Report

Columbia Slough Sediment Study

State of Oregon
Department of Environmental Quality

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EXECUTIVE SUMMARY

E.1 Introduction

The Oregon Department of Environmental Quality, as part of our ongoing efforts to understand risks associated with toxics in the Columbia Slough, completed sediment and biological tissue sampling and analysis in the Slough. This report summarizes the results from this most recent study, completed between 2010 through 2012, which was designed to build on prior Slough studies.

Over the last 20 years, a series of environmental investigations performed by City of Portland, Bureau of Environmental Services and the Oregon Department of Environmental Quality (DEQ) have focused on the Columbia Slough watershed. As a result, actions have been implemented to improve sediment quality. The investigations have shown widespread, low-level contamination throughout the slough's sediments with a few isolated areas of higher contamination. On a relative risk basis, the more significant contaminants are polychlorinated biphenyls (PCBs) and chlorinated pesticides due to their potential to bioaccumulate in fish which are subsequently consumed by people and wildlife.

In 2011, DEQ completed sampling of sediment and analysis of both sediment and tissue in three reaches of the Columbia Slough. DEQ evaluated this data, in conjunction with existing data from previous investigations to improve our understanding of bioaccumulation potential for PCBs and pesticides.

Specifically, goals of this investigation were to:

1) Determine average concentrations of contaminants in sediment in particular reaches of the slough corresponding to the typical geographic range of carp;
2) Evaluate the feasibility of developing predictive relationships between newly collected sediment and existing carp tissue data collected by Portland's Bureau of Environmental Services (BES); and,
3) Perform exploratory multivariate analyses to gain insight regarding likely sources of PCBs using PCB congener data collected in this and other investigations in the Columbia River.

E.2 Sampling Design and Strategy

The general sampling strategy included two sample designs: a compositing strategy paralleling established incremental sampling (IS) methodologies and a more traditional compositing approach. The IS sampling was performed to determine average sediment concentrations throughout the segments sampled and reduce the impact of heterogeneities in sediment concentrations over spatial scales relevant for resident fish. The IS compositing approach, as

opposed to averaging highly variable discrete samples, provides a representative sediment concentration that can be related to proximally collected tissue concentrations.

The more traditional composite samples were used to represent four specific targeted locations where worm (*Lumbriculus variegates*) bioaccumulation assays were also performed. The locations were selected to assess bioaccumulation potential of sediment contaminants across a range of representative conditions. PCB congeners and organochlorine pesticides were analyzed in all samples by high-resolution EPA methods 1668 and 1699.

E.3 Sediment Results

The 2011 sediment sampling confirmed our conceptual understanding of regional contaminant spatial patterns associated with historic land uses, with PCB concentrations decreasing from the lower slough toward the upper slough, while pesticide concentrations increased in the upper reaches. The targeted composite samples represented a range of PCB and pesticide concentrations from low part per billion levels to moderately elevated in the tens of parts per billion (ug/kg), with one total PCB estimate at 114 ug/kg. These concentrations reasonably represent the range of sediment contamination that occur throughout the Columbia Slough.

E.4 *Lumbriculus* Bioassays

Using the bioassay results, biota-sediment accumulation factors (BSAFs) were calculated for analytes detected in both sediment and invertebrate tissue at each of the four locations. In general, a higher BSAF indicates a greater amount of contaminant in the lipids of the sampled organisms relative to the amount in sediment and hence a greater bioaccumulation potential.

For PCBs, the calculated BSAFs revealed that the magnitude of the invertebrate BSAFs are widely variable depending on the specific PCB congener being measured. Generally, the lowest calculated BSAFs in the range of 0.2 to 0.4[1] were calculated for the most highly chlorinated congeners, the hepta- to deca-substituted congeners with very high log octanol-water partition coefficients. The highest BSAFs were calculated among the hexa-, hepta-, and penta-substituted congeners. A good proportion (36%) were less than 1, primarily among the least soluble and more highly chlorinated congeners.

Notably, the BSAFs estimated using total PCBs as a sum of congeners (EPA method 1668) in sediment resulted in a different answer from using total PCBs estimated from Aroclors (EPA method 8082). The estimated BSAFs using congeners were less than or only slightly exceeded one, whereas BSAFs using Aroclors ranged from 3.1 to 4.3. These latter estimates are higher

[1] A BSAF of one (1) means that an equal amount of PCB is in both tissue lipid and sediment organic carbon, less than one means more in sediment relative to tissue, and greater than one means more in tissue relative to sediment.

because the Aroclor method detected less total PCB in sediments relative to the congener method resulting in a higher normalized ratio of tissue to sediment. Thus, for total PCBs the calculation of BSAF appears to be dependent on the analytical method used.

For organochlorine pesticides, the sampling confirms that the pesticides which are of relatively greater concern for bioaccumulation potential in the Columbia Slough are the DDT metabolites (DDD and DDE), aldrin, dieldrin, and occasionally endosulfan and chlordane. The upper slough tends to have higher levels of the organochlorine pesticides and the Fairview Lake outlet location appears to have relatively higher bioaccumulation potential, based on the magnitude of the BSAFs calculated at this location.

E.5 Predictive Modeling

Empirical modeling was used to assess relationships between sediment, water, and carp tissue. For PCB congeners, water samples were assumed to be represented by concentrations detected in semi-permeable membrane devices (SPMDs) collected in prior U.S. Geological Survey (USGS) investigations sponsored by the City of Portland. Generally, only weak relationships between sediment and SPMD results were identified, with some apparent differences based on level of chlorination. Sediment concentrations were more closely correlated with carp tissue concentrations than were SPMD concentrations. Thus only sediment was used to develop simple regression models and to back-calculate sediment levels corresponding to acceptable levels in tissue for a recreational fishing scenario (discussed below). For pesticides, no relation between sediment and carp tissue could be quantified. If any such relationship exists, DEQs evaluation suggests it would be chemical specific.

E.5.1 Calculated Risk-Based Sediment Levels

DEQ estimated sediment levels corresponding to published acceptable fish tissue concentrations in a recreational fishing scenario. The calculated sediment levels were then compared to actual measured levels in sediment. In broad terms, dioxin-like PCB congeners in the lower slough exceed the calculated sediment criteria by a factor of 10 or less while the other reaches did not exceed criteria. Total PCB sediment levels based on Aroclors exceeded the calculated sediment concentrations by a larger margin.

One notable outcome of this analysis was that acceptable sediment levels calculated were found to be reach specific. Regression models showed clear differences between reaches in predicted tissue concentrations associated with the same sediment level. While it was possible to quantify a predictive relationship for PCB congeners, the magnitude of bioaccumulation appears to be site-specific.

E.5.2 Comparison of Total PCB and Congener-Specific Risk-Based Sediment Levels

When model-predicted total PCB risk-based sediment levels were compared to measured total PCB sediment concentrations, the magnitude of exceedance was high throughout the slough system, ranging from approximately 100 to as much as 1,000 in the lower slough. Predicted total PCB risk-based sediment levels varied by location, ranging from 0.034 to 0.94 ug/kg. The existing DEQ published criteria for total PCBs for recreational consumption of fish is 0.39 ug/kg; which falls within the range calculated in this investigation. This finding indicates that DEQ's existing default PCB sediment screening values are likely reasonable for most sites. For the dioxin-like PCB congeners, the calculated risk-based sediment levels for the lower slough are roughly comparable to those published in DEQ guidance, with some variation.

E.6 Source Attribution Modeling

Evaluation of PCB congener patterns using multivariate modeling was performed to gain insight into possible sources of PCBs to sediment, and potentially tissue. DEQ compiled PCB congener data from a variety of sources into a comprehensive database, and exploratory multivariate analyses were performed to identify patterns. Generally, the PCB congener patterns in the Columbia River and Slough appear to be distinct from other regional data in the Willamette River and, as expected, there are clear differences between media (water, tissue and sediment). A receptor modeling method was applied in an attempt to "unmix" the source profiles in Columbia River and Slough sediment samples.

Four distinct profiles were resolved using this method. One profile, representing a small proportion of most samples, is associated with samples that have low concentrations (<3 ug/kg) and are located away from any known sources. This profile is suspected to represent regional or longer range atmospheric transport. A second profile, abundant in more highly chlorinated congeners, is suspected to represent a weathered profile and is identifiable in a significant proportion of the of the Columbia Slough samples. The third and fourth profiles represent a less chlorinated Aroclor such as 1242 or 1248 and a more highly chlorinated Aroclor such as 1254, respectively. Further work is needed to validate and confirm the interpretations of these profiles. If correct, the two profiles associated with distinct sources (i.e., those consistent with particular Aroclors) and consequently have the greatest potential to be controlled or reduced are estimated to represent between 42% and 87% of the total PCBs in Columbia Slough samples. If such a proportional reduction was applied to the existing levels in Columbia Slough sediment, PCB concentrations could theoretically be reduced to single digit parts per billion. Given the ubiquitous nature of PCBs in the urban environment, this level of reduction may prove challenging. Further investigation of congener profiles in tissue and dissolved phase in surface water may shed insight on the bioavailability of residual area wide PCB concentrations in sediment, informing decisions regarding the most effective control strategies.

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1.0 INTRODUCTION

The Columbia Slough area in Portland, Oregon has a long history of farming and industrial use. Chemicals associated with these uses, such as pesticides and PCBs, are found in Columbia Slough sediments above acceptable limits for bioaccumulation in fish over much of the Slough. Information collected will be combined with prior sediment work in the Columbia Slough to refine DEQ's understanding of bioaccumulation and the potential for transfer of contaminants to higher trophic level organisms in the slough.

1.1 **Report Organization**

This report is organized as follows:

- Section 1 provides a brief overview of the project and objectives.
- Section 2 describes the Columbia Slough Watershed with more detailed information on the focus area of this study.
- Section 3 summarizes sample collection methods, analytical procedures, and the data quality review.
- Section 4 presents the sample results
- Section 5 summarizes the predictive modeling approach and results
- Section 6 presents the source attribution modeling results
- Section 7 outlines the conclusions of the project

1.2 **Study Objectives**

Following up on DEQ's 2009 work in the Columbia Slough, incremental sampling methods were implemented in three additional segments with the overall objectives including:

1) Determine average concentrations of contaminants in slough sediment and developing new, updated estimates of baseline concentrations in the sampled segments. This data also serves to validate our understanding of the Columbia Slough concerning which contaminants are relatively more or less elevated in each of the segments.

2) Development of predictive relationships between sediment and fish tissue: DEQ's 2009 work found good correlations between sediment and fish tissue. The follow-up sampling was performed to confirm if the same or similar predictive relationships could be developed in other reaches (DEQ 2011).

3) Validate DEQ's Bioaccumulation guidance using an empirically-based approach: The predictive relationships developed and associated risk-based sediment concentrations are compared to DEQ's existing sediment bioaccumulation screening levels.

4) Perform exploratory multivariate analyses and PCB source attribution: The PCB congener data collected in this investigation was combined with PCB congener data from several other regional investigations and used to consider what inferences may be made about sources of PCBs in the Columbia Slough (Section 6.0).

The sediment sampling work and resulting concentrations in each of the sampled reaches is documented in Sections 4 and 5 of this report. The findings confirm that the methods used were effective in developing good estimates of average concentrations of contaminants in each of the sampled reaches and were sufficient for completing the evaluations described in objectives 1 through 4.

2.0 AREA BACKGROUND

The Columbia Slough Watershed drains approximately 32,700 acres of land (see Figure 1). Portland's city limits end at approximately NE 185th Avenue on the east, but the watershed includes Fairview Lake and Fairview Creek, and portions of Troutdale, Fairview, Gresham, Maywood Park, Wood Village, and unincorporated Multnomah County. The Watershed historically contained a vast system of side channels, streams, ponds, lakes, and wetlands that covered the floodplain of the Columbia River between the mouths of the Willamette and Sandy Rivers. High water seasonally inundated the floodplain, cutting new channels and depositing sediment. Native Americans used these waterways and the uplands for fishing, hunting, and gathering food. Fishing continues in this area.

Over the years, the watershed and waterway have been drastically altered. Beginning in 1918, levees were built and wetlands were drained and filled to provide flood protection and allow for development. The waterway was channelized, and dozens of streams were diverted from natural channels to underground pipes. Today, the Columbia Slough comprises a 19-mile main channel that parallels the Columbia River, as well as approximately 12 additional miles of secondary waterways. Other remaining major surface water features include Fairview Creek, Fairview Lake, and Smith and Bybee Lakes. Floodplain development has resulted in an extensively managed surface water system that includes levees, pumps, and other water control structures. The levee system has greatly changed the historic floodplain and reduced the area available to floodwaters.

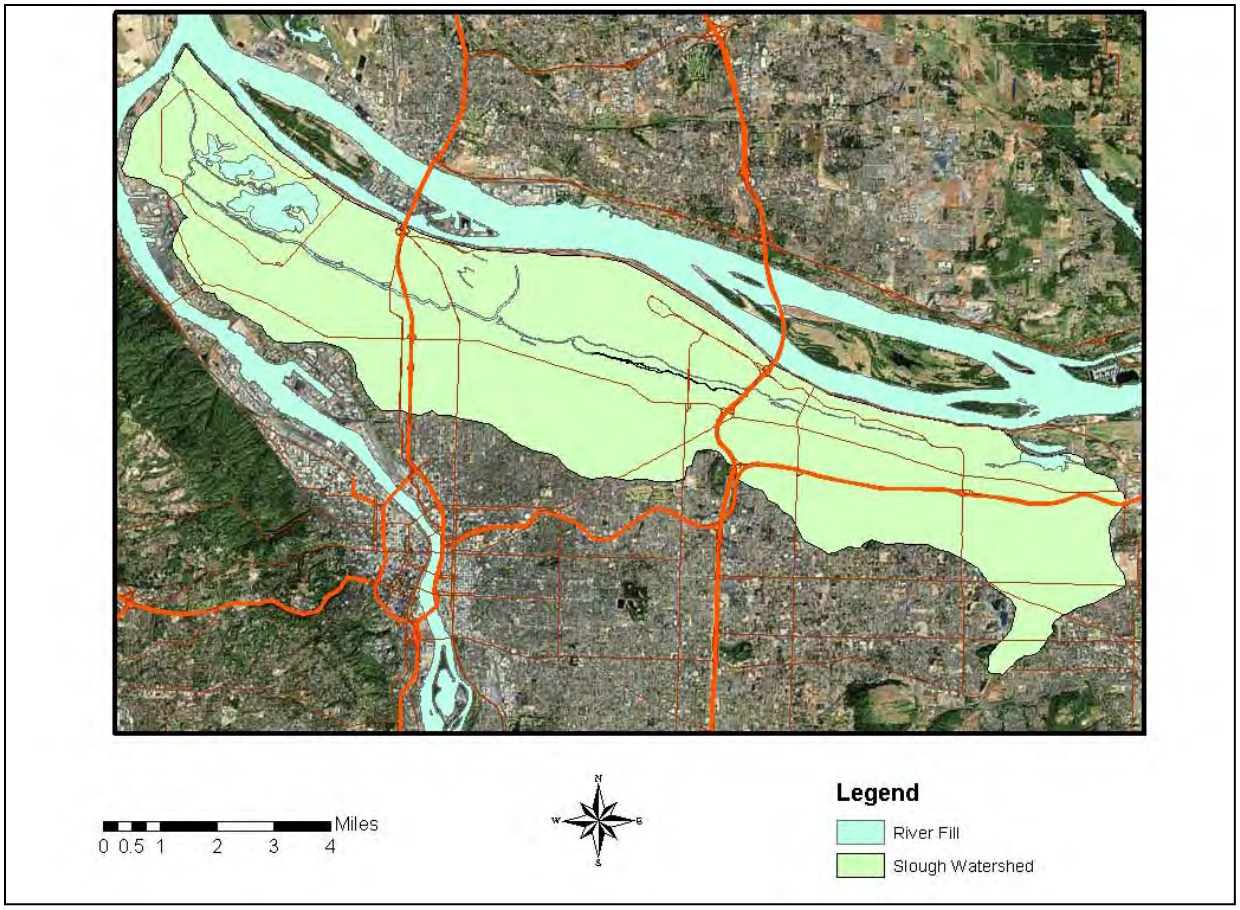

Figure 1. Columbia Slough Watershed; Portland, Oregon

The Columbia Slough Watershed includes virtually every type of land use: residential neighborhoods, commercial and industrial development, agriculture, Portland International Airport (PDX), interstate highways, railroad corridors, 54 schools, and large open spaces. Much of Portland's industrial and commercial land is located within the watershed. In addition to industrial development in the area north of Columbia Boulevard and the Rivergate area, land is preserved for industrial uses in the Columbia South Shore area between NE 82nd and NE 185th Avenues north of Sandy Boulevard.

The Slough is divided into three sections, based on hydraulic characteristics:

- The **Upper Slough** starts at the mouth of Fairview Lake on the east and flows west to the mid-dike levee at NE 142nd Avenue. It receives water from Fairview Lake, Fairview Creek, Wilkes Creek, stormwater outfalls, natural springs, groundwater, and overland flow.

- The **Middle Slough** extends from the mid-dike levee near NE 142nd Avenue to the Pen 2 levee near NE 18th Avenue. It includes a substantial southern arm complex of sloughs

and lakes, including Prison Pond, Mays Lake, Johnson Lake, Whitaker Slough, Whitaker Ponds, and Buffalo Slough. The Middle Slough receives water from the Upper Slough, stormwater outfalls, natural springs, overland flow, and groundwater. Pumps are used to move water from the Upper and Middle Slough to the Lower Slough.

- The **Lower Slough** starts at the Pen 2 levee, near NE 18th Avenue, and extends approximately 8.5 miles to the Willamette River. The lowlands of the Lower Slough Watershed are subject to flooding because they are not protected by levees. Water flow and levels in the Lower Slough are affected primarily by the Columbia River and Willamette River stage and the ocean tides, as well as by pumping. During high tide, the Columbia and Willamette Rivers create a backwater effect that complicates flow patterns.

During the Columbia Slough Screening Level Risk Assessment performed in 1994, virtually every sediment sample analyzed contained one or more contaminants at concentrations exceeding risk-based sediment screening levels based on impacts to aquatic life and fish consumers. Sediment contaminants of concern included metals, pesticides, polyaromatic hydrocarbons (PAHs), phthalates, and polychlorinated biphenyls (PCBs). In 2009, DEQ completed a study similar to this one for a priority area located at the eastern end of the Lower Slough (DEQ 2011).

DEQ's Water Quality program has established a Total Maximum Daily Load (TMDL)[2] for the Columbia Slough. The TMDL, part of the Clean Water Act, includes DDT/DDE, dioxin, lead, and PCBs reduction strategies for the water column. Oregon Health Authority has issued a fish advisory discouraging the consumption of fish in the Slough because of high PCB levels[3].

2.1 **Project Area**

DEQ selected three separate reaches of the Slough for additional sampling because of known contamination in those reaches and to complement previous sediment work in the Columbia Slough (DEQ 2011). These three reaches were selected to represent a range of contaminant conditions and to correspond to locations were previous investigations had collected carp data and where semi-permeable membrane devices (SPMDs) had been deployed (See Section 3.0).

- Lower Middle Columbia Slough & Buffalo Slough Reach: This 2.5 mile stretch begins at the Peninsula Drainage District Levee (PEN2) which divides the lower slough from the middle slough at about NE 17th Ave and continues upstream (eastward) to about NE 47th Ave. The reach also includes the Buffalo Slough, an approximate 0.5 mile inlet/waterway connected to the Middle Slough. There is one targeted sediment sample scheduled in this reach, just upstream of the PEN2 levee. This reach has relatively low

[2] http://www.deq.state.or.us/wq/TMDLs/approved90s.htm
[3] http://www.oregon.gov/DHS/news/2010news/2010-0225a.pdf

levels of pesticides and PCBs, but prior data indicate pesticide levels are slightly above screening levels.

- Upper Middle Columbia Slough Reach: The next 2.5 mile stretch starts upstream of NE 82nd Ave and stretches east under I-205 to the cross channel levee near NE 138th Ave. This area contains high levels of pesticides in sediments, due to historic farming practices. PCBs have been found in the upper section of the reach. One targeted sediment sample is located east of I-205 at the channel between the Columbia Slough and Marx-Whitaker Slough.

- Upper- Upper Columbia Slough Reach: This approximately 1. 5 mile stretch between Fairview Lake and NE 158th Ave contains the highest sediment and fish tissue pesticide values in the entire slough system. PCB's have been detected in sediments in this stretch below screening levels. Targeted sediment sites between Wagner Mining (ECSI#331) and Fairview Lake will bracket the reach and may represent sources. This area also contains the Army Corps of Engineers 1135 Project, where sediment removal and island creation in a portion of the reach took place in 2000.

Figure 2. Upper Middle Columbia Slough

2.2 **Primary Contaminants of Concern**

This study focuses on bioaccumulative contaminants found in Columbia Slough fish tissue, including PCBs and pesticides. PCBs have been found on many industrial sites throughout the slough basin, particularly the lower slough. While PCBs were banned in 1979, they persist in upland soils and sediments. In the past 10 years substantial efforts by property owners, the City of Portland and DEQ have worked to prevent runoff from upland contaminant sources source areas from entering the Slough via stormwater.

Pesticides, including DDT/DDE, dieldrin and chlordane were applied as part of historic farming practices. Currently a substantial portion of the basin has been converted from agricultural use to industrial or residential use, except in the upper portion of the basin where some farms remain. Similar to PCBs, the pesticides listed above are persistent in soils and sediments. PCBs and several of the pesticides noted above are classified as known or suspected carcinogens by the US EPA, and therefore have very low, health-protective, risk- based concentrations for soils, sediment and surface water. Due to their persistence, and the bioaccumulative nature of several of these chemicals, the concentrations measured in Columbia Slough sediment and fish tissue are well above DEQ's established risk-based levels. These findings are the primary basis for the Oregon Public Health Authority advisory on eating fish from the Columbia Slough. Because these two classes of compounds pose the greatest risk potential to human health, they were the focus of this investigation.

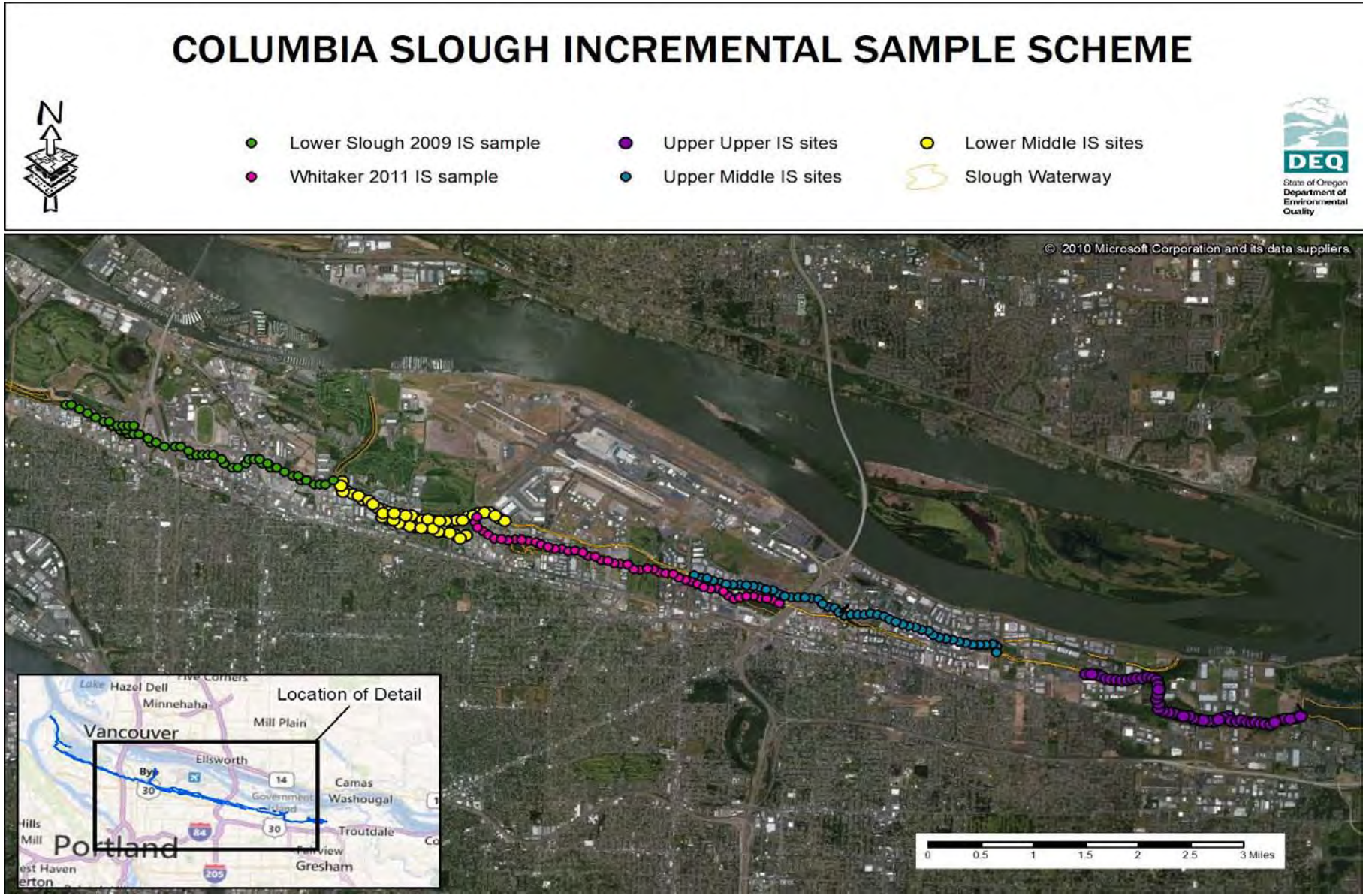

Figure 3. Map of Project Areas

2.3 **Previous Sampling Investigations**

For this study, DEQ used results from several prior, but recent, investigations completed in the Columbia Slough

a. DEQ performed sediment sampling in the Lower Columbia Slough in 2009 and Whitaker Slough in 2011, which is represented in Figure 3. These sampling studies included incremental sediment sampling – the collection of multiple individual samples over a geographic section that are then combined for each section to get a result that represents the average concentration over that section.
b. In 2005, the City of Portland conducted a fish tissue analysis in the Columbia Slough. Sediment incremental sample reaches in this study were selected to overlap the 2005 fish tissue collection points, as much as practical.
c. In 2004 - 2006, the U.S. Geological Survey performed a Semi-permeable Membrane Device (SPMD) water column study in the Columbia Slough. Water column SPMD data that was collected in locations that coincided with this project were included in this analysis.

3.0 SAMPLE DESIGN AND STRATEGY

DEQ's sampling strategy included two sample designs: an incremental sampling (IS) strategy to determine average sediment concentrations in each of the three selected segments and several targeted samples in locations where DEQ suspected higher concentration contamination sources within each of the study reaches. The IS approach provides a reliable, defensible, and cost-effective method to determine average concentrations within each reach. The purpose of dividing the area into reaches was to generate a baseline sediment concentration for each reach and determine average exposure concentration for the typical three-mile home range of carp. The baseline sediment concentrations can then be used to assess the feasibility of active cleanup measures within the reach and may help improve understanding of bioaccumulation into fish.

