PRELIMINARY ASSESSMENT OF POLYCHLORINATED BIPHENYL (PCBs) CONGENERS, AROCLORS, DIOXINS, AND FURANS IN THE SEDIMENT AND SOIL AT THE UNITED STATES DEPARTMENT OF ENERGY (DOE) PORTSMOUTH GASEOUS DIFFUSION PLANT (PORTS), PIKETON, OHIO

Jennifer Bowman, Dina Lopez, Natalie Kruse and Elizabeth Migliore

Sponsored by Ohio University's PORTSfuture Project

The PORTSfuture project is funded by a grant from the U.S. Department of Energy Office of Environmental Management Portsmouth/Paducah Project Office

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Table of Contents

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Persistent organic pollutants (POPs) are toxic chemicals that adversely affect the health of humans and animals. They are transported easily by air and water and, therefore, disperse widely from their sources. They do not readily breakdown in nature, so they continue to exist in the environment and bio-accumulate along the food chain. Under the United Nations Global Stockholm Convention Treaty of May 2001, 12 chemicals were declared the ‘dirty dozen’. The countries involved decided to reduce or eliminate the use of these 12 POPs. Polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (dioxins), and polychlorinated dibenzofurans (furans) are included in this list (USEPA, 2009a). PCBs have been identified in previous studies at the United States (US) Department of Energy’s Portsmouth Gaseous Diffusion Plant (PORTS) and some remediation methods have been applied to solve the problem. Ohio University (OU) was commissioned to make a new investigation of the site to determine if PCBs, dioxins and furans are present in the sediment and if so, what is the fate, degradation and/or transformation of these chemicals in the environment at PORTS. This investigation was carried out during 2011 and 2012 by Ohio University. The study consists of two projects: ‘Expedited Field Survey and Sampling Techniques for Polychlorinated Biphenyl (PCB) Congeners and Dioxins’ and ‘Graphical Information System (GIS) Mapping of PCB Congeners and Dioxins in Sediments and Soils: Preliminary Assessment of Sediments on the PORTS Site’. This report covers the second project; the first project is presented in a separate report.

1.1 Location

The Portsmouth Gaseous Diffusion Plant (PORTS) facility is located in Pike County, near Piketon Ohio. The location of the approximate centroid of the PORTS facilities is 39.0087°N and -83.0004°W. The facility is approximately 70 miles south of Columbus, Ohio, and 21 miles north of Portsmouth, Ohio (Figure 1.1). Based on meteorological data collected from 1981-2010 in Waverly, Ohio, at NOAA station ID: USC00338830 (39.111°N, -82.980°W), annual average temperatures range from 20.3°F to 86.3°F with annual average temperature of 53.3°F and annual average precipitation at 40.56 inches (NOAA, 2010).

Figure 1.1 Location of PORTS in Ohio

1.2 Purpose of study

The purpose of the expedited PCB field survey and preliminary assessment study is for Ohio University researchers to develop an expedited field survey method and sampling technique for measuring PCB congeners and dioxins in sediment and soil (Part 1- separate report). Part 2 is to conduct a preliminary assessment of PCB congeners, dioxins, and furans presence and fate, including geochemical transformation (i.e., aging or weathering), in sediments and soil at the PORTS site. For this study, sample locations were chosen based on previous data and history of PCB use. The X-533A Switchyard, holding ponds X-230J6 and X-230L, and Little Beaver Creek (Figure 1.2), were chosen as a test bed for the expedited survey and sampling techniques. The two parts of this study are designed to complement each other, such that the soil and sediment samples collected served two purposes.

A 3.1 mile-long section of Little Beaver Creek was investigated in this study. Fifteen sample sites were identified along Little Beaver Creek, its tributaries, X-533A Switchyard's drainage ditches, and holding ponds X-230J6 and X-230L (Figure 1.2).

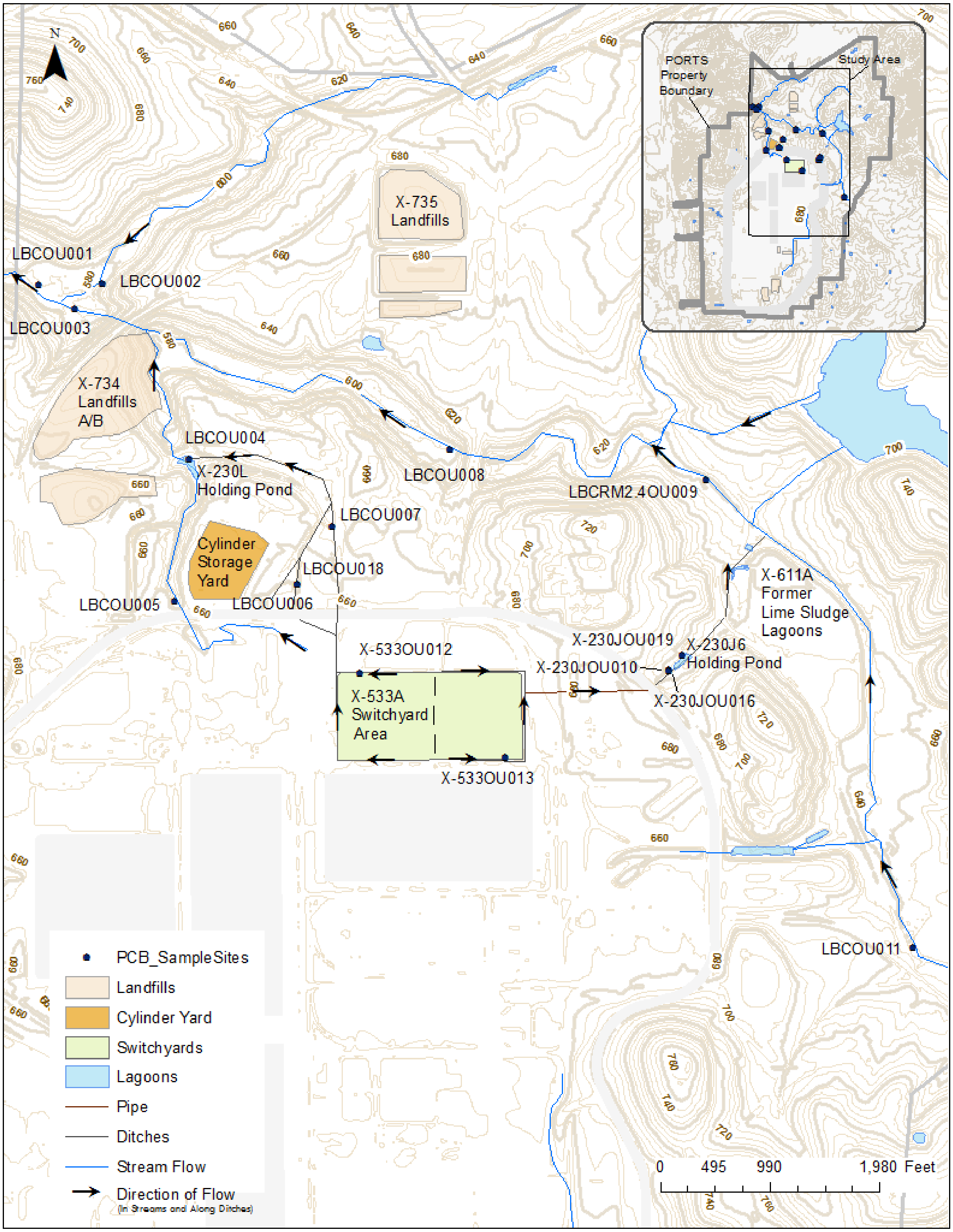

Figure 1.2 Map of the PORTS PCB study area

2. BACKGROUND

PCBs are manmade chemicals that have been in existence since 1929. PCBs were used widely in industrial and commercial applications due to their chemical properties, including non-flammability, chemical stability, resistance to acids and bases, high boiling point, and electrical insulating properties. However these same qualities also cause PCBs to be stable and persistent in the environment. Manufacturing of PCBs stopped in 1977 and their use was banned in the United States in 1979, due to adverse health effects in humans and animals affecting their immune, reproductive, nervous, and endocrine systems (USEPA, 2012). By the time production stopped in 1977 it is estimated that 1.25 billion pounds of PCBS were sold by U.S. industries (USEPA, 1993). PCB waste is regulated under the *Toxic Substances Control Act* (TSCA) of 1976 (40 CFR 761).

While seemingly a useful chemical, it was discovered that PCBs are a major environmental pollutant. According to Kakareka and Kukharchyk (2005), “PCBs in electrical equipment are potentially the greatest source of environmental pollution by PCBs due to leaks from operating installations, installations at storage or disposal and they are considered as a priority source of environment pollution by PCBs in several emission inventories.”

Section 3.0 summarizes environmental investigation and reports DOE and Ohio Environmental Protection Agency (OEPA) have conducted in Little Beaver Creek on multiple occasions over the past twenty years, which are directly related to this study. At PORTS, a more recent investigation into the sources of PCB contamination in Little Beaver Creek conducted by the DOE in 2007 discovered PCBs present in the X-533A Switchyard within the top foot of sediment beside transformers and a drainage line. Transformer oil leaks and spills in this switchyard were discovered to contain PCBs through analysis of surface wipes. Discharges from the X-533A Switchyard and its drainage ditches provided a continual source of PCBs into Little Beaver Creek. Upon this finding, soils contaminated with PCBs in three hot-spots were removed from the X-533A Switchyard in 2010 as part of the Resource Conservation and Recovery Act (RCRA) Corrective Action Investigation (DOE, 2011a). However, with these past releases into the environment coupled with the persistence of dioxin-like compounds, the potential exists for ‘sinks/reservoirs’ within the environment (i.e. holding ponds, soft sediment along streams, biota, etc.) to be a source of PCBs for years into the future.

2.1 Polychlorinated Biphenyls (PCBs)

PCBs are a class of chlorinated chemical compounds formed by two benzene rings linked by a single carbon-carbon bond. There are various degrees of substitution of chlorine atoms for hydrogen around the biphenyl structure. On the biphenyl structure there are 209 possible arrangements of chlorine atoms, called congeners (USEPA, 2011b). PCB congeners vary in their chemical and physical properties, depending on the degree and position of chlorination (USEPA, 2011b). In general, PCB compounds are oily liquids characterized as stable, relatively insoluble and having the ability to sorb strongly to organic matter (USEPA, 1980). Lighter PCBs (mono-, di-, and tri-chlorinated) tend to volatize from the soil, leaving the heavier compounds in the soil (Winters, 2003). As the chlorine content and molecular weight increases, the solubility of the compound decreases and the mixture becomes more viscous. In addition, PCBs are lipophilic and bioaccumulate in fish tissue (USEPA, 1980).

Considering only the number of chlorine atoms in the chemical structure, there are ten PCB homologues. This is the term used to describe all PCBs with the same number of chlorine molecules (e.g. monochlorobiphenyls contain one chlorine molecule while Octachlorobiphenyls contain eight chlorines). Isomers refer to homologues with different substitution patterns. For example, Heptachlorobiphenyl homologue contains 24 isomers all with a molecular weight of 395.3 (Table 2.1) (Kakareka and Kukharchyk, 2005).

Table 2.1 PCBs physical properties (Kakareka and Kukharchyk, 2005)

Homologue	**Molecular formula**	**Molecular weight**	**Number of isomer**
Monochlorobiphenyls	$C_{12}H_9Cl$	189.0	3
Dichlorobiphenyls	$C_{12}H_8Cl_2$	233.1	12
Trichlorobiphenyls	$C_{12}H_7Cl_3$	257.5	24
Tetrachlorobiphenyls	$C_{12}H_6Cl_4$	292	42
Pentachlorobiphenyls	$C_{12}H_5Cl_5$	326	46
Hexachlorobiphenyls	$C_{12}H_4Cl_6$	361	42
Heptachlorobiphenyl	$C_{12}H_3Cl_7$	395.3	24
Octachlorobiphenyls	$C_{12}H_2Cl_8$	430.0	12
Nonachlorbiphenyls	$C_{12}HCl_9$	464.2	3
Decachlorbiphenyls	$C_{12}Cl_{10}$	498.6	1

The amount and placement of chlorine molecules attached to the biphenyl affect the toxicity of individual PCBs. Twelve PCBs have been identified as “dioxin-like” with relative toxicities 100–1000 times higher than other PCB congeners. The dioxin-like PCBs have toxic equivalency factors (TEFs) similarly to dioxins and furans (Kakareka and Kukharchyk, 2005) (Table 2.2). Dioxin-like PCBs are known to have toxic responses but to a lesser degree like those caused by 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD); the most toxic dioxin compound. For example, PCB118 has a TEF value of 0.00003 making it about 30,000 times less toxic than TCDD (Table 2.2) (WHO, 2005). These compounds affect development in the immune, nervous and reproductive systems while also causing endocrine effects and chloracne (Winters, 2003).

Table 2.2 List of dioxin-like PCB congeners with their associated toxic equivalency factor (WHO, 2005)

Congener	IUPAC Number	Toxic equivalency factor (TEF)
3,3’,4,4’-TeCB	77	0.0001
3,4,4’,5-TeCB	81	0.0003
2,3,3’,4,4’-PeCB	105	0.00003
2,3,4,4’,5-PeCB	114	0.00003
2,3’,4,4’,5-PeCB	118	0.00003
2’,3,4,’4,5-PeCB	123	0.00003
3,3’,4,4’,5-PeCB	126	0.1
2,3,3’,4,4’,5-HxCB	156	0.00003
2,3,3’,4,4’,5’-HxCB	157	0.00003
2,3’,4,4’,5,5’-HxCB	167	0.00003
3,3’,4,4’,5,5’-HxCB	169	0.03
2,3,3’,4,4’,5,5’-HpCB	189	0.00003

2.1.1 Aroclors

The term Aroclor refers to a trade name for a mixture of PCB congeners produced commercially in the United States, mostly by Monsanto Chemical Company (USDHHS, 1995). Aroclors are identified by a 4-digit numeric code; the first two digits denote the number of carbon atoms in the biphenyl ring while the last two digits refer to the percentage of chlorine in the mixture. Aroclors 1254 and 1260 were the main mixtures used before 1950; in the 1950s and 1960s, Aroclor 1242 was used, then this mixture was phased out in 1971 in favor of Aroclor 1016 (Hutzinger et al., 1974). Each Aroclor is made of a unique blend of congeners. Table 2.3, displays specific congeners that are major components in common Aroclors, while Table 2.4, shows the molecular composition of two common Aroclors, 1254 and 1260.

Table 2.3 Specific PCB congeners that are major components in common Aroclors (USEPA, 2007)

		Aroclor						
Congener	**IUPAC Number**	**1016**	**1221**	**1232**	**1242**	**1248**	**1254**	**1260**
Biphenyl	--		X					
2-CB	1	X	X	X	X			
2,3-DCB	5	X	X	X	X	X		
3,4-DCB	12	X		X	X	X		
2,4,4’-TCB	28*	X		X	X	X	X	
2,2’,3,5’-TCB	44			X	X	X	X	X
2,3’,4,4’-TCB	66*					X	X	X
2,3,3’,4’,6-PCB	110						X	
2,3’4,4’,5-PCB	118*						X	X
2,2’,4,4’,5,5’-HCB	153							X
2,2’,3,4,4’,5’-HCB	138							X
2,2’,3,4,4’,5,5’-HpCB	180							X
2,2’3,3’,4,4’5-HpCB	170							X

* Apparent co-elution of: 28 with 31 (2,4’,5-trichlorobiphenyl)
66 with 95 (2,2’,3,5’,6-pentachlorobiphenyly)
118 with 149 (2,2’,3,4’,5’,6-hexachlorobiphenyl)

This table is not intended to illustrate all of the congeners that may be present in a given Aroclor, but rather to illustrate the major congener components.

Table 2.4 Molecular composition of two common Aroclors (Hutzinger et al., 1974)

Aroclor	**Molecular Composition**	**Aroclor**	**Molecular Composition**
1254		**1260**	
	11% $C_{12}H_6Cl_4$		12% $C_{12}H_5Cl_5$
	49% $C_{12}H_5Cl_5$		38% $C_{12}H_4Cl_6$
	34% $C_{12}H_4Cl_6$		41% $C_{12}H_3Cl_7$
	6% $C_{12}H_3Cl_7$		8% $C_{12}H_2Cl_8$
			1% $C_{12}HCl_9$

2.1.2 Dioxins and Furans

Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are made up of a family of 75 and 135 different polychlorinated dioxins and furans, respectively. Chlorinated dibenzo-p-dioxins (CDDs) are divided into eight groups depending on the number of chlorine atoms in the compounds. For example, a group with two chlorine atoms is called di-chlorinated dioxin (DCDD) (ATSDR, 2000). Dioxins and furans are significantly more toxic than PCBs (USDON, 1990, CADHS, 1998). The toxicity level of these dioxins vary and is explained using a toxic equivalency factors (TEFs) to relate their toxicity to that of TCDD, where tetrachlorodibenzo-p-dioxin (TCDD), the most toxic dioxin, has a TEF value of 1 (Table 2.1.2). For example, 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (OCDD) has a TEF value of

0.0003 making it about 3,000 times less toxic than TCDD (WHO, 2005). Toxic equivalents (TEQs) are used to report the toxicity-weighted masses of mixtures of dioxins. The TEQ method offers a toxicity information about the mixture and is often more meaningful than simply reporting the concentrations of a single toxic compound (WHO, 2005). ‘TEQ WHO 2005’ is used when referring to the toxicity weighted mass of the dioxins and furans in this study.

The United States Environmental Protection Agency (USEPA) has determined that a mixture of CDDs with six chlorine atoms with 4 of the 6 chlorine atoms at the 2, 3, 7, and 8 positions is a probable human carcinogen (ATSDR, 2000). A source of PCDD and PCDF in the environment is the combustion of PCBs through either explosion or fires in PCB filled transformers (CADHS, 1998). “Under certain conditions such as industrial fires or explosions, furan and dioxin products can be generated from PCBs” (USDON, 1990). In addition, concentrations of PCDD and PCDF will often be orders of magnitude less than the ‘parent’ PCB making them more difficult to detect (USDON, 1990).

2.2 PCB Sources

PCBs held a wide variety of uses prior to 1977. A list of PCBs uses is found in the following: “nominally closed appliances such as capacitors, transformers, and heat transfer and hydraulic fluids; open-end applications such as flame retardants, inks, adhesives, microencapsulation of dyes for carbonless duplicating paper, paints, pesticide extenders, plasticizers, polyolefin catalyst carriers, slide-mounting mediums for microscopes, surface coatings, wire insulators, and metal coatings” (IARC, 1979). Today, PCBs can be released into the environment from poorly maintained hazardous PCB waste sites, improper dumping of PCB wastes, and leaks or releases from electrical transformers containing PCBs (USDHHS, 1995, WHO, 2003). Table 2.5 summarizes the former uses of the various Aroclors.

Table 2.5 Summary of former end used for various Aroclors (IARC, 1979)

End Use	**Aroclor**								
	1016	**1221**	**1232**	**1242**	**1248**	**1254**	**1260**	**1262**	**1268**
Capacitors	x	x				x			
Transformers				x		x	x		
Heat transfer				x					
Hydraulics/lubricants:									
Hydraulic fluids			x	x	x	x	x		
Vacuum pumps					x	x			
Gas-transmission turbines		x		x					
Plasticizers:									
Rubbers			x	x	x	x			x
Synthetic resins					x	x	x	x	x
Carbonless paper				x					
Miscellaneous:									
Adhesives		x	x	x	x	x			
Wax extenders				x		x			x
Dedusting agents						x	x		
Inks						x			
Cutting oils						x			
Pesticide extenders						x			
Sealants and caulking compounds						x			

2.3 PCB Weathering and Environmental Sinks

In surface waters, PCBs can remain buried in sediments and be slowly released into the water or evaporated into the air over time (WHO, 2003). Sediments in water therefore act as a reservoir for PCBs because PCBs do not readily dissolve in water; rather they bind strongly to soil (ATSDR 2000). Sinkkonen and Paasivirta (2000) determined degradation half-life times for environmental fate modeling purposes. Data presented in Table 2.6 suggests PCBs can remain in sediment for many years. From their studies they found PCB 118 is estimated to have a half-life of 6.8 years (Sinkkonen and Paasivirta, 2000). However others estimate the biodegradation half-life times of PCBs in sediments and soils vary from several years to decades (Shelton and Tiedje, 1984; Brown and Wagner, 1990; Lake et al., 1992; Beurskens et al., 1995). PCBs, particularly the highly chlorinated congeners, adsorb strongly to sediment and soil (Krauss et al., 2000) where they tend to persist with half-lives on the order of months to years (USEPA, 2011).

Table 2.6 Suggested half-life times (yrs) of selected PCB congeners in air, water, soil, and sediment for Baltic Proper environment (annual average temperature about +7°C). (Sinkkonen and Paasivirta, 2000)

Congener	Structure	Air	Water	Soil	Sediment
PCB 28	244'-trichloro-	0.008	0.165	2.966	2.976
PCB 52	22'55'-tetra-	0.171	3.422	9.993	9.993
PCB 77	33'44'-tetra-	0.171	3.422	9.993	9.993
PCB 101	22'455'-penta-	0.342	6.845	9.993	9.993
PCB 105	233'44'-penta-	0.342	6.845	9.993	9.993
PCB 118	23'44'5-penta-	0.342	6.845	6.845	6.845
PCB 126	33'44'5-penta-	0.342	6.845	9.993	9.993
PCB 138	22'44'5'-hexta-	0.684	13.689	18.823	18.823
PCB 153	22'44'55'-hexta-	0.684	13.689	18.823	18.823
PCB 169	33'44'55'-hexta	0.684	13.689	18.823	18.823
PCB 180	22'344'55'-hepta-	1.369	27.379	37.645	37.988

The PCBs that preferentially persist are often referred to as "weathered" PCBs. These weathered PCBs are often highly chlorinated containing 6-9 chlorine atoms (more toxic) (USEPA, 2009b). "Weathering occurs due to differences in volatilization, partitioning, chemical transformation, photo-degradation, biodegradation, or bioaccumulation of individual PCB congeners" (Erickson, 1997). As a result of this weathering it can be difficult to match sample results to a specific Aroclor, as well as difficulties in quantification of all PCB congeners present (Rushneck et al., 2004).

2.4 PCB Transformation and Degradation

The ability of PCBs to degrade or transform in the environment depends on the degree of chlorination of the biphenyl molecule and on the chlorination pattern (Callahan et al., 1979; Leifer et al., 1983; USEPA, 1988a), typically the higher the number of chlorines, particularly greater than 6, the more persistent the PCB congener. Researchers in Northern Italy found that "heavy congeners (i.e. contain more chlorine) are less volatile and more persistent in soil than the lighter congeners, light congeners were also more rapidly degraded and thus were not transported as far as the heavier congeners" (Notarianni et al., 1998). Environmental factors controlling PCB transformation and degradation are described by the World Health Organization (Faroon et al., 2003) (Tables 2.7 and 2.8). In general, PCBs in soil and sediment are broken down by microorganisms (biodegradation). This process is affected by numerous factors, including the number and location of chlorines, PCB concentration, the type of microorganism present, available nutrients, and temperature. The breakdown of PCBs by microorganisms is slow and can occur with or without oxygen. This type of breakdown is also possible in water but is usually limited; typically, PCBs in water are broken down by sunlight. In river sediments, PCB levels have been measured at different depths (Pollack and Butterfield, 2005). Samples show the highest PCB concentrations in sediment layers buried during the time of PCB manufacturing. PCBs are much lower in sediment layers that formed following the ban on production and use of PCBs.

Table 2.7 PCB degradation and transformation factors (WHO, 2003, unless specified)

Degradation and Transformation Factors	**Comments**
Sunlight	Photolysis (mostly atmosphere and water)
Microorganisms	These two factors help reductive dechlorination
Organic Soil Content (Krauss et al., 2000)	
Evaporation (Harrad et al. 2994)	Loss of lower chlorinated PCBs
Sediment transport	Movement downstream of source
Depth transfer	PCB distribution at depth (usually heavier PCBs)
Temperature	Influences PCB removal and bacteria
Leaching (Krauss et al., 2000)	Depth and presence in ground water

Table 2.8 PCB soil adsorption factors (WHO 2003, unless specified)

Soil Adsorption Factors	**Comments**
Organic Carbon Content (Krauss et al., 2000)	PCBs have an affinity for organic carbon
Vegetation (Notarianni et al., 1998)	Will scavenge PCBs from atmosphere and then release them upon decay
Amount of Chlorination	Heavily-chlorinated PCBs will be less likely to volatize
Atmospheric Deposition: wet (dissolved in precipitation or aerosols) or dry: turbulence, diffusion, gravity	Most common method, especially at distances away from contamination site
Climate (Larsson & Soedergren, 1987, WHO, 2003).	Temperature, latitude and longitude , evaporation more readily in warmer climates, slower to breakdown in colder climates
Atmospheric transport	Evaporation, precipitation, etc.

3. PREVIOUS STUDIES

In this section, the results of previous investigations in PCBs at the PORTS site are described.

3.1 1976 Battelle Research and Evaluation of Selected Environmental Aspects at PORTS

One of the earliest environmental investigations conducted at PORTS was in 1976, a research and evaluation of selected environment aspects conducted by Battelle Laboratories from Columbus Ohio. This research aimed to obtain baseline data to accurately evaluate the ecology of the PORTS area. Battelle gathered data for one-year. The studies included sampling and analysis of terrestrial and aquatic ecosystems in the PORTS area.

According to Battelle researchers, Little Beaver Creek receives effluent from minor plant processes; upstream of this discharge, the stream is fairly clean and unpolluted (Andersen et al., 1976). Downstream of the plant outfall, most algal species were eliminated. The invertebrate community was almost eliminated and the abundance of fish species was greatly reduced. Further downstream, recovery was evident but remained a stressed condition (Andersen et al., 1976). “Five species and 48 individuals were collected upstream, but no fish were encountered downstream” of the plant (DOE, 1996). PCB fish tissue analysis conducted as part of this study was below 0.5 ug/g, with the highest concentration found in a green sunfish in Big Run Creek (0.42 ug/kg) (Andersen et al., 1976).

3.2 1989 Annual Site-wide Evaluation Report for PORTS

3.2.1 Background

In 1989, the annual site-wide investigation conducted at PORTS described the PCB waste storage and sources on site at that time. According to this report (DOE 1989), PORTS operated six waste storage areas for PCBs. At the time, 1.2 million kg of PCB waste were in storage; the waste is regulated by TSCA. Sources of PCBs at PORTS were primarily dielectric fluids used in electrical equipment. PCB-contaminated oil drips from ventilation gaskets presented a widespread source of contamination. PORTS, at the time, had 159 transformers in service that were filled with PCBs. Dikes and concrete pads were used to prevent introduction into the environment in the case of a spill. PCB wastes were stored in the X-333, X-330, and X-326 process buildings and in the X-334 PCB transfer building. “During 1989 a total of 38,481 L of PCB-contaminates fluids and 168,196 kg of PCB equipment were placed into storage for disposal (DOE, 1989).” Of the 104 reported spills, forty of them were PCB-contaminated oil spills, most were from drips from the ventilation ducts.

3.2.2 Fish Tissue Analysis

Fish tissue sampling from Little Beaver Creek at the plant discharge outfall and downstream revealed a sunfish with PCB level at 2.2 ug/g, while the FDA limit for PCBS in food is 2 ug/g.

Two additional smallmouth bass were sampled, one had a PCB level of 1.4 ug/g while the other was below detection level.

3.3 1992 OEPA Evaluation and Biological Community Summary

In 1992, OEPA conducted biological community, fish tissue, and sediment sampling in Little Beaver Creek. While other contaminants in the sediment and fish tissue were a concern at this time, the PCB data was inconclusive due to the inadequate detection limits used in the laboratory (detection limits of 2,400 to 4,800 ug/kg were used). All samples were below these high detection levels. The macroinvertebrate community of Little Beaver Creek showed good conditions. The Index of Biotic Integrity (IBI) score reflected a healthy fish community in Little Beaver Creek. This report recommended that the current Warmwater Habitat (WWH) aquatic life use status be maintained for Little Beaver Creek, with more thorough evaluation needed in the future that includes PCB sampling of fish tissue using lower detection limits (OEPA, 1993).

3.4 1996 -1997 RCRA Facility Investigation and Baseline Ecological Risk Assessment

3.4.1 Background

In 1996, as part of the RCRA Facility Investigation (RFI) at PORTS, an extensive assessment was conducted to show potential impacts PCB releases as well as other contaminants from PORTS may have on ecological receptors. Little Beaver Creek is one of the watershed areas included in this investigation. Among other ecological receptors, fish were one of the targets. PCBs were tested from in soil, sediment, surface water, and groundwater, among many other parameters.

