Budd Inlet
Sediment Dioxin Source Study
Olympia, WA

Final Report

Prepared for

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September 2015

Publication: 16-09-101

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List of Acronyms

ALS	Alternating Least Squares
ATSDR	Agency for Toxic Substances and Disease Registry
cfs	cubic feet per second
CSO	combined sewer overflow
cy	cubic yards
dioxin	polychlorinated dibenzo-*p*-dioxin
DNR	Department of Natural Resources
EBRS	East Bay Redevelopment Site
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
EMPC	estimated maximum possible concentration
EPA	United States Environmental Protection Agency
FS	feasibility study
furan	polychlorinated dibenzofuran
HCA	Hierarchical Cluster Analysis
HFB	hog fuel boiler
LDW	Lower Duwamish Waterway
LOTT	Lacey-Olympia-Tumwater-Thurston County Clean Water Alliance
MBL	multiple benefits line
MCDD	monochlorodibenzo-*p*-dioxin
MCDF	monochlorodibenzofuran
MLLW	mean lower low water
Na-PCP	sodium pentachlorophenol
ng/kg	nanograms per kilogram
OCDD	octachlorodibenzo-*p*-dioxin
OCDF	octachlorodibenzofuran
PAH	polycyclic aromatic hydrocarbon
PCA	principal components analysis
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
Port	Port of Olympia
RI	remedial investigation
SAIC	Science Applications International Corporation
TCDD	tetrachlorodibenzo-*p*-dioxin
TEF	toxicity equivalency factor
TEQ	toxic equivalency
TOC	total organic carbon
USFS	United States Forest Service
USGS	United States Geological Survey
WHO	World Health Organization

Forward

This Budd Inlet Sediment Dioxin Source Study documents the chemometric evaluation and interpretations of Budd Inlet sediment dioxin/furan congener data. The chemometric process involves the analysis of dioxin/furan data from sediment samples using a multivariate approach. There are numerous multivariate approaches that can be used by themselves or with others.

The Department of Ecology and the Port of Olympia conducted separate dioxin/furan chemometric analyses of Budd Inlet sediment data. Using different but, similar in function multivariate analyses and similar data sets, both analyses resulted in the identification of three nearly identical congener factor profiles. The primary difference between the two reports is the interpretation of the factor profiles.

Table 1. Differences in interpretation of Factor profiles by Ecology and Port of Olympia.

Department of Ecology (Newfields 2015)	**Port of Olympia (Anchor 2015, Appendix D)**
Factor – 1 Hog fuel burning.	Factor – 3 Hog fuel burning.
Factor – 2 Pentachlorophenol (PCP). Historical use Current contamination	Factor – 2 Mixed urban source Regional sediment profiles Urban background Sewage Nearby catch basins.
Factor – 3 Polychlorinated biphenyls (PCBs). Historical use at and around the Port Peninsula	Factor – 1 Mixed combustion source Truck diesel, highway Asphalt burn barrels Medical waste incineration.

The Department of Ecology, after consultation with regional experts, disagrees with the Port of Olympia's chemometric analysis for the following reasons:

- The Port's interpretation cannot explain the presence of dioxin/furan contamination hot-spots.
- The primary sources/factors identified by the Port of Olympia's analysis were only diffuse sources (Table 1)
- The Port of Olympia's source factor profiles are not supported by their own site investigation data and site history.
- The Port of Olympia does not address historical dioxin/furan contamination and the dispersion and mixing pattern of the sediments.

As the Department of Ecology moves forward with the cleanup of Budd Inlet sediments we will base all future decisions on the results and interpretation found in the Ecology study (*Budd Inlet Sediment Dioxin Source Study Olympia, WA* (Newfields 2015)).

NewFields L.L.C, 2015. Technical Memorandum: Budd Inlet Sediment Chemometrics – Profile Interpretation and Lines of Evidence. Prepared by Newfields, LLC for the Washington Department of Ecology

Anchor, QEA, 2015. Final Investigation Report Port of Olympia Budd Inlet Sediment Site, Section 6.5.2 and Appendix D. Prepared by Anchor QEA for the Port of Olympia, Olympia, WA

1.0 Introduction

In support of the Washington State Department of Ecology's (Ecology) Puget Sound Initiative, Budd Inlet was selected as one of several embayments targeted for cleanup of sediment contamination. Ecology is responsible for overseeing source control, cleanup, and restoration of the Inlet.

In 2006, the Port of Olympia (Port) conducted a sediment characterization study in preparation for dredging the Olympia Harbor navigational channel and the Port's berthing areas. The results revealed elevated concentrations of dioxin/furan congeners in areas scheduled for dredging (SAIC 2008). These elevated concentrations raised concerns about the extent of dioxin/furan contamination throughout Budd Inlet and the potential risk to human health and the environment. As a result, Ecology initiated the Budd Inlet Sediment Investigation in 2007 to characterize the nature and distribution of dioxin/furan congeners throughout Budd Inlet (SAIC 2008).

The analysis of sediment samples collected during this investigation revealed elevated concentrations of dioxin/furan toxic equivalencies (TEQ) throughout the inlet, particularly at the Port's shipping berths (4,210 and 230 ng TEQ/kg), near the discharge of Moxlie Creek (60.0 ng TEQ/kg), and adjacent to Hardel Mutual Plywood (59.8 ng TEQ/kg). Concentrations throughout the bay averaged nearly 20 TEQ/kg, a level higher than most other Puget Sound embayments.

A preliminary analysis of the dioxin/furan congener profiles indicated that the main source of the contamination was from pentachlorophenol (PCP), a wood-preservative treatment that was historically applied to wood at industrial facilities in Budd Inlet (SAIC 2008). However, other potential sources may exist, including industrial chemical releases, deposition of hog fuel boiler stack emissions, dumping of ash from hog fuel boilers, or loadings from stormwater outfalls. The objectives of this investigation are to perform a more statistically rigorous chemometric analysis to better quantitate the contribution to dioxin/furan contamination from PCP and other sources.

This Budd Inlet Sediment Dioxin Source Study documents the chemometric evaluation and interpretations of Budd Inlet sediment dioxin/furan congener data. The report presents an in-depth discussion of the data evaluation process, results, and conclusions regarding probable sources of dioxin/furan contamination currently found in the surface and subsurface sediments of Budd Inlet.

1.1 Site Summary

Budd Inlet is a small embayment of southern Puget Sound, with the city of Olympia, WA, at the head of the inlet (Figure 1). The southern portion of Budd Inlet has historically supported wood product industries including milling, processing, and treatment, as well as boat industries and recreational marinas. A primary feature of Budd Inlet is the peninsula that extends from the southern portion of the embayment and divides the Inlet into the East and West Bays. This peninsula is home to most of the operations of the Port of Olympia, including the shipping berths on the east side of the West Bay. The Olympia Harbor federal navigation channel and turning basin are maintained in inner West Bay, while a smaller navigational channel is maintained as far south as the Swantown Boatworks in the East Bay (Figure 1).

Budd Inlet has been altered considerably since the late 1800's. The blue outline in Figure 1 shows the extent of the intertidal area in 1873. The western shore of the West Bay, the southern half of the East Bay, and nearly all of the center peninsula have been filled with a variety of materials including dredge spoils, wood debris, and construction material. The Deschutes River formerly flowed freely into the West Bay. In 1951 the river was dammed, creating a freshwater lake (Capitol Lake) over what had previously been tidal flats.

1.2 Overview of Dioxins/Furans

Dioxins and furans are two classes of chemicals that are structurally similar in that they both contain two carbon ring structures. All dioxins include two oxygen atoms, while all furans include one oxygen atom. There are 210 unique dioxin/furan compounds, or congeners (75 dioxin and 135 furan congeners), which differ from each other in the number and position of chlorine atoms on the carbon rings.

Dioxin/furan congeners contain one to eight chlorine atoms, resulting in eight families, or homolog groups, ranging from those containing one chlorine atom, monochlorodibenzo-*p*-dioxins (MCDDs) and monochlorodibenzofurans (MCDFs), to those containing eight, octachlorodibenzo-*p*-dioxins (OCDDs) and octachlorodibenzofurans (OCDFs).

Although there are 210 unique dioxin/furan congeners, only 17 of these are typically evaluated because they are considered by the U.S. Environmental Protection Agency (EPA) and the World Health Organization (WHO) to be the most toxic. These 17 congeners have chlorine atoms in the 2, 3, 7, and 8 positions. Only the 2,3,7,8-substituted congeners are discussed in this study (Table 1).

Concentrations of the 17 dioxin/furan congeners of primary interest are often expressed as a TEQ relative to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD). This means that the concentrations of the other 16 congeners have been adjusted based on a toxicity equivalency factor (TEF) that scales each congener's potency relative to 2,3,7,8-TCDD. The concentrations are presented as mass of chemical per mass of sediment. The TEFs assigned to each congener are consistent with Ecology guidance (Ecology 2007; Van den Berg et al. 2006) and are presented in Table 1. The congeners considered most toxic, 2,3,7,8-TCDD and 1,2,3,7,8-PeCDD, are assigned a TEF of 1, while those considered least toxic, OCDD and OCDF, have the smallest TEF, 0.0003.

Regulatory agencies are interested in dioxin/furan congeners because of their toxicity to humans and wildlife. Once released into the environment, dioxins/furans resist degradation, do not dissolve in water, and adhere to organic material on particles such as soil, dust, and sediment. Despite their persistence and ubiquitous presence, concentrations of dioxins/furans in the environment have been declining since the 1970s because of improvements in air pollution control technologies for combustion and incineration facilities and cleanup of contaminated areas (EPA 2003).

Dioxins/furans enter the environment from a variety of sources. Except for small quantities used in research, neither compound is created intentionally. Dioxin/furan congeners are byproducts of chemical manufacturing or combustion/ incineration processes involving chlorine compounds. Major contributors of dioxin/furan congeners to the environment include:

- Incineration of municipal solid waste and medical waste;
- Secondary copper smelting;
- Forest fires;
- Land applications of sewage sludge;
- Cement kilns;
- Vehicle emissions, combustion of gasoline and diesel;
- Coal-fired power plants;
- Residential wood burning;
- Chlorine bleaching of wood pulp;
- Backyard burning of household waste;
- Byproducts and derivatives of chemical production, e.g., pentachlorophenol (PCP), polychlorinated biphenyls (PCBs), 2,4,5-T; and
- Hog fuel boilers (HFBs) burning salt-laden wood.

Dioxin/furan contamination is present at some level throughout the environment and can be found in a variety of matrices. Dioxin/furan concentrations tend to be elevated near industrial areas but are present in varying amounts in urban, rural, and even remote areas. Urban soil and sediment dioxins/furans are commonly composed of a mixture of sources. The goal of chemometrics analysis is to determine the amount that individual sources may have contributed to this mixture.

1.3 Overview of Dioxin/Furan Chemometrics

Each of the dioxin/furan sources listed in Section 1.2 produces a unique mix of the 17 congeners. Some sources may preferentially produce either dioxin or furan congeners, or congeners of a specific molecular weight. The abundance of these congeners relative to each other is known as a congener profile, or in simpler terms, a chemical fingerprint.

Chemometrics, often referred to as environmental forensics, is a blanket term that includes several multivariate statistical methods such as clustering, principal components analysis (PCA), and alternating least squares (ALS). While each of these methods serves a slightly different purpose, the overall goal of the analysis is to reduce the complexity of the data-set to allow comparisons to the congener profiles of known sources.

Dioxin/furan contamination in sediment samples is generally representative of a variety of sources. Chemometrics, particularly ALS, are used to reduce the mixed profiles measured in the sediment samples into a small number of modeled congener profiles, or factors. If these factors match the congener profiles of the known sources, spatial modeling can then be used to map the distribution of each source. The spatial modeling along with other lines of evidence including circulation studies and historical site usage are then used to reinforce the statistical results.

1.4 Study Objectives

The purpose of this study is to perform a chemometrics analysis for dioxin/furan congeners to help discern the potential sources of contamination in Budd Inlet sediments, identify potential upland sources, and determine the relative contribution from each source. More specifically:

- Identify unique dioxin/furan congener profiles present in Budd Inlet sediments, and when possible match the profiles to known sources;
- Calculate the relative contribution of the identified dioxin/furan source profiles to harbor-wide contamination; and
- Determine potential upland source areas by integrating spatial patterns of each dioxin/furan congener source profile and knowledge of historic and modern upland activities.

The results of this study are expected to assist Ecology in identifying potential sources of the dioxins/furans in Budd Inlet. It is not Ecology's intention to use the findings to perform detailed quantitative allocations among potential point/nonpoint sources or to apportion liability to potentially liable parties.

1.5 Report Organization

Section 1.0 presents an introduction to Budd Inlet, chemometric methods, dioxin/furan congeners, and the objectives of the study. Section 2.0 provides a more detailed background of Budd Inlet, including some of the sites that are thought to be contributors to dioxin/furan contamination. Circulation and sediment transport patterns are also discussed. Section 3.0 outlines the chemometric methods and how they were applied to the Budd Inlet data-set. Section 4.0 matches the modeled factors of the chemometric unmixing model to the source library. The results are presented spatially and discussed on a site by site basis in Section 5.0 with the goal of determining the sources and pathways for each factor. References are presented in Section 6.0.

2.0 Site Background

Efforts to cleanup dioxin/furan contaminated sediments in Budd Inlet have been ongoing for the last three decades. A number of studies have been conducted at various facilities and other suspected sources such as outfalls. These studies include baywide investigations, interim action plans, remedial investigations (RI), feasibility studies (FS), dredge material characterizations, source control determinations, and more. This section presents a summary of the facilities with the greatest potential to have contributed to sediment dioxin/furan contamination.

This section also includes available information about hydrodynamics and sediment deposition in Budd Inlet. Spatial distributions of surface and subsurface dioxin/furan concentrations are then presented to show contamination gradients and make connections between facility locations, transport mechanisms, and depositional areas.

2.1 Summary of Facilities and Potential Sources

Facilities and other potential sources (such as major outfalls) are presented in Figure 1. Descriptions of these facilities and sediment conditions throughout Budd Inlet are limited to readily available study data. This is particularly important for an embayment like Budd Inlet which has been industrialized for, and undergone considerable change over, the last century. Therefore, it is not possible to account for all of the changes and potential contaminant releases during the operational period for each individual facility. This summary only includes information relevant to contamination or source tracing for dioxin/furan congeners. Ecology and the Port of Olympia have both compiled larger records of Budd Inlet related study documents for an expanded suite of chemicals of concern (SAIC 2007; Anchor QEA 2012a).

2.1.1 Cascade Pole Company

The Cascade Pole Company operated on land leased from the Port of Olympia (Figure 1). Wood treatment by Cascade Pole and its predecessors occurred at the site beginning in the early 1940s and ending in 1986. Prior to 1967, creosote was the primary preservative used on wood. In the 1960's Cascade Pole began using PCP for wood treatment (Landau Associates 1999). The discovery of contaminated soil in the early 1980's prompted environmental cleanup efforts. The *Public Participation Plan* for Cascade Pole includes a timeline describing many of the cleanup actions including: 1) installation of a groundwater pump to treat contaminated water; 2) construction of a near-shore sheet pile to block further releases of wood treatment chemicals to Budd Inlet; 3) dredging of contaminated sediments; and 4) paving of the upland area (Ecology 2010). Dredging activities occurred in an area enclosed within a boundary referred to as the multiple benefits line (MBL). A total of 35,000 cubic yards (cy) of sediment were removed, and the area was backfilled with clean, granular sand in order to return the area to pre-excavation grade (Landau Associates 2014).

While this site is not expected to be an ongoing source, historical discharges of PCP may have been responsible for some of the elevated dioxin/furan concentrations currently observed throughout Budd Inlet. Pre-cleanup surface sediment samples have been incorporated into the source library (Section 3.1.2).

2.1.2 Port of Olympia Marine Terminal Berths 1, 2, and 3

The Port of Olympia maintains three berthing areas along the east side of the West Bay. This area is of particular interest because of high dioxin/furan concentrations that have been measured in nearby sediment (SAIC 2007; Anchor QEA 2013).

The upland area adjacent to the berths has been used for log and lumber storage, including storage of wood that may have been treated with sap-stain (Anchor QEA 2012b). Storm drain solids samples collected as recently as 2013 from the catch basins near the storage yard had dioxin/furan concentrations as high as 1,500 ng TEQ/kg. In addition to treated wood storage, a historical opening in the pier was present at Berth 3 (Figure 1). This opening was noted in aerial images as recent as 1960, but was not present in images from or after 1970 (Anchor 2013). The original purpose of this opening in the pier is unknown. However, concentrations of several contaminants are elevated in its vicinity, including dioxin/furan congeners, metals, semi-volatile organic contaminants (SVOC), polycyclic aromatic hydrocarbons (PAH), and PCBs.

Portions of Berth's 2 and 3 were dredged to -39 feet mean lower low water (MLLW) in February 2009, resulting in the removal of 22,300 cy of sediment (Anchor QEA 2009). A clean cap of granular sand was placed on top of the exposed surface to prevent any release or movement of contaminated sediments. Post-dredge monitoring occurred at 3, 9, 15, and 21 month intervals to determine ongoing sedimentation within the dredged area.

Additional dredging along Berth's 1, 2, and parts of 3 was conducted from November 25 to December 6, 2013 with the removal of 40,000 cy of contaminated sediment. As in the previous dredging, a clean cap of granular sand was placed on top of the exposed surface to prevent any release or movement of contaminated sediments.

No sediment data used in this report were collected during or after the 2013 dredging. Because of this, figures reflect surface sediment conditions following the 2009 dredging activities. A discussion of the 2013 dredge area and all of the affected samples is provided in Section 5.3.2.

2.1.3 Moxlie Creek and LOTT Outfalls

Numerous outfalls discharge to Budd Inlet from municipal, Port, and private drainages. Two of the largest are the Lacey-Olympia-Tumwater-Thurston County Clean Water Alliance (LOTT) outfall and the Moxlie Creek outfall (Figure 1).

The LOTT wastewater treatment plant receives an average of nearly 11.5 million gallons of wastewater per day. Treated water is discharged through a 48 inch outfall pipe located offshore of the north end of the Peninsula. No studies specifically characterized sediments near the LOTT outfall. However, one proximal surface grab and subsurface core interval contained dioxin/furan concentrations well below the baywide average (Anchor QEA 2013).

Moxlie Creek discharges through a large (72 inch) outfall at the south end of the East Bay. Moxlie Creek originates as an artesian spring approximately 1.5 miles south of the East Bay (Anchor QEA 2013). The creek is fully covered prior to discharging into Budd Inlet. In addition to the creek, the outfall also drains 4.5 square miles of developed area in the city of Olympia. Historically, this outfall functioned as a combined sewer overflow (CSO; Anchor QEA 2013). Elevated surface sediment concentrations of dioxin/furan congeners were noted in the south end of East Bay during the 2007 Sediment Investigation (SAIC 2008). Subsurface cores collected in

2013 had some of the highest dioxin/furan concentrations measured in Budd Inlet (Anchor QEA 2013). Determining whether the outfall or other historical activities were the source of these dioxins/furans is a key component of this study and is discussed in Section 5.2.

2.1.4 East Bay Redevelopment Site

The East Bay Redevelopment Site (EBRS) is located on the western side of the southern portion of the East Bay (Figure 1). Most of the site is built upon fill material placed continuously since the late 1800s. The fill consists of dredge spoils, wood debris from processing operations, construction debris, and roadway fill (GeoEngineers 2008).

Lumber milling operations occurred at the site from 1888 through 1968 under a variety of owners and operators. Since lumber operations ceased, the Port and its tenants have used portions of the EBRS for commercial and light industrial activities and storage (GeoEngineers 2008). HFBs and one refuse burner were present on site while lumber milling was performed (Figure 1). Soil borings for dioxin/furan contamination have found concentrations up to 645 ng TEQ/kg, although it was unclear if the contamination source was site operations or fill materials.

The site is currently undergoing redevelopment as a part of revitalizing downtown Olympia. The first round of upland excavations occurred in 2009, related to the installation of utilities, roads, bike lanes, and sidewalks (Pioneer 2010). Samples collected from piles of excavated soil are included in this report as part of the source library (Section 3.1.2).

2.1.5 Hardel Plywood

Hardel Plywood was a former plywood manufacturing facility located on the western shore of the West Bay (Figure 1). The site was formerly tidal flats, but was filled sometime prior to being used as a lumber business in 1924. The site contains 6.7 acres of upland area, and 11.1 acres of tidal flats. Hardel Plywood operated the site from 1956 through 1996, when a fire destroyed the manufacturing facility (Ecology 2012). A 2013 report shows that one HFB was present onsite during at least a portion of the lumber processing operations (Anchor QEA 2013). Despite the presence of the HFB, dioxin/furan congeners were not a contaminant of concern for the upland area. All cleanup activities for upland areas of the site were completed during an interim action.

During the 2007 Baywide Sediment Investigation (SAIC 2007) and the Hardel Plywood remedial action investigation, sediment samples were collected that contained dioxin/furan concentrations greater than the baywide average. However, the cleanup of dioxin/furan contamination in sediment was not required as part of the cleanup action plan (Ecology 2012).

2.1.6 West Bay Marina/Buchanan Lumber Company

The West Bay Marina has operated as either a marina or combined marina/boatyard since 1966 on land leased from the Washington Department of Natural Resources (DNR). Despite the name, West Bay Marina is located at the southern end of central Budd Inlet (Figure 1). Like most of the industrial sites in Budd Inlet, the upland areas of the marina consist of fill material.

Between 1919 and 1966 the site was used for various lumber milling activities by Buchanan Lumber Company. One HFB was present along the northern boundary of the site (Figure 1). Recent soil samples collected in the vicinity of the hog fuel boiler had detected concentrations of

dioxin/furan congeners, as did intertidal samples collected within the marina (Hart Crowser 2011; Hart Crowser 2012).

2.1.7 Solid Wood Incorporated/West Bay Park

The Solid Wood Incorporated/West Bay Park site, located across West Bay from Port Berths 1 and 2, was previously home to lumber milling operations. The most recent operator was Solid Wood Incorporated, which closed in 2002. Railroad tracks run the length of the site, and were believed to be in use from the late 1800's through 1996 (Parametrix 2008). Intertidal sampling was conducted along the tracks and adjacent to the site of a historical HFB (Figure 1). Samples were tested for dioxins/furans, but no results exceeded 10 ng TEQ/kg. A soil excavation was conducted in the vicinity of the former boiler. A sample from an ash layer was submitted for analysis and had a dioxin/furan concentration of 18.4 ng/TEQ kg. Additional test pits were excavated to delineate contamination, but concentrations were less than 4 ng TEQ/kg. The Solid Wood/West Bay Park site is currently conducting supplemental sediment sampling as part of their RI/FS process.

The City of Olympia purchased the property in 2006 for development as a waterfront park (West Bay Park).

2.1.8 Reliable Steel

Prior to 1941, site operations consisted of lumber milling. In 1941, the site was purchased by Reliable Steel, which operated until around 2009. Site activities included steel tank and structural beam fabrication and painting (GeoEngineers 2013). PCP was detected in one soil sample (out of 30) at a level that exceeded proposed cleanup levels for the site. Reliable Steel has completed their RI/FS studies and has submitted a Cleanup Action Plan.

2.2 Circulation and Sediment Transport

Hydrodynamics and circulation within Budd Inlet plays an important role in the transport and distribution of dioxin/furan contamination.

2.2.1 Hydrodynamic Setting

At 7 miles long and up to 2 miles wide, Budd Inlet has an elongated morphology which narrows at both the mouth and the head of the bay. The inlet may be described in three general sections to reflect the unique bathymetry and circulation patterns (Figure 2):

- From Gull Harbor north to the mouth, the Outer Inlet is distinguished by two parallel channels up to 30 m deep, separated by a natural bathymetric ridge.
- The Central Inlet makes up the widest part of Budd Inlet and is characterized by relatively gently, sloping bathymetry between 5 - 15 meters depth, with a pronounced shoal feature at its center (Olympia Shoal).
- The Inner Inlet extends from Priest Point to the heads of East and West Bay, which are separated by a natural peninsula that has been extended and broadened by fill. The Inner Inlet is predominantly intertidal and shallow (<5 meters water depth), with the exception

of the navigational channels. With a tidal range exceeding 14 feet, the Inner Inlet drains over 70% of its volume during a typical tidal cycle.