3.1 **Collection and Field Activities**

Field activities were carried out in accordance with the Sampling and Analysis Plan *Columbia Slough Sediment Investigation; ECSI#1283;* document number DEQ11-LQ-0012-SAP which referenced the Quality Assurance Project Plan, *Columbia Slough Outfall 59-65 Sediment Study* (DEQ, 2009); document number DEQ09-LQ-0046-QAPP. Deviations from the 2009 QAPP are described in Section 3.7. Sediment was analyzed for a variety of chemicals at all locations and bioassays were performed at selected locations. Additionally, sample collection procedures and analyses were matched to previous City of Portland studies when applicable. Preservation and labeling followed laboratory guidelines.

A Nationwide Permit for Survey Activities (NWP-2009-439) from the Army Corps of Engineers was obtained to collect sediment within the waters of the United States. An Oregon Department of State Lands dredge/fill permit was not required for the project. Multnomah County Drainage District provided logistical support including Slough access and boat storage. DEQ Laboratory and Environmental Assessment Division provided sampling equipment for field collection.

3.2 **Sediment Sample Location Selection**

Sample locations were selected based on the two sampling strategies: Increment samples and targeted composites. See Appendix A for detailed sample location maps. Sites were located with a Garmin handheld GPS, with an average accuracy of +/- 15 feet. While all efforts were made to collect the sediment at mapped locations, some site locations deviated due to safety concerns or heavy macrophyte growth. The majority of the sites were within 15 feet or less of the intended sample point.

Incremental Sampling Locations: The IS strategy was designed to integrate sediment information from throughout the length of the Slough reaches. Grid points were evenly spaced across the east/west length of the slough and the placement north/south was randomized to provide coverage for the entire width of the slough. Aquatic weeds were prevalent throughout each reach and many increments were biased towards patches of fewer macrophytes in the general area of the intended location, so that the desired sediment sample depth could be reached. The upper 10 cm of sediment from 50 locations was randomly combined such that each of three samples (designated A, B, and C), contained sediment from 30 of the 50 different locations shown in Figure 8.

Targeted Samples: The targeted sampling strategy involved a small array of composite sampling points (Figure 9). At each sampling station, sediment was collected from six discrete points in an array; sediment from each point was composited into a sample representing the area. The goal was to collect samples of the upper 10 cm of sediment; however macrophyte mats on the sediment bottom impeded dredge depth at some collection points. Composites were biased towards areas with fewer macrophytes in the intended composite area. PEN2 composite sites were moved due to safety concerns near the pump station. All sediment samples were collected from the surface to between 7-10 cm deep.

Figure 4. Sample in stainless steel bowl

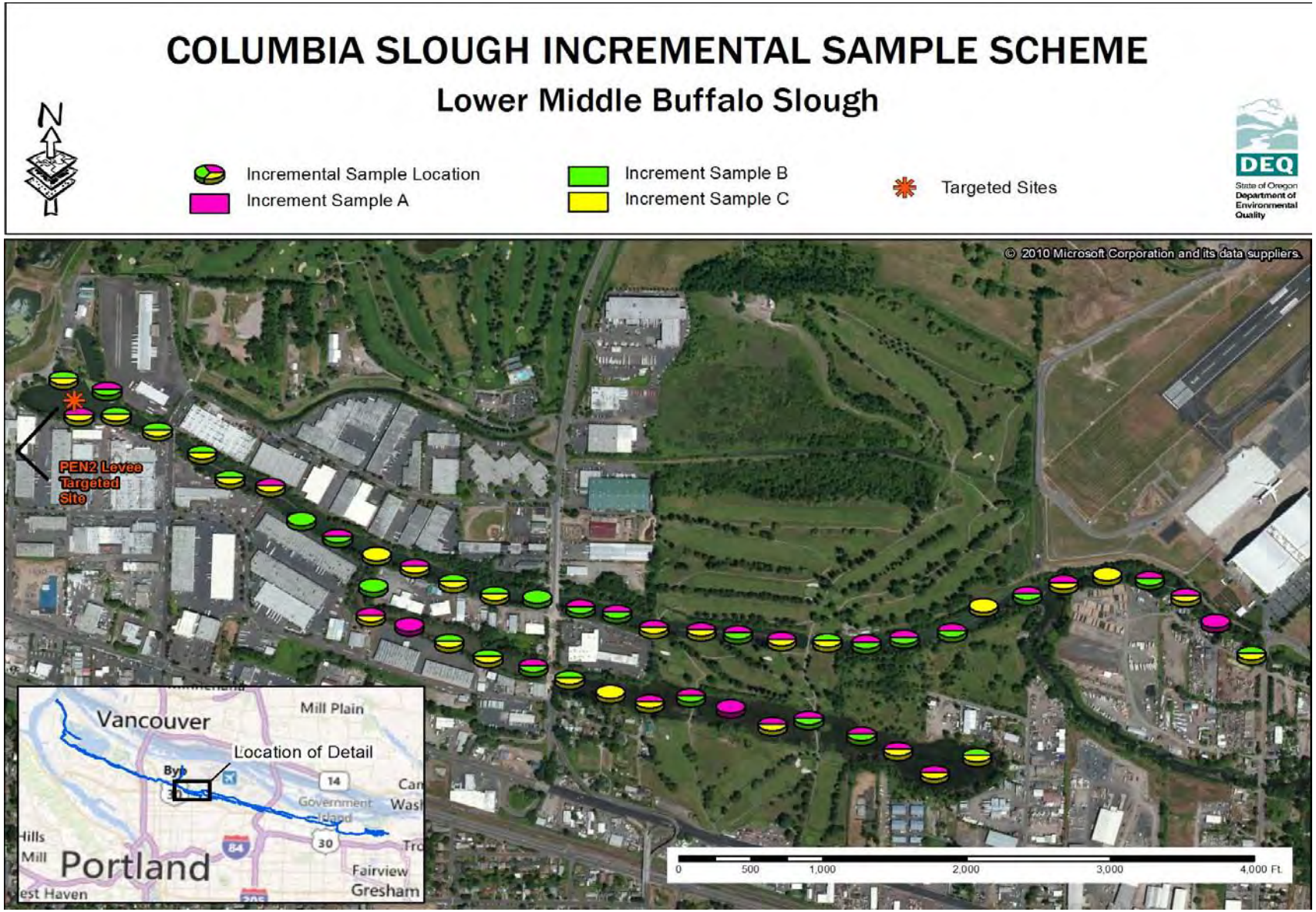

Figure 5. Lower Middle Slough Sample Map

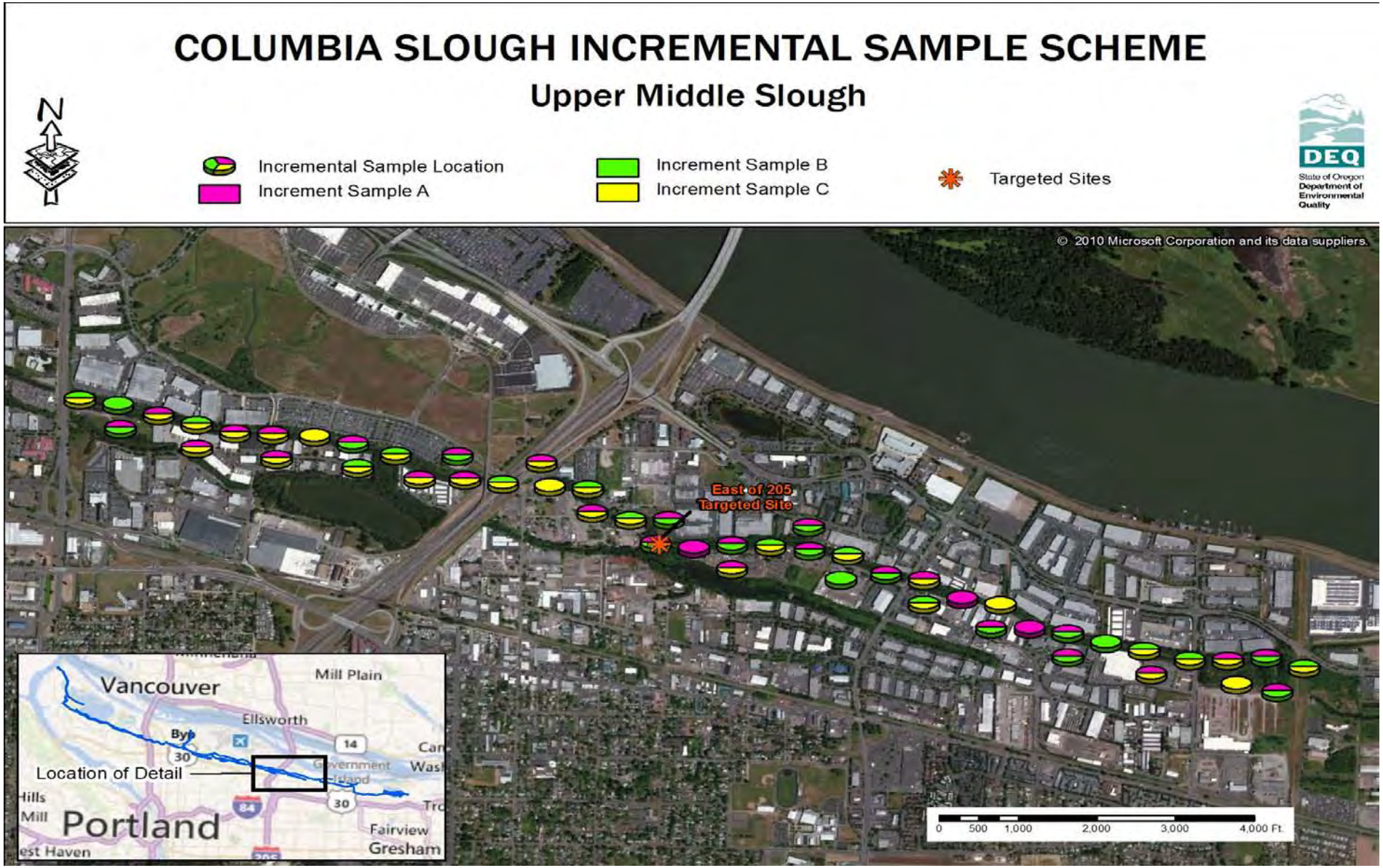

Figure 6. Upper Middle Slough Sample Map

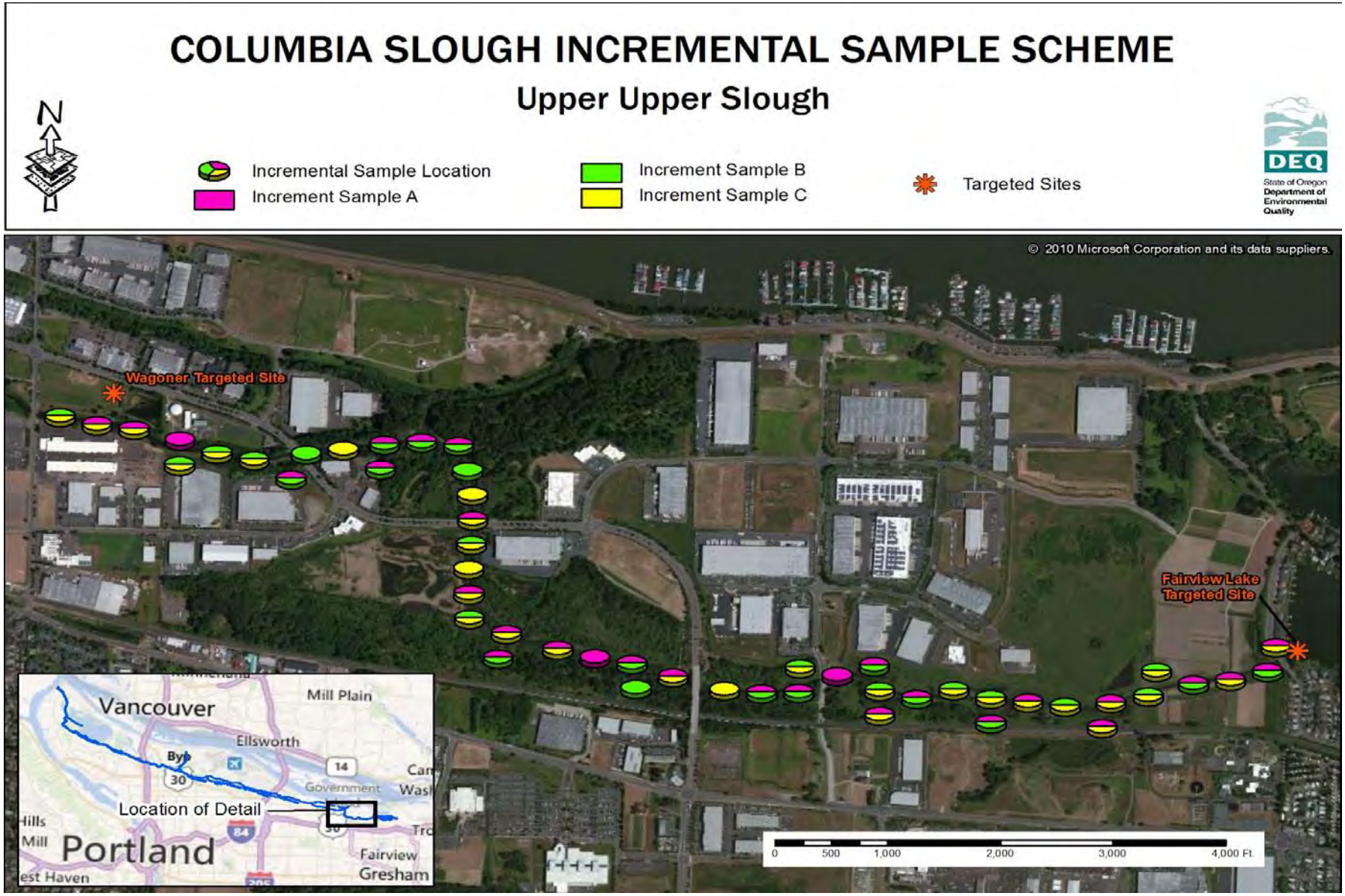

Figure 7. Upper Upper Slough Sample Map

3.3 **Sampling Procedure**

All samples were collected during a three week period in July 2011. The DEQ crew used an electric powered boat or wading to gain access to the sites. Samples were collected using an Ekman Dredge at deep water sites or by stainless steel spoon or clam gun at shallow sites. Sampling equipment was rinsed and washed between sites. Once samples were collected and labeled, they were placed on ice for preservation and transport to the laboratory.

3.3.1 Incremental Sampling

At each increment point, 50 g of sediment, collected as described above, was weighed with a digital scale. The sediment was then placed in the appropriate triplicate glass jar. The sediment was later dried and homogenized at the laboratory.

Figure 8. Placing increment sample on scale

3.3.1 Targeted Sampling

Each sample consisted of six composited subsamples. The total sediment mass required 12.5 gallons for bioassay and chemical analyses. The field crew placed the sediment in 5 gallon buckets. On dry land, field crews homogenized buckets by stirring with a stainless steel spoon and collected a chemistry sample by inserting a clam gun to obtain a subsample of each bucket. The subsample was then homogenized in a stainless steel bowl and filled in glass jars. The remaining sediment was placed back in the bioassay sample buckets. Targeted samples were dried to be consistent with composite samples. Field information was collected at each site

including sample depth, presence of woody debris or vegetation, observation of oil sheen, and other information (see Appendix B).

3.4 **Analytical Methods**

Sediment samples were sent to Pace Analytical, Inc in Seattle for chemical analysis. Bioaccumulation sediment samples were sent to Northwestern Aquatic Sciences (NAS), based in Newport, Oregon.

3.4.1 Chemical Analyses

The chemical analyses chosen reflect legacy bioaccumulation compounds found in Columbia Slough sediment. Sediments were analyzed for PCB Aroclors, PCB congeners, pesticides, grain size and total organic carbon.

Once all IS samples were collected, the laboratory prepared the sediment for chemical analysis. For the IS samples this included drying, homogenization, sieving (<2mm), and sub-sampling. Loss of these types of contaminants due to temperature, light, biodegradation, etc. for normal drying times (1-3 days) is assumed to be minimal. The analytical methods used can be found in Table 1.

3.4.2 Bioaccumulation Analysis

One freshwater sediment bioaccumulation test with *Lumbriculus spp.* (worms) was performed on five sediment samples in accordance with ASTM method E1688. First, a 4-day toxicity screening test was conducted to determine survivability of the worms in the test sediments. Then worms were placed in sediments for 28-days and half of the overlying water was replaced 3 times each week. After 28 days, the worms were removed, cleaned of sediments and allowed to depurate. Worms were sent to Pace for chemical analysis.

Figure 9. Sampling Equipment

Table 1: Sampling and Analytical Methods

Sample Type	Analytical Parameters	Reference Method	Data Package Level
Sediment	IS Sample preparation	MIS Procedure by Pace	Level II
Sediment	Targeted Sample chemistry preparation-Drying	MIS Procedure by Pace	Level II
Sediment	Total Organic Carbon	EPA 9060	Level II
Sediment	Grain Size	ASTM 422	Level II
Sediment & water	Polychlorinated Biphenyls Aroclors	EPA 8082	Level II
Sediment & Tissue	Polychlorinated Biphenyls Congeners	EPA 1668A	Level II
Tissue	Percent Lipid	EPA 1668A	Level II
Sediment & Tissue	Pesticides	EPA 1699	Level II
Sediment	Bioaccumulation test with *Lumbriculus*	ASTM E 1688 EPA 600/R-99/064	Level II

From document DEQ11-LQ-0012-SAP

Table 2: Summary of sediment sampling locations, sample types, and expected number of increments or composites.

Sample ID	Sample Type	Site	Pesticide (1699)	PCB-Aroclor	PCB Congener	grain size	TOC/solid	Bio-accumulation test	Increment/ Composite number	Data Level
UCS-A	Incremental	Upper Columbia Slough between NE 158th and Fairview Lake outlet Triplicate A	X	X	X	X	X		30	II
UCS-B	Incremental	Upper Columbia Slough between NE 158th and Fairview Lake outlet Triplicate B	X	X	X	X	X		30	II
UCS-C	Incremental	Upper Columbia Slough between NE 158th and Fairview Lake outlet Triplicate C	X	X	X	X	X		30	II
LMCS-A	Incremental	Lower Middle Columbia Slough & Buffalo Slough Triplicate A	X	X	X	X	X		30	II
LMCS-B	Incremental	Lower Middle Columbia Slough & Buffalo Slough Triplicate B	X	X	X	X	X		30	II
LMCS-C	Incremental	Lower Middle Columbia Slough & Buffalo Slough Triplicate C	X	X	X	X	X		30	II
UMCS-A	Incremental	Upper Middle Columbia Slough Triplicate A	X	X	X	X	X		30	II
UMCS-B	Incremental	Upper Middle Columbia Slough Triplicate B	X	X	X	X	X		30	II
UMCS-C	Incremental	Upper Middle Columbia Slough Triplicate C	X	X	X	X	X		30	II
US-FLO	Composite	Fairview Lake Outlet	X	X	X	X	X	X	6	**III**
US-FLO-QA	Composite	Fairview Lake Outlet-QA	X	X	X	X	X	X	6	**III**
US-WgrM	Composite	Wagner Mining Outfall	X	X	X	X	X	X	6	II
LMCS-PEN2	Composite	Lower Middle Slough- near PEN2 Levee	X	X	X	X	X	X	6	II
UMCS-I205	Composite	Upper Middle Slough- east of I205	X	X	X	X	X	X	6	II

Sample ID	Sample Type	Site	Pesticide (1699)	PCB-Aroclor	PCB Congener	grain size	TOC/solid	Bio-accumulation test	Increment/ Composite number	Data Level
SRM	Standard Reference Material	Standard Reference Material	X	X	X	X	X		NA	II
BLK	Rinsate Blank	Rinsate Blank		X						II

All media will be sediment/soils except water rinsate blank

3.5 **Data Usability**

Sample collection and analyses followed all methods, quality control procedures and reporting as described in the Sampling and Analysis (DEQ11-LQ-0012-SAP, (DEQ, 2010) and associated documents, except as noted below. DEQ conducted a data validation check to ensure data acceptability. Below is a brief summary of data quality controls outlined in the SAP and areas where the project deviated from the SAP. A full data quality assurance review can be found in Appendix E.

3.6 **Summary of Quality Control**

Three categories of quality control (QC) were used to assess data quality: sample design and methods, field sampling QC and analytical QC. Sampling designs were chosen to provide quality control for IS and targeted sampling.

3.6.1 Sample Design and Methods

Integrated Samples: A triplicate sampling QC method, based on *'Draft Guidance on Multi-Increment Soil Sampling'* (Alaska Department of Environmental Conservation, 2009) was used for the incremental sampling. In this case long reaches of the Columbia Slough served as sampling units enabling determination of a reach-wide average or baseline concentration. This length was also appropriate for evaluating bioaccumulation as it is consistent with the average home range of carp. The IS procedure controls compositional heterogeneity and distributional heterogeneity, two major sources of error in sediment sampling. Grouping and segregation error is controlled by collecting multiple randomly located sample increments to address distributional heterogeneity. The collection of triplicate samples allows for the calculation of relative standard deviation (RSD=100* Standard Deviation/mean) which provides an indication of how well the IS sample represents the decision unit. All results under 30% RSD were considered representative of the decision unit. If the RSD is greater than 35% the data distribution becomes 'non-normal' and the confidence of the results is weakened.

Figure 10. Sample drying & waiting to be processed with IS analytical methods

Targeted Samples: Standard duplicate samples were collected at a rate of 10 percent of the outfall sites, in this case one site: Fairview Lake Outlet (FLO). Relative percent difference was calculated to determine precision/accuracy of results. Field duplicate precision was considered acceptable when RPD <50% for organics. The analytical quality control target included precision of 20% for all analytes. Accuracy limits varied, depending on laboratory methods. The reporting limit was requested to be the lower of the Limit of Quantitation or Columbia Slough Risk Based Screening Levels. In some cases, estimates were reported and used. Analytical instruments were maintained and inspected within manufacturer's guidelines.

3.6.2 Field Sampling QC

Daily Activities Log: Daily Activities were recorded on Chain of Custody forms and Columbia Slough Sediment Field Forms, which include date/time, location changes, sample depth and any other unusual observations. Field notes are summarized in Appendix B. Sample depth was expected to be 10 cm, the average depth for samples was approximately 8.5 cm. Mats of macrophytes limited sample depths.

Location: Locations were as outlined in the SAP, with the exceptions of the PEN2 levee sample due to safety concerns. Mats of macrophytes also limited the location accuracy. Minor tracking changes were noted on the field sheet.

Quality control in the field included decontamination of field sampling gear between sites, use of an electric boat motor rather than gasoline, and isolation of the sediment, whenever possible, to minimize cross contamination.

Figure 11. Aquatic weeds limiting sample depth and location

3.6.3 Analytical QC

All analytical QA/QC was deemed acceptable, except for deviations noted below (Section 3.7). Quality Control included duplicates, matrix spikes, laboratory control standards/calibrations and equipment calibrations. Dilutions were needed for several analyses to minimize interferences. Duplicate sample precision and relative percent difference for the incremental samples are evaluated and discussed in Section 4.3.2.

Appropriate methods were used for all analyses, ensuring good comparability with other data. Targeted samples were dried prior to analysis to match the IS protocol of drying sediments. Analytical accuracy and precision were determined to be generally acceptable, with noted exceptions. Qualifiers were assigned to data points that exceeded project data criteria. All data was reported and considered representative of the samples collected, except as noted by qualifiers.

A Standard Reference Material was analyzed for PCB congeners. PCB-87, -195 and -201 were found outside the SAP matrix spike limits. An equipment rinsate blank did not find any residual contaminants on equipment.

Bioaccumulation quality control included water quality testing, replicates and a control sediment test. A 4-day toxicity screening was performed prior to the bioaccumulation test; all sediments showed a survival rate for organisms of 97% or more in the control samples, indicating good test performance.

3.7 **Deviations from Quality Assurance Project Plan**

Some of the laboratory estimated concentration results were used after careful consideration by the project managers. For example, some values were estimated to the method detection limit rather than using the method reporting limit and those sample results were used in the analysis.

Targeted Samples: Some PEN2 levee composite samples were moved during field collection as wooden booms restricted access in the sample area.

Incremental Samples: For the IS samples, all results under 30% relative standard deviation (RSD) were considered representative of the decision unit. The QA criteria for a representative sample were met for 66%, 70% and 98% of the analytes, supporting their use in developing baseline concentrations for the Lower Middle Slough, Upper Middle Slough and Upper Upper Slough, respectively. PCB congener analysis produced slightly better RSD results than the PCB Aroclor analysis. One PCB triplicate result in both Middle Slough segments was approximately 2x higher than the other two triplicates, suggesting one of the increments may be located at an unidentified localized pocket of PCB. Additionally, selected pesticides also failed to meet the RSD in these two segments. The Upper Upper Slough segment only had one RSD fail for Endosulfan Sulfate. There is only one known PCB source in this segment and pesticides are known to be wide spread throughout this area. In addition, a portion of the Upper Upper Slough was dredged by the Army Corps of Engineers (1109 project) in 2000, which may have removed surficial chemical heterogeneities. Appendix C contains a complete list of incremental sample RSD values.

Table 3: Incremental Sample Relative Standard Deviation (RSD) Failures-above 30%

Slough Segment	Chemical	Relative Standard Deviation (RSD) %
Lower Middle Slough	Total PCB Aroclors	54
Lower Middle Slough	Total PCB Congeners	41
Lower Middle Slough	Aldrin	68
Lower Middle Slough	Endosulfan I	42
Upper Middle Slough	Total PCB Aroclors	69
Upper Middle Slough	Total PCB Congeners	36
Upper Middle Slough	4-4 DDT	35
Upper Middle Slough	Endosulfan Sulfate	49
Upper Upper Slough	Endosulfan Sulfate	35

Bioaccumulation sediment samples were held in the DEQ Laboratory refrigerator and shipped to NAS at the end of the sampling period. Tissue samples were sent via UPS from NAS to Pace Analytical, Inc. in Wisconsin for analytical work. Tissue samples were marked to be sent via air to Pace Analytical; however the label was misread and shipped by truck. Upon arrival, sample temperature was above 6°C, but this was assumed to have minimal effect on PCB and pesticide analyses.

Results met the project completeness goal of 100% for targeted samples after some collection locations were moved by the field crew because of obstacles (i.e. weed patches). The incremental sampling met the project completeness goal of 100%. Project managers believe the dataset is useable and meets the goals outlined in the Study Objectives. Future data users must evaluate whether this data is acceptable for their project's data quality objectives.

