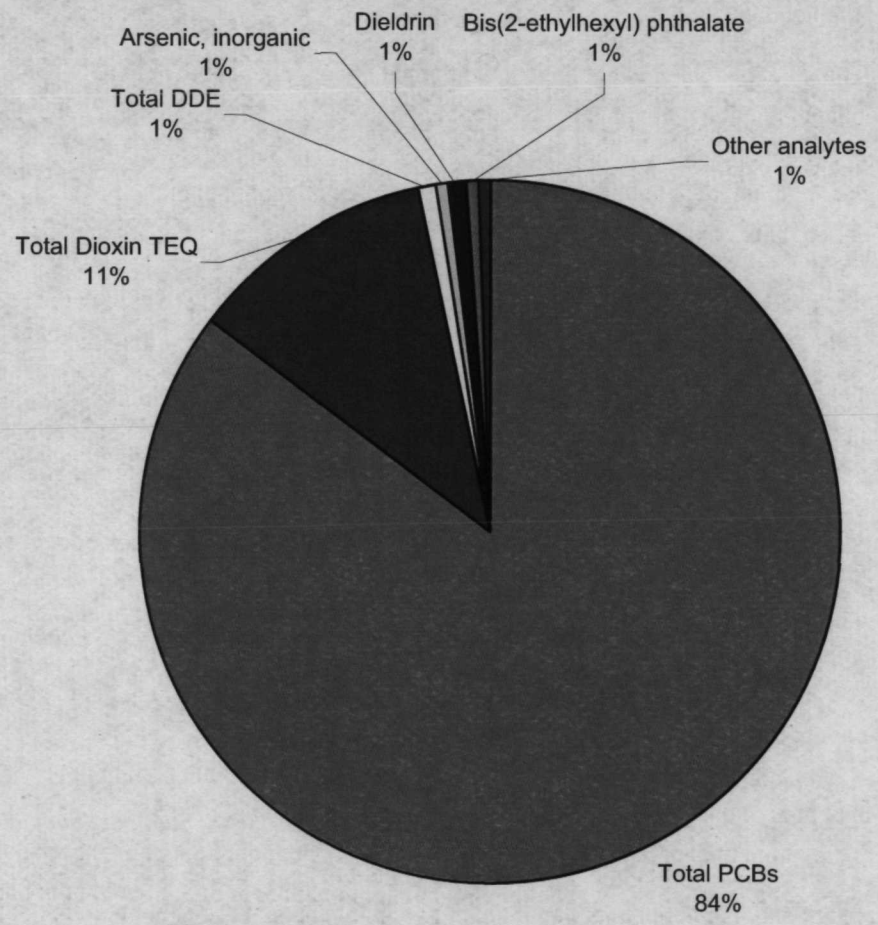


Figure 8-2. Relative Contribution of Individual Analytes to Cumulative Site-Wide Risk for Non-tribal Adult, Multi-species Whole Body Tissue Consumption, High Consumption Rate, Central Tendancy Scenario



PORTLAND HARBOR RI/FS

COMPREHENSIVE ROUND 2 SITE CHARACTERIZATION SUMMARY AND DATA GAPS REPORT

APPENDIX F:

ROUND 2 HUMAN HEALTH RISK ASSESSMENT

Attachment F1: Upstream Tissue Data Assessment

Prepared for:
The Lower Willamette Group

Prepared by:
Kennedy/Jenks Consultants

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Table 9. Calculation of Cancer Risks and Noncancer Hazards - Non-Tribal Child Upstream Fish Consumption, Single Species Diet, Brown Bullhead, Mean Exposure.
Table 10. Exposure Point Concentration Summary, Upstream Smallmouth Bass Tissue.
Table 11. Exposure Point Concentration Summary, Upstream Brown Bullhead Tissue.

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1.0 UPSTREAM TISSUE DATA ASSESSMENT

Fish tissue samples were collected at two upstream locations as part of the Round 1 sampling effort. This attachment presents a summary of the upstream tissue data as well as the methods that were used to estimate risks from fish consumption based on upstream tissue.

1.1 DATA EVALUATION

Available Data

The upstream sampling effort was initiated at the end of October 2002, which is the same time as the Lower Willamette Group (LWG) Round 1 tissue sampling within the Study Area, which includes river mile (RM) 2 to RM 11. The upstream sampling took place at two locations, one above and one below Willamette Falls. The first location was designated RM 20 and included fish collected between approximately RM 20 to RM 24.5. The second location was designated RM 28 and included fish collected between RM 28 to RM 34.5.

Brown bullhead and smallmouth bass, which are target fish species for the Round 2 human health risk assessment (HHRA), were collected at both upstream sampling locations and were used in this evaluation of upstream tissue. The composite schemes for the upstream samples were developed consistent with the rules that were used in the Study Area whenever possible. A total of six smallmouth bass and three brown bullhead samples were collected and used in this evaluation. A summary of the composite information for those samples is presented in Table1.

Use of Data

Upstream tissue data were handled in the same manner as tissue data for the Study Area, including the handling of non-detects and summed concentrations for certain analyte groups. The methods are described in Section 2.2 of Appendix F.

Those analytes which resulted in exceedances of 10^{-6} cancer risk or a hazard quotient (HQ) of 1 for any resident species tissue scenario within the Study Area were retained for evaluation in upstream tissue data. Fifteen analytes in upstream tissue were assessed for risk from fish consumption, as shown in Tables 2-9.

1.2 EXPOSURE AND TOXICITY ASSESSMENT

Since upstream data are available for only two resident species, only single-species diet scenarios were assessed using the upstream tissue data (see Appendix F, Section 3.4). The receptor populations and intake parameters were the same as those used in the Round 2 HHRA for single-species diet fish consumption. Risks from consumption of the upstream fish tissue were evaluated using the same ingestion rates and exposure assumptions as the adult and child non-tribal fish consumers, and are discussed in detail in Section 3 of Appendix F.

Exposure point concentrations (EPCs) were calculated for upstream samples combining the two sampling locations into a single exposure area. EPCs were calculated for both the upper confidence limit (UCL) and arithmetic mean, using the same approach as for the tissue collected within the Study Area, which is described in Section 3.5.5 of Appendix F. EPCs for smallmouth bass and brown bullhead are presented in Tables 10 and 11, respectively.

Toxicity values used in the assessment of upstream tissue were the same as those used for the toxicity assessment for the Study Area, and are described in Section 4 of Appendix F.

1.3 RISK CHARACTERIZATION

Estimates for noncancer and cancer health risks were calculated in the same manner as for the Round 2 HHRA, which is described in Section 5.1 of Appendix F. Risk characterization results for upstream tissue are summarized below, and presented in Tables 2 through 9.

The cumulative cancer risks ranged from 2×10^{-5} to 2×10^{-3}. The hazard indices (HIs), which were not endpoint specific, ranged from 0.6 to 70. The cumulative cancer risks are primarily driven by polychlorinated biphenyls (PCBs) and dioxins/furans. In the scenario with the highest HI, the PCB HQ is approximately 3 times higher than the next highest HQ, which is from mercury. PCBs and mercury are the only chemicals with HQs greater than 1 for any of the scenarios. The evaluation of risks from upstream tissue demonstrates that upstream contributions result in cumulative cancer risks that exceed the target risk of 10^{-4} and noncancer hazards that exceed the target HI of 1.

Table 1. Summary of Composite Information for Upstream Tissue Samples.

Station	Species	Comp	Number of Fish	Dates Collected	Min. Length (mm)	Max. Length (mm)	Average Length (mm)	Min. Weight (g)	Max. Weight (g)	Average Weight (g)	Total Weight (g)
20R001	SB	1	5	10/21/02 - 10/25/02	232	351	307.4	131.6	593.4	426.2	2131.2
20R001	SB	2	5	10/31/02 - 11/8/02	386	487	422.0	991.1	1871.0	1232.7	6163.30
20R001	SB	3	5	10/28/02 - 11/1/02	257	457	371.4	240.3	1332.0	849.7	4248.5
28R001	SB	1	5	10/24/02 - 10/29/02	241	398	324.6	210.2	889.8	539.3	2696.4
28R001	SB	2	5	10/23/02 - 10/29/02	249	412	315.4	197.2	951.7	500.4	2502
28R001	SB	3	5	10/23/02 - 10/31/02	256	416	312.0	200.2	1247.2	501.7	2508.7
20R001	BB	1	5	11/5/02	228	300	262.8	145.7	399.4	238.1	1190.3
20R001	BB	2	5	11/5/02	232	310	260.6	194.6	389.1	242.9	1214.30
28R001	BB	1	5	10/28/02 - 11/7/02	245	290	260.8	157.5	296.1	217.4	1087

Abbreviations:

SB = Smallmouth bass.
BB = Brown bullhead.
mm = millimeter.
g = grams.