3.4.2 Fish Community Results

Forage fish were collected in 1993 in support of the Baseline Ecological Risk Assessment (BERA), and showed a mean concentration of Aroclor 1260 varying from 0.9 to 1.7 ug/g at contaminated sites including Little Beaver Creek, Big Run Creek, and West Drainage Ditch. Previous analysis by OEPA found Aroclor 1260 varying from 0.61 to 1.70 ug/g in spotted bass from Little Beaver Creek (Counts and Altfater, 1993). Although these results indicated that PCB contamination was present in fish during this time period, the BERA indicated in the executive summary the following, “The weight of available evidence indicates a negligible risk to fish in Little Beaver Creek. Fish survey data are the most realistic indicator of the effects of PORTS on the fish community and suggest that there are no significant toxic effects in Little Beaver Creek” (DOE, 1996).

3.4.3 Soil, Sediment, Surface Water and Groundwater Results

During the RFI and BERA sampling, PCBs were detected in groundwater at only one location, a site west of holding pond X-230L (0.63 ug/l) and in only two surface water locations near the Peter Kiewit Landfill (seep) and Big Run Creek (2.0 ug/l and 0.5 J ug/l, respectively). (Note: This section of Big Run Creek has since been relocated east away from the Peter Kiewit

Landfill). During the RFI the method detection limit and practical quantification limit for PCB analyses in soil and sediment was 80 ug/kg. Soil was sampled from 1 to 24 feet at 1007 sampling locations. “At least one PCB compound was detected at 98 of the 1007 sampling locations during the RFI and BERA sampling activities” (DOE, 1997). The greatest number and highest concentrations of PCBs were found between 0-4 feet of depth. No PCBs were found greater than 8 feet. Highest concentration was found at the Peter Kiewit Landfill (460,000 ug/kg). At four stations along Little Beaver Creek concentrations of Aroclor 1260 in the soil/sediment varied from 180 ug/kg to 9,000 ug/kg. At the X-230J6 Holding Pond concentrations of Arcolor 1260 varied from 3,300 ug/kg to 6,600 ug/kg.

3.5 1997 OEPA Biological and Water Quality Study of Little Beaver Creek Summary

3.5.1 Background

In 1997, a biological and water quality study of Little Beaver Creek was conducted by the OEPA Division of Surface Water and Emergency and Remedial Response. The study area included the lower four miles of Little Beaver Creek and lower six miles of Big Beaver Creek, both have a WWH designation. The purpose of the study was to determine the possible impacts of PORTS to the aquatic ecosystem, as this facility has discharges into Little Beaver Creek. The OEPA set out to assess the aquatic biology and sediment quality in both Little Beaver Creek and the lower reaches of Big Beaver Creek in order to determine the potential accumulation of stream sediment contamination, the influences of the National Pollutant Discharge Elimination System (NPDES) discharges from the PORTS site. The study set out to determine the attainment status of the current WWH aquatic life use designation and to follow up the conditions found during the 1992 OEPA survey.

3.5.2 Data Collection

Fish and macroinvertebrate sampling were conducted at seven locations. Sediment sampling was conducted at six locations, PCBs as well as other contaminants. Use attainment status was determined by using two biological fish indexes, the IBI and the Modified Index of Well-Being (MIwb), as well as a regional reference site approach. Physical stream habitat assessment was conducted using the Qualitative Habitat Evaluation Index (QHEI). Quarterly surface water chemistry sampling was also conducted at six sites.

3.5.3 Results

Macroinvertebrate sampling of Little Beaver Creek showed low diversity with only eight taxa, and only one high quality Ephemeroptera, Plecotera, or Trichoptera (EPT) taxa. Macroinvertebrate communities in Little Beaver Creek ranged from poor to exceptional, with the artificial effluent of non-contact cooling water from outfall 001 providing the nutrients to sustain the community immediately downstream of the outfall. Locations sampled in this study are shown in Figure 3.1. Downstream from the East Drainage Ditch (RM 3.1), the macroinvertebrate community was poor, with an ICI score of four. At RM 2.5, the ICI score was

26, within the fair range. The lower 1.5 miles of Little Beaver Creek had ICI scores of 52 and 58, within the exceptional range, and had high taxa diversity. Changes in the macroinvertebrate community between 1992 and 1997 showed a decline in ICI score from 20 to 0 in upstream site of Little Beaver Creek, most likely due to drying of channel and artificial substrates in an isolated pool. Sites downstream of the holding pond discharge showed a decline in ICI score from 22 to 4, most likely due to lack of base flow. The site at RM 2.5 had an improvement in ICI score from 16 to 26, most likely due to the discontinuation of Lime Sludge Lagoon discharges in 1996. The mouth of Little Beaver Creek improved from an ICI score of 42 to 58.

Fish sampling resulted in 7,381 individuals and 49 species. Fish communities in Little Beaver Creek ranged from fair to exceptional, with the quality of wastewater discharges not appearing to have a negative impact. Sampling in Little Beaver Creek was in the upper fair IBI range upstream of the holding pond effluent and in the good to exceptional IBI range downstream of the discharge. The fish community between 1992, 1993, and 1997 showed a 12 point decrease in IBI at RM 3.1 in Little Beaver Creek. Two miles of Little Beaver Creek were in full attainment of WWH use designation. Non-attainment status occurred in upper Little Beaver Creek, with the effluent discharge not appearing to affect the attainment status. The Qualitative Habitat Evaluation Index (QHEI) average score for Little Beaver Creek was 75.3, indicating good to excellent stream and riparian habitat.

Sediment samples from Little Beaver Creek and Big Beaver Creek downstream of the confluence exceeded Lowest Effect Level one polychlorinated biphenyl (PCB) sample. PCBs found in sediment samples include: Aroclor 1221, 1016, 1232, 1242, 1248, 1254, 1260. Aroclor 1260 exceeded Severe Effect Level; sediment concentrations were 11.4 ug/kg (ppb) at RM 3.0 and 83.1 ug/kg (ppb) at RM 1.43 in Little Beaver Creek downstream of PORTS.

The PORTS NPDES which drains into Little Beaver Creek did not chemically impair the water quality, with parameters all below the 30-day or daily maximum permit limits (OEPA, 1998).

3.6 2005 OEPA Biological and Water Quality Study of the Portsmouth Gaseous Diffusion Plant Streams

3.6.1 Background

In 2005, a water resource assessment of streams on or adjacent to PORTS property was conducted in the summer and fall of 2005 by the OEPA Division of Surface Water. The study included five locations over 3.3 miles of Little Beaver Creek, four locations on Big Beaver Creek, three locations in Big Run, one site in the West Ditch, and three locations on the Scioto River. The purpose of this study was to determine possible impacts of effluents from PORTS to the aquatic ecosystem, as the facility has active discharges into Little Beaver Creek, Big Run, West Ditch, and the Scioto River. Specifically, the OEPA aimed to determine biological conditions in each water body studied through fish and macroinvertebrate sampling, to determine the levels of contaminants in sediments, surface water and fish in each stream, to find the influences of the PORTS outfalls, to determine the attainment status of WWH or Exceptional Warmwater Habitat (EWH) aquatic life use designation and to compare the results with previous studies.

3.6.2 Data Collection

Fish and macroinvertebrate were analyzed at 16 locations and 14 locations, respectively. Tissue fillet samples were collected from fish of edible size, and whole body fish samples were collected from adult fish of a size consumed by birds and mammals. Sediment sampling was conducted at 15 locations, which were analyzed for PCBs as well as other contaminants. Use attainment status was determined by the IBI, MIwb, and regional reference site approach. A habitat assessment was conducted using the QHEI. Surface water chemistry sampling was conducted twice at 16 locations, and evaluated using Ohio Water Quality Standards for PCBs as well as other contaminants.

3.6.3 Results

At Little Beaver Creek RM 1.4, PCBs were not detected. Elevated PCBs were found in Little Beaver Creek RM 2.4 and 1.4. The fish community assessment included 24,896 fish from 70 species. IBI scores for Little Beaver Creek fish communities were within the exceptional range, except for RM 3.3 which was in the fair range. WWH was not attained at RM 3.3, due to the low flow conditions; remaining downstream sites met WWH or EWH criteria. According to this study, effluent from the PORTS outfalls did not impact the ecological condition of fish communities, while fish communities have shown overall improvement since 1992.

Whole body samples from 11 fish species and fillet samples from 4 species were analyzed. Testing of PCBs as well as other metals resulted in exceedance of Ohio Fish Consumption Advisory level of one meal per week. PCB levels in three whole body samples from Little Beaver Creek exceeded Ohio Water Quality criteria for the protection of wildlife. The highest concentrations of PCBs were in Little Beaver Creek, with slightly elevated levels also present in Big Run, West Ditch, Big Beaver Creek downstream from Little Beaver Creek, and the Scioto River downstream of Big Beaver Creek. Aroclors 1016, 1221, 1232, 1242, 1248, 1254, and 1260 were found. Total PCB levels were as high as 1400 ug/kg (ppb) in fish tissue samples from Little Beaver Creek, as shown in Table 3.1 (OEPA 2006), Ohio Water Quality Standards to protect against adverse effects on wildlife are 640 ug/kg (wet weight) of a whole organism sample (OEPA, 2005).

Table 3.1 PCBs measured in whole fish samples on and near the PORTS site (OEPA 2005).

Stream	River Mile	Fish Species	Total PCBs (ug/kg)
Little Beaver Creek	2.4	green sunfish	710
Little Beaver Creek	2.4	yellow bullhead	1400
Little Beaver Creek	1.4	rockbass, g. sunfish, l.ear. sunfish	1400
Scioto River	24.6	smallmouth redhorse	800

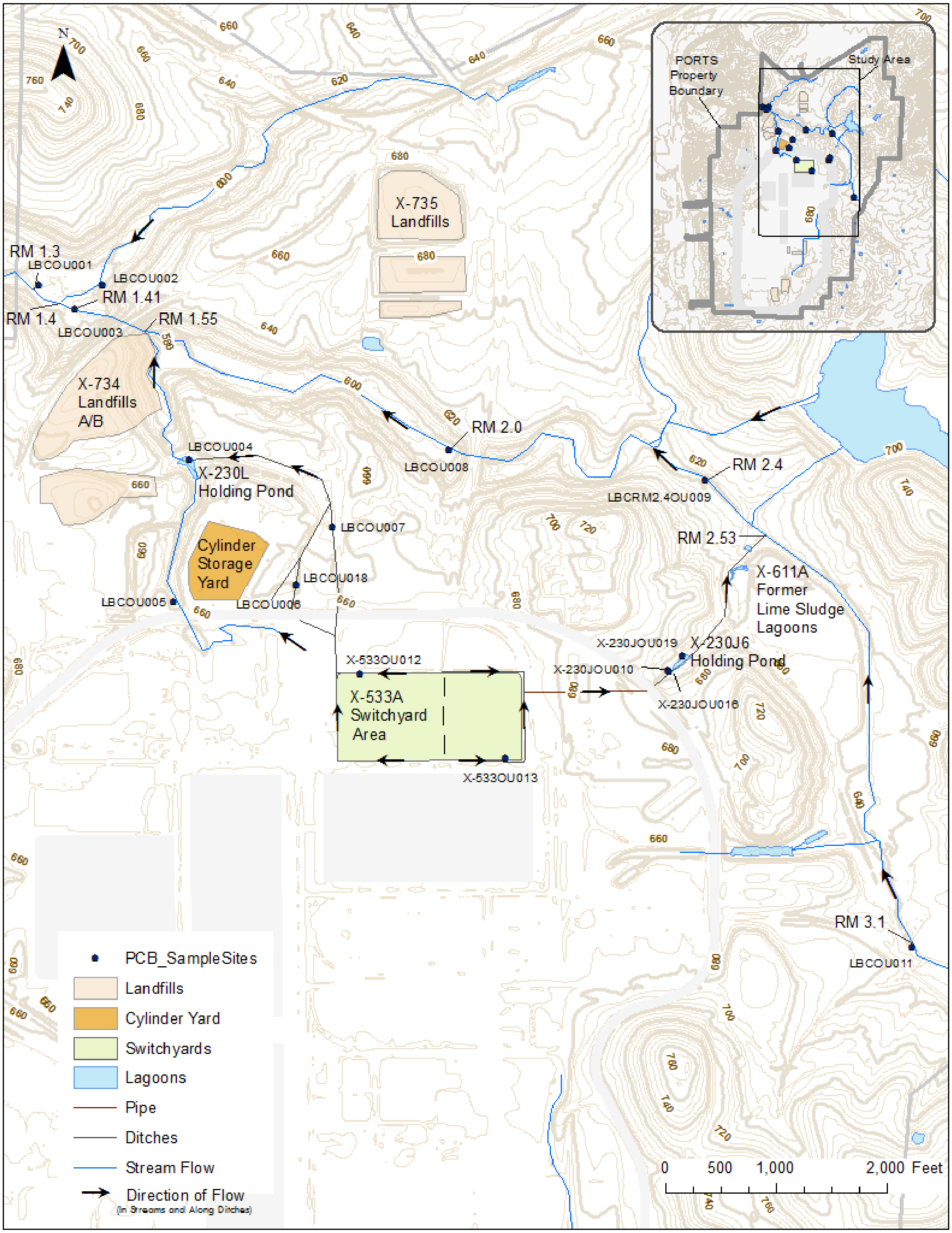

Figure 3.1 River mile designations along Little Beaver Creek

3.7 2007 DOE Investigation of Potential Sources of PCB Contamination in Little Beaver Creek at the Portsmouth Gaseous Diffusion Plant, Piketon, Ohio

3.7.1 Background

A study was conducted in 2007 by the DOE to determine the sources of PCB contamination in Little Beaver Creek at PORTS. The study was initiated due to the 2005 OEPA findings of PCBs in fish tissue samples that exceeded Ohio Consumption Advisory restriction levels and Ohio Water Quality criteria for the protection of wildlife.

The study site included Little Beaver Creek, East Drainage Ditch, Northeast Drainage Ditch, and North Drainage Ditch, the North, Northeast, and East Holding Ponds, and the drainage ditches from the Switchyard sediment basins (Figure 3.2).

3.7.2 Data Collection

Soil samples were collected beneath the X-533A Switchyard gravel, at locations with the highest probability of PCB contamination based on drainage and previous spills. Sediment samples were taken from the North, Northeast, and East Drainage Ditches; the North, Northeast, and East Holding Ponds; Little Beaver Creek; and the drainage ditches from the Switchyard sediment basins. Surface water sampling was conducted with grab samples collected at thirty-one locations from each discharge into Little Beaver Creek from PORTS. High-volume water samples were taken at four locations at the drainage ditches and from Little Beaver Creek. This allows for the detection of low levels of PCBs. PCB wipe samples were also collected from equipment in the X-533A Switchyard and transformers in the X-633 Pump House.

3.7.3 Results

Soil samples detected PCBs at five of fourteen locations along the buried drainage pipe. Aroclor-1260 and 1254 were detected, with the highest concentrations at three to four feet below the gravel. All samples were less than 15 ug/kg (ppb), except for one location with a concentration of 280 ug/kg (ppb). Sediment samples detected Aroclor-1260 in three of eight samples from Little Beaver Creek, with concentrations ranging from 8.2 ug/kg (ppb) to 290 ug/kg (ppb). These levels were generally lower than in the 2005 OEPA Stream Study. PCBs were also detected in each drainage ditch, with concentrations as high as 1,300 ug/kg (ppb). Surface water sampling detected PCBs in one of sixty-two surface water grab samples, with Arcolor-1260 detected near the X-533A Switchyard. PCBs were detected in all four high-volume water samples, including Aroclor-1254 and 1260. This shows that PCBs are carried in the surface water of Little Beaver Creek and the three drainage ditches, in the suspended particulate matter and dissolved phase. Wipe samples detected Aroclor-1260, showing past and current oil leaks in the Switchyard contain PCBs (DOE, 2007).

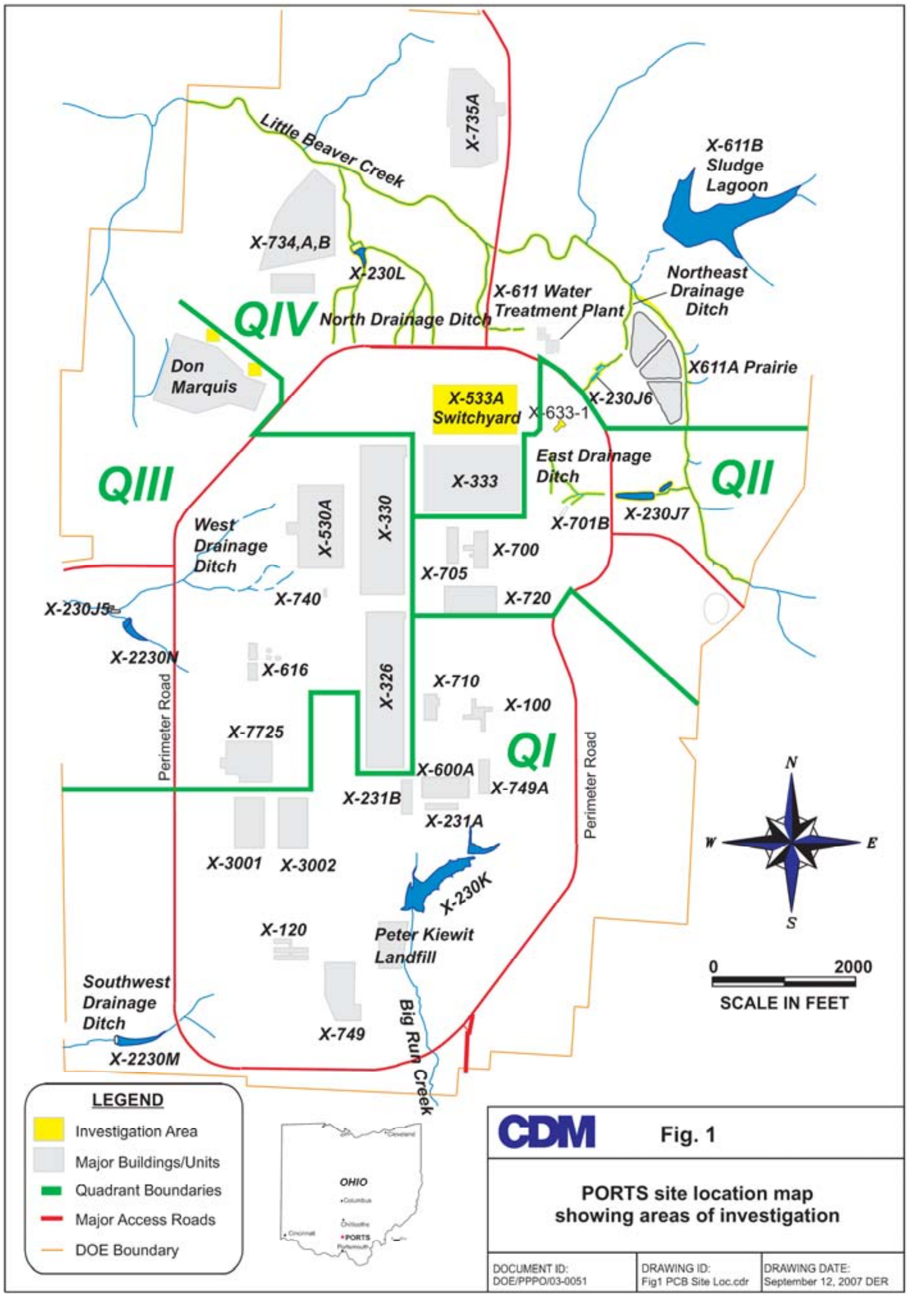

Figure 3.2 Areas of investigation at PORTS for the DOE 2007 study

3.8 2010 DOE Resource Conservation and Recovery Act Investigation and Soil Removal Report for the X-533A Switchyard Complex at the Portsmouth Gaseous Diffusion Plant Piketon, Ohio

3.8.1 Background

A RCRA investigation and soil removal was conducted in 2010 by the DOE. Following the findings of PCB contamination in the X-533A Switchyard in the 2007 DOE study, decontamination and decommissioning of the switchyard was conducted in 2010. Soil sampling was conducted during this time to determine areas of contamination. Soil contaminated with PCBs was removed from two heavily contaminated sites within the switchyard.

3.8.2 Data Collection

Soil sampling was conducted between March and June of 2010, with 228 soil samples collected from the first 12 inches of soil in the X-533A Switchyard Complex. Sites were chosen based on the highest probability of contamination. In September, further sampling at fifteen sites was conducted around chosen removal areas in order to determine the extent of contamination, using direct push technology (DPT) to sample up to 8 feet below the gravel. In November, additional soil samples using DPT were taken from nine locations adjacent to one of the removal areas, in order to further determine the extent of contamination.

3.8.3 Results

Soil sampling resulted in the detection of PCBs above background levels. Two samples located in areas #1 and #2 had PCB concentrations exceeding preliminary remediation goals (PRGs) of 25 mg/kg (ppm) 1,400 and 190 mg/kg, respectively. Contaminated soil was excavated and removed from the "hot spot" sites (Figure 3.3). Soil removed from area #1 and #2 was characterized as TCSA hazardous waste and sent to a hazardous waste landfill; Environmental Quality Company's Wayne Disposal, Inc. landfill in Belleville, Michigan, for disposal. Soil removed from area #3 did not exceed the PRG for PCBs rather a heavy metal and was sent to a non-hazardous landfill, Pike Sanitation Inc., in Pike County, Ohio (DOE, 2011a).

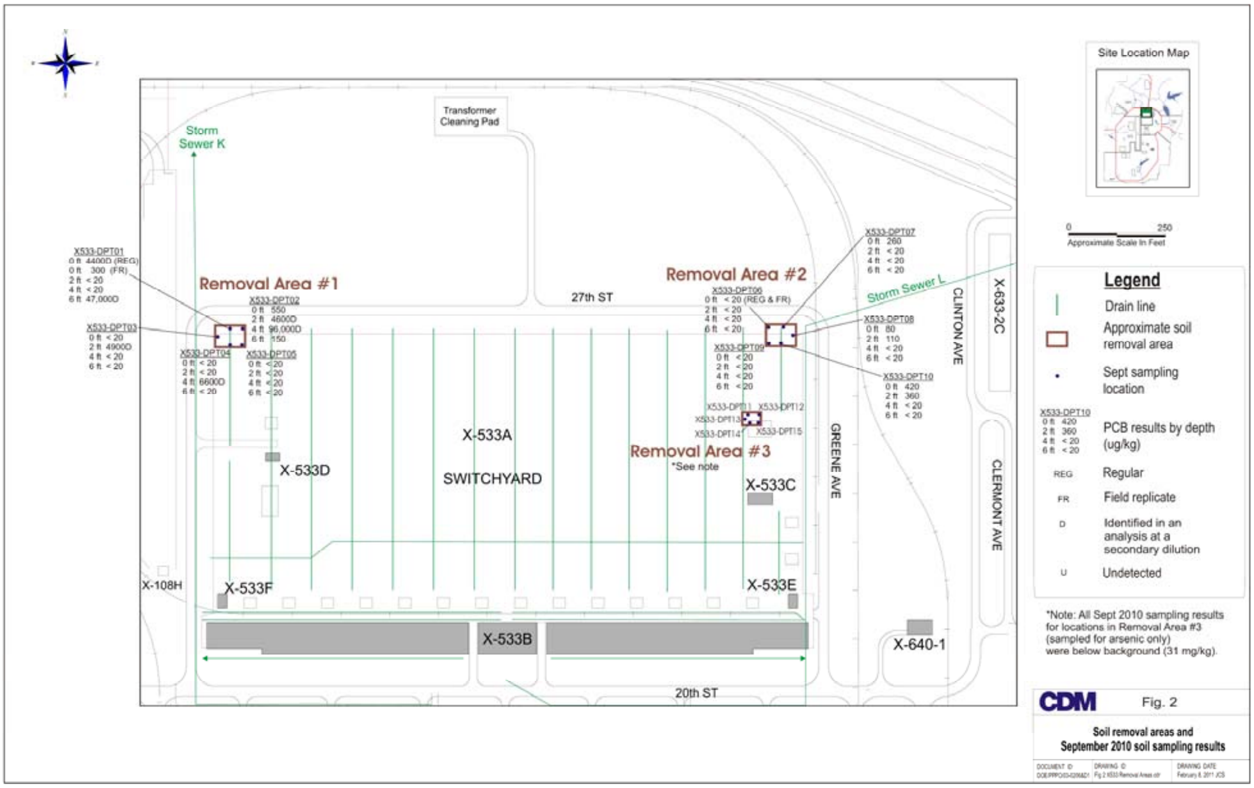

Figure 3.3 Location of three removal zones in the X-533A Switchyard (DOE, 2011a)

4. METHODS

Site selection for the Ohio University assessment was based on previous knowledge of PCB contamination in Little Beaver Creek and the X-533A Switchyard (OEPA, 1997; OEPA, 2005; OEPA, 2007; DOE, 2011a). Pre-screening of sites for radioactivity was conducted; all sites tested negative. PCBs are insoluble in water and bind strongly to organic matter, therefore soft sediment in the stream substrate were targeted for sampling. Table 4.1 displays sample sites, a description of the characteristics of the site, locational information and a river mile designation for sites along Little Beaver Creek and/or an indication of where the confluence of unnamed tributaries discharge into Little Beaver Creek.

Table 4.1 Description of sample site locations

Sample site	Description	Latitude	Longitude	River mile along Little Beaver Creek (LBC)
LBCOU001	Stream, pool	39.03153	-83.00573	1.30
LBCOU002	Stream, oxbow (dst. of the X-735 landfills)	39.03155	-83.00415	enters LBC @ 1.40
LBCOU003	Stream	39.03078	-83.00551	1.41
LBCOU004	inlet to holding pond (near the X-734A/B landfills)	39.02723	-83.00201	enters LBC @ 1.55
LBCOU005	Tributary	39.02371	-83.00238	
LBCOU006	Tributary	39.02413	-82.99935	
LBCOU018	Site 6 duplicate sample	39.02413	-82.99935	
LBCOU007	Tributary	39.02555	-82.99846	
X-533OU012	Ditch, wet	39.02192	-82.99779	
LBCOU008	Stream	39.02746	-82.99556	2.00
LBCRM2.4OU009	Stream	39.02672	-82.98923	2.40
X-230JOU019	Holding pond, bottom sludge	39.02236	-82.98981	
X-230JOU010	inlet to holding pond	39.02201	-82.99016	
X-230JOU016	inlet to holding pond	39.022	-82.99014	
X-533OU013	Ditch	39.01986	-82.99419	
LBCOU011	Stream	39.01516	-82.98411	3.10

4.1 Description of Sampling Sites

Moving upstream from the mouth of Little Beaver Creek to each sampling site, including effluent from unnamed tributaries, a detailed description of each site follows (Figure 1.2).

Site LBCOU001 is located furthest downstream in the main steam of Little Beaver Creek of all sampling locations, at RM 1.3. Samples were retrieved from soft sediment accumulated at the edge of the stream (Figure 4.1).

Site LBCOU002 is located near the mouth of an unnamed tributary draining from the north. This tributary formed a natural oxbow near its mouth where soft sediments accumulate; samples were collected from this pooled, sludgy area (Figure 4.2). The X-735 landfill is located near the headwaters of this tributary. The X-735 landfill contains several distinct waste management units. The main unit, furthest north, consists of hazardous waste and is a RCRA Landfill. The middle unit contains industrial solid waste and asbestos disposal cells, while the southern unit contains the chromium sludge monocells A and B (DOE, 2011b).

Site LBCOU003 is located along the mainstem of Little Beaver Creek directly upstream (10 feet) of the confluence with the unnamed tributary from the north at river mile 1.41. Soft sediment accumulation areas were difficult to find along this stream reach. A clay bank was chosen for sampling, trying to target soft sediments, rather than the abundant gravely riffles (Figure 4.3). However, as a result, this site represents an erosional section of the stream morphology rather than a depositional area (i.e. pool). Just south of this area are Landfills X-734 A and B. Detailed records of contents were not kept for landfills X-734A and B. However, some known wastes disposed of in these landfills includes construction waste, wood from clearing and grubbing, empty drums, waste contaminated with metals, empty paint cans, and uranium-contaminated soil from the X-342 area (DOE, 2011b).

Figure 4.1 Site LBCOU001

Figure 4.2 Site LBCOU002

Figure 4.3 Site LBCOU003

Site LBCOU004 is located at the eastern inlet to north holding pond X-230L. A depositional area with soft sediments directly at the inlet from an unnamed tributary to the east of the holding pond was targeted (Figure 4.4). Landfills X-734A and B are located directly west of this unnamed tributary that connects effluent from the X-230L holding pond to Little Beaver Creek at river mile 1.55

Site LBCOU005 is situated in the headwaters of an unnamed tributary draining into the X-230L holding pond from the south (Figure 4.5). The stream substrate targeted for collection was pooled water heavy in silt and clay.