4.0 SEDIMENT RESULTS

4.1 **Increment Samples Results**

Increment sample (IS) results correlated with previous studies that found lower PCB concentrations in the upper slough relative to the Whitaker Slough and Lower Slough. All IS mean concentrations of total PCB as Aroclors were at or above the previous Slough baseline value which was based on the detection limit. IS mean pesticide values were generally at or above baseline values in all sections of the slough for DDE, dieldrin and trans-chlordane. DDT values were below previous baseline values, suggesting DDT is breaking down into metabolite byproducts (DDD, DDE). Baseline values represent sediment values believed to be the average Slough-wide concentration prior to this work. Baseline values were originally developed by graphical methods applied to all available data for the slough and have been used by DEQ to determine feasible cleanup levels for slough sediment. In some cases, detection limits were elevated for historical samples and baseline concentrations were set at the appropriate achievable detection limit.

Table 4: Increment Sample Summary – Representative Results

	IS Mean Summary					**Previous Slough-wide baseline values**
Organics (ug/kg)	**Lower Slough**	**Whitaker Slough**	**Lower Middle**	**Upper Middle**	**Upper Slough**	
PCB Aroclor 1260	18.7	21	5 u	5	7	24
Total PCB Aroclors	45	21	9	24	15	10
Total PCB Congener	38	161	40	50	34	n/a
DDD	3.7	4.5	3.6	5.3	6.2	6.1
DDE	6.3	6.6	6.8	9.2	13.2	7
DDT	0.47	0.95	0.91	0.98	0.84	2.5
Dieldrin	0.7	1.45	1.6	1.33	1	1
trans-Chlordane (gamma)	1	2.24	2.21	1	1.6	1
Total organic carbon(mg/kg)	11,333	30,933	17,467	25,100	26,467	n/a

n/a – Not applicable.

u – under detection limit

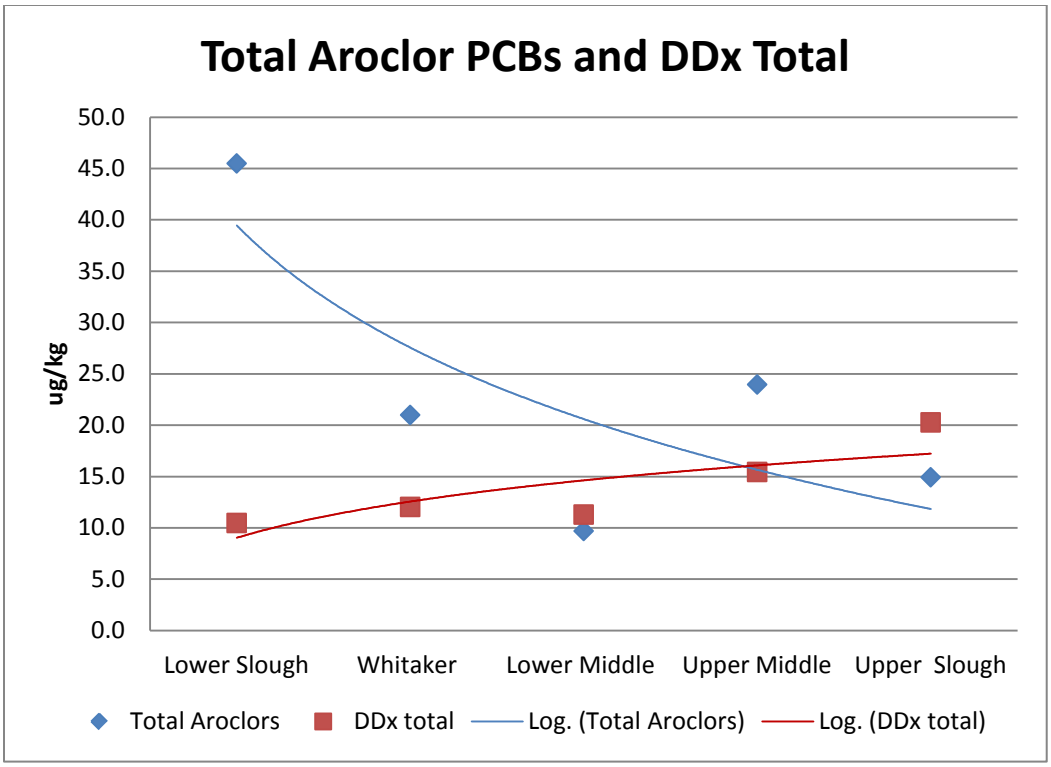

Figure 12. Columbia Slough Average Total Aroclor PCB and DDx Concentrations

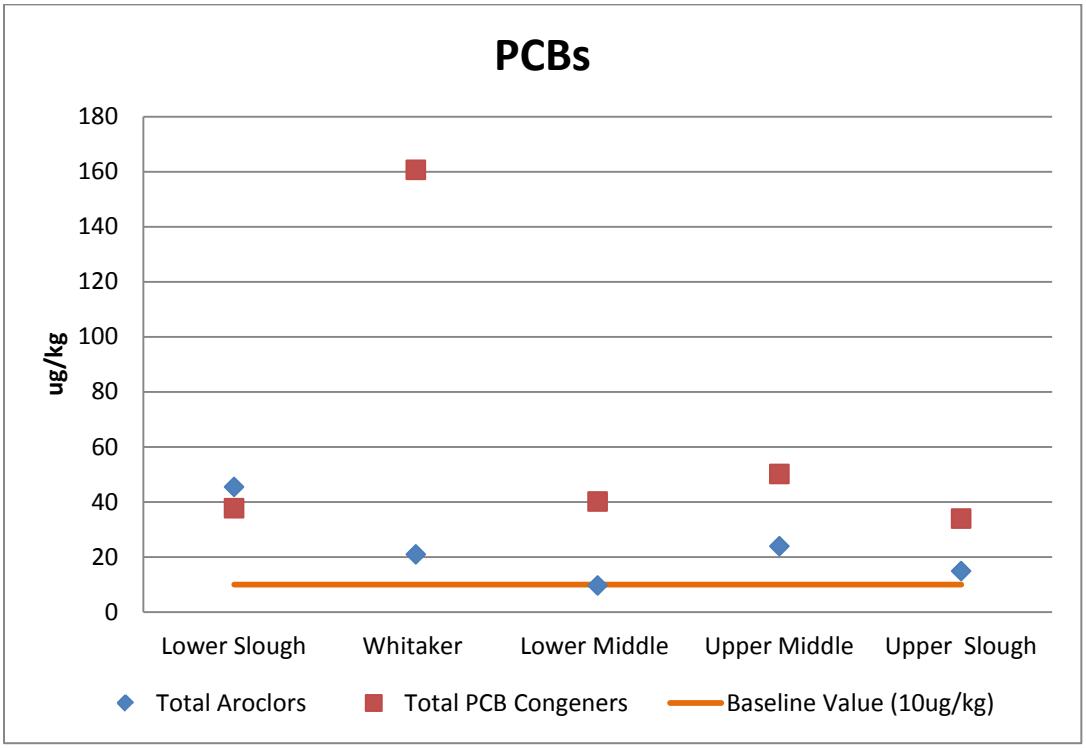

Figure 13. Columbia Slough PCB Average Concentrations

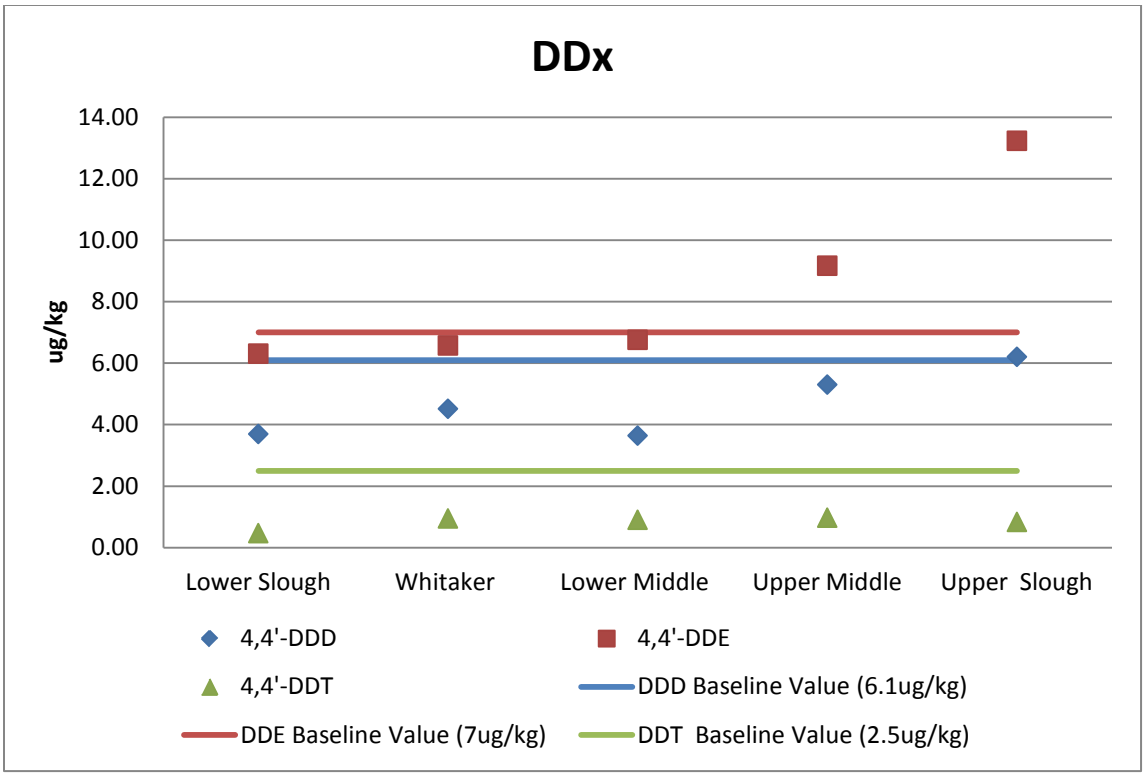

Figure 14. Columbia Slough Average DDx Concentrations

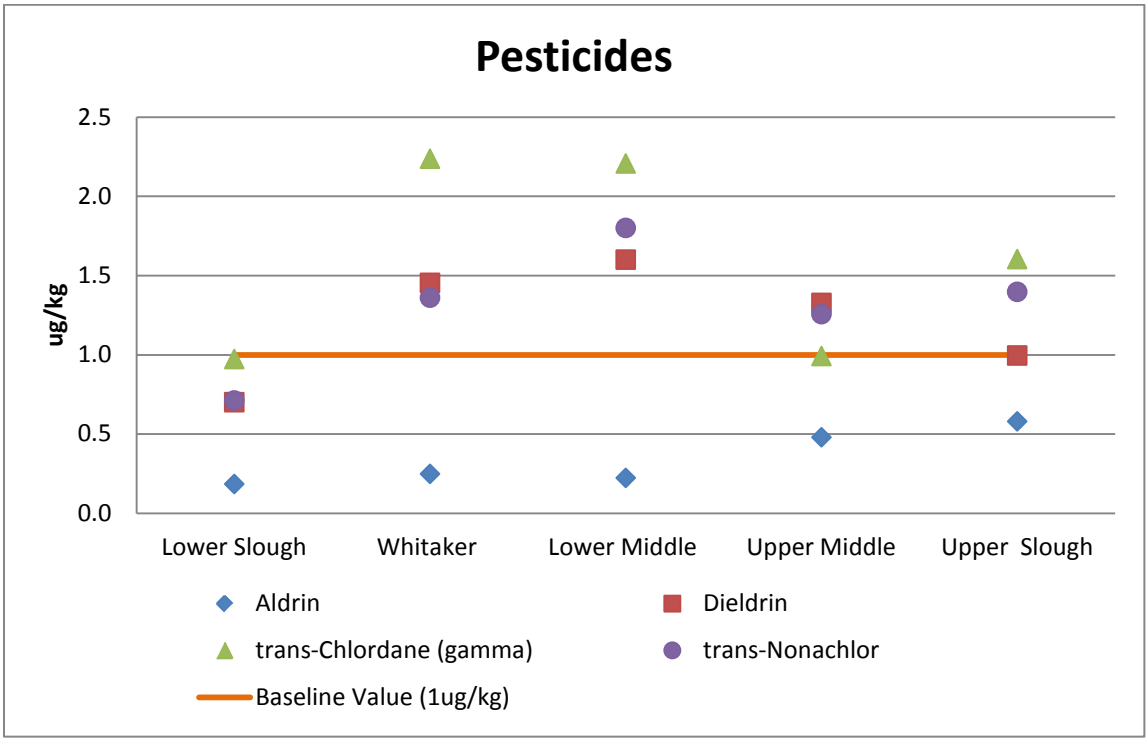

Figure 15. Columbia Slough Average Pesticide Concentrations

4.2 **Targeted Samples**

The sediment chemistry results for targeted sites were elevated in comparison to the average IS concentrations, except for the Fairview Lake sample. This result was expected as the targeted locations were placed in areas of suspected sources within the study segments. In addition, the sediment concentrations were also used for the bioaccumulation analysis discussed in Section 4.3. Information on targeted sites in the Lower Slough and Whitaker Slough were reported in previous DEQ reports (DEQ 2011 & DEQ 2012).

Table 5: Detections for Targeted Samples – Representative Results

Organics (ug/kg)	**Lower Middle near PEN2 Levee**	**Upper Middle east of I-205**	**Upper Slough Wagner Mining**	**Fairview Lake**	**Previous Slough-wide Baseline**
Total PCB Aroclors	**7.7**	**15**	**29**	**3u**	**10**
Total PCB Congener	**39**	**39**	**114**	**3**	**n/a**
DDD	**3**	**21**	**11**	**3**	**6.1**
DDE	**6**	**42**	**23**	**6**	**7**
DDT	**0.6**	**6**	**2**	**0.4**	**2.5**
Dieldrin	**1.3**	**3.6**	**2.6**	**0.2**	**1**
trans-Chlordane (gamma)	**1.2**	**4.0**	**2.8**	**0.3**	**1**
Total organic carbon(mg/kg)	**21,600**	**37,100**	**33,500**	**11,900**	**n/a**

n/a – Not available.

U – Qualified as a below the limit of detection.

4.3 ***Lumbriculus*** **Bioaccumulation Assays**

In addition to sediment bulk chemistry, bioaccumulation tests, as described in Section 3.4.2 were performed using the test species *Lumbriculus variegates* (an oligochaete worm) in four locations to assess the potential for uptake from sediment to worm tissue. Using sample specific organic carbon and lipid measurements, sediment accumulation factors were calculated for each analyte using equation D-2 from DEQs 2007 bioaccumulation guidance (DEQ 2007). To avoid introducing bias or error, the calculation was performed only where an analyte (either PCB congener or pesticide) was detected in both a sediment and corresponding tissue sample.

These calculations are presented in Tables F.1 and F.2, Appendix F. Table F.1 includes the number of chlorines on each PCB congener and the Log octanol-water partition coefficient (K_{ow}) as estimated by Hawker and Connell 1988.

4.3.1 Polychlorinated Biphenyls

For PCBs, the calculated Biota-Sediment Accumulation Factors (BSAFs)[4] reveal the following trends.

- The magnitude of the invertebrate PCB BSAFs are widely variable depending on the specific PCB congener being measured. Generally, the lowest calculated BSAFs, in the range of 0.2 to 0.4, were calculated for the most highly chlorinated congeners, the hepta- to deca-substituted congeners with very high log octanol-water partition coefficients (Log K_{ow}). This suggests that samples that are abundant in these congeners are likely to be less bioavailable and remain in the sediment reservoir without significant accumulation into biotic tissues (See Section 6.2, Figure 39).

- The highest BSAFs were calculated among the hexa-, hepta, and penta-substituted congeners. The log K_{ow}s for these congeners is in the range of 6.5 to 7.5. The relative solubility appears to be an important factor in the bioavailability and subsequent accumulation potential, and the accumulation factors appear to show a parabolic relationship with K_{ow} (See Figure 16). This finding is consistent with what has been reported by others (WDOH 1995, Moermond et. al. 2005).

- The highest BSAFs were generally in the range of 4 to 5, although some outliers exist up to a maximum of 13 (not shown on figure). A good proportion (36%) were less than 1, primarily among the least soluble and more highly chlorinated congeners (See Figure 16).

- Interestingly, the BSAFs as a whole appear to be log normally distributed with a mean of 1.6 and a median of 1.2. Figure 17 illustrates the total distribution of invertebrate congener BSAFs. The finding of a mean BSAF of 1.6 is in line with theoretical expectations under equilibrium conditions (US EPA 2009). Morrison et al. (1996), report that if chemical equilibrium between water and sediments exists, the BSAF should be approximately 1.6, while Wong et al. (2001) reported that a BSAF value of 1.6 can be derived from non-equilibrium steady-state bioaccumulation models. Moermond et al., 2005 report BSAFs from field collected oligochaetes in the range of 0.01 to 1.6, slightly lower but generally comparable to those observed in the current investigation.

- The differences between locations were mostly minor with excellent agreement between the Fairview Lake outlet sample and its quality assurance duplicate. The BSAFs at the Fairview outlet location were higher, likely attributable to the lower sediment PCB

[4] BSAFs are ratios of lipid normalized tissue contaminant concentrations to organic carbon normalized sediment concentrations of the same contaminant, collected at the same location. Full details are presented in Appendix D of DEQ 2007, as well as many other EPA documents and published literature.

concentrations at this location. The corresponding *Lumbriculus* PCB concentrations were not substantially lower relative to samples at other locations. Therefore, the resulting ratios of lipid normalized tissue to organic carbon normalized sediment were higher at the Fairview Lake locations relative to other sample locations. We think this illustrates one of the limitations of the BSAF method. That is, the tissue concentrations do not appear to vary linearly with sediment over the concentrations observed, suggesting that factors other than absolute concentration in sediment influence the tissue concentration. If the concentration of PCBs dissolved in pore water is more influential and less variable relative to sediment, this could explain why tissue concentrations do not vary linearly in response to sediment.[5]

- Notably, the BSAFs estimated by using total PCBs as a sum of congeners in sediment and by estimation of total PCBs as Aroclors are substantially different. BSAFs based on congener sums were less than or only slightly exceeded 1.0, whereas BSAF estimates using Aroclor results are 3.1 to 4.3. The Aroclor-based estimates are higher because the Aroclor method detected less PCB in sediment, relative to the congener method resulting in a higher normalized ratio of tissue to sediment. We believe the congener estimates of total PCB in sediment are more accurate. The difference in BSAF estimates based on the sediment analytical method again illustrates a limitation of the BSAF method, which relies heavily on quantification in sediment. The two PCB analytical methods (8082-Aroclor and 1668-congener) often vary substantially in the resulting estimate of total PCBs (See Tables 4 and 5). The total PCB BSAF estimate depends directly on these estimates.

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[5] Current understanding of equilibrium partitioning of non-polar organic chemicals between interstitial water and sediment indicates that measures of pore-water concentrations more accurately predict toxicity, as compared to whole-sediment concentrations (ITRC 2011). Therefore, we hypothesize here that tissue concentrations in laboratory exposed *Lumbriculus* worms may be more responsive to pore-water concentrations relative to whole sediments. Pore-water concentrations were not measured in this investigation.

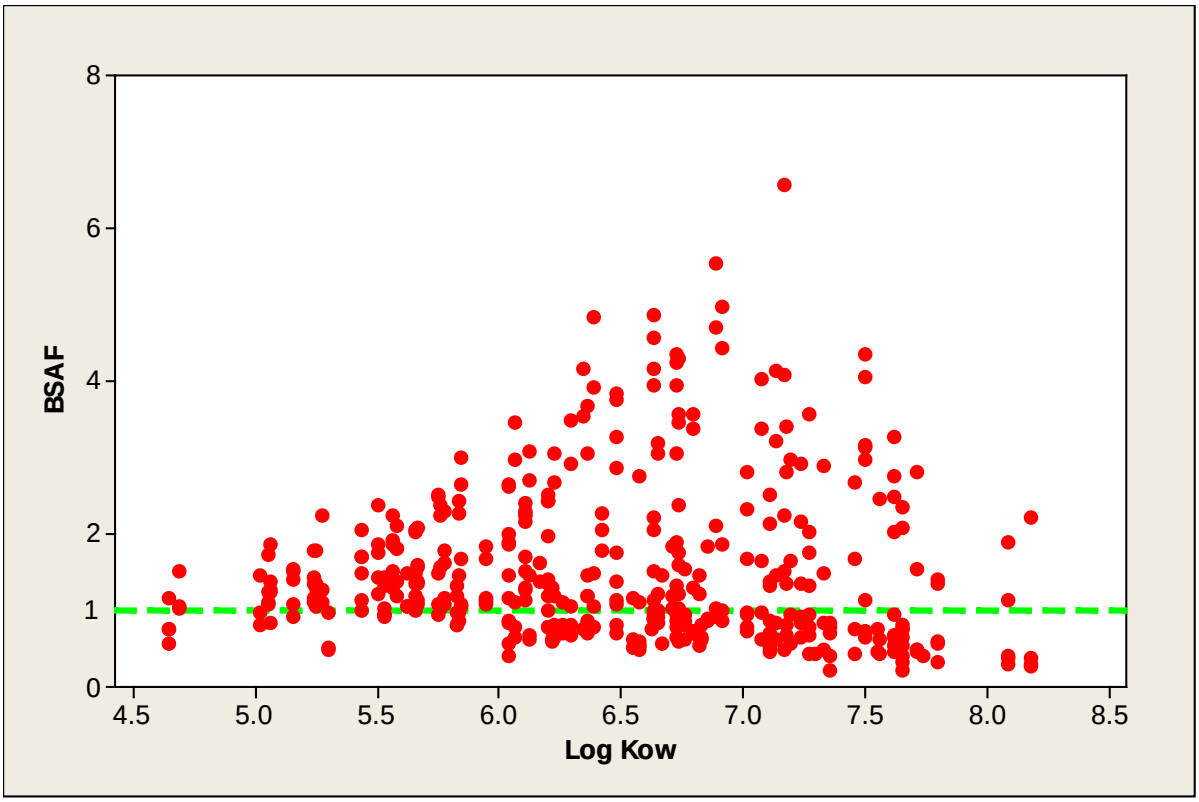

Figure 16. ***Lumbriculus*** **BSAF vs. Log Kow for PCB Congeners** ***(Reference line at BSAF of 1.0)***

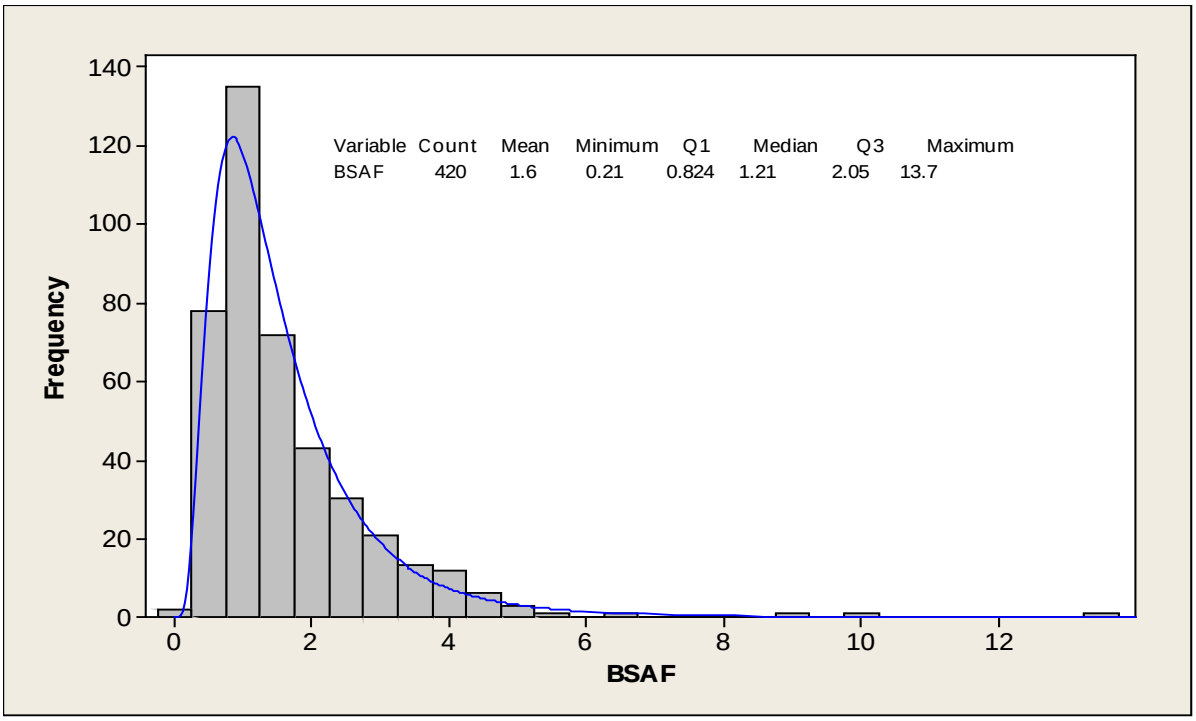

Figure 17. Histogram of ***Lumbriculus*** **BSAFs for PCB Congeners**

4.3.2 Organochlorine Pesticides

Table 6 presents the sample and chemical-specific *Lumbriculus* BSAFs calculated at each sampling location. Table 6 was created using only analytes that were detected in both sediment and *Lumbriculus* tissue by EPA method 1699. It is noteworthy that a number of additional pesticides were detected in the *Lumbriculus* 28-day bioaccumulation assay beyond those that were detected in Portland BES's 2005 carp fish tissue sampling. This allowed calculation of invertebrate BSAFs for a broader group of analytes. The reason for the increased number of detected pesticides in invertebrates relative to carp is unknown, but likely has to do with close association of the invertebrates with the contaminated sediments and the use of a sensitive analytical method in this investigation (method 1699). [6]

One feature of the pesticides BSAFs is a clear chemical-specificity of the calculated values. The BSAF values are relatively similar for the same chemical regardless of the sampled location, and the chemical specific BSAFs do not vary substantially. For these pesticides, the chemical properties appear to be a more important factor than the location sampled. This differs from what was observed with PCBs; where the location sampled and analytical method appeared to be factors in BSAF estimation (see Section 4.3.1).

Lindane (Gamma-BHC) showed the highest calculated BSAFs. However, these were based on tissue concentrations that were qualified with an "E" as outside the calculated calibration range of the analytical instrument, and more significantly both the time zero and control samples had results similar to or higher than the 28-day results.[7] Therefore, while lindane was detected in sediment and tissue, the BSAF estimates for lindane are not believed to be valid.

All other analytes had BSAF estimates of 5.6 or less. Broadly, the pesticides DDD, DDE, aldrin, dieldrin, chlordane and endosulfan sulfate tended to have the highest BSAF estimates among the detected compounds listed in Table 6. Pesticides that are not typically detected in slough sediments, but that were detected in these samples, tended to have BSAF estimates less than one. With the exception of the Fairview Lake outlet, the sampling locations had generally similar BSAF estimates. The Fairview Lake outlet generally has the highest estimated BSAFs of the four locations.[8] Overall these results support the conceptual model for the slough that pesticides, DDE, DDD, dieldrin, and chlordane are of most concern, with other pesticides occurring infrequently in Columbia Slough sediment.