Budd Inlet is characterized as a tidal estuary, experiencing seasonal variations in freshwater input from precipitation and releases from Capitol Lake regulated by gates at the lake's mouth. Typical discharge from Capitol Lake varies by an order of magnitude between summer and winter, with average peak flows of 50 cubic feet per second (cfs) and 600 cfs, respectively. To maintain a constant water level in Capitol Lake, freshwater is discharged into Budd Inlet as high flow releases during low tides. These releases may last several hours and are separated by longer periods with no discharge. The intermittent flows can be an order of magnitude greater than the natural condition. A distinct freshwater plume can be identified in surface waters during the discharge events.

2.2.2 General Circulation Pattern

A current study was conducted in 1996 and 1997 which revealed spatial and temporal patterns in vertical salinity structure and net circulation within Budd Inlet (Ebbesmeyer et al. 1998). North-south temperature and salinity contours revealed a lens of low-salinity surface water associated with Capitol Lake discharge extending the length of the inlet along the eastern shoreline. Colder, more saline marine waters originating in Puget Sound were almost always identified along the western shore. A counter-clockwise gyre exists in the Central Inlet with a zone of no-net-motion separating inflowing and outflowing currents.

Volume transport calculations show Budd Inlet to be among the more vigorously circulated inlets in Puget Sound, with an average flushing time ranging from 8 to 12 days. Tidal pumping was identified as the base mechanism driving circulation in Budd Inlet, augmented seasonally by the freshwater inputs mentioned above.

Tidal pumping is the physical process by which deep, inflowing waters are deflected upward by a bathymetric gradient during flood tide, resulting in upwelling which contributes additional volume to the shallow, outflowing surface layer. This process can also serve as a transport mechanism for suspended sediment near the benthic boundary layer, driving suspended solids toward depositional areas at the head of inlets or in tidal channels.

2.2.3 Inner Inlet Sedimentation Patterns

Both East and West Bays contain a variety of intertidal areas which may be subject to sediment resuspension and deposition from tidal currents and freshwater inputs. However, fine-scale current patterns which may impact sediment transport have not been well characterized.

Time-series measurements in the West Bay suggest a linkage between freshwater discharge from Capitol Lake and both water-column structure and current velocity (Ebbesmeyer et al. 1998). These data reveal strong 2-layer estuarine circulation in West Bay which may last for a few hours, 2 to 4 times per day. This 2-layer circulation is typical of estuarine systems and results in increased sediment deposition where the outgoing freshwater surface layer converges with the incoming saline bottom flow.

Sediment trap observations collected as part of the 1998 Puget Sound Research Study along with radioisotope sediment core profiles were used to estimate sediment loadings to the Inner Inlet. A

sedimentation rate of 2 cm/yr was determined using lead-210 geochronology of West Bay sediment cores. This rate was twice as large as Central Inlet stations, and over 5 times greater than the Outer Inlet stations. Other studies (summarized in Anchor QEA 2013) found similar results in that sedimentation rates were greatest in the Inner Inlet. This was true for locations in both the East and West Bays.

Seasonal variations in lead-210 activity for sediments retained in the Inner Inlet sediment trap also suggest a dynamic transport setting. Decreases in lead-210 activity were interpreted as indicators of freshwater sediment inputs, or as deposition of older, reworked sediment. Pairing the sediment trap data with lead-210 sediment core geochronology suggested that approximately 50 percent of Inner Inlet deposition could be attributed to sediment resuspended and transported from other regions. While direct observations of sediment deposition were not made along the lower-energy Port of Olympia berths open to West Bay, these areas likely represent sinks for resuspended material and sediments discharged from Capitol Lake.

The United States Geological Survey (USGS) conducted a study to model the transport of fine-grained sediments from Capitol Lake under the conditions of dam removal (USGS 2008). Although the study was conducted as a hypothetical scenario, the patterns of deposition observed in the simulation because of dam removal may also identify areas where net deposition is likely to occur under current conditions. The model revealed that the highest sedimentation rates would occur along the Port berths and marinas of West Bay, identifying the northern portion of the Inner Inlet as having little to no net deposition (USGS 2008; Figure 2). This finding is supported by a Sediment Profile Imagery (SPI) survey conducted along the Port berths as part of the post dredge monitoring. The SPI survey identified recent deposition of fine-grained material within the berths which resembled the character of Capitol Lake sediments observed following drawdown events (Anchor QEA 2010; Anchor QEA 2011).

Less information was available describing the transport and depositional patterns in the East Bay. Significant amounts of deposition have occurred, particularly in Swantown Marina where there was only eight inches of water present during a typical low tide prior to 2013 dredging.

2.3 Spatial Patterns of Dioxin/Furan Contamination

An interpolation of surface sediment dioxin/furan TEQ concentrations is presented in Figure 3. For this report, surface sediment includes any sample collected from the top 0 to 1 foot (30.5 cm) layer. The subsurface concentrations could not be interpolated because: 1) they lack wide spatial coverage; and 2) multiple depth intervals exist within each core. Figure 4 presents the highest dioxin/furan concentration measured in subsurface sediments from each core. This figure identifies all locations where subsurface samples have been collected, highlights areas of elevated subsurface concentrations near Berth 3 and the south end of East Bay, and demonstrates that dioxin/furan TEQ concentrations are both higher and more variable in subsurface sediment than surface sediment.

Cascade Pole MBL and Berths 2 and 3 post-dredge/cover monitoring samples were not included in Figures 3 and 4. All other sample locations were present, including low TEQ samples that were screened for the chemometric evaluation (Section 3.2.1)

Interpolated surface concentrations are somewhat variable through much of the Inner Inlet (Figure 3). The high concentration contour noted at the south end of the East Bay is attributable

to one sample (POBI-SC-49-0-1) with a concentration of 318 ng TEQ/kg. This sample is from core POBI-SC-49. The top 0.5 to 2 feet of this core was described as consisting of decomposed woody debris with 60 percent organics and a strong hydrogen sulfide odor (Anchor QEA 2013).

Low concentrations were noted around the southwest corner of the West Bay and at the north end of the Port peninsula near the discharge of the LOTT outfall. Another area with low concentrations was the intertidal portion of Priest Point Park. Thirty samples were collected in this area and all had concentrations less than 5 ng TEQ/kg. This area is influenced by the discharge from Ellis Creek, whose watershed covers nearly 1,500 acres of mixed use land cover.

Though not shown, two samples were collected in Capitol Lake as part of the 2007 Sediment Investigation. Both samples had concentrations less than 4 ng TEQ/kg, indicating that incoming material from the Deschutes River is clean relative to sediments in Budd Inlet.

Subsurface samples are mainly limited to the footprint of the navigational channel. Overall these samples show much more variability in TEQ concentration than the surface samples (Figure 4). Two cores at the south end of the East Bay (POBI-SC-50 and POBI-SC-49) have elevated concentrations, with the 1 to 2 foot interval of POBI-SC-49 exceeding 1,200 ng TEQ/kg. As mentioned above, the top intervals of this core contained substantial amounts of woody debris. A concentration of 167 ng TEQ/kg was measured in the 8-10 foot interval of POBI-SC-50, and a concentration of 212 ng TEQ/kg was measured in the bottom interval (10.5 to 11.4 feet) of POBI-SC-49, indicating the contamination has a significant vertical component. Subsurface concentrations at the north end of the East Bay are typically less than 10 ng TEQ/kg and lower than surface concentrations.

Elevated concentrations were also present in the vicinity of Berth 3, near the location of the historical pier opening. The highest concentrations were typically observed at depths greater than 3 feet. The 6-7 foot interval of BI-C5 had a concentration of 4,210 ng TEQ/kg, the highest observed in Budd Inlet sediments. The 14-16 foot interval of POBI-SC-07 had a concentration of 59.3 ng TEQ/kg, indicating the depth of contamination is substantial in this area as well. Subsurface concentrations in the central portions of the West Bay and the western side of the East Bay were lower than their respective surface sediment concentrations.

2.4 Chemometric Analysis by Other Parties

The Port conducted a chemometric analysis of Budd Inlet sediment data using the sampling results of the 2013 Sediment Investigation combined with select historical samples (Anchor QEA 2015). The data-set used by the Port differed from that employed in this study by Ecology, and slightly different multivariate statistical methods were applied between the two studies. However, there remained several similarities between the Port study and the current report:

- Three factors were the best fit for describing the variability of dioxin/furan congener profiles in Budd Inlet.
- The congener profiles of the three factors were similar in appearance, indicating both models converged on similar sources (see Appendix C for comparison of profiles).
- Spatial distribution of the factors in Budd Inlet sediments were in agreement.

The above bullets demonstrate that there were no major differences between the Port and Ecology models in terms of statistical output. Despite this, there were differences between the two studies relating to the interpretation of the model results.

3.0 Methods

This section describes the methods used to conduct the chemometric analysis, beginning with the compilation of available recent and historical sampling results from within Budd Inlet. This is followed by a discussion of data screening, chemometric unmixing techniques, and uncertainties related to the analysis.

3.1 Available Data-sets

The usability of available and relevant site data were evaluated in a technical memorandum submitted prior to conducting the chemometric analysis (NewFields 2014a; Appendix A). Data evaluation required identifying all sample locations within Budd Inlet and the surrounding watershed that include dioxin/furan congener results. Dioxin/furan congener data from 20 individual data-sets were presented in the memorandum, and all but one had data available in Ecology's Environmental Information Management (EIM) database.

Additional research identified data that was missed during the initial review, and was therefore not included in the original technical memorandum. The name of these studies, a brief description of their contents, and the relevant citation are as follows:

- Priest Point Park Sediment Sampling Project (Thurston County 2010) – this report presented the analytical results of a series of intertidal sediment samples collected in the vicinity of Priest Point Park. The study was conducted with the intent of determining whether human health risks due to dioxin/furan contamination were present in nearshore sediments.
- Infrastructure Interim Action Report for East Bay Redevelopment Site (Pioneer Technologies 2010) – This document includes a summary of recent excavation activities at the East Bay Redevelopment Site. Subsamples of the excavated soil were analyzed for dioxin/furan congeners.
- Port of Olympia Source Control Investigations (Anchor QEA 2012b) – These investigations were conducted to evaluate concentrations of dioxin/furan congeners in storm drain solids collected from Port of Olympia storm drains near Berths 1 and 2. Additional samples collected at the same locations were provided to NewFields by Anchor QEA (J. Dunay, personal communication, August 19, 2014)
- City of Olympia Catch Basin Solids – solids from select City owned storm drain catch basins were collected and analyzed for dioxin/furan congeners. Data were provided to NewFields by Anchor QEA (J. Dunay, personal communication, August 19, 2014)
- Cascade Pole Supplemental Site Investigation Report (Landau Associates 1993) – Some sediment data from the Cascade Pole site was available in EIM as Study ID CASCADRI. However, this data was limited to 15 congeners. The Supplemental Site Investigation Report included data from the early 1990's for all 17 congeners.

Table 2 presents a summary of the studies listed above including the study name, reference or EIM Study ID, validation level, collection date, and whether the samples represent sediment or soil samples. Surface samples include any sediment collected from the 0 to 1 foot (30.5 cm) interval. However, the majority of surface sediment samples were collected from the 0 to 10 cm

interval. Samples in Table 2 are divided into two groups for one of two purposes in the chemometric process:

1. *Unmixing Data-set* – samples under this category include the sediment results that represented the input data-set for the chemometric analysis.
2. *Local Subset of Source Library* – samples under this category include the sediment, soil, or catch basin solids results that may have represented sources or pathways of dioxin/furan contamination to Budd Inlet. The congener profiles from these samples, along with a larger source library, were compared with the output of the chemometric analysis performed on the *Unmixing Data-set.*

These two types of data are explained in more detail in the following sections. The compiled *Unmixing Data-set*, including reported concentrations and calculated total TEQs, is presented electronically as Appendix D.

3.1.1 Unmixing Data-set

The chemometric process is used to determine the number and composition of unique dioxin/furan congener profiles that contribute to concentrations measured in Budd Inlet sediments. The data used for this analysis consisted of intertidal and subtidal sediment samples from Budd Inlet, plus two freshwater samples from Capitol Lake. Both surface and subsurface samples were incorporated. The complete data-set consisted of 244 surface, 251 subsurface, and 26 unspecified interval sediment samples (Table 2). These sediment data were compiled into a project database with a single coordinate system and consistent concentration units.

Not all samples in the data-set were included in the final analysis. Dredging along the Port of Olympia Berths 2 & 3 was conducted in February 2009 for the first time in nearly 30 years (Anchor QEA 2009; EIM Study ID OlyMarineTerminal08). Samples collected prior to dredging were included in the data-set, as they represented the historical record of deposition and resuspension along the berths. Select post-dredge samples were also included as they were found to contain elevated dioxin/furan concentrations that also represent historical deposition. At the completion of the dredging event, a clean sand cover was placed over the dredged area. Since this cover represents known non-native material, no post-cover samples were used in the chemometric analysis.

Similarly, samples collected as part of the sediment cap monitoring at the Cascade Pole site were not incorporated into the analysis (Landau Associates 2014; EIM Study ID FS1385). These samples were collected from the clean, non-native fill, placed within the Cascade Pole MBL.

Additional samples were excluded from the *Unmixing Data-set* because of frequent non-detects or having a distinct congener profile not shared with other samples. These samples and the reason for their exclusion are discussed in Section 3.2.1.

3.1.2 Comparison Data-set

Many of the samples presented in Table 2 did not meet the criteria necessary for inclusion in the *Unmixing Data-set*. However, these samples may be informative as potential source profiles.

Dioxin/furan results for these samples were added to NewFields' library of congener profiles previously used for a chemometric evaluation of Port Angeles and Oakland Bay sediments (NewFields 2013; NewFields 2014b). The library consists of dioxin/furan congener profiles from a wide range of potential source materials, industrial processes, and environmental samples.

The combination of NewFields' source library and the local subset of data from Table 2 is considered the *Comparison Data-set*. The local sample results added to the *Comparison Data-set* may provide insight as to the local sources and pathways responsible for sediment contamination in Budd Inlet. The local subset of the source library consists of:

- Upland soil samples from areas that potentially display unique congener profiles.
    - The East Bay redevelopment site is built on fill from historical wood waste and dredge spoils from Budd Inlet. It may also contain dioxin/furan contamination from historical on-site wood processing facilities. The fill may have a profile(s) that match sediments elsewhere in the East Bay (Pioneer Technologies 2010; GeoEngineers 2008).
    - Soil samples from West Bay Marina were collected in the vicinity of a former hog fuel boiler and may represent an ash profile (Hart Crowser 2011; Hart Crowser 2012).
    - Additional soil sample results were available from the Phase II Environmental Site Assessment and the former Solid Wood, Inc. (Table 2), but the high frequency of non-detects in the data precluded their use in the source library.
- Sediment samples collected from the Cascade Pole site prior to any remedial actions. Thirteen samples with dioxin/furan concentrations greater than 50 ng TEQ/kg were taken from the site RI (Landau Associates 1993). These samples were assumed to represent the congener profile of wood treatment chemicals such as PCP.
- Ash samples from the Simpson Timber Company in Shelton, WA were incorporated into the source library as a profile for hog fuel boiler ash (CH2M Hill 1987). While these samples are not specific to Budd Inlet, it is likely the same type of wood waste (hog fuel) was burned in both Olympia and Shelton.
- Storm drain solids samples collected upland on Port of Olympia property adjacent to Berth's 2 and 3 (Anchor QEA 2012b; J. Dunay, personal communication, August 19, 2014). These samples are representative of ongoing releases from the upland property which was historically used to store treated lumber.
- Storm drain samples collected from City of Olympia catch basins are potentially representative of upland runoff (J. Dunay, personal communication, August 19, 2014).

3.2 Chemometric Analysis

Multiple dioxin/furan sources may contribute to the concentrations measured in Budd Inlet sediments, such that each sample can be assumed to reflect the combined contributions from a

number of potential sources. This means that the congener profile from the majority of samples will not be a direct match to any of the profiles in the source library. Understanding the sources that account for measured environmental concentrations of dioxin/furan congeners requires decomposition, or unmixing, of the bulk measured concentrations.

Chemometrics is the application of mathematical and statistical methods to perform this unmixing on chemical data-sets. Multivariate analysis techniques were applied to the measured concentrations of the seventeen dioxin/furan congeners in Budd Inlet sediments to develop a more simplified model for the data-set. The chemometric evaluations included two equally important parts:

1. Unmixing, or the mathematical decomposition of sample measurements into their factors; and
2. A statistical means of identifying the factors (congener profiles) mathematically identified by the unmixing analysis.

In the decomposition step, the data are treated purely as numbers stripped of all other attributes. No information related to location, sediment characteristics (e.g., grain size or total organic carbon [TOC]), or proximity to discharge points or upland facilities influence the mathematical solution to the unmixing model. All of the non-numerical attributes of samples, however, are considered in step 2, the interpretation of the results of the mathematical analyses. Those interpretations also consider the similarity of unmixed congener profiles to the profiles documented for known source types.

The chemometric decomposition of the data-set combined with comparisons to the source library, known sample attributes, and knowledge of the study area all provide lines of evidence for the identification of sources and their pathways to Budd Inlet sediments. A brief description of the chemometric analysis methods is provided in this section. Additional details are found in Appendix B.

3.2.1 Data Screening

The cumulative Budd Inlet *Unmixing Data-set*, as identified in Section 3.1.1, included well over 500 sample results (Table 2). Given the sensitivity of the chemometric analysis to samples with unique congener profiles, it was very important to first screen the data to remove samples that would complicate the analysis.

The first step in data screening was to remove samples with a large number of non-detected congeners. Non-detects in a sample were replaced with one-half the detection limit. If several congeners are not detected, the congener profile becomes more representative of laboratory detection limits rather than sediment conditions. Given that chemometric analysis is a comparison of congener profiles, including a large number of samples defined by non-detects can impair the analysis by reducing the amount of variability explained by the model and producing factor profiles defined largely by non-detected congeners.

In addition, the frequency of undetected results became more pronounced for samples with very low total TEQ values. In general, low TEQ samples aren't as important to the analysis as high TEQ samples because they aren't as likely to be representative of a pure source.

Samples were removed from the *Unmixing Data-set* based on the following non-detect criteria:

- Eight or more non-detected congeners; or
- Non-detected congeners contributing to more than 50 percent of the total dioxin/furan TEQ concentration, when non-detected congeners are assigned a value of one-half the detection limit.

For this analysis, non-detected congeners included samples with a U or K qualifier. K qualified data, also referred to as estimated maximum possible concentration (EMPC), represents a value reported by the laboratory that does not meet all the method specific identification criteria. K qualified data were considered non-detects at the reported concentration.

Non-detect screening resulted in the removal of 102 samples. Dioxin/furan concentrations for these samples ranged from 0.0878 to 16.1 ng TEQ/kg, with an average concentration of 1.25 ng TEQ/kg.

Further evaluation of the data (using residual outlier tools in principal components analysis [PCA]; Section 3.2.3) found several samples with somewhat atypical congener profiles. Each of these samples was removed from the *Unmixing Data-set* as potential outliers (Table 3). Most of these samples had low TEQ concentrations and 4-7 non-detected congeners. These samples were considered to have undue influence from non-detects and were removed as outliers (Table 3).

Five of the excluded samples had TEQs greater than 10 ng TEQ/kg (Table 3). One of these samples, BI-C5-6-7 FT, had a TEQ of 4,210 ng TEQ/kg. With a TEQ this high it is likely the sample represents a direct influence from source material. Therefore, the sample was added to the source library rather than completely removing it from the analysis.

The residual outlier analysis flagged the Table 3 samples as having a unique congener profiles. While it is possible that the unique congener profiles may represent an unidentified source, it is also possible these samples are biased for other reasons such as analytical variability. Regardless of the reason, the inclusion of a few samples (1% of the total) with high residuals forces the model to account for the unique congener profiles. This in turn reduces the variance explained by the primary factors in the majority of the data-set. Therefore, the samples in Table 3 were excluded from the chemometric unmixing analysis.

3.2.2 Data Scaling

Dioxin/furan sample results were reported from the lab as bulk congener concentrations, in ng/kg dry weight. It was typical for certain congeners, such as OCDD, to be present at concentrations multiple orders of magnitude greater than other congeners. If multivariate analysis were to be performed on the raw data in which the measurements vary by such large amounts, those congeners with the greatest concentrations would drive the analysis, which in turn would reduce the statistical power. To allow for better interpretation of the differences in congener profiles, it is customary to scale the individual congeners, or variables, such that they are all roughly at the same order of magnitude.

Evaluation of Potential Scaling Methods

There are several approaches to accomplish variable scaling, however different methods may not produce equivalent results. In most chemometric studies in which the measurements are discrete and not continuous (i.e. individual samples), each measurement is scaled by either the range or the standard deviation of the measure across all samples (Wold et al. 1987; Kramer 1998; Craig et al. 2006). These scaling methods are generally referred to as variance-scaling. The result is that each scaled variable will either have a range of 0 to 1 or a variance of 1. These variance-scaling methods have three major drawbacks:

1. The scaling factor is a function of the samples that are included in the calculation and would therefore change if different samples were included.
2. There is a risk that a variable of little importance with congener peaks in the noise level will be magnified to the same importance as variables with real, diagnostic signals. This could lead to rarely detected, or low concentration congeners, driving the unmixing model and therefore the unmixed source profiles.
3. Because the scaling factors are specific to the data-set being scaled, the resulting congener profiles cannot be directly compared to profiles outside of the data-set, such as a profile library.

Because of these variance-scaling shortcomings, the alternative method of TEF-scaling for dioxin/furan congener data has frequently been applied (Lohmann and Jones 1998; Alcock et al. 2002; Hilscherova et al. 2003; E&E and Glass 2011; NewFields 2013). This method of scaling based on congener toxicity relative to 2,3,7,8-TCDD has three distinct advantages over variance-scaling:

1. Scaling factors (congener-specific TEFs) are independent of the samples in the data-set being processed.
2. Because the scaling factors can be applied universally to dioxin/furan congener data, analysis results can be compared to profile libraries scaled by the same means.
3. Chemometric analysis of TEF-scaled data identifies dioxin/furan profiles that contribute to a significant portion of sample TEQ. This is useful for decision making, as human health risk, ecological risk, and cleanup criteria are all based on TEQ.

For data exploration purposes, both variance-scaling and TEF-scaling methods were applied to the *Unmixing Data-set* and the full chemometric process was performed. A comparison of the results for both scaling methods is presented in Appendix B.

Chemometric analyses based on variance-scaling did not result in a more informative unmixing model than results performed by TEF-scaling. For this reason, as well as the advantages of TEF-scaling discussed above, only the evaluations using TEF-scaled data are discussed for the remainder of the document.

Applied Scaling Methods

Bulk dioxin/furan congener concentrations of samples in the *Unmixing Data-set* were scaled for relative toxicity using the current set of TEF values (Table 1). The presentation order of

congeners does not impact the data analysis. However, the order customarily used in studies of this type—increasing chlorination and increasing substitution position—was imposed and is shown in Table 1.

These TEF-scaled values for each sample were summed to obtain total TEQ concentrations. Because chemometric analyses are concerned with the patterns of dioxins/furans rather than the TEQ magnitudes across samples, the 17-congener profiles for samples were normalized by dividing each congener component by the sample total TEQ. The resulting values represent the fractional contribution to total sample TEQ from each congener, with the sum over 17 congeners equal to 1 for each individual sample in the data-set. These TEF-scaled, TEQ-normalized profiles served as the input data-set for the chemometric unmixing model. The same scaling method was applied to the Comparison Data-set.