Site LBCOU006 and duplicate sample LBCOU018 are situated in the headwaters of the western branch of unnamed tributary draining into the X-230L holding pond from the east (Figure 4.6). Pooled water with soft sediments was targeted for sampling. The X-745G Cylinder Storage Yard lies between sites LBCOU005 and LBCOU006. Depleted uranium cylinders are stored here. Some cylinders may have paint containing greater than 50 ppm of PCBs present on the outside of the cylinders (DOE, 2011b). “The cylinders are stored in accordance with an agreement with U.S. EPA that includes monitoring of PCBs in surface water and sediment in drainage basins downstream from the cylinder storage yards” (DOE, 2011b).

Figure 4.4 Site LBCOU004

Figure 4.5 Site LBCOU005

Figure 4.6 Site LBCOU006

Site LBCOU007 is situated in the eastern branch of this same unnamed tributary draining into X-230L holding pond from the east. A pooled section of stream was targeted for sampling (Figure 4.7).

The X-533A Switchyard lies in the headwaters of the unnamed tributary that directs drainage into the X-230L holding pond. The drainage off of the X-533A Switchyard is divided, the west drains towards the X-230L holding pond via an unnamed tributary while the other half drains to the east towards the X-230J6 holding pond via an underground drainage pipe (Figure 1.2). The X-533A Switchyard consisted of electrical transformers and circuit breakers, associated support buildings, and a transformer cleaning pad. The surface water, sediments, and groundwater in this vicinity were identified as an area of concern for potential PCBs and metal contamination (DOE 2011). Site X-533OU012 is located in the northwest corner of the X-533A Switchyard. A wet depression pooled with water and soft sediments in the drainage ditch was targeted for sampling (Figure 4.8). This site was previously remediated in 2010 (DOE, 2011a). Site X-533OU13 is located in the southeast corner and drains towards the X-230J6 holding pond. Wet sediments in drainage ditch were targeted for sampling (Figure 4.9).

Figure 4.7 Site LBCOU007

Figure 4.8 Site X-533OU012

Figure 4.9 Site X-533OU013

Moving further upstream along the mainstem of Little Beaver Creek, site LBCOU008 (river mile 2.0) is situated immediately downstream of multiple large road culverts tunneling under the North Entrance Road. The flow through the culverts has created a large and deep scour pool. Samples were collected from the soft sediments near the edge of the pool (Figure 4.10).

Site LBCRM2.4OU009 located further upstream at river mile 2.4 in Little Beaver Creek south of Fog Road, near the lime lagoon pull-off. Stream morphology is gravely riffles and runs, therefore accumulation of soft sediment was difficult to locate. Along the edge of the creek, an area of relatively soft sediment accumulation was located. However, a higher percentage of gravel and sand exists at this site (Figure 4.11).

Figure 4.10 Site LBCOU008

Figure 4.11 Site LBCRM2.4OU009

The X-230J6 holding pond drains into Little Beaver Creek via an unnamed tributary near the former lime sludge lagoon (X-611A) at river mile 2.53. The X-230J6 holding pond was sampled at three locations. Site X-230JOU019 is located in the deep section of the holding pond. The sludge at the bottom of the pond was targeted for sampling. Sample was retrieved via a row boat and clamshell sampler suspended by a rope (Figure 4.12).

Sites X-230JOU010 and X-230JOU016 are located in the inlet channel to the pond upstream of the foot bridge. These two sites are situated three feet apart. X-230JOU010 was sampled from the left bank while X-230JOU016 was sampled from the right bank (looking downstream). Water was stagnant in this channel with a high accumulation of clayey sediments (Figure 4.13).

Figure 4.12 Site X-230JOU019

Figure 4.13 Site X-230JOU010 and X-230JOU016

Site LBCOU011 located in the headwaters of Little Beaver Creek at river mile 3.10; represents our control site upstream of the X-533A Switchyard and holding ponds. Depositional area with soft sediments was identified for sample collection (Figure 4.14.)

Figure 4.14 Site LBCOU011

A list of materials, equipment, and supplies are displayed in Appendix H.

4.2 Description of Laboratory Sample Analysis

Two sets of samples were collected at fifteen different site locations (except X-230JOU019 this was a surface only site). In addition one duplicate sample was collected at site LBCOU006 (LBCOU018 duplicate sample surface only). A total of 30 samples were collected for various parameters described below. One field reconnaissance day was spent identifying twenty-five possible sample locations and pre-screening each location for radioactivity (June 3rd, 2011). Fifteen sites were chosen for laboratory analysis with GEL Laboratories and their affiliates.

On December 13, 2011 the following sites were sampled: X-533OU012 (soil only, no water sample), X-533OU013 (soil only, no water sample), X-230JOU010, X-230JOU016, and LBCRM2.4OU009 (Figure 1.2). The two sites in the switchyard were soil samples only no surface water samples were collected. On April 23, 2012, the following creek sites were sampled: LBCOU001, LBCOU002, LBCOU003, and LBCOU004. On April 24, 2012 sites LBCOU005, LBCOU006, LBCOU018 (surface only), LBCOU007, LBCOU008, LBCOU011, and X-230JOU019 (surface only) were sampled. All 209 congeners (Appendix A) were sampled on April 23, 2012 at the surface and subsurface at site LBCOU003. Aroclors and dioxin-like PCBs were sampled at the surface and subsurface of all sampling locations (Appendix B). Toxic dioxin and furans (Appendix D) samples were collected during the two April sampling events, the five sites sampled in December 2011 were excluded from this set of analysis. Total organic carbon, soil pH, and iron in the sediment were collected at all sites at the surface and subsurface. The following water quality parameters were collected at all creek sites in the surficial sample only: nitrate, ortho-phospahte, sulfate, pH, and alkalinity (Appendix E).

GEL laboratories in Charleston, South Carolina conducted the analyses presented here in partnership with their affiliate laboratory Cape Fear Analytical, LLC who analyzed for the PCB congeners, dioxins and furans (Method USEPA 1668, USEPA 1613B) and subcontracted to laboratory Shaw Environmental and Infrastructure Group who completed the grain size analysis. GEL laboratories are audited by U.S. Department of Energy's Consolidated Audit Program (DOECAP) every year and are in good standing. Table 4.2 displays the laboratory parameters that were analyzed for, methods, the third-party laboratory conducting the analysis, the holding times, and the quantity of samples per set of analytes. Laboratory Quality Assurance and Quality Control are described in *"GEL laboratories Quality Assurance Plan"* (GEL, 2011).

Table 4.2 List of laboratory parameters, methods, holding times, laboratory preforming the analysis and the quantity of sites and samples collected on each sampling date

Parameter	GEL Labs LLC	Shaw	Cape Fear	Method	Holding Time	5 sites on 12-13-11 # of samples	4 sites on 4-23-12 # of samples	6 sites (+1 dup.) on 4-24-12 # of samples
Nitrate*	X			SW 9056A	48 hrs	3	4	7
o-phosphate*	X			SW 9056A	48 hrs	3	4	7
Sulfate*	X			SW 9056A	28 d	3	4	7
Ammonia*	X			EPA 350.1	28 d	3	4	7
pH*	X			SW 9040C	Immed.	3	4	7
Alkalinity – bicarb. and carbonate*	X			SM 2320B	14 d	3	4	7
PCB Aroclors	X			SW 8082	1 yr	10	8	12
PCB congeners (WHO list)			X	EPA 1668	1 yr	10	8	12
Total organic carbon	X			SW 9060A	28 d	10	8	12
Soil pH	X			SW 9045D	Immed.	10	8	12
Iron	X			SW 6010C	6 m	10	8	12
Grain size		X		ASTM D 422	None	10	8	12
209 PCB congeners (site LBCOU003 only)			X	EPA 1668	1 yr	0	2	0
Dioxin and furans			X	EPA 1613B	1 yr	0	8	12

*Water parameters collected at the surface only at all creek sites.

4.3 Field Methods

4.3.1. Wet Sediment Samples for Chemical Analysis and Organic Matter Content

Fifteen different sampling sites were sampled for wet sediment from the stream substrate of Little Beaver Creek, ditches draining the X-533A Switchyard, and two holding ponds. Two samples were collected at each site. Surface sediment was collected from depths less than 10 centimeters, and subsurface sediment was collected from depths between 20 and 30 centimeters (USEPA, 1994). Collection of all samples was conducted by Fluor BW-Portsmouth (FBP) contractors. Sample locations were chosen in order to target finer sediments thought to be sinks for PCBs.

Either a stainless steel hand trowel, stainless steel sediment corer or stainless steel auger was used to take a sample of sediment at less than 10 centimeters depth within approximately a 30 centimeter square area. Standing water was decanted and samples were homogenized in a stainless steel bowl before being stored in amber glass jars at 4°C (DOE, 2007). Sample jars were filled as much as possible to avoid oxidation. Subsurface sediment samples were taken from between 20 and 30 centimeters using either a stainless steel corer or a stainless steel auger. Water was decanted from the sample before being homogenized in a stainless steel bowl and stored in an amber glass jar at 4°C.

Organic matter content has to be analyzed in the sediment samples because of the great affinity of organic matter with PCB compounds. During collection and handling, total organic carbon can be lost due to microbial degradation, sample drying, oxidation, volatilization, and sample processing biases (selective removal of carbon-bearing compounds), so care should be taken when collecting these samples (Schumacher, 2002). Large particles such as tree branches, wood chips, etc. were removed before the sample was stored and analyzed. The water from the sediment sample was decanted before homogenation. Once the samples were collected, the samples were placed into labeled amber glass jars with Teflon-lined lids and stored at 4°C with a holding time of up to 28 days (Schumacher, 2002). The sediment samples obtained for the PCB analysis were analyzed for organic matter content as well as pH and iron measurements to avoid duplication.

4.3.2 Collection of Samples for Grain Size Analysis

The results of grain-size analyses are sensitive to the manner in which the samples are collected, handled, and stored, so certain precautions must be taken in the field (USGS, 2000). Over-penetration by the sampling device or jarring/bumping the collection device should be avoided (USGS, 2000). Approximately a four-pound grab sample was obtained using a stainless steel trowel, a stainless steel corer or a stainless steel auger and sealed in two (double-lined) plastic one gallon zip-lock bags.

4.3.3 Collection of Water Samples for Nutrient, pH, Alkalinity, and Ammonia Analysis

Water samples were collected from all wet sediment sample locations. Grab samples were collected prior to the sediment sampling to avoid collection of suspended particles mobilized during substrate disturbance. A one-liter non-preserved bottle and a smaller 250 ml bottle were filled and stored at 4°C.

4.4 Equipment Decontamination

Decontamination between sampling sites followed the USEPA SOP #2006 for sample equipment decontamination. Gross contamination was removed using brushes and water, after which equipment was washed with Phosphate-free Liquinox soap, rinsed with tap water, rinsed with ASTM distilled water, and cleaned with hexane wipe and air dried. All clean, decontaminated and dry equipment was wrapped in aluminum foil or plastic bags to maintain decontamination.

4.5 Chain of Custody and Sample Shipping

The Ohio University team followed GEL's laboratory procedures for proper documentation and shipping and handling of samples. The soil and sediment samples were properly stored in labeled, amber glass jars with Teflon lids and kept on ice at 4°C during shipping and handling. Water samples were stored in two labeled plastic bottles; one preserved with sulfuric acid and the other a non-preserved sample and kept on ice at 4°C during shipping and handling. These samples were placed in a secure cooler with padding for transport to the necessary destination.

4.6 Field Quality Assurance and Quality Control

All samples were collected by Fluor B&W Portsmouth (FBP) contractors in the presence of Ohio University researchers. USEPA Standard Operating Procedures #2016 (USEPA, 1994) were followed for decontamination between sampling sites. Much of the equipment used to collect soil and wet sediment data were not disposable, i.e. hand augers, hand corers, trowel, stainless steel bowls, these items were cleaned and decontaminated between each site. The following additional quality assurance and quality control practices were followed:

- Accuracy - Duplicate samples were collected at one of the fifteen locations to calculate percent error in laboratory results (Site LBCOU006 and LBCOU018 were duplicate samples).
- Representative – Areas with fine sediment were targeted for sampling to account for the area where PCB contaminants are most likely to bind to the fine sediment particles. Samples were homogenized in a stainless steel bowl to ensure representativeness. Standard method procedures were followed (USEPA, 1994; USGS, 2000; USEPA, 1994; DOE, 2007).

5. RESULTS AND DISCUSSION

5.1 Descriptive Statistics

The concentrations of the different congeners, dioxin-like chemicals, and iron in the studied sediments are presented in Table 5.1. As discussed in the Methods section, sediments were collected at the surface and at a depth of approximately 1 foot (20-30 cm). Descriptive statistics for the total sediment samples, for the sediments collected at the surface, and for the sediments collected at 30 cm are presented in Table 5.2a. In Table 5.2a, only chemical species that were detected in four or more sampling sites of the total population, and at least three in the separated surface and 30 cm depth data sets, are considered. Aroclors are the compounds that present the highest concentrations, from a few ug/kg of sediment up to 224 ug/kg for total Aroclor. As Aroclors are a combination of many different PCB compounds, it is clear from the data presented in Table 5.2a that the individually analyzed PCB compounds are possibly only a very small fraction of the total PCBs present in the sediments. Only one site was analyzed for all 209 PCB congeners in the sediments, all other sites were analyzed for just the dioxin-like PCBs and most toxic dioxins (7 congeners) and furans (10 congeners). The analytes present a wide range of values, from a fraction of ug/kg of sediment up to 21.7 ug/kg for the dioxin compound 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (OCDD). For this contaminant, the sample concentrations varied from 0.016 to 21.7 ug/kg, with a standard deviation of 4.95 ug/kg. For the surficial sediment samples the highest average concentration was for OCDD with a concentration of 21.7 ug/kg, but for the sediment samples at 30 cm depth, the highest average concentration was for 2,3',4,4',5-Pentachlorobiphenyl (PCB118) with a concentration of 5.8 ug/kg. In order to visualize and compare the variations in concentrations at the surface and at 30 cm depth, the ratios between the average concentration for the surficial samples and the average concentration at a depth of 30 cm were found. It is clear from the data that this ratio is usually greater than one for the majority of the contaminants (except for 2,3,4,4',5-Pentachlorobiphenyl (114) that had a ratio of 0.8), indicating a higher concentration of the contaminant in the surficial sample. However, the concentration of organic carbon is also higher in the surficial sediments, with a ratio equal to two indicating that the surficial samples have an average of two times the concentration of organic carbon at the surface compared with 30 cm depth.

According to the report “Methods for conducting human health risk assessments and risk evaluations at the Portsmouth gaseous diffusion plant” (DOE 2012), an exceedence of a HHRA Type 1 screening values warrants immediate action, where an exceedence of a HHRA Type 2 screening levels prompts further investigation. Concentrations that are lower than the Type 2 screening levels typically indicates that no further action is necessary (DOE 2012). Looking at the maximum concentrations for all sites determined from the descriptive statistics, site X-230JOU019A stands out with many of the highest concentrations. Some of these values exceed the Type 1 and 2 HHRA screening values (DOE 2012). Table 5.2b displays these screening values and the exceedences of the screening values for PCBs: Total Aroclor, Aroclor 1260, Aroclor 1254, and Dioxins: OCDD, and HpCDD, discussed further in Section 5.9.

Organic matter, iron and manganese oxides and hydroxides, and clay minerals are very important in the sorption processes of contaminants from liquid solution to the solid phase in sediments and soils (Manahan, 2009). However, organic matter is usually the most important phase to sorb the contaminants due to its high surface area (Appelo and Postma, 2005). The results presented in Table 5.2a suggest that the concentration of organic carbon in the surficial soils is probably producing a higher retention of the contaminants in the surficial samples. For that reason, the original concentrations were normalized dividing the concentration reported by the laboratory analysis by the concentration of organic carbon in the sediments to reproduce the data in units of micrograms of contaminant/kg of organic carbon.

Table 5.1 Laboratory analysis results for sediment samples, blanks indicate data not collected.

	Average grain size (mm)	Average grain size (<2mm)	OCDD	1,2,3,4,6,7,8-HpCDD	PCB189	PCB156	PCB157	PCB105	PCB167	PCB114	PCB118	PCB123	PCB126	PCB77	Aroclor-1254	Aroclor-1260	Aroclor-1268	Aroclor-Total	Iron	TEQ WHO2005 ND=0	TEQ WHO2005 ND=0.5	Total HpCDD	TOC	Total TCDF
LBCOU001A	0.57	0.09	0.26	0.02	0.11	1.01	0.01	1.81	0.37	0.07	4.42	0.06	0.03	0.10	25.40	30.00	<1.00E-03	55.40	18200	0.52	6.27	0.04	6.55	0.01
LBCOU001B	8.75	0.18	0.16	<5.00E-03	0.01	0.05	0.00	0.08	0.02	0.00	0.22	0.00	0.00	0.01	3.31	4.95	<1.00E-03	8.25	16700	0.05	5.25	0.01	0.83	<1.00E-03
LBCOU002A	3.14	0.25	0.15	<5.00E-03	0.01	0.07	0.00	0.20	0.03	0.01	0.47	0.01	<2.00E-03	0.02	14.40	12.20	<1.00E-03	26.60	44200	0.18	6.07	<5.00E-03	2.72	0.00
LBCOU002B	8.06	0.34	0.25	0.01	0.15	1.27	0.00	2.42	0.55	0.06	5.85	0.09	<2.00E-03	0.07	6.61	8.50	<1.00E-03	15.10	89100	0.46	5.68	0.01	0.85	0.01
LBCOU003A	0.05	0.04	0.02	<5.00E-03	<1.00E-03	0.00	0.00	<2.00E-03	<2.00E-03	<2.00E-03	0.00	<2.00E-03	<2.00E-03	<2.00E-03	<1.00E-03	<1.00E-03	<1.00E-03	<1.50E+00	7790	0.01	5.47	<5.00E-03	0.73	<1.00E-03
LBCOU003B	0.18	0.04	0.02	<5.00E-03	<2.00E-03	0.00	0.00	<2.00E-03	<2.00E-03	<2.00E-03	<4.00E-03	<2.00E-03	<2.00E-03	<2.00E-03	<1.00E-03	<1.00E-03	<1.00E-03	<1.50E+00	10800	0.00	5.18	<5.00E-03	0.88	<1.00E-03
LBCOU004A	2.58	0.43	0.12	<5.50E-02	<2.00E-02	0.11	0.04	0.22	0.05	<2.00E-02	0.49	<2.00E-02	<2.00E-02	<2.00E-02	11.20	12.20	<1.00E-03	23.50	78700	0.04	62.80	<5.50E-02	0.96	<1.00E-02
LBCOU004B	9.53	0.47	0.20	<4.50E-02	<2.00E-02	0.22	0.04	0.50	0.08	0.03	1.18	0.02	<2.00E-02	0.02	7.27	9.42	<1.00E-03	16.70	62800	0.06	52.20	<4.50E-02	0.90	<1.00E-02
LBCOU005A	2.57	0.17	0.28	<5.00E-03	<2.00E-02	0.04	0.04	0.09	<2.00E-02	<2.00E-02	0.21	<2.00E-02	<2.00E-02	<2.00E-02	10.10	9.24	2.63	21.90	52000	0.08	5.60	<5.00E-03	0.33	<1.00E-03
LBCOU005B	1.89	0.23	0.98	0.02	<2.00E-02	0.04	0.04	0.05	<2.00E-02	<2.00E-02	0.11	<2.00E-02	<2.00E-02	<2.00E-02	51.70	22.20	<1.00E-03	73.80	33800	0.45	6.01	0.03	0.29	<1.00E-03
LBCOU006A	0.66	0.08	0.10	0.01	0.02	0.28	0.04	0.45	0.08	<2.00E-02	0.90	<2.00E-02	<2.00E-02	<2.00E-02	9.11	8.42	2.25	19.80	30900	0.10	5.08	0.01	0.21	0.00
LBCOU006B	0.36	0.06	0.11	<5.00E-03	<2.00E-02	0.06	0.03	0.11	0.02	<2.00E-02	0.25	<2.00E-02	<2.00E-02	<2.00E-02	9.31	7.78	<1.00E-03	17.10	34200	0.03	52.10	<4.50E-02	0.06	<1.00E-02
LBCOU007A	2.65	0.10	1.02	<4.50E-02	0.03	0.06	0.05	0.04	0.04	<2.00E-02	0.11	<2.00E-02	<2.00E-02	<2.00E-02	<1.00E-03	48.90	<1.00E-03	48.90	21700	0.31	62.00	<5.50E-02	1.73	<1.00E-02
LBCOU007B	0.68	0.10	0.75	<5.50E-02	0.05	0.12	0.04	0.08	0.08	<2.00E-02	0.24	<2.00E-02	<2.00E-02	<2.00E-02	40.00	19.70	<1.00E-03	59.70	24700	0.23	52.90	<4.50E-02	1.45	<1.00E-03
LBCOU008A	0.32	0.06	4.20	0.04	<2.00E-02	0.04	0.04	<2.00E-02	<2.00E-02	<2.00E-02	<4.00E-02	<2.00E-02	<2.00E-02	<2.00E-02	<1.00E-03	<1.00E-03	<1.00E-03	<1.50E+00	26300	1.63	7.70	0.08	0.37	<1.00E-03
LBCOU008B	0.61	0.07	2.70	0.02	<2.00E-02	0.04	0.04	<2.00E-02	<2.00E-02	<2.00E-02	<4.00E-02	<2.00E-02	<2.00E-02	<2.00E-02	<1.00E-03	<1.00E-03	<1.00E-03	<1.50E+00	34400	1.01	6.84	0.05	0.10	<1.00E-03
LBCOU011A	0.11	0.10	0.02	<5.00E-03	<2.00E-02	0.04	0.04	<2.00E-02	<2.00E-02	<2.00E-02	<4.00E-02	<2.00E-02	<2.00E-02	0.02	<1.00E-03	<1.00E-03	<1.00E-03	<1.50E+00	29400	0.01	5.10	<5.00E-03	1.14	<1.00E-03
LBCOU011B	2.12	0.18	0.05	<5.00E-03	<2.00E-02	0.04	0.04	<2.00E-02	<2.00E-02	<2.00E-02	<4.00E-02	<2.00E-02	<2.00E-02	<2.00E-02	1.48	<1.00E-03	<1.00E-03	1.48	26700	0.02	5.34	<5.00E-03	0.51	<1.00E-03
LBCOU018A	0.42	0.08	<9.09E-02	<4.54E-02	0.01	0.08	0.00	0.14	0.03	0.00	0.28	0.00	0.00	0.01	4.11	4.15	1.86	10.10	36500		51.80	<4.50E-02	0.14	<9.09E-03
LBCRM2.4OU009A	4.79	0.49			0.05	0.43	<4.00E-03	0.82	0.15	0.04	2.40	0.03	0.01	0.04	26.40	22.30	<1.00E-03	48.70	20400				1.99	
LBCRM2.4OU009B	5.21	0.60			0.09	0.53	<4.00E-03	0.99	0.19	0.05	2.83	0.03	0.03	0.04	44.60	34.40	<1.00E-03	79.00	128000				1.87	
X-230JOU010A	2.52	0.11			0.03	0.09	<4.00E-03	0.05	0.04	<2.00E-03	0.19	<2.00E-03	0.01	0.01	5.07	11.00	<1.00E-03	16.10	24800				0.82	
X-230JOU010B	1.31	0.09			0.02	0.05	<4.00E-03	0.07	0.03	<2.00E-03	0.39	0.00	<2.00E-03	0.01	<1.00E-03	3.44	<1.00E-03	3.44	26100				0.87	
X-230JOU016A	2.28	0.11			0.02	0.07	<4.00E-03	0.04	0.04	<2.00E-03	0.16	<2.00E-03	0.01	0.01	8.81	15.30	<1.00E-03	24.10	47100				1.09	
X-230JOU016B	1.43	0.09			0.01	0.05	<4.00E-03	0.02	0.02	<2.00E-03	0.08	<2.00E-03	0.00	0.00	<1.00E-03	<1.00E-03	<1.00E-03	<1.50E+00	39300				0.69	
X230JOU019A	0.06	0.06	21.70	2.29	0.39	1.63	0.10	1.14	0.73	<4.80E-02	4.81	<4.80E-02	<4.80E-02	0.17	70.70	154.00	<3.00E-03	224.00	28900	44.20	121.00	4.59	7.06	<1.00E-02
X-533OU012A	0.27	0.06			0.02	0.03	<4.00E-03	0.01	0.03	<2.00E-03	0.03	<2.00E-03	0.00	<2.00E-03	<1.00E-03	11.10	<1.00E-03	11.10	32800				0.62	
X-533OU012B	0.10	0.05			0.02	0.02	<2.00E-02	<9.79E-03	0.03	<1.00E-02	0.02	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-03	15.30	<1.00E-03	15.30	34600				0.34	
X-533OU013A	0.62	0.12			0.18	1.26	<4.00E-03	1.30	0.48	0.02	3.22	0.05	0.02	0.02	38.30	60.80	<1.00E-03	99.20	18300				1.86	
X-533OU013B	1.87	0.15			0.03	0.16	<4.00E-03	0.12	0.08	<2.00E-03	0.41	0.01	0.01	<2.00E-03	<1.00E-03	5.76	<1.00E-03	5.76	14600				0.57	

Units: grain size mm, Fe in mg/kg, TOC in %, TEQ in pg/g, all others in ppb or ug/kg, '<' denotes below detection level

Table 5.2a Descriptive statistics for sediment analysis

data in ug/kg, organic matter in mg/g	OCDD	1,2,3,4,6,7,8-HpCDD	PCB189	PCB156	PCB157	PCB105	PCB167	PCB114	PCB118	PCB123	PCB126	PCB77	Aroclor-1254	Aroclor-1260	Aroclor-1268	Aroclor-Total	TEQ (ND=0)	TEQ (ND=0.5)	Total HpCDD	Total TCDF	Total Organic Carbon
All sampling sites																					
average	1.742	0.342	0.065	0.263	0.030	0.468	0.143	0.031	1.171	0.028	0.011	0.035	20.415	23.090	2.247	38.543	0.003	0.027	0.603	0.006	12.840
max	**21.700**	2.290	0.392	1.630	0.095	2.420	0.729	0.073	**5.850**	0.090	0.028	0.170	70.700	154.000	2.630	224.000	0.044	0.121	4.590	0.011	70.600
min	0.016	0.006	0.006	0.004	0.004	0.006	0.019	0.003	0.004	0.003	0.002	0.003	1.480	3.440	1.860	1.480	0.000	0.005	0.006	0.001	0.641
SD	4.950	0.859	0.093	0.435	0.023	0.653	0.200	0.025	1.709	0.028	0.010	0.046	19.700	31.965	0.385	47.454	0.010	0.032	1.611	0.005	16.297
Surface sampling sites																					
average	2.787	0.588	0.078	0.328	0.033	0.485	0.171	0.028	1.263	0.029	0.011	0.038	20.327	30.739	2.247	48.415	0.015	0.03081	1.18155	0.005	17.704
max	**21.700**	2.290	0.392	1.630	0.095	1.810	0.729	0.073	4.810	0.061	0.025	0.170	70.700	154.000	2.630	224.000	0.044	0.12100	4.59000	0.011	70.600
min	0.020	0.007	0.006	0.004	0.004	0.006	0.026	0.005	0.004	0.004	0.002	0.000	4.110	4.150	1.860	10.100	0.001	0.00508	0.01380	0.001	1.410
SD	6.767	1.135	0.116	0.507	0.027	0.592	0.230	0.028	1.708	0.024	0.010	0.054	19.749	40.689	0.385	58.147	0.025	0.03863	2.27248	0.006	20.933
30 cm depth sampling sites																					
average	0.581	0.013	0.046	0.190	0.027	0.438	0.099	0.035	1.054	0.026	0.011	0.024	20.535	13.145		26.875	0.000	0.021	0.024	0.010	7.280
max	2.700	0.020	0.147	1.270	0.044	2.420	0.545	0.061	**5.850**	0.090	0.028	0.070	51.700	34.400	0.000	79.000	0.001	0.053	0.048	0.010	18.700
min	0.016	0.006	0.007	0.004	0.004	0.000	0.000	0.003	0.023	0.003	0.003	0.003	1.480	3.440	0.000	1.480	0.000	0.005	0.006	0.010	0.641
SD	0.861	0.007	0.048	0.339	0.018	0.761	0.157	0.026	1.787	0.033	0.012	0.026	20.993	9.784		29.077	0.000	0.023	0.019		4.947
Average surface/ average 30 cm	4.8	43.7	1.7	1.7	1.2	1.1	1.7	**0.8**	1.2	1.1	1.0	1.6	1.0	2.3		1.8	60.3	1.4	49.5	**0.5**	2.4

Table 5.2b HHRA type 1 and 2 screening levels (DOE 2012) and the exeedences of the maximum concentration determined from the descriptive statistics for the following parameters.