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[6] Detection and reporting limits for the high resolution method 1699 are lower than those for the more commonly used method 8081. In this investigation, reporting limits for pesticides in the range of 0.01 to 0.1 ug/kg were achieved.

[7] The reason for the similarity between time zero, control and 28-day results is unknown.

[8] DEQ may further consider this, as appropriate, as part of any future work.

Table 6: Calculated *Lumbriculus* BSAFs for detected pesticides

	Sample Location			
Pesticide	**LMCS-PEN2**	**UMCS-1205**	**US-FLO**	**US-WGNRM**
2,4'-DDD	0.97	1.1	1.6	0.97
2,4'-DDE	1.3	1.6	2.9	1.2
4,4'-DDD	1.1	1.3	1.8	1.1
4,4'-DDE	1.8	2.0	4.5	1.6
Aldrin	2.1	3.6	5.6	2.8
alpha-BHC	1.4	3.0	2.1	1.2
cis-Chlordane (alpha)	1.1	1.3	3.1	1.0
cis-Heptachlor Epoxide	0.94	0.86	NA	0.82
cis-Nonachlor	1.0	1.1	1.9	0.78
Dieldrin	1.4	1.5	1.2	1.2
Endosulfan I (alpha)	0.92	NA	NA	0.48
Endosulfan II (beta)	1.5	NA	NA	0.83
Endosulfan Sulfate	1.3	1.6	4.6	1.1
Hexachlorobenzene	NA	1.0	0.85	0.81
Hexachlorobutadiene	0.21	1.7	0.62	0.76
Lindane (gamma-BHC)	107	102	83	55
Oxychlordane	3.1	NA	NA	1.0
trans-Chlordane (gamma)	0.89	0.94	2.09	0.83
trans-Nonachlor	0.80	0.90	1.60	0.76

NA- Not Applicable - Analyte not detected
LMCS-PEN2- Lower Middle Slough, near PEN 2 Levee
UMCS-1205 – Upper Middle Slough, east of I-205
US-FLO- Upper Slough, Fairview Lake Outlet
US-WGNRM – Upper Slough, near the former Wagner Mining Site.

4.3.3 Conclusions from *Lumbriculus* Bioassays

Lumbriculus bioaccumulation assays confirm that the accumulation of PCBs into invertebrate worms is consistent with what is expected based on the literature, and the accumulation of individual PCB congeners is highly variable depending on the physicochemical properties of the specific congeners (see Figures 16 and 17). The implication is that PCB congener patterns could be expected to vary substantially in biota tissue from that observed in sediment, and that is observed in the current investigation (see Section 6.2; Figure 39). This has bearing on risk potential, since congeners vary considerably with respect to relative toxic potency.[9] Only after biological uptake do concentrations in tissue consumed by people or fish-eating predators become useful for estimating risk potential.

For organochlorine pesticides, the sampling confirms that the pesticides which are of relatively greater concern for bioaccumulation potential in the Columbia Slough are the DDT metabolites (DDD and DDE), aldrin, dieldrin and occasionally endosulfan and chlordane. The upper slough tends to have higher levels of the organochlorine pesticides and the Fairview Lake outlet location appears to have relatively higher bioaccumulation potential, based on the magnitude of the BSAFs calculated at that location.

5.0 PREDICTIVE MODELING

This section presents the results of efforts to model contaminant uptake from sediment to carp for both PCBs and pesticides. In addition, for PCBs, we also compared the results of surface water concentrations as measured by semi-permeable membrane devices (SPMDs) with results from other media.

5.1 **Polychlorinated Biphenyls**

This section presents the results of evaluations of PCB congeners from 2011 sediment samples, 2005 carp tissue samples (GeoSyntec and BES 2007), and from surface water in semi-permeable membrane devices (SPMDs) deployed by the City of Portland and U.S. Geological Survey in

[9] Toxicity is commonly evaluated for 12-"dioxin-like" PCB congeners after concentrations are normalized according to toxic potency relative to 2,3,7,8- Tetrachlorodibenzo-p-dioxin (TCDD). The sum of the normalized concentrations may then be compared to effects-based criteria for TCDD. However, the normalized concentration, often referred to as "TEQ" is most relevant at the point of potential toxic action *internal to the organism's body*. TEQ normalized concentrations in abiotic media, such as sediment have little value in predicting toxicity, since fate and transport processes and bioavailability factors will vary congener-specifically resulting in a substantially different TEQ makeup in tissue, relative to what is observed in sediment. Because of this effect, DEQ recommends that when toxicity is to be estimated, tissue concentrations be used, or partitioning to tissue from sediment be modeled congener-specifically.

2003 through 2006 (McCarthy 2006; McCarthy 2008). In this section, PCB congener concentrations in all three media within these reaches are compared.

5.1.1 SPMD vs. Sediment Comparisons

Because not all PCB congeners were chromatographically resolved in all media and because only the 12 dioxin-like congeners were analyzed in carp tissue, all three media (carp, surface water and sediment) cannot be fully represented on a single plot. However, those congeners that are reported as uniquely eluting in both the sediment and SPMD analyses are plotted together.

Figures 18 through 25 are plots of concentrations the PCB congeners in sediment relative to SPMDs on a logarithmic scale. To the degree that any trend line is visually apparent, it suggests a relationship between sediment and SPMDs as surrogate for surface water. Quantitatively, the strength of such relations can be measured by a metric referred to as a correlation coefficient. There are multiple types of such coefficients that can be used depending on the assumptions applied to the data. Three types of coefficients are used in the plots, along with a probability or "p-value" that shows the statistical significance[10] of the relation. As shown in the figures, all three coefficients provide a similar interpretation. The data points are color coded according to homologue class (i.e., the number of chlorines on each molecule) to identify if any trends may be specific to homologue class. Finally, the larger the correlation coefficient the stronger the observed relation is interpreted to be. A Pearson's R coefficient of one would be a perfect correspondence and straight line with no scatter, while a coefficient of zero would correspond to a horizontal line with no trend at all. Smoothing lines have been used on the figures to help visualize any trends that may be apparent.

There is substantial scatter in the apparent relationships, even on the logarithmic scale. While these findings are not completely consistent, generally, the less chlorinated congeners (mono- through tri-substituted homologues) tend to be more abundant in the SPMDs, as shown by falling "above the line" in Figures 18-25. The more highly chlorinated hepta- through nona-substituted congeners were more abundant in sediment, thereby falling "below the line" in Figures 18-25. Congeners that are roughly equal in abundance in both surface water (SPMDs) and sediment fall closer to the center of the line (tetra- through hexa-substituted).

If solubility, as opposed to absolute sediment concentrations is a more important factor in loadings to fish tissue, then those congeners shown as being more abundant in SPMD samples should also be relatively more abundant in fish tissue samples. If alternatively, both solubility and sediment concentration are factors, the tetra- through hexa-substituted congeners should be

[10] Statistical significance is a term that refers to the probability of a measured effect occurring by chance alone. For example a probability "P-value" of 0.05 means that there are only 5 times out of 100 (5%) one would expect see the observed relation by chance alone, smaller values are more significant and larger values indicate a higher chance the observed effect is not significant. The cutoff for determination of significance is arbitrary, but it is common for values greater than 0.05 to be interpreted as non-significant.

relatively abundant in fish tissue. These ideas cannot be tested in the Columbia Slough since no complete PCB congener tissue data sets are available, except in invertebrate samples. However, additional work with PCB congener samples collected elsewhere may help inform this question.

Generally, it appears that the relation between sediment and surface water is strongest in the lower slough, where PCB levels are highest (DEQ 2011) and weakest (or nonexistent) in the upper slough where PCB levels are very low. Overall, although the correlations are significant, they are also weak, with Pearson's R and Spearman's Rho correlation coefficients up to 0.46, suggesting something other than sediment as a reservoir of PCBs is loading to the overlying surface water. Several of the nonparametric smoothing lines show a curvature suggesting that, at the lower sediment concentrations, there could be another source in addition to the sediment that is contributing to surface water (SPMD) PCB levels. This source is unknown, but may include stormwater runoff or regional atmospheric deposition (Hope 2008; Ecology 2011). Because sediment and surface water appear to have some degree of correlation, using both these media together when modeling to fish tissue would result in some degree of co-linearity[11]. Therefore, for the purposes of model building, it is likely better to use one or the other (sediment or water) but not both.

The reason why Whitaker slough sediment bears no relation to the PCBs in the SPMD 21B sample is unknown, but may have to do with this SPMD's placement being located near the confluence with the middle slough. The location may not adequately represent the Whitaker Slough.

A significant question of interest is which of the two media (sediment or surface water) is a stronger contributor to fish tissue loading? Since the available tissue data are limited to the 12 "dioxin-like" congeners in a subset of samples (Geosyntec and BES 2007), DEQ cannot directly address this question until a complete PCB congener data set is available in fish tissue for comparison to the surface water and sediment samples.

The reason that the 12 congeners measured in carp tissue are insufficient to address the question of which media is more important for fish body burden has to do with the methods that would be used to inform this question as well as the wide range of physicochemical properties that differ congener-specifically. As shown in Figure 16, the congeners vary substantially with respect to log-octanol water partition coefficient, which itself is directly related to solubility and bioaccumulation potential. It is likely that congeners that have greater relative solubility are more bioavailable and would be more abundant in tissue relative to the more insoluble congeners that are associated more exclusively with sediment. In order to investigate these relationships, the full spectrum of congeners representing the full range of properties and their relative

[11] Co-linearity is the statistical term for correlation between variables used as predictors in a regression model. It is an undesirable property for factors used in regression models.

proportions in each medium is needed. Moreover, these relationships would be investigated using modern multivariate statistical approaches which cannot be used with the more limited subset of data, or when they are only analyzed in a subset of samples. A complete set of samples and all congeners in each media analyzed by method 1668 is required for empirical analysis and interpretation of this question.

Figure 21 shows that in the upper middle slough there is poor correlation between sediment and SPMD location 158. (See Appendix H for SPMD deployment location maps). However, when SPMD 92B is used, this correlation improves somewhat (Figure 22). Therefore, in this case, the selection of which SPMD to use to represent this reach of the slough makes a difference in the interpretation. SPMD 158 was deployed above the upper end of the reach sampled in 2011, whereas SPMD 92B was deployed within the sampled reach just west of Interstate 205. This finding appears to validate that SPMD 92B is a better representation of the upper middle slough due to its location within the sampled reach.

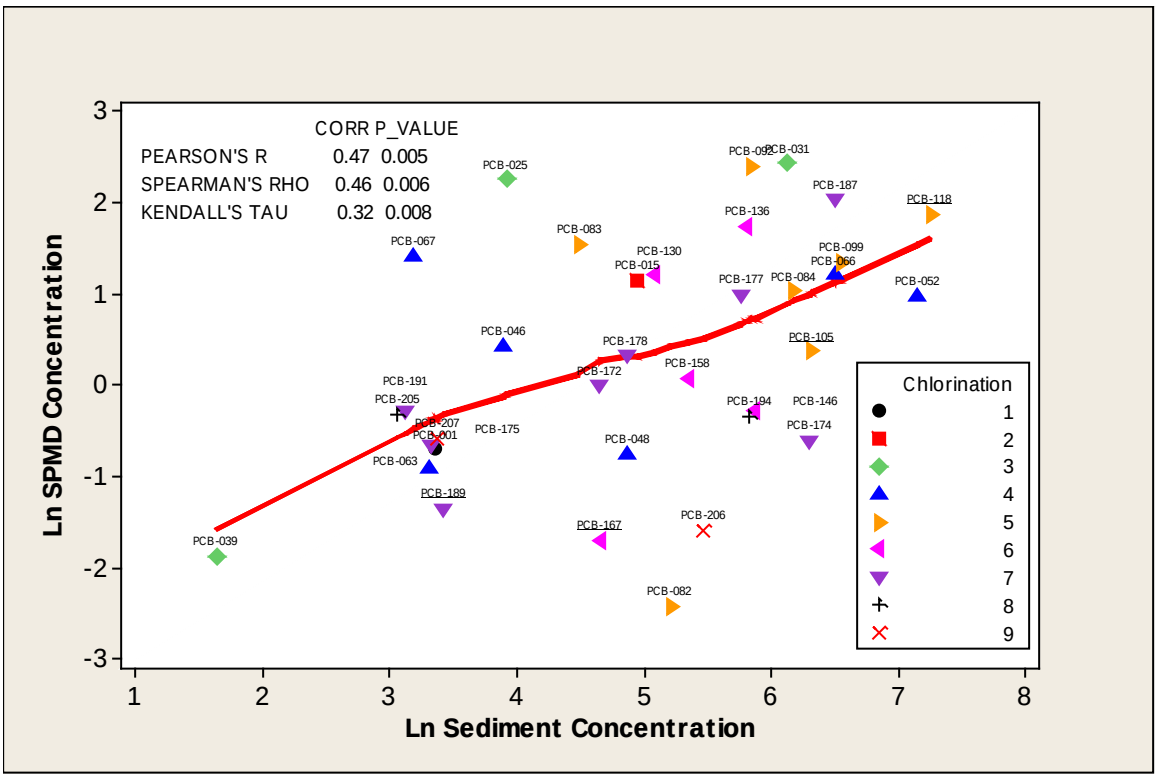

Figure 18. Lower Slough PCB Congeners in Sediment and SPMD by Chlorination

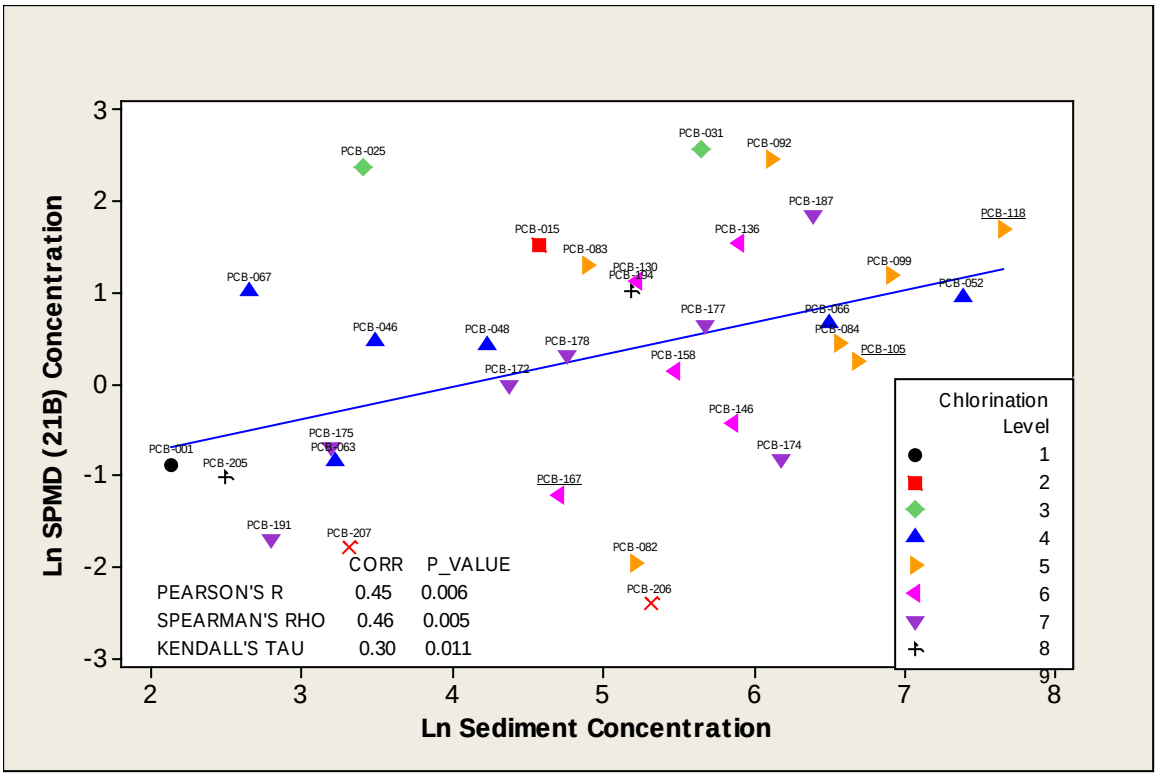

Figure 19. Lower Middle Slough PCB Congeners in Sediment and SPMD by Chlorination

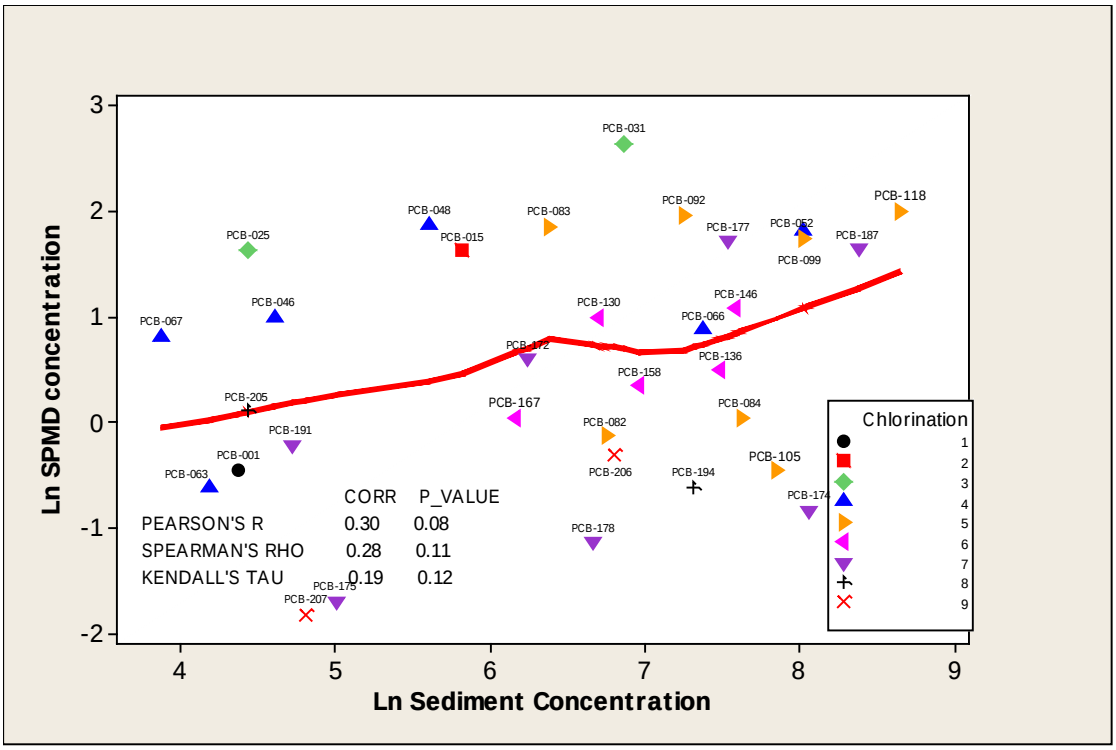

Figure 20. Whitaker Slough PCB Congener in Sediment and SPMD by Chlorination

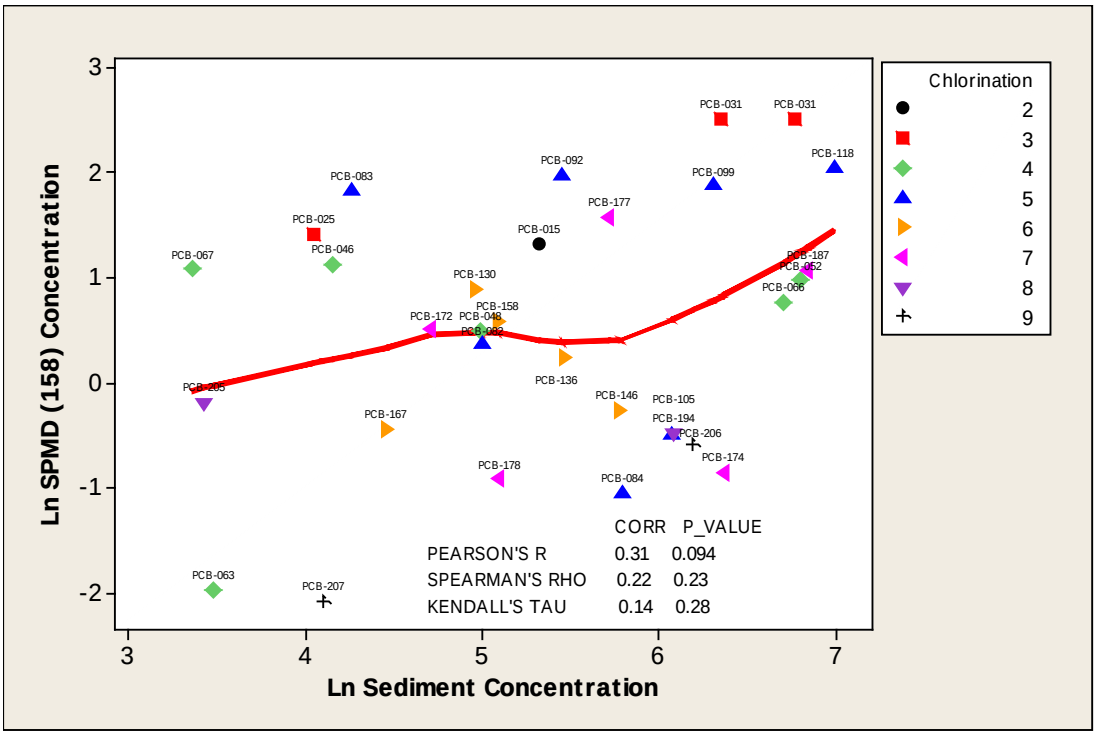

Figure 21. Upper Middle Slough PCB Congeners in Sediment and SPMD (158) by Chlorination

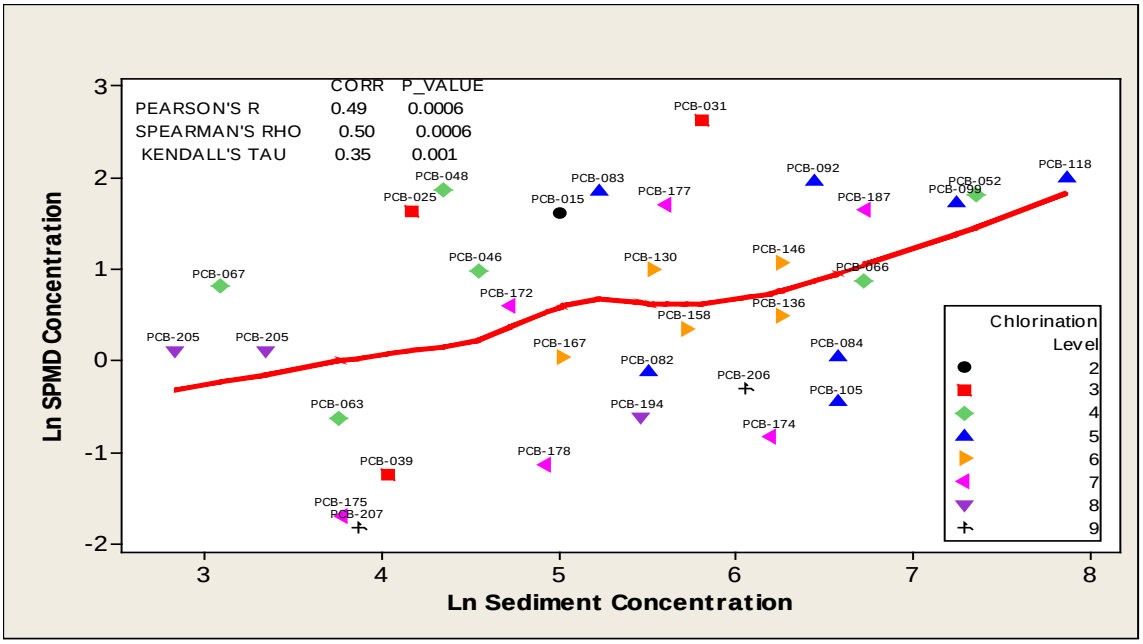

Figure 22. Upper Middle Slough PCB Congeners in Sediment and SPMD (92B) by Chlorination

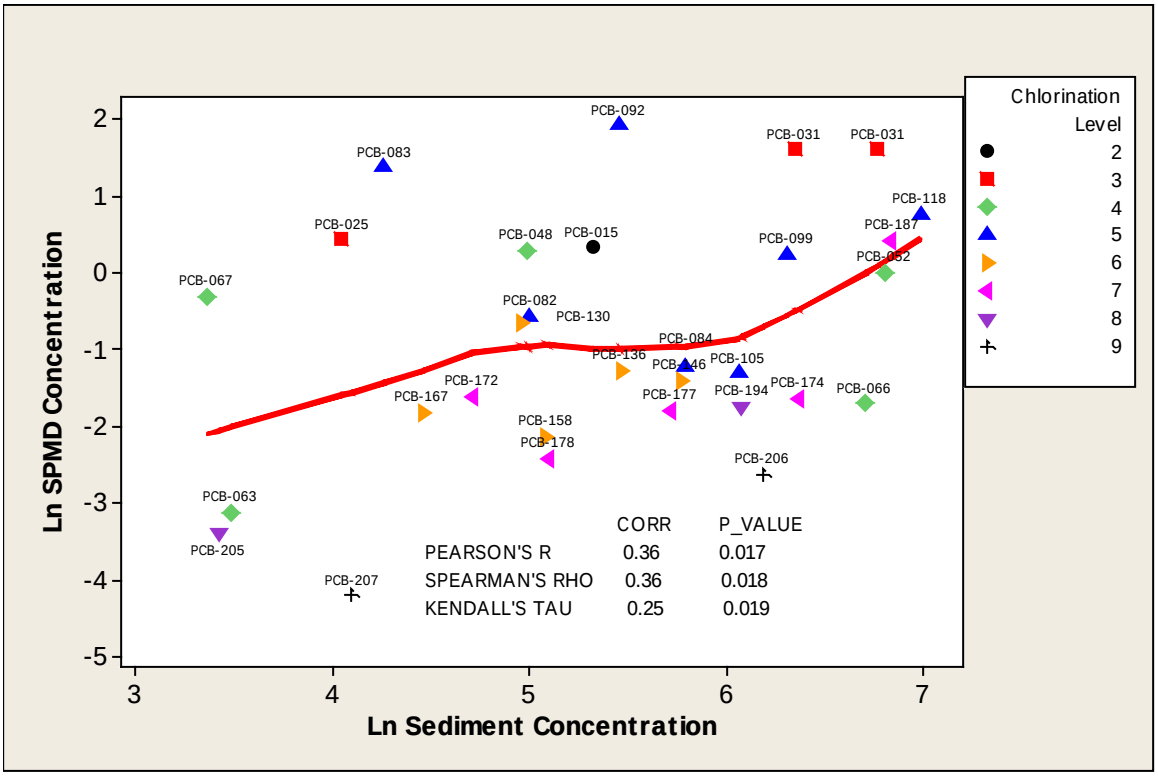

Figure 23. Upper Upper Slough PCB Congeners in Sediment and SPMD by Chlorination

Buffalo Slough

During 2003 and 2004, SPMDs were deployed in the Buffalo Slough near the sediment bed (deep sample) and mid-depth in the surface water column (shallow sample) (McCarthy 2006). The purpose of these depth discrete deployments was to compare location in the water column as a factor in monitoring concentrations. McCarthy 2008 reports that at sites where SPMDs were deployed at multiple depths, results suggested that bed sediments were not the primary source of contaminants. This conclusion was, in part, confounded by differences in effective sampling rates[12] between SPMD locations. However, McCarthy 2008 indicates that contaminant concentrations in SPMDs deployed at the stream bed were low relative to those higher in the water column, attributable to higher flow velocities in the water column. SPMD sampling rates within the main channel were considered generally similar throughout all deployments. Overall, McCarthy apparently concluded that SPMDs in the water column sequestered higher concentrations of contaminants than those near the bedded sediment. This finding is consistent

[12] SPMD concentrations are influenced by factors such as time of deployment, sampler volume, chemical-specific partition coefficients, water temperature and water velocity. All these factors are needed to estimate a sampling rate and water concentration from the SPMD result which was not done in this investigation, due to significant potential for propagated measurement error.

with the concept that the available fraction of contaminants in overlying water might be a relatively more important contributor to fish tissue relative to bedded sediments. As previously described in this section, the question of which medium (sediment or water) is relatively more important for fish tissue body burdens cannot be investigated at this time due to the absence of complete PCB congener data in all media.