Table 2.
Calculation of Cancer Risks and Noncancer Hazards - Non-tribal Adult Upstream Fish Consumption, Single Species Diet, Smallmouth Bass,
95 UCL or Maximum Exposure

Scenario Timeframe: Current/Future
Receptor Population: Non-tribal Fisher (Single Species Diet)
Receptor Age: Adult
Exposure Medium Smallmouth Bass Tissue (Whole Body)
Expsure Route: Ingestion

Exposure Medium	Exposure Point	Chemical of Potential Concern	EPC Value	EPC Units	Cancer Risk Calculations: Oral Cancer Slope Factor (mg/kg-day)$^{-1}$	Ingestion Rate: 142 g/day LADI (mg/kg-day)	Ingestion Rate: 142 g/day Cancer Risk	Ingestion Rate: 73.5 g/day LADI (mg/kg-day)	Ingestion Rate: 73.5 g/day Cancer Risk	Ingestion Rate: 17.5 g/day LADI (mg/kg-day)	Ingestion Rate: 17.5 g/day Cancer Risk	Noncancer Hazard Calculations: Oral RfD (mg/kg-day)	Ingestion Rate: 142 g/day CDI (mg/kg-day)	Ingestion Rate: 142 g/day Noncancer Hazard Quotient	Ingestion Rate: 73.5 g/day CDI (mg/kg-day)	Ingestion Rate: 73.5 g/day Noncancer Hazard Quotient	Ingestion Rate: 17.5 g/day CDI (mg/kg-day)	Ingestion Rate: 17.5 g/day Noncancer Hazard Quotient
WB tissue	Upstream	**Metals**																
		Arsenic, inorganic	3.2E+00	ug/kg	1.5E+00	2.8E-06	4.E-06	1.4E-06	2.E-06	3.4E-07	5.E-07	3.0E-04	6.5E-06	2.E-02	3.3E-06	1.E-02	8.0E-07	3.E-03
		Mercury	4.6E+02	ug/kg	--	4.0E-04	--	2.1E-04	--	4.9E-05	--	1.0E-04	9.3E-04	9.E+00	4.8E-04	5.E+00	1.1E-04	1.E+00
		Phthalates																
		Bis(2-ethylhexyl) phthalate	4.8E+03	ug/kg	1.4E-02	4.2E-03	6.E-05	2.1E-03	3.E-05	5.1E-04	7.E-06	2.0E-02	9.7E-03	5.E-01	5.0E-03	3.E-01	1.2E-03	6.E-02
		Semi-Volatile Organic Compounds																
		Hexachlorobenzene	1.2E+00	ug/kg	1.6E+00	1.0E-06	2.E-06	5.1E-07	8.E-07	1.2E-07	2.E-07	8.0E-04	2.3E-06	3.E-03	1.2E-06	1.E-03	2.9E-07	4.E-04
		Polychlorinated Biphenyls																
		Total Aroclors	2.5E+02	ug/kg	2.0E+00	2.2E-04	4.E-04	1.1E-04	2.E-04	2.7E-05	5.E-05	2.0E-05	5.0E-04	3.E+01	2.6E-04	1.E+01	6.2E-05	3.E+00
		Total Congeners Without Dioxin-like PCBs	2.3E+02	ug/kg	2.0E+00	2.0E-04	4.E-04	1.0E-04	2.E-04	2.4E-05	5.E-05	--	4.6E-04	--	2.4E-04	--	5.6E-05	--
		Total PCB TEQ	7.1E-03	ug/kg	1.5E+05	6.2E-09	9.E-04	3.2E-09	5.E-04	7.6E-10	1.E-04	--	1.4E-08	--	7.4E-09	--	1.8E-09	--
		Dioxin/Furan																
		Total Dioxin TEQ	2.2E-03	ug/kg	1.5E+05	1.9E-09	3.E-04	9.7E-10	1.E-04	2.3E-10	3.E-05	--	4.4E-09	--	2.3E-09	--	5.4E-10	--
		Pesticides																
		Dieldrin	3.7E+00	ug/kg	1.6E+01	3.2E-06	5.E-05	1.6E-06	3.E-05	3.9E-07	6.E-06	5.0E-05	7.4E-06	1.E-01	3.8E-06	8.E-02	9.2E-07	2.E-02
		Heptachlor	5.0E-01	ug/kg	4.5E+00	4.3E-07	2.E-06	2.2E-07	1.E-06	5.4E-08	2.E-07	5.0E-04	1.0E-06	2.E-03	5.2E-07	1.E-03	1.3E-07	3.E-04
		alpha-Hexachlorocyclohexane	5.0E-01	ug/kg	6.3E+00	4.3E-07	3.E-06	2.2E-07	1.E-06	5.4E-08	3.E-07	8.0E-03	1.0E-06	1.E-04	5.2E-07	7.E-05	1.3E-07	2.E-05
		beta-Hexachlorocyclohexane	2.0E+00	ug/kg	1.8E+00	1.7E-06	3.E-06	8.9E-07	2.E-06	2.1E-07	4.E-07	6.0E-04	4.1E-06	7.E-03	2.1E-06	3.E-03	5.0E-07	8.E-04
		gamma-Hexachlorocyclohexane	4.0E+00	ug/kg	1.3E+00	3.5E-06	5.E-06	1.8E-06	2.E-06	4.3E-07	6.E-07	3.0E-04	8.2E-06	3.E-02	4.2E-06	1.E-02	1.0E-06	3.E-03
		Total Chlordane	1.2E+01	ug/kg	3.5E-01	1.0E-05	4.E-06	5.2E-06	2.E-06	1.2E-06	4.E-07	5.0E-04	2.4E-05	5.E-02	1.2E-05	2.E-02	2.9E-06	6.E-03
		Total DDD	1.5E+01	ug/kg	2.4E-01	1.3E-05	3.E-06	6.8E-06	2.E-06	1.6E-06	4.E-07	5.0E-04	3.1E-05	6.E-02	1.6E-05	3.E-02	3.8E-06	8.E-03
		Total DDE	5.8E+01	ug/kg	3.4E-01	5.0E-05	2.E-05	2.6E-05	9.E-06	6.2E-06	2.E-06	5.0E-04	1.2E-04	2.E-01	6.1E-05	1.E-01	1.5E-05	3.E-02
		Total DDT	3.4E+01	ug/kg	3.4E-01	3.0E-05	1.E-05	1.5E-05	5.E-06	3.7E-06	1.E-06	5.0E-04	7.0E-05	1.E-01	3.6E-05	7.E-02	8.6E-06	2.E-02
	Exposure Point Total[a]						2.E-03		9.E-04		2.E-04			4.E+01		2.E+01		4.E+00

Notes:

[a] = PCB congeners used in cumulative risk calculations for tissue. Aroclors use for hazard index calculations.
Numbers presented are rounded values. Sums calculated before rounding.

Abbreviations:

-- = Not evaluated.
CDI = Chronic daily intake
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.
EPC = Exposure point concentration.
LADI = Lifetime average daily intake.
mg/kg = milligrams per kilogram.
PAHs = Polynuclear aromatic hydrocarbons.
PCB = Polychlorinated biphenyls
RfD = Reference dose.
TEQ = Toxic equivalents.
ug/kg = micrograms per kilogram.
WB = Whole body.

Table 3.
Calculation of Cancer Risks and Noncancer Hazards - Non-tribal Adult Upstream Fish Consumption, Single Species Diet, Smallmouth Bass.
Mean Exposure

Scenario Timeframe: Current/Future
Receptor Population: Non-tribal Fisher (Single Species Diet)
Receptor Age: Adult
Exposure Medium Smallmouth Bass Tissue (Whole Body)
Exposure Route: Ingestion