Type 1 and 2 HHRA screening values ug/kg (ppb)	Aroclor 1254	Total Aroclor and 1260, 1268	TCDD	OCDD	HpCDD	PCBs w/TEF 0.00003 *	PCB 126	PCB 77	max value ug/kg	OCDD	1,2,3,4,6,7,8-HpCDD	PCB 189	PCB 156	PCB 157	PCB 105	PCB 167	PCB 114	PCB 118	PCB 123	PCB 126	PCB 77	Aroclor 1254	Aroclor 1260	Aroclor 1268	Aroclor Total
										21.700	2.290	0.392	1.630	0.095	2.420	0.729	0.073	5.850	0.090	0.028	0.170	70.7	154.0	2.630	224.0
Type 1										**Type 1**															
resident	3370.0	22100.0	0.216	720.0	21.6	7200.0	2.16	2160.0		pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
soil-to-gw	163.0	176.0	0.299	996.7	29.9	9966.7	2.99	2990.0		pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	Exceed
outer worker	35400.0	82600.0	2.040	6800.0	204.0	68000.0	20.40	20400.0		pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
industrial worker	123000.0	286000.0	4.400	14666.7	440.0	146666.7	44.00	44000.0		pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
Type 2										**Type 2**															
resident	112.0	221.0	0.004	15.0	0.4	149.7	0.04	44.9		Exceed	Exceed	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	Exceed
soil-to-gw	8.2	8.8	0.015	50.0	1.5	500.0	0.15	150.0		pass	Exceed	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	Exceed	Exceed	pass	Exceed
outer worker	1180.0	826.0	0.020	68.0	2.0	680.0	0.20	204.0		pass	Exceed	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass
industrial worker	4090.0	2860.0	0.044	146.7	4.4	1466.7	0.44	440.0		pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass	pass

*** Dioxin-like PCBs with TEF value of 0.00003 include: PCB 105, 114, 118, 123, 156, 157, 167, 189**

The corrected data is presented in Table 5.3, and the descriptive statistics for these new data is presented in Table 5.4. The normalized data show, again, a wide range of values for the different contaminants as well as a large standard deviation. Other than the Aroclors, the contaminant OCDD occurs in higher concentrations per kilogram of organic carbon in the total data analysis, as well as in the separate surficial and 30 cm deep sample data analysis. For this contaminant, the average concentration per kilogram of organic carbon (OC) is higher for the deeper sediments than for the surficial sediments (2.842 and 1.123 ug/kg of OC, respectively). In a similar way, the ratios of concentration in the surficial sediments divided by the concentration in the 30 cm depth sediments show values lower than 1 for all the analyzed contaminants, with the exception of the dioxins 1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin and Total Heptachlorodibenzo-p-dioxin (ratio equal to 1.3 and 1.5, respectively). These results suggest that the majority of the contaminants are retained in the surficial layer of sediments due to sorption processes and high concentration of organic carbon. However, at depth, the average concentrations of contaminants per kilogram of OC, are higher than at the surface suggesting that some of the contaminants have migrated downward from the surficial layer and have been sorbed on a smaller fraction of OC. Of the three dioxins, OCDD behaves similar to the other compounds, but 1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin and Total Heptachlorodibenzo-p-dioxin are strongly attached to the OC at the surface, migration has not moved enough Heptachlorodibenzo-p-dioxins to increase the normalized concentrations at depth.

Water samples were collected and analyzed at the sampling sites, results for total alkalinity; nitrate, ammonia, pH, and sulfate are presented in Appendix E together with their descriptive statistics. Phosphate is not reported because it was below the detection level of the laboratory. Total alkalinity is the same as carbonate alkalinity for these waters. All the values were below the standards for drinking water.

Table 5.3 Laboratory analysis results of sediment samples normalized by total organic carbon. Blank cells signify values below detection limits and normalized value could not be generated.

Data in ug/kg of OC	OCDD	1,2,3,4,6,7,8-HpCDD	PCB189	PCB156	PCB157	PCB105	PCB167	PCB114	PCB118	PCB123	PCB126	PCB77	Aroclor 1254	Aroclor 1260	Aroclor 1268	Aroclor-Total	Total HpCDD	Total TCDF
LBCOU001A	3.98	0.26	1.68	15.42	0.10	27.63	5.62	1.11	67.48	0.93	0.38	1.48	387.79	458.02		845.80	0.59	0.17
LBCOU001B	19.42		0.85	6.25	0.49	10.23	2.32	0.39	27.02	0.31	0.36	0.62	399.28	597.10		995.17	0.74	
LBCOU002A	5.48		0.28	2.75	0.16	7.43	1.11	0.32	17.43	0.28		0.56	529.41	448.53		977.94		0.05
LBCOU002B	29.83	0.67	17.33	149.76	0.44	285.38	64.27	7.23	689.86	10.66		8.21	779.48	1002.36		1780.66	1.38	1.13
LBCOU003A	2.67			0.51	0.51				0.61									
LBCOU003B	1.78			0.50	0.50													
LBCOU004A	12.81			11.67	4.18	23.33	4.92	0.00	50.73				1166.67	1270.83		2447.92		
LBCOU004B	22.63			24.30	4.86	55.18	8.41	2.94	131.55	2.55		2.47	810.48	1050.17		1861.76		
LBCOU005A	84.24			11.52	11.52	27.91			62.42				3060.61	2800.00	796.97	6636.36		
LBCOU005B	342.51	5.23		14.67	14.67	18.92			39.37				18013.94	7735.19		25714.29	10.52	
LBCOU006A	47.80	3.33	12.00	138.05	20.54	220.00	40.00		440.00				4443.90	4107.32	1097.56	9658.54	6.73	0.58
LBCOU006B	166.93			101.25	53.35	173.17	37.44		390.02				14524.18	12137.29		26677.07		
LBCOU007A	58.96		1.51	3.49	2.61	2.35	2.28		6.42					2826.59		2826.59		
LBCOU007B	51.79		3.74	8.28	2.70	5.79	5.27		16.55				2758.62	1358.62		4117.24		
LBCOU008A	1122.99	9.84		11.20	11.20												22.41	
LBCOU008B	2842.11	20.63		40.74	40.74												50.00	
LBCOU011A	1.72			3.29	3.29							1.85						
LBCOU011B	10.16			7.28	7.28								291.91			291.91		
LBCOU018A			4.45	57.23	2.66	96.45	18.16	3.33	197.16	2.79	1.35	3.64	2914.89	2943.26	1319.15	7163.12		
LBCRM2.4OU009A			2.34	21.56		41.26	7.59	1.78	120.60	1.43	0.67	2.09	1326.63	1120.60		2447.24		
LBCRM2.4OU009B			4.58	28.34		53.10	10.32	2.69	151.34	1.57	1.51	1.96	2385.03	1839.57		4224.60		
X-230JOU010A			3.39	10.34		5.97	4.84		22.82		0.64	0.68	615.29	1334.95		1953.88		
X-230JOU010B			1.84	5.84		7.78	3.34		45.27	0.32		0.72		397.23		397.23		
X-230JOU016A			1.64	6.17		3.58	3.25		14.50		0.60	0.53	808.26	1403.67		2211.01		
X-230JOU016B			1.42	6.55		2.71	3.12		11.52		0.51	0.40						
X230JOU019A	307.37	32.44	5.55	23.09	1.35	16.15	10.33		68.13			2.41	1001.42	2181.30		3172.80	65.01	
X-533OU012A			3.05	4.39		0.97	4.37		4.40		0.47			1790.32		1790.32		
X-533OU012B			7.04	5.80			8.20		6.72					4526.63		4526.63		
X-533OU013A			9.46	67.74		69.89	25.54	0.97	173.12	2.45	1.26	1.21	2059.14	3268.82		5333.33		
X-533OU013B			4.97	28.67		20.45	13.81		71.33	1.84	1.49			1006.99		1006.99		

Table 5.4 Descriptive statistics of sediment data normalized for total organic carbon.

DATA in ug/kg of OC	**OCDD**	**1,2,3,4,6,7,8-HpCDD**	**PCB189**	**PCB156**	**PCB157**	**PCB105**	**PCB167**	**PCB114**	**PCB118**	**PCB123**	**PCB126**	**PCB77**	**Aroclor-1254**	**Aroclor-1260**	**Aroclor-1268**	**Aroclor-Total**	**TEQ (ND=0)**	**TEQ (ND=0.5)**	**Total HpCDD**	**Total TCDF**
All sampling sites																				
average	270.273	10.342	4.585	27.221	9.157	51.115	12.931	2.308	113.054	2.285	0.841	1.922	3067.21	2504.58	1071.23	4960.77	0.133	7.966	19.673	0.483
max	2842.105	32.436	17.335	149.764	53.354	285.377	64.269	7.229	689.858	10.660	1.513	8.208	18013.94	12137.29	1319.15	26677.07	1.063	81.279	65.014	1.125
min	1.719	0.260	0.278	0.495	0.098	0.971	1.110	0.321	0.613	0.283	0.364	0.397	291.91	397.23	796.97	291.91	0.001	0.096	0.589	0.051
SD	675.281	12.005	4.312	38.757	14.241	75.357	15.742	2.149	164.863	2.925	0.461	1.974	4824.43	2690.65	262.08	6938.07	0.280	19.009	24.760	0.484
Surface sampling sites																				
average	164.804	11.466	3.588	21.377	5.283	39.419	9.314	1.637	82.515	1.360	0.685	1.655	1625.49	1890.45	1071.23	3510.96	0.167	5.120	23.685	0.269
max	1122.995	32.436	12.000	138.049	20.537	220.000	40.000	3.333	440.000	2.794	1.348	3.638	4443.90	4107.32	1319.15	9658.54	0.626	36.738	65.014	0.580
min	1.719	0.260	0.278	0.512	0.098	0.971	1.110	0.321	0.613	0.283	0.382	0.532	387.79	448.53	796.97	845.80	0.007	0.096	0.589	0.051
SD	349.137	14.540	3.333	35.156	6.459	62.680	11.202	1.279	120.853	1.066	0.343	1.080	1365.31	1106.77	262.08	2768.94	0.255	10.649	29.043	0.277
30 cm depth sampling sites																				
average	387.462	8.844	5.221	30.588	13.892	63.272	15.648	3.314	143.685	2.876	0.970	2.396	4995.36	3165.11		6508.50	0.150	11.443	15.661	
max	2842.105	20.632	17.335	149.764	53.354	285.377	64.269	7.229	689.858	10.660	1.513	8.208	18013.94	12137.29		26677.07	1.063	81.279	50.000	
min	1.781	0.675	0.852	0.495	0.441	2.713	2.316	0.394	6.716	0.311	0.364	0.397	291.91	397.23		291.91	0.001	0.591	0.742	
SD	927.103	10.459	5.314	42.917	19.587	93.239	19.924	2.851	212.367	3.914	0.619	2.964	7077.45	3891.92		9854.43	0.346	26.300	23.325	
Average surface/ average 30 cm	0.4	1.3	0.7	0.7	0.4	0.6	0.6	0.5	0.6	0.5	0.7	0.7	0.3	0.6		0.5	1.1	0.4	1.5	

5.2 Duplicate Sample Differences

One set of duplicate samples was taken during the March 2012 sampling event. The analytical results for the duplicate samples were not consistent with each other (see results for samples LBCOU006 and LBCOU018). Congener analyses were typically 70-90% different, with only six congeners found in both samples while five congeners were found in only one of the samples; however, concentrations were very low, ranging from 0.006 ppb to 0.902 ppb. The difference in total Aroclor was 49%, while specific Aroclors showed analytical differences between the duplicate samples of 17-55%; the concentrations of Aroclors were also low, ranging from 1.86 ppb to 9.11 ppb for individual Aroclors and from 10.1 ppb to 19.8 ppb for total Aroclor. The percent difference in iron was 18%, with concentrations ranging from 30,900,000 ppb to 36,500,000 ppb, and in total organic carbon was 31%, with concentrations varying from 1,410,000 ppb to 2,050,000 ppb. The difference between the WHO2005 analyses was over 900%, although the concentrations were very low, varying from 0.00508 ppb to 0.518 ppb. Total Heptachlorodibenzo-p-dioxin was only detected in one of the samples at a level of 0.0138 ppb.

There are several potential explanations for the discrepancy between the samples. Even though samples were taken from the same location, a large quantity of soil or sediment was extracted and homogenized by only by hand. In the clayey, wet sediments, homogenization was difficult to achieve and it is likely that the samples were not truly homogenized before they were split into separate sample containers. Beyond the heterogeneity of the larger sample that was split, sub-sampling in the laboratory could compound the inherent heterogeneity of the clayey sediments. During analysis, PCBs are typically extracted from the sub-sample using organic solvents and heat. The accuracy and precision of extraction depend upon the sample matrix, sample preparation, cleanup and calibration (USEPA, 2007a and 200b). At the low concentrations found in this study, varying extraction efficiencies caused by varying sample matrix could account for differences between the duplicate samples.

5.3 Analysis of the Complete Suite of 209 Congeners

LBCOU003, the site selected for the full 209 congeners analysis proved to be nearly non-detect for all PCBs congeners and Aroclors. Congeners above detection level were less than 5 ppt in concentration and represented congeners that are found in Aroclors 1260, 1254, and 1248 (Appendix C).

5.4 Correlation Between Variables

The possible correlation between the different variables that were determined in the laboratory was investigated. The non-normalized and the TOC normalized data were investigated for possible correlations. First, the correlation matrix was created with the Data Analysis tools of EXCEL and the Pearson correlation coefficient ‘r’ was obtained for every pair of variables. The test of significance of the correlation coefficient (Davis, 2002) was applied to determine the level of significance of the different ‘r’ values. With the r values and the number of data points ‘n’ for each pair of variables, the statistic student t-values were found using the following equation:

$$t = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}}$$

This t-value was used to find the p-value corresponding to the correlation of the pair of variables, values of p lower than 0.05 are considered statistically significant. Appendix F presents the results of the p-values for the correlation of all the different variables for the non-normalized and the TOC normalized data. For the average grain size and the average grain size for the fraction smaller than 2 mm, only iron was significantly correlated. More pairs of parameters were correlated for the non-normalized data than for the normalized data. For the non-normalized data the compound OCDD was significantly correlated with all the other compounds except Aroclor 1268. The OCDD was correlated only with 2,3,3',4,4',5'-Hexachlorobiphenyl (157), Aroclor-1260, and Total Heptachlorodibenzo-p-dioxin. The chlorobiphenyl congeners were generally significantly correlated between them for the non-normalized and the TOC normalized data. These significant correlations for the dioxins and the chlorobiphenyl congeners suggest a common contamination source.

The water chemistry data collected in this investigation was also analyzed to see if some correlation existed between the concentration of contaminants and chemistry of the water. Only nitrate, ammonia, and pH were found to have significant correlation with some of the contaminants. Nitrate was well correlated ($p<0.05$) with 2,3,3',4,4',5-Hexachlorobiphenyl (156), 2,3,4,4',5-Pentachlorobiphenyl (114), 2',3,4,4',5-Pentachlorobiphenyl (123), and alkalinity. Ammonia has a significant correlation with the average grain size, 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin, 3,3',4,4',5-Pentachlorobiphenyl (126), 3,3',4,4'-Tetrachlorobiphenyl (77), Aroclor 1260, Total Aroclor, and alkalinity. pH was well correlated with 2,3,4,4',5-Pentachlorobiphenyl (114) and Aroclor 1254.

5.5 Average Grain Size of Collected Sediments

Grain size analysis was done on each of the collected sediment samples. Data is shown in Table 5.5. The average grain size for each sediment sample was calculated in the following way:

$$X_i = (\text{Grain size sieve } A + \text{Grain size sieve } B)/2$$

$$X = \sum_{i=1}^{n} X_i . f_i$$

where, X_i is the average grain size of size fraction i, *Grain size sieve A* is the upper grain size limit for fraction i, and *Grain size sieve B* is the lower grain size limit for fraction i, f_i is the fraction of the total sediment weight in each sieve and is the average grain size for the sediment sample. Average grain sizes for the total sediments and for sediments smaller than 2 mm were found. Figure 5.1 shows a graph of the average grain size for the fraction smaller than 2 mm versus the average grain size for all the sediment samples. Figure 5.1 shows that the grain size of the smaller fraction of sediments increases as the average grain size of the whole sample increases in a more or less linear trend, except for the samples with very large grain size (gravel). This behavior suggests that the grain size composition of the finer fraction of sediments is larger when the sediments are coarser.

Table 5.5 Average grain size and average grain size lower than 2mm

Sample	Average grain size (mm)	Average grain size lower than 2mm (mm)
X-533OU012A	0.27	0.06
X-533OU012B	0.10	0.05
X-533OU013A	0.62	0.12
X-533OU013B	1.87	0.15
X-230JOU010A	2.52	0.11
X-230JOU010B	1.31	0.09
X-230JOU016A	2.28	0.11
X-230JO6016B	1.43	0.09
LBCRM2.4OU009A	4.79	0.49
LBCRM2.4OU009B	5.21	0.60
LBCOU001A	0.57	0.09
LBCOU001B	8.75	0.18
LBCOU002A	3.14	0.25
LBCOU002B	8.06	0.34
LBCOU003A	0.05	0.04
LBCOU003B	0.18	0.04
LBCOU004A	2.58	0.43
LBCOU004B	9.53	0.47
LBCOU005A	2.57	0.17
LBCOU005B	1.89	0.23
LBCOU006A	0.66	0.08
LBCOU018A	0.42	0.08
LBCOU006B	0.36	0.06
LBCOU007A	2.65	0.10
LBCOU007B	0.68	0.10
LBCOU008A	0.32	0.06
LBCOU008B	0.61	0.07
LBCOU011A	0.11	0.10
LBCOU011B	2.12	0.18
X230JOU19A	0.06	0.06

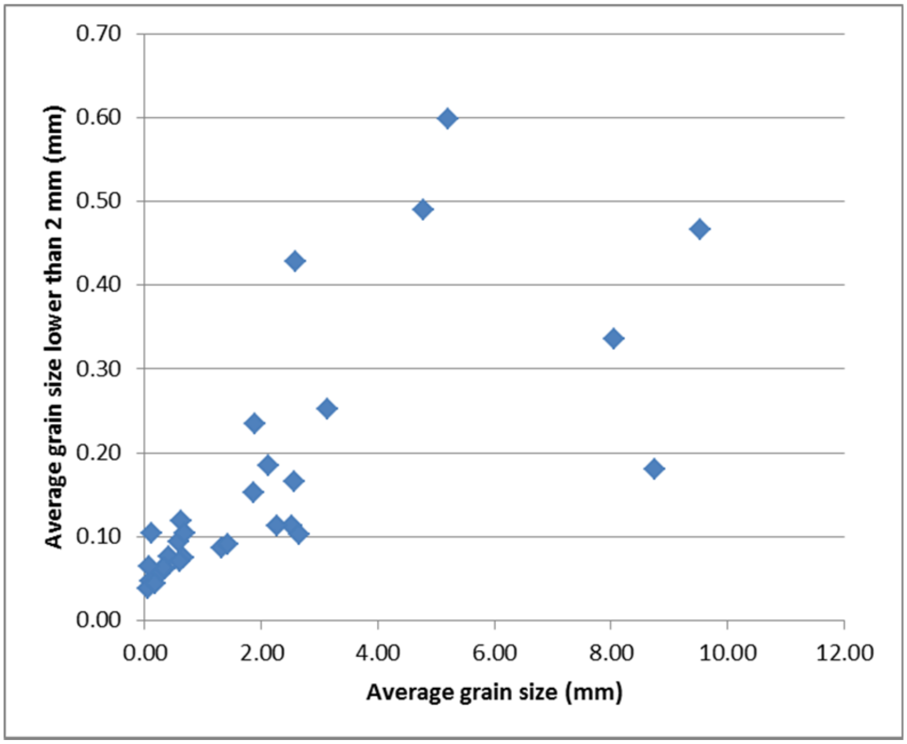

Figure 5.1. Average grain size for the fraction of sediments smaller than 2 mm versus the average grain size of the whole sample. A lineal trend is observed for the samples of moderate or small average grain size. The three samples with large average grain size do not fall in the main trend, indicating that samples with extremely high average grain size behave different

5.6 Sediment Composition of Collected Samples

Sites X-533OU012, LBCOU008, and LBCOU003 contain the highest percent of the finest particle sizes, clays, (Figure 5.2) with average grain size for the fraction lower than 2 mm at 0.06/0.05 mm, 0.06/0.07 mm, and 0.04/0.04 mm, respectively (surface/subsurface) (Figure 5.3). All three of these sites evidently also exhibited very low PCB concentrations, near non-detection level, for many of the congeners measured (Figure 5.4). Whereas, sample sites containing higher average grain size also have higher concentrations of congeners. For example, stream substrate at site LBCRM2.4OU009 contains a large percentage of sand and shows a concentration of 0.82 and 0.99 ug/kg of PCB105 at the surface and subsurface respectively and 48.7 and 79.0 ug/kg of Total Aroclor at the surface and subsurface, respectively (Figure 5.5 and 5.6). However, site LBCOU008, just downstream of site LBCRM2.4OU009, where clay and silt composition dominate the substrate with an average size < 2mm value at 0.06 mm at the surface shows PCB118 and Total Aroclor are below detection level.

From the accumulative frequency graphs for grain size provided by Shaw Environmental and Infrastructure Group as part of our data package, the clay fraction was calculated (fraction lower than 2 um in diameter). Correlation coefficient and their p-values were calculated to determine which correlations between clay fraction and concentration of the different PCB congeners, Aroclors and dioxins were statistically significant (Appendix G). There was an inverse relationship with congeners PCB118, 105, 156 as well as total organic carbon (TOC), p-values for PCB118, 105, 156, and TOC were 0.012, 0.029, 0.058, and 0.032 respectively. In all these correlations the correlation coefficients were negative, indicating that the concentration of the chemical extracted from the sediments decreases with the clay content. This result is unexpected because clays and organic carbon have been found to sorb strongly these organic contaminants (Thibodeaux, 1996). This data suggests one of two possibilities. Either no PCBs are found at these sites because they did not migrate to these sampling locations or the PCBs bind so strongly to clay that the extraction efficiencies in the laboratory are low especially at the low concentrations of PCB found in this area. The second possibility is more likely the case since it is well documented that adsorption of PCBs increase as organic matter and clay increase (USEPA, 1980, Erickson, 1997). In addition, Uzgiris et al., 1995 described that during thermal desorption a certain fraction of PCBs remain bound to the montmorillonite clay soils, the recalcitrant fraction is presumably tightly bound in the intercrystalline water layers of the clays. Guidance provided in USEPA's standard method 8082A for Aroclors states the extraction efficiencies for clays range from 28 to 99 (n=6) for Aroclor 1254 and from 61-113 (n=6) for Aroclor 1260 both at a spiked concentration of 5 ppm. While, the extraction efficiencies in soils range from 63-70 (n=5) for Aroclor 1254 and from 82-98 (n=7) for Aroclor 1260 at 5 ppm (USEPA, 2007). The low levels of PCBs found in the other samples suggests that the presence of abundant clay can affect the desorption process even more than high 5 ppm the USEPA found.

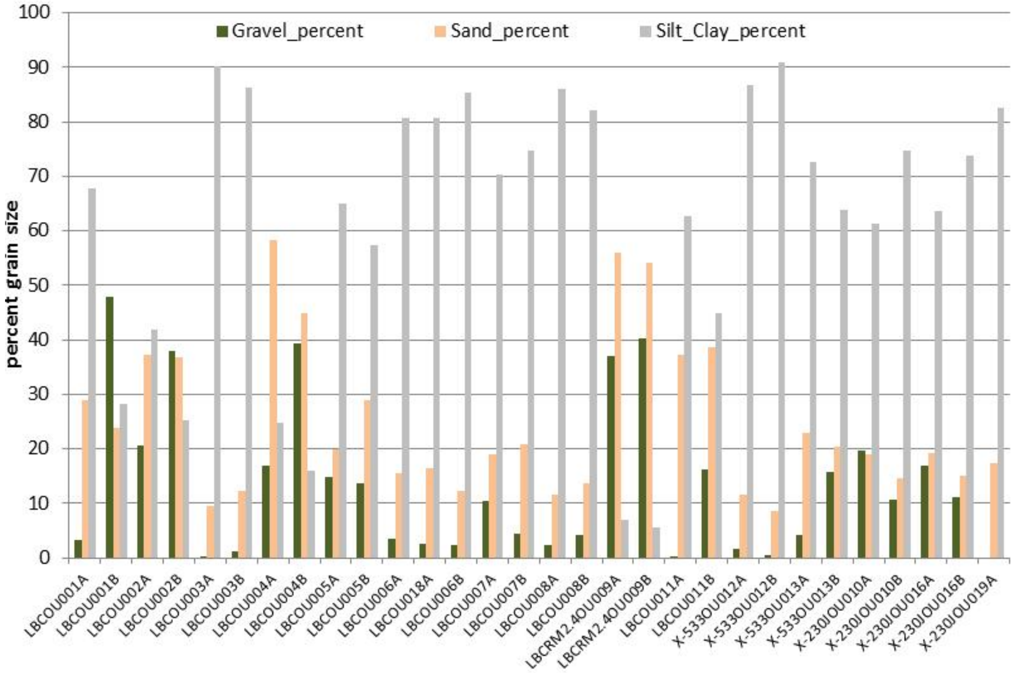

Figure 5.2 Percent grain size at each site, 'A' denotes samples collected at the surface 0-10 cm, while 'B' denotes samples collected at the subsurface, 20-30 cm

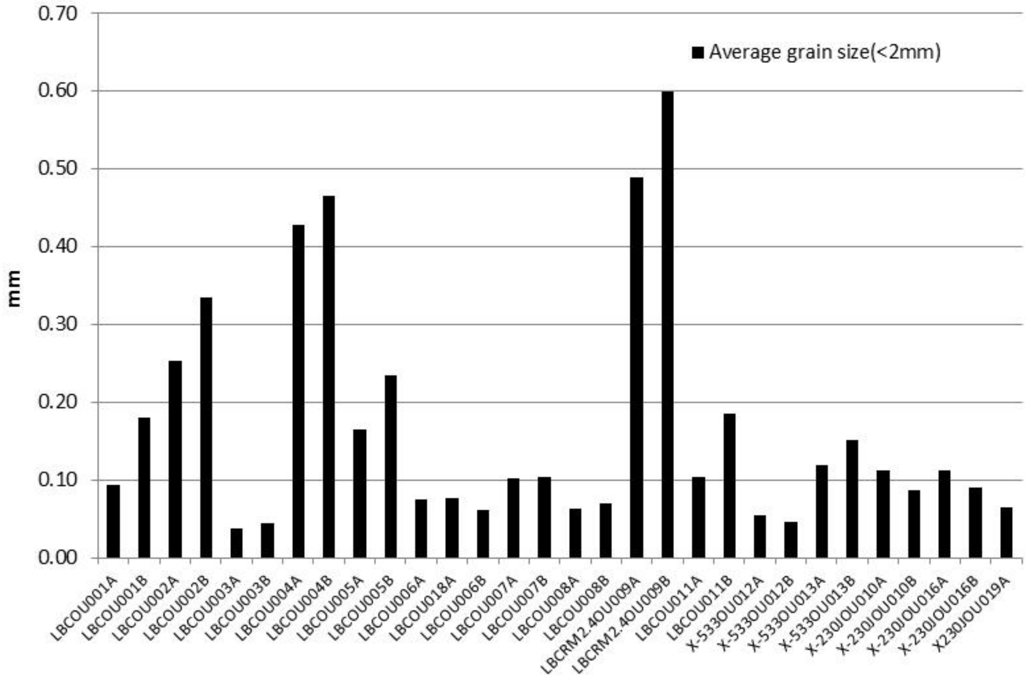

Figure 5.3 Average grain size <2 mm at sites, 'A' denotes samples collected at the surface 0-10 cm, while 'B' denotes samples collected at the subsurface, 20-30 cm