3.2.3 Unmixing Model

The software Pirouette (Infometrix, Bothell, WA) was used for the application of chemometric modeling. The mathematical model of the *Unmixing Data-set* produces the following results:

- The number of factors contributing to the sample measurements;
- The chemical patterns (congener profiles) of these factors;
- The fractional contribution of each factor to each sample; and
- A characterization of the model's goodness-of-fit through residuals (congener-by-congener differences between modeled and measured values for every sample) and deviations of summed factor amounts from 1.

Chemometric analyses are a form of receptor-oriented modeling. Starting from the receptor (sediment) measurements, and without any prior assumptions about the number or patterns of potential factors, the analyses mathematically derive a model of the factors – conceptually "working backwards" from receptors to sources. There are several similar mathematical approaches used for unmixing evaluations. In this study, a combination of Principal Component Analysis (PCA) and Alternating Least Squares (ALS) methods was used. Both methods are included in the Pirouette statistical software suite.

Principal Component Analysis

Because 17 TEF-scaled dioxin/furan congeners define the congener profile for each sample, each sample can be plotted in 17-dimensional space. Samples with similar congener profiles would plot near one another in this space. PCA functions to reduce the number of dimensions required to plot the data, while still accounting most of the variability in the data-set so that similar samples still plot near one another. Each reduced dimension is a component that represents some combination of the congeners. Each successive component accounts for less of the overall variance.

The number of PCA components required to account for nearly all of the data-set variance is an indication of the number of factors to be included in the model. Diagnostic criteria can be used to evaluate the number of PCA components, and models with different numbers of components can be explored when the difference in total variance is small. It should be noted that the PCA components or axes do not themselves define source or factor profiles. Instead, visualization of

PCA results can help guide an interpretation by identifying clusters of similar samples, outliers that do not cluster with other samples, or samples located intermediate between others (implying they might be mixtures).

Alternating Least Squares

Mixture analysis algorithms are designed to extract the patterns from which sample mixtures are composed. For this study, an ALS method was used for unmixing. The ALS method assumes the data-set reflects the variable contributions from a fixed number of factors. Therefore, the measured values are assumed to be the product of the chemical patterns for the factors and the amounts contributed from each factor to each sample. This product is calculated iteratively using matrix algebra, with one matrix of factor profiles and a second matrix of source contributions to samples. Starting values are assigned to both matrices to begin the calculations. As the iteration proceeds, constraints are applied; for example, one constraint is that no negative contributions from factors are allowed, because negative contributions lack physical meaning. When the iterative calculations converge, the unmixing model is complete. The solution provided consists of the chemical profiles of factors and their contributions to each sample (i.e., sample composition). The residuals of the resulting model illustrate the goodness-of-fit.

The ALS analysis was run in non-closure mode, in which the sum of the source amounts was not constrained to equal 1 (or 100 percent). This is appropriate when it cannot be assumed or demonstrated that the model includes all possible factors contributing to the measurements. When the sum of the source amounts does equal 1 for a sample, it means the modeled factors fully describe the congener profile. Deviations from 1 were generally small and are another indication of model goodness-of-fit.

The factor fractional contributions in the model are relative measures of the sample compositions. Interpretations of the unmixing model results benefit from absolute measures of the impacts of individual factors. The contributions of individual factors to total sample TEQ are obtained by multiplying the factor fractional contributions by the total TEQ for the sample. The results are termed factor "TEQ increments." The sum of those model TEQ increments will differ from the measured sample TEQ to the degree that the sum of factor fractional contributions differs from 1 (non-closure analysis approach).

3.2.4 Model Interpretation

A source library of comparison dioxin/furan congener profiles was compiled to support possible interpretations of the factor profiles obtained through chemometric modeling. The source library includes over 300 candidate profiles compiled from published literature, regional environmental samples, and site-specific studies. Examples of source types present in the library include air emissions, effluent discharges, ash, and various chemicals known to include dioxins/furans from their manufacture. Also part of the source library was the *Comparison Data-set*, composed of samples relevant to the study area, but not included in the *Unmixing Data-set* (Section 3.1.2).

Comparisons of factor profiles from the ALS model to those in the compiled source library were made by two means:

1. Hierarchical Cluster Analysis (HCA)
2. Tabulation of correlation coefficients

As the name implies, HCA is a method of evaluating similarity by organizing data into a hierarchy of clusters. The results of HCA are best represented graphically by a dendrogram, or similarity tree. This manner of representation displays highly similar sample pairs with relatively small separation distances. As applied to this study, HCA was used to identify library source profiles with high similarity to the ALS-derived factor profiles.

A correlation coefficient can be calculated for sample pairs as a measure of the strength and direction of their relationship. Correlation between two samples can be either positive or negative, with perfect positive correlation having a value of one. Correlation analyses were performed for ALS-derived factor profiles against the entire source library. Source library profiles with high correlations to factor profiles were considered to be a match.

These two approaches for interpreting chemical patterns are complementary and provide likely source matches that allow for further evaluation based on Budd Inlet history and the likely presence of actual sources or facilities matching the candidates. It should be noted that the comparisons of profiles does not in and of itself identify any specific physical source. Multiple sources with the same dioxin/furan profiles can exist, which have to be discriminated based on factors other than just chemical pattern.

3.2.5 Uncertainties

Chemometric pattern evaluations are subject to uncertainty, as is common to all modeling efforts. The main source of uncertainty, congener profiles composed of non-detect results, was partially addressed during data screening. Some additional sources of uncertainty may include:

- Laboratory analytical issues, such as co-elution of congeners, that affect reported profiles;
- An incomplete source inventory, missing comparison source profiles that are relevant to study profiles;
- Non-representativeness of source inventory profiles from literature reports or other locations for the site-specific sources of similar type;
- Variability in source profiles over time (e.g., because of changes in facility operations, processes, or pollution control systems);
- Changes in profiles between emission sources and receptor media (e.g., sediments) due to differential fate and transport processes and degradation (losses post-deposition);
- Highly-correlated impacts from multiple sources that produce composite profiles, affecting comparisons to single source profiles from a source inventory; and
- Multiple sources contributing to a single pathway, as is likely the case with stormwater runoff, which includes contributions from a range of potential upland sources.

For any study, the overall uncertainty associated with chemical pattern evaluations should be assessed in light of identified potential uncertainty factors. The consistency and strength of data interpretations from multiple lines of evidence should also be assessed.

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4.0 Results

The results of chemometric unmixing analyses are summarized in this section, with supporting information provided in Appendices B and D. Results for models with 3 and 4 factors are discussed in this section along with a comparison of the factor profiles to the source library. The general distributions of the fractional contributions and TEQ increments are summarized at the end of the section.

Several key terms were introduced in Section 3.0 that will be used extensively throughout the Results and Discussions sections. For clarification and review the terms and their definitions are as follows:

- A **factor** is a solution from the ALS unmixing model. The congener profile of the factor is a statistical construct and it does not necessarily correspond to a source until matched with the source library.
- A **source** is a facility or process that produced dioxin/furan congeners. Multiple sources are listed in Section 1.2. For the most part, each source has a unique congener profile. NewFields' library contains over 300 congener profiles from a variety of sources.
- A **pathway** is the means by which dioxin/furan contamination from a source enters the environment. Pathways include atmospheric deposition and discharges from stormwater outfalls and CSOs.
- The **fractional contribution** is part of the ALS output. It is the amount that each factor contributes to a given sample.
- The **TEQ increment** is the amount of the total sample TEQ that is due to a given factor. Mathematically it is the fractional contribution multiplied by the total TEQ.

4.1 Chemometrics

After data-set screening, which resulted in 358 sediment samples retained for evaluation, a PCA analysis was performed. As mentioned, a key output of the PCA analysis is a plot of the cumulative variance explained by each factor. Typically, the first factor comprises greater than 80 percent of the total variability. Each successive factor accounts for less variance, until a point is reached where additional factors have no more explanatory power. Generally, once 98 to 99 percent of the variability is explained, there is no further need to evaluate additional factors. Figure 5 shows cumulative variance plots for three recent baywide dioxin/furan fingerprinting studies conducted for Ecology, including Budd Inlet. The black dashed line in this Figure represents 98 percent.

Four factors were selected to explain the variance at Port Angeles Harbor (NewFields 2013). For Oakland Bay, nearly 99 percent of the variance was explained with just two factors (NewFields 2014b). For Budd Inlet, the first factor included 83.6 percent of the variability. The second factor represented 12.2 percent, and the third factor represented 2.2 percent. The cumulative variance explained by the three factors was 98.0 percent. The fourth factor only added an additional 0.8 percent to the total.

After conducting the outlier screening in PCA (Table 3), congener unmixing was carried out using ALS. Based on the cumulative variance, the ALS model was run using 2-, 3-, 4-, and 5-factors.

The fractional contribution and TEQ increments were mapped throughout Budd Inlet to evaluate the distribution of the factors from each of these model runs. Compared to the 3-factor model, the 2-factor model did not capture all of the congener profile variability in areas near the Port berths and near Moxlie Creek. The 5-factor model did not demonstrate any unique source areas beyond those of the 3- and 4-factor models.

Based on this evaluation it was decided 3- or 4- factors were suitable for explaining the distribution of dioxin/furan congeners in Budd Inlet sediments (Table 4). Sections 4.2 and 4.3 include a description of and comparison between the 3- and 4- factor models, and the reasoning behind selecting the 3-factor model as the best fit for the Budd Inlet analysis.

4.2 Four Factor Model

Factor congener profiles were compared to the source library using the two methods described in Section 3.2.4. Source comparisons using HCA were qualitative in nature, in that a source was assigned to a profile based on how it grouped proximal to samples from the library. The correlations were more quantitative. Samples from the source library that had a correlation coefficient (r-value) greater than or equal to 0.95 were considered matches. Lesser r-values were also evaluated depending on clustering results. Example figures depicting the portions of the HCA dendrogram associated with each factor and a profile correlation using the source library are included in Appendix B. Source library matches to the 4-factor model profiles are summarized in Table 4.

4.2.1 Factor 1

The Factor 1 TEQ congener profile is dominated by the contribution from the dioxin congener 1,2,3,7,8-PeCDD (49 percent). The next largest contributors are 2,3,4,7,8-PeCDF at 11 percent, and 2,3,7,8-TCDD at 10 percent (Figure 6). Both clustering and correlation analysis demonstrated matches to profiles from the source library relating to HFB emissions, HFB ash, and select effluent and sludge samples from a facility operating a HFB (Table 4).

There were also matches to the *Local Library* – the local potential source samples that were added to the source library. Two of the three baghouse ash samples from Oakland Bay (CH2M Hill 1987) clustered with Factor 1 in HCA, and both of these samples also correlated to the Factor 1 profile (one with an r of 0.948). One soil pile sample from the EBRS also correlated to Factor 1. While wood waste burners were historically present at EBRS, it is also possible that this congener profile is present in the soil due to the large amounts of fill used to create the peninsula (GeoEngineers 2008). This possibility is discussed further in Section 5.3.4

Wood processing facilities generate large amounts of waste in the form of bark, shavings, and wood dust. Ground to a consistent size, this waste was referred to as hogged fuel and burned for heat or energy in industrial boilers. Dioxin/furan congeners were an inadvertent byproduct of this combustion. Dioxin/furan concentrations in HFB emissions/ash can be highly variable depending on whether or not the wood was salt-laden prior to processing. The differences between burning salt-laden and clean hog fuel is described in detail in the Port Angeles chemometrics study, with

orders of magnitude higher concentrations measured in the salt-laden wood (NewFields 2013). Site specific documentation was not available for the Budd Inlet HFBs to determine whether or not they burned salt-laden wood. But, historical photos ranging from the early 1940s through the early 1990s show a continuous presence of floating log rafts in Budd Inlet.

No HFBs are currently in use in Budd Inlet. However, at least nine hog fuel boilers were known to operate historically in Budd Inlet, and many of them operated for multiple decades (Anchor 2013; Figure 1). A 1999 Ecology survey of boilers throughout Washington State found that ash production was highly variable, ranging between just a few tons per year to over 10,000 tons per year for some of the larger facilities (Ecology 2004). The number of HFBs in Budd Inlet, time span of their operation, and their potential annual ash production makes for a significant input of dioxin/furan contamination.

Other combustion sources have congener profiles that are similar, but not as strongly correlated to Factor 1. These diffuse sources include vehicle emissions, forest fires, and residential wood burning. It is possible that these and other common combustion sources contribute to this profile.

4.2.2 Factor 2

The Factor 2 TEQ congener profile has the largest contribution from one dioxin congener, 1,2,3,4,6,7,8-HpCDD (43 percent), with additional contributions of 11 and 16 percent from two additional dioxin congeners (OCDD and 1,2,3,6,7,8-HxCDD, respectively). One furan congener, 1,2,3,4,6,7,8-HpCDF, accounts for most of the furan contributions (Figure 6, Factor 2). Clustering and correlation analyses identified numerous PCP-related profiles (Table 4).

Several local samples from the *Local Library* correlated to the Factor 2 profile. Five upland soil samples from the West Bay Marina matched with Factor 2. Four of these samples had an elevated (~15 percent) contribution from 1,2,3,7,8-PeCDD suggesting a contribution from HFBs, while sample HC-WB-US-009 was a better match at an r-value of 0.978. One soil pile sample from the EBRS was a match to Factor 2, but this sample also appeared to include a component of the HFB signature.

Two storm drain solid samples collected from Port of Olympia property along Berths 2 and 3 correlated to Factor 2 at 0.95, while an additional three had r-values above 0.90. Eleven of the twelve historical sediment samples from the Cascade Pole site that were included in the *Comparison Data-set* matched the Factor 2 TEQ congener profile.

PCP is notable for having among the highest dioxin/furan TEQ content among manufactured chemicals, even though dioxin/furan congeners were only an impurity of PCP production. PCP was used as a wood treatment to prevent discoloration of lumber to be milled (sap-stain), or decay of wood used for outdoor purposes like utility poles. It was used by Cascade Pole beginning in the mid-1960s (Landau Associates 1999). PCP may have been used at other facilities in Budd Inlet, but was not mentioned in any of the reviewed documents.

A substantial amount of PCP would have been used for wood treatment. United States Forest Service (USFS) documentation from this time period recommended using 6 to 30 pounds of sodium pentachlorophenate (NaPCP; the a more soluble form of PCP) per 100 gallons of water, or 5 to 10 gallons of PCP per 100 gallons of oil (Scheffer 1958). Site specific documentation for

Cascade Pole corroborates that they typically dissolved the PCP in a medium aromatic oil to form a 5 percent solution (Landau Associates 1999).

4.2.3 Factor 3

While Factors 1 and 2 were dominated by dioxin congeners, the Factor 3 congener profile was predominantly furans. Congener 1,2,3,4,7,8-HxCDF comprised 25.8 percent of the total, followed by 2,3,4,7,8-PeCDF with 23.2 percent. Two dioxin peaks, 1,2,3,6,7,8-HxCDD and 1,2,3,4,6,7,8-HpCDD, were present at 12.9 and 4.6 percent, respectively (Figure 6).

Though less abundant, these two dioxin congeners were present at almost the same ratio relative to each other in Factor 3 as they were in the PCP Factor 2. It is possible that the samples characterized by Factor 3 represent a mixed source rather than a pure profile. This idea gains some credence when comparing Factor 3 to the source library.

Source library profiles that clustered with Factor 3 and were weakly correlated (r-value greater than 0.75) included several PCB Aroclor profiles (Table 4). TEQ congener profiles for PCBs contain elevated 2,3,4,7-PeCDF through 1,2,3,6,7,8-HxCDF furans, and almost no dioxin congeners. PCBs could have been used in hydraulic fluid, electrical transformers, and other equipment at many of the industrial sites in Budd Inlet. Any PCBs released to the environment may have mixed with existing sediments to result in the profile seen in Factor 3.

Only sample BI-C5-6-7-FT was correlated to Factor 3 at an r-value greater than 0.95. This sample has the dioxin congener peaks the PCB profiles lack, making it representative of the PCB/PCP composite. It also has a TEQ of 4,210 ng TEQ/kg, meaning it is the purest available example of Factor 3. While this sample was excluded from analysis (Section 3.2.1), other samples with similar profiles and high TEQs drove the statistical determination of the Factor 3 profile.

While the contributions from dioxin congeners mean Factor 3 cannot be a pure PCB profile, PCBs provide the most similar pattern for Factor 3 among those present in the source library.

4.2.4 Factor 4

The Factor 4 TEQ congener profile was dominated by 1,2,3,4,6,7,8-HpCDF, which accounts for nearly 50 percent of the total (Figure 6). Two dioxin congener peaks each comprised about 10 percent of the total. Comparison to the source library revealed only one matching profile (Table 4). However, results from only three congeners were reported for this matching profile. This means the correlation and clustering comparisons were made only between three congeners, rather than the full 17. There is insufficient information in the library to match the profile of Factor 4.

4.3 Three Factor Model

The 3-factor model explained nearly the same amount of total variance in the data-set as the 4-factor model (Figure 5). In general, the factor profiles between the two model runs were comparable. Visual comparisons of the profiles for the 3- and 4-factor models can be made in Figures 6 and 7, respectively. Some of the specific comparisons between the model runs include;

- The profiles for Factor 1 in the 3- and 4-factor models are almost identical. Dioxin congeners dominate in both profiles. The only substantial difference is that furan congener1,2,3,4,6,7,8-HpCDF constitutes 3.6 percent of the profile in the 3-factor model, and 0 percent in the 4-factor model. Figure 8a presents example profiles form the source library for HFB ash, ash from the Oakland Bay baghouse, and the EBRS soil pile. The Factor 1 profile is included as a dashed line for reference. The soil pile sample contains a small peak of 1,2,3,4,6,7,8-HpCDD, which is the main indicator of Factor 2. This may be evidence of a mixed profile from the EBRS soil sample.
- The profiles for Factor 2 in the 3- and 4-factor models are almost identical. Dioxin congeners dominate in both profiles. Like Factor 1, the main difference between the two profiles is the increased abundance of furan congener 1,2,3,4,6,7,8-HpCDF in the 3-Factor model relative to the 4-factor model (5.8 percent compared to 4.4 percent, respectively). Figure 8b includes congener profiles from the source library for a PCP wood preserving formulation, upland sample HC-WB-US-009 from West Bay Marina, a Port of Olympia storm drain solids sample, and a pre-cleanup Cascade Pole sediment sample. The Factor 2 profile is include as a dashed line for reference.
- Factor 3 of the 3-factor model (Figure 7) is a composite of Factors 3 and 4 of the 4-factor model (Figure 6). Factor 3 is dominated by furan congeners1,2,3,4,6,7,8-HpCDF (21.3 percent), 1,2,3,4,7,8-HxCDF (20.3 percent), 2,3,4,7,8-PeCDF (16.4 percent). The most prevalent dioxin congener from both models is 1,2,3,6,7,8-HxCDF at 6.4 percent. TEQ congener profiles for PCBs contain elevated 2,3,4,7-PeCDF through 1,2,3,6,7,8-HxCDF furans, and almost no dioxin congeners (Figure 8c). Only sample BI-C5-6-7-FT was correlated to Factor 3 at an r-value greater than 0.95. This sample has the dioxin congener peaks the PCB profiles lack (Figure 8c), making it representative of a possible composite with Factor 2.

As described above, Factors 1 and 2 were similar regardless of the model run. The main difference between the two models was Factor 3.

Factor 3 of the 3-factor model weakly correlated (r-value greater than 0.75) to Aroclor 1268 from the source library and sample BI-C5-6-7-FT. It also clustered with a soil sample from West Bay Marina and two of the EBRS soil piles. However these soil samples likely represented mixtures of all factors.

The decision was made to retain the 3-factor model for the following reasons:

1. A full explanation of all peaks was not possible with either model run. Factor 3 from the 4-factor model was indicative of PCBs, with some additional unidentified contributions from dioxin congeners. Factor 4 from the 4-factor model was unidentified. Factor 3 from the 3-factor model contains the furan peaks that indicate PCBs, plus the other unidentified peaks from the 4-factor model.

2. Factors 3 and 4 from the 4-factor model have the same spatial distribution, suggesting similar origins. Using separate maps to show similar distributions would be redundant.

Overall, the 3-source model offers a simpler solution without sacrificing any information. Based on the source library used for this evaluation, Factor 1 represents HFB ash and emissions, Factor

2 represents PCP used as a wood preservative, and Factor 3 represents PCBs plus some unidentified congener peaks.

4.4 Fractional Contribution and TEQ Increments

Fractional contributions and TEQ increments are presented as histograms for each factor in Figure 9 and 10, respectively. The histograms display both surface (0 to 1 foot interval) and subsurface sediment intervals. Each of these histograms includes 196 surface sediment samples, and 161 subsurface sediment samples.

Figure 9 shows the fractional contribution histograms for the three factors. The left column (Figures 9a, 9c, and 9e) represents the surface sediment, while the right column (Figures 9b, 9d, and 9f) represents the subsurface sediment. The x-axis of this Figure is the fractional contribution binned in 5 percent intervals (0.05), and the y-axis of the Figure is the number of samples in each bin.

For each factor, the fractional contribution across all of Budd Inlet surface sediments had a nearly normal distribution and lacking outlier values. This was evidence of the surface layer being more homogenous with regards to source inputs. On average, Factor 2 (Figure 9b) was the largest contributor to surface sediments, followed by Factor 1 (Figure 9c), then Factor 3 (Figure 9e).

There was more variability in the subsurface sediments, where the fractional contribution ranged across almost all bins for the three factors (Figures 9b, 9d, and 9f). This increased variability suggested there was less historical mixing of the sources in the sediments. The subsurface sediments also contain some high fractional contributions (>80 percent) that were indicative of purer sources of the factors.

Figure 10 shows the histograms for the TEQ increments of the surface and subsurface sediments. The bins on the x-axis represent the TEQ increment concentrations, ranging from 0 to 5 ng TEQ/kg to greater than 500 ng TEQ/kg (note the increasing scale of the bin size concentrations). The y-axis represents sample count.

The distribution of TEQ increments was the same between the surface and subsurface sediments for Factor 1 (Figures 10a and 10b). One subsurface sample had an elevated TEQ increment, but the remainder were below 50 ng TEQ/kg. Most of the relatively low TEQ samples represented by Factor 1 were found in the deeper sediment intervals from the central portion of West Bay, and in surface sediments along the east shore of the East Bay.

Factor 2 consistently had the highest TEQ increments throughout Budd Inlet (Figures 10c and 10d). In terms of concentration, this factor had the most influence on surface sediments with nearly half of its TEQ increments greater than 10 ng TEQ/kg. In the subsurface sediments, Factor 2 was responsible for some of the highest observed TEQ increments, with 14 samples over 50 ng TEQ/kg, including two > 500 ng TEQ/kg (Figure 10d).

The left skew of the histograms in Figures 10e and 10f indicate that Factor 3 was a small contributor to nearly all surface and most subsurface sediment samples. With two exceptions, the TEQ increments of Factor 3 to surface sediments were all under 10 ng TEQ/kg. The majority of the subsurface TEQ increments are also low, but 14 samples exceeded 50 ng TEQ/kg.

In summary, Factor 1 was present throughout the inlet at fairly consistent (and low) concentrations. Factor 2 was also present throughout the inlet, but at more elevated concentrations. Factor 2 was also present in higher concentrations at some localalized, and mainly subsurface, hotspots. Factor 3 was a minor contributor to most inlet sediments, but was present at high concentrations at select, mainly subsurface, locations. The spatial distribution of these high TEQ increment samples for Factors 2 and 3 are discussed in more detail in the site specific discussions in Section 5.0.