Exposure Medium	Exposure Point	Chemical of Potential Concern	EPC Value	EPC Units	Cancer Risk Calculations: Oral Cancer Slope Factor (mg/kg-day)$^{-1}$	Ingestion Rate: 142 g/day LADI (mg/kg-day)	Ingestion Rate: 142 g/day Cancer Risk	Ingestion Rate: 73.5 g/day LADI (mg/kg-day)	Ingestion Rate: 73.5 g/day Cancer Risk	Ingestion Rate: 17.5 g/day LADI (mg/kg-day)	Ingestion Rate: 17.5 g/day Cancer Risk	Noncancer Hazard Calculations: Oral RfD (mg/kg-day)	Ingestion Rate: 142 g/day CDI (mg/kg-day)	Ingestion Rate: 142 g/day Noncancer Hazard Quotient	Ingestion Rate: 73.5 g/day CDI (mg/kg-day)	Ingestion Rate: 73.5 g/day Noncancer Hazard Quotient	Ingestion Rate: 17.5 g/day CDI (mg/kg-day)	Ingestion Rate: 17.5 g/day Noncancer Hazard Quotient
WB tissue	Upstream	**Metals**																
		Arsenic, Inorganic	2.3E+01	ug/kg	1.5E+00	2.0E-05	3.E-05	1.0E-05	2.E-05	2.5E-06	4.E-06	3.0E-04	4.7E-05	2.E-01	2.4E-05	8.E-02	5.8E-06	2.E-02
		Mercury	3.2E+02	ug/kg	–	2.8E-04	–	1.4E-04	–	3.4E-05	–	1.0E-04	6.5E-04	7.E+00	3.4E-04	3.E+00	8.0E-05	8.E-01
		Phthalates																
		Bis(2-ethylhexyl) phthalate	9.0E+02	ug/kg	1.4E-02	7.8E-04	1.E-05	4.0E-04	6.E-06	9.6E-05	1.E-06	2.0E-02	1.8E-03	9.E-02	9.4E-04	5.E-02	2.2E-04	1.E-02
		Semi-Volatile Organic Compounds																
		Hexachlorobenzene	8.8E-01	ug/kg	1.6E+00	7.7E-07	1.E-06	3.9E-07	6.E-07	9.5E-08	2.E-07	8.0E-04	1.8E-06	2.E-03	9.2E-07	1.E-03	2.2E-07	3.E-04
		Polychlorinated Biphenyls																
		Total Aroclors	1.5E+02	ug/kg	2.0E+00	1.3E-04	3.E-04	6.6E-05	1.E-04	1.6E-05	3.E-05	2.0E-05	3.0E-04	2.E+01	1.5E-04	8.E+00	3.7E-05	2.E+00
		Total Congeners Without Dioxin-like PCBs	1.5E+02	ug/kg	2.0E+00	1.3E-04	3.E-04	6.8E-05	1.E-04	1.6E-05	3.E-05	–	3.1E-04	–	1.6E-04	–	3.8E-05	–
		Total PCB TEQ	5.0E-03	ug/kg	1.5E+05	4.4E-09	7.E-04	2.3E-09	3.E-04	5.4E-10	8.E-05	–	1.0E-08	–	5.3E-09	–	1.3E-09	–
		Dioxin/Furan																
		Total Dioxin TEQ	1.6E-03	ug/kg	1.5E+05	1.4E-09	2.E-04	7.1E-10	1.E-04	1.7E-10	3.E-05	–	3.2E-09	–	1.7E-09	–	4.0E-10	–
		Pesticides																
		Dieldrin	2.8E+00	ug/kg	1.6E+01	2.5E-06	4.E-05	1.3E-06	2.E-05	3.0E-07	5.E-06	5.0E-05	5.7E-06	1.E-01	3.0E-06	6.E-02	7.1E-07	1.E-02
		Heptachlor	5.0E-01	ug/kg	4.5E+00	4.3E-07	2.E-06	2.2E-07	1.E-06	5.4E-08	2.E-07	5.0E-04	1.0E-06	2.E-03	5.2E-07	1.E-03	1.3E-07	3.E-04
		alpha-Hexachlorocyclohexane	5.0E-01	ug/kg	6.3E+00	4.3E-07	3.E-06	2.2E-07	1.E-06	5.4E-08	3.E-07	8.0E-03	1.0E-06	1.E-04	5.2E-07	7.E-05	1.3E-07	2.E-05
		beta-Hexachlorocyclohexane	1.6E+00	ug/kg	1.8E+00	1.4E-06	3.E-06	7.3E-07	1.E-06	1.8E-07	3.E-07	6.0E-04	3.3E-06	6.E-03	1.7E-06	3.E-03	4.1E-07	7.E-04
		gamma-Hexachlorocyclohexane	3.1E+00	ug/kg	1.3E+00	2.7E-06	4.E-06	1.4E-06	2.E-06	3.3E-07	4.E-07	3.0E-04	6.3E-06	2.E-02	3.2E-06	1.E-02	7.8E-07	3.E-03
		Total Chlordane	8.6E+00	ug/kg	3.5E-01	7.4E-06	3.E-06	3.8E-06	1.E-06	9.2E-07	3.E-07	5.0E-04	1.7E-05	3.E-02	8.9E-06	2.E-02	2.1E-06	4.E-03
		Total DDD	1.2E+01	ug/kg	2.4E-01	1.0E-05	2.E-06	5.2E-06	1.E-06	1.2E-06	3.E-07	5.0E-04	2.4E-05	5.E-02	1.2E-05	2.E-02	2.9E-06	6.E-03
		Total DDE	4.9E+01	ug/kg	3.4E-01	4.2E-05	1.E-05	2.2E-05	7.E-06	5.2E-06	2.E-06	5.0E-04	9.9E-05	2.E-01	5.1E-05	1.E-01	1.2E-05	2.E-02
		Total DDT	2.5E+01	ug/kg	3.4E-01	2.2E-05	7.E-06	1.1E-05	4.E-06	2.7E-06	9.E-07	5.0E-04	5.1E-05	1.E-01	2.6E-05	5.E-02	6.2E-06	1.E-02
	Exposure Point Total*						1.E-03		6.E-04		2.E-04			2.E+01		1.E+01		3.E+00

Notes:
* = PCB congeners used in cumulative risk calculations for tissue, Aroclors use for hazard index calculations.
Numbers presented are rounded values. Sums calculated before rounding.

Abbreviations:
– = Not evaluated.
CDI = Chronic daily intake.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.
EPC = Exposure point concentration.
LADI = Lifetime average daily intake.
mg/kg = milligrams per kilogram.
PAHs = Polynuclear aromatic hydrocarbons.
PCB = Polychlorinated biphenyls.
RfD = Reference dose.
TEQ = Toxic equivalents.
ug/kg = micrograms per kilogram.
WB = Whole body.

Table 4.
Calculation of Cancer Risks and Noncancer Hazards - Non-tribal Child Upstream Fish Consumption, Single Species Diet, Smallmouth Bass.
95 UCL or Maximum Exposure

Scenario Timeframe: Current/Future
Receptor Population: Non-tribal Fisher (Single Species Diet)
Receptor Age: Child
Exposure Medium: Smallmouth Bass Tissue (Whole Body)
Exposure Route: Ingestion

Exposure Medium	Exposure Point	Chemical of Potential Concern	EPC Value	EPC Units	Cancer Risk Calculations: Oral Cancer Slope Factor (mg/kg-day)[1]	Ingestion Rate: 60 g/day LADI (mg/kg-day)	Ingestion Rate: 60 g/day Cancer Risk	Ingestion Rate: 31 g/day LADI (mg/kg-day)	Ingestion Rate: 31 g/day Cancer Risk	Ingestion Rate: 7 g/day LADI (mg/kg-day)	Ingestion Rate: 7 g/day Cancer Risk	Noncancer Hazard Calculations: Oral RfD (mg/kg-day)	Ingestion Rate: 60 g/day CDI (mg/kg-day)	Ingestion Rate: 60 g/day Noncancer Hazard Quotient	Ingestion Rate: 31 g/day CDI (mg/kg-day)	Ingestion Rate: 31 g/day Noncancer Hazard Quotient	Ingestion Rate: 7 g/day CDI (mg/kg-day)	Ingestion Rate: 7 g/day Noncancer Hazard Quotient
WB tissue	Upstream	**Metals**																
		Arsenic, inorganic	3.2E+00	ug/kg	1.5E+00	1.1E-06	2.E-06	5.7E-07	9.E-07	1.3E-07	2.E-07	3.0E-04	1.3E-05	4.E-02	6.6E-06	2.E-02	1.5E-06	5.E-03
		Mercury	4.6E+02	ug/kg	–	1.6E-04	–	8.1E-05	–	1.8E-05	–	1.0E-04	1.8E-03	2.E+01	9.5E-04	9.E+00	2.1E-04	2.E+00
		Phthalates																
		Bis(2-ethylhexyl) phthalate	4.8E+03	ug/kg	1.4E-02	1.6E-03	2.E-05	8.5E-04	1.E-05	1.9E-04	3.E-06	2.0E-02	1.9E-02	1.E+00	9.9E-03	5.E-01	2.2E-03	1.E-01
		Semi-Volatile Organic Compounds																
		Hexachlorobenzene	1.2E+00	ug/kg	1.6E+00	3.9E-07	6.E-07	2.0E-07	3.E-07	4.6E-08	7.E-08	8.0E-04	4.6E-06	6.E-03	2.4E-06	3.E-03	5.4E-07	7.E-04
		Polychlorinated Biphenyls																
		Total Aroclors	2.5E+02	ug/kg	2.0E+00	8.5E-05	2.E-04	4.4E-05	9.E-05	9.9E-06	2.E-05	2.0E-05	9.9E-04	5.E+01	5.1E-04	3.E+01	1.2E-04	6.E+00
		Total Congeners Without Dioxin-like PCBs	2.3E+02	ug/kg	2.0E+00	7.7E-05	2.E-04	4.0E-05	8.E-05	9.0E-06	2.E-05	–	9.0E-04	–	4.7E-04	–	1.1E-04	–
		Total PCB TEQ	7.1E-03	ug/kg	1.5E+05	2.4E-09	4.E-04	1.3E-09	2.E-04	2.8E-10	4.E-05	–	2.8E-08	–	1.5E-08	–	3.3E-09	–
		Dioxin/Furan																
		Total Dioxin TEQ	2.2E-03	ug/kg	1.5E+05	7.4E-10	1.E-04	3.8E-10	6.E-05	8.6E-11	1.E-05	–	8.6E-09	–	4.5E-09	–	1.0E-09	–
		Pesticides																
		Dieldrin	3.7E+00	ug/kg	1.6E+01	1.3E-06	2.E-05	6.5E-07	1.E-05	1.5E-07	2.E-06	5.0E-05	1.5E-05	3.E-01	7.6E-06	2.E-01	1.7E-06	3.E-02
		Heptachlor	5.0E-01	ug/kg	4.5E+00	1.7E-07	8.E-07	8.9E-08	4.E-07	2.0E-08	9.E-08	5.0E-04	2.0E-06	4.E-03	1.0E-06	2.E-03	2.3E-07	5.E-04
		alpha-Hexachlorocyclohexane	5.0E-01	ug/kg	6.3E+00	1.7E-07	1.E-06	8.9E-08	6.E-07	2.0E-08	1.E-07	8.0E-03	2.0E-06	3.E-04	1.0E-06	1.E-04	2.3E-07	3.E-05
		beta-Hexachlorocyclohexane	2.0E+00	ug/kg	1.8E+00	6.9E-07	1.E-06	3.5E-07	6.E-07	8.0E-08	1.E-07	6.0E-04	8.0E-06	1.E-02	4.1E-06	7.E-03	9.3E-07	2.E-03
		gamma-Hexachlorocyclohexane	4.0E+00	ug/kg	1.3E+00	1.4E-06	2.E-06	7.1E-07	9.E-07	1.6E-07	2.E-07	3.0E-04	1.6E-05	5.E-02	8.3E-06	3.E-02	1.9E-06	6.E-03
		Total Chlordane	1.2E+01	ug/kg	3.5E-01	4.0E-06	1.E-06	2.1E-06	7.E-07	4.6E-07	2.E-07	5.0E-04	4.6E-05	9.E-02	2.4E-05	5.E-02	5.4E-06	1.E-02
		Total DDD	1.5E+01	ug/kg	2.4E-01	5.2E-06	1.E-06	2.7E-06	6.E-07	6.1E-07	1.E-07	5.0E-04	6.1E-05	1.E-01	3.1E-05	6.E-02	7.1E-06	1.E-02
		Total DDE	5.8E+01	ug/kg	3.4E-01	2.0E-05	7.E-06	1.0E-05	3.E-06	2.3E-06	8.E-07	5.0E-04	2.3E-04	5.E-01	1.2E-04	2.E-01	2.7E-05	5.E-02
		Total DDT	3.4E+01	ug/kg	3.4E-01	1.2E-05	4.E-06	6.1E-06	2.E-06	1.4E-06	5.E-07	5.0E-04	1.4E-04	3.E-01	7.1E-05	1.E-01	1.6E-05	3.E-02
	Exposure Point Total[a]						7.E-04		4.E-04		8.E-05			7.E+01		4.E+01		8.E+00