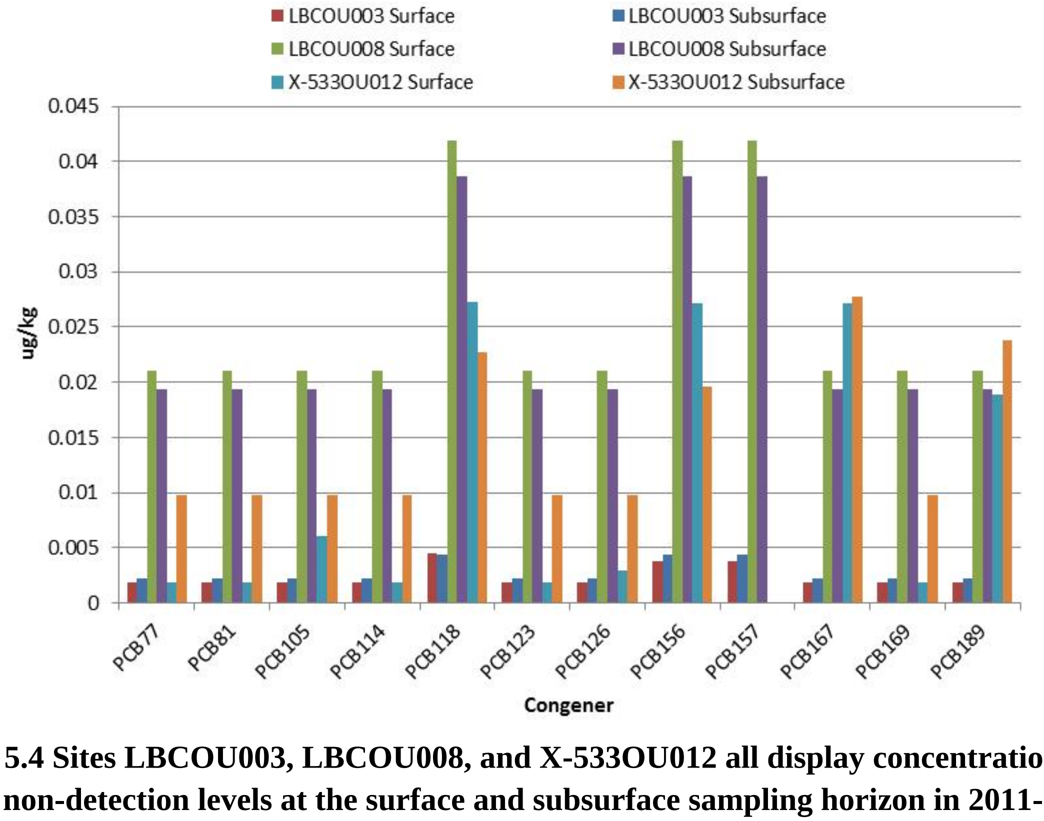

Figure 5.4 Sites LBCOU003, LBCOU008, and X-533OU012 all display concentration near or at non-detection levels at the surface and subsurface sampling horizon in 2011-2012

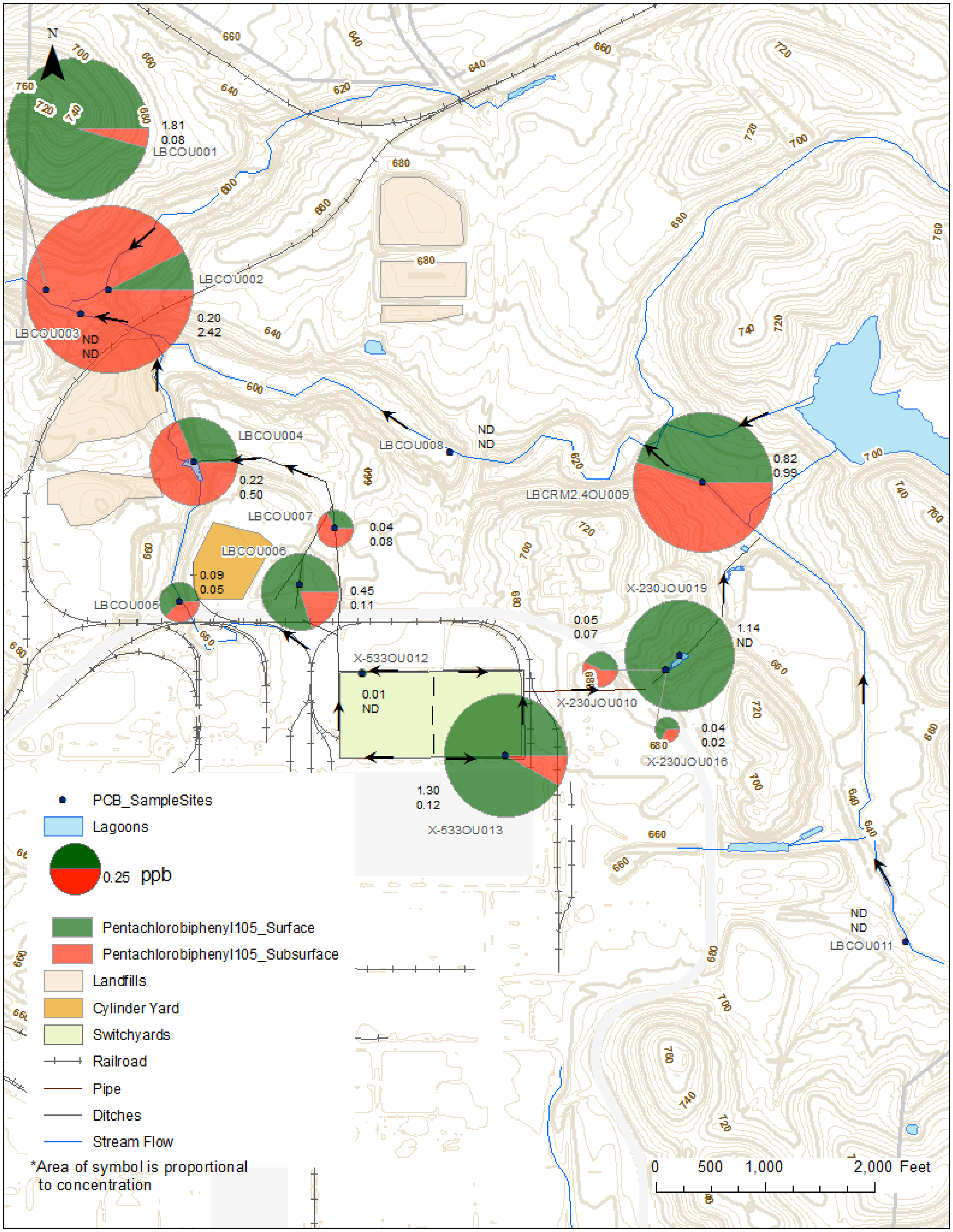

Figure 5.5 Concentrations ug/kg (ppb) of PCB105 shown in pie chart at the surface (green) and subsurface (red) at each study area site collected in 2011-2012 at PORTS, size is proportional to concentration

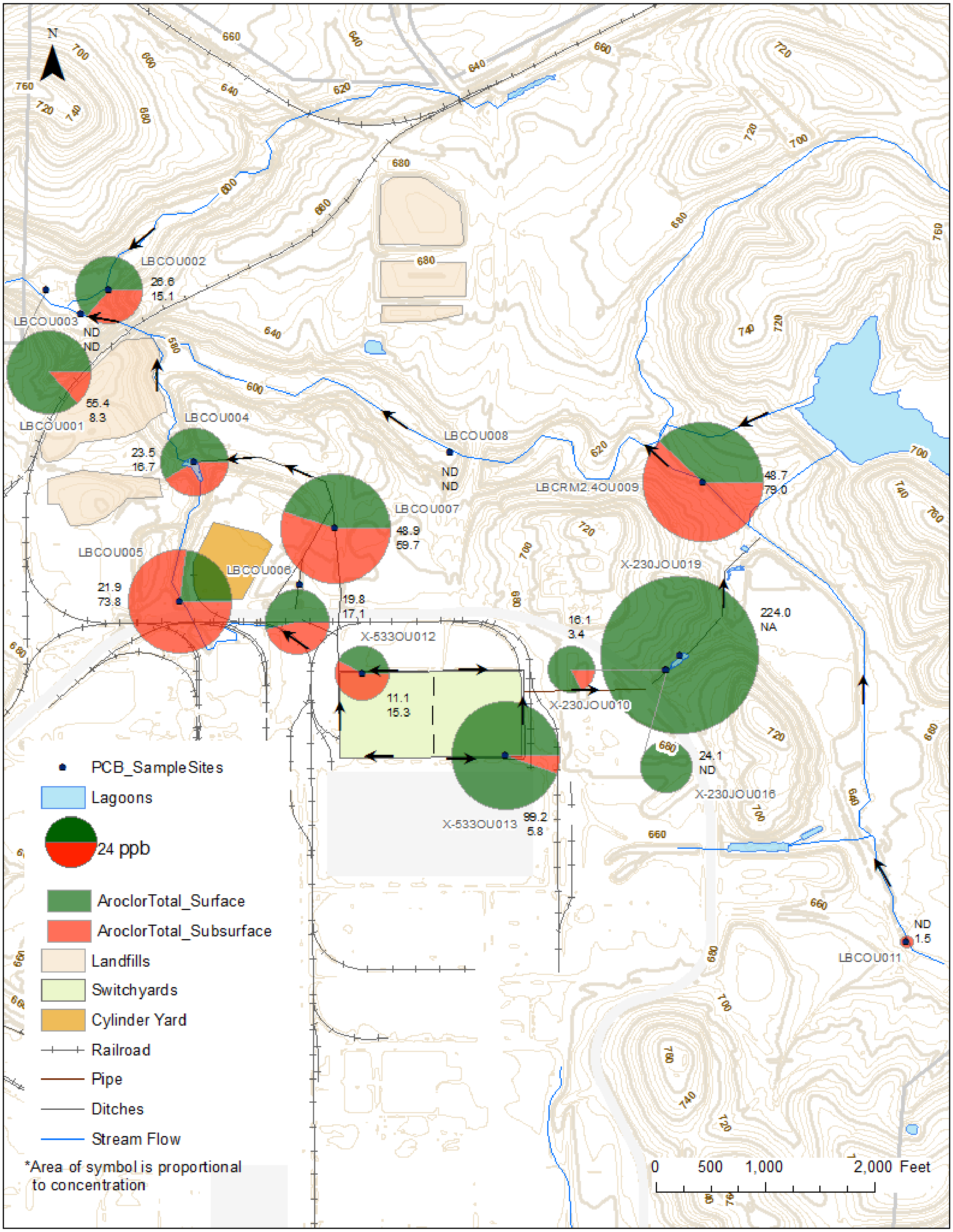

Figure 5.6 Concentrations ug/kg (ppb) of Total Aroclor shown in pie chart at the surface (green) and subsurface (red) at each study area site collected in 2011-2012 at PORTS, size is proportional to concentration

5.7 Signature Set of Congeners

Of the dioxin-like PCBs analyzed, a set of signature congeners are consistently found across the study area sites: PCB105, 118, 156, 167, and 189. The suite of congeners presents themselves consistently at varying ranges of concentrations. Figure 5.7, site X-230JOU010, shows the same set of congeners present at an order of magnitude lower concentrations (Figures 5.8 and 5.9). Of the suite of congeners found, PCB118 was shown as having the highest concentrations consistently across the sampling area (Table 5.1).

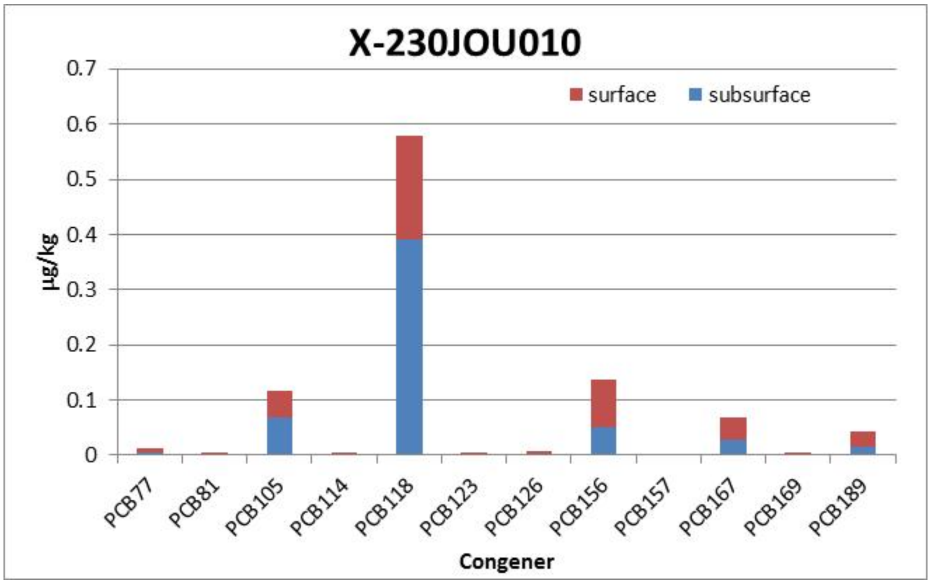

Figure 5.7 Site X-230JOU010 concentrations of dioxin-like PCBs at the surface and subsurface, signature set of congeners PCB105, 118, 156, 167, 189, ranging from 0 to 0.392 ug/kg

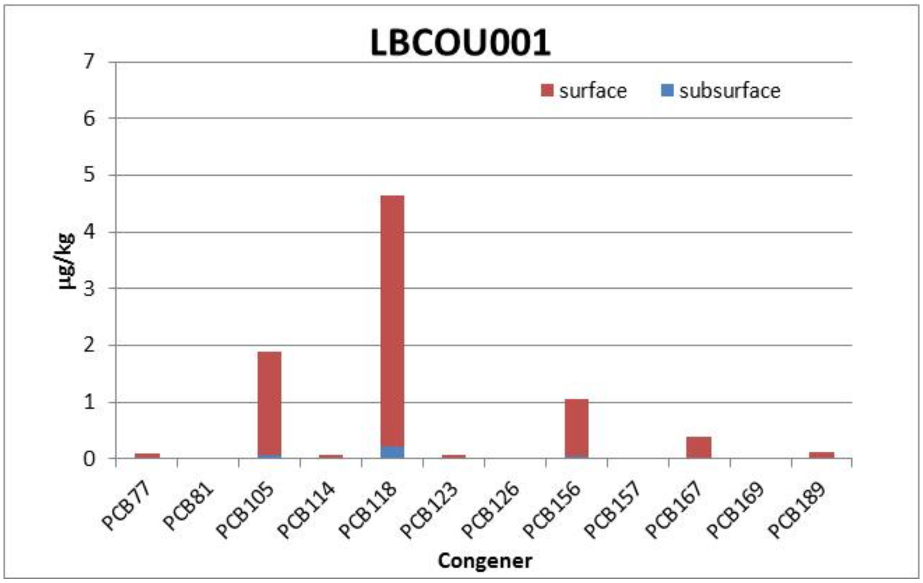

Figure 5.8 Site LBCOU001 concentrations of dioxin-like PCBs at the surface and subsurface, signature set of congeners PCB105, 118, 156, 167, 189, ranging from 0 to 4.42 ug/kg

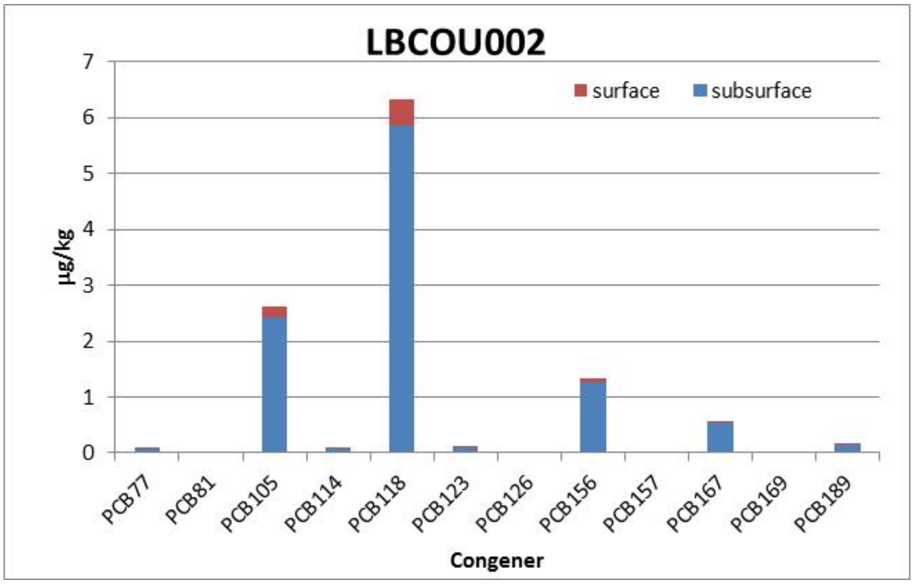

Figure 5.9 Site LBCOU002 concentrations of dioxin-like PCBs at the surface and subsurface, signature set of congeners PCB105, 118, 156, 167, 189, ranging from 0 to 5.85 ug/kg

5.8 Comparison Between Contaminant Composition of Surficial and Subsurface Sediment

The comparison between average concentration of the different contaminants studied in this research for the samples collected at the surface and the samples collected at 20-30 cm depth suggested that for the majority of the non-normalized data, the surficial sediments had a higher average concentration than the deeper samples, and that for the TOC normalized data, the deeper samples have a higher average concentration. However, those average values were found considering all the samples collected at the surface and all the samples collected at depth without considering that at some points a particular contaminant was detected only in one of the samples instead of both. If the concentration at every point where the contaminant has been detected in both samples is considered, a different behavior is observed. Figure 5.10 shows the concentration of TOC and selected contaminants (e.g., 2,3,3',4,4',5-Hexachlorobiphenyl (156) and Total Aroclor) at the surface versus the concentration at 30 cm depth for non-normalized data. Figure 5.10, Total Organic Carbon, shows that the TOC content is considerably higher at the surface than at 30 cm depth and that the contaminants present a more dispersed behavior but with the higher concentrations often occurring in the deeper sample, especially for some samples with the highest concentrations. This behavior seems to be enhanced when the TOC normalized data is considered. Figure 5.11 shows the concentration at 30 cm depth versus the surficial concentration for the contaminants 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin, 2,3,3',4,4',5-Hexachlorobiphenyl (156), and Total Aroclor. Most samples present a higher concentration per kilogram of organic matter at 30 cm depth than at the surface. Similar behavior is observed for the other congeners. This behavior suggests that for some of the sampling points, vertical migration of the contaminants has happened. As the depth of the sampled sediments is only 30 cm, further sampling is needed at a greater depth to know if there are greater concentrations at depth.

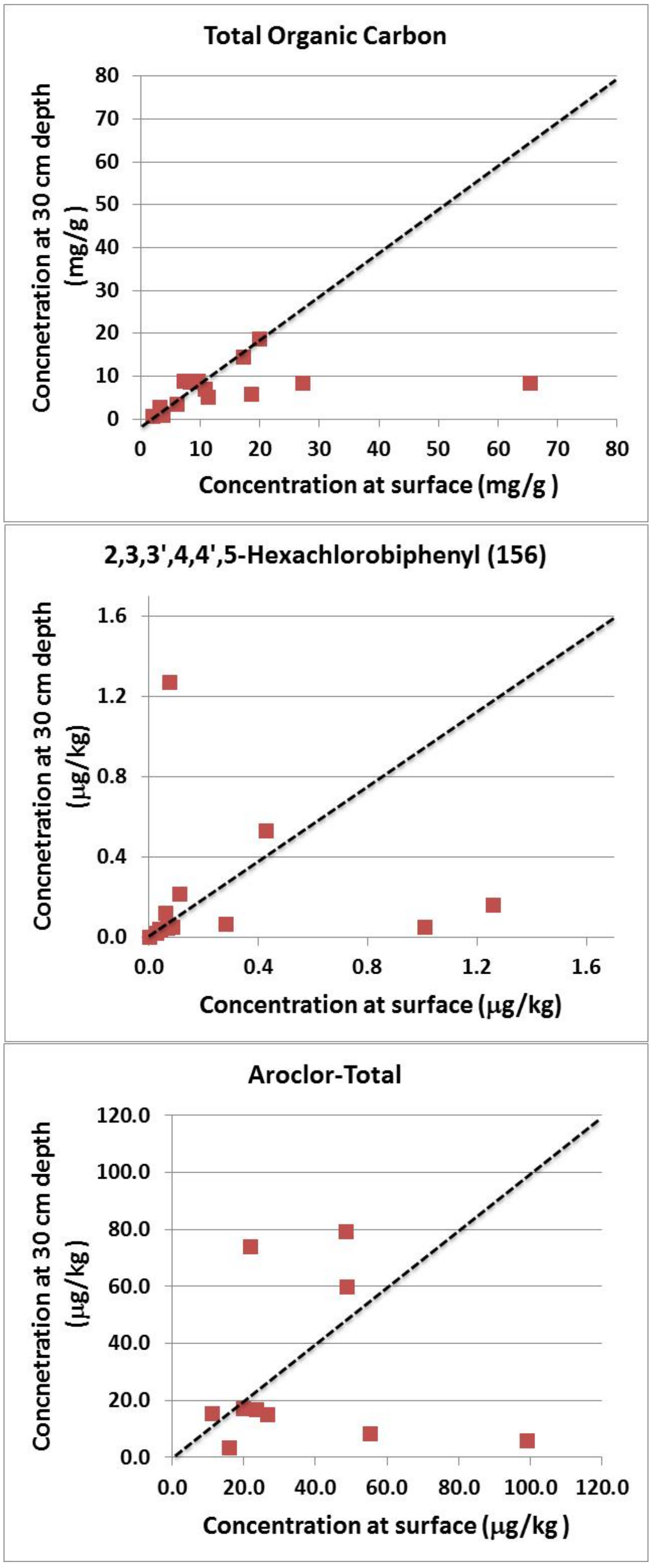

Figure 5.10 Bivariate diagrams for non-normalized chemical composition of sediments collected at PORTS. Units are microgram of chemical /kg of sediment, and for organic carbon, mg of organic carbon/g of sediment

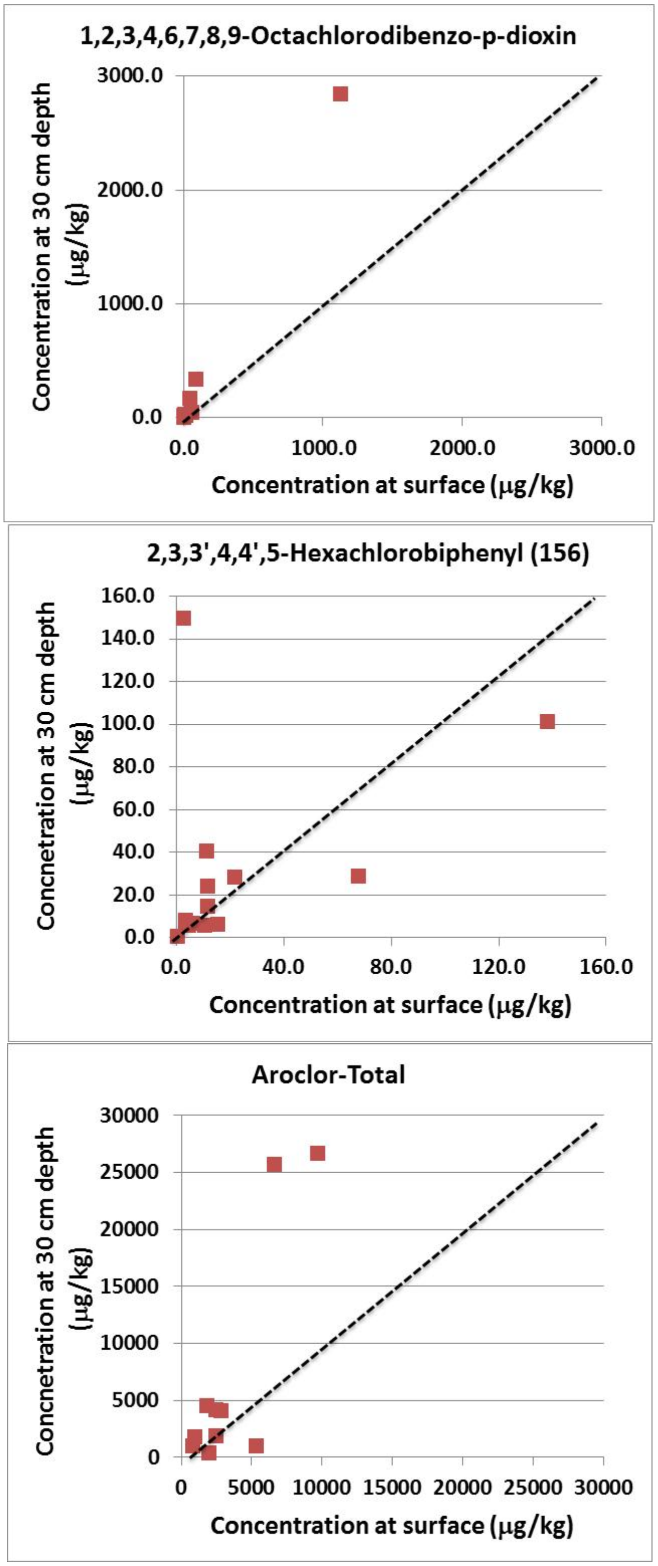

Figure 5.11 Bivariate diagrams for TOC normalized chemical composition of sediments collected at PORTS. Units are microgram of chemical /kg of organic carbon

Higher concentrations of PCB118 are typically found at the surface (0-10 cm) at sites that have a lower residence time (e.g. creeks with moving water, see Table 5.12). While sites that inherently have long residences times (e.g. holding ponds, stagnant backwaters), display higher concentrations of PCB118 in the subsurface horizon (30 cm) (Figure 5.12 and Table 5.1). With the exception of site LBCRM2.4OU009, that showed nearly equal concentrations at the surface as in the subsurface. Movement and storage of congener PCB118 as a function of residence time along drainage ditches, streams, and holding ponds can be explained by the data collected as part of this study. Given the appropriate residence time, PCBs are more likely to accumulate in the deeper soil horizon providing long-term storage and/or a source of slow continual release (Garvey et al., 2002). LBCOU002 could be providing a continual source of PCBs from its sediment to downstream sites LBCOU001. Where site LBCOU002, a stagnant backwater area, displays higher concentrations of the suite of congeners detected in study area samples in the subsurface horizon (Figure 5.9), while site LBCOU001, a site located in Little Beaver Creek with continual movement of water has higher concentrations of PCBs at the surface (Figure 5.8).

Table 5.6 Shows sample sites with concentrations of congener PCB118 greater than 1 ug/kg either at the surface or subsurface sample and their occurrence of greater values at the surface (0-10 cm) or subsurface (20-30 cm) horizon according to their site type.