Figures 24 and 25 compare the correlation of lower middle slough sediment to the water concentration at mid depth to the correlation of lower middle slough sediment to water concentration at the sediment bed depth near the confluence with Buffalo and Middle Slough (McCarthy's location A2). The shallow sample shows only weak and possibly insignificant correlation with sediment, while the deeper sample shows no correlation overall, but appears to show some correlation with the soluble less chlorinated mono through tetra-substituted congeners, as illustrated by the orange dashed line. The less chlorinated and soluble congeners clearly differ from the more insoluble, highly chlorinated congeners in the deep sample. The implication is that the relatively more water soluble congeners could be a more important factor in loading to SPMDs (and possibly to fish tissue) relative to the tightly bound insoluble sediment fraction.

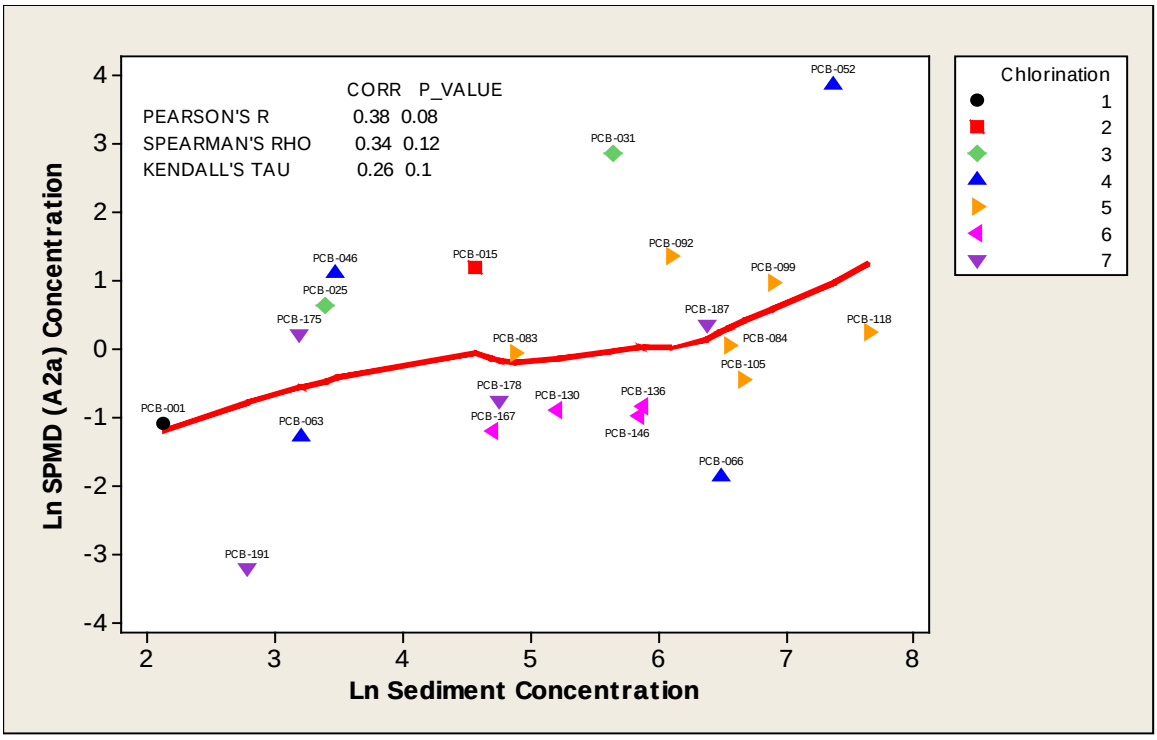

Figure 24. 2004 Lower Middle/Buffalo Slough PCB Congeners in Sediment and Shallow SPMD by Chlorination

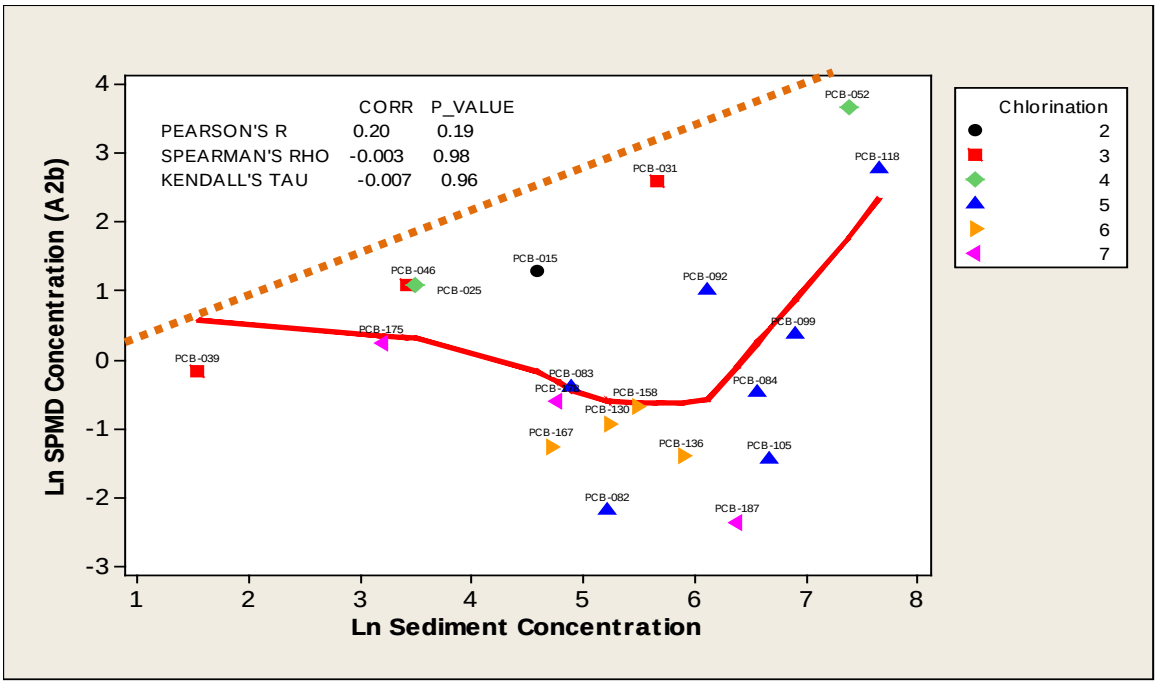

Figure 25. 2004 Lower Middle/Buffalo Slough PCB Congeners in Sediment and Deep SPMD by Chlorination

Overall, the SPMD and sediment correlations indicate a possible, yet weak relation between the two media, which may vary by PCB homologue class (i.e., the number of chlorines on each congener). It is unclear however, if sediment is the secondary source to overlying surface water, or if stormwater is a source to surface water, and secondarily to sediment as contaminants precipitate to bedded sediment from suspended particulate. The question of which of these mechanisms are relatively more important factors for tissue body burdens is unresolved.

5.1.2 Water (SPMD) and Fish Tissue Comparisons

As shown in Figure 26, regressions were prepared between PCB congener concentrations in SPMDs and carp tissue. In this case, the upper middle Columbia Slough reach (UMCS) appears to be dissimilar from other reaches.

In general, both SPMDs and sediment concentrations appear to be predictive of carp tissue concentrations. However, the sediment regressions against carp (see Figure 28) appear more nearly linear with less scatter. Moreover, sediment data is easier to collect, and surface water is not a medium that can be easily remediated to affect fish tissue. Therefore, for all these reasons, further work presented here focuses exclusively on sediment. The question of which medium, sediment or water, is more important for loading to fish tissue remains unresolved. If water is the more important medium, mass removal of sediment alone may not be sufficient to reduce fish tissue concentrations, if either: sufficient contaminant remains in sediment to re-dissolve into the water column or if ongoing sources, such as stormwater continue to load surface water.

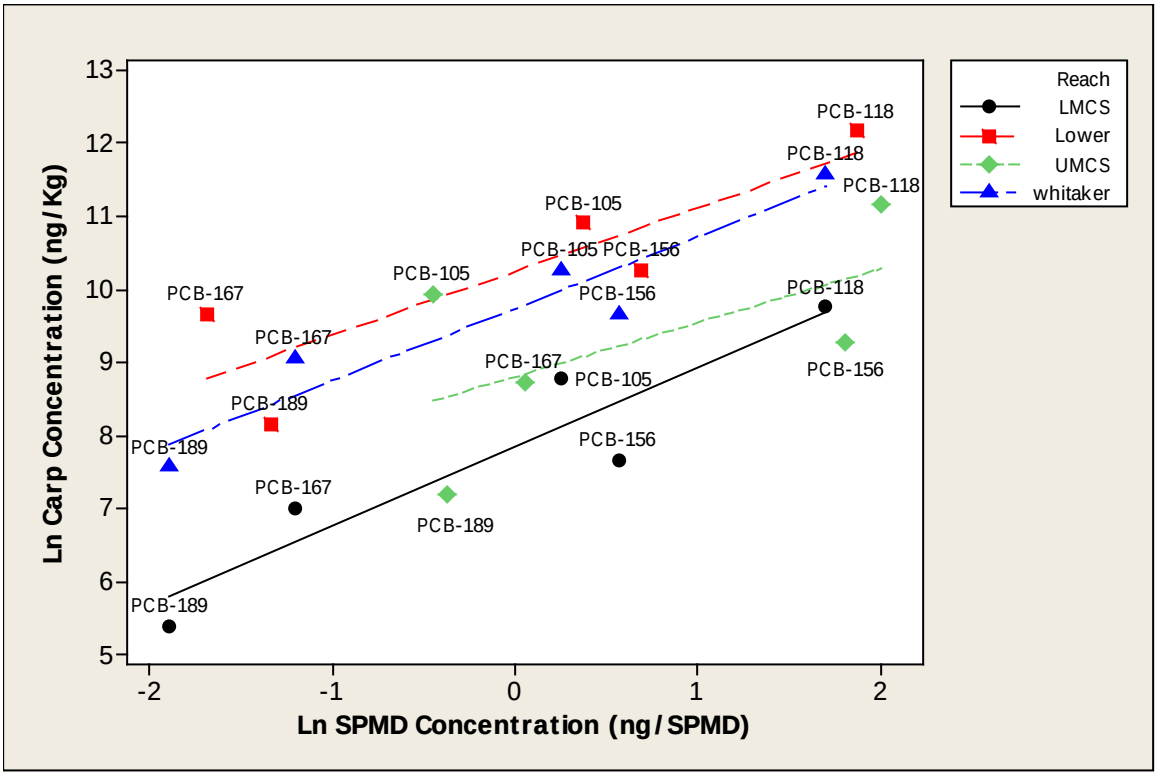

Figure 26. PCB Congeners detected in Carp and SPMDs

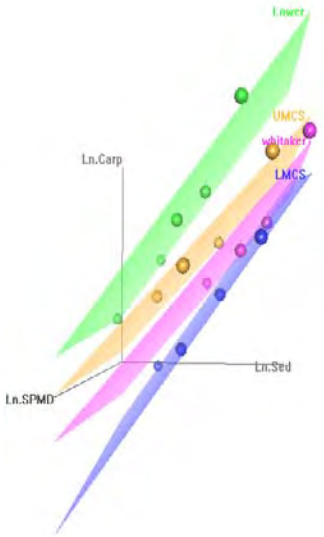

Figure 27. 3-dimensional scatter plot of PCB congeners in Carp, SPMDs and Sediment

DEQ also evaluated three-dimensional scatter plots to study the possible relations between SPMD results, sediment concentrations, and carp tissue concentrations in a single analysis

(Figure 27). Figure 27 is a three-dimensional depiction of the influence the both sediment and SPMDs (as a surrogate for water) have on PCB congener concentrations in carp. The color-coded surfaces are reach-specific regression "planes" as opposed to two dimensional lines color-coded by reach. The overall interpretation is that the surfaces show nearly parallel planes and both water and sediment have a relation to carp, and this relation is similar in each reach. As previously described (see Section 5.1.1) an insufficient number of congeners were analyzed in carp to provide a more detailed evaluation.

While the foregoing work suggests some relation between sediment and water and a correlation exists between SPMD samples and fish tissue, sufficient data are not available to use both sediment and SPMD PCB congener concentration estimates to predict fish tissue concentrations. If future fish tissue sampling includes an expanded suite of PCB congeners this may change and it may be possible to address whether sediment or the dissolved fraction in surface water is the more important factor in loading to fish tissue.

5.1.3 Sediment and Fish Tissue Comparisons

As described in DEQ 2011, the lower slough sediment results were used in a simple linear regression method[13] to derive a relationship between sediment and carp tissue for the common bioaccumulative compounds. The logs of the values were plotted to create a regression with a slope used to estimate the BSAF. On further review, it was discovered that this conflicts with EPA 2009 guidance. With these data, transformation is necessary to linearize the data sets and reduce the high leverage[14] associated with extreme values. Additionally, transformation is required to create a data set that adequately meets the assumptions required for ordinary least square regression (OLS). However, EPA in their 2009 guidance states that in log-log regressions, the slope is not the same as the BSAF. Rather, EPA reports that the intercept is the log of the BSAF.

Moreover, OLS regression has the property that it will underestimate the predicted variable (i.e., fish tissue) when the predictor variable is measured with error, as our sediment results are (Helsel and Hirsh 2002). For this, reason EPA 2009 recommends using alternative methods such a major axis regression. Another similar alternative approach is the "line of organic correlation" (LOC), recommended by Helsel and Hirsch when the y axis (fish tissue) may be needed to estimate the x-variable (sediment) in addition to the converse (Helsel and Hirsh 2002). Therefore, future work with these data sets, if any, may focus on using the line of organic correlation to derive estimates of fish tissue concentrations from sediment, or sediment goals from various fish tissue concentrations.

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[13] Logarithms used to linearize data and reduce the influence of extreme values.

[14] Leverage is a term used to indicate values that have extreme influence on interpretation of the data.

Based on the foregoing considerations, and given the limitations of BSAFs identified and discussed in Section 4.3.1, DEQ determined that it was appropriate to move away from attempts to define a single numeric factor to estimate bioaccumulation (i.e., BSAF) for the current work. Instead, OLS regression is used in this report to compare accumulation between segments, and the full OLS equations are used to estimate sediment concentrations from tissue and the results compared to those obtained using default uptake factors in DEQ's existing guidance (DEQ 2007). It is acknowledged that by its properties, the OLS regression approach inherently underestimates the tissue concentration, since it accounts only for variability in the vertical y-axis variable, and because when performed in ln-space it predicts toward the geometric mean (Helsel and Hirsch 2002).

The OLS regressions were performed with dioxin-like congeners that were detected in both sediment and carp tissue. Although OLS regressions are typically performed for a single chemical, these PCB congeners are considered sufficiently similar with respect to physicochemical properties that they can be treated as if they were a single compound for the purposes of this analysis. Table 7 shows a comparison of log Kow and level of chlorination for the congeners used in these regressions.

Table 7: Log Kow, and chlorination level for detected PCB dioxin-like congeners.

PCB Congener	**Log Kow [a]**	**Chlorination Level**
PCB-077	6.6	4
PCB-105	6.7	5
PCB-114	6.7	5
PCB-118	6.7	5
PCB-123	6.7	5
PCB-126	6.9	5
PCB-156/157 *	7.2	6
PCB-167	7.3	6
PCB-189	7.7	7

a - As estimated by Hawker and Connell 1988.

* PCB Congeners 156 and 157 co-elute on chromatographic columns.

Figure 28 shows a scatter plot with regressions of all PCB congeners analyzed in common between carp tissue and sediment for each of the reaches where fish tissue data are available.[15] Overall, with the exception of Whitaker slough, the regression lines appear to be parallel with a common slope. This indicates that, while the carp tissue PCB concentrations were higher in the lower slough, followed by the upper middle slough and then the lower middle slough, the

[15] No fish samples were analyzed in the upper slough for PCB Congeners in 2005 (Geosyntec and BES 2007).

relationship between sediment and carp tissue is common in all three reaches. Thus, whatever the mechanism of bioaccumulation is, it appears to be a common process, likely occurring at a similar rate throughout the slough system. The slopes of these three regression lines were formally tested for equivalence using the analysis of variance (ANOVA) procedure in R[16] yielding the results shown in Table 8.

Table 8: Analysis of Variance (AOV)

Variable	DF [b]	Sum of Squares	Mean Sum of Squares	F statistic	Probability
Ln Sediment	1	30.7	30.7	65.6	4.7E-07
Slough Reach	2	28.5	14.3	30.5	3.5E-06
Ln Sediment:Slough Reach [a]	2	0.067	0.034	0.072	0.93
Residuals	16	7.5	0.46		

a - Interaction term between Sediment and the sampled reach
b – Degrees of freedom for the variable shown

For this test, the results in Table 8 confirm that both sediment concentration and the slough reach are very significant factors in predicting the Ln transformed fish tissue concentration. There is no significant interaction between these two factors, allowing a conclusion that the slopes are not different. The Whitaker slough is not included in this comparison based on visual inspection of Figures 28 and 29, showing that Whitaker slough clearly has a different and possibly non-linear slope as compared to the other three reaches.

The results of this test suggest that while the concentration differences in PCB levels in carp are apparent between the three slough reaches, the relation or rate of change between sediment and carp tissue is the same. Therefore, while the rate and mechanism of bioaccumulation is likely similar between reaches, the sediment concentrations in each reach associated with the same fish tissue concentration is different. This may indicate that another factor, in addition to sediment concentration, is influencing carp tissue concentrations. It is unknown if this factor could be stormwater loading or something else, but these results are consistent with stormwater as a source of PCB loading to fish tissue. The concept of different stormwater loadings in each reach as an explanatory reach-specific factor could be tested by obtaining estimates of PCB loadings from stormwater to each reach. This could be done using geographic information systems (GIS) tools and estimating the flow and concentration from each outfall in each reach. PCB loading estimates derived in this manner could be included in regression models to inform this question.

[16] http://cran.r-project.org/

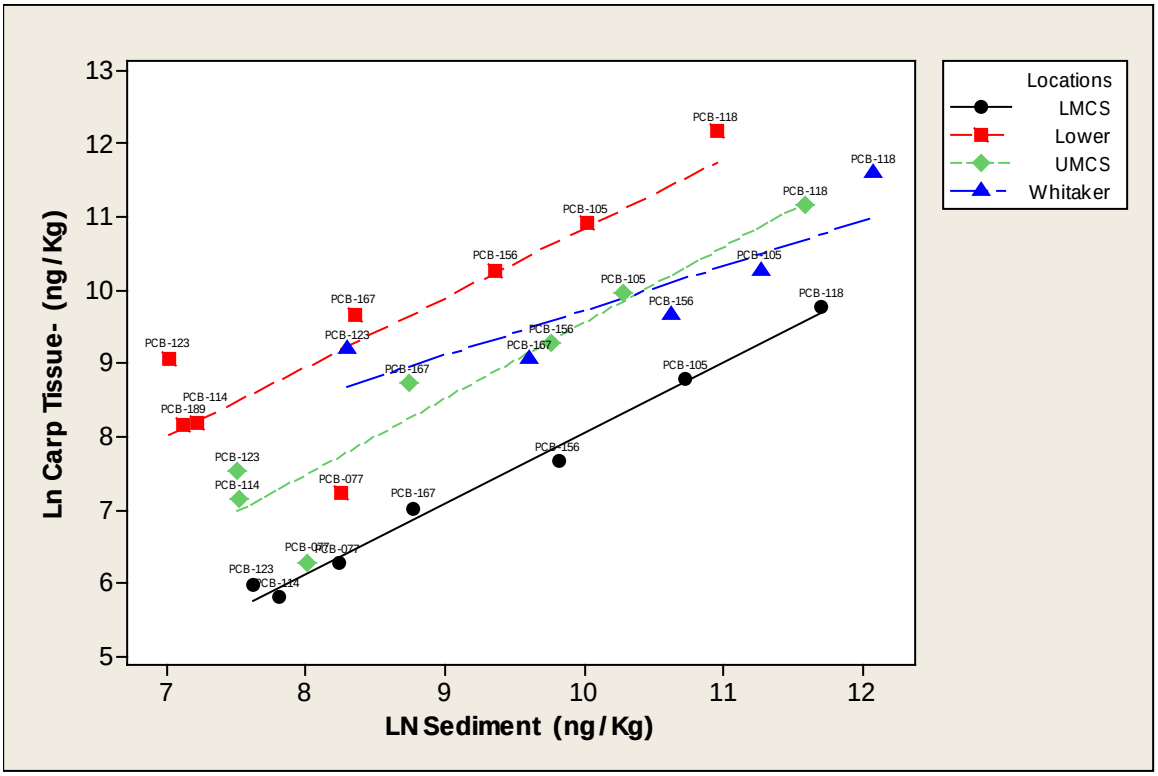


Figure 28. Regression of sediment vs. carp in four slough reaches

Because the regressions in each reach are significantly different, although the slopes are not, separate regressions are presented in this section for each reach. Note that the regression for the lower slough presented in DEQ 2011 differs from that presented here due to the exclusion of Aroclor 1254. This is done here because Aroclor 1254 introduces high leverage as an extremely influential data point, and because the physiochemical properties of an Aroclor, as a complex mixture of congeners, are substantially different from those of individual congeners (see Figure 16).

Figure 29 shows the non-linear nature of the relation between sediment and carp in the Whitaker slough, with a quadratic line fit to the data. The reason for the difference between the Whitaker slough and the other three reaches for PCBs in carp is not known. However, the carp captured in the Whitaker slough was captured near the confluence with the middle slough, and may have been exposed to water and sediment outside of the Whitaker Slough. Therefore, the Whitaker Slough sediment may not adequately represent the carp captured near the confluence. Additionally, Whitaker slough is the one reach where Aroclor 1260 was detected and the Whitaker slough IS samples indicate a relative high abundance of highly chlorinated congeners, consistent with a detection of Aroclor 1260. These differences may have some influence on the relative magnitude of concentrations of individual congeners detected in carp vs. sediment.

In each case, as shown in Figures 30, 31 and 32 for upper middle, lower middle and lower slough respectively, the regression slope coefficients are very close to one and the intercepts differ.