Notes:
[a] = PCB congeners used in cumulative risk calculations for tissue, Aroclors use for hazard index calculations.
Numbers presented are rounded values. Sums calculated before rounding.

Abbreviations:
– = Not evaluated.
CDI = Chronic daily intake.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.
EPC = Exposure point concentration.
LADI = Lifetime average daily intake.
mg/kg = milligrams per kilogram.
PAHs = Polynuclear aromatic hydrocarbons.
PCB = Polychlorinated biphenyls.
RfD = Reference dose.
TEQ = Toxic equivalents.
ug/kg = micrograms per kilogram.
WB = Whole body.

Table 5.
Calculation of Cancer Risks and Noncancer Hazards - Non-tribal Child Upstream Fish Consumption, Single Species Diet, Smallmouth Bass.
Mean Exposure

Scenario Timeframe: Current/Future
Receptor Population: Non-tribal Fisher (Single Species Diet)
Receptor Age: Child
Exposure Medium Smallmouth Bass Tissue (Whole Body)
Exposure Route: Ingestion

Exposure Medium	Exposure Point	Chemical of Potential Concern	EPC Value	EPC Units	Cancer Risk Calculations: Oral Cancer Slope Factor (mg/kg-day)$^{-1}$	Ingestion Rate: 60 g/day LADI (mg/kg-day)	Ingestion Rate: 60 g/day Cancer Risk	Ingestion Rate: 31 g/day LADI (mg/kg-day)	Ingestion Rate: 31 g/day Cancer Risk	Ingestion Rate: 7 g/day LADI (mg/kg-day)	Ingestion Rate: 7 g/day Cancer Risk	Noncancer Hazard Calculations: Oral RfD (mg/kg-day)	Ingestion Rate: 60 g/day CDI (mg/kg-day)	Ingestion Rate: 60 g/day Noncancer Hazard Quotient	Ingestion Rate: 31 g/day CDI (mg/kg-day)	Ingestion Rate: 31 g/day Noncancer Hazard Quotient	Ingestion Rate: 7 g/day CDI (mg/kg-day)	Ingestion Rate: 7 g/day Noncancer Hazard Quotient
WB tissue	Upstream	**Metals**																
		Arsenic, inorganic	2.3E+01	ug/kg	1.5E+00	8.0E-06	1.E-05	4.1E-06	6.E-06	9.3E-07	1.E-06	3.0E-04	9.3E-05	3.E-01	4.8E-05	2.E-01	1.1E-05	4.E-02
		Mercury	3.2E+02	ug/kg	–	1.1E-04	–	5.7E-05	–	1.3E-05	–	1.0E-04	1.3E-03	1.E+01	6.7E-04	7.E+00	1.5E-04	2.E+00
		Phthalates																
		Bis(2-ethylhexyl) phthalate	8.0E+02	ug/kg	1.4E-02	3.1E-04	4.E-06	1.6E-04	2.E-06	3.6E-05	5.E-07	2.0E-02	3.6E-03	2.E-01	1.9E-03	9.E-02	4.2E-04	2.E-02
		Semi-Volatile Organic Compounds																
		Hexachlorobenzene	8.8E-01	ug/kg	1.6E+00	3.0E-07	5.E-07	1.6E-07	3.E-07	3.5E-08	6.E-08	8.0E-04	3.5E-06	4.E-03	1.8E-06	2.E-03	4.1E-07	5.E-04
		Polychlorinated Biphenyls																
		Total Aroclors	1.5E+02	ug/kg	2.0E+00	5.1E-05	1.E-04	2.6E-05	5.E-05	5.9E-06	1.E-05	2.0E-05	5.9E-04	3.E+01	3.1E-04	2.E+01	6.9E-05	3.E+00
		Total Congeners Without Dioxin-like PCBs	1.5E+02	ug/kg	2.0E+00	5.2E-05	1.E-04	2.7E-05	5.E-05	6.1E-06	1.E-05	–	6.1E-04	–	3.1E-04	–	7.1E-05	–
		Total PCB TEQ	5.0E-03	ug/kg	1.5E+05	1.7E-09	3.E-04	8.9E-10	1.E-04	2.0E-10	3.E-05	–	2.0E-08	–	1.0E-08	–	2.4E-09	–
		Dioxin/Furan																
		Total Dioxin TEQ	1.6E-03	ug/kg	1.5E+05	5.5E-10	8.E-05	2.8E-10	4.E-05	6.4E-11	1.E-05	–	6.4E-09	–	3.3E-09	–	7.4E-10	–
		Pesticides																
		Dieldrin	2.8E+00	ug/kg	1.6E+01	9.7E-07	2.E-05	5.0E-07	8.E-06	1.1E-07	2.E-06	5.0E-05	1.1E-05	2.E-01	5.9E-06	1.E-01	1.3E-06	3.E-02
		Heptachlor	5.0E-01	ug/kg	4.5E+00	1.7E-07	8.E-07	8.9E-08	4.E-07	2.0E-08	9.E-08	5.0E-04	2.0E-06	4.E-03	1.0E-06	2.E-03	2.3E-07	5.E-04
		alpha-Hexachlorocyclohexane	5.0E-01	ug/kg	6.3E+00	1.7E-07	1.E-06	8.9E-08	6.E-07	2.0E-08	1.E-07	8.0E-03	2.0E-06	3.E-04	1.0E-06	1.E-04	2.3E-07	3.E-05
		beta-Hexachlorocyclohexane	1.6E+00	ug/kg	1.8E+00	5.6E-07	1.E-06	2.9E-07	5.E-07	6.6E-08	1.E-07	6.0E-04	6.6E-06	1.E-02	3.4E-06	6.E-03	7.7E-07	1.E-03
		gamma-Hexachlorocyclohexane	3.1E+00	ug/kg	1.3E+00	1.1E-06	1.E-06	5.5E-07	7.E-07	1.2E-07	2.E-07	3.0E-04	1.2E-05	4.E-02	6.4E-06	2.E-02	1.5E-06	5.E-03
		Total Chlordane	8.6E+00	ug/kg	3.5E-01	2.9E-06	1.E-06	1.5E-06	5.E-07	3.4E-07	1.E-07	5.0E-04	3.4E-05	7.E-02	1.8E-05	4.E-02	4.0E-06	8.E-03
		Total DDD	1.2E+01	ug/kg	2.4E-01	4.0E-06	1.E-06	2.1E-06	5.E-07	4.7E-07	1.E-07	5.0E-04	4.7E-05	9.E-02	2.4E-05	5.E-02	5.4E-06	1.E-02
		Total DDE	4.9E+01	ug/kg	3.4E-01	1.7E-05	6.E-06	8.6E-06	3.E-06	1.9E-06	7.E-07	5.0E-04	1.9E-04	4.E-01	1.0E-04	2.E-01	2.3E-05	5.E-02
		Total DDT	2.5E+01	ug/kg	3.4E-01	8.5E-06	3.E-06	4.4E-06	2.E-06	1.0E-06	3.E-07	5.0E-04	1.0E-04	2.E-01	5.2E-05	1.E-01	1.2E-05	2.E-02
	Exposure Point Total[a]						5.E-04		3.E-04		6.E-05			4.E+01		2.E+01		5.E+00

Notes:
[a] = PCB congeners used in cumulative risk calculations for tissue, Aroclors use for hazard index calculations.
Numbers presented are rounded values. Sums calculated before rounding

Abbreviations:
– = Not evaluated.
CDI = Chronic daily intake.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.
EPC = Exposure point concentration.
LADI = Lifetime average daily intake.
mg/kg = milligrams per kilogram.
PAHs = Polynuclear aromatic hydrocarbons.
PCB = Polychlorinated biphenyls.
RfD = Reference dose.
TEQ = Toxic equivalents.
ug/kg = micrograms per kilogram.
WB = Whole body.