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5.0 Discussion

This section includes a discussion of the spatial distributions of Factors 1, 2, and 3 in relation to their sources identified in Section 4.0. This general discussion is followed by a more site specific summary of individual cleanup sites or otherwise relevant areas and how they may be pathways for these sources to Budd Inlet. All spatial patterns are discussed in relation to the circulation patterns and potential inputs summarized in Section 2.0.

5.1 Distribution of TEQ Increments

TEQ increments identified by the unmixing modeling can be spatially displayed to aid in the identification of patterns. Spatial interpretation of the TEQ increments from individual factors illustrates the relative scale of contribution, and can be used as a link to potential sources.

In most cases the easiest way to visualize patterns in concentration across a wide area is to use an interpolation, as was done in Figure 3. The interpolated surface sediment TEQ Increments for Factors 1, 2, and 3 are presented in Figures 11, 12, and 13, respectively.

It was not possible to interpolate the subsurface sediment intervals. Instead, the TEQ increments were displayed along a north-south gradient to make it possible to visualize spikes in concentration. Figures 14, 15, and 16 show surface and subsurface TEQ increments for West Bay, East Bay, and North Inlet, respectively. Each of these figures includes a map to show the area of interest with labels indicating features. The three plots on each figure represent the three factors. The x-axis is the log-normalized TEQ increment concentration of each source, and the y-axis is the latitude of the sampling location (1,000 feet between each line) corresponding to the spatial extent of the map.

A vertical reference line was drawn in each source Figure at 10 ng TEQ/kg to provide a means of better evaluating concentrations. The following discussion incorporates the surface sediment interpolations and the combined surface/subsurface plots to describe source apportionment throughout Budd Inlet.

5.1.1 Factor 1 TEQ Increments – Hog Fuel Boilers

Surface sediment TEQ Increments for Factor 1 are interpolated in Figure 11. Concentrations for much of the spatial area were less than 5 ng TEQ/kg. Surface sediment concentrations in the West Bay were lower than those in the East Bay. In central West Bay, TEQ increments of Factor 1 were similar in surface and much deeper subsurface sediments (Figure 14).

Higher surface sediment concentration contours were present in the vicinity of Hardel Plywood (Figure 11). In particular, there were four surface samples with TEQ increments of almost 20 ng TEQ/kg in the contour nearest Hardel Plywood. Three of these samples were within 200 feet of the site (Section 5.3.5). The highest subsurface TEQ increments were found adjacent to Berth 3 (labeled samples on Figure 14).

Surface sediment TEQ increments from Factor 1 were highest in the East Bay (Figure 11). The highest concentrations were from a few samples at the south end of the bay. Several surface sediment samples near the Moxlie Creek outfall had TEQ increments between 10 and 20 ng

TEQ/kg, and one sample had a concentration just above 45 ng TEQ/kg (POBI-SC-49). Figure 15 shows that subsurface TEQ increments for Factor 1 were higher in the southern East Bay as well.

The low TEQ increments in the southern portion of the North Inlet were associated with Priest Point Park (Figure 16). Ellis Creek drains through the park and provides an influx of clean sediment compared to that transported out of the East and West Bays. Concentrations in the center of the inlet are higher. However there appears to be a slight decrease in TEQ increment moving north through the inlet. This can be seen in the deviation away from the reference line in Figure 16.

As discussed in Section 4.2.1, the congener profile of Factor 1 matched with HFB ash and emissions. There were nine historically identified HFBs in Budd Inlet. Each HFB had multiple pathways for dioxin/furan contamination to enter Budd Inlet. It is important to consider the aerial transport of Factor 1, subsequent deposition, remobilization, and delivery to the harbor when identifying likely transport pathways to sediments. Dioxin/furan congeners produced in HFBs are not only associated with stack emissions, but also boiler ash that is handled as solid waste by the HFB operators. Prior to deposition in the harbor, transport of dioxin/furan contamination from HFBs may involve:

- Direct atmospheric deposition of HFB emissions onto the surface of Budd Inlet;
- Indirect atmospheric deposition of HFB emissions in the uplands and subsequent delivery to the harbor as part of stormwater runoff and municipal effluent;
- Erosion/runoff of HFB ash from industrial properties and disposal sites;
- Incorporation of HFB ash into industrial process water and effluent;
- Direct disposal of HFB ash into the harbor; and
- Placement of ash or debris containing ash as fill material.

While it is possible that ash was used as fill or directly disposed of in portions of Budd Inlet, no documentation detailing the incorporation of ash into effluent or the direct disposal into the harbor was found in writing this report.

Atmospheric deposition from the HFBs would have occurred both over water (direct) and over land (indirect). Indirect deposition can be transported to the sediment through stormwater runoff. Therefore, runoff entering Budd Inlet from creeks, outfalls, and CSO may continue to contribute this profile to sediments (see storm drain solids summary in Section 5.2.1). Factor 1 was also associated with residential wood burning (Section 4.2.1; Appendix B), representing a current source that would share the same pathways as the historical HFBs.

5.1.2 Factor 2 TEQ Increments - Pentachlorophenol

Surface sediment TEQ increments of Factor 2 were highest at the south end of East Bay, and lowest around the LOTT outfall and in the vicinity of Priest Point Park likely because of the influx of more recent, cleaner sediments (Figure 12).

In the West Bay, subsurface increments of Factor 2 were highest in the vicinity of Berth 3 (Figure 14). Five samples near Berth 3 had TEQ increment concentrations greater than 100 ng TEQ/kg. TEQ increments greater than 20 ng TEQ/kg were present south to Berth 1 (Figure 14).

The subsurface samples with the low TEQ increments in Figure 14 were located in the central portion of West Bay.

In the East Bay, subsurface TEQ increments were highest in the vicinity of EBRS/Moxlie Creek. Core POBI-SC-49 had some of the highest concentrations (Figure 15). TEQ increments in this core averaged nearly 150 ng TEQ/kg with a maximum greater than 550 ng TEQ/kg. TEQ increments in core POBI-SC-50 were similar. Except for these two cores, the remainder of the subsurface cores in the East Bay had TEQ increments lower than the surface sediment. The pattern of decreasing TEQ increments of Factor 2 in the north inlet was similar to Factor 1 (Figure 16).

Factor 2 was a match with PCP profiles from wood treatment and the historical sediment samples from Cascade Pole where PCP-containing wood treatments were used. In general terms, the use of wood-treating chemicals was a messy process. The following excerpt was taken from the U.S. Congress Office of Technology Assessments document *Cleaning Up Contaminated Wood-Treating Sites* (U.S. Congress 1995):

> At these sites, wood was generally treated under pressure with creosote or PCP in a heated oil-based solution. After treatment, the wood was removed from the pressure chamber and allowed to drip dry outside, resulting in large volumes of contaminated soil. Other treatment wastes include wastewater and sludges. Wastewater was generated as a condensate in the treatment process and also by rinsing tanks and equipment. After separation of recoverable chemicals, wastewater was often spread onsite or stored in evaporation ponds. An oily sludge gradually accumulates in wastewater evaporation areas and also in treatment cylinders and storage tanks. This sludge was historically dumped into unlined pits onsite. Sludge pits found at wood treating sites can contain very high concentration of the preservative chemicals, which may limit treatment options for these areas.

This process was not specific to Cascade Pole, but many of the same processes likely applied to their use of wood treatment chemicals. Extensive soil and groundwater contamination, elevated dioxin/furan concentrations in storm drain solids, and the presence of Factor 2 near a historical pier opening (Figure 1) are all documented pathways for PCP entering Budd Inlet (Anchor QEA 2012b; Anchor QEA 2013; Landau Associates 1999).

While Factor 2 is linked to PCP and historical wood treatment is considered one of the sources to Budd Inlet, more diffuse sources of PCP may exist. EPA has long suspected that PCP related dioxins/furans are a constituent of urban runoff. In Canada, emissions from in-service treated poles in are estimated to represent 47 percent of total emissions to soil (Bulle et al., 2010). The extent and means by which dioxin/furans could be released from treated wood are described below:

- In 1996, USEPA estimated that the use PCP over the previous 25 years to treat wood was approximately 336,000 metric tons in the US, with an associated 672 kg of dioxin toxic equivalents (TEQ). Of this, about 80% was for the treatment of utility poles.
- EPA has been unable to estimate the rate of release of dioxins/furans from treated utility poles into the environment. However, if only a small portion of PCP-associated dioxin is released to the environment from utility poles, they would constitute a significant contemporary source.

- There have been limited efforts to study the movement of PCP and dioxin/furans from treated utility poles into the environment. However, depletion of these chemicals has been recognized as poles age (Ruddick, 1991).
- Studies have shown that dioxins/furans migrate from the interior of a utility pole to its surface as the pole ages (Winters et al., 1999; Lorber et al., 2002). It is hypothesized that this dioxin/furan diffusion gradient is driven by environmental release through rainwater leaching and volatilization into the atmosphere. Dioxins/furans leaching from treated poles into the surrounding soils has been documented (Bulle et al., 2010; Gurprasas et al., 1995).

More detail on specific sources and pathways of PCP are provided in Section 5.2.

5.1.3 Factor 3 TEQ Increments – Polychlorinated Biphenyls

In most Budd Inlet surface sediments the TEQ increments from Factor 3 were lower than those from Factors 1 and 2 (Figure 13). The south end of the East Bay was the only area with elevated Factor 3 increments in surface sediment.

In the West Bay, subsurface increments of Factor 3 were highest near Berth 3, with concentrations ranging up to 436 ng TEQ/kg. TEQ increments between 10 and 38 ng TEQ/kg were present along Berths 1 and 2 (Figure 14). In the East Bay, subsurface TEQ increments of Factor 3 were highest at the south end (Figure 15). Four samples in this area exceeded 100 ng TEQ/kg, with a maximum of 575 ng TEQ/kg.

In the North Inlet, TEQ increments of Factor 3 decreased moving north, the same pattern that was also present for concentration increments of Factors 1 and 2 (Figure 16).

Factor 3 was identified mainly as a PCB profile. PCBs were historically used as coolants and lubricants in electrical equipment such as transformers and capacitors, and they were also found in older fluorescent lighting fixtures and electrical appliances, paints, pesticide additives, sealants, building materials, and hydraulic oils (Agency for Toxic Substances and Disease Registry [ATSDR] 2000).

A historical opening in the Berth 3 pier was present near the elevated Factor 3 increments in the West Bay. A historical overwater structure was present in the vicinity of the elevated Factor 3 increments in the East Bay (Anchor QEA 2013). PCBs used in electrical or hydraulic equipment at these locations may have leaked into the sediment. No written record of PCB use on or near these structures was found for this report, but PCB concentration data supports this assumption.

Ninety of the dioxin/furan samples included in the umixing model also had results for PCB Aroclors. These samples are presented in Figure 17 on a north/south gradient for the East and West Bays. The y-axis is scaled the same as Figures 14 and 15.

Subsurface sediment concentrations of PCB Aroclors near Berth 3 ranged from 110 to 2,400 µg/kg compared to lower concentrations in the rest of the West Bay (Figure 17). In the East Bay, PCB sediment concentrations peaked in cores POBI-SC-49 and POBI-SC-50 (Figure 17). With one exception, PCB Aroclor concentrations in intervals from these two cores all exceeded 90 µg/kg, with three intervals exceeding 1,000 µg/kg.

5.2 Distribution of Fractional Contributions

The previous section focused on the distribution of TEQ increments for each factor since the TEQ represents the measure of greatest regulatory concern. The spatial distribution of the fractional contributions can be just as important from a source control perspective. Areas where one factor contributes a high percentage to the congener profile are indicative of a particular source or pathway.

The fractional contributions of each factor in surface sediment followed an approximately normal distribution (Figure 9). These distributions were divided in to quintiles (20^{th} percentiles). The arrow in Figures 9a, 9c, and 9e mark the upper quintile for each factor. The samples in each upper quintile are plotted in Figure 18 using the following symbology:

- Blue circles represent the upper quintile of Factor 1 which includes samples with a fractional contribution greater than 34 percent (Figure 9a).
- Red circles represent the upper quintile of Factor 2 which includes samples with a fraction contribution greater than 64 percent (Figure 9c).
- Yellow circles represent the upper quintile of Factor 3 which includes samples with a fractional contribution greater than 20 percent (Figure 9e).
- Small black circles represent samples where no one factor represented the upper quintile of the distribution.

Summary statistics for each of the above groups plus the total surface sediment data-set are presented in Table 5. Listed concentrations represent the total dioxin/furan TEQ.

5.2.1 Factor 1 Fractional Contribution

The upper quintile of Factor 1 consisted of 41 sediment samples with an average concentration of 12.2 ng TEQ/kg, lower than the bay-wide average of 21.1 ng TEQ/kg (Table 5). Many of the Factor 1 enriched samples were located in areas with low surface sediment TEQ concentrations (Figure 3). One cluster of samples was present around the LOTT outfall, while another was present near Priest Point Park (Figure 18). Both of these areas receive solids from relatively clean sources (the Ellis Creek watershed for Priest Point Park, and the treated wastewater stream for the LOTT outfall).

Factor 1 contributions were also elevated in sediment samples near the west shore of the West Bay, and the east shore of the East Bay (Figure 18). These areas receive runoff from upland areas of Olympia. No soil samples were collected for this study, but a chemometric evaluation of soils at Port Angeles Harbor identified an upland signature from HFB caused by historical emissions (E&E and Glass 2011). A similar upland signature containing dioxin/furan congeners from historical emissions and residential wood burning is likely for Olympia soils.

Select storm drain solids samples were available from City of Olympia property. Samples were collected from catch basins in both the West and East Bays (Figure 19). Total TEQ concentrations and the fractional contribution of these samples are presented in Table 6. Catch basin samples with available congener data were run through the chemometric model with the *Unmixing Data-set*. The fractional contributions of the City of Olympia catch basin samples

were consistent with the upper quintile samples from Factor 1 in that they contained greater than 34 percent Factor 1 and less than 64 percent Factor 2 (Table 6).

5.2.2 Factor 2 Fractional Contribution

The upper quintile of Factor 2 consisted of 44 sediment samples with an average concentration of 24.7 ng TEQ/kg, nearly twice as high as Factor 1 (Table 5). Factor 2 was elevated adjacent to Reliable Steel and West Bay Marina/Buchannon Lumber on the west shore of the West Bay (Figure 18). These sites are described in more detail in Section 5.3. Factor 2 was also elevated along the east shore of West Bay, in the vicinity of the Cascade Pole site, and at the south end of East Bay (Figure 18).

Factor 2 was most closely associated with PCP. Many of the sediment samples that were analyzed for dioxin/furan congeners were also analyzed for PCP. Figure 19 shows the spatial distribution of surface and subsurface samples analyzed for PCP. Locations where PCP was present in the subsurface are marked in red, and surface detections are marked in green. Concentrations were not included due to the difficulty in quantifying PCP (nearly all detected concentrations were qualified).

PCP was detected in surface sediments at Fiddlehead and Martin Marinas (Figure 19). Factor 2 was dominant in the same samples, averaging 75 percent of the fractional contribution (Figure 18). Total TEQs in these marinas averaged 29.8 ng TEQ/kg. The fractional contributions in sediments from the marinas were consistent with the fractional contributions from storm drain solids from Port property in that they contained no Factor 3. However, this area is drained by City of Olympia storm drains and no City catch basin solids samples from this area were available for comparison.

PCP was also detected in surface samples at the south end of East Bay. Total TEQ in these samples was 60.3 and 98.9 ng TEQ/kg, with Factor 2 contributions of 96 and 79 percent, respectively.

Factor 2 was also elevated adjacent to Berths 2 and 3. PCP was detected in subsurface sediment samples in this area. Few surface samples in this area were submitted for PCP analysis. The same is true for the area around Cascade Pole. Factor 2 was the primary contributor to surface sediment concentrations around Cascade Pole, but only two samples in this area were analyzed for PCP.

Catch basin solids samples were collected adjacent to the Port of Olympia Berths (Anchor QEA 2012b; Figure 19). Total TEQ concentrations in these samples ranged from below 5 ng TEQ/kg up to 2,020 ng TEQ/kg. The fractional contributions of these samples are listed in Table 6. The fractional contributions are generally consistent with the upper quintile samples from Factor 2 in that Factor 1 is less than 34 percent and Factor 2 is greater than 64 percent (Table 6).

Upland areas in the vicinity of these storm drains had historically been used for log and lumber storage, including storage of wood that may have been treated with sap-stain (Anchor QEA 2012b). Residual PCP may still be present in these areas. Total TEQ concentrations in these catch basins are atypical for Puget Sound. Figure 20 shows a comparison of storm drain solids from the Port and City of Olympia (concentrations from Table 6) and the Lower Duwamish

Waterway[1] (LDW). The concentrations in the LDW can be assumed to represent urban/industrial levels for Puget Sound. Even the highest concentrations measured in the LDW storm drain solids were an order of magnitude lower than the more "PCP like" catch basin samples in Table 6.

Samples in the upper quintile for Factor 2 are in areas collocated with PCP or its suspected sources. But as shown in Figure 9 nearly all Budd Inlet samples had some contribution from Factor 2. The presence of Factor 2 throughout the Inlet can be attributed to two main influences:

1. The same circulation and dispersion processes that are hypothesized to have spread Factor 3 (Section 5.2.3) throughout the Inlet may have also carried Factor 2.
2. Factor 2 may also enter sediments as a component of urban runoff due to leaching from treated wood as proposed in Section 5.1.2. All urban areas contain PCP treated utility poles. If leaching does occur to the extent proposed in the literature, there may be a wide-scale source of PCP-based dioxins/furans to stormwater separate from the more direct source associated with pole treatment activities.

It is not possible to fully apportion general urban contributions versus more direct discharges. However, if emissions from urban treated poles were the only source of Factor 2, the TEQ increments and fractional contributions of Factor 2 would be more consistent throughout Budd Inlet. Instead, there are clusters of elevated contributions and concentrations of Factor 2 (above that expected from general urban runoff) in areas where PCP is still detected in sediments. Additional work is needed to determine the amount of Factor 2 present in storm drain solids from areas without a history of PCP wood treatment as a confounding factor.

5.2.3 Factor 3 Fractional Contribution

The upper quintile of Factor 3 included 39 samples. Sediment concentrations associated with Factor 3 were much higher at the south end of the East Bay than the north inlet. The average concentration listed in Table 5 isn't representative due to the high standard deviation amongst these samples.

The fractional contribution of Factor 3 was elevated in two sediment samples at the south end of East Bay, one of which had a total TEQ of 318 ng TEQ/kg. This same sample (POBI-SC-49-0-1) was noted as containing significant woody debris (Section 2.3). Several samples in the West Bay were in the upper quintile of Factor 3, but with no clear grouping. The majority of samples with elevated Factor 3 were found in the North Inlet (Figure 18).

Factor 3 is considered to be a "tracer" for the transport of historical dioxin/furan contamination throughout Budd Inlet. The Factor 3 congener profile was predominantly a match to PCBs, which have been banned for nearly 40 years. Factor 3 contributes little or nothing through ongoing pathways such storm water runoff. This is apparent as recent sediment inputs in the vicinity of Priest Point Park and the storm drain solids samples collected around the City and Port of Olympia contained little or no Factor 3 (Table 6 and Figure 19). Potential historical

[1] The LDW data represent all available sediment trap, catch basin grabs, and inline grab samples that were analyzed for dioxin/furan congeners through 2011. A summary of these samples is provided in the report "Lower Duwamish Waterway, Source Tracing Data Evaluation: Stormwater Pathway" available at: https://fortress.wa.gov/ecy/gsp/CleanupSiteDocuments.aspx?csid=1643.

source areas for Factor 3 were identified through the analysis of sediment cores near Berth 3 and at the south end of East Bay (Figures 14 and 15). The high contributions of Factor 3 throughout the North Inlet suggest sediment transport mechanisms from Inner Inlet source regions to the Northern Inlet.

The tidal pumping and general circulation (Section 2.2) of Budd Inlet were responsible for the transport of historical dioxin/furan contamination throughout southern Budd Inlet and into the North Inlet. This historical transport would have contained all three factors. More recent deposition containing a mix of Factors 1 and 2 now dominate surface sediments in the East and West Bays where greater sediment deposition rates have been measured, while Factor 3 still comprises greater than 20 percent of the fractional contribution of North Inlet samples.

PCB-related dioxin/furan contamination that can't be linked to ongoing pathways is still a large contributor to dioxin/furan contamination in Budd Inlet. Twenty four samples out of 29 present in the North Inlet were in the upper quintile for Factor 3, with an average total concentration of 16.7 ng TEQ/kg. This concentration exceeds that of the Factor 1 inputs to the East and West Bays (average of 12.2 ng TEQ/kg; Table 5).

5.3 Site Specific Source and Pathways to Budd Inlet

This section includes a discussion of the dioxin/furan congener profiles in the vicinity of each of the Budd Inlet sites and summarizes the current conditions at each site.

5.3.1 Cascade Pole Company

Historical pre-cleanup sediment data from within the Cascade Pole MBL was not included in the unmixing model. Twelve high concentration samples were included for comparison in the *Comparison Data-set*. These historical samples were a match with Factor 2 and other PCP samples from the source library (Figure 8b). These pre-cleanup samples represented a relatively pure signature of PCP, not a comingled profile like that near Berth 3 or the more recent well-mixed surface sediments. TEQ concentrations in the historical Cascade Pole sediments were high, with a maximum of 1,090 ng TEQ/kg.

Seven recent surface sediment samples were collected between 2007 and 2013 in the vicinity of Cascade Pole. These samples were included in the *Unmixing Data-set*. All seven of these samples were in the upper quintile of Factor 2, with an average fractional contribution of 72 percent (Figure 18). Not enough samples were analyzed in this area to confirm the presence of PCP. Even though PCP contamination in this area may remain, total TEQ concentrations were low. The average concentration between these samples was 16.7 ng TEQ/kg, and only one sample had a concentration greater than the average for all Budd Inlet surface sediments (Table 5).

5.3.2 Port of Olympia Marine Terminal Berths 1, 2, and 3

Figure 14 showed elevated TEQ increments of Factors 2 and 3 in subsurface sediments in the vicinity of Berth's 1, 2, and 3, with a large spike in concentration near Berth 3. However, dredging events in 2009 and 2013 have removed much of this sediment.

The 2009 dredging removed sediment along Berth 2 and part of Berth 3 (Anchor QEA 2009). The exposed surface was covered with a clean sand cap. Eleven total samples (surface and subsurface) that were part of the *Unmixing Data-set* were removed by this action (Figure 21). The average TEQ across all 11 samples was 34.9 ng TEQ/kg. The dredged area was resampled as part of 3, 9, 15, and 21 month monitoring. The 15 and 21 month monitoring studies indicated deposition of clean Capitol Lake sediments on top of clean cap after a series of flushing events in Capitol Lake (Anchor QEA 2010; Anchor QEA 2011).

Additional maintenance dredging was conducted in a much larger area along the berths in late 2013 (Figure 21). As with the first round of dredging, a clean sand cap was placed over the exposed surface. The footprint of this dredging is shown in Figure 21. The 2013 dredging resulted in the removal of most of the surface samples identified in Section 5.2.2 as having a large contribution from Factor 2. The congener profiles in the catch basin solids were consistent with PCP and with the profiles of the surface sediment. It was hypothesized that stormwater runoff from Port property was the pathway for this surface sediment contamination. With a clean cap in place, this hypothesis can be tested through future monitoring efforts.

Elevated dioxin/furan TEQs remain in subsurface sediments at the north end of Berth 3. Figure 22a shows the average TEQ increments with depth for this area (Figure 21). Core intervals were averaged into two foot bins for this figure based on the midpoint of the sampled core interval. For example, both a 2 to 3 (midpoint 2.5) and 0 to 4 (midpoint 2) foot core interval would be placed in the 2 to 4 foot bin. This system resulted in some overlap, but the differences are assumed to be minor.

A total of 23 discrete core intervals were averaged into Figure 22a representing Berth 3. TEQ concentrations increased with depth, and TEQ from Factor 3 was higher than Factor 2 in all but the 0 to 2 foot interval. Maximum concentrations were in the 6 to 8 foot interval, where both Factor 2 and Factor 3 TEQ increments exceeded 200 ng TEQ/kg. Factor 1 was a minor contributor to all intervals.