Site	Surface PCB118 (ug/kg)	Subsurface PCB118 (ug/kg)	Site type	Long residence time
LBCOU001	4.420	0.224	Creek sed. moving water	No
LBCOU002	0.474	5.850	Creek sed. backwater stagnant	Yes
LBCOU004	0.487	1.180	Soft sed. inlet to holding pond	Yes
LBCRM2.4OU009	2.400	2.830	Creek sed. moving water	No
X-533OU013	3.220	0.408	Mucky wet sediment in ditch	No
X-230JOU019	4.810	Surface only sample	Sludge bottom of holding pond	Yes

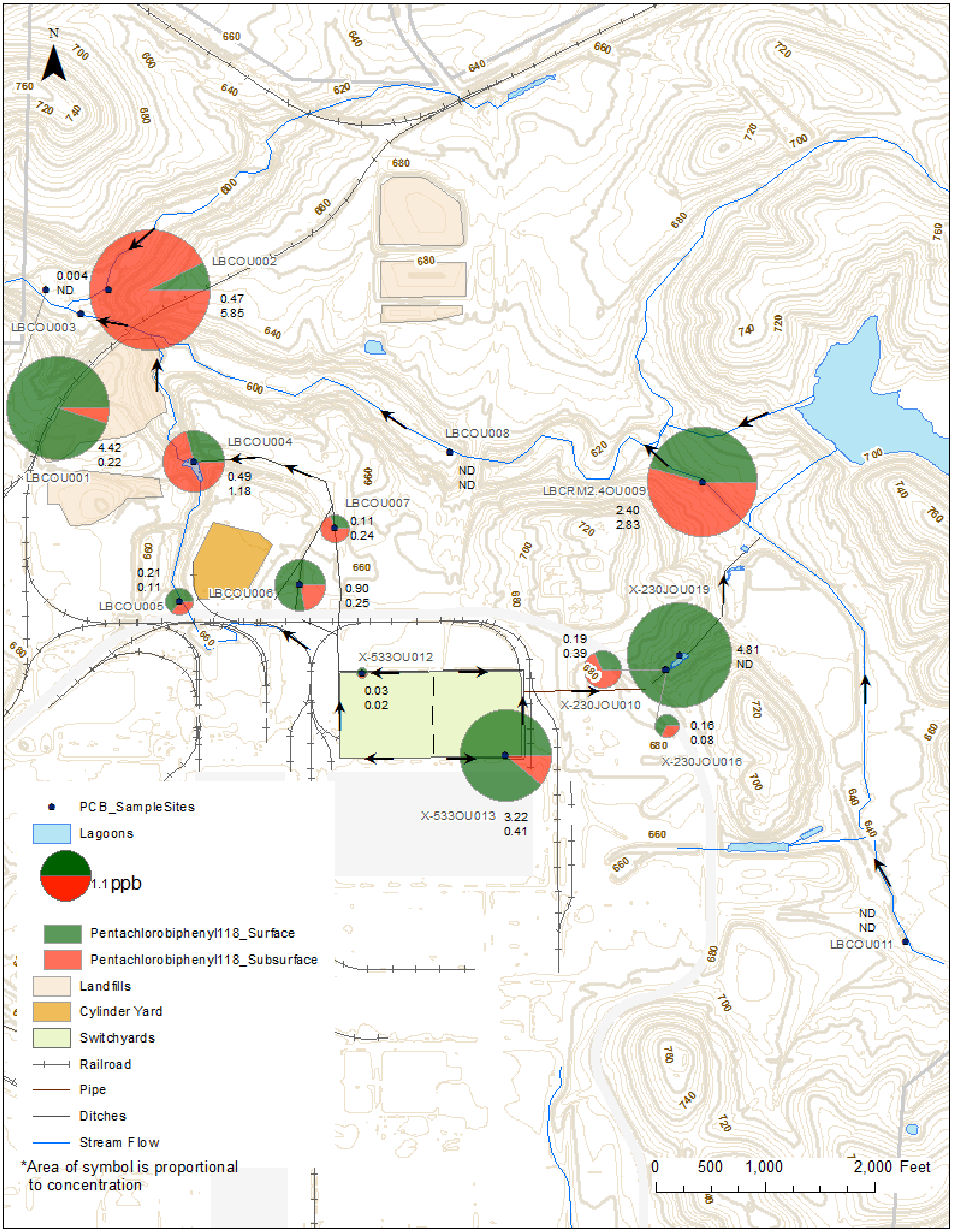

Figure 5.12 Concentrations ug/kg (ppb) of PCB118 shown in pie chart at the surface (green) and subsurface (red) at each study area site collected in 2011-2012 at PORTS, size is proportional to concentration

5.9 Dioxin and Furan

According to records at PORTS during the "1950s and early 1960s there were some fires at both the X-533A and X-530 Switchyards due to transformer explosions" (John Sokol 2012, personal communication). A range of dioxins and furans were tested for during the April 23rd and 24th, 2012 sampling events, the December 2011 sampling event was excluded. Concentrations ranged from non-detect (1,2,3,7,8-Pentachlorodibenzofuran, 2,3,7,8-Tetrachlorodibenzofuran, and Total Tetrachlorodibenzofuran) to 4.59 and 21.70 ug/kg for Total Heptachlorodibenzo-p-dioxin and 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (OCDD), respectively. The dioxins and furans found at PORTS may have been generated as a result of transformer explosions and fires. Site X-230JOU019, sludge from the bottom of the holding pond draining the east side of the X-533A Switchyard, showed the highest concentration of the dioxins and furans tested. Figure 5.13 shows the concentrations of OCDD at sites sampled on April 23rd and 24th, 2012, highest concentrations were found at site X-230JOU019 (21.70 ug/kg) followed by site LBCOU008 in Little Beaver Creek (4.20 ug/kg). Both of these sites are directly downstream of drainage off the X-533A Switchyard. At site X-230JOU19, the Toxic Equivalents (TEQ) based on World Health Organization (WHO) report produced in 2005 (Berg et al., 2005) where non-detect values were handled as zeros, the TEQ WHO 2005 value was 0.044 and where more conservatively the non-detect values were handled as 0.5 the TEQ WHO 2005 value was 0.121 ug/kg. At PORTS, the decontamination and decommissioning team is using 1e-6 ug/kg body weight/day as the screening criteria for dioxin and furans (DOE 2012). The Human Health Risk Assessment (HHRA) develops chemical risk for dioxins/furans using a reference dose (RfD) of 1E-9mg/kg body weight/day. This value corresponds to toxicity for 2,3,7,8-TCDD (TEF =1) and OCDD (TEF = 0.0003) (Table 5.7). (DOE 2012, USEPA, 2010).

Table 5.7 Cancer risk (1E-6 or HQ=0.1) screening values for soil in Human Health Risk Assessment (HHRA) for TCDD and other dioxins and furans based on their TEF values that were detected at PORTS (ug/kg) (DOE 2012).

	TCDD	2,3,4,7,8-PeCDF	TCDF	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDF	1,2,3,7,8-PeCDF	1,2,3,4,6,7,8-HpCDD	1,2,3,4,6,7,8-HpCDF	OCDD	OCDF
TEF	1	0.3	0.1	0.1	0.1	0.03	0.01	0.01	0.0003	0.0003
Resident	4.49e-3	0.015	0.044	0.044	0.044	0.149	0.149	0.449	15	15
Soil-to-ground-water	1.50e-2	0.05	0.015	0.15	0.15	0.5	1.5	1.5	50	50
Outer Worker	2.04e-2	0.068	0.020	0.204	0.204	0.68	2.04	2.04	68	68
Industrial Worker	4.40e-2	0.146	0.04	0.44	0.44	1.46	4.4	4.4	147	147

TCDD values were below detection levels for all samples collected. Two sites were above the detection level for TCDF, site LBCOU001 and LBCOU002 with concentrations of 0.00275 ug/kg and 0.00172 ug/kg, respectively. However, both of these values of TCDF are less than the most conservative health risk assessment value used for residential purposes at a value of 0.045 ug/kg (Table 5.8).

All sites contain various levels of OCDD, however only one site, X-230JOU019 the eastern holding pond (X-230J6), exhibited a concentration of OCDD (21.7 ug/kg) which is greater than the stringent designated use, ‘Resident’ (15 ug/kg) (Table 5.8). All values of OCDD are lower than the ‘Soil-to-groundwater’, ‘Outer worker’, and ‘Industrial worker’ risk assessment use designations.

In fact, site X-230OU019 exceeded the ‘resident’ HHRA cancer risk screening values for six of the dioxins and furans tested: OCDD, 1,2,3,4,6,7,8-HpCDD, 1,2,3,4,6,7,8-HpCDF, 1,2,3,6,7,8 HxCDD, 1,2,3,7,8,9 HxCDF, and 2,3,4,7,8-PeCDF. While only two of these contaminants are high enough to also exceed the ‘soil-to-groundwater’ and ‘outer worker’ HHRA cancer risk screening values (1,2,3,4,6,7,8-HpCDD and 2,3,4,7,8-PeCDF) (Table 5.8). Table 5.9 shows the maximum concentrations at either the surface or subsurface of dioxins and furans tested for in the study area. All dioxin and furan data collected within in this study area were below the HHRA Type 1 (DOE 2012) screening levels for dioxins and furans.

Table 5.8 Exceedence of Human Health Risk Assessment (HHRA) Type 2 screening values for various end uses at site X-230JOU019 for all dioxins and furans measured above detection level (DOE 2012).

Parameter	X-230JOU-019 ug/kg	Resident HHRA screening level ug/kg		Soil-to-GW HHRA screening level ug/kg		Outer worker HHRA screening level ug/kg		Industrial worker HHRA screening level ug/kg	
OCDF	1.69	15.0	pass	50.0	pass	68.0	pass	146.7	pass
OCDD	21.70	15.0	Exceed	50.0	pass	68.0	pass	146.7	pass
1,2,3,4,6,7,8-HpCDF	0.466	0.449	Exceed	1.500	pass	2.040	pass	4.400	pass
1,2,3,4,6,7,8-HpCDD	2.290	0.449	Exceed	1.500	Exceed	2.040	Exceed	4.400	pass
1,2,3,6,7,8-HxCDD	0.096	0.045	Exceed	0.150	pass	0.204	pass	0.440	pass
1,2,3,7,8,9-HxCDF	0.071	0.045	Exceed	0.150	pass	0.204	pass	0.440	pass
1,2,3,7,8-PeCDF	0.005	0.150	pass	0.500	pass	0.680	pass	1.467	pass
2,3,4,7,8-PeCDF	0.071	0.015	Exceed	0.050	Exceed	0.068	Exceed	0.147	pass
2,3,7,8-TCDF	0.003	0.045	pass	0.015	pass	0.020	pass	0.044	pass

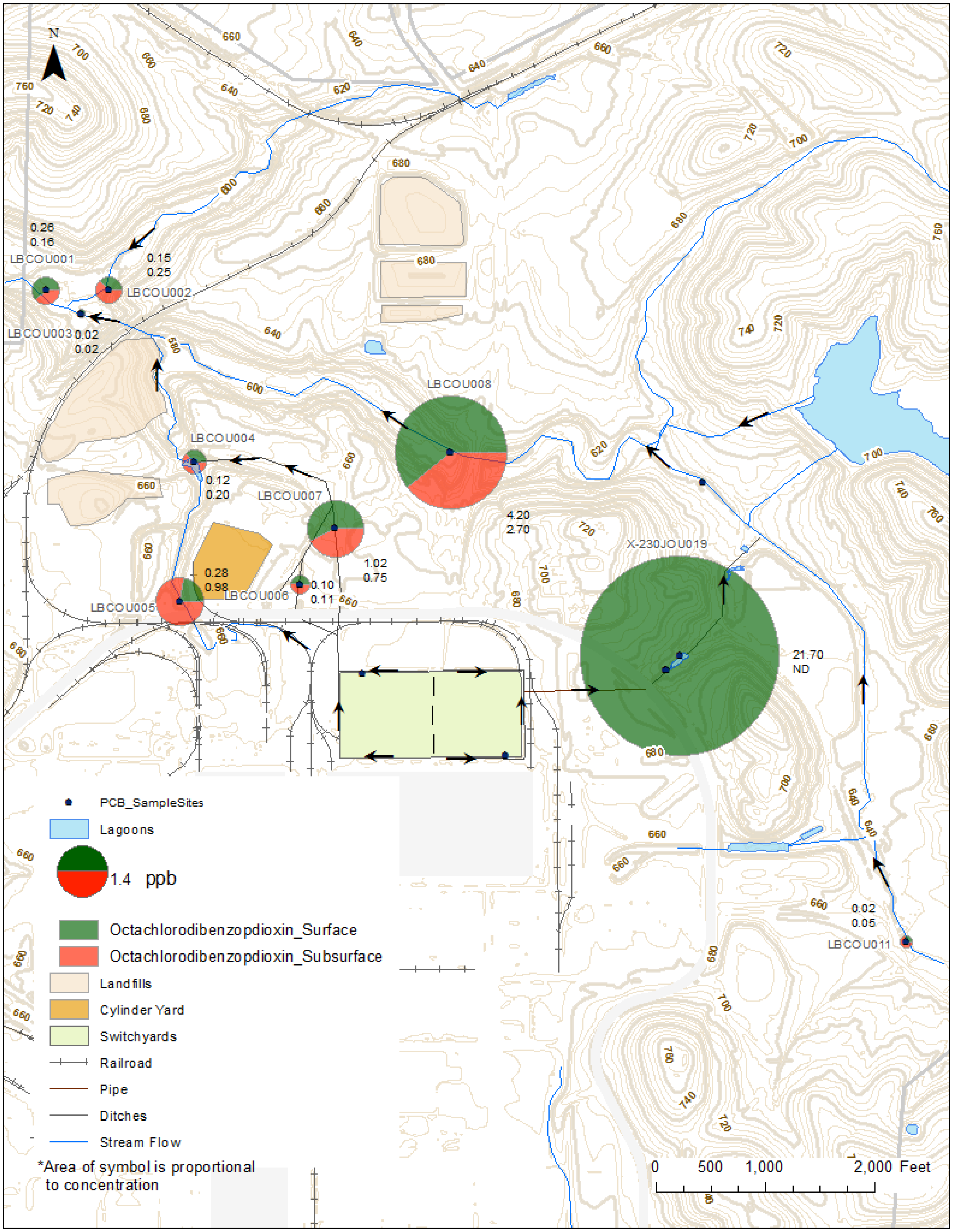

Figure 5.13 Concentrations ug/kg (ppb) of octachlorodibenzo-p-dioxin shown in pie chart at the surface (green) and subsurface (red) at each study area site collected April 2012 at PORTS, size is proportional to concentration (Note: site X-230JOU019 only surface sampled)

Table 5.9 Maximum concentrations of dioxins and furans found at either the surface or subsurface at PORTS sites sampled April 2012, blank cells indicate below detection level.

Parameter	**LBCOU001**	**LBCOU002**	**LBCOU003**	**LBCOU004**	**LBCOU005**	**LBCOU006**	**LBCOU007**	**LBCOU008**	**LBCOU011**	**X230JOU019**	**Max. conc ug/kg**
1,2,3,4,6,7,8,9-Octachlorodibenzofuran										1.69	1.69
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	0.261	0.253	0.0196	0.203	0.983	0.107	1.02	4.2	0.0515	21.7	21.7
1,2,3,4,6,7,8-Heptachlorodibenzofuran									0.0044	0.466	0.466
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	0.017	0.0057			0.015	0.0068		0.0368		2.29	2.29
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin										0.0959	0.0959
1,2,3,7,8,9-Hexachlorodibenzofuran										0.0711	0.0711
1,2,3,7,8-Pentachlorodibenzofuran		0.0053									0.0053
2,3,4,7,8-Pentachlorodibenzofuran						0.0044				0.0711	0.0711
2,3,7,8-Tetrachlorodibenzofuran	0.0028	0.0017									0.0028
Total Heptachlorodibenzofuran	0.0070									2.32	2.32
Total Heptachlorodibenzo-p-dioxin	0.0386	0.0117			0.0302	0.0138		0.0838		4.59	4.59
Total Hexachlorodibenzofuran										0.656	0.656
Total Hexachlorodibenzo-p-dioxin										0.644	0.644
Total Pentachlorodibenzofuran		0.0053				0.0044				0.0891	0.0891
Total Pentachlorodibenzo-p-dioxin						0.0044				0.0711	0.0711
Total Tetrachlorodibenzofuran	0.0114	0.0095				0.0012					0.0114
Total Tetrachlorodibenzo-p-dioxin										0.0511	0.0511
Maximum concentration μg/kg	0.261	0.253	0.0196	0.203	0.983	0.107	1.02	4.2	0.0515	21.7	21.7

5.10 Concentration Compared to Previous Studies in Little Beaver Creek

Between 1997 and 2012, the PCB levels within the sediments of Little Beaver Creek appear to generally decline. The detected levels of PCBs in 2005 and 2006 were highest (max 230 ug/kg), and were likely higher than the 1997 levels due to improved sampling methodology. Since 2006, there has been an overall steady decrease in detected PCB levels. A small spike between 2007 and 2009 levels is likely due to differences in sampling methodology, particularly regarding depth of sediment sampled and changing sample locations from year to year. Data from 2011-2012 shows a general decrease in Aroclor 1254 and 1260 contamination as compared to previous years, with levels between 1.48 and 44.6 ug/kg (Figure 5.14) along Little Beaver Creek.

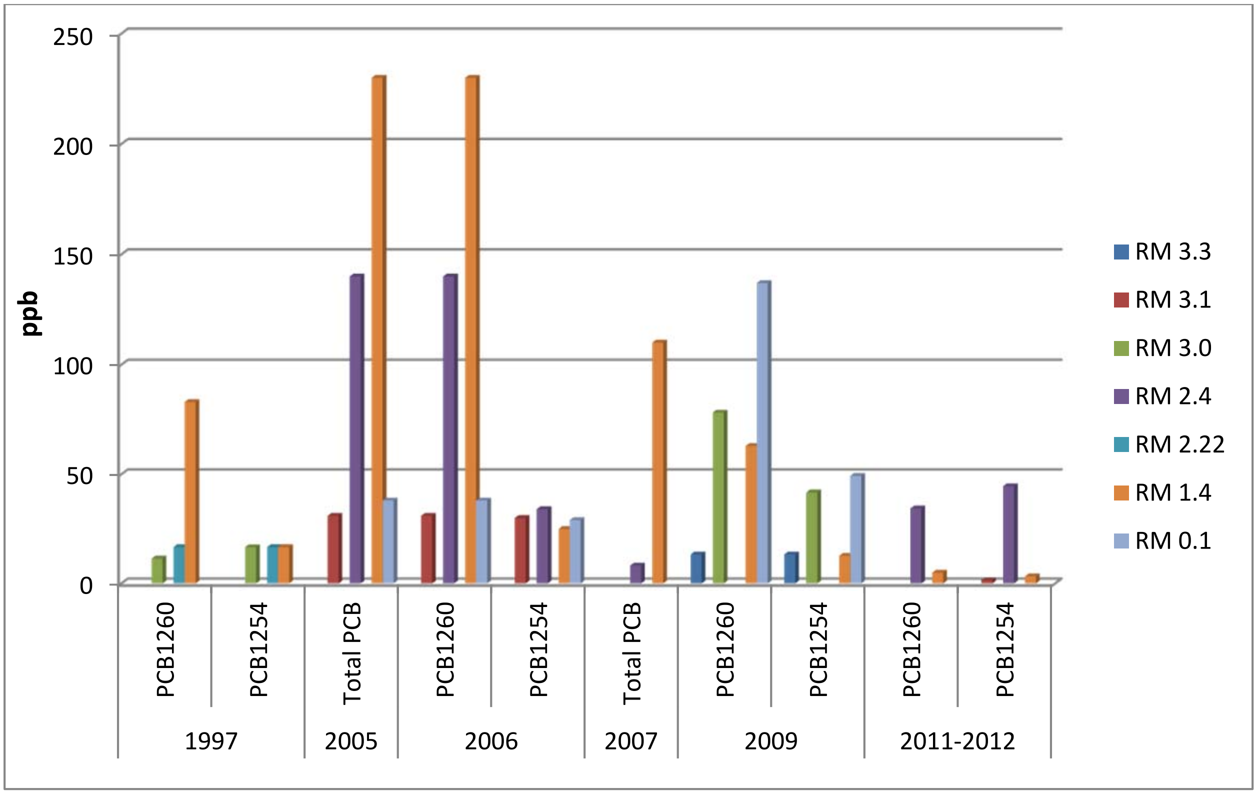

Figure 5.14 Concentrations of Aroclor 1260 and 1254 ug/kg (ppb) in the sediments along Little Beaver Creek from 1997 to 2012

6. CONCLUSIONS AND RECOMMENDATIONS

From the PCB, Aroclor, dioxin, and furan data collected as part of this study the following conclusions and recommendations for future investigations are made.

A consistent ‘signature’ set of dioxin-like PCB congeners were found across the study area: PCB 118, 105, 156, 167, and 189. PCB 118 showed the highest concentrations varying from 0.004 to 5.85 ug/kg. Typically higher concentrations of PCB118 were found at depth when the water at the sites exhibited longer residence times (e.g. pools) and at the surface when sites exhibited short residence times (e.g. moving streams). An inverse correlation of the most abundant congeners (PCB118, 105, 156) with clay content suggest that the congeners could be present in higher concentrations but strongly attached to the clays and could not be easily extracted in the laboratory. This suggests that these PCBs are less bioavailable even though that may be present in higher concentrations than the ones found in this study. This finding suggests that fine clays could be used to remediate sites that have high levels of PCBs because they seem to immobilize these chemicals, if this finding was confirmed with further research.

Data from 2011-2012 collected along Little Beaver Creek shows a general decrease in Aroclor 1254 and 1269 contamination as compared to previous studies conducted by DOE and OEPA, with levels between 1.48 and 44.6 ug/kg. Looking at all sites sampled in this study area Total Aroclors range from 1.48 to 224 ug/kg. Higher concentrations were found at 20-30 cm depth and at the bottom of the X-230J6 holding pond. This suggests that in areas where the water is moving slow or static, either migration of contaminants to depth occur or that deeper soil horizons represent the period of time in history when PCBs were still in use, prior to 1977. It is suggested that a closer look at the holding ponds at greater depths (i.e. greater than 30 cm) and across the surface could give more information about the storage and fate of the PCBs in this system and their vertical migration. This study is limited to the sites that did not have radiation levels (switchyards on the western side of the plant with known radioactive contamination were excluded from this study), so the results cannot be extrapolated to the whole site. However, all of the pre-screened samples tested for this study were not radioactive.

The site previously remediated in 2010 as part of the clean-up effort, X-533OU012, indicated nearly non-detect for PCBs. Concentrations of Aroclor 1260 at the surface were 0.011 ug/kg while the subsurface value was 0.027 ug/kg. Dioxins and furans were not tested for at this site.

Of the toxic dioxins and furans sampled for OCDD was found across many of the sites in the study area, most sites have levels of OCDD lower than the screening values established by the human health risk assessment (HHRA). However, site X-230JOU019, the east holding pond, has concentrations greater that the HHRA cancer screening values for ‘residents’, ‘soil to groundwater’ and ‘outer worker’ use designations (DOE 2012). On one hand this is positive since the holding pond was established as a best management practice to isolate run-off from the X-533A Switchyard; it is doing what it was intended to do. On the other hand, regular upkeep of this holding pond must be maintained to continue to store these toxic compounds and avoid its release to the environment.

The levels of PCBs found in site LBCOU002 are higher than those found in LBCOU001 and LBCOU003. According to the surficial water flow regime in the area, this should not be occurring if the source of those PCB were the PORTS installations. This behavior requires further investigation of the headwaters of site LBCOU002. Either toxic PCB contaminants are transported during flooding events and deposited into the floodplain of site LBCOU002 from the mainstem of Little Beaver Creek or an unidentified source of PCBs could exist in the headwaters of this tributary.

It is recommended that the full set of 209 congener analysis be conducted again at a few sites where various levels of PCBs and dioxins are present. Site LBCOU003 proved to be nearly non-detect for all PCBs, dioxins, and furans. Some of the other sites in this study, where concentrations of the dioxin-like PCBs and Aroclors exist would be a better choice for this type of analysis (e.g. X-230JOU019, LBCRM2.4OU009, LBCOU002, and/or LBCOU001).

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Appendix A

List of 209 Congeners

Revised as of November 2003

Table of PCB Species by Congener Number

Descriptor*	CASRN	Congener Number	IUPAC Name	Type
	1336-36-3		Polychlorinated biphenyl (PCB)	Category
CP1_---_--_-	2051-60-7	1	2-Chlorobiphenyl	Congener
CP0_---_--_-	2051-61-8	2	3-Chlorobiphenyl	Congener
CP0_---_--_-	2051-62-9	3	4-Chlorobiphenyl	Congener
---_---_--_-	13029-08-8	4	2,2'-Dichlorobiphenyl	Congener
CP1_---_--_-	16605-91-7	5	2,3-Dichlorobiphenyl	Congener
CP1_---_--_-	25569-80-6	6	2,3'-Dichlorobiphenyl	Congener
CP1_---_--_-	33284-50-3	7	2,4-Dichlorobiphenyl	Congener
CP1_---_--_-	34883-43-7	8	2,4'-Dichlorobiphenyl	Congener
CP1_---_--_-	34883-39-1	9	2,5-Dichlorobiphenyl	Congener
---_---_--_-	33146-45-1	10	2,6-Dichlorobiphenyl	Congener
CP0_---_--_2M	2050-67-1	11	3,3'-Dichlorobiphenyl	Congener
CP0_---_--_-	2974-92-7	12	3,4-Dichlorobiphenyl	Congener
CP0_---_--_-	2974-90-5	13	3,4'-Dichlorobiphenyl	Congener
CP0_---_--_2M	34883-41-5	14	3,5-Dichlorobiphenyl	Congener
CP0_---_PP_-	2050-68-2	15	4,4'-Dichlorobiphenyl	Congener
---_---_--_-	38444-78-9	16	2,2',3-Trichlorobiphenyl	Congener
---_---_--_-	37680-66-3	17	2,2',4-Trichlorobiphenyl	Congener
---_---_--_-	37680-65-2	18	2,2',5-Trichlorobiphenyl	Congener
---_---_--_-	38444-73-4	19	2,2',6-Trichlorobiphenyl	Congener
CP1_---_--_2M	38444-84-7	20	2,3,3'-Trichlorobiphenyl	Congener
CP1_---_--_-	55702-46-0	21	2,3,4-Trichlorobiphenyl	Congener
CP1_---_--_-	38444-85-8	22	2,3,4'-Trichlorobiphenyl	Congener
CP1_---_--_2M	55720-44-0	23	2,3,5-Trichlorobiphenyl	Congener
---_---_--_-	55702-45-9	24	2,3,6-Trichlorobiphenyl	Congener
CP1_---_--_-	55712-37-3	25	2,3',4-Trichlorobiphenyl	Congener
CP1_---_--_2M	38444-81-4	26	2,3',5-Trichlorobiphenyl	Congener
---_---_--_-	38444-76-7	27	2,3',6-Trichlorobiphenyl	Congener
CP1_---_PP_-	7012-37-5	28	2,4,4'-Trichlorobiphenyl	Congener

Descriptor*	**CASRN**	**Congener Number**	**IUPAC Name**	**Type**
CP1_---_--_-	15862-07-4	29	2,4,5-Trichlorobiphenyl	Congener
---_---_--_-	35693-92-6	30	2,4,6-Trichlorobiphenyl	Congener
CP1_---_--_-	16606-02-3	31	2,4',5-Trichlorobiphenyl	Congener
---_---_--_-	38444-77-8	32	2,4',6-Trichlorobiphenyl	Congener
CP1_---_--_-	38444-86-9	33	2,3',4'-Trichlorobiphenyl	Congener
CP1_---_--_2M	37680-68-5	34	2,3',5'-Trichlorobiphenyl	Congener
CP0_---_--_2M	37680-69-6	35	3,3',4-Trichlorobiphenyl	Congener
CP0_---_--_2M	38444-87-0	36	3,3',5-Trichlorobiphenyl	Congener
CP0_---_PP_-	38444-90-5	37	3,4,4'-Trichlorobiphenyl	Congener
CP0_---_--_2M	53555-66-1	38	3,4,5-Trichlorobiphenyl	Congener
CP0_---_--_2M	38444-88-1	39	3,4',5-Trichlorobiphenyl	Congener
---_4CL_--_2M	38444-93-8	40	2,2',3,3'-Tetrachlorobiphenyl	Congener
---_4CL_--_-	52663-59-9	41	2,2',3,4-Tetrachlorobiphenyl	Congener
---_4CL_--_-	36559-22-5	42	2,2',3,4'-Tetrachlorobiphenyl	Congener
---_4CL_--_2M	70362-46-8	43	2,2',3,5-Tetrachlorobiphenyl	Congener
---_4CL_--_2M	41464-39-5	44	2,2',3,5'-Tetrachlorobiphenyl	Congener
---_4CL_--_-	70362-45-7	45	2,2',3,6-Tetrachlorobiphenyl	Congener
---_4CL_--_-	41464-47-5	46	2,2',3,6'-Tetrachlorobiphenyl	Congener
---_4CL_PP_-	2437-79-8	47	2,2',4,4'-Tetrachlorobiphenyl	Congener
---_4CL_--_-	70362-47-9	48	2,2',4,5-Tetrachlorobiphenyl	Congener
---_4CL_--_-	41464-40-8	49	2,2',4,5'-Tetrachlorobiphenyl	Congener
---_4CL_--_-	62796-65-0	50	2,2',4,6-Tetrachlorobiphenyl	Congener
---_4CL_--_-	68194-04-7	51	2,2',4,6'-Tetrachlorobiphenyl	Congener
---_4CL_--_2M	35693-99-3	52	2,2',5,5'-Tetrachlorobiphenyl	Congener
---_4CL_--_-	41464-41-9	53	2,2',5,6'-Tetrachlorobiphenyl	Congener
---_4CL_--_-	15968-05-5	54	2,2',6,6'-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	74338-24-2	55	2,3,3',4-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	41464-43-1	56	2,3,3',4'-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	70424-67-8	57	2,3,3',5-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	41464-49-7	58	2,3,3',5'-Tetrachlorobiphenyl	Congener
---_4CL_--_2M	74472-33-6	59	2,3,3',6-Tetrachlorobiphenyl	Congener
CP1_4CL_PP_-	33025-41-1	60	2,3,4,4'-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	33284-53-6	61	2,3,4,5-Tetrachlorobiphenyl	Congener