Table 6.
Calculation of Cancer Risks and Noncancer Hazards - Non-tribal Adult Upstream Fish Consumption, Single Species Diet, Brown Bullhead,
Maximum Exposure

Scenario Timeframe: Current/Future
Receptor Population: Non-tribal Fisher (Single Species Diet)
Receptor Age: Adult
Exposure Medium Brown Bullhead Tissue (Whole Body)
Expsure Route: Ingestion

Exposure Medium	Exposure Point	Chemical of Potential Concern	EPC		Cancer Risk Calculations							Noncancer Hazard Calculations						
					Oral Cancer Slope Factor (mg/kg-day)$^{-1}$	Ingestion Rate: 142 g/day		Ingestion Rate 73.5 g/day		Ingestion Rate: 17.5 g/day		Oral RfD (mg/kg-day)	Ingestion Rate 142 g/day		Ingestion Rate: 73.5 g/day		Ingestion Rate: 17.5 g/day	
			Value	Units		LADI (mg/kg-day)	Cancer Risk	LADI (mg/kg-day)	Cancer Risk	LADI (mg/kg-day)	Cancer Risk		CDI (mg/kg-day)	Noncancer Hazard Quotient	CDI (mg/kg-day)	Noncancer Hazard Quotient	CDI (mg/kg-day)	Noncancer Hazard Quotient
WB tissue	Upstream	**Metals**																
		Arsenic, Inorganic	9.0E+00	ug/kg	1.5E+00	7.8E-06	1.E-05	4.0E-06	6.E-06	9.6E-07	1.E-06	3.0E-04	1.8E-05	6.E-02	9.4E-06	3.E-02	2.3E-06	8.E-03
		Mercury	9.4E+01	ug/kg	–	8.2E-05	–	4.2E-05	–	1.0E-05	–	1.0E-04	1.9E-04	2.E+00	9.8E-05	1.E+00	2.4E-05	2.E-01
		Phthalates																
		Bis(2-ethylhexyl) phthalate	3.0E+03	ug/kg	1.4E-02	2.6E-03	4.E-05	1.3E-03	2.E-05	3.2E-04	5.E-06	2.0E-02	6.1E-03	3.E-01	3.1E-03	2.E-01	7.5E-04	4.E-02
		Semi-Volatile Organic Compounds																
		Hexachlorobenzene	1.7E+01	ug/kg	1.6E+00	1.4E-05	2.E-05	7.4E-06	1.E-05	1.8E-06	3.E-06	8.0E-04	3.3E-05	4.E-02	1.7E-05	2.E-02	4.1E-06	5.E-03
		Polychlorinated Biphenyls																
		Total Aroclors	4.9E+01	ug/kg	2.0E+00	4.2E-05	8.E-05	2.2E-05	4.E-05	5.2E-06	1.E-05	2.0E-05	9.9E-05	5.E+00	5.1E-05	3.E+00	1.2E-05	6.E-01
		Total Congeners Without Dioxin-like PCBs	5.0E+01	ug/kg	2.0E+00	4.3E-05	9.E-05	2.2E-05	4.E-05	5.3E-06	1.E-05	–	1.0E-04	–	5.2E-05	–	1.2E-05	–
		Total PCB TEQ	2.0E-03	ug/kg	1.5E+05	1.7E-09	3.E-04	8.7E-10	1.E-04	2.1E-10	3.E-05	–	4.0E-09	–	2.0E-09	–	4.9E-10	–
		Dioxin/Furan																
		Total Dioxin TEQ	2.9E-03	ug/kg	1.5E+05	2.6E-09	4.E-04	1.3E-09	2.E-04	3.2E-10	5.E-05	–	6.0E-09	–	3.1E-09	–	7.4E-10	–
		Pesticides																
		Dieldrin	1.2E+00	ug/kg	1.6E+01	1.0E-06	2.E-05	5.4E-07	9.E-06	1.3E-07	2.E-06	5.0E-05	2.4E-06	5.E-02	1.3E-06	3.E-02	3.0E-07	6.E-03
		Heptachlor	5.5E-01	ug/kg	4.5E+00	4.8E-07	2.E-06	2.5E-07	1.E-06	5.9E-08	3.E-07	5.0E-04	1.1E-06	2.E-03	5.7E-07	1.E-03	1.4E-07	3.E-04
		alpha-Hexachlorocyclohexane	5.0E-01	ug/kg	6.3E+00	4.3E-07	3.E-06	2.2E-07	1.E-06	5.4E-08	3.E-07	8.0E-03	1.0E-06	1.E-04	5.2E-07	7.E-05	1.3E-07	2.E-05
		beta-Hexachlorocyclohexane	9.0E-01	ug/kg	1.8E+00	7.8E-07	1.E-06	4.0E-07	7.E-07	9.6E-08	2.E-07	6.0E-04	1.8E-06	3.E-03	9.4E-07	2.E-03	2.3E-07	4.E-04
		gamma-Hexachlorocyclohexane	5.0E-01	ug/kg	1.3E+00	4.3E-07	6.E-07	2.2E-07	3.E-07	5.4E-08	7.E-08	3.0E-04	1.0E-06	3.E-03	5.2E-07	2.E-03	1.3E-07	4.E-04
		Total Chlordane	3.7E+00	ug/kg	3.5E-01	3.2E-06	1.E-06	1.7E-06	6.E-07	4.0E-07	1.E-07	5.0E-04	7.5E-06	2.E-02	3.9E-06	8.E-03	9.3E-07	2.E-03
		Total DDD	4.5E+00	ug/kg	2.4E-01	3.9E-06	9.E-07	2.0E-06	5.E-07	4.8E-07	1.E-07	5.0E-04	9.1E-06	2.E-02	4.7E-06	9.E-03	1.1E-06	2.E-03
		Total DDE	3.7E+01	ug/kg	3.4E-01	3.2E-05	1.E-05	1.7E-05	6.E-06	4.0E-06	1.E-06	5.0E-04	7.5E-05	2.E-01	3.9E-05	8.E-02	9.3E-06	2.E-02
		Total DDT	1.1E+01	ug/kg	3.4E-01	9.1E-06	3.E-06	4.7E-06	2.E-06	1.1E-06	4.E-07	5.0E-04	2.1E-05	4.E-02	1.1E-05	2.E-02	2.6E-06	5.E-03
	Exposure Point Total*						8.E-04		4.E-04		1.E-04			8.E+00		4.E+00		9.E+01

Notes:

* = PCB congeners used in cumulative risk calculations for tissue. Aroclors use for hazard index calculations.
Numbers presented are rounded values. Sums calculated before rounding.

Abbreviations:

– = Not evaluated.
CDI = Chronic daily intake.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.
EPC = Exposure point concentration.
LADI = Lifetime average daily intake.
mg/kg = milligrams per kilogram.
PAHs = Polynuclear aromatic hydrocarbons.
PCB = Polychlorinated biphenyls.
RfD = Reference dose.
TEQ = Toxic equivalents.
ug/kg = micrograms per kilogram.
WB = Whole body.

Table 7.
Calculation of Cancer Risks and Noncancer Hazards - Non-tribal Adult Upstream Fish Consumption, Single Species Diet, Brown Bullhead.
Mean Exposure

Scenario Timeframe: Current/Future
Receptor Population: Non-tribal Fisher (Single Species Diet)
Receptor Age: Adult
Exposure Medium: Brown Bullhead Tissue (Whole Body)
Expsure Route: Ingestion