Figure 22b shows the averaged TEQ increments with depth for the Berth 1 sediments removed as part of the 2013 dredging (Figure 21). Nineteen core intervals were averaged in this figure. Compared to Berth 3, sediments at Berth 1 included relatively greater contributions from Factor 1 and much less from Factor 3. TEQ concentrations were much lower at Berth 1 (note concentration differences on x-axis).

The differences in both TEQ concentration and fractional contribution between Berth 3 and Berth 1 imply a unique historical source to Berth 3. PCBs were present at much higher concentrations at Berth 3 than Berth 1 (Figure 17) and hydrocarbon like odors were identified in 5 of 6 Berth 3 cores (core logs from Anchor QEA 2013). By contrast, only 1 of 9 cores along Berth's 2 and 3 had any identified hydrocarbon odor. Hydrocarbons are commonly associated with both PCBs and PCP (Sections 5.1.3 and 4.2.2).

For comparison to Berth sediments, the 32 core intervals in the area labeled Central West Bay in Figure 21 were averaged and plotted in Figure 22c. The TEQ increments for Factors 1 and 3 are similar to those from Berth 1. The TEQ increments for Factor 2 are lower in 4 of the 5 intervals compared to Berth 1, showing that the contribution of Factor 2 in sediments decreases moving west from the Port Berths and that a unique pathway was/is present in this area.

5.3.3 Moxlie Creek and LOTT Outfalls

Total TEQ concentrations in the vicinity of the LOTT outfall contained elevated contributions of Factor 1 and were low relative to the rest of the bay (Figure 3). Because of this, sediments near the outfall were considered recent deposition. The LOTT outfall is not considered a significant pathway of contamination to Budd Inlet.

Sediments near the Moxlie Creek outfall have some of the highest TEQ concentrations in Budd Inlet, but most of this area has more in common with the historical contamination near Berth 3 than with the congener profiles of the storm drain solids. Figure 22d shows the averaged TEQ intervals from 17 core intervals. The samples included in this average are part of the box labeled Southern East Bay in Figure 21.

Like Berth 3, subsurface sediment concentrations in the Southern East Bay were high and comprised mainly of Factors 2 and 3 (Figure 22d). Also like Berth 3, cores from this area (POBI-SC-49 and POBI-SC-50) contained hydrocarbon like odors (core logs from Anchor QEA 2013). A historical overwater structure was identified in this area as well.

While the sediment samples contained both Factors 2 and 3, catch basin solids samples collected from East Bay drainages by the City of Olympia had elevated amounts of Factor 1 and contained almost no Factor 3 (Table 6). There is evidence of elevated Factor 1 in Southern East Bay sediments relative to Berth 3 (Figure 22), so there may be some contribution from Moxlie Creek or other outfalls as a long-term pathway for Factor 1 to local sediments.

This would be consistent with other surface sediments from East Bay. A band of lower concentration, elevated Factor 1, surface sediment samples along the east shore of East Bay were identified in Figure 18 and described in Section 5.2.1. These samples were hypothesized to have been influenced by surface runoff from the City of Olympia.

5.3.4 East Bay Redevelopment Site

It is difficult to piece together a consistent history of activities on the EBRS because of the multitude of owners and continually changing shoreline.

The Remedial Investigation Work Plan for the EBRS contained a description of potential historical source areas for multiple chemicals of concern, including dioxin/furan congeners and PCBs (GeoEngineers 2008). This report included a brief discussion of four test pits that were dug and sampled in 2007 to evaluate below ground dioxin/furan concentrations. The samples were collected at depths from 1.5 to 3.5 feet that corresponded to the historical working ground level prior to the placement of additional fill. One pit targeted the location of a former HFB and had a concentration of 645 ng TEQ/kg. Another pit that was dug, targeting a former power house, had a concentration of 57.9 ng TEQ/kg. Two other pits were dug at random, with resulting concentrations of 108 and 430 ng TEQ/kg. These concentrations are in the same range as those observed in Southern East Bay sediments (Figure 22d).

The GeoEngineers 2008 report included soil/sediment profiles for 6 transects across the EBRS site. Several pockets of silt with shredded wood were noted in these transects. The description of these pockets is similar to the two high TEQ concentration intervals (318 and 1,283 ng TEQ/kg) of core POBI-SC-49 that contained a mix of woody debris and fines (Section 2.3; core logs from Anchor QEA 2013). Historical fill used at EBRS may extend into East Bay below the mudline.

In addition to the possibility of fill, historical aerial images include an overwater structure that was present near EBRS (Anchor QEA 2013). Electrical equipment or PCB containing hydraulic oils may have been present on this structure to assist in loading vessels. Similar equipment may have existed on Berth 3 for the same purpose. In both instances, leaks or spills would have resulted in sediment contamination.

5.3.5 Hardel Plywood

Six surface sediment samples fell within 200 feet of the Hardel Plywood site (including paired samples at BI-S7). Total TEQ concentrations of these samples were all above the surface sediment average with concentrations ranging from 25.5 to 62.5 ng TEQ/kg. A pattern of high fractional contributions from Factor 1 was noted along the west shore of the West Bay (Section5.2.1), but only one sample in the vicinity of Hardel Plywood was part of the upper quintile (Figure 18). There is no evidence that the HFB at Hardel Plywood was more of a source than any of the other HFBs in the West Bay.

5.3.6 West Bay Marina/Buchanan Lumber Company

Buchanan Lumber operated at this site until 1966, when West Bay Marina began their lease. A historical HFB operated onsite until the closure of the lumber company. Between 2011 and 2012 eleven soil samples from various depths were collected in the vicinity of the former HFB. The results of these samples were included in the *Comparison Data-set*. One of these samples did correlate to Factor 1 HFB, but five samples correlated to Factor 2. Two intertidal samples were collected from within the marina. Extensive wood waste was present in the intertidal area. Both samples were in the upper quintile for Factor 2 (Figure 18), but the concentrations were below average for Budd Inlet (10.9 and 13.2 ng TEQ/kg).

Hart-Crowser interviewed the former site owner. The following excerpt was taken from the RI Addendum (Hart-Crowser 2012):

> According to an interview with the former property owner, Mr. Buchanan, the Site was filled with soil that sloughed off the steep bank to the west and wood debris from mill operations. Mr. Buchanan also indicated that lumber was never treated at this location, and the closest lumber treating operation was located approximately one mile southeast of the Site on the opposite side of Budd Inlet.

Wood treatment may not have occurred on site, but treated lumber may have been present. More than two samples are needed to confirm the presence of Factor 2.

5.3.7 Solid Wood Incorporated/West Bay Park

One historical HFB was present on the Solid Wood Incorporated site, but soil excavations near its former location did not reveal any dioxin/furan concentrations greater than 20 ng TEQ/kg. Surface sediment concentrations near Solid Wood were mostly low with contributions from Factor 2 in the upper quintile (Figure 18)

5.3.8 Reliable Steel

Three surface sediment samples were located near reliable steel. The fractional contribution of Factor 2 in these three samples averaged 76 percent. PCP was detected in one upland soil sample

(out of 30) at a level that exceeded proposed cleanup levels for the site. No other possible source for PCP was proposed at this location.

6.0 Conclusions

This study was conducted in an effort to increase the understanding of dioxin/furan sediment contamination throughout Budd Inlet. The primary objectives of the study were to:

- Identify unique dioxin/furan congener profiles present in Budd Inlet sediments, and when possible match the profiles to known sources;
- Calculate the relative contribution of the identified dioxin/furan source profiles to harbor-wide contamination; and
- Determine potential upland source areas by integrating spatial patterns of each dioxin/furan congener source profile and knowledge of historic and modern upland activities.

The chemometric analysis identified three unique factor patterns that accounted for 98 percent of variance in the data-set. These three factors were well mixed throughout the surface sediment layer (0 to 1 foot), but showed considerable variability in the subsurface core intervals.

Factor 1 correlated to HFB emissions and ash. Nine documented HFBs were historically operating in Budd Inlet. These boilers were primarily a diffuse source of dioxin/furans. As a result Factor 1 was not found at the same high TEQ increments as Factors 2 and 3. There were no subsurface hotspots of Factor 1. In surface sediments, the fractional contribution of Factor 1 was highest near Priest Point Park, the LOTT outfall, and the nearshore areas of the East and West Bays opposite the peninsula. Stormwater runoff was implicated as the primary source to surface sediments.

Factor 2 correlated to wood treatment processes containing PCP. Two subsurface areas, one near Berth 3, and one at the south end of the East Bay, had elevated TEQ increments of Factor 2 that suggested a direct pathway to sediments. Overwater structures were/are present at both locations. The fractional contribution of Factor 2 was highest in surface sediments near the Cascade Pole site, along the Port of Olympia berths, and in Fiddlehead and Martin Marinas. Storm drain solids from Port catch basins contained more Factor 2 than the City catch basins. Stormwater runoff from the Port peninsula was implicated as the primary source to surface sediments near the shipping Berths. Dredging activities conducted in late 2013 have removed most of the Factor 2 enriched sediments adjacent to the Port berths and added a clean sand layer. The collection and chemometric analysis of dioxin/furan data during future monitoring efforts will help to determine the full extent of recontamination from stormwater runoff.

Additional catch basin samples are needed from City of Olympia storm drains discharging to Fiddlehead and Martin Marinas in order to determine if ongoing upland sources exist in this area. A proposed sediment trap investigation may also help to evaluate the importance of recent deposition to the observed profiles, though efforts should be made to ensure the sediment captured in the traps is representative of fresh inputs as opposed to resuspended sediment due to active transport mechanisms in Budd Inlet.

Factor 3 contained furan peaks representative of PCBs, but included additional congener peaks that were not identified using the source library. The greatest TEQ increments from Factor 3 were collocated with those of Factor 2 in subsurface cores near Berth 3 and at the south end of East Bay. In addition, Factor 3 had minimal to no contribution to storm drain solids samples

from both the City and Port. For the above reasons, contamination from Factor 3 was considered historical. Fractional contributions of Factor 3 in surface sediment were highest in samples from the North Inlet indicating the extent of historical sediment transport from inner Budd Inlet.

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Figures

Figure 1. Overview of Budd Inlet Inner Harbor

NewFields

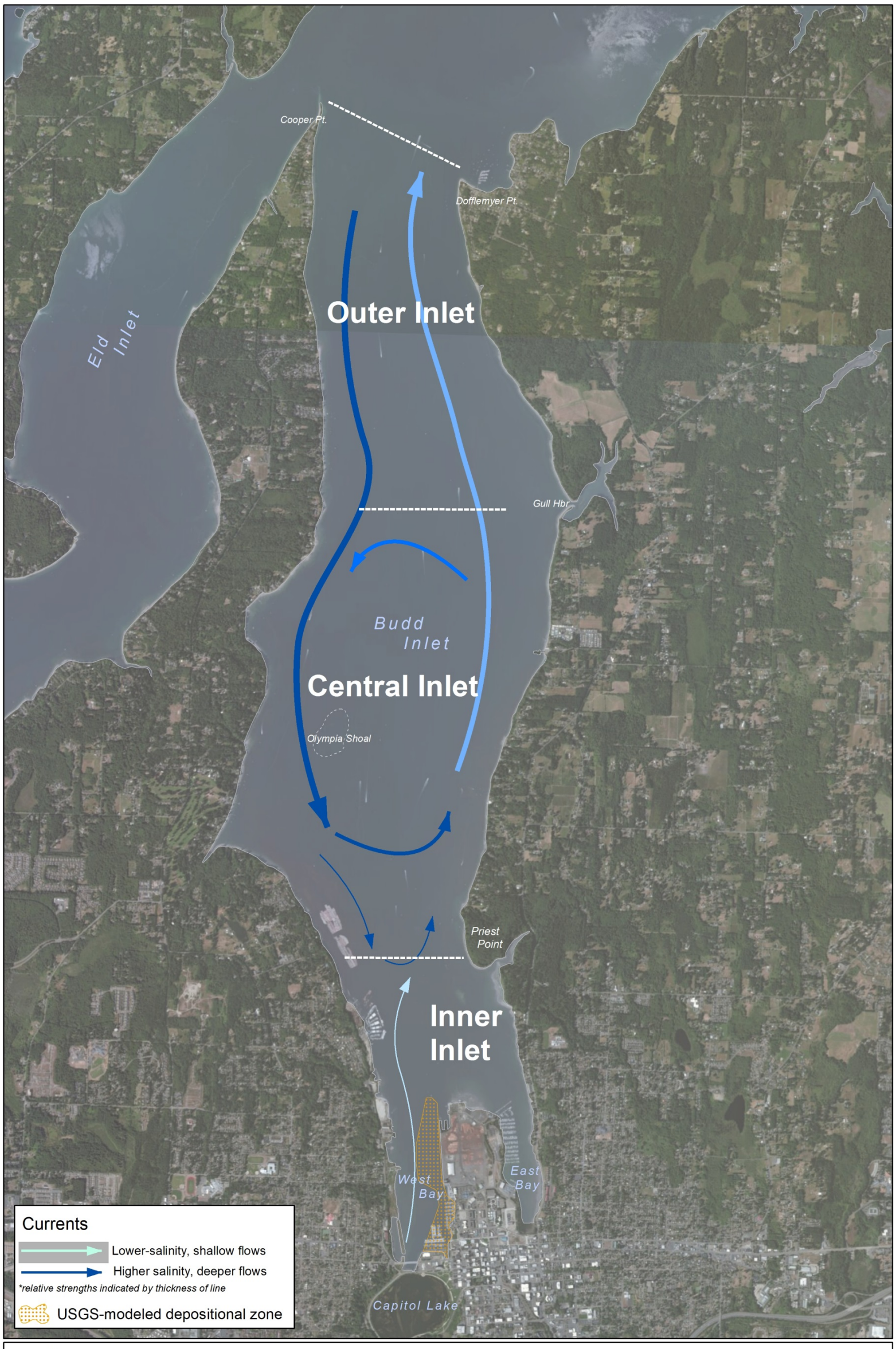

Figure 2. Overview of Circulation and Sediment Deposition in Budd Inlet

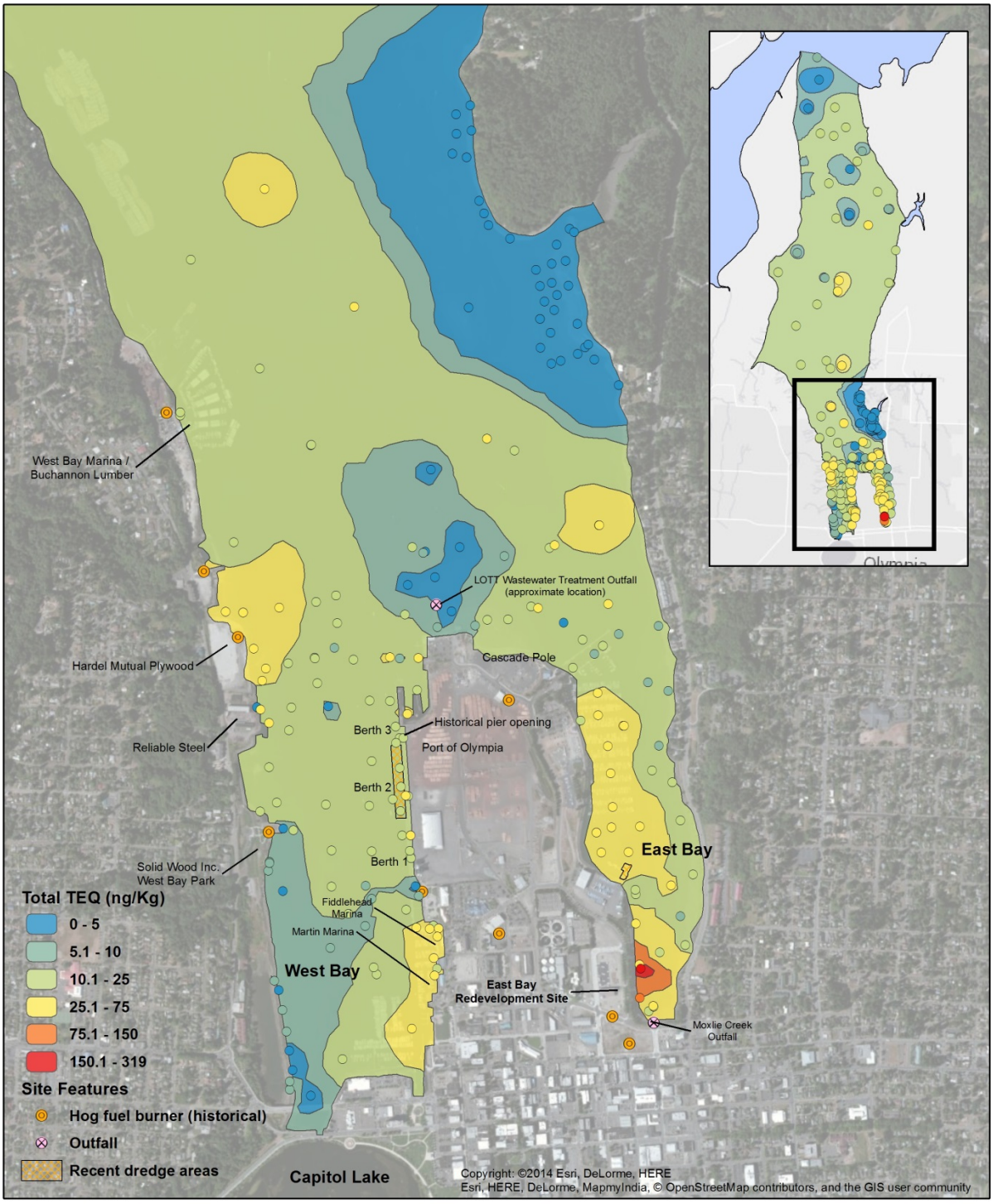

Figure 3. Interpolation of Surface Sediment Dioxin/Furan TEQ Concentrations in Budd Inlet

N

0 500 1,000 2,000 Feet

NewFields

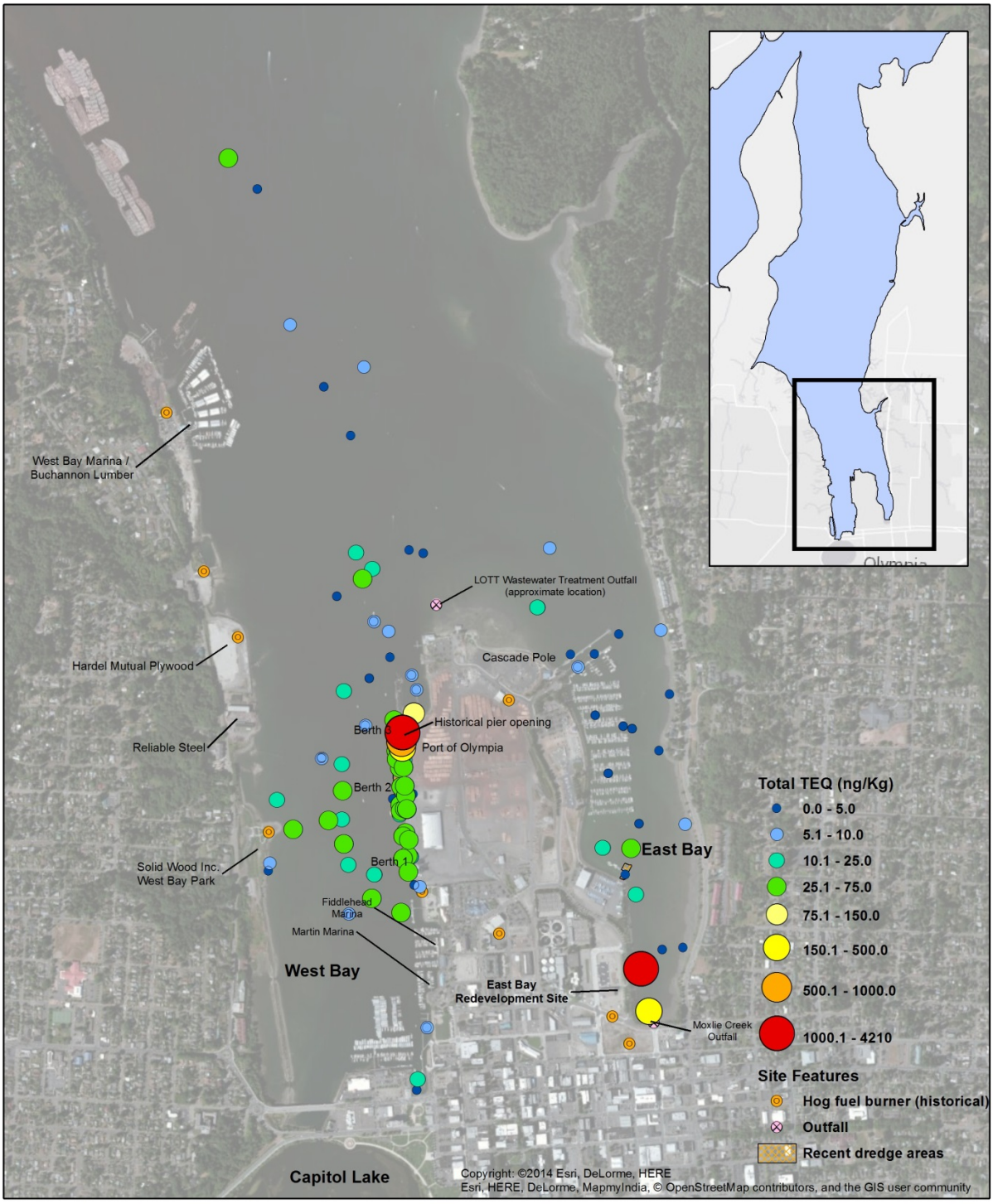

Figure 4. Subsurface Dioxin/Furan Contamination Represented by the Highest Concentration from Each Core

N

0 500 1,000 2,000 Feet

NewFields

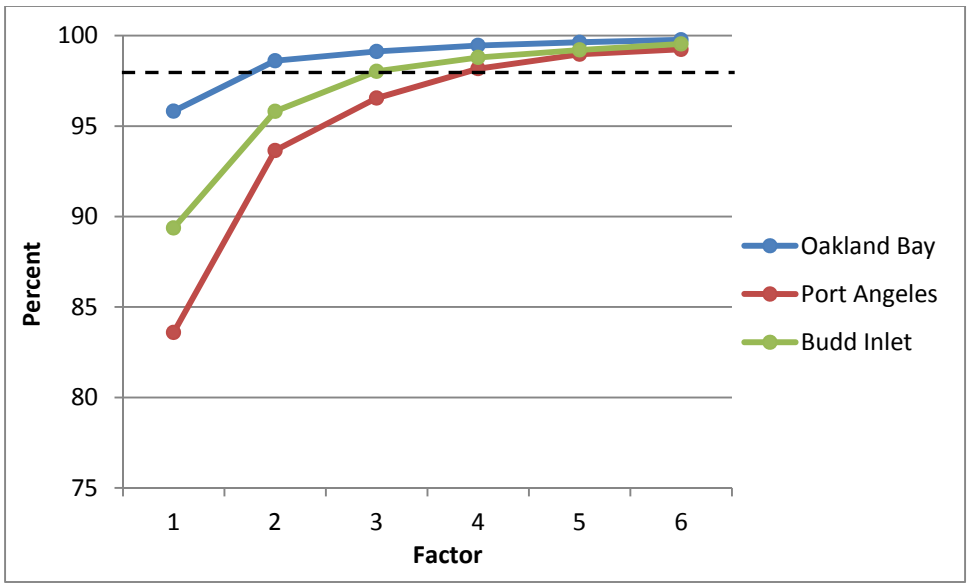

Figure 5. Cumulative Percent Variance Explained by the First Six Factors at Budd Inlet, Port Angeles Harbor, and Oakland Bay