Descriptor*	CASRN	Congener Number	IUPAC Name	Type
---_4CL_--_-	54230-22-7	62	2,3,4,6-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	74472-34-7	63	2,3,4',5-Tetrachlorobiphenyl	Congener
---_4CL_--_-	52663-58-8	64	2,3,4',6-Tetrachlorobiphenyl	Congener
---_4CL_--_2M	33284-54-7	65	2,3,5,6-Tetrachlorobiphenyl	Congener
CP1_4CL_PP_-	32598-10-0	66	2,3',4,4'-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	73575-53-8	67	2,3',4,5-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	73575-52-7	68	2,3',4,5'-Tetrachlorobiphenyl	Congener
---_4CL_--_-	60233-24-1	69	2,3',4,6-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	32598-11-1	70	2,3',4',5-Tetrachlorobiphenyl	Congener
---_4CL_--_-	41464-46-4	71	2,3',4',6-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	41464-42-0	72	2,3',5,5'-Tetrachlorobiphenyl	Congener
---_4CL_--_2M	74338-23-1	73	2,3',5',6-Tetrachlorobiphenyl	Congener
CP1_4CL_PP_-	32690-93-0	74	2,4,4',5-Tetrachlorobiphenyl	Congener
---_4CL_PP_-	32598-12-2	75	2,4,4',6-Tetrachlorobiphenyl	Congener
CP1_4CL_--_2M	70362-48-0	76	2,3',4',5'-Tetrachlorobiphenyl	Congener
CP0_4CL_PP_2M	32598-13-3	77	3,3',4,4'-Tetrachlorobiphenyl	Congener
CP0_4CL_--_2M	70362-49-1	78	3,3',4,5-Tetrachlorobiphenyl	Congener
CP0_4CL_--_2M	41464-48-6	79	3,3',4,5'-Tetrachlorobiphenyl	Congener
CP0_4CL_--_2M	33284-52-5	80	3,3',5,5'-Tetrachlorobiphenyl	Congener
CP0_4CL_PP_2M	70362-50-4	81	3,4,4',5-Tetrachlorobiphenyl	Congener
---_4CL_--_2M	52663-62-4	82	2,2',3,3',4-Pentachlorobiphenyl	Congener
---_4CL_--_2M	60145-20-2	83	2,2',3,3',5-Pentachlorobiphenyl	Congener
---_4CL_--_2M	52663-60-2	84	2,2',3,3',6-Pentachlorobiphenyl	Congener
---_4CL_PP_-	65510-45-4	85	2,2',3,4,4'-Pentachlorobiphenyl	Congener
---_4CL_--_2M	55312-69-1	86	2,2',3,4,5-Pentachlorobiphenyl	Congener
---_4CL_--_2M	38380-02-8	87	2,2',3,4,5'-Pentachlorobiphenyl	Congener
---_4CL_--_-	55215-17-3	88	2,2',3,4,6-Pentachlorobiphenyl	Congener
---_4CL_--_-	73575-57-2	89	2,2',3,4,6'-Pentachlorobiphenyl	Congener
---_4CL_--_2M	68194-07-0	90	2,2',3,4',5-Pentachlorobiphenyl	Congener
---_4CL_--_-	68194-05-8	91	2,2',3,4',6-Pentachlorobiphenyl	Congener
---_4CL_--_2M	52663-61-3	92	2,2',3,5,5'-Pentachlorobiphenyl	Congener
---_4CL_--_2M	73575-56-1	93	2,2',3,5,6-Pentachlorobiphenyl	Congener
---_4CL_--_2M	73575-55-0	94	2,2',3,5,6'-Pentachlorobiphenyl	Congener

Descriptor*	CASRN	Congener Number	IUPAC Name	Type
---_4CL_--_2M	38379-99-6	95	2,2',3,5',6-Pentachlorobiphenyl	Congener
---_4CL_--_-	73575-54-9	96	2,2',3,6,6'-Pentachlorobiphenyl	Congener
---_4CL_--_2M	41464-51-1	97	2,2',3,4',5'-Pentachlorobiphenyl	Congener
---_4CL_--_-	60233-25-2	98	2,2',3,4',6'-Pentachlorobiphenyl	Congener
---_4CL_PP_-	38380-01-7	99	2,2',4,4',5-Pentachlorobiphenyl	Congener
---_4CL_PP_-	39485-83-1	100	2,2',4,4',6-Pentachlorobiphenyl	Congener
---_4CL_--_2M	37680-73-2	101	2,2',4,5,5'-Pentachlorobiphenyl	Congener
---_4CL_--_-	68194-06-9	102	2,2',4,5,6'-Pentachlorobiphenyl	Congener
---_4CL_--_-	60145-21-3	103	2,2',4,5',6-Pentachlorobiphenyl	Congener
---_4CL_--_-	56558-16-8	104	2,2',4,6,6'-Pentachlorobiphenyl	Congener
CP1_4CL_PP_2M	32598-14-4	105	2,3,3',4,4'-Pentachlorobiphenyl	Congener
CP1_4CL_--_2M	70424-69-0	106	2,3,3',4,5-Pentachlorobiphenyl	Congener
CP1_4CL_--_2M	70424-68-9	107	2,3,3',4',5-Pentachlorobiphenyl	Congener
CP1_4CL_--_2M	70362-41-3	108	2,3,3',4,5'-Pentachlorobiphenyl	Congener
---_4CL_--_2M	74472-35-8	109	2,3,3',4,6-Pentachlorobiphenyl	Congener
---_4CL_--_2M	38380-03-9	110	2,3,3',4',6-Pentachlorobiphenyl	Congener
CP1_4CL_--_2M	39635-32-0	111	2,3,3',5,5'-Pentachlorobiphenyl	Congener
---_4CL_--_2M	74472-36-9	112	2,3,3',5,6-Pentachlorobiphenyl	Congener
---_4CL_--_2M	68194-10-5	113	2,3,3',5',6-Pentachlorobiphenyl	Congener
CP1_4CL_PP_2M	74472-37-0	114	2,3,4,4',5-Pentachlorobiphenyl	Congener
---_4CL_PP_-	74472-38-1	115	2,3,4,4',6-Pentachlorobiphenyl	Congener
---_4CL_--_2M	18259-05-7	116	2,3,4,5,6-Pentachlorobiphenyl	Congener
---_4CL_--_2M	68194-11-6	117	2,3,4',5,6-Pentachlorobiphenyl	Congener
CP1_4CL_PP_2M	31508-00-6	118	2,3',4,4',5-Pentachlorobiphenyl	Congener
---_4CL_PP_-	56558-17-9	119	2,3',4,4',6-Pentachlorobiphenyl	Congener
CP1_4CL_--_2M	68194-12-7	120	2,3',4,5,5'-Pentachlorobiphenyl	Congener
---_4CL_--_2M	56558-18-0	121	2,3',4,5',6-Pentachlorobiphenyl	Congener
CP1_4CL_--_2M	76842-07-4	122	2,3,3',4',5'-Pentachlorobiphenyl	Congener
CP1_4CL_PP_2M	65510-44-3	123	2,3',4,4',5'-Pentachlorobiphenyl	Congener
CP1_4CL_--_2M	70424-70-3	124	2,3',4',5,5'-Pentachlorobiphenyl	Congener
---_4CL_--_2M	74472-39-2	125	2,3',4',5',6-Pentachlorobiphenyl	Congener
CP0_4CL_PP_2M	57465-28-8	126	3,3',4,4',5-Pentachlorobiphenyl	Congener
CP0_4CL_--_2M	39635-33-1	127	3,3',4,5,5'-Pentachlorobiphenyl	Congener

Descriptor*	CASRN	Congener Number	IUPAC Name	Type
---_4CL_PP_2M	38380-07-3	128	2,2',3,3',4,4'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	55215-18-4	129	2,2',3,3',4,5-Hexachlorobiphenyl	Congener
---_4CL_---_2M	52663-66-8	130	2,2',3,3',4,5'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	61798-70-7	131	2,2',3,3',4,6-Hexachlorobiphenyl	Congener
---_4CL_---_2M	38380-05-1	132	2,2',3,3',4,6'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	35694-04-3	133	2,2',3,3',5,5'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	52704-70-8	134	2,2',3,3',5,6-Hexachlorobiphenyl	Congener
---_4CL_---_2M	52744-13-5	135	2,2',3,3',5,6'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	38411-22-2	136	2,2',3,3',6,6'-Hexachlorobiphenyl	Congener
---_4CL_PP_2M	35694-06-5	137	2,2',3,4,4',5-Hexachlorobiphenyl	Congener
---_4CL_PP_2M	35065-28-2	138	2,2',3,4,4',5'-Hexachlorobiphenyl	Congener
---_4CL_PP_-	56030-56-9	139	2,2',3,4,4',6-Hexachlorobiphenyl	Congener
---_4CL_PP_-	59291-64-4	140	2,2',3,4,4',6'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	52712-04-6	141	2,2',3,4,5,5'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	41411-61-4	142	2,2',3,4,5,6-Hexachlorobiphenyl	Congener
---_4CL_---_2M	68194-15-0	143	2,2',3,4,5,6'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	68194-14-9	144	2,2',3,4,5',6-Hexachlorobiphenyl	Congener
---_4CL_---_-	74472-40-5	145	2,2',3,4,6,6'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	51908-16-8	146	2,2',3,4',5,5'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	68194-13-8	147	2,2',3,4',5,6-Hexachlorobiphenyl	Congener
---_4CL_---_2M	74472-41-6	148	2,2',3,4',5,6'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	38380-04-0	149	2,2',3,4',5',6-Hexachlorobiphenyl	Congener
---_4CL_---_-	68194-08-1	150	2,2',3,4',6,6'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	52663-63-5	151	2,2',3,5,5',6-Hexachlorobiphenyl	Congener
---_4CL_---_2M	68194-09-2	152	2,2',3,5,6,6'-Hexachlorobiphenyl	Congener
---_4CL_PP_2M	35065-27-1	153	2,2',4,4',5,5'-Hexachlorobiphenyl	Congener
---_4CL_PP_-	60145-22-4	154	2,2',4,4',5,6'-Hexachlorobiphenyl	Congener
---_4CL_PP_-	33979-03-2	155	2,2',4,4',6,6'-Hexachlorobiphenyl	Congener
CP1_4CL_PP_2M	38380-08-4	156	2,3,3',4,4',5-Hexachlorobiphenyl	Congener
CP1_4CL_PP_2M	69782-90-7	157	2,3,3',4,4',5'-Hexachlorobiphenyl	Congener
---_4CL_PP_2M	74472-42-7	158	2,3,3',4,4',6-Hexachlorobiphenyl	Congener
CP1_4CL_---_2M	39635-35-3	159	2,3,3',4,5,5'-Hexachlorobiphenyl	Congener
---_4CL_---_2M	41411-62-5	160	2,3,3',4,5,6-Hexachlorobiphenyl	Congener

Descriptor*	CASRN	Congener Number	IUPAC Name	Type
---_4CL_--_2M	74472-43-8	161	2,3,3',4,5',6-Hexachlorobiphenyl	Congener
CP1_4CL_--_2M	39635-34-2	162	2,3,3',4',5,5'-Hexachlorobiphenyl	Congener
---_4CL_--_2M	74472-44-9	163	2,3,3',4',5,6-Hexachlorobiphenyl	Congener
---_4CL_--_2M	74472-45-0	164	2,3,3',4',5',6-Hexachlorobiphenyl	Congener
---_4CL_--_2M	74472-46-1	165	2,3,3',5,5',6-Hexachlorobiphenyl	Congener
---_4CL_PP_2M	41411-63-6	166	2,3,4,4',5,6-Hexachlorobiphenyl	Congener
CP1_4CL_PP_2M	52663-72-6	167	2,3',4,4',5,5'-Hexachlorobiphenyl	Congener
---_4CL_PP_2M	59291-65-5	168	2,3',4,4',5',6-Hexachlorobiphenyl	Congener
CP0_4CL_PP_2M	32774-16-6	169	3,3',4,4',5,5'-Hexachlorobiphenyl	Congener
---_4CL_PP_2M	35065-30-6	170	2,2',3,3',4,4',5-Heptachlorobiphenyl	Congener
---_4CL_PP_2M	52663-71-5	171	2,2',3,3',4,4',6-Heptachlorobiphenyl	Congener
---_4CL_--_2M	52663-74-8	172	2,2',3,3',4,5,5'-Heptachlorobiphenyl	Congener
---_4CL_--_2M	68194-16-1	173	2,2',3,3',4,5,6-Heptachlorobiphenyl	Congener
---_4CL_--_2M	38411-25-5	174	2,2',3,3',4,5,6'-Heptachlorobiphenyl	Congener
---_4CL_--_2M	40186-70-7	175	2,2',3,3',4,5',6-Heptachlorobiphenyl	Congener
---_4CL_--_2M	52663-65-7	176	2,2',3,3',4,6,6'-Heptachlorobiphenyl	Congener
---_4CL_--_2M	52663-70-4	177	2,2',3,3',4,5',6'-Heptachlorobiphenyl	Congener
---_4CL_--_2M	52663-67-9	178	2,2',3,3',5,5',6-Heptachlorobiphenyl	Congener
---_4CL_--_2M	52663-64-6	179	2,2',3,3',5,6,6'-Heptachlorobiphenyl	Congener
---_4CL_PP_2M	35065-29-3	180	2,2',3,4,4',5,5'-Heptachlorobiphenyl	Congener
---_4CL_PP_2M	74472-47-2	181	2,2',3,4,4',5,6-Heptachlorobiphenyl	Congener
---_4CL_PP_2M	60145-23-5	182	2,2',3,4,4',5,6'-Heptachlorobiphenyl	Congener
---_4CL_PP_2M	52663-69-1	183	2,2',3,4,4',5',6-Heptachlorobiphenyl	Congener
---_4CL_PP_-	74472-48-3	184	2,2',3,4,4',6,6'-Heptachlorobiphenyl	Congener
---_4CL_--_2M	52712-05-7	185	2,2',3,4,5,5',6-Heptachlorobiphenyl	Congener
---_4CL_--_2M	74472-49-4	186	2,2',3,4,5,6,6'-Heptachlorobiphenyl	Congener
---_4CL_--_2M	52663-68-0	187	2,2',3,4',5,5',6-Heptachlorobiphenyl	Congener
---_4CL_--_2M	74487-85-7	188	2,2',3,4',5,6,6'-Heptachlorobiphenyl	Congener
CP1_4CL_PP_2M	39635-31-9	189	2,3,3',4,4',5,5'-Heptachlorobiphenyl	Congener
---_4CL_PP_2M	41411-64-7	190	2,3,3',4,4',5,6-Heptachlorobiphenyl	Congener
---_4CL_PP_2M	74472-50-7	191	2,3,3',4,4',5',6-Heptachlorobiphenyl	Congener
---_4CL_--_2M	74472-51-8	192	2,3,3',4,5,5',6-Heptachlorobiphenyl	Congener
---_4CL_--_2M	69782-91-8	193	2,3,3',4',5,5',6-Heptachlorobiphenyl	Congener

Descriptor*	CASRN	Congener Number	IUPAC Name	Type
---_4CL_PP_2M	35694-08-7	194	2,2',3,3',4,4',5,5'-Octachlorobiphenyl	Congener
---_4CL_PP_2M	52663-78-2	195	2,2',3,3',4,4',5,6-Octachlorobiphenyl	Congener
---_4CL_PP_2M	42740-50-1	196	2,2',3,3',4,4',5,6'-Octachlorobiphenyl	Congener
---_4CL_PP_2M	33091-17-7	197	2,2',3,3',4,4',6,6'-Octachlorobiphenyl	Congener
---_4CL_--_2M	68194-17-2	198	2,2',3,3',4,5,5',6-Octachlorobiphenyl	Congener
---_4CL_--_2M	52663-75-9	199	2,2',3,3',4,5,5',6'-Octachlorobiphenyl	Congener
---_4CL_--_2M	52663-73-7	200	2,2',3,3',4,5,6,6'-Octachlorobiphenyl	Congener
---_4CL_--_2M	40186-71-8	201	2,2',3,3',4,5',6,6'-Octachlorobiphenyl	Congener
---_4CL_--_2M	2136-99-4	202	2,2',3,3',5,5',6,6'-Octachlorobiphenyl	Congener
---_4CL_PP_2M	52663-76-0	203	2,2',3,4,4',5,5',6-Octachlorobiphenyl	Congener
---_4CL_PP_2M	74472-52-9	204	2,2',3,4,4',5,6,6'-Octachlorobiphenyl	Congener
---_4CL_PP_2M	74472-53-0	205	2,3,3',4,4',5,5',6-Octachlorobiphenyl	Congener
---_4CL_PP_2M	40186-72-9	206	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	Congener
---_4CL_PP_2M	52663-79-3	207	2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl	Congener
---_4CL_--_2M	52663-77-1	208	2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl	Congener
---_---_--_-	2051-24-3	209	Decachlorobiphenyl	Congener

*Key to Table Columns

Descriptors	
CP0 / CP1	These 68 co-planar congeners include 20 with chlorine substitution at none (CP0, non-ortho) and 48 with chlorine substitution at only one (CP1, mono-ortho) of the 2, 2', 6, or 6' positions.
4CL	These 169 congeners have a total of four or more chlorine substituents (regardless of position).
PP	These 54 congeners have both para positions (4 and 4') chlorinated.
2M	These 140 congeners have two or more of the meta positions (3, 3', 5, and 5') chlorinated.
NOTE: The 12 "Dioxin-like" congeners are those that display all four of the above Descriptors.	
CASRN	
Chemical Abstracts Service (CAS) Registry Number.	
Congener Number	
The numbering presented in the table is identical to that published by Ballschmiter et al., 1992.	
IUPAC Name	

The names presented in the table are the IUPAC names.

Type

The type of the PCB entity: Congener, Homolog, Mixture, Category.

Appendix B

List of Dioxin-like PCBs and Aroclors Analyzed

Appendix B – List of Dioxin-like PCBs and Aroclors analyzed

World Health Organization’s (WHO) list of dioxin-like PCBs

Congener	IUPAC PCB Number
3,3',4,4'-Tetrachlorobiphenyl	77
3,4,4',5-Tetrachlorobiphenyl	81
2,3,3',4,4'-Pentachlorobiphenyl	105
2,3,4,4',5-Pentachlorobiphenyl	114
2,3',4,4',5-Pentachlorobiphenyl	118
2',3,4,4',5-Pentachlorobiphenyl	123
3,3',4,4',5-Pentachlorobiphenyl	126
2,3,3',4,4',5-Hexachlorobiphenyl	156
2,3',4,4',5,5'-Hexachlorobiphenyl	167
3,3',4,4',5,5'-Hexachlorobiphenyl	169
2,3,3',4,4',5,5'-Heptachlorobiphenyl	189

List of Aroclors

Aroclor-1016
Aroclor-1221
Aroclor-1232
Aroclor-1242
Aroclor-1248
Aroclor-1254
Aroclor-1260
Aroclor-1262
Aroclor-1268
Aroclor-Total

Appendix C

Congener Composition of Common Aroclors

Table 4-5. Polychlorinated Biphenyl Congener Compositions (in Weight Percent)[a] in Aroclors[b]

		Aroclor						
PCB No.	Chlorine positions	1016[c]	1242[d]	1248[e]	1248[f]	1254[g] "Late"	1254[h]	1260[i]
1	2	0.52	0.54	0.05	0.02	0.02	—	0.02
2	3	0.02	0.03	—	—	—	—	—
3	4	0.15	0.18	0.01	—	—	—	—
4	2,2′	3.62	3.08	0.32	0.04	0.02	0.06	0.02
5	2,3	0.17	0.14	0.00	—	—	—	—
6	2,3′	1.64	1.43	0.13	0.00	0.01	0.02	0.01
7	2,4	0.29	0.26	0.02	—	—	—	—
8	2,4′	8.29	7.05	0.81	0.26	0.05	0.13	0.04
9	2,5	0.58	0.50	0.04	—	—	—	—
10	2,6	0.23	0.20	—	—	—	—	—
11	3,3′	—	—	—	—	—	—	—
12	3,4	0.07	0.06	—	—	—	—	—
13	3,4′	0.24	0.22	0.02	—	—	—	—
14	3,5	—	—	—	—	—	—	—
15	4,4′	2.40	2.10	0.22	0.06	0.01	0.03	0.01
16	2,2′,3	3.88	3.14	1.04	0.71	0.02	0.09	0.01
17	2,2′,4	3.98	3.13	1.05	0.93	0.02	0.08	0.02
18	2,2′,5	10.86	8.53	4.29	3.29	0.08	0.25	0.05
19	2,2′,6	0.99	0.80	0.22	0.14	—	—	—
20	2,3,3′	0.88	0.72	0.14	0.08	—	—	—
21	2,3,4	NM	NM	—	—	—	—	—
22	2,3,4′	3.50	2.84	1.33	1.38	0.02	0.04	0.01
23	2,3,5	0.01	0.01	—	0.00	—	—	—
24	2,3,6	0.16	0.13	0.01	—	—	—	—
25	2,3′,4	0.72	0.59	0.11	0.04	—	—	—
26	2,3′,5	1.57	1.28	0.40	0.23	—	0.03	—
27	2,3,6	0.51	0.41	0.12	0.07	—	—	—
28	2,4,4′	8.50	6.86	3.59	5.57	0.06	0.19	0.03
29	2,4,5	0.10	0.08	0.00	0.01	—	—	—
30	2,4,6	0.00	—	—	—	—	—	—
31	2,4′,5	9.32	7.34	5.07	5.47	0.11	0.28	0.04
32	2,4′,6	2.37	1.90	0.88	0.93	0.01	0.05	0.01
33	2′,3,4	6.21	5.01	2.23	2.21	0.05	0.16	0.03

Table 4-5. Polychlorinated Biphenyl Congener Compositions (in Weight Percent)[a] in Aroclors[b] *(continued)*

		Aroclor						
PCB No.	Chlorine positions	1016[c]	1242[d]	1248[e]	1248[f]	1254[g] “Late”	1254[h]	1260[i]
34	2′,3,5	0.03	0.02	0.00	0.00	—	—	—
35	3,3′,4	0.05	0.08	0.00	—	—	—	—
36	3,3′,5	—	—	—	—	—	—	—
37	3,4,4′	1.02	2.03	0.79	0.95	0.01	0.07	0.01
38	3,4,5	—	—	—	—	—	—	—
39	3,4′,5	—	—	—	—	—	—	—
40	2,2′,3,3′	0.58	0.76	1.13	0.92	0.15	0.12	—
41	2,2′,3,4	0.76	0.68	0.77	0.75	0.02	0.01	—
42	2,2′,3,4′	1.59	1.19	1.67	1.79	0.09	0.15	0.01
43	2,2′,3,5	0.28	0.18	0.30	0.19	—	—	—
44	2,2′,3,5′	4.47	3.55	6.31	5.09	0.67	2.31	0.03
45	2,2′,3,6	1.23	0.89	1.09	0.91	0.02	0.05	—
46	2,2′,3,6′	0.49	0.36	0.47	0.39	—	—	—
47	2,2′,4,4′	1.26	0.93	1.49	2.41	0.07	0.14	—
48	2,2′,4,5	1.61	1.18	1.66	1.54	0.05	0.12	—
49	2,2′,4,5′	3.35	2.53	4.12	4.17	0.26	1.10	0.01
50	2,2′,4,6	0.01	0.00	—	—	—	—	—
51	2,2′,4,6′	0.32	0.23	0.30	0.31	—	—	—
52	2,2′,5,5′	4.63	3.53	6.93	5.58	0.83	5.38	0.24
53	2,2′,5,6′	0.95	0.71	1.05	0.88	0.04	0.12	—
54	2,2′,6,6′	0.01	0.01	—	0.01	—	—	—
55	2,3,3′,4	—	0.10	0.06	0.05	—	—	—
56	2,3,3′,4′	0.07	1.81	3.16	3.19	1.70	0.55	0.02
57	2,3,3′,5	0.01	0.02	0.02	0.02	—	—	—
58	2,3,3′,5′	—	—	—	—	—	—	—
59	2,3,3′,6	0.41	0.32	0.37	0.23	0.01	0.02	—
60	2,3,4,4′	0.04	1.18	1.85	2.67	0.95	0.18	0.04
61	2,3,4,5	—	—	—	—	—	—	—
62	2,3,4,6	—	—	—	—	—	—	—
63	2,3,4′,5	0.06	0.12	0.17	0.19	0.07	0.02	—
64	2,3,4′,6	1.87	1.70	3.01	3.32	0.36	0.59	0.01
65	2,3,5,6	—	—	—	—	—	—	—
66	2,3′,4,4′	0.39	3.39	5.84	7.22	3.56	1.01	0.02
67	2,3′,4,5	0.06	0.16	0.13	0.10	0.01	—	—

Table 4-5. Polychlorinated Biphenyl Congener Compositions (in Weight Percent)[a] in Aroclors[b] *(continued)*

		Aroclor						
PCB No.	Chlorine positions	1016[c]	1242[d]	1248[e]	1248[f]	1254[g] "Late"	1254[h]	1260[i]
68	2,3′,4,5′	—	—	—	—	—	—	—
69	2,3′,4,6	0.00	—	—	—	—	—	—
70	2,3′,4′,5	0.59	3.73	7.28	7.39	6.83	3.49	0.04
71	2,3′,4′,6	1.16	1.03	1.67	1.86	0.11	0.15	0.01
72	2,3′,5,5′	0.00	0.01	0.02	0.01	—	—	—
73	2,3′,5′,6	0.00	0.00	—	—	—	—	—
74	2,4,4′,5	0.33	1.81	3.14	4.67	2.19	0.84	0.05
75	2,4,4′,6	0.06	0.04	0.08	0.08	—	—	—
76	2′,3,4,5	—	0.08	0.13	0.13	0.03	0.02	—
77	3,3′,4,4′	—	0.31	0.41	0.52	0.20	0.03	—
78	3,3′,4,5	—	—	—	—	—	—	—
79	3,3′,4,5′	—	—	—	—	—	—	—
80	3,3′,5,5′	—	—	—	—	—	—	—
81	3,4,4′,5	—	0.01	0.01	0.02	0.00	—	—
82	2,2′,3,3′,4	—	0.26	0.81	0.62	1.53	1.11	—
83	2,2′,3,3′,5	—	0.11	0.26	0.20	0.56	0.48	0.01
84	2,2′,3,3′,6	0.05	0.41	1.26	0.91	1.58	2.32	0.11
85	2,2′,3,4,4′	—	0.31	0.98	1.14	2.49	1.28	0.01
86	2,2′,3,4,5	—	0.03	0.11	0.09	0.10	0.06	—
87	2,2′,3,4,5′	—	0.46	1.45	1.11	3.41	3.99	0.41
88	2,2′,3,4,6	—	0.00	0.02	0.02	—	—	—
89	2,2′,3,4,6′	—	0.09	0.20	0.17	0.11	0.09	—
90	2,2′,3,4′,5	—	—	NM	NM	NM	NM	—
91	2,2′,3,4′,6	0.06	0.21	0.63	0.56	0.53	0.93	0.01
92	2,2′,3,5,5′	—	0.09	0.38	0.25	0.57	1.29	0.30
93	2,2′,3,5,6	—	0.00	0.04	0.03	—	—	—
94	2,2′,3,5,6′	—	0.01	0.03	0.02	0.01	0.02	—
95	2,2′,3,5′,6	0.31	0.61	1.96	1.43	1.84	6.25	2.45
96	2,2′,3,6,6′	0.04	0.03	0.08	0.06	0.01	0.04	—
97	2,2′,3′,4,5	—	0.38	1.22	0.97	2.78	2.62	0.09
98	2,2′,3′,4,6	—	—	—	—	—	—	—
99	2,2′,3′,4′,5	0.01	0.46	1.47	1.81	4.53	3.02	0.04
100	2,2′,4′,4′,6	—	—	—	—	—	—	—
101	2,2′,4,5,5′	0.04	0.69	2.22	1.89	5.49	8.02	3.13

Table 4-5. Polychlorinated Biphenyl Congener Compositions (in Weight Percent)[a] in Aroclors[b] *(continued)*

		Aroclor						
PCB No.	Chlorine positions	1016[c]	1242[d]	1248[e]	1248[f]	1254[g] "Late"	1254[h]	1260[i]
102	2,2′,4,5,6′	0.04	0.07	0.19	0.17	0.09	0.15	—
103	2,2′,4,5′,6	—	—	0.02	0.01	—	0.03	—
104	2,2′,4,6,6′	—	—	—	—	—	—	—
105	2,3,3′,4,4′	0.00	0.47	1.60	1.45	7.37	2.99	0.22
106	2,3,3′,4,5	—	—	—	—	—	—	—
107	2,3,3′,4′,5	—	—	—	—	—	—	—
108	2,3,3′,4,5′	—	—	—	—	—	—	—
109	2,3,3′,4,6	—	0.06	0.18	0.13	0.78	0.37	0.01
110	2,3,3′,4′,6	—	0.83	2.97	2.55	8.42	9.29	1.33
111	2,3,3′,5,5′	—	—	—	—	—	—	—
112	2,3,3′,5,6	—	—	—	—	—	—	—
113	2,3,3′,5′,6	—	—	—	—	0.01	—	—
114	2,3,4,4′,5	—	0.04	0.12	0.12	0.50	0.18	—
115	2,3,4,4′,6	—	0.04	0.11	0.11	0.37	0.20	—
116	2,3,4,5,6	—	—	—	—	—	—	—
117	2,3,4′,5,6	—	0.03	0.09	0.10	0.19	0.23	—
118	2,3′,4,4′,5	—	0.66	2.29	2.35	13.59	7.35	0.48
119	2,3′,4,4′,6	—	—	0.06	0.06	0.12	0.08	—
120	2,3′,4,5,5′	—	—	—	—	—	—	—
121	2,3′,4,5′,6	—	—	—	—	—	—	—
122	2′,3,3′,4,5	—	0.01	0.06	0.05	0.25	0.10	—
123	2′,3,4,4′,5	—	0.03	0.07	0.08	0.32	0.15	—
124	2′,3,4,5,5′	—	0.03	0.10	0.07	0.47	0.29	0.01
125	2′,3,4,5,6′	—	0.02	0.04	0.03	0.03	0.02	—
126	3,3′,4,4′,5	—	—	0.00	0.00	0.02	0.00	—
127	3,3′,4,5,5′	—	—	—	—	—	—	—
128	2,2′,3,3′,4,4′	—	0.02	0.12	0.08	1.71	1.42	0.53
129	2,2′,3,3′,4,5	—	—	0.02		0.39	0.38	0.14
130	2,2′,3,3′,4,5′	—	—	0.04	0.01	0.50	0.60	0.22
131	2,2′,3,3′,4,6	—	—	—	—	0.14	0.19	0.07
132	2,2′,3,3′,4,6′	—	0.04	0.15	0.14	1.50	2.29	2.90
133	2,2′,3,3′,5,5′	—	—	—	—	—	0.11	0.07
134	2,2′,3,3′,5,6	—	—	—	0.01	0.20	0.37	0.34
135	2,2′,3,3′,5,6′	—	—	0.04	0.04	0.28	0.61	1.08