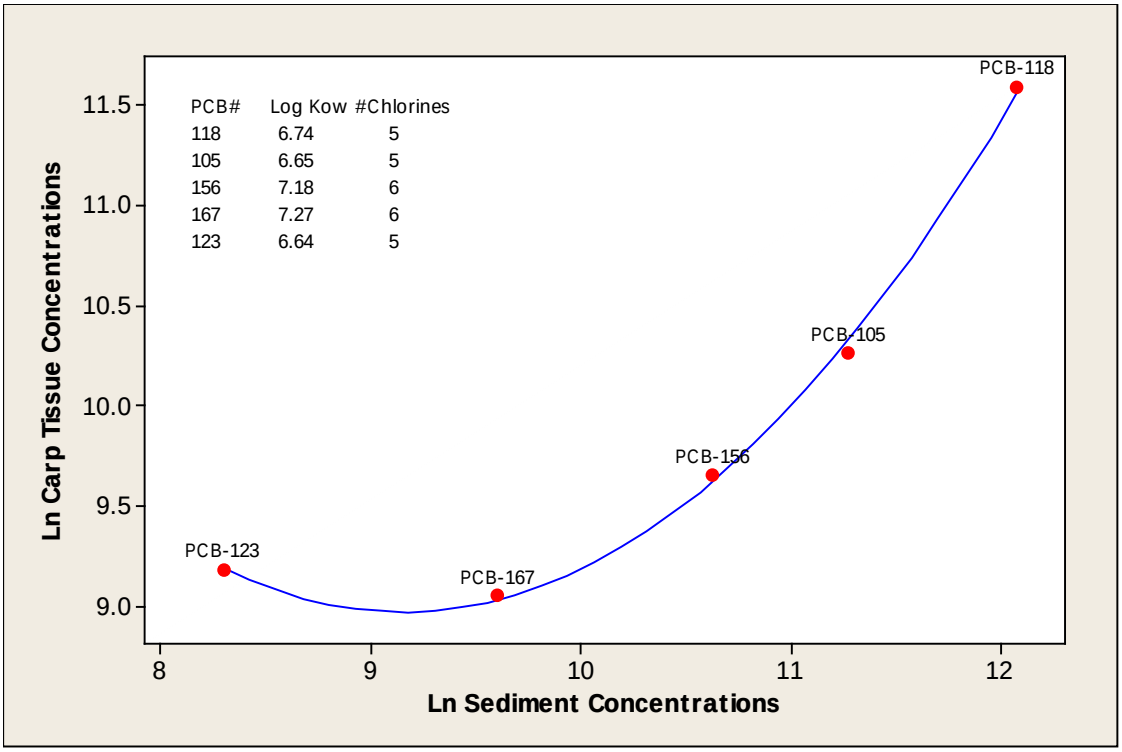


Figure 29. Whitaker Slough: Quadratic fit to PCB Dioxin-like Congeners

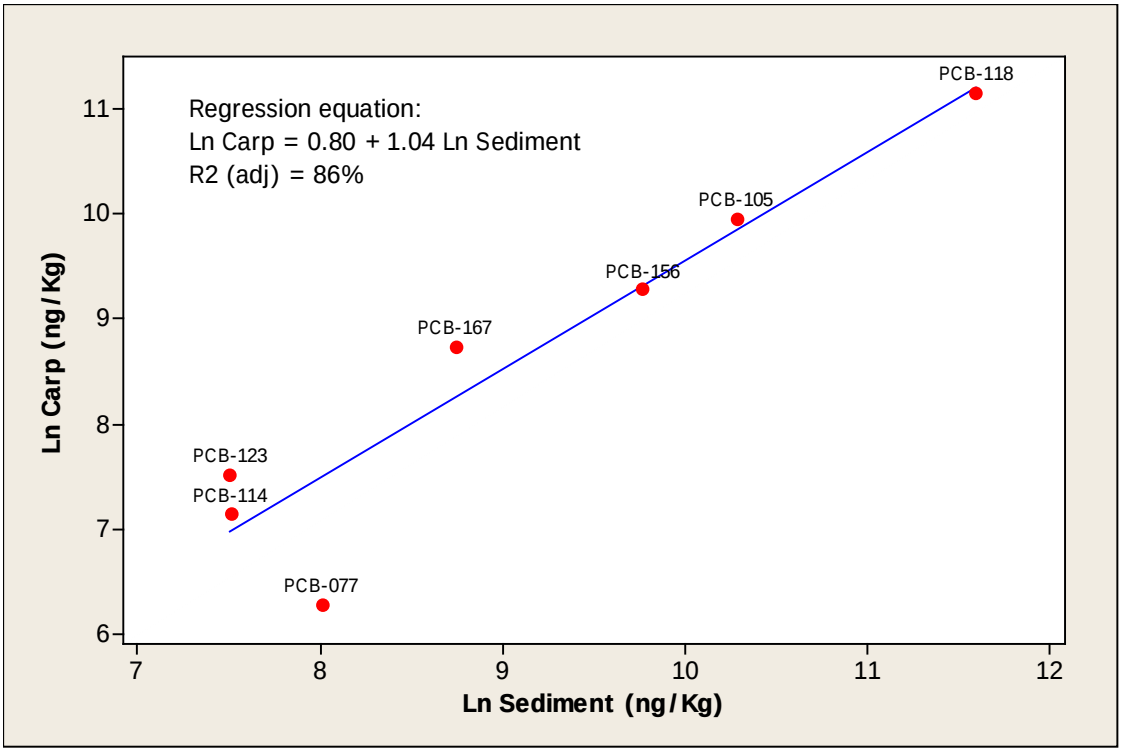


Figure 30. Upper Middle Slough: Logarithmic Linear regression of Sediment Congeners to Carp Congeners

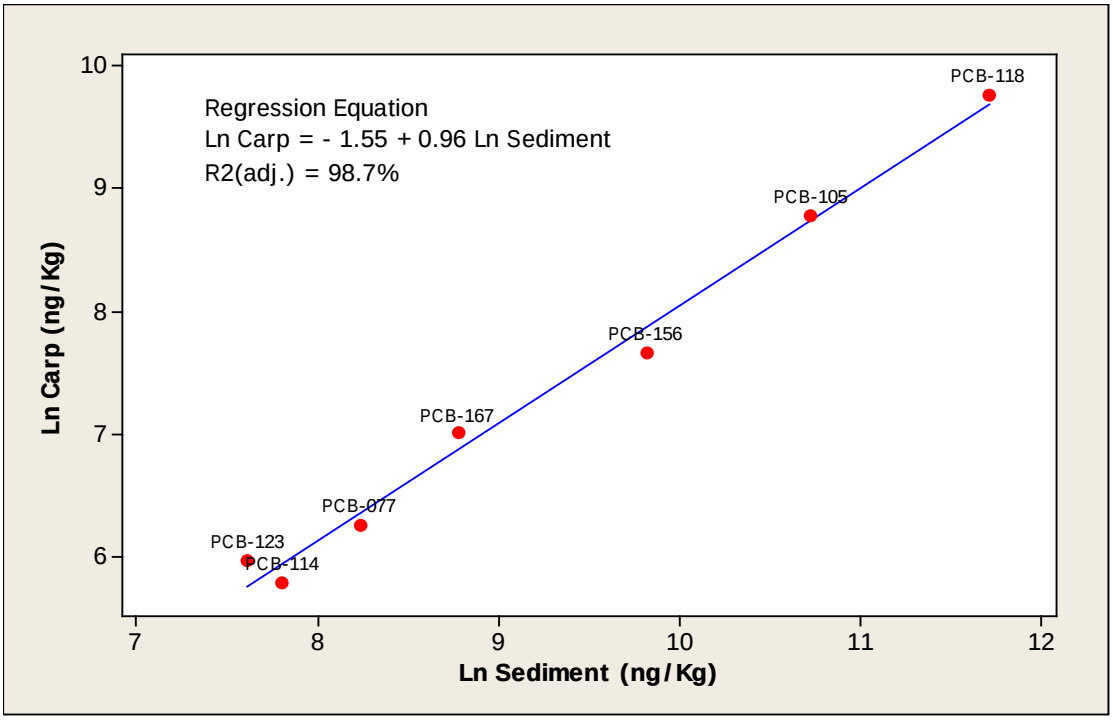


Figure 31. Lower Middle Slough: Logarithmic Linear regression of Sediment Congeners to Carp Congeners

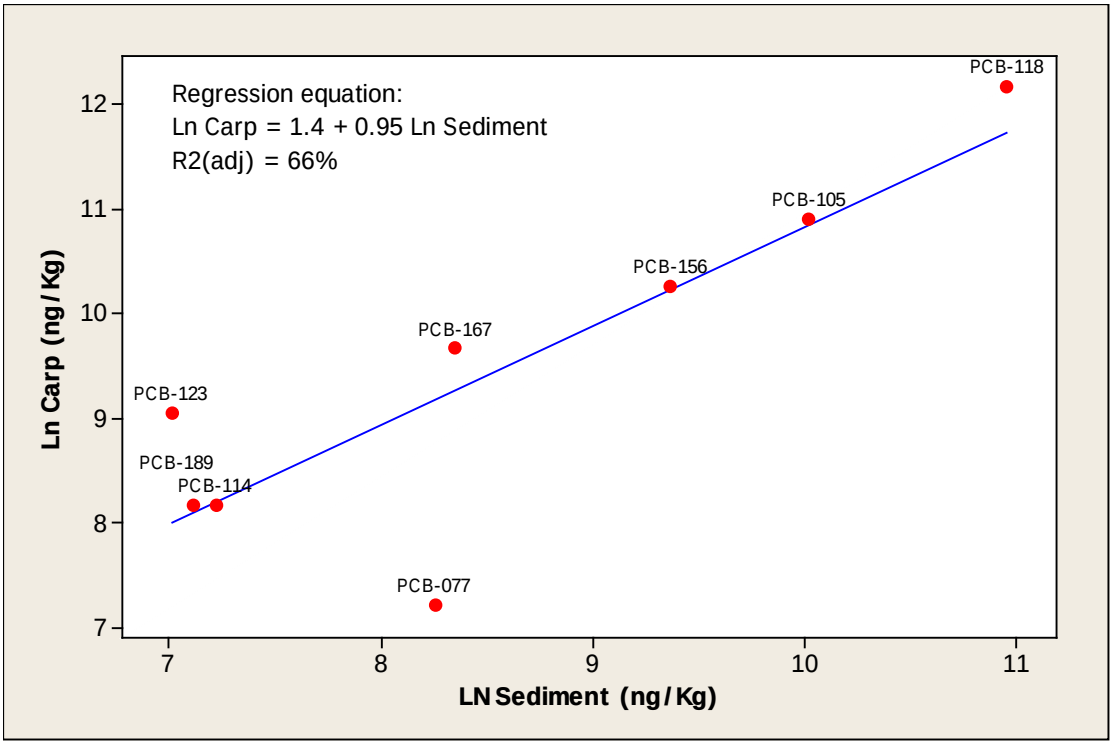


Figure 32. Lower Slough: Logarithmic Linear regression of Sediment Congeners to Carp

Congeners5.1.4 Regression Estimated Sediment Levels

In this section the regression equations described and shown in Figures 30-32, for the lower middle, upper middle and lower slough are used to develop sediment concentrations corresponding to acceptable tissue levels (ATLs) in fish as provided in DEQ 2007. This procedure is performed by using the acceptable tissue level (ATL) associated with a 1 x 10^{-6} cancer risk in the regression equations to estimate a corresponding "risk-based" sediment value. These predicted sediment levels are presented in Table 9 and corresponding actual measured sediment levels are presented in Table 10 for comparative purposes. A more complete presentation of the data is provided Appendix D.

Acceptable tissue levels (ATLs) for each of the dioxin like PCB-congeners, as well as total PCB as Aroclor, are presented in Table A-3b of DEQs 2007 Sediment bioaccumulation Guidance (DEQ 2007). The general recreational values based on the carcinogenic potential of PCBs were used together with the regression equations derived here to predict the organic carbon (OC) normalized sediment concentration corresponding to these ATLs. These OC normalized concentrations were then converted to dry weight estimates using the mean organic carbon estimates from each reach of the Slough.

Table 9: Regression Predicted Sediment corresponding to Acceptable Tissue Levels

	Regression Predicted Sediment SLVs (ug/kg-dry weight) [a]		
PCB Congener	**Lower Slough**	**Upper Middle Slough**	**Lower Middle Slough**
PCB-77	0.037	0.66	1.0
PCB-81	0.012	0.17	0.33
PCB-105	0.13	3.0	3.7
PCB-114	0.13	3.0	3.7
PCB-118	0.13	3.0	3.7
PCB-123	0.13	3.0	3.7
PCB-126	0.000026	0.00012	0.00077
PCB-156	0.13	3.01	3.7
PCB-157	0.13	3.01	3.7
PCB-167	0.13	3.01	3.7
PCB-169	0.000093	0.00053	0.0027
PCB-189	0.13	3.0	3.7
Total PCB TEQ	0.00002	0.0001	0.0006
Total PCB as Aroclor [b]	0.034	0.59	0.94

a- Concentrations developed using Acceptable Tissue Levels from DEQ 2007 and reach-specific regression equations.

b- Approximated by using Aroclor ATL in reach-specific equations.

Table 10: Incremental Sample (IS) Mean Sediment Values for PCB Congeners

	IS Sediment Mean (ug/kg-dry weight)		
PCB Congener	**Lower Slough**	**Upper Middle Slough**	**Lower Middle Slough**
PCB-77	0.096	0.074u	0.065
PCB-81	0.003	0.033u	0.006u
PCB-105	0.559	0.720	0.791
PCB-114	0.034	0.045	0.42
PCB-118	1.43	2.620	2.104
PCB-123	0.027	0.037	0.035
PCB-126	0.008	0.023u	0.008
PCB-156+157	0.270	0.420	0.315
PCB-167	0.105	0.151	0.111
PCB-169	0.005u	0.026u	0.005u
PCB-189	0.031	0.318u	0.064u
Total Dioxin Like PCB Congener (TEQ Normalized)	0.00092	0.00013	0.0005
Total PCB Congener	38	50	40
Total PCB as Aroclor	45	24	9.4

a- u-under reporting limit

Total PCBs

The regression predictions and intercepts for total PCBs vary by reach (see Section 5.1.3). Hence the same tissue concentration corresponds with a different sediment concentration in each reach. The reach-specific organic carbon and lipid measurements also affect the estimated sediment concentrations. The reasons for this reach-specificity are unclear.

The total modeled PCB (as Aroclor) sediment screening values are comparable in the upper and lower middle slough, and both are very similar to the default general recreational fisher total PCB sediment screening level in DEQ guidance of 0.39 ug/kg (DEQ 2007). This result suggests that for the Columbia Slough, the default sediment screening levels in DEQ guidance are appropriate and reasonable approximations. When these two sediment concentrations (upper and lower middle slough totals as Aroclors) are compared to actual measured levels in these slough reaches (Table 10), they are exceeded by approximately a factor of 10 to 50.

The predicted total PCB sediment risk-based concentration for the lower slough is a factor of 10 lower than the 2007 DEQ estimated default screening level and approximately 10 times lower than the value calculated for the other two reaches (see Table 9). When compared to actual sediment concentrations in the lower slough in Table 9, the SLV is exceeded by approximately a factor of 1,000.

However, as presented in Appendix C of BES and GeoSyntec 2007, the actual PCB congener concentrations measured in carp in the lower slough exceed DEQ recreational fisher ATLs (DEQ 2007) on the order of approximately 100-fold. The discrepancy between the sediment and tissue comparisons suggests that the regression estimated total PCB sediment risk-based concentration may be predicted too low in the lower slough.

Two comparisons are made in this section: 1) comparison of actual sediment to the calculated sediment SLV, and; 2) comparison of actual tissue to tissue ATL. Possible sources of discrepancy in conclusions between the two comparisons include: 1) Attributes of the regression model, 2) Sampling and analytical errors in both tissue and sediment sampling, and; 3) factors not accounted for in sediment modeling that influence tissue levels, such as direct loadings to surface water. The precise reason for the differences cannot be determined, only that they provide different conclusions. If one were to assume that the direct fish tissue comparison is more accurate, then it suggests that the regression model may be predicting a sediment SLV that is too low in the lower slough.

Total TEQ Normalized PCB and Dioxin Like Congeners

Sediment criteria based on Total PCB normalized TEQ were estimated by taking the reciprocal of the sum of the reciprocals of the congener-specific sediment screening levels per DEQ guidance (DEQ 2003). When these total TEQ sediment concentrations are compared to actual total TEQ normalized sediment levels only the lower slough IS average sediment exceeds, by roughly a factor of 45.

The individual dioxin-like congeners alone in lower slough sediments exceed criteria in Table 9 by factors ranging from 2 to 11, excluding congener 126 and 169, while the upper, middle and lower middle slough concentrations do not exceed their respective risk-based levels, a result comparable to the TEQ results. The exception is PCB-126 in the lower slough and the lower middle slough. It should be noted that these detections in sediment were qualified as an estimated maximum probable concentration (EMPC). Thus, this result is somewhat more uncertain, and PCB-126 was not detected in fish tissue.

The reason for the apparent discrepancy between congener specific exceedances (ranging from 2 to 11) and the TEQ exceedance of 45 in the lower slough has to do with the method of calculation of a TEQ-specific screening level. Because it is calculated as the reciprocal of the sum of the reciprocals of congener-specific values, it represents a scaled aggregate measure considering all congeners together, each with varying degrees of toxic potency. The most potent congener is PCB-126. PCB-126 is difficult to quantify in sediment due to the low levels at which it occurs. In the lower slough, PCB-126 was reported at an estimated maximum probable concentration (EMPC) of 0.008 ug/kg. The EMPC qualifier indicates that this estimate likely has a high bias. PCB-126 was not detected in any of the carp tissue samples. If PCB-126 were

excluded from the aggregate TEQ RBC, the magnitudes of exceedances would be comparable to the congener-specific comparisons (i.e., factor of 10).

Interpretation of Sediment Comparisons

Excluding PCB-126, the predicted congener-specific sediment screening levels are exceeded by actual sediment concentrations in the lower slough, by PCB-118, followed by PCB-105, PCB-77 and PCB-156 (co-eluting with PCB-157). Although PCB-126 is the most toxic congener it was not detected in carp tissue, [17] PCB-126 is rarely detected and is expected to be present at very low concentrations. It may pose risks, but they cannot be accurately quantified here due to the absence of tissue detections. Apparently, PCB-118 and 105 contributed the majority of "dioxin-like" PCB risk. The total PCB risk estimated by comparing the Aroclor sediment concentrations to sediment SLVs predicted by the regressions is substantially greater than that estimated by individual congeners or TEQ. This could be explained if there is another mechanism for PCB toxicity in addition to the known aryl hydrocarbon receptor binding, or possibly the total PCB risk is overestimated or TEQ risk is underestimated. If PCB-126 had been detected in carp tissue, it is likely that the TEQ and total PCB risks would more closely correspond, suggesting that the majority of PCB cancer risk is associated with PCB-126 and a few other congeners that are difficult to quantify. It should be noted that the ATL for Aroclor used in this calculation is based on an upper bound estimate of carcinogenic potency from U.S. EPA of two (2) $(mg/kg\text{-}day)^{-1}$. The central tendency estimate is one (1) $(mg/kg\text{-}day)^{-1}$. If the central tendency estimate were used, Aroclor sediment screening values would be twice the value estimated here. Regardless of the explanation, the total "dioxin-like" PCB risk measured either by individual congeners or total TEQ (excluding PCB-126) can be reduced to acceptable levels if sediment concentrations are reduced by approximately 10-fold, or roughly 90%. This may be an achievable goal. Using the total PCBs based on Aroclor SLVs, concentrations reductions of 100-fold or 99% would be required. This may not be feasible currently due to widespread "ambient" concentrations of PCBs.

Given that current risk-based concentrations for total PCBs either as Aroclors or as congeners are below likely ambient levels in the lower Columbia and Willamette River systems, an improved understanding of the sources of PCBs and which congeners are resulting in risks from trophic transfer in the food chain would be desirable to understand which sources may be controlled and potentially reduced over time. This issue is discussed in more detail in Section 6.0

[17] PCB 126 and PCB 169 are the two congeners "driving" TEQ RBCs, as shown in Table 10. The TEQ results here have some ambiguity, since PCB-169 was not detected in the sediment samples, but was detected in carp tissue, Similarly, PCB 126 was detected (although qualified) in sediment, but was not detected in carp tissue.

5.2 **Organochlorine Pesticides**

A regression was initially performed on all pesticides together (Figure 33). This figure is similar to one that appeared in DEQ 2011. However, now that more data are available, the observed pattern in the scatter plot reveals considerable "clumpiness", with apparent "clusters" by analyte. Pesticides appear in two or three rough groups, and the overall data set is not homogenous. Previously, in 2011, all OC pesticides were used together as a chemical class because insufficient data were available to do otherwise, and the data were too sparse to identify any apparent lack of homogeneity by analyte.

The current graphic (Figure 33) shows that the data are not homogenous and hence the data in aggregate are not suitable for a regression approach. This is consistent with the fact that these pesticides vary substantially in their physicochemical properties, more so than similar individual PCB congeners. Thus, if the regression approach were to be workable, it would be necessary to perform it on individual specific pesticides. Scatter plots with the limited available data for each pesticide detected in both carp tissue and sediment are presented in Figures 34-38.

Some general observations are apparent. It appears that these data confirm that pesticide concentrations are generally higher in carp tissue in the upper middle and upper slough as originally reported in BES and Geosyntec 2007. The upper reaches of the Slough is where agricultural use was more prevalent than in the other reaches.[18] Endosulfan is apparently higher in the lower middle slough reach. The reason for the relative elevation in middle slough carp is unknown.

[18] The Marx_Whitaker subbasin of the Whitaker Slough (easternmost portion) has high pesticide detections in sediment and fish tissue and was not included in this investigation.