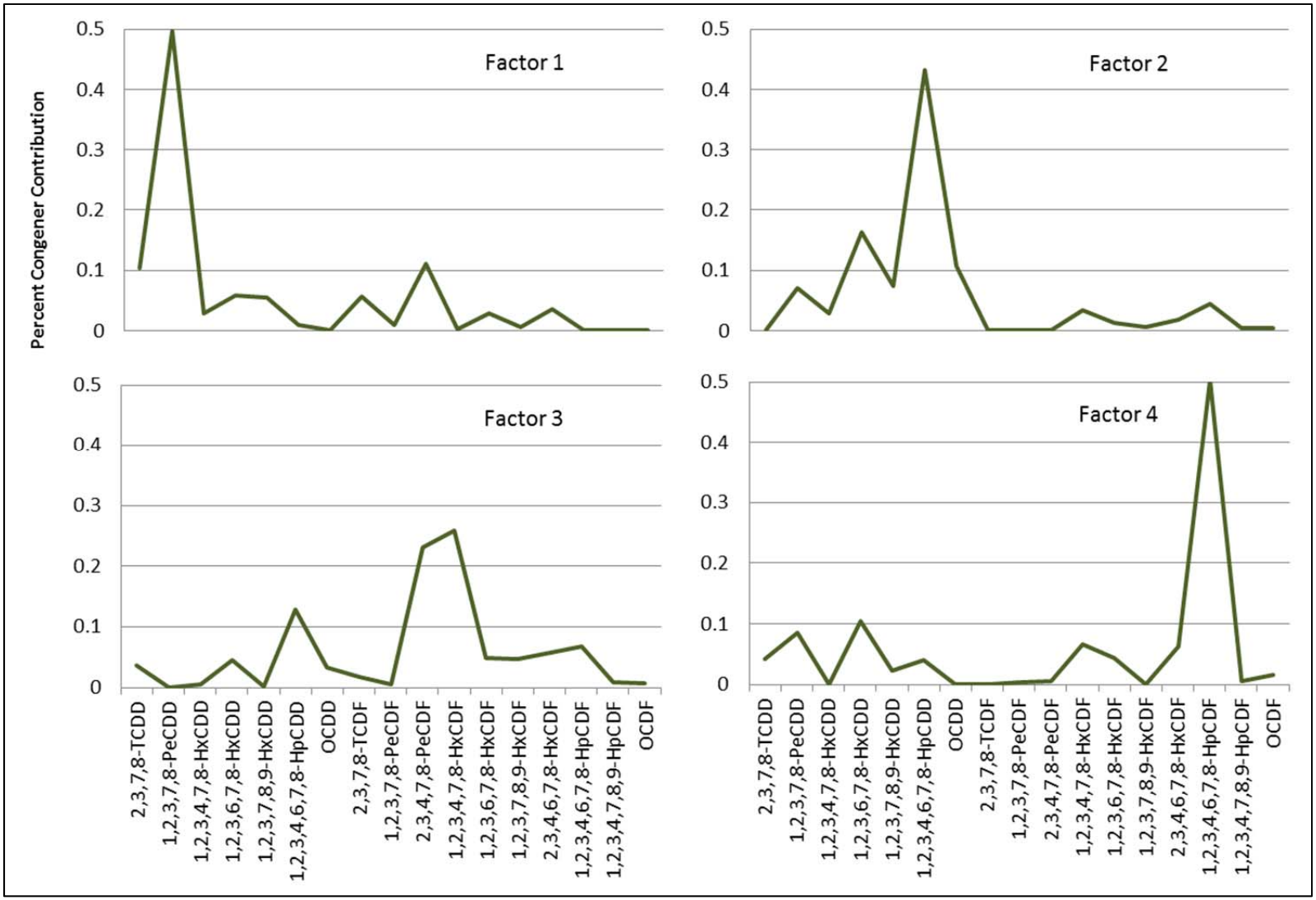

Figure 6. ALS Factor Profiles Using the 4-Factor Model

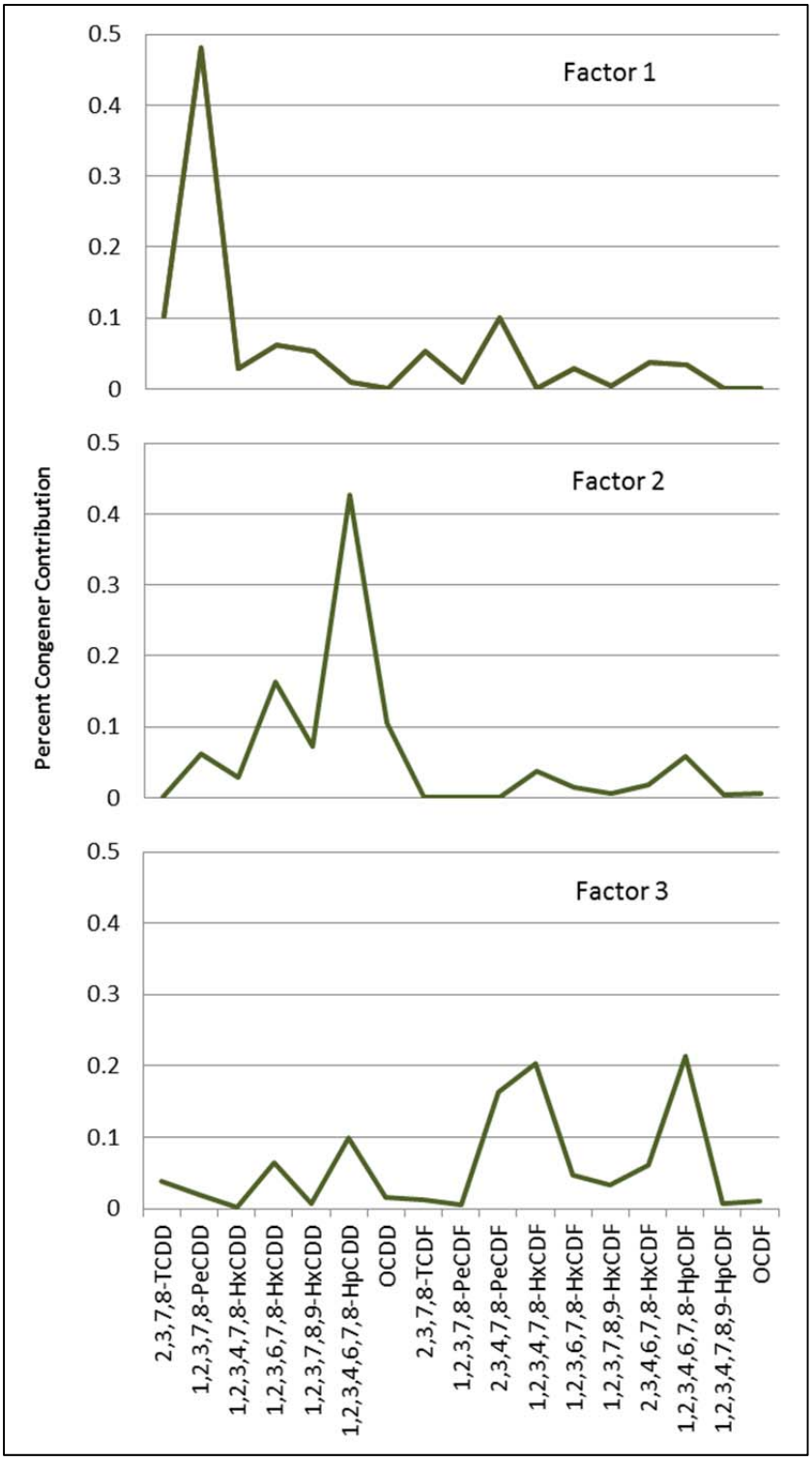

Figure 7. ALS Factor Profiles Using the 3-Factor Model

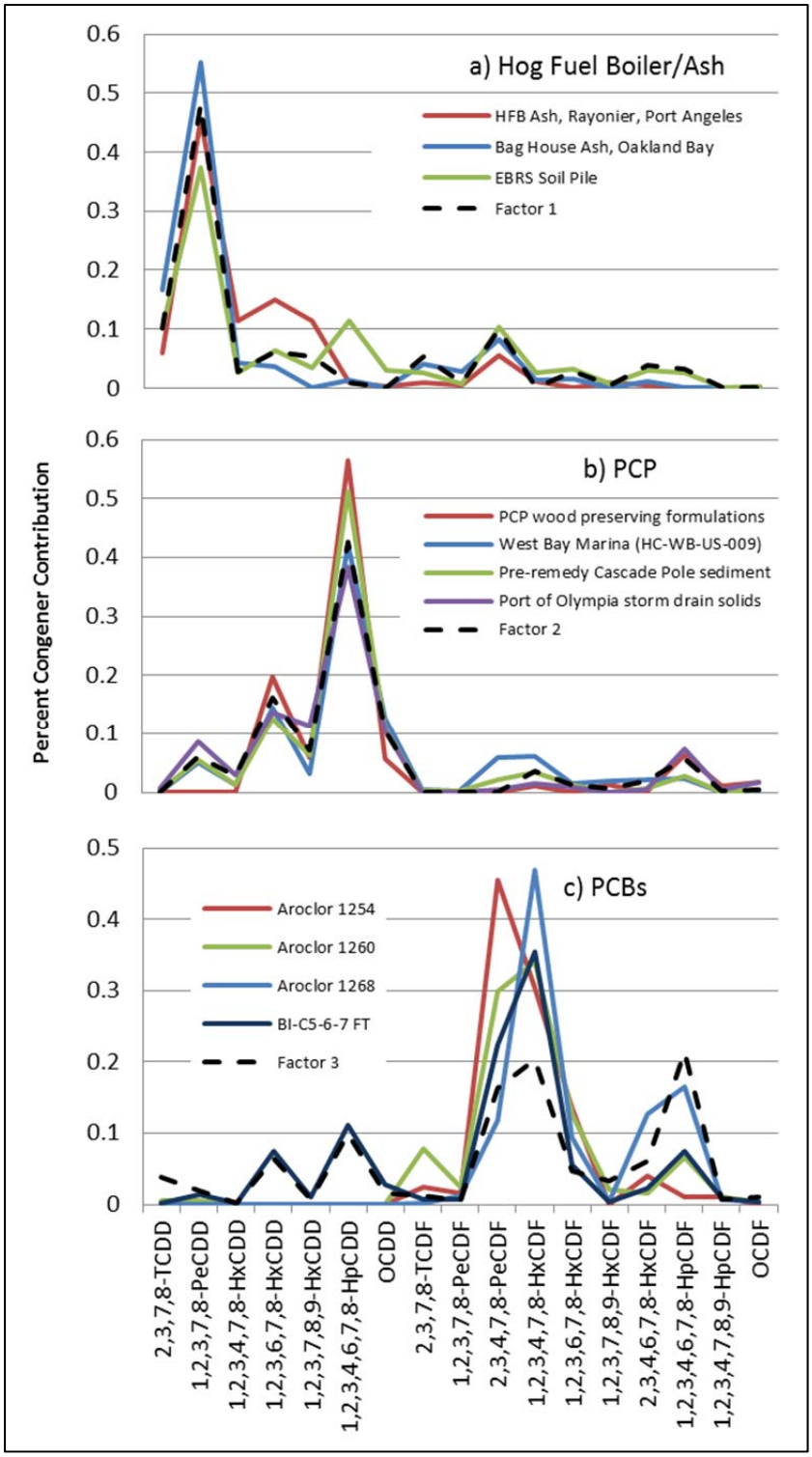

Figure 8. Representative Library Profiles for Source Identification Compared to Factor Profiles from the Three Factor Model

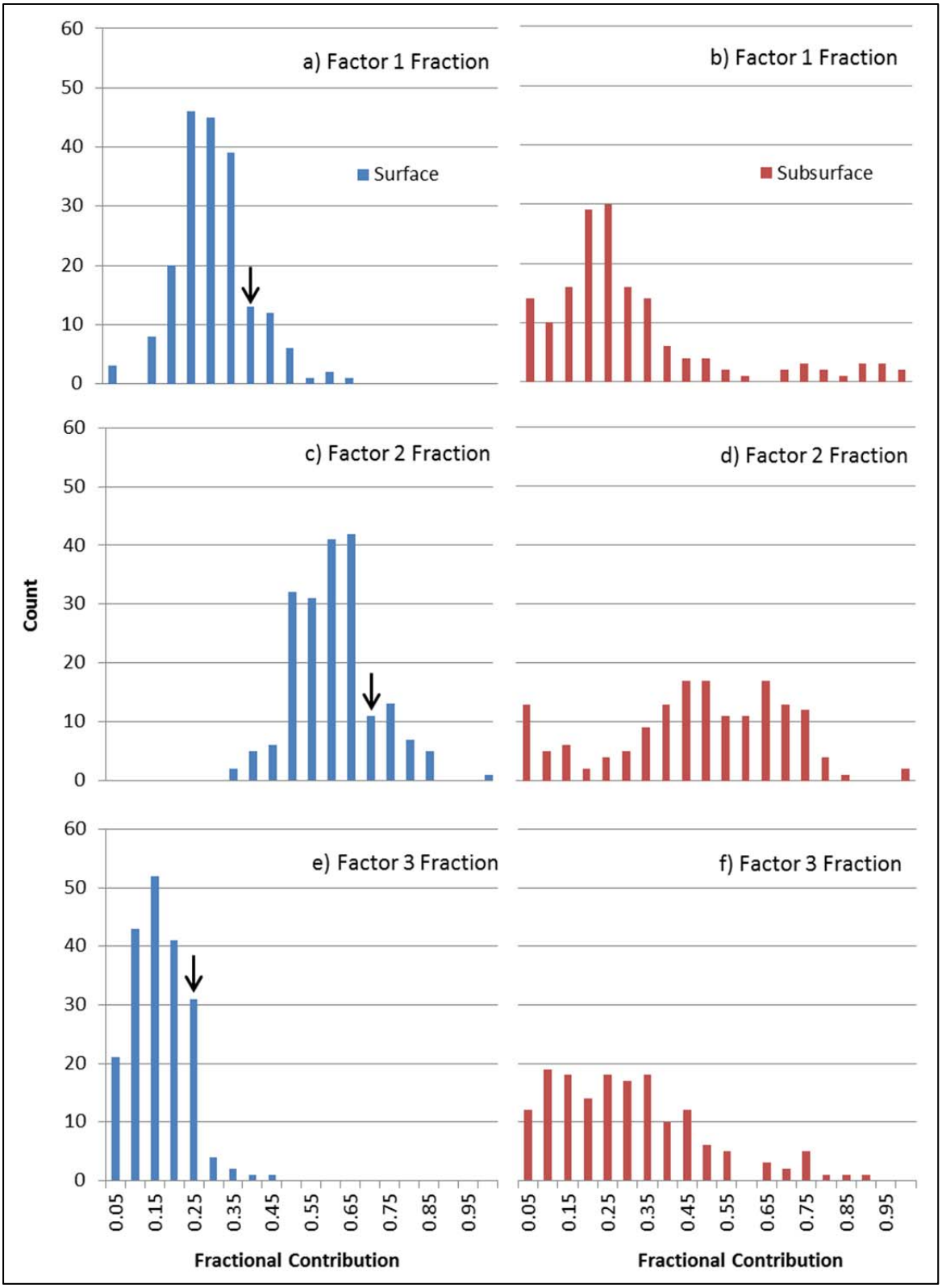

Figure 9. Histograms of the Fractional Contributions for Factors 1, 2, and 3 in Surface and Subsurface Sediments

Note: The top quintile of the surface sediments (represented by the black arrow) from each factor are mapped in Figure 18.

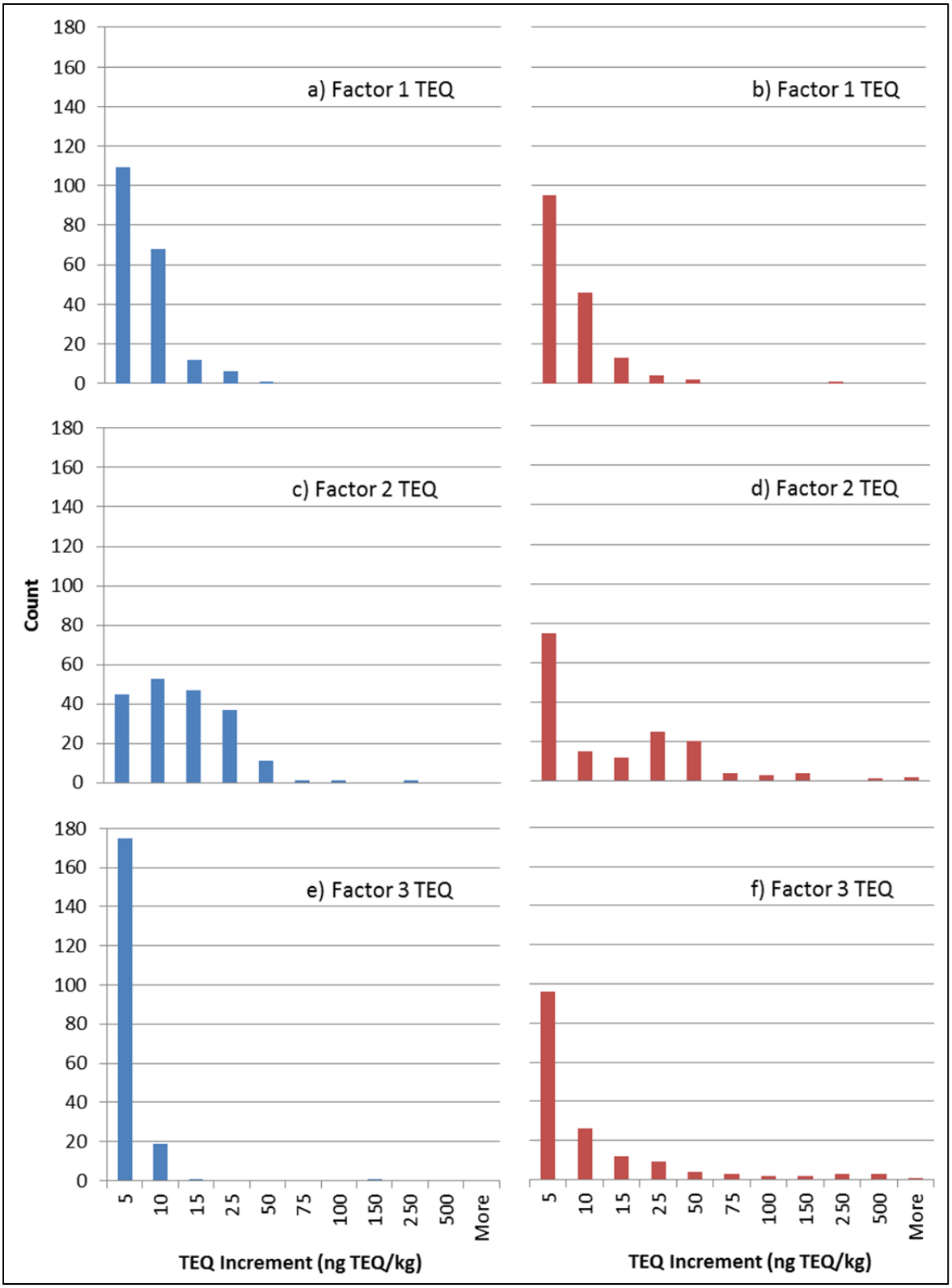

Figure 10. Histograms of the TEQ increments for Factors 1, 2, and 3 in Surface and Subsurface Sediments.

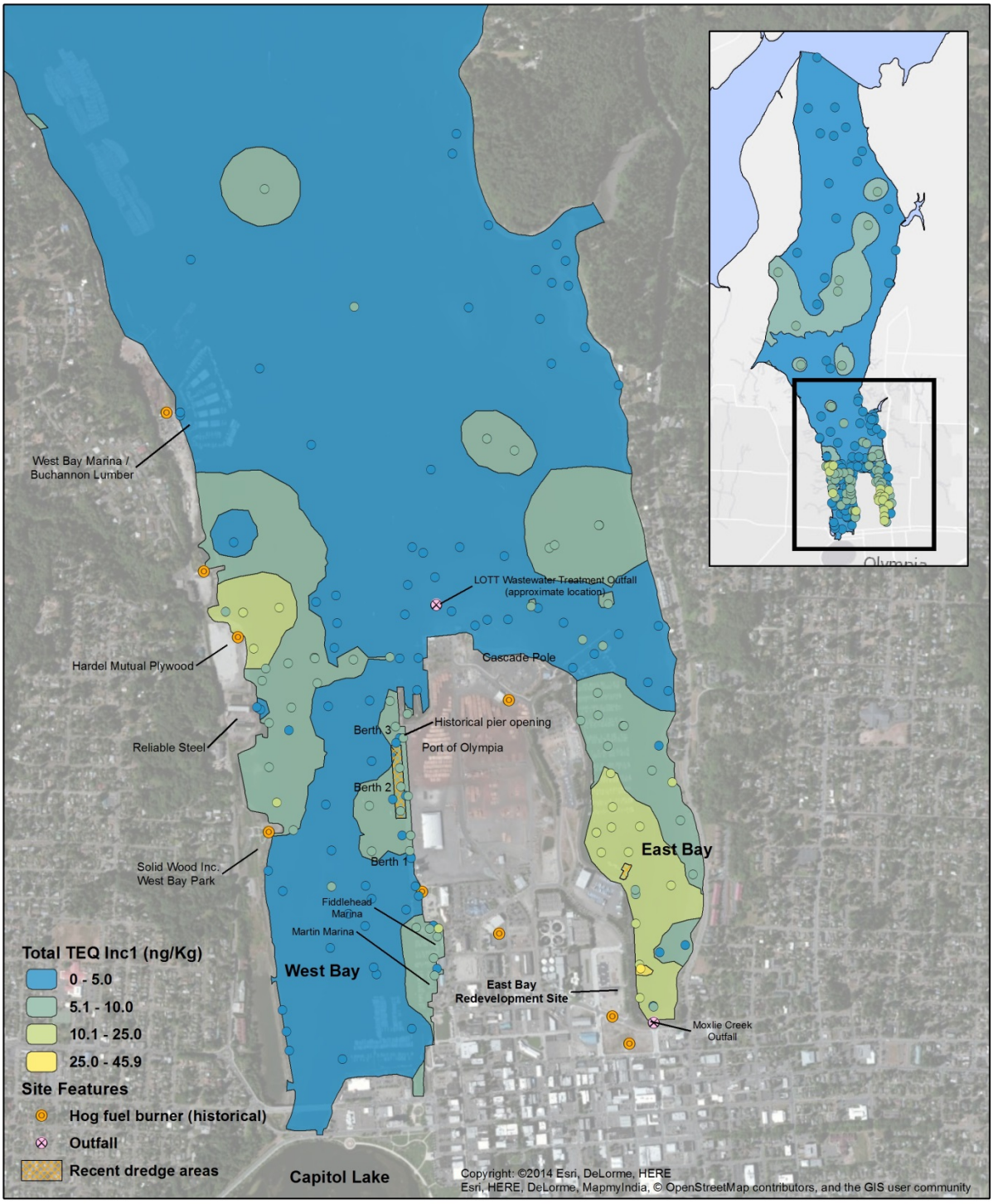

Figure 11. Interpolation of Surface Sediment Dioxin/Furan TEQ Increments for Factor 1