Exposure Medium	Exposure Point	Chemical of Potential Concern	EPC		Cancer Risk Calculations							Noncancer Hazard Calculations						
					Oral Cancer Slope Factor (mg/kg-day)[1]	Ingestion Rate: 142 g/day		Ingestion Rate: 73.5 g/day		Ingestion Rate: 17.5 g/day		Oral RfD (mg/kg-day)	Ingestion Rate: 142 g/day		Ingestion Rate: 73.5 g/day		Ingestion Rate: 17.5 g/day	
			Value	Units		LADI (mg/kg-day)	Cancer Risk	LADI (mg/kg-day)	Cancer Risk	LADI (mg/kg-day)	Cancer Risk		CDI (mg/kg-day)	Noncancer Hazard Quotient	CDI (mg/kg-day)	Noncancer Hazard Quotient	CDI (mg/kg-day)	Noncancer Hazard Quotient
WB tissue	Upstream	**Metals**																
		Arsenic, inorganic	8.0E+00	ug/kg	1.5E+00	7.0E-06	1.E-05	3.6E-06	5.E-06	8.6E-07	1.E-06	3.0E-04	1.6E-05	5.E-02	8.3E-06	3.E-02	2.0E-06	7.E-03
		Mercury	7.2E+01	ug/kg	–	6.2E-05	–	3.2E-05	–	7.7E-06	–	1.0E-04	1.5E-04	1.E+00	7.5E-05	7.E-01	1.8E-05	2.E-01
		Phthalates																
		Bis(2-ethylhexyl) phthalate	1.0E+03	ug/kg	1.4E-02	9.0E-04	1.E-05	4.6E-04	6.E-06	1.1E-04	2.E-06	2.0E-02	2.1E-03	1.E-01	1.1E-03	5.E-02	2.6E-04	1.E-02
		Semi-Volatile Organic Compounds																
		Hexachlorobenzene	1.1E+01	ug/kg	1.6E+00	9.7E-06	2.E-05	5.0E-06	8.E-06	1.2E-06	2.E-06	8.0E-04	2.3E-05	3.E-02	1.2E-05	1.E-02	2.8E-06	3.E-03
		Polychlorinated Biphenyls																
		Total Aroclors	3.1E+01	ug/kg	2.0E+00	2.7E-05	5.E-05	1.4E-05	3.E-05	3.4E-06	7.E-06	2.0E-05	6.3E-05	3.E+00	3.3E-05	2.E+00	7.8E-06	4.E-01
		Total Congeners Without Dioxin-like PCBs	2.9E+01	ug/kg	2.0E+00	2.5E-05	5.E-05	1.3E-05	3.E-05	3.1E-06	6.E-06	–	5.8E-05	–	3.1E-05	–	7.3E-06	–
		Total PCB TEQ	1.2E-03	ug/kg	1.5E+05	1.1E-09	2.E-04	5.5E-10	8.E-05	1.3E-10	2.E-05	–	2.5E-09	–	1.3E-09	–	3.1E-10	–
		Dioxin/Furan																
		Total Dioxin TEQ	1.4E-03	ug/kg	1.5E+05	1.2E-09	2.E-04	6.4E-10	1.E-04	1.5E-10	2.E-05	–	2.9E-09	–	1.5E-09	–	3.6E-10	–
		Pesticides																
		Dieldrin	9.7E-01	ug/kg	1.6E+01	8.4E-07	1.E-05	4.3E-07	7.E-06	1.0E-07	2.E-06	5.0E-05	2.0E-06	4.E-02	1.0E-06	2.E-02	2.4E-07	5.E-03
		Heptachlor	5.2E-01	ug/kg	4.5E+00	4.5E-07	2.E-06	2.3E-07	1.E-06	5.5E-08	2.E-07	5.0E-04	1.0E-06	2.E-03	5.4E-07	1.E-03	1.3E-07	3.E-04
		alpha-Hexachlorocyclohexane	5.0E-01	ug/kg	6.3E+00	4.3E-07	3.E-06	2.2E-07	1.E-06	5.4E-08	3.E-07	8.0E-03	1.0E-06	1.E-04	5.2E-07	7.E-05	1.3E-07	2.E-05
		beta-Hexachlorocyclohexane	7.0E-01	ug/kg	1.8E+00	6.1E-07	1.E-06	3.1E-07	6.E-07	7.5E-08	1.E-07	6.0E-04	1.4E-06	2.E-03	7.3E-07	1.E-03	1.8E-07	3.E-04
		gamma-Hexachlorocyclohexane	5.0E-01	ug/kg	1.3E+00	4.3E-07	6.E-07	2.2E-07	3.E-07	5.4E-08	7.E-08	3.0E-04	1.0E-06	3.E-03	5.2E-07	2.E-03	1.3E-07	4.E-04
		Total Chlordane	2.6E+00	ug/kg	3.5E-01	2.3E-06	8.E-07	1.2E-06	4.E-07	2.8E-07	1.E-07	5.0E-04	5.3E-06	1.E-02	2.7E-06	5.E-03	6.6E-07	1.E-03
		Total DDD	3.8E+00	ug/kg	2.4E-01	3.3E-06	8.E-07	1.7E-06	4.E-07	4.1E-07	1.E-07	5.0E-04	7.8E-06	2.E-02	4.0E-06	8.E-03	9.6E-07	2.E-03
		Total DDE	2.0E+01	ug/kg	3.4E-01	1.8E-05	6.E-06	9.1E-06	3.E-06	2.2E-06	7.E-07	5.0E-04	4.1E-05	8.E-02	2.1E-05	4.E-02	5.1E-06	1.E-02
		Total DDT	6.1E+00	ug/kg	3.4E-01	5.3E-06	2.E-06	2.7E-06	9.E-07	6.6E-07	2.E-07	5.0E-04	1.2E-05	2.E-02	6.4E-06	1.E-02	1.5E-06	3.E-03
	Exposure Point Total[a]						5.E-04		2.E-04		6.E-05			5.E+00		3.E+00		6.E+00

Notes:

[a] = PCB congeners used in cumulative risk calculations for tissue, Aroclors use for hazard index calculations.
Numbers presented are rounded values. Sums calculated before rounding.

Abbreviations:

– = Not evaluated.
CDI = Chronic daily intake.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.
EPC = Exposure point concentration.
LADI = Lifetime average daily intake.
mg/kg = milligrams per kilogram.
PAHs = Polynuclear aromatic hydrocarbons.
PCB = Polychlorinated biphenyls.
RfD = Reference dose.
TEQ = Toxic equivalents.
ug/kg = micrograms per kilogram.
WB = Whole body.

Table 8
Calculation of Cancer Risks and Noncancer Hazards - Non-tribal Child Upstream Fish Consumption, Single Species Diet, Brown Bullhead.
Maximum Exposure

Scenario Timeframe: Current/Future
Receptor Population: Non-tribal Fisher (Single Species Diet)
Receptor Age: Child
Exposure Medium Brown Bullhead Tissue (Whole Body)
Expsure Route: Ingestion

Exposure Medium	Exposure Point	Chemical of Potential Concern	EPC Value	EPC Units	Cancer Risk Calculations: Oral Cancer Slope Factor (mg/kg-day)$^{-1}$	Ingestion Rate: 60 g/day LADI (mg/kg-day)	Ingestion Rate: 60 g/day Cancer Risk	Ingestion Rate: 31 g/day LADI (mg/kg-day)	Ingestion Rate: 31 g/day Cancer Risk	Ingestion Rate: 7 g/day LADI (mg/kg-day)	Ingestion Rate: 7 g/day Cancer Risk	Noncancer Hazard Calculations: Oral RfD (mg/kg-day)	Ingestion Rate: 60 g/day CDI (mg/kg-day)	Ingestion Rate: 60 g/day Noncancer Hazard Quotient	Ingestion Rate: 31 g/day CDI (mg/kg-day)	Ingestion Rate: 31 g/day Noncancer Hazard Quotient	Ingestion Rate: 7 g/day CDI (mg/kg-day)	Ingestion Rate: 7 g/day Noncancer Hazard Quotient
WB tissue	Upstream	**Metals**																
		Arsenic, inorganic	9.0E+00	ug/kg	1.5E+00	3.1E-06	5.E-06	1.6E-06	2.E-06	3.6E-07	5.E-07	3.0E-04	3.6E-05	1.E-01	1.9E-05	6.E-02	4.2E-06	1.E-02
		Mercury	9.4E+01	ug/kg	–	3.2E-05	–	1.7E-05	–	3.8E-06	–	1.0E-04	3.8E-04	4.E+00	1.9E-04	2.E+00	4.4E-05	4.E-01
		Phthalates																
		Bis(2-ethylhexyl) phthalate	3.0E+03	ug/kg	1.4E-02	1.0E-03	1 E-05	5.3E-04	7.E-06	1.2E-04	2.E-06	2.0E-02	1.2E-02	6.E-01	6.2E-03	3.E-01	1.4E-03	7.E-02
		Semi-Volatile Organic Compounds																
		Hexachlorobenzene	1.7E+01	ug/kg	1.6E+00	5.7E-06	9.E-06	2.9E-06	5.E-06	6.6E-07	1.E-06	8.0E-04	6.6E-05	8.E-02	3.4E-05	4.E-02	7.7E-06	1.E-02
		Polychlorinated Biphenyls																
		Total Aroclors	4.9E+01	ug/kg	2.0E+00	1.7E-05	3.E-05	8.7E-06	2.E-05	2.0E-06	4.E-06	2.0E-05	2.0E-04	1.E+01	1.0E-04	5.E+00	2.3E-05	1.E+00
		Total Congeners Without Dioxin-like PCBs	5.0E+01	ug/kg	2.0E+00	1.7E-05	3.E-05	8.8E-06	2.E-05	2.0E-06	4.E-06	–	2.0E-04	–	1.0E-04	–	2.3E-05	–
		Total PCB TEQ	2.0E-03	ug/kg	1.5E+05	6.7E-10	1.E-04	3.5E-10	5.E-05	7.8E-11	1.E-05	–	7.8E-09	–	4.0E-09	–	9.1E-10	–
		Dioxin/Furan																
		Total Dioxin TEQ	2.9E-03	ug/kg	1.5E+05	1.0E-09	2.E-04	5.2E-10	8.E-05	1.2E-10	2.E-05	–	1.2E-08	–	6.1E-09	–	1.4E-09	–
		Pesticides																
		Dieldrin	1.2E+00	ug/kg	1.6E+01	4.1E-07	7.E-06	2.1E-07	3.E-06	4.8E-08	8.E-07	5.0E-05	4.8E-06	1.E-01	2.5E-06	5 E-02	5.6E-07	1.E-02
		Heptachlor	5.5E-01	ug/kg	4.5E+00	1.9E-07	8.E-07	9.7E-08	4.E-07	2.2E-08	1.E-07	5.0E-04	2.2E-06	4.E-03	1.1E-06	2.E-03	2.6E-07	5.E-04
		alpha-Hexachlorocyclohexane	5.0E-01	ug/kg	6.3E+00	1.7E-07	1.E-06	8.9E-08	6.E-07	2.0E-08	1.E-07	8.0E-03	2.0E-06	3.E-04	1.0E-06	1.E-04	2.3E-07	3.E-05
		beta-Hexachlorocyclohexane	9.0E-01	ug/kg	1.8E+00	3.1E-07	6.E-07	1.6E-07	3.E-07	3.6E-08	6.E-08	6.0E-04	3.6E-06	6.E-03	1.9E-06	3.E-03	4.2E-07	7.E-04
		gamma-Hexachlorocyclohexane	5.0E-01	ug/kg	1.3E+00	1.7E-07	2.E-07	8.9E-08	1.E-07	2.0E-08	3.E-08	3.0E-04	2.0E-06	7.E-03	1.0E-06	3.E-03	2.3E-07	8.E-04
		Total Chlordane	3.7E+00	ug/kg	3.5E-01	1.3E-06	4.E-07	6.6E-07	2.E-07	1.5E-07	5.E-08	5.0E-04	1.5E-05	3.E-02	7.6E-06	2.E-02	1.7E-06	3.E-03
		Total DDD	4.5E+00	ug/kg	2.4E-01	1.5E-06	4.E-07	8.0E-07	2.E-07	1.8E-07	4.E-08	5.0E-04	1.8E-05	4.E-02	9.3E-06	2.E-02	2.1E-06	4.E-03
		Total DDE	3.7E+01	ug/kg	3.4E-01	1.3E-05	4.E-06	6.6E-06	2.E-06	1.5E-06	5.E-07	5.0E-04	1.5E-04	3.E-01	7.6E-05	2.E-01	1.7E-05	3.E-02
		Total DDT	1.1E+01	ug/kg	3.4E-01	3.6E-06	1.E-06	1.9E-06	6.E-07	4.2E-07	1.E-07	5.0E-04	4.2E-05	8.E-02	2.2E-05	4.E-02	4.9E-06	1.E-02
	Exposure Point Total[a]						3.E-04		2.E-04		4.E-05			1.E+01		8.E+00		2.E+00