Table 4-5. Polychlorinated Biphenyl Congener Compositions (in Weight Percent)[a] in Aroclors[b] *(continued)*

		Aroclor						
PCB No.	Chlorine positions	1016[c]	1242[d]	1248[e]	1248[f]	1254[g] "Late"	1254[h]	1260[i]
136	2,2′,3,3′,6,6′	—	—	0.05	0.06	0.24	0.70	1.46
137	2,2′,3,4,4′,5	—	—	0.03	0.02	0.52	0.42	0.02
138	2,2′,3,4,4′,5′	—	0.10	0.38	0.41	5.95	5.80	6.54
139	2,2′,3,4,4′,6	—	—	—	—	0.14	0.15	—
140	2,2′,3,4,4′,6′	—	—	—	—	—	—	—
141	2,2′,3,4,5,5′	—	0.01	0.07	0.09	0.69	0.98	2.62
142	2,2′,3,4,5,6	—	—	—	—	—	—	—
143	2,2′,3,4,5,6′	—	—	—	—	—	—	—
144	2,2′,3,4,5′,6	—	—	—	0.01	0.12	0.24	0.61
145	2,2′,3,4′,6,6′	—	—	—	—	—	—	—
146	2,2′,3,4′,5,5′	—	—	0.04	0.05	0.45	0.67	1.15
147	2,2′,3,4′,5,6	—	—	—	—	0.02	0.10	—
148	2,2′,3,4′,5,6′	—	—	—	—	—	—	—
149	2,2′,3,4′,5′,6	—	0.06	0.24	0.33	1.82	3.65	8.75
150	2,2′,3,4′,5,6′	—	—	—	—	—	—	—
151	2,2′,3,5,5′,6	—	—	0.04	0.08	0.22	0.69	3.04
152	2,2′,3,5,6,6′	—	—	—	—	—	—	—
153	2,2′,4,4′,5,5′	—	0.06	0.23	0.43	3.29	3.77	9.39
154	2,2′,4,4′,5,6′	—	—	—	—	0.02	0.04	—
155	2,2′,4,4′,6,6′	—	—	—	—	—	—	—
156	2,3,3′,4,4′,5	—	0.01	0.06	0.04	1.13	0.82	0.52
157	2,3,3′,4,4′,5′	—	—	0.01	0.00	0.30	0.19	0.02
158	2,3,3′,4,4′,6	—	0.01	0.04	0.04	0.90	0.81	0.58
159	2,3,3′,4,5,5′	—	—	—	—	—	—	—
160	2,3,3′,4,5,6	—	—	—	—	—	—	—
161	2,3,3′,4,5′,6	—	—	—	—	—	—	—
162	2,3,3′,4′,5,5′	—	—	—	—	—	—	—
163	2,3,3′,4′,5,6	—	0.01	0.06	0.08	0.70	1.03	2.42
164	2,3,3′,4′,5′,6	—	—	0.02	0.03	0.31	0.40	0.69
165	2,3,3′,5,5′,6	—	—	—	—	—	—	—
166	2,3,4,4′,5,6	—	—	—	—	0.05	0.05	—
167	2,3′,4,4′,5,5′	—	—	0.01	0.01	0.35	0.27	0.19
168	2,3′,4,4′,5′,6	—	—	—	—	—	—	—
169	3,3′,4,4′,5,5′	—	—	—	—	—	—	—

Table 4-5. Polychlorinated Biphenyl Congener Compositions (in Weight Percent)[a] in Aroclors[b] *(continued)*

		Aroclor						
PCB No.	Chlorine positions	1016[c]	1242[d]	1248[e]	1248[f]	1254[g] “Late”	1254[h]	1260[i]
170	2,2′,3,3′,4,4′,5	—	—	—	0.08	0.35	0.52	4.11
171	2,2′,3,3′,4,4′,6	—	—	—	—	0.08	0.14	1.11
172	2,2′,3,3′,4,5,5′	—	—	—	—	0.03	0.07	0.70
173	2,2′,3,3′,4,5,6	—	—	—	—	—	—	0.10
174	2,2′,3,3′,4,5,6′	—	—	—	0.08	0.14	0.34	4.96
175	2,2′,3,3′,4,5′,6	—	—	—	—	—	—	0.17
176	2,2′,3,3′,4,6,6′	—	—	—	—	0.01	0.04	0.59
177	2,2′,3,3′,4′,5,6	—	—	—	0.03	0.08	0.20	2.57
178	2,2′,3,3′,5,5′,6,	—	—	—	—	—	0.03	0.83
179	2,2′,3,3′,5,6,6′	—	—	—	0.02	0.02	0.10	2.03
180	2,2′,3,4,4′,5,5′	—	—	0.02	0.21	0.42	0.67	11.38
181	2,2′,3,4,4′,5,6	—	—	—	—	—	—	0.01
182	2,2′,3,4,4′,5,6′	—	—	—	—	—	—	—
183	2,2′,3,4,4′,5′,6	—	—	—	0.06	0.09	0.18	2.41
184	2,2′,3,4,4′,6,6′	—	—	—	—	—	—	—
185	2,2′,3,4,5,5′,6	—	—	—	—	—	—	0.55
186	2,2′,3,4,5,6,6′	—	—	—	—	—	—	—
187	2,2′,3,4′,5,5′,6	—	—	—	0.09	0.09	0.25	5.40
188	2,2′,3,4′,5,6,6′	—	—	—	—	—	—	—
189	2,3,3′,4,4′,5,5′	—	—	—	—	0.01	0.01	0.10
190	2,3,3′,4,4′,5,6	—	—	—	—	0.05	0.07	0.82
191	2,3,3′,4,4′,5′,6	—	—	—	—	—	—	0.17
192	2,3,3′,4,5,5′,6	—	—	—	—	—	—	—
193	2,3,3′,4′,5,5′,6	—	—	—	—	—	0.03	0.53
194	2,2′,3,3′,4,4′,5,5′	—	—	—	—	—	0.01	2.07
195	2,2′,3,3′,4,4′,5,6	—	—	—	—	—	—	0.84
196	2,2′,3,3′,4,4′,5,6′	—	—	—	—	—	—	1.09
197	2,2′,3,3′,4,4′,6,6′	—	—	—	—	—	—	0.07
198	2,2′,3,3′,4,5,5′,6	—	—	—	—	—	—	0.10
199	2,2′,3,3′,4,5,5′,6′	—	—	—	—	—	0.01	1.78
200	2,2′,3,3′,4,5,6,6′	—	—	—	—	—	—	0.25
201	2,2′,3,3′,4,5′,6,6′	—	—	—	—	—	—	0.24
202	2,2′,3,3′,5,5′,6,6′	—	—	—	—	—	—	0.33
203	2,2′,3,4,4′,5,5′,6	—	—	—	—	—	0.02	1.40

Table 4-5. Polychlorinated Biphenyl Congener Compositions (in Weight Percent)[a] in Aroclors[b] *(continued)*

		Aroclor						
PCB No.	Chlorine positions	1016[c]	1242[d]	1248[e]	1248[f]	1254[g] "Late"	1254[h]	1260[i]
204	2,2′,3,4,4′,5,6,6′	—	—	—	—	—	—	—
205	2,3,3′,4,4′,5,5′,6	—	—	—	—	—	—	0.10
206	2,2′,3,3′,4,4′,5,5′,6	—	—	—	—	0.03	0.03	0.53
207	2,2′,3,3′,4,4′,5,6,6′	—	—	—	—	—	—	0.05
208	2,2′,3,3′,4,5,5′,6,6′	—	—	—	—	0.01	0.01	0.13
209	2,2′,3,3′,4,4′,5,5′,6,6′	—	—	—	—	—	—	NM
Sum of weight percents =		100.0	100.0	100.2	100.2	100.2	100.4	100.3

[a] Weight percent values in table are biased high with respect to mole percent values (not calculated).
[b] Source: Frame et al. (1996)
[c] Lot A2 Aroclor 1016
[d] Mean of three Lots of Aroclor 1242
[e] Lot A3.5 Aroclor 1248
[f] Lot G3.5 Aroclor 1248
[g] Lot A4 Aroclor 1254 (Monsanto Lot KI-02-6024) from abnormal late production (1974–1977)
[h] Lot G4 Aroclor 1254 (GE/118-peak analytical standard)
[i] Mean of three Lots of Aroclor 1260

NM = congener not measured, but present at trace level.

Appendix D

List of Dioxins and Furans Analyzed

Parameter	Abbreviated Name
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	OCDF
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	OCDD
1,2,3,4,6,7,8-Heptachlorodibenzofuran	1,2,3,4,6,7,8-HpCDF
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	1,2,3,4,6,7,8-HpCDD
1,2,3,4,7,8,9-Heptachlorodibenzofuran	1,2,3,4,7,8,9-HpCDF
1,2,3,4,7,8-Hexachlorodibenzofuran	1,2,3,4,7,8-HxCDF
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	1,2,3,4,7,8-HxCDD
1,2,3,6,7,8-Hexachlorodibenzofuran	1,2,3,6,7,8-HxCDF
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	1,2,3,6,7,8-HxCDD
1,2,3,7,8,9-Hexachlorodibenzofuran	1,2,3,7,8,9-HxCDF
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	1,2,3,7,8,9-HxCDD
1,2,3,7,8-Pentachlorodibenzofuran	PeCDF
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	PeCDD
2,3,4,6,7,8-Hexachlorodibenzofuran	2,3,4,6,7,8-HxCDF
2,3,4,7,8-Pentachlorodibenzofuran	2,3,4,7,8-PeCDF
2,3,7,8-Tetrachlorodibenzofuran	TCDF
2,3,7,8-Tetrachlorodibenzo-p-dioxin	TCDD
TEQ WHO2005 ND=0	TEQ (ND=0)
TEQ WHO2005 ND=0.5	TEQ (ND=0.5)
Total Heptachlorodibenzofuran	Total HpCDF
Total Heptachlorodibenzo-p-dioxin	Total HpCDD
Total Hexachlorodibenzofuran	Total HxCDF
Total Hexachlorodibenzo-p-dioxin	Total HxCDD
Total Pentachlorodibenzofuran	Total PeCDF
Total Pentachlorodibenzo-p-dioxin	Total PeCDD
Total Tetrachlorodibenzofuran	Total TCDF
Total Tetrachlorodibenzo-p-dioxin	Total TCDD

Appendix E

Water Quality Parameters Tested and Data Analysis

Sampling site	Total Alkalinity as CaCO3 mg/L	Nitrate mg/L	Nitrogen, Ammonia mg/L	pH	Sulfate mg/L
LBCOU001A	56	0.19	0.05	7.5	54.5
LBCOU002A	86	0.10	0.04	7.7	68.6
LBCOU003A	56	0.20	0.04	7.3	54.6
LBCOU004A	68	0.31	0.08	7.7	45.9
LBCOU005A	75	0.25	0.13	7.3	58.6
LBCOU006A	59	0.73	0.15	7.3	37.5
LBCOU007A	52	0.24	0.09	7.3	45.7
LBCOU008A	49	0.13	0.32	7.5	58.2
LBCOU011A	47	0.10	0.14	6.9	170.0
LBCOU018A	56	0.73	0.23	7.3	37.5
LBCRM2.4OU009A	42	0.33	0.03	7.5	70.5
X-230JOU010A	172	0.73	0.04	7.5	111.0
X-230JOU016A	173	0.72	0.08	7.5	112.0
X230JOU019A	112	0.36	0.21	7.8	79.3
average	79	0.37	0.12	7.4	71.7
max	173	0.73	0.32	7.8	170.0
min	42	0.10	0.03	6.9	37.5
SD	44	0.25	0.09	0.2	36.7

Total and bicarbonate alkalinity are the same. Phosphate was not detected in all water samples.

Appendix F

P-values for Statistical Correlation Between Normalized and Non-normalized Variables

Appendix G: p-values for TOC normalized variables

p-values for correlations of TOC normalized data

	Avg grain size (mm)	Avg grain size(<2 mm)	OCDD	1,2,3,4,6,7,8-HpCDD	PCB189	PCB156	PCB157	PCB105	PCB167	PCB114
Avg grain size (mm)										
Avg grain size(<2mm)	7.36E-06									
OCDD	3.62E-01	3.10E-01								
1,2,3,4,6,7,8-HpCDD	3.22E-01	2.64E-01	3.18E-01							
PCB189	5.97E-01	7.25E-01	8.75E-01	6.81E-01						
PCB156	4.43E-01	7.25E-01	9.08E-01	3.83E-01	6.67E-08					
PCB157	2.81E-01	3.12E-01	1.57E-02	6.56E-01	2.66E-01	6.73E-02				
PCB105	4.41E-01	7.27E-01	7.34E-01	4.39E-01	1.07E-07	2.61E-16	1.50E-01			
PCB167	6.11E-01	9.36E-01	7.66E-01		1.91E-10	1.56E-14	1.94E-01	1.02E-13		
PCB114	3.73E-01	4.89E-01	1.22E-01		9.39E-03	2.64E-03	7.37E-01	1.40E-04	2.65E-03	
PCB118	2.18E-01	4.19E-01	8.78E-01	5.85E-01	3.59E-07	1.18E-15	1.52E-01	6.99E-20	1.25E-14	1.70E-04
PCB123	3.02E-01	6.18E-01	1.48E-01		5.03E-05	2.30E-06	9.76E-01	1.83E-08	4.73E-07	1.85E-04
PCB126	6.87E-01	3.14E-01			9.85E-03	8.40E-03	9.96E-02	2.11E-02	5.00E-03	1.06E-01
PCB77	2.06E-01	3.06E-01	8.78E-01	7.55E-01	1.55E-04	4.49E-06	9.86E-01	5.25E-08	4.55E-06	3.73E-06
Aroclor-1254	2.42E-01	5.24E-01	9.25E-03	8.00E-01	2.03E-01	3.79E-01	3.42E-03	5.12E-01	1.07E-01	6.90E-01
Aroclor-1260	9.85E-02	2.34E-01	3.51E-02	9.67E-01	8.18E-02	9.35E-02	3.26E-06	1.16E-01	5.71E-02	8.02E-01
Aroclor-1268	2.11E-01	2.85E-01				7.12E-01	7.26E-01			
Aroclor-Total	2.13E-01	5.20E-01	9.22E-03	8.68E-01	5.36E-02	1.04E-01	3.82E-04	1.74E-01	3.24E-02	7.08E-01
Iron	7.67E-03	8.38E-06	8.35E-01	5.59E-01	1.66E-01	1.61E-01	9.89E-01	1.79E-01	2.68E-01	9.91E-02
Total HpCDD	1.84E-01	1.79E-01	1.34E-01	7.94E-06	8.56E-01	5.18E-01	3.70E-01	5.93E-01	7.38E-01	1.77E-01
Total TCDF	2.72E-01	5.35E-01	3.37E-01	9.59E-01	2.25E-02	8.63E-02	8.51E-01	4.12E-02	1.08E-02	3.36E-08

yellow = p-values < 0.05

orange = p-values <0.1 and >0.05

Appendix G: p-values for TOC normalized variables

p-values for correlations of TOC normalized data

	PCB118	PCB123	PCB126	PCB77	Aroclor 1254	Aroclor 1260	Aroclor 1268	Aroclor Total	Iron	Total HpCDD
Avg grain size (mm)										
Avg grain size(<2mm)										
OCDD										
1,2,3,4,6,7,8-HpCDD										
PCB189										
PCB156										
PCB157										
PCB105										
PCB167										
PCB114										
PCB118										
PCB123	6.92E-09									
PCB126	8.58E-03	4.24E-02								
PCB77	5.58E-08	3.50E-06	6.63E-02							
Aroclor-1254	5.63E-01	9.78E-01	2.63E-04	6.23E-01						
Aroclor-1260	1.87E-01	6.49E-01	1.03E-01	6.72E-01	1.89E-07					
Aroclor-1268	7.15E-01				1.00E+00	8.81E-01				
Aroclor-Total	2.14E-01	6.96E-01	5.52E-02	5.14E-01	2.50E-13	1.70E-11	8.40E-01			
Iron	8.34E-02	1.73E-01	2.15E-01	8.80E-02	7.33E-01	7.01E-01	4.43E-01	8.98E-01		
Total HpCDD	5.81E-01	1.50E-01		8.60E-01	8.83E-01	8.94E-01		9.37E-01	7.31E-01	
Total TCDF	1.25E-02	3.13E-02		4.24E-03	7.92E-01	7.21E-01		7.72E-01	2.07E-01	9.78E-01

yellow = p-values < 0.05

orange = p-values <0.1 and >0.05

Appendix F: p-values for non-normalized variables

p-values for correlation of non-normalized data

p values	Avg grain size (mm)	Avg grain size(<2mm)	OCDD	1,2,3,4,6,7,8-HpCDD	PCB189	PCB156	PCB157	PCB105	PCB167
Avg grain size (mm)									
Avg grain size(<2mm)	7.36E-06								
OCDD	3.50E-01	3.34E-01							
1,2,3,4,6,7,8-HpCDD	5.65E-01	5.26E-01	7.42E-05						
PCB189	6.66E-01	9.45E-01	1.22E-03	5.42E-02					
PCB156	5.37E-01	4.04E-01	2.55E-03	1.07E-01	6.33E-08				
PCB157	3.72E-01	9.40E-01	6.11E-04	2.16E-02	3.61E-02	2.60E-01			
PCB105	2.82E-01	2.06E-01	4.78E-01	9.73E-01	5.59E-03	2.99E-08	6.10E-01		
PCB167	9.55E-01	7.99E-01	1.13E-02		2.05E-09	1.10E-19	2.76E-01	8.62E-07	
PCB114	9.83E-01	4.67E-01	3.49E-03		1.18E-01	4.88E-02	9.82E-01	3.48E-03	5.24E-02
PCB118	2.80E-01	1.59E-01	8.32E-02	6.51E-01	7.30E-05	4.78E-13	7.05E-01	8.74E-14	3.91E-10
PCB123	6.66E-01	6.06E-01	2.78E-02		1.21E-03	4.27E-05	8.54E-01	2.69E-09	1.46E-05
PCB126	9.95E-01	9.74E-02			5.62E-04	5.93E-04	3.37E-02	9.82E-05	7.59E-04
PCB77	5.72E-01	9.07E-01	3.83E-04	1.69E-01	3.65E-05	1.09E-04	7.46E-02	1.11E-02	7.54E-05
Aroclor-1254	1.97E-01	8.81E-01	3.40E-03	1.31E-01	1.40E-03	1.69E-02	1.16E-02	3.76E-01	5.46E-03
Aroclor-1260	2.61E-01	5.91E-01	1.03E-07	1.29E-03	2.89E-07	1.59E-04	2.17E-03	1.33E-01	1.01E-04
Aroclor-1268	2.71E-01	3.45E-01				9.00E-01	3.91E-01		
Aroclor-Total	2.93E-01	9.81E-01	5.01E-07	4.08E-02	1.60E-07	9.48E-05	3.34E-03	1.08E-01	5.17E-05
Iron	7.67E-03	8.38E-06	7.00E-01	7.23E-01	7.17E-01	3.54E-01	8.23E-01	1.79E-01	6.29E-01
Total HpCDD	4.79E-01	4.54E-01	1.34E-05	2.50E-14	2.33E-02	7.12E-02	1.48E-02	9.05E-01	2.93E-01
Total Organic Carbon Avg	6.90E-01	8.93E-01	3.38E-03	9.39E-02	3.61E-04	1.13E-05	2.61E-01	1.21E-02	3.94E-04
Total TCDF	7.26E-01	8.72E-01	3.55E-02	4.30E-01	7.47E-02	6.73E-02	4.40E-01	7.67E-02	1.02E-01

yellow = p-values < 0.05

orange = p-values <0.1 and >0.05

Appendix F: p-values for non-normalized variables

p-values for correlation of non-normalized data

p values	PCB114	PCB118	PCB123	PCB126	PCB77	Aroclor 1254	Aroclor 1260	Aroclor 1268	Aroclor Total
Avg grain size (mm)									
Avg grain size(<2mm)									
OCDD									
1,2,3,4,6,7,8-HpCDD									
PCB189									
PCB156									
PCB157									
PCB105									
PCB167									
PCB114									
PCB118	2.17E-03								
PCB123	6.69E-03	6.95E-08							
PCB126	6.52E-02	3.24E-05	1.40E-02						
PCB77	8.19E-05	4.00E-04	2.15E-03	2.39E-02					
Aroclor-1254	3.33E-01	1.01E-01	5.74E-01	4.36E-04	5.58E-03				
Aroclor-1260	5.46E-01	9.08E-03	2.28E-01	5.36E-03	6.14E-04	7.59E-05			
Aroclor-1268		9.45E-01				2.30E-01	2.33E-01		
Aroclor-Total	4.38E-01	6.56E-03	2.51E-01	3.04E-04	7.28E-04	9.08E-08	4.22E-13	2.22E-01	
Iron	3.13E-01	1.60E-01	3.25E-01	2.14E-01	9.49E-01	9.99E-01	6.68E-01	5.03E-01	9.85E-01
Total HpCDD	4.67E-01	4.35E-01	7.79E-01		1.72E-01	7.70E-02	2.51E-04		3.48E-03
Total Organic Carbon Avg	9.99E-02	3.58E-04	2.36E-01	1.77E-02	2.09E-05	8.41E-03	4.33E-05	1.22E-01	4.19E-05
Total TCDF	2.99E-05	6.94E-02	3.41E-01		1.03E-01	5.74E-01	3.81E-01		4.88E-01

yellow = p-values < 0.05

orange = p-values <0.1 and >0.05

Appendix F: p-values for non-normalized variables

p-values for correlation of non-normalized data

p values	Iron	Total HpCDD	Total Organic Carbon Avg
Avg grain size (mm)			
Avg grain size(<2mm)			
OCDD			
1,2,3,4,6,7,8-HpCDD			
PCB189			
PCB156			
PCB157			
PCB105			
PCB167			
PCB114			
PCB118			
PCB123			
PCB126			
PCB77			
Aroclor-1254			
Aroclor-1260			
Aroclor-1268			
Aroclor-Total			
Iron			
Total HpCDD	7.99E-01		
Total Organic Carbon Avg	7.42E-01	6.02E-02	
Total TCDF	8.32E-01	6.02E-01	4.31E-01

yellow = p-values < 0.05

orange = p-values <0.1 and >0.05

Appendix G

P-values for Statistical Correlation Between Clay Fraction of the Sediment and Variables

Appendix G: P-Values for Clay Fraction

p values	*CLAY FRACTION %*	*silt/clay%*	OCDD	1,2,3,4,6,7,8-HpCDD	PCB189	PCB156	PCB157	PCB105	PCB167	PCB114	PCB118
CLAY FRACTION %											
silt/clay%	8.24E-07										
OCDD	9.29E-01	2.52E-01									
1,2,3,4,6,7,8-HpCDD	5.37E-01	5.37E-01	7.42E-05								
PCB189	3.28E-01	8.50E-01	1.22E-03	5.42E-02							
PCB156	5.82E-02	4.30E-01	2.55E-03	1.07E-01	6.33E-08						
PCB157	4.59E-01	5.30E-01	6.11E-04	2.16E-02	3.61E-02	2.60E-01					
PCB105	2.92E-02	1.87E-01	4.78E-01	9.73E-01	5.59E-03	2.99E-08	6.10E-01				
PCB167	2.08E-01	8.44E-01	1.13E-02		2.05E-09	1.10E-19	2.76E-01	8.62E-07			
PCB114	2.45E-01	6.00E-01	3.49E-03		1.18E-01	4.88E-02	9.82E-01	3.48E-03	5.24E-02		
PCB118	1.30E-02	1.46E-01	8.32E-02	6.51E-01	7.30E-05	4.78E-13	7.05E-01	8.74E-14	3.91E-10	2.17E-03	
PCB123	3.76E-01	6.16E-01	2.78E-02		1.21E-03	4.27E-05	8.54E-01	2.69E-09	1.46E-05	6.69E-03	6.95E-08
PCB126	9.26E-02	2.47E-01			5.62E-04	5.93E-04	3.37E-02	9.82E-05	7.59E-04	6.52E-02	3.24E-05
PCB77	2.90E-01	6.98E-01	3.83E-04	1.69E-01	3.65E-05	1.09E-04	7.46E-02	1.11E-02	7.54E-05	8.19E-05	4.00E-04
Aroclor-1254	9.23E-01	5.76E-01	3.40E-03	1.31E-01	1.40E-03	1.69E-02	1.16E-02	3.76E-01	5.46E-03	3.33E-01	1.01E-01
Aroclor-1260	5.63E-01	4.27E-01	1.03E-07	1.29E-03	2.89E-07	1.59E-04	2.17E-03	1.33E-01	1.01E-04	5.46E-01	9.08E-03
Aroclor-1268	3.38E-01	3.38E-01				9.00E-01	3.91E-01				9.45E-01
Aroclor-Total	5.23E-01	6.34E-01	5.01E-07	4.08E-02	1.60E-07	9.48E-05	3.34E-03	1.08E-01	5.17E-05	4.38E-01	6.56E-03
Iron	6.18E-02	5.39E-04	7.00E-01	7.23E-01	7.17E-01	3.54E-01	8.23E-01	1.79E-01	6.29E-01	3.13E-01	1.60E-01
Total HpCDD	6.23E-01	4.44E-01	1.34E-05	2.50E-14	2.33E-02	7.12E-02	1.48E-02	9.05E-01	2.93E-01	4.67E-01	4.35E-01
TOC	3.25E-02	7.89E-01	3.38E-03	9.39E-02	3.61E-04	1.13E-05	2.61E-01	1.21E-02	3.94E-04	9.99E-02	3.58E-04
Total TCDD	4.73E-01	7.50E-01	3.55E-02	4.30E-01	7.47E-02	6.73E-02	4.40E-01	7.67E-02	1.02E-01	2.99E-05	6.94E-02

Yellow = p-values <0.05

Orange = p-values <0.1 and >0.05

Appendix G: P-Values for Clay Fraction

p values	PCB123	PCB126	PCB77	Aroclor-1254	Aroclor-1260	Aroclor-1268	Aroclor-Total	Iron	Total HPCDD	TOC	Total TCDF
CLAY FRACTION %											
silt/clay%											
OCDD											
1,2,3,4,6,7,8-HpCDD											
PCB189											
PCB156											
PCB157											
PCB105											
PCB167											
PCB114											
PCB118											
PCB123											
PCB126	1.40E-02										
PCB77	2.15E-03	2.39E-02									
Aroclor-1254	5.74E-01	4.36E-04	5.58E-03								
Aroclor-1260	2.28E-01	5.36E-03	6.14E-04	7.59E-05							
Aroclor-1268				2.30E-01	2.33E-01						
Aroclor-Total	2.51E-01	3.04E-04	7.28E-04	9.08E-08	4.22E-13	2.22E-01					
Iron	3.25E-01	2.14E-01	9.49E-01	9.99E-01	6.68E-01	5.03E-01	9.85E-01				
Total HpCDD	7.79E-01		1.72E-01	7.70E-02	2.51E-04		3.48E-03	7.99E-01			
TOC	2.36E-01	1.77E-02	2.09E-05	8.41E-03	4.33E-05	1.22E-01	4.19E-05	7.42E-01	6.02E-02		
Total TCDD	3.41E-01		1.03E-01	5.74E-01	3.81E-01		4.88E-01	8.32E-01	6.02E-01	4.31E-01	

Yellow = p-values <0.05

Orange = p-values <0.1 and >0.05

Appendix H

List of Field Supplies

Appendix H - Materials and supplies list

1. Radioactivity detector
2. Measuring tape
3. Ruler
4. Plastic wrap
5. 2 Stainless steel bucket
6. 2 Stainless steel hand trowel
7. Stainless steel hand auger
8. Stainless steel hand corer sampler
9. Decontamination supplies: soap, water, methanol rinse, hexane rinse
10. Catchment container for decontamination rinses
11. 3 Coolers
12. Glass amber sampling jars
13. Plastic water bottles
14. Plastic 1 gallon zip-lock bags
15. GPS
16. Camera
17. Ice
18. Permanent marker
19. Clipboard with maps and sampling locations identified