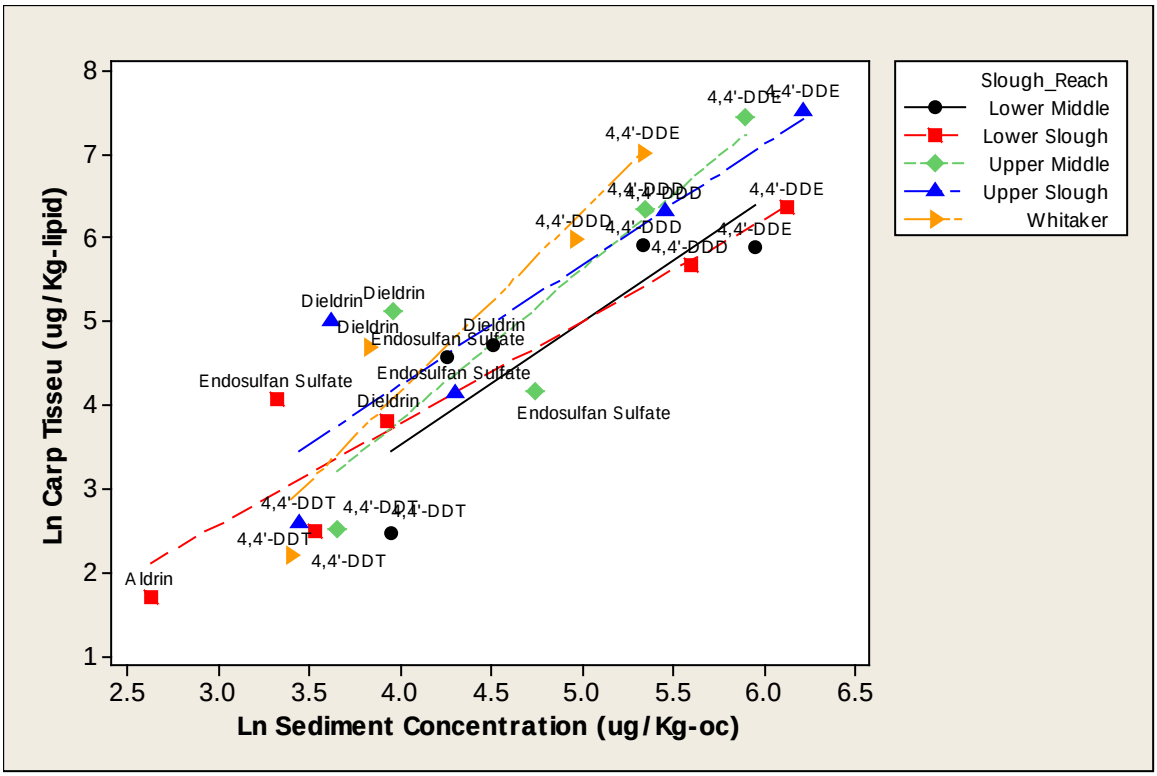


Figure 33. Scatter plot of Carp Tissue vs. Sediment

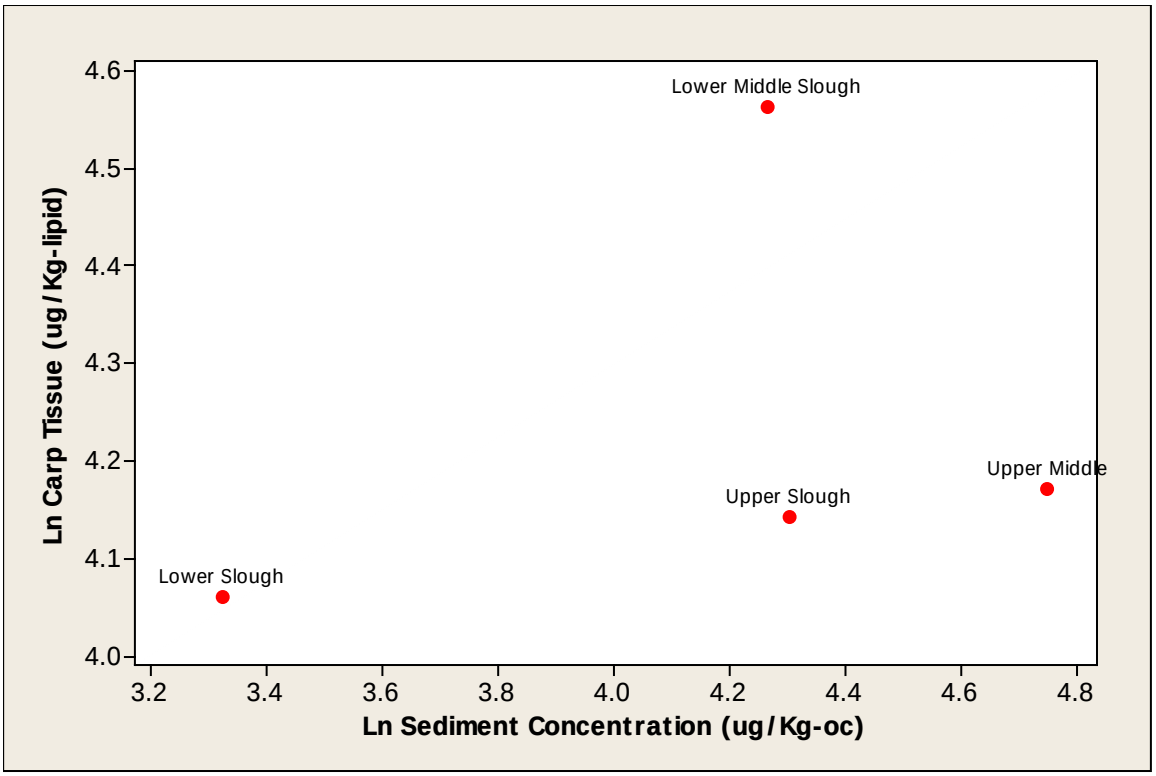


Figure 34. Endosulfan: Carp Tissue vs. Sediment Concentrations

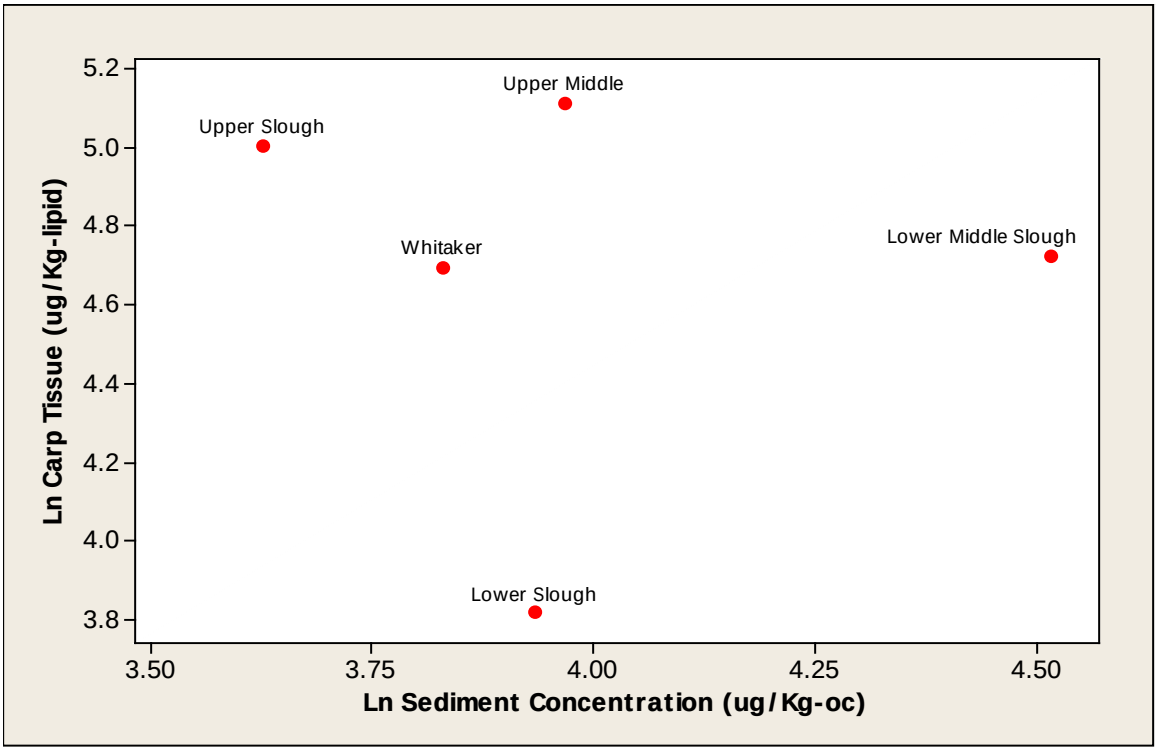


Figure 35. Dieldrin: Carp Tissue vs. Sediment Concentrations

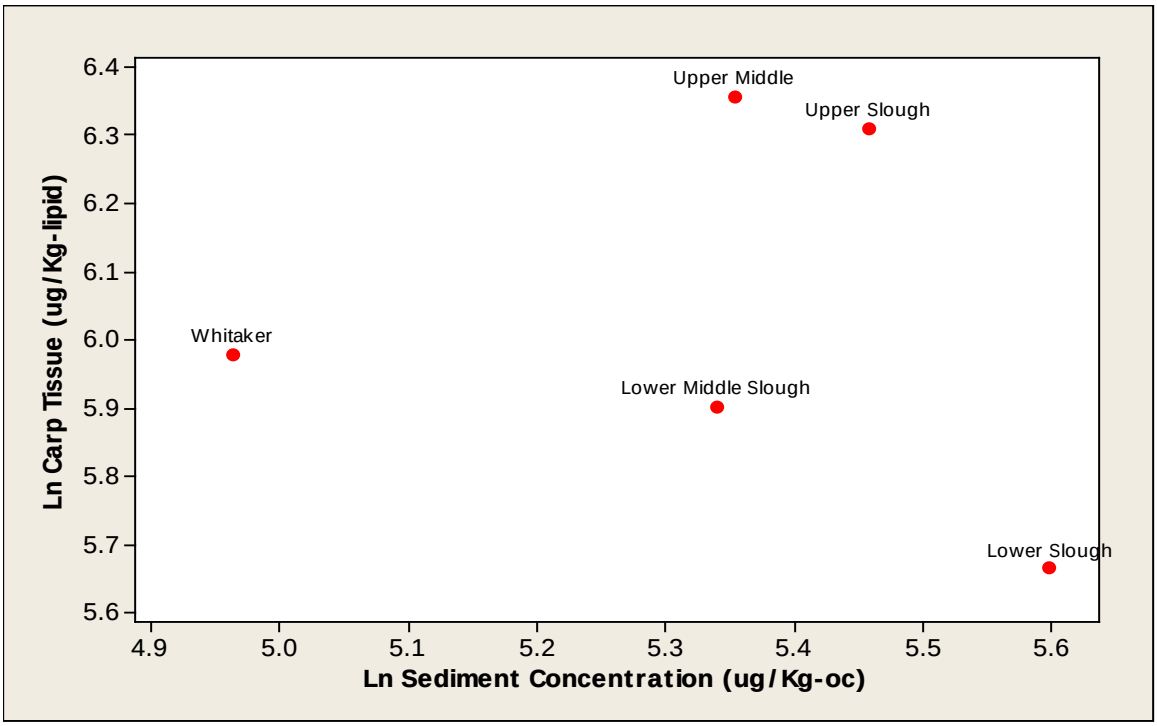


Figure 36. DDD: Carp Tissue vs. Sediment Concentrations

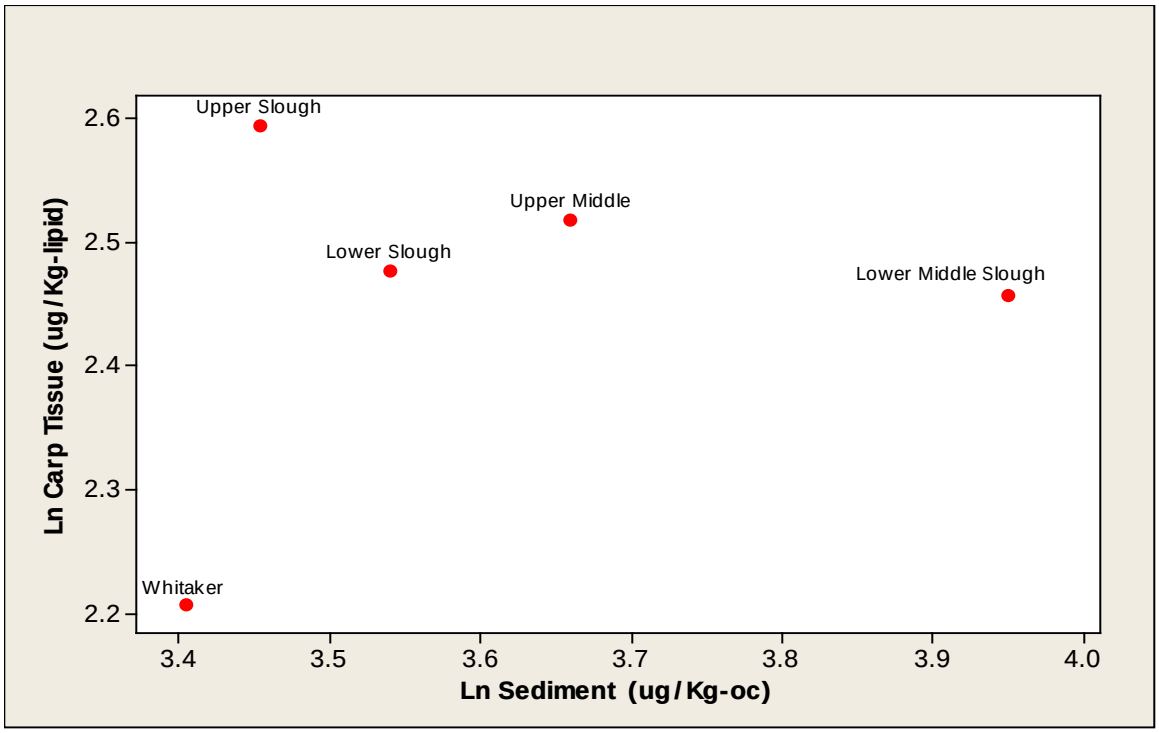


Figure 37. DDT: Carp Tissue vs. Sediment Concentrations

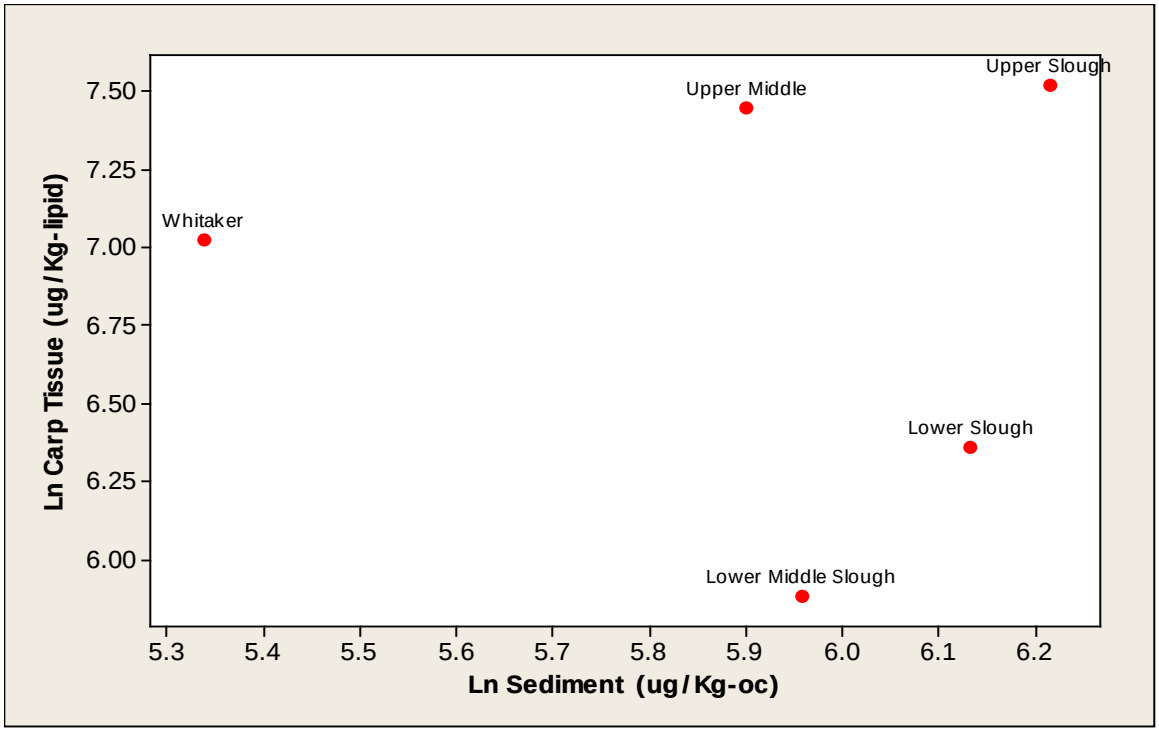


Figure 38. DDE: Carp Tissue vs. Sediment Concentrations

5.3 **Conclusions**

5.3.1 Polychlorinated Biphenyls

The regression between organic carbon normalized sediment and lipid normalized carp tissue in each of the four reaches with available PCB congener tissue data provide the following overall interpretation:

1) While the carp PCB concentrations measured by Portland BES vary by location as a function of sediment concentrations, organic carbon in sediment, lipid in tissue and apparently other unmeasured factors. The slopes generated for each reach do not differ, except for the Whitaker slough, suggesting the process of accumulation is identical in all reaches.

2) The sediment concentrations calculated for tissue levels corresponding to a one in a million cancer risk for recreational fishers vary. There is substantial uncertainty with the estimation process. These uncertainties include:
    a. Spatial relationship between available tissue and sediment samples,
    b. Normal sampling and measurement errors with various analytes,
    c. Use of the ordinary least squares (OLS) method which assumes no error in the sediment measurements,
    d. Unknown relative importance of water exposures relative to the sediment source.

    Given the overall uncertainty, and the consistency of the upper and lower middle slough estimated SLVs with DEQ's default PCB sediment screening value of 0.39 ug/kg, it is recommended that the existing 2007 default value be used throughout the Columbia Slough and elsewhere, except where there is sufficient site specific information to justify another value. It should be noted that the default SLV is itself below ambient levels in many locations, including in the Columbia Slough.

Overall, the results suggest that a reduction of total PCB concentrations (Aroclors) by approximately a factor of 100 would be required to approach risk-based levels for total PCBs, but a factor of 10 reduction might be sufficient to reach risk-based levels for the dioxin-like congeners only, excluding PCB-126. Expected concentration reductions once local sources are controlled is uncertain, but concentration reductions of 100-fold seems unlikely given existing area-wide ambient levels. However, reducing concentrations to less than 10 ug/kg dry weight might be achievable.

The mechanism by which carp (or other fish) obtain their body burden was not the subject of this investigation. If the PCB body burden is being obtained from transfer of dissolved phase PCBs across the gills or from dietary exposure to prey that are primarily exposed to dissolved phase PCBs, and the source of dissolved PCBs is not well represented by bulk sediment contamination, then reducing overall sediment contaminant mass or concentrations may not be the best measure

to estimate reductions in tissue concentrations over time. In order to quantify reductions in tissue concentrations it will likely be necessary to understand the mechanism by which the exposure to fish is occurring as well as contaminant loadings to surface water, whether occurring from desorption from sediment carbon, resuspension of particulates, stormwater sources, or atmospheric deposition and the relative importance of each of these sources. Given that current risk-based concentrations for total PCBs are below the likely ambient levels in the lower Columbia and Willamette River systems, an improved understanding of the sources of PCBs would be desirable to understand which sources may be controlled and potentially reduced over time. This issue is discussed in more detail in Section 6.0.

5.3.2 Organochlorine Pesticides

For pesticides, the data indicate greater pesticide impacts in the upper sections of the slough. However, no relation between sediment and carp tissue can be quantified. DEQ's earlier work on pesticides in sediment (DEQ 2011) is identified as a spurious result after inspection of additional data. The available information neither supports, nor contradicts DEQs existing bioaccumulation guidance with respect to organochlorine pesticides. In essence, insufficient information is available to quantify any potential relationship between sediment chemistry and fish tissue concentrations.

6.0 Source Attribution Modeling

In order to investigate if differences in sources might be inferred for the PCBs measured in this study, exploratory multivariate analysis was performed on PCB congener data from multiple sites. The use of modern chemometric methods was selected as an approach to maximize the interpretive value of available data.

6.1 **Data Preprocessing:**

The following sources of PCB data were used:

1) Lower Willamette River, collected as part of the Portland Harbor Remedial Investigation (2008-2011);
2) Ocean Research Vessel Bold, Puget Sound Investigation (2008)
3) St. Helens, Oregon data sets collected during remedial investigation (2010)
4) US ACOE, Bonneville Dam, collected during remedial Investigation (2007-2011)
5) Columbia Slough (2009-2011)
6) Local sources in the Mid-Columbia River, collected during Remedial Investigations (2011)

The PCB congener data were pre-processed according to the following Rules.

- When the result reported was for a PCB with one or more co-elutors, the reported analytical result was assigned to the first congener reported and the remaining values were set as zero or not reported. These co-eluting congeners were removed from the database leaving 80 congeners with reported values.

- Once the co-eluting congeners were removed from the database, it was necessary to develop a method to address non-detected values. Two possible general approaches can be used. In the first approach, congeners that are not detected can be removed from the database. In the second approach, the non-detected values can be estimated in a process called "imputation". The former approach has the advantage of avoiding biases or artifacts of the imputation approach, but has the disadvantage of eliminating variables from further analysis that may have some importance and improve the ability to discriminate between different types of samples. The latter approach retains these variables, but may introduce some potential biases. For this project, an intermediate approach was selected whereby infrequently detected congeners were deleted.

- Generally, if any congener was detected in fewer than 70% of samples across all media and data sets, it was excluded. Three congeners with detection frequencies below 70% were retained. These three were: PCB-118(64%), PCB-126(57%) and PCB-205(65%). Two were retained because of their significance for toxicity (PCB-118, 126), one of these two was modeled by Hope 2008 (PCB-118)[19] and the third (PCB-205) was retained for representation of the nona-substituted homologue class.

- For imputation, several options exist, but care must be used in selection of the approach given the data set to be examined. Replacing values with a mean value of a congener concentration preserves the central tendency of the observations but may distort that data with a bias towards central tendency. Other approaches use regression models to estimate values but increase observed correlations (Everitt and Hothorn 2011). There is no one best solution. For this work, the data set was separated in groups by media: sediment, water and biotic tissues, a model-based approach, as implemented in US EPA's ProUCL 4.0.0.4 software was used to estimate missing values.

After completion of all data pre-processing the final data matrix consisted of 957 samples and 80 PCB congeners. This data matrix is provided as Appendix G, Table G.1.

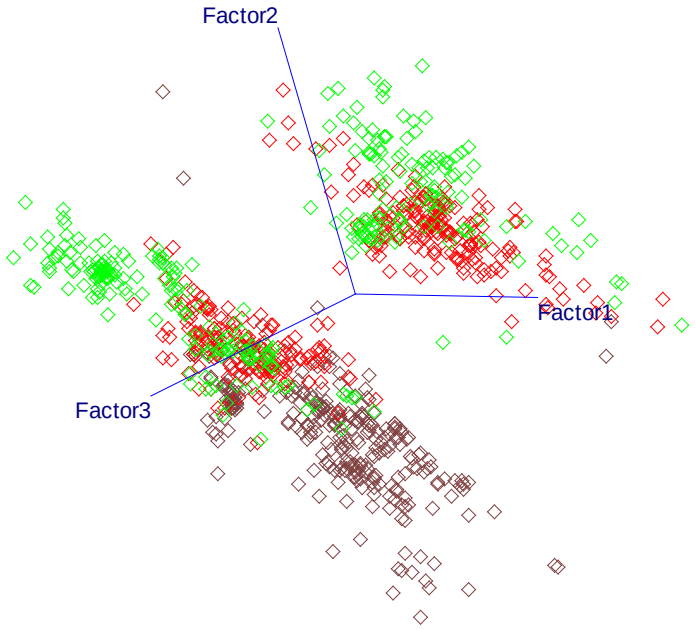
6.2 **Exploratory Analyses**

For initial analyses all media were retained. Because the congener analytical data concentrations may vary dramatically, it is necessary to put all results on a similar scale. This was done by "autoscaling" followed by log-transformation. In this process, each result has the mean

[19] Hope 2008, modeled PCB-118 as representative for PCB-126, which is rarely detected in environmental media. Hope concluded that concentration of PCB-118 measured in environmental media could be explained by global atmospheric advective transport. Therefore, PCB-118 is used here by reference as potential indicator for atmospheric sources.

concentration subtracted from it and is divided or normalized by the standard deviation. This prevents the concentration difference from dominating the interpretation, allowing any underlying patterns to be discerned. These were subsequently log-transformed and then used as input for Principle Components Analysis (PCA) and Hierarchical Cluster Analysis (HCA) for preliminary visualization of patterns in the data.

A PCA score plot is used to visualize the results in multidimensional space. Figure 39 shows a score plot[20] with all samples, color coded by matrix. The red symbols represent sediment, brown symbols are biotic tissues, and green symbols represent water samples, either stormwater or high-volume water samples. Cumulatively, the first three factors (aka, principle components) represent over 94% of the variance among all samples.



[20] Score Plot provides a visual summary of the relationship between individual samples. The original variables are PCB congener concentrations. Principle components analysis or PCA is then applied to these original variables as a dimensionality reduction method. The original variables are reduced to a smaller number of principle components, shown in Figure herein as "Factors". These factors explain the majority of the variance between samples. Because each sample is assigned a score for each of its factors, the samples can be plotted according to their factor scores.

Figure 39. PCB Congener Samples plotted in 3-Dimensional Factor Space

Green=water; Red=Sediment; Brown=tissue

Figure 39 reveals two features of the overall data set. First, the samples appear to aggregate to two major domains or regions of the plot. Second, the tissue samples in brown appear to be generally distinct from all other samples. This is likely attributable to preferential uptake of relatively more bioavailable congeners, and metabolism, resulting in a more homogenous congener profile among tissue samples relative to the sediment and water samples.[21] The sediment and water samples are relatively more intermixed and exist in both regions of the plot where samples tend to cluster. Because of the apparent distinction among matrices, subsequent analyses are focused on the same matrices to simplify interpretation.

6.2.1 Exploratory Analysis: Sediment

The same process of data transformation and visualization was repeated on the sediment matrix alone with a data set of 365 samples. A high degree of correlation was observed between PCB congeners. This correlation is often observed in what is termed "compositional" data when the measurements are a portion of some larger total, as is the case with PCBs. In this instance, there are additional transformations that can be used to "open" the data, reducing the correlation, and improving the ability to discriminate differences between samples. In this case, the additive log ratio method was used to open the data set before PCA analysis was performed (Aitchison 1986). The result was an improved separation over autoscaling and log-transformation alone with reduced correlation among the congeners. The score plot created from this transformation in sediment is shown in Figure 40. The color-codings are created from an HCA analysis in which similar samples were given the same color.

In this view, two separate domains are clearly indicated, as presented in Figure 40. The bolded pink samples on the left side of the plot are the Columbia Slough samples. Other samples on this side of the plot, and therefore more similar to the Columba Slough in gray and green, are mid-Columbia River samples, generally taken in the vicinity of Cascade Locks, Oregon. The red color samples and some of the green symbols below the Slough samples are taken from Puget Sound as part of the 2008 OSV Bold survey in Puget Sound[22].

The right side of the plot contains samples taken almost exclusively from the Willamette River in the Portland Harbor. The samples bolded in Blue are the upriver samples taken with the intent to represent upriver background or ambient conditions. One interpretation for this exploratory work appears to be that there is some geographic distinctiveness to the PCB congener profiles in

[21] Differences in homologue classes between matrices was not tested, but could be further considered to assess which congeners are relatively more important from a bioaccumulation standpoint and whether the source in water or sediment is likely to be most significant for loadings to tissue.

[22] http://www.epa.gov'pugetsound/bold.html

sediment samples taken from different areas. In this case, samples from Puget Sound can be differentiated from those in the Lower Willamette and samples from the lower Willamette River are different from the Columbia Slough and Columbia Rivers. Puget Sound Samples are marine samples, but do bear some general similarity in terms of PCB composition to the Columbia River and Slough samples. In general, samples plotting toward the top of the plot tend to be influenced by lower molecular weight and less chlorinated congeners.

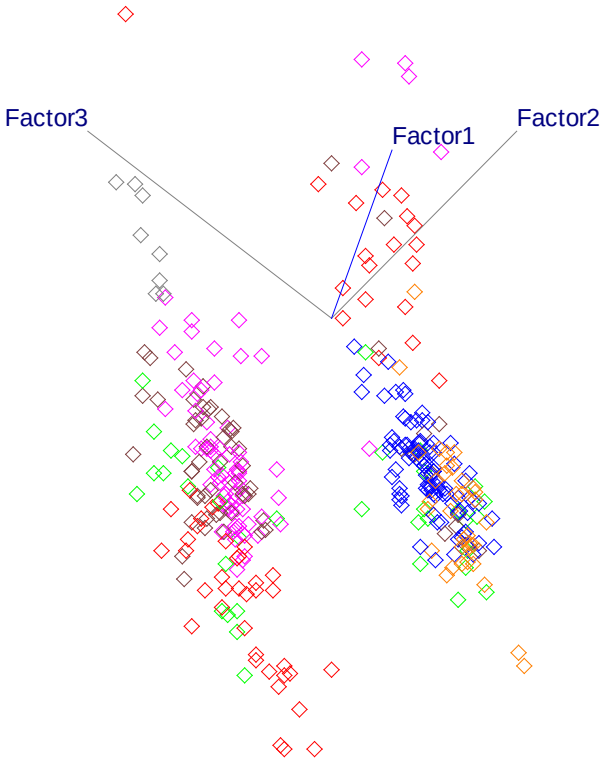


Figure 40. Sediment Samples Alone

Left Cluster: Columbia Slough/Columbia River Samples: Bolded=Columbia Slough samples; Gray & Green=Columbia River samples; Red=Puget Sound samples.
Right Cluster: All Lower Willamette River Samples; Bolded Blue=upriver (Willamette) samples. Orange are further downriver, affected by urban sources.

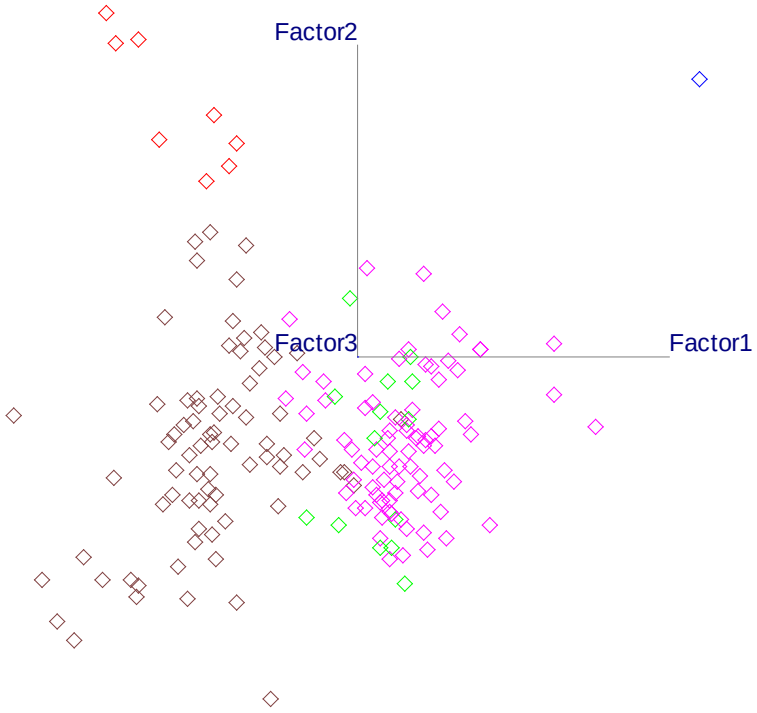


Figure 41. Sediment Samples, Willamette River excluded

Pink: Columbia Slough; Gray & Green=Columbia River; Red=Puget Sound

6.3 **Receptor Modeling**

In order to make inferences about potential sources of PCBs in Columbia River and Columbia Slough sediments, an unmixing algorithm was applied to the available sediment data. This approach attempts to address the complex mixture of PCB congeners in sediment and "unmix" them to derive an estimate of the profile of the original PCB released. If inferences can be made about the source of those releases, then it may assist in developing effective strategies to reduce concentrations. The general process is described in detail elsewhere (Murphy and Morrison 2007; Magar et. al. 2005; Jarman et. al. 1997; Johnson et. al. 2000).

In this work the alternating least squares (ALS) algorithm was used as implemented in Pirouette® (Infometrix, Bothell, WA, USA) chemometric software. In order to successfully obtain profiles using ALS it was necessary to modify the data transformation. Instead of using the additive log ratio, the data were transformed with a simple ratio using congener PCB-66, but not subsequently log-transformed.

6.3.1 Source Profiles

Figures 42-45 present the profiles from a 4-source ALS solution and show the relative abundance of the congeners shown in each of the four profiles. Discussion of the interpretation of each profile is also presented. The x-axis is organized from left to right by PCB congener number and the y axis is the relative abundance of each congener in this specific source profile.