Notes:
[a] = PCB congeners used in cumulative risk calculations for tissue, Aroclors use for hazard index calculations.
Numbers presented are rounded values. Sums calculated before rounding.

Abbreviations:
– = Not evaluated
CDI = Chronic daily intake.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.
EPC = Exposure point concentration.
LADI = Lifetime average daily intake.
mg/kg = milligrams per kilogram.
PAHs = Polynuclear aromatic hydrocarbons.
PCB = Polychlorinated biphenyls.
RfD = Reference dose.
TEQ = Toxic equivalents.
ug/kg = micrograms per kilogram.
WB = Whole body.

Table 9.
Calculation of Cancer Risks and Noncancer Hazards - Non-tribal Child Upstream Fish Consumption, Single Species Diet, Brown Bullhead.
Mean Exposure

Scenario Timeframe: Current/Future
Receptor Population: Non-tribal Fisher (Single Species Diet)
Receptor Age: Child
Exposure Medium: Brown Bullhead Tissue (Whole Body)
Expsure Route: Ingestion

Exposure Medium	Exposure Point	Chemical of Potential Concern	EPC		Cancer Risk Calculations							Noncancer Hazard Calculations						
					Oral Cancer Slope Factor (mg/kg-day)$^{-1}$	Ingestion Rate: 60 g/day		Ingestion Rate: 31 g/day		Ingestion Rate: 7 g/day		Oral RfD (mg/kg-day)	Ingestion Rate: 60 g/day		Ingestion Rate: 31 g/day		Ingestion Rate: 7 g/day	
			Value	Units		LADI (mg/kg-day)	Cancer Risk	LADI (mg/kg-day)	Cancer Risk	LADI (mg/kg-day)	Cancer Risk		CDI (mg/kg-day)	Noncancer Hazard Quotient	CDI (mg/kg-day)	Noncancer Hazard Quotient	CDI (mg/kg-day)	Noncancer Hazard Quotient
WB tissue	Upstream	**Metals**																
		Arsenic, inorganic	8.0E+00	ug/kg	1.5E+00	2.7E-06	4.E-06	1.4E-06	2.E-06	3.2E-07	5.E-07	3.0E-04	3.2E-05	1.E-01	1.7E-05	6.E-02	3.7E-06	1.E-02
		Mercury	7.2E+01	ug/kg	–	2.5E-05	–	1.3E-05	–	2.9E-06	–	1.0E-04	2.9E-04	3.E+00	1.5E-04	1.E+00	3.3E-05	3.E-01
		Phthalates																
		Bis(2-ethylhexyl) phthalate	1.0E+03	ug/kg	1.4E-02	3.5E-04	5.E-06	1.8E-04	3.E-06	4.1E-05	6.E-07	2.0E-02	4.1E-03	2.E-01	2.1E-03	1.E-01	4.8E-04	2.E-02
		Semi-Volatile Organic Compounds																
		Hexachlorobenzene	1.1E+01	ug/kg	1.6E+00	3.8E-06	6.E-06	2.0E-06	3.E-06	4.5E-07	7.E-07	8.0E-04	4.5E-05	6.E-02	2.3E-05	3.E-02	5.2E-06	7.E-03
		Polychlorinated Biphenyls																
		Total Aroclors	3.1E+01	ug/kg	2.0E+00	1.1E-05	2.E-05	5.5E-06	1.E-05	1.3E-06	3.E-06	2.0E-05	1.3E-04	6.E+00	6.5E-05	3.E+00	1.5E-05	7.E-01
		Total Congeners Without Dioxin-like PCBs	2.9E+01	ug/kg	2.0E+00	1.0E-05	2.E-05	5.2E-06	1.E-05	1.2E-06	2.E-06	–	1.2E-04	–	6.0E-05	–	1.4E-05	–
		Total PCB TEQ	1.2E-03	ug/kg	1.5E+05	4.3E-10	6.E-05	2.2E-10	3.E-05	5.0E-11	7.E-06	–	5.0E-09	–	2.6E-09	–	5.8E-10	–
		Dioxin/Furan																
		Total Dioxin TEQ	1.4E-03	ug/kg	1.5E+05	4.9E-10	7.E-05	2.5E-10	4.E-05	5.7E-11	9.E-06	–	5.7E-09	–	2.9E-09	–	6.7E-10	–
		Pesticides																
		Dieldrin	9.7E-01	ug/kg	1.6E+01	3.3E-07	5.E-06	1.7E-07	3.E-06	3.9E-08	6.E-07	5.0E-05	3.9E-06	8.E-02	2.0E-06	4.E-02	4.5E-07	9.E-03
		Heptachlor	5.2E-01	ug/kg	4.5E+00	1.8E-07	8.E-07	9.2E-08	4.E-07	2.1E-08	9.E-08	5.0E-04	2.1E-06	4.E-03	1.1E-06	2.E-03	2.4E-07	5.E-04
		alpha-Hexachlorocyclohexane	5.0E-01	ug/kg	6.3E+00	1.7E-07	1.E-06	8.9E-08	6.E-07	2.0E-08	1.E-07	8.0E-03	2.0E-06	3.E-04	1.0E-06	1.E-04	2.3E-07	3.E-05
		beta-Hexachlorocyclohexane	7.0E-01	ug/kg	1.8E+00	2.4E-07	4.E-07	1.2E-07	2.E-07	2.8E-08	5.E-08	6.0E-04	2.8E-06	5.E-03	1.4E-06	2.E-03	3.3E-07	5.E-04
		gamma-Hexachlorocyclohexane	5.0E-01	ug/kg	1.3E+00	1.7E-07	2.E-07	8.9E-08	1.E-07	2.0E-08	3.E-08	3.0E-04	2.0E-06	7.E-03	1.0E-06	3.E-03	2.3E-07	8.E-04
		Total Chlordane	2.6E+00	ug/kg	3.5E-01	9.0E-07	3.E-07	4.7E-07	2.E-07	1.1E-07	4.E-08	5.0E-04	1.1E-05	2.E-02	5.4E-06	1.E-02	1.2E-06	2.E-03
		Total DDD	3.8E+00	ug/kg	2.4E-01	1.3E-06	3.E-07	6.8E-07	2.E-07	1.5E-07	4.E-08	5.0E-04	1.5E-05	3.E-02	7.9E-06	2.E-02	1.8E-06	4.E-03
		Total DDE	2.0E+01	ug/kg	3.4E-01	7.0E-06	2.E-06	3.6E-06	1.E-06	8.1E-07	3.E-07	5.0E-04	8.1E-05	2.E-01	4.2E-05	8.E-02	9.5E-06	2.E-02
		Total DDT	6.1E+00	ug/kg	3.4E-01	2.1E-06	7.E-07	1.1E-06	4.E-07	2.5E-07	8.E-08	5.0E-04	2.5E-05	5.E-02	1.3E-05	3.E-02	2.9E-06	6.E-03
	Exposure Point Total[a]						2.E-04		1.E-04		2.E-05			1.E+01		5.E+00		1.E+00

Notes:

[a] = PCB congeners used in cumulative risk calculations for tissue, Aroclors use for hazard index calculations.
Numbers presented are rounded values. Sums calculated before rounding.