N

0 500 1,000 2,000 Feet

NewFields

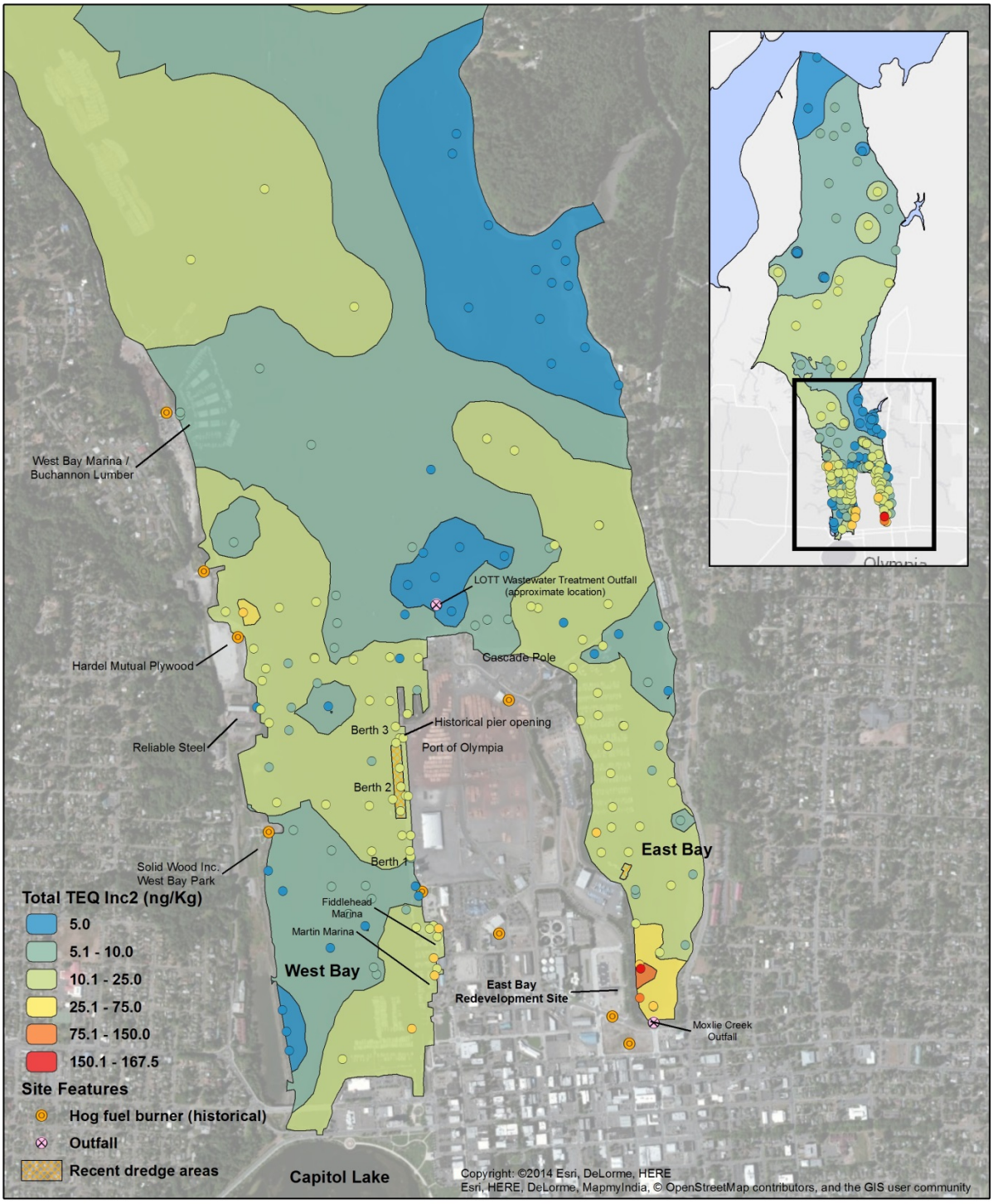

Figure 12. Interpolation of Surface Sediment Dioxin/Furan TEQ Increments for Factor 2

N

0 500 1,000 2,000 Feet

NewFields

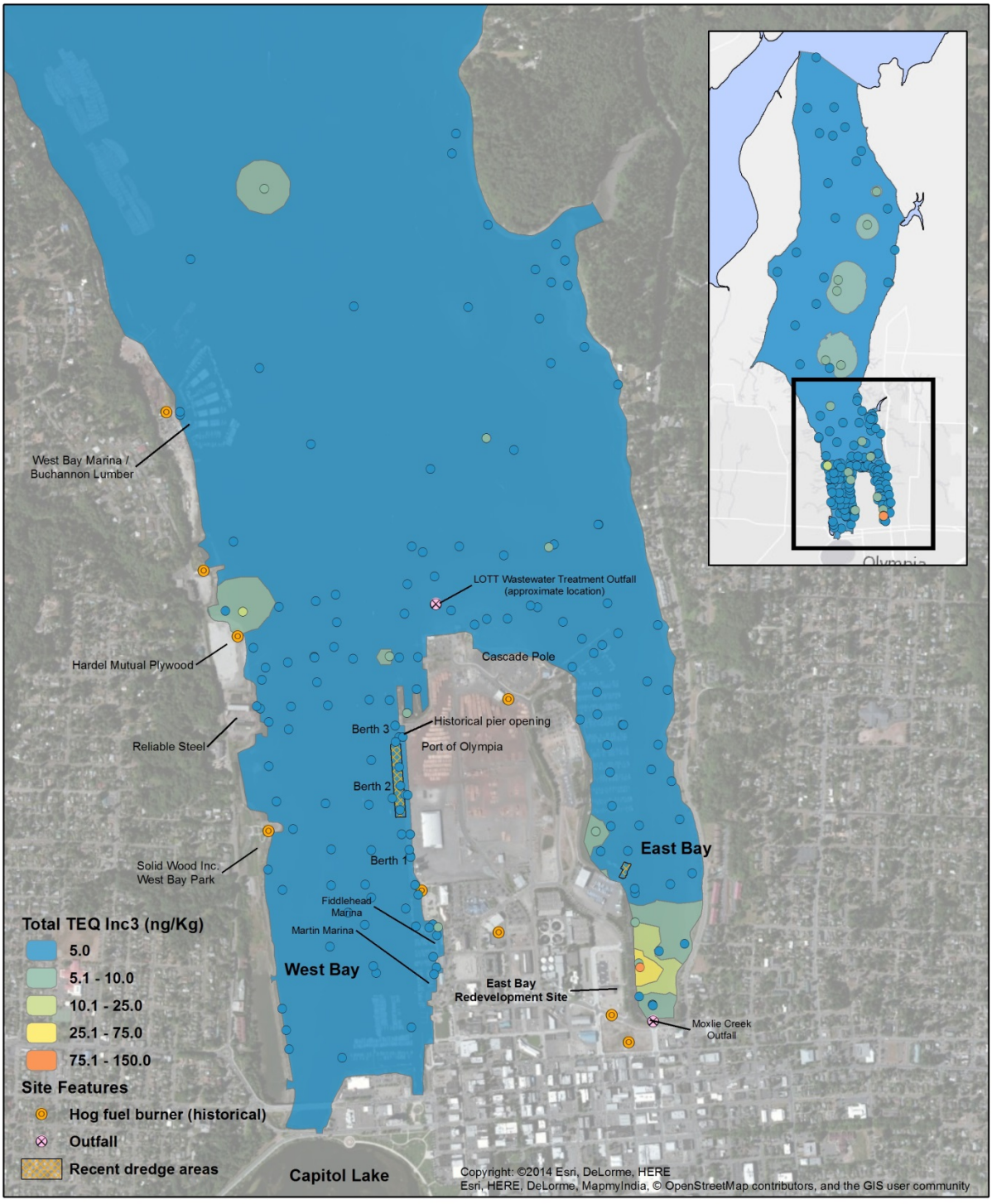

Figure 13. Interpolation of Surface Sediment Dioxin/Furan TEQ Increments for Factor 3

NewFields

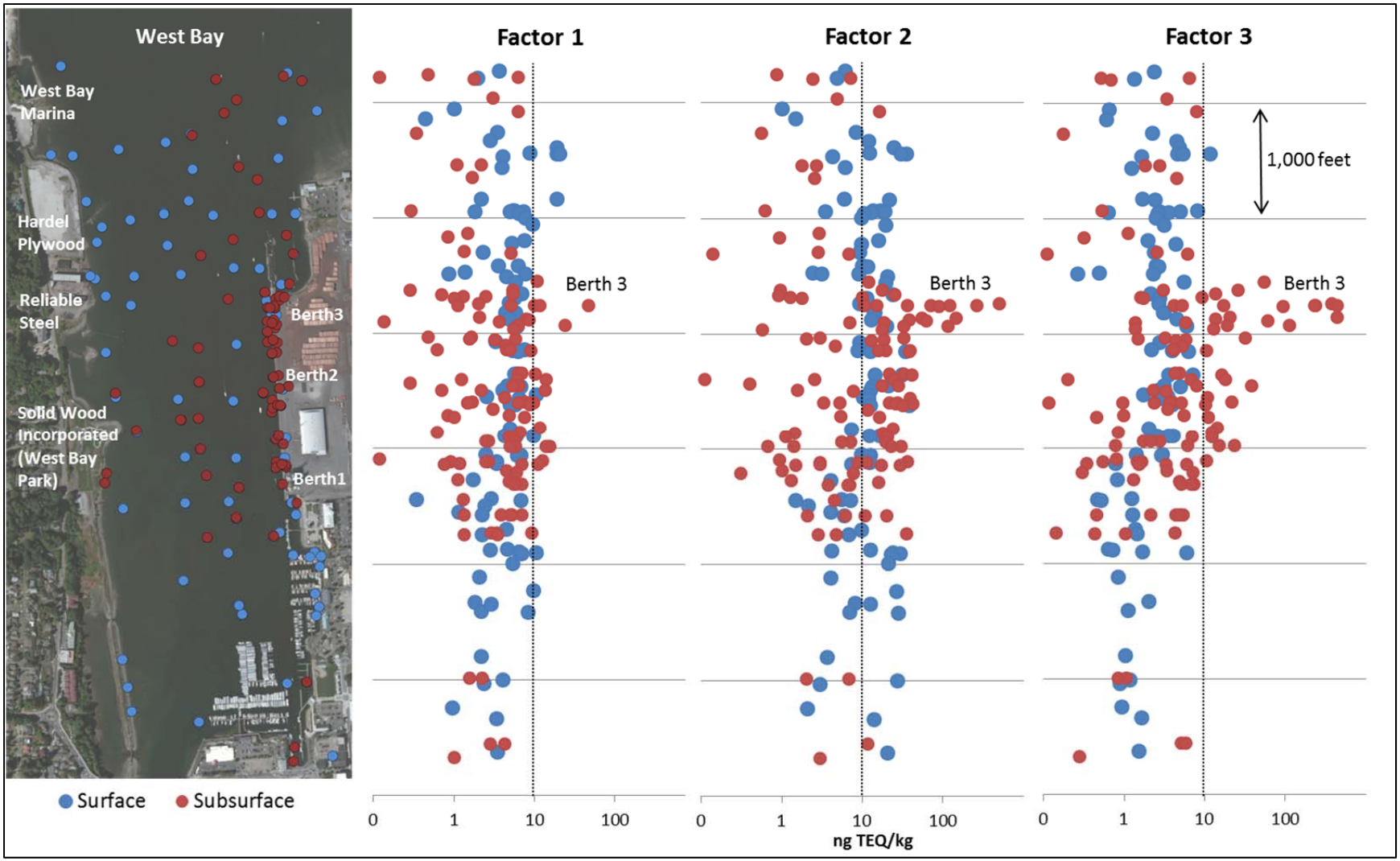

Figure 14. North/South Distribution of TEQ Increments in the West Bay

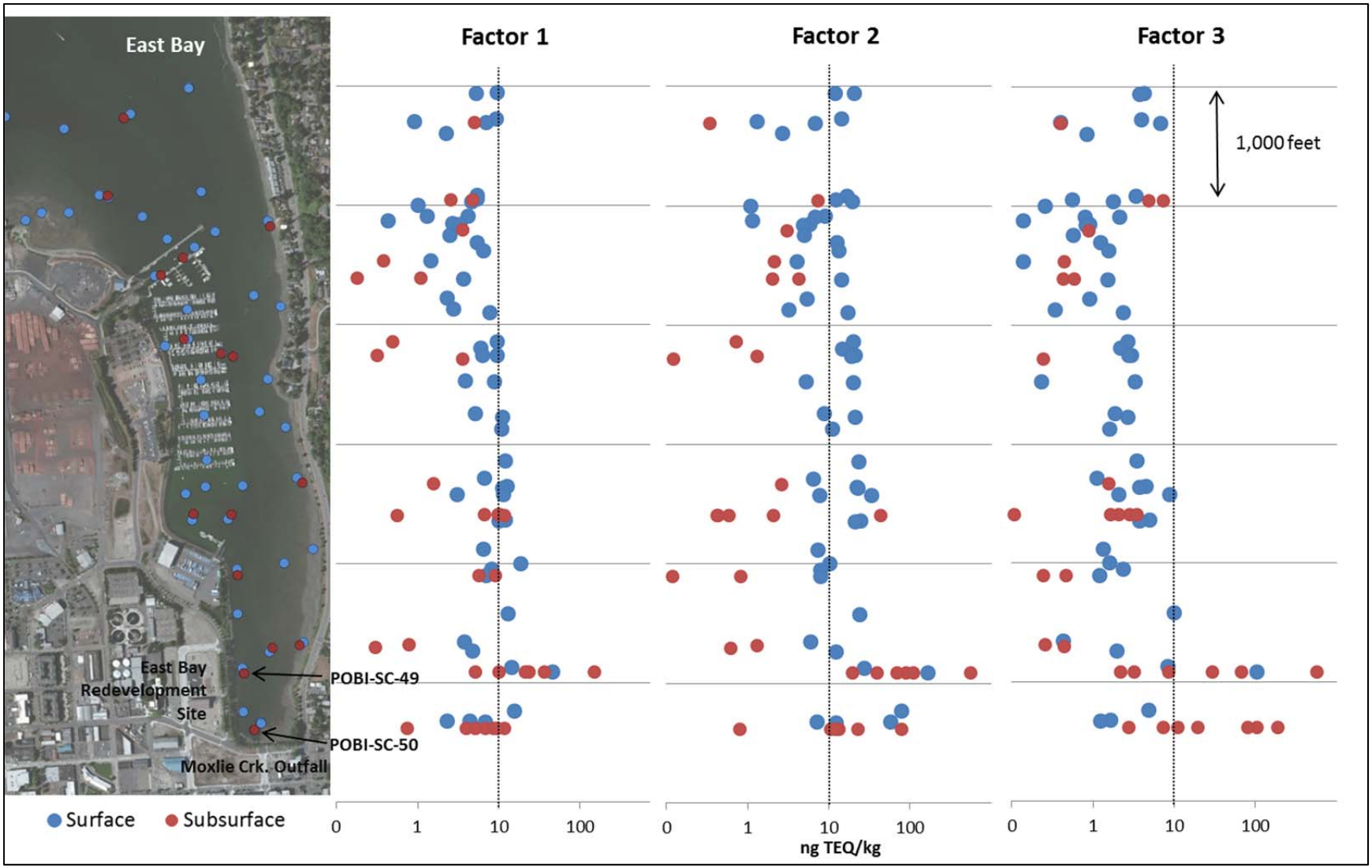

Figure 15. North/South Distribution of TEQ Increments in the East Bay

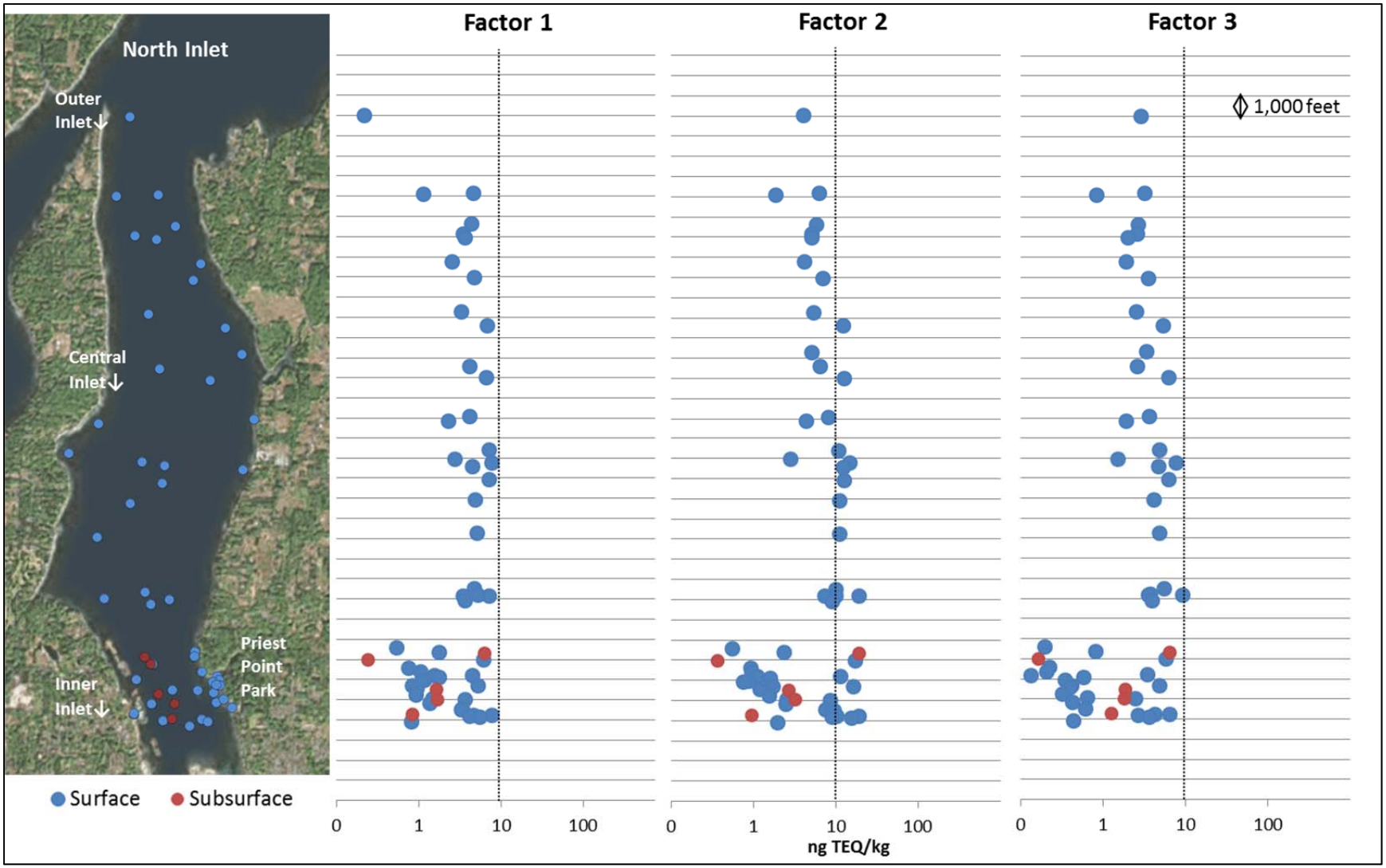

Figure 16. North/South Distribution of TEQ Increments in the North Inlet

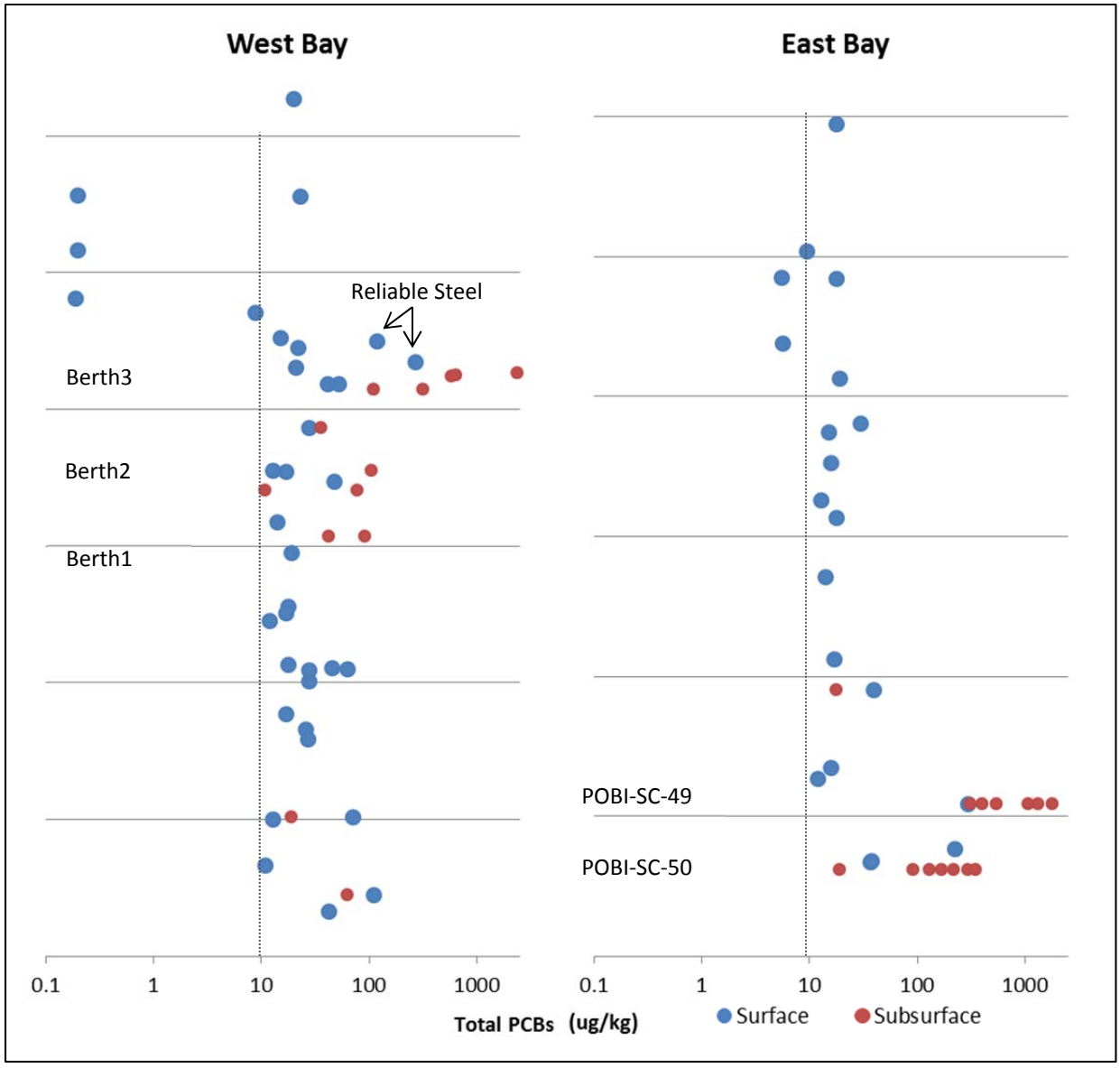

Figure 17. North/South Distribution of PCB Aroclor Concentrations in the East and West Bays

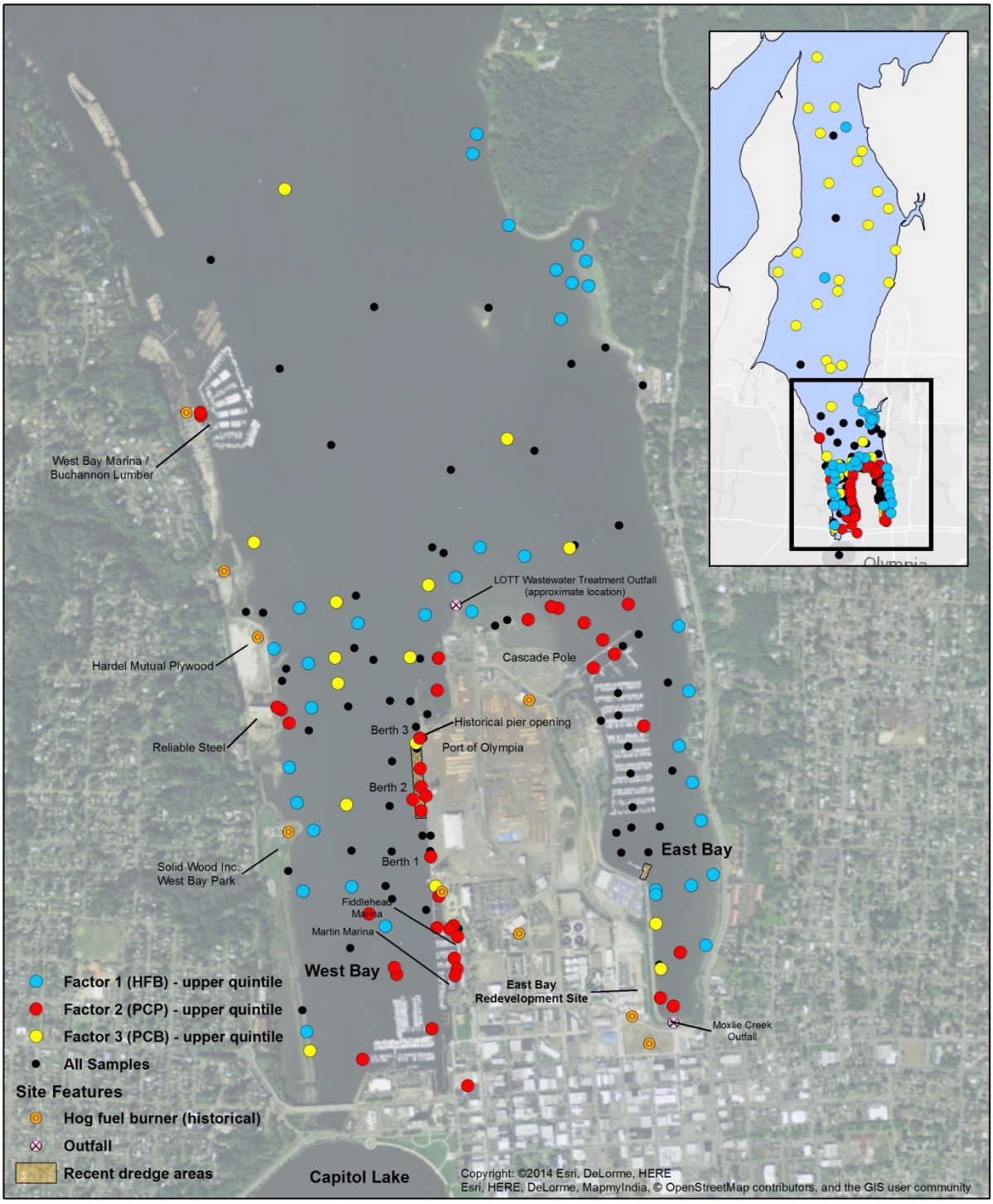

Figure 18. Maximum Fractional Contribution for each Factor

N

0 500 1,000 2,000 Feet

NewFields

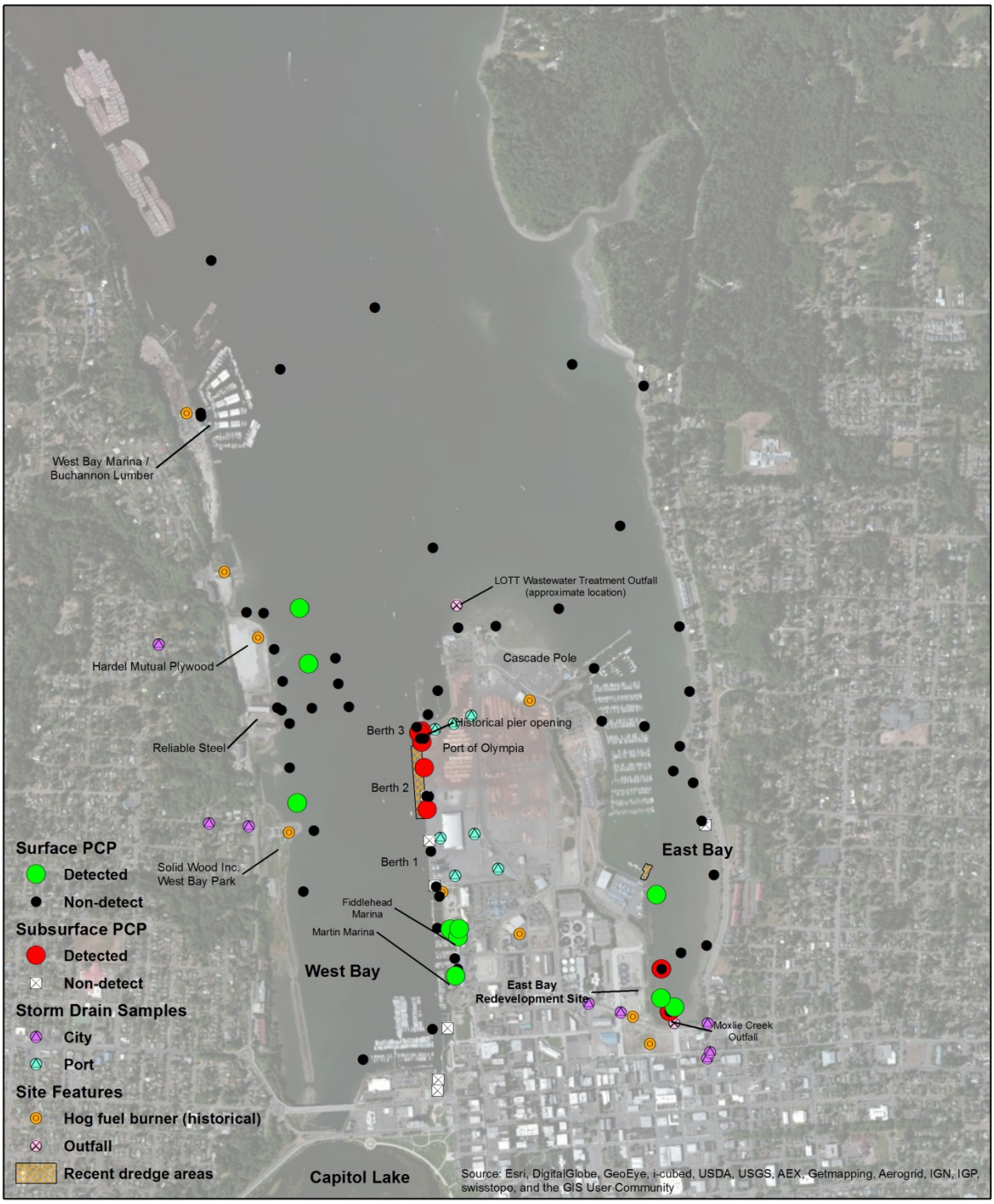

Figure 19. Detected Pentachlorophenol Concentrations in Budd Inlet and Locations of Catch Basin Solids Samples

NewFields

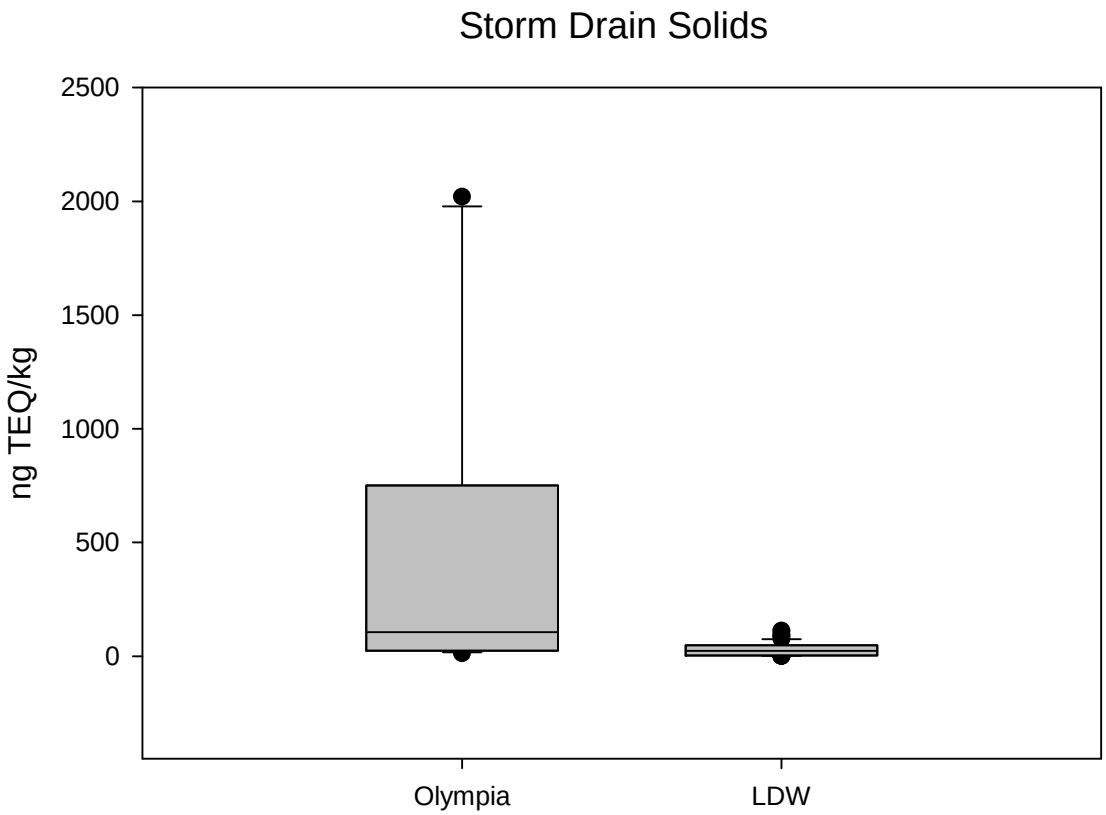

Figure 20. Comparison of Dioxin/Furan TEQ Concentrations in Storm Drain Solids in Olympia and the Lower Duwamish Waterway

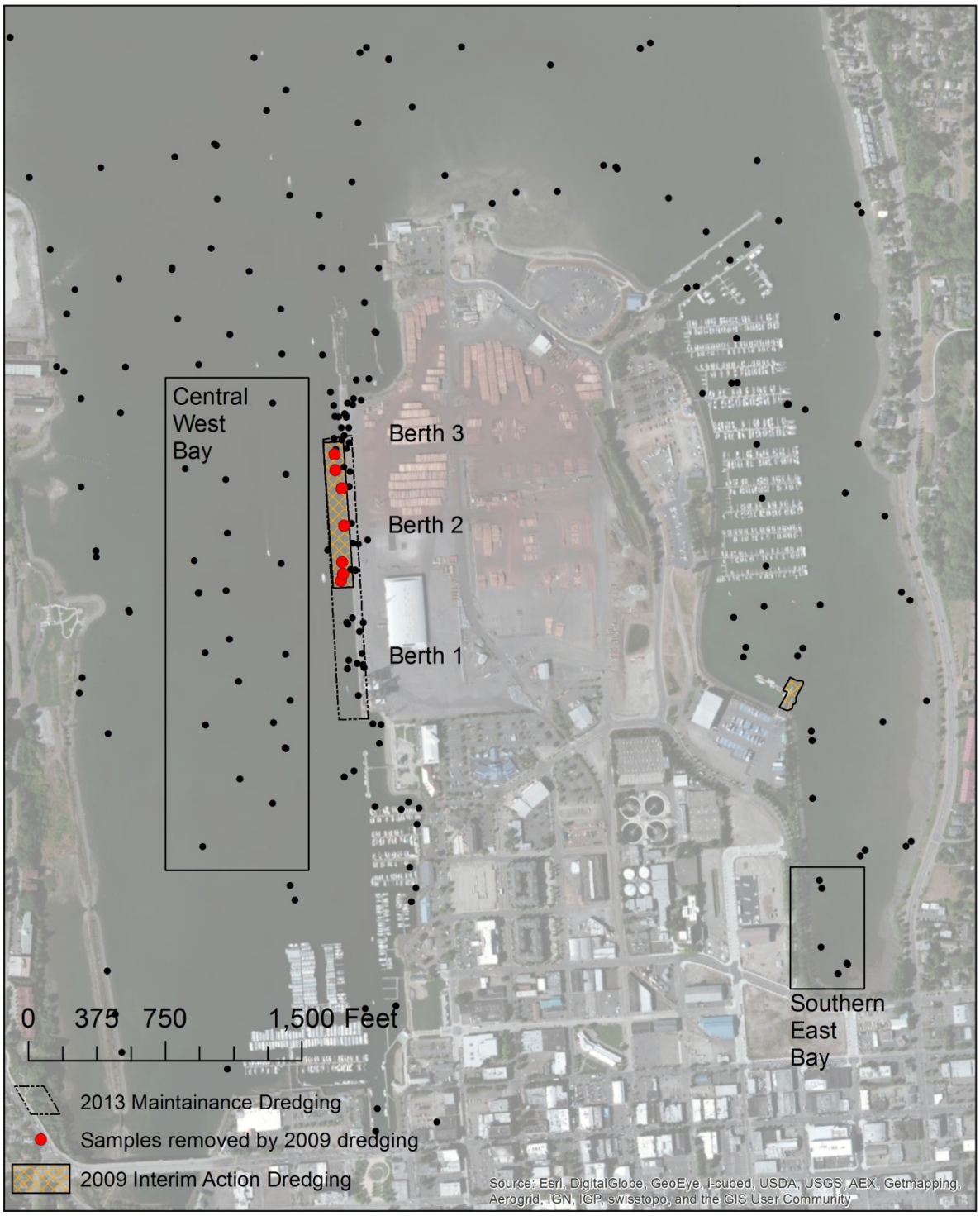

Figure 21. Samples Removed During 2009 Dredging and Locations of Samples Summarized in Figure 22

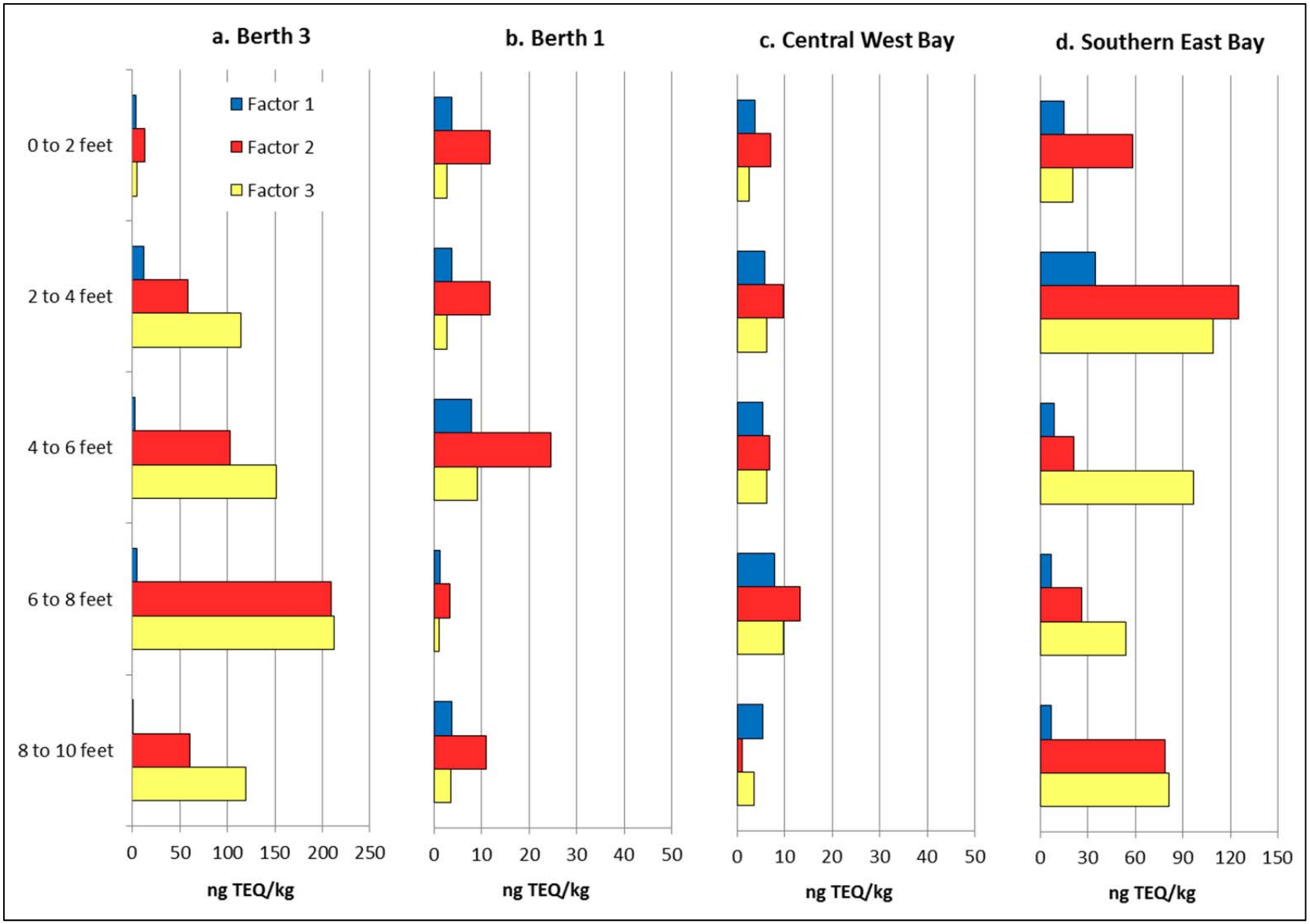

Figure 22. Averaged TEQ Increments with Depth for Four Areas in Budd Inlet

Tables

Table 1. Dioxin/Furan Homologue Groups and Seventeen Congeners of Greatest Concern

Homologue Group	Congener	Abbreviation	TEF
Dioxins			
Tetrachlorodibenzo-p-dioxins		TCDD	--
	2,3,7,8-tetrachlorodibenzo-p-dioxin	2,3,7,8-TCDD	1
Pentachlorodibenzo-p-dioxins		PeCDD	--
	1,2,3,7,8-pentachlorodibenzo-p-dioxin	1,2,3,7,8-PeCDD	1
Hexachlorodibenzo-p-dioxins		HxCDD	--
	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	1,2,3,4,7,8-HxCDD	0.1
	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	1,2,3,6,7,8-HxCDD	0.1
	1,2,3,7,8,9-hexachlorodibenzo-p-dioxin	1,2,3,7,8,9-HxCDD	0.1
Heptachlorodibenzo-p-dioxins		HpCDD	--
	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	1,2,3,4,6,7,8-HpCDD	0.01
Octachlorodibenzo-p-dioxin	Octachlorodibenzo-p-dioxin	OCDD	0.0003
Furans			
Tetrachlorodibenzofurans		TCDF	--
	2,3,7,8-tetrachlorodibenzofuran	2,3,7,8-TCDF	0.1
Pentachlorodibenzofurans		PeCDF	--
	1,2,3,7,8-pentachlorodibenzofuran	1,2,3,7,8-PeCDF	0.03
	2,3,4,7,8-pentachlorodibenzofuran	2,3,4,7,8-PeCDF	0.3
Hexachlorodibenzofurans		HxCDF	--
	1,2,3,4,7,8-hexachlorodibenzofuran	1,2,3,4,7,8-HxCDF	0.1
	1,2,3,6,7,8-hexachlorodibenzofuran	1,2,3,6,7,8-HxCDF	0.1
	1,2,3,7,8,9-hexachlorodibenzofuran	1,2,3,7,8,9-HxCDF	0.1
	2,3,4,6,7,8-hexachlorodibenzofuran	2,3,4,6,7,8-HxCDF	0.1
Heptachlorodibenzofurans		HpCDF	--
	1,2,3,4,6,7,8-heptachlorodibenzofuran	1,2,3,4,6,7,8-HpCDF	0.01
	1,2,3,4,7,8,9-heptachlorodibenzofuran	1,2,3,4,7,8,9-HpCDF	0.01
Octachlorodibenzofuran	Octachlorodibenzofuran	OCDF	0.0003

Table 2. Combined Data-set for the Budd Inlet Chemometric Evaluation

Study Name	EIM Study ID/Reference	Study QA Level Assessment	Field Collection Start Date†	Field Collection End Date†	Marine/Intertidal Sediment			Freshwater Sediment	Upland Soil		
					Surface Samples	Subsurface Samples	Unknown Interval	Surface Samples	Surface Samples	Subsurface Samples	Unknown Interval
Unmixing Data-set											
Investigation Report Port of Olympia Budd Inlet Sediment Site	Not in EIM/Anchor QEA 2013	Level 4	25-Feb-13	14-Mar-13	76	121	--	--	--	--	--
Budd Inlet and Oakland Bay Dioxin Study	BuddOakDioxins	Level 3	1-Jun-11	21-Jun-11	30	--	--	--	--	--	--
Port of Olympia: Berth 2 & 3 Interim Action Cleanup Sampling to Characterize Pre-Dredge, Post-Dredge, and Post-Cover conditions.	OlyMarineTerminal08/ Anchor QEA 2009	Level 5	25-Sep-08	16-Mar-09	19	12	--	--	--	--	--
Percival Landing Redevelopment Project - Antidegradation Evaluation, DY10	PERLA08	Level 2 (QA1)	14-Feb-08	14-Feb-08	--	6	--	--	--	--	--
West Bay of Budd Inlet - Sediment Characterization Study: Berths 2 and 3 Interim Action Project.	Budd Inlet W Bay 07	Level 4	26-Aug-07	29-Aug-07	--	23	--	--	--	--	--
C396_Hardel EIM Results.	Budd Inlet Hardel 07	Level 2 (QA1)	13-Aug-07	13-Aug-07	3*	--	--	--	--	--	--
Budd Inlet Sediment Characterization	BUDD07/SAIC 2008	Level 4	2-Apr-07	15-Jun-07	54	41	--	2	--	--	--
Solid Wood Inc. (West Bay Park) RI/FS, Olympia, WA. Agreed Order # DE-08-TCP SR-5415	WB1577RIFS	Level 3	9-Feb-07	25-Oct-12	9*	2*	--	--	--	--	--
Solid Wood Inc. (West Bay Park) Rail Spur Phase II Environmental Site Assessment, Olympia, WA. Agreed Order # DE-08-TCP SR-5415	FS94656838Ph2	Level 1	8-Feb-07	9-Feb-07	--	--	6*	--	--	--	--
Olympia Harbor - Supplemental Dioxin Study, DY07	OHPSD06	Level 2 (QA1)	7-Mar-06	10-Mar-06	3	34	--	--	--	--	--
Cascade Pole Longterm Groundwater Compliance Monitoring and Sediment Sampling, Olympia, WA	FS1385	Level 5	24-Jun-05	1-Oct-13	8	12	20*	--	--	--	--

Table 2. (continued) Combined Data-set for the Budd Inlet Chemometric Evaluation.

Study Name	EIM Study ID/Reference	Study QA Level Assessment	Field Collection Start Date†	Field Collection End Date†	Marine/Intertidal Sediment			Freshwater Sediment	Upland Soil		
					Surface Samples	Subsurface Samples	Unknown Interval	Surface Samples	Surface Samples	Subsurface Samples	Unknown Interval
Unmixing Data-set											
Budd Inlet Dioxin & Tissue Mon-Post Sediment Remediation - Cascade Pole Company (CPC)	CASMON03	Level 2 (QA1)	11-Apr-02	10-Jun-02	9	--	--	--	--	--	--
Field Sampling Priest Point Park	Thurston County 2010	Level 2 (QA1)	9-Oct-10	10-Oct-10	30	--	--	--	--	--	--
West Bay Marina Remedial Investigation, Olympia, WA	AODE5272	Level 4	19-Aug-09	28-Feb-12	2	--	--	--			--
Local Subset of Source Library											
Solid Wood Inc. (West Bay Park) RI/FS, Olympia, WA. Agreed Order # DE-08-TCP SR-5415	WB1577RIFS	Level 3	9-Feb-07	25-Oct-12	--	--	--	--	--	4*	11*
Solid Wood Inc. (West Bay Park) Rail Spur Phase II Environmental Site