Profile Number 1

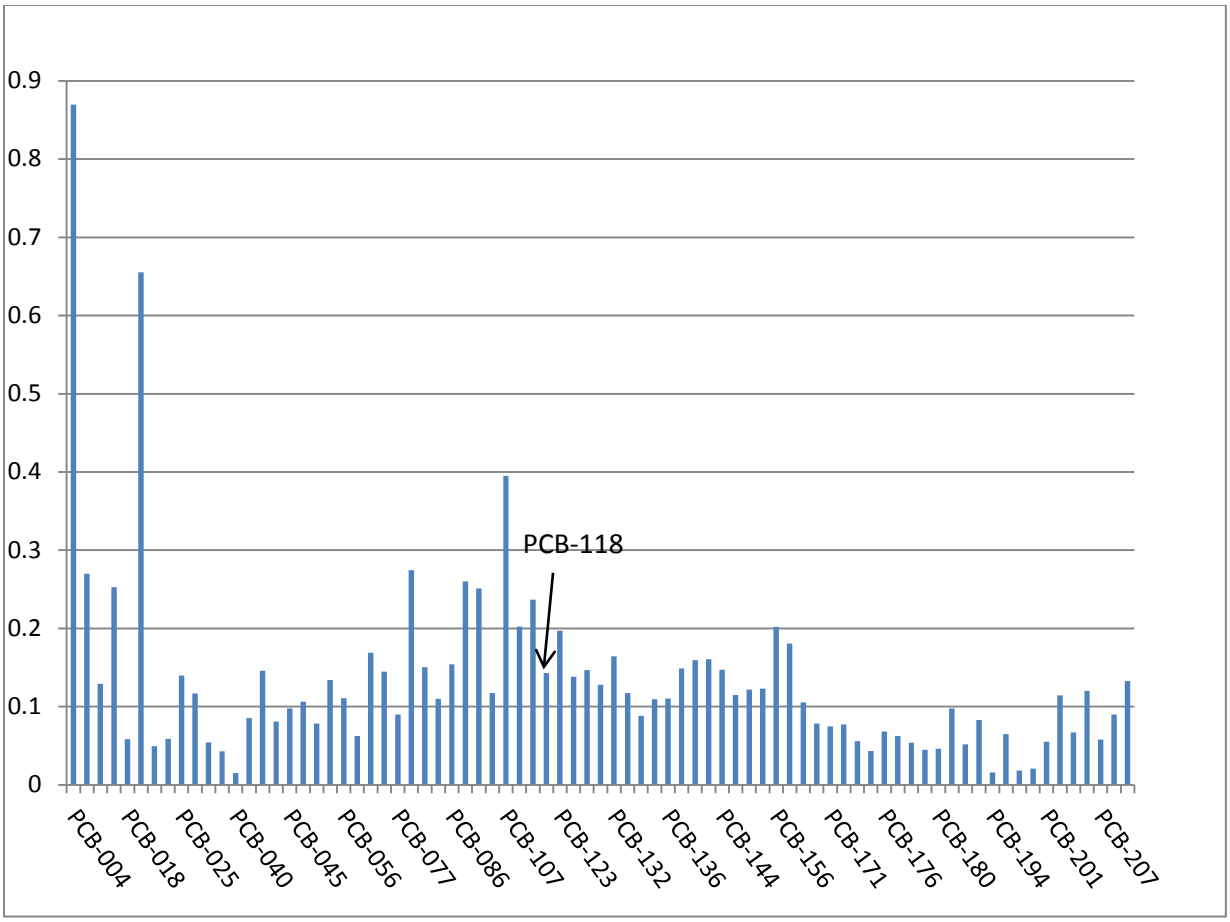


Figure 42. PCB Congener Source Profile #1

Profile number 1 shows a high abundance of the relatively low molecular weight congeners in the range between PCB-4 and PCB-18. These congeners are the di-substituted homologues and are more volatile, relative to the higher molecular weight, more highly chlorinated congeners. It has been reported that PCB-11 is associated with atmospheric deposition (Hu et al. 2008, Du et al. 2009). PCB-11 was not included in this run, but the apparent abundance other related congeners suggest that this could be associated with atmospheric sources. Moreover, this profile contains a significant component or hump in the range of the tetra through hexa-substituted congeners, including PCB-118. PCB-118 was modeled by Hope 2008 who concluded that atmospheric advective transport alone could explain the concentrations of PCB-118 observed area-wide in the Willamette Basin. The “mid-range” congeners may be more resistant to photo-

oxidation making them susceptible to atmospheric transport. It is also interesting to note that PCB-118 is a major contributor to the TEQ risk identified in carp and sediment detected in Columbia Slough carp and sediment samples, although profile 1 was a minor proportion of the total PCBs in slough sediment samples (see Table 11). Profile 1 was a minor component of most samples, typically less than 5% and often negligible in the urban sediment samples. However, in some rural samples away from any known or suspected sources, it comprised a major proportion although absolute concentrations were low (< 3 ug/kg dry). One Columbia River sample which was estimated to be entirely from this profile had a total PCB concentration (as a sum of the congeners) of approximately 3 ug/kg.

Profile Number 2

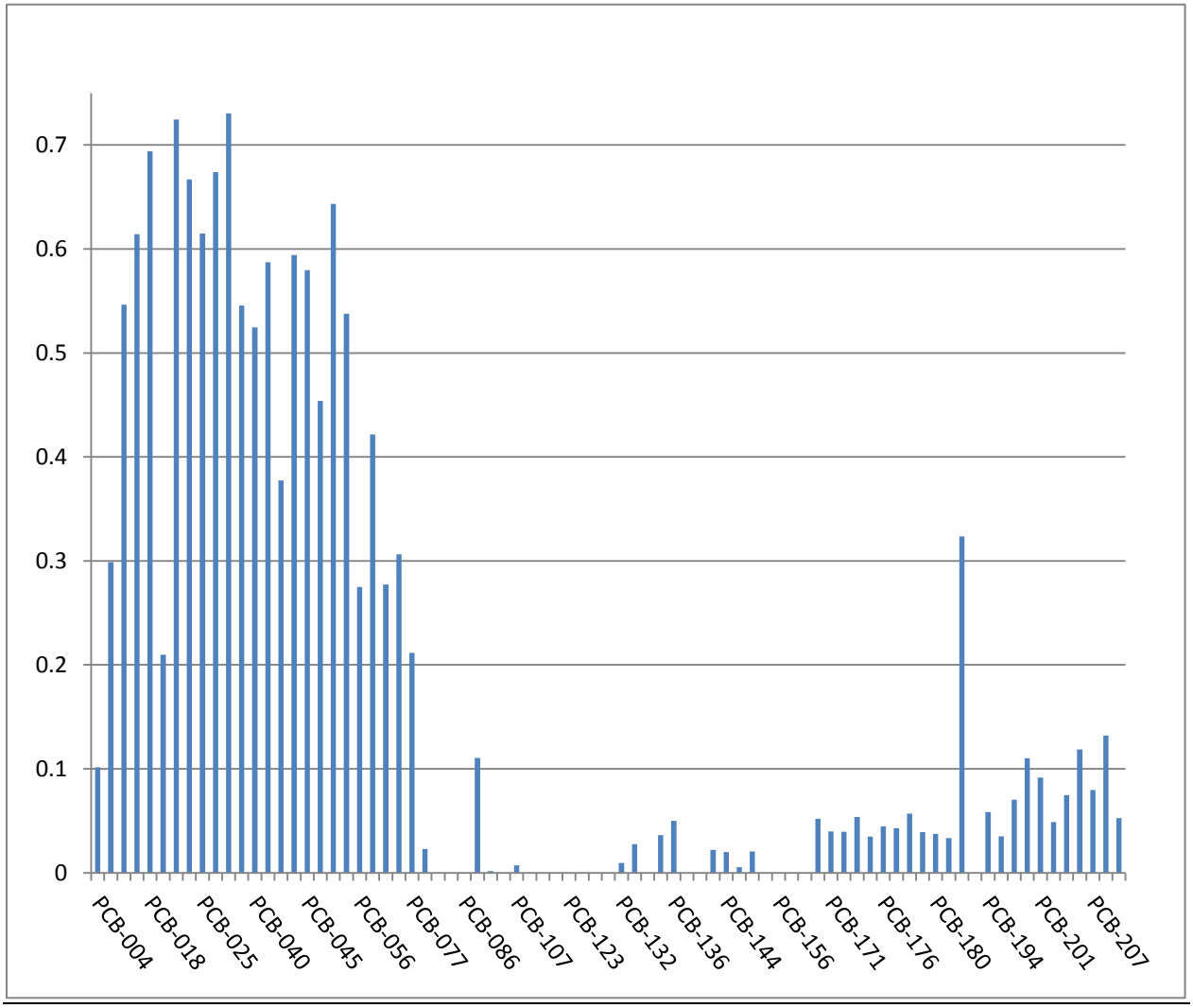


Figure 43. PCB Congener Source Profile #2

Profile number 2 shows a high abundance of congeners in the range between PCB-18 and PCB-77. Few intermediate range congeners and a component of higher molecular weight congeners are present. These are the tri and tetra-substituted congeners. The samples associated with this profile included some Puget Sound sediment and some Columbia River sediments. It is posited that this profile appears to reflect lower chlorinated sources such as Aroclor 1248 or Aroclor 1242.

Profile Number 3

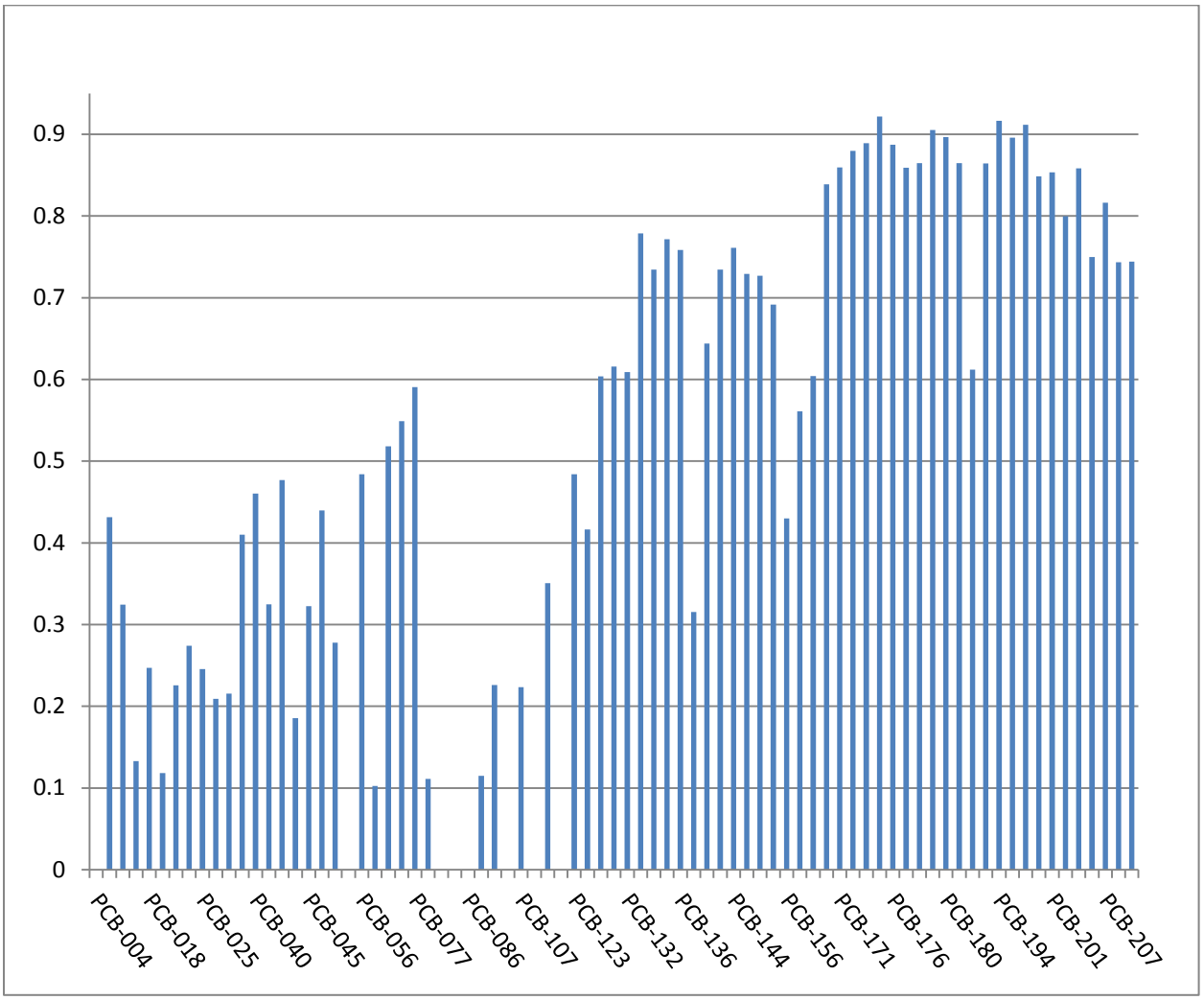


Figure 44. PCB Congener Source Profile #3

Profile 3 is dissimilar from any original Aroclor source and is abundant in high-molecular weight hexa- through nona-substituted congeners that are resistant to biodegradation, volatilization, or other weathering mechanisms. It has low abundance in the congeners that are more susceptible to weathering. The samples that had a high proportion of this profiles included the Whitaker slough, which is known to have been affected by a remediated release of Aroclor 1260 (former Wagner Mining site, ECSI #331); and samples in the Columbia River away from any known

source, but in the general vicinity of former industrial activities. Based on the foregoing, profile 3 is interpreted as a highly weathered PCB, generally associated with residual contamination.

Profile Number 4

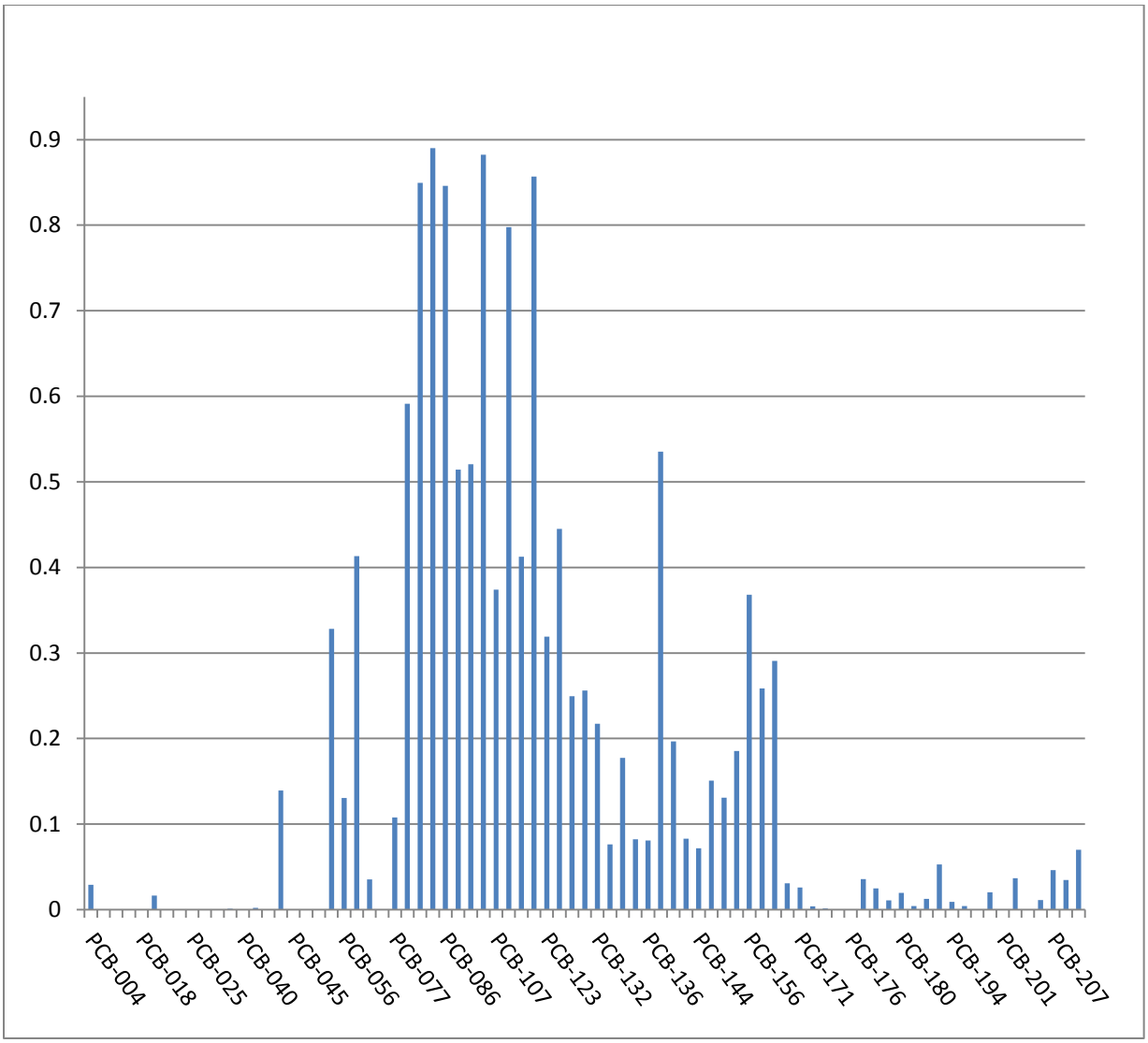


Figure 45. PCB Congener Source Profile #4

Profile 4 has a high relative abundance of congeners between PCB-80 through PCB-170. It is generally similar to the profile expected for Aroclor 1254. The samples that were characterized as a high proportion of this profile were collected near of known discharge of electrical equipment into the Columbia River, where the transformer oil had been characterized as an Aroclor 1254.

6.3.2 Proportions of Source Profiles in Columbia Slough Samples

One of the features of the receptor modeling approach is the ability to estimate the relative proportion of each profile identified in sediment to the total amount of PCB measured in each

sample. Table 11 presents the estimated proportions of the 4 identified profiles in the Columbia Slough Samples for each reach evaluated.

Table 9: Proportions of Source Profiles in Columbia Slough Samples

	Proportion in Source Profile			
Slough Segment	**Profile 1**	**Profile 2**	**Profile 3**	**Profile 4**
Lower Slough A	0%	30%	27%	43%
Lower Slough B	0%	31%	28%	41%
Lower Slough C	0%	38%	26%	36%
UMCS-A	0%	42%	20%	38%
UMCS-B	1%	26%	16%	56%
UMCS-C	1%	26%	27%	46%
Whitaker Slough A	0%	24%	58%	18%
Whitaker Slough B	0%	11%	30%	59%
Whitaker Slough C	0%	34%	50%	15%
LMCS-A	0%	16%	26%	57%
LMCS-B	0%	24%	34%	42%
LMCS-C	1%	26%	12%	62%
UCS-A	0%	52%	21%	27%
UCS-B	0%	43%	27%	30%
UCS-C	0%	40%	28%	32%

6.4 **Receptor Modeling Conclusions**

Four distinct profiles of PCB congeners were identified in regional sediments collected from the Columbia Slough, and Columbia River. It should be noted that the Lower Willamette River samples were excluded from this analysis because they appeared to be distinctly different (as shown in Figure 40) and our focus was on the Columbia Slough. However, this analysis could be performed separately for the Lower Willamette sediments as a group, as means to verify whether these same profiles exist in other regional sediments.

If the four profiles identified, their interpretations, and the relative proportions are valid, the evaluation suggests that two major profiles associated with releases may potentially be controlled (Profile 2 and Profile 4) or remediated as they may be associated with more localized contamination areas or stormwater inputs. These two profiles comprise between 42% and 87% of the total PCB burden found on sediment samples during this investigation. The general similarity in abundance between these two profiles is similar to Basu et al. 2009 who reported an approximate 1:1 ratio between Aroclor 1242 and Aroclor 1254 in air sampling near the Great Lakes. Sources of the more weathered contamination reflected by profile 3 may be addressed over the long-term through watershed-wide source control efforts and natural recovery mechanisms in the sediment.

As described in Section 5.1.4, a 90% reduction in concentrations would apparently be required to reduce TEQ risks to acceptable levels; however a 90% reduction would not be sufficient to reduce total PCB[23] risk to the statutory acceptable level of one in a million excess cancer risk in the lower slough (ORS 465.315). Given the apparent ubiquitous nature of PCBs which were or are present in many consumer products produced before the ban on PCB production and as recently as 2008 (Rodenburg et. al., 2010; Fraser 2010, Hu and Hornbuckle 2010) and the episodic recirculation of PCBs in the urban environment, PCBs will likely continue to be detected in the environment for decades to come.

More work is needed to determine the full congener profile in fish tissue and the sources contributing to fish body burdens is needed to improve our understanding of the causes of PCB bioaccumulation and associated risks.

7.0 CONCLUSIONS

Sampling of sediments was effective in determining reliable average concentrations of PCBs and pesticides throughout the Columbia Slough system.

Pesticide concentrations in the upper slough tend to have higher concentrations and the Fairview Lake outlet location appears to have relatively higher bioaccumulation potential, based on *Lumbriculus* assays, however no apparent relation between sediment and carp tissue could be quantified for pesticides. The pesticides which are of relatively greater concern for bioaccumulation potential in the Columbia Slough are the DDT metabolites (DDD and DDE) aldrin, dieldrin and occasionally endosulfan and chlordane.

It does appear possible to relate PCB concentrations in sediment to carp tissue or possibly surface water (SPMD concentrations). Development of sediment goals that are generally consistent with fish tissue comparisons to acceptable tissue levels (ATLs) is possible using this approach. However, the more highly chlorinated PCBs found in sediment may not be bioavailable and potentially may not contributing significantly to fish tissue burdens. Sources other than sediment may be acting to load fish tissue, although this could not be evaluated in this investigation.

Bioaccumulation assays confirm that the accumulation of PCBs into invertebrate worms occurs as expected, and the accumulation of individual PCB congeners is highly variable depending on the specific properties of the individual congeners, with the lower molecular weight, more soluble congeners showing relatively greater bioaccumulation potential. PCB congener patterns

[23] As discussed in Section 5.1.4. The proportion of total PCB risk that may be attributable to PCB-126 (or PCB-169) is unclear due to the inability to reliably detect these congeners in sediment and fish tissue.

in biota tissue vary substantially from patterns observed in sediment. This has bearing on risk potential, since congeners vary considerably with respect to relative toxic potency.

Generally, it appears that the relation between sediment and surface water is strongest in the lower slough where PCB levels are highest and lowest in the upper slough where PCB levels are very low. Overall, the correlations between sediment and surface water are weak, suggesting something other than sediment as a reservoir of PCBs is loading to the overlying surface water, and this may vary by homologue classes (i.e., degree of chlorination). This source is unknown, but could include stormwater runoff and a possibly a very small fraction of regional atmospheric deposition.

Overall, a reduction of total PCB sediment concentrations (Aroclor) by approximately a factor of 100 would be required to approach risk-based levels for total PCBs in fish tissue, but a factor of 10 reduction might be sufficient to reach risk-based fish tissue levels for the dioxin-like congeners only. Given the ubiquitous nature of PCBs, which were and apparently are present in many consumer products and the episodic recirculation of PCBs in the urban environment it appears that achieving Oregon's current risk-based criterion of 0.39 ug/kg poses significant challenges.

Regionally available data was recombined with data collected in this investigation to evaluate PCB congener patterns in sediment. After exploratory analysis, the scope of work was narrowed to Columbia River and Slough samples, and receptor modeling methods applied to unmix original sources to sediment. Four different profiles were identified as historic sources to regional sediments. These four sources are hypothesized to represent a lower and more highly chlorinated Aroclor, a weathered ambient and a possible atmospheric source. The specific sources of the Aroclors are unknown but may include local point sources and stormwater. The finding of two types of Aroclor mixtures is consistent with other reports in the literature.

Efforts to identify the sources and release mechanisms (e.g., stormwater, local point sources) could potentially be effective in significantly reducing PCB concentrations in the environment and reducing contaminant body burdens in fish and the birds, mammals and people that eat them. Additional work to identify the most important sources causing loading to fish body burdens (i.e. sediment or dissolved phase in water) and the congener-specific partitioning into tissue is recommended to prioritize sources and identify the most effective contaminant control strategies.

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9.0 STATISTICAL GLOSSARY

Alternating Least Squares (ALS): A mixture analysis algorithm. It is based on the same mathematical approach as ordinary least squares (OLS) but is an iteratively solved optimization routine. It is one of a class of unmixing algorithms that may be used to resolve complex mixtures and estimate the composition of original sources.

Analysis of Variance (AOV): A model in which the observed variance in a particular variable ((e.g., fish tissue concentration) is partitioned into components attributable to different sources of variation (e.g., sediment concentration or slough reach). It can be used to test the significance of each of the model components.

Correlation: Refers to statistical dependence between two variables or measurements on the same object. For example, sediment and pore-water collected at the same location and time might be expected to show such a dependent relationship, possibly allowing prediction of one from the other.

Correlation Coefficient: This is a number that measures the strength of any correlation. They come in several varieties which include Pearson's R, Spearman's Rho, and Kendall's tau. The different coefficients vary based on the assumptions which underlie them and one may be preferred over another in different circumstances. Pearson's R and Spearman's Rho are on the same scale and 0.15 to 0.2 should be added to Kendall's Tau to put on an equivalent scale. When data are linear and three coefficients will agree.

Degrees of Freedom (DF): This is the number of values in the final calculation of a statistic that are free to vary. When estimating parameter values in general linear model (such as regression or ANOVA), adding variables used in model means fewer observations are free to vary. The term is defined by vector geometry.

Distribution or distributed: A probability distribution assigns a probability to each of the possible outcomes of a random observation. These distributions may take a variety of forms. The most commonly used in environmental sciences are normal and students t-distributions, and the log-normal distribution, which is commonly used to model positively skewed data with few relatively high observations that commonly occur with environmental contaminants.

F statistic: A commonly used statistic. A common use is to test for equivalence in two variances, as in the analysis of variance (ANOVA).

Hierarchical cluster analysis (HCA): A multivariate procedure for assigning objects (such as samples) into groups. A variety of methods are possible. Hierarchical cluster analysis is an agglomerative technique, that starts with each object in a separate cluster and combines the clusters sequentially until only one cluster is left. Various measurements may be used top create the groups, such as chemical concentrations.

Incremental Sampling (IS): This could be considered as type of composite sampling with very specific requirements to control sampling errors that would otherwise be introduced by spatial and particles size heterogeneties. It reduces variability in analytical results and improves reproducibility in replicate samples measuring the same sampled unit.

Kendalls Tau: A type of nonparametric correlation coefficient.

Line of Organic Correlation (LOC): An alternative to ordinary least squares regression. It has the advantage of predicting data that collectively have the same variance as the original data, and results in the same equation regardless of which variable are plotted on horizontal or vertical axes. It accounts for measurement error in data on both axes, unlike OLS regression.

Major Axis Regression: This is the same as the principle component line through a bivariate (or multivariate) data set. It seeks to minimize the variance of residuals in all directions.

Mean Sum of Squares: This a measure of error associated with a parameter estimate and is derived the by subtracting the residual of each observation from the parameter estimate taking square and summing the results.

Ordinary Least Square (OLS): This is the most common method used is a method for estimating the unknown parameters in a linear regression model. This method minimizes the sum of squared vertical distances between the observed values on the vertical axis and the responses predicted by the linear approximation. It does not account for variation on the horizontal of x-axis. It relies on assumptions of normally distributed data and no interaction or co-linearity among predictor (horizontal axis) variables.

P-value: This is statistic used to illustrate significance findings in many statistical tests. It may be thought of as a probability value, or estimate of the probability that a result would occur by chance alone.

Pearson's R: A type of parametric correlation coefficient. It is commonly used. It relies on assumption of normally distributed data.

Principle components analysis (PCA): A mathematical decomposition procedure that converts a set of measurements (such as PCB congener concentrations) into a smaller set of uncorrelated factors called principal components. The number of principal components is less than or equal to the number of original variables. The first principal component has the largest possible variance and each succeeding component in turn has the highest variance possible to (i.e., uncorrelated with) the preceding components.

Probability: This a number expressing the likelihood of the occurrence of some event by chance.

R2: R squared: This is the coefficient of determination, which is used in regression analysis to explain how much variation is explained by the model and how much remains unexplained.

Regression: Regression is a type statistical analysis assessing the association between two or more variables. It is used to find a quantitative relationship between two variables and can be used for prediction. There are multiple types of regression.

Spearman's Rho: A type of nonparametric correlation coefficient.

Transformation: To change to a variable by one or more of many possible operations, intended to achieve some desirable property that will allow further subsequent analysis. Common transformations include adding or subtracting a constant to the variable, multiplying pr dividing the variable by a constant or taking a logarithm.