Abbreviations:

– = Not evaluated.
CDI = Chronic daily intake.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.
EPC = Exposure point concentration.
LADI = Lifetime average daily intake.
mg/kg = milligrams per kilogram.
PAHs = Polynuclear aromatic hydrocarbons.
PCB = Polychlorinated biphenyls.
RfD = Reference dose.
TEQ = Toxic equivalents
ug/kg = micrograms per kilogram.
WB = Whole body.

TABLE 10.
Exposure Point Concentration Summary.

Scenario Timeframe: Current/Future
Medium: Smallmouth Bass
Exposure Medium: Upstream Smallmouth Bass Tissue (Whole Body)

Exposure Point	Chemical of Potential Concern[a]	Units	Non-Detects	Total Samples	Arithmetic Mean	Maximum Concentration	95% UCL			Exposure Point Concentration	
							Distribution	95% UCL Method	Value	CT (mean)[b]	RME (95UCL/Max)[b]
Upstream of Site	**Metals**										
	Arsenic, inorganic	ug/kg	0	6	2.3E+01	3.6E+01	normal	Student's-t UCL	3.2E+01	2.3E+00	3.2E+00
	Mercury	ug/kg	0	6	3.2E+02	5.5E+02	normal	Student's-t UCL	4.6E+02	3.2E+02	4.6E+02
	Phthalates										
	Bis(2-ethylhexyl) phthalate	ug/kg	5	6	9.0E+02	4.8E+03	NA	less than 5 detects	NA	9.0E+02	4.8E+03
	Semi-Volatile Organic Compounds										
	Hexachlorobenzene	ug/kg	6	6	8.8E-01	1.2E+00	NA	less than 5 detects	NA	8.8E-01	1.2E+00
	Polychlorinated Biphenyls										
	Total Aroclors	ug/kg	0	6	1.5E+02	3.2E+02	normal	Student's-t UCL	2.5E+02	1.5E+02	2.5E+02
	Total Congeners Without Dioxin-like PCBs	ug/kg	0	6	1.5E+02	2.9E+02	normal	Student's-t UCL	2.3E+02	1.5E+02	2.3E+02
	Total PCB TEQ	ug/kg	0	6	5.0E-03	8.2E-03	normal	Student's-t UCL	7.1E-03	5.0E-03	7.1E-03
	Dioxin/Furan										
	Total Dioxin TEQ	ug/kg	0	6	1.6E-03	2.8E-03	normal	Student's-t UCL	2.2E-03	1.6E-03	2.2E-03
	Pesticides										
	Dieldrin	*ug/kg*	*0*	*6*	*2.8E+00*	*4.5E+00*	*normal*	*Student's-t UCL*	*3.7E+00*	*2.8E+00*	*3.7E+00*
	Heptachlor	ug/kg	6	6	5.0E-01	5.0E-01	NA	less than 5 detects	NA	5.0E-01	5.0E-01
	alpha-Hexachlorocyclohexane	ug/kg	6	6	5.0E-01	5.0E-01	NA	less than 5 detects	NA	5.0E-01	5.0E-01
	beta-Hexachlorocyclohexane	ug/kg	6	6	1.6E+00	2.0E+00	NA	less than 5 detects	NA	1.6E+00	2.0E+00
	gamma-Hexachlorocyclohexane	ug/kg	1	6	3.1E+00	4.3E+00	normal	Student's-t UCL	4.0E+00	3.1E+00	4.0E+00
	Total Chlordane	ug/kg	0	6	8.6E+00	1.5E+01	normal	Student's-t UCL	1.2E+01	8.6E+00	1.2E+01
	Total DDD	ug/kg	0	6	1.2E+01	1.7E+01	normal	Student's-t UCL	1.5E+01	1.2E+01	1.5E+01
	Total DDE	ug/kg	0	6	4.9E+01	6.0E+01	normal	Student's-t UCL	5.8E+01	4.9E+01	5.8E+01
	Total DDT	ug/kg	0	6	2.5E+01	4.3E+01	normal	Student's-t UCL	3.4E+01	2.5E+01	3.4E+01

Notes:

[a]Chemicals listed are those resulting in an estimated cancer risk greater than 10-6 or an estimated hazard quotient greater than 1 for tissue exposure scenarios within the Study Area.

[b] CT and RME exposure parameters are not evaluated for tissue scenarios. Use of CT exposure point concentrations is referred to as mean exposure, and use of RME exposure point concentrations *is referred to as 95UCL/Max exposure for the purposes of the Round 2 HHRA.*

Abbreviations:

95% UCL = 95% Upper Confidence Limit on the Mean.
CT = Central Tendency.
RME = Reasonable Maximum Exposure.
ug/kg = micrograms per kilogram.
PCB = Polychlorinated Biphenyl.
TEQ = Toxic Equivalents.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.

TABLE 11.
Exposure Point Concentration Summary.

Scenario Timeframe: Current/Future
Medium: Brown Bullhead
Exposure Medium: Upstream Brown Bullhead Tissue (Whole Body)

Exposure Point	Chemical of Potential Concern[a]	Units	Non-Detects	Total Samples	Arithmetic Mean	Maximum Concentration	95% UCL			Exposure Point Concentration	
							Distribution	95% UCL Method	Value	CT (mean)[b]	RME (95UCL/Max)[b]
Upstream of Site	**Metals**										
	Arsenic, inorganic	ug/kg	0	3	8.0E+00	9.0E+00				8.0E+00	9.0E+00
	Mercury	ug/kg	0	3	7.2E+01	9.4E+01	95 UCL not calculated for exposure areas with less than 5 samples			7.2E+01	9.4E+01
	Phthalates										
	Bis(2-ethylhexyl) phthalate	ug/kg	2	3	1.0E+03	3.0E+03				1.0E+03	3.0E+03
	Semi-Volatile Organic Compounds										
	Hexachlorobenzene	ug/kg	3	3	1.1E+01	1.7E+01				1.1E+01	1.7E+01
	Polychlorinated Biphenyls										
	Total Aroclors	ug/kg	0	3	3.1E+01	4.9E+01				3.1E+01	4.9E+01
	Total Congeners Without Dioxin-like PCBs	ug/kg	0	3	2.9E+01	5.0E+01				2.9E+01	5.0E+01
	Total PCB TEQ	ug/kg	0	3	1.2E-03	2.0E-03				1.2E-03	2.0E-03
	Dioxin/Furan										
	Total Dioxin TEQ	ug/kg	0	3	1.4E-03	2.9E-03				1.4E-03	2.9E-03
	Pesticides										
	Dieldrin	ug/kg	1	3	9.7E-01	1.2E+00				9.7E-01	1.2E+00
	Heptachlor	ug/kg	3	3	5.2E-01	5.5E-01				5.2E-01	5.5E-01
	alpha-Hexachlorocyclohexane	ug/kg	3	3	5.0E-01	5.0E-01				5.0E-01	5.0E-01
	beta-Hexachlorocyclohexane	ug/kg	3	3	7.0E-01	9.0E-01				7.0E-01	9.0E-01
	gamma-Hexachlorocyclohexane	ug/kg	3	3	5.0E-01	5.0E-01				5.0E-01	5.0E-01
	Total Chlordane	ug/kg	0	3	2.6E+00	3.7E+00				2.6E+00	3.7E+00
	Total DDD	ug/kg	0	3	3.8E+00	4.5E+00				3.8E+00	4.5E+00
	Total DDE	ug/kg	0	3	2.0E+01	3.7E+01				2.0E+01	3.7E+01
	Total DDT	ug/kg	0	3	6.1E+00	1.1E+01				6.1E+00	1.1E+01

Notes:

[a]Chemicals listed are those resulting in an estimated cancer risk greater than 10-6 or an estimated hazard quotient greater than 1 for tissue exposure scenarios within the Study Area.

[b] CT and RME exposure parameters are not evaluated for tissue scenarios. Use of CT exposure point concentrations is referred to as mean exposure, and use of RME exposure point concentrations is referred to as 95UCL/Max exposure for the purposes of the Round 2 HHRA.

Abbreviations:

95% UCL = 95% Upper Confidence Limit on the Mean.
CT = Central Tendency.
RME = Reasonable Maximum Exposure.
ug/kg = micrograms per kilogram.
PCB = Polychlorinated Biphenyl.
TEQ = Toxic Equivalents.
DDD = Dichlorodiphenyldichloroethane.
DDE = Dichlorodiphenyldichloroethylene.
DDT = Dichlorodiphenyltrichloroethane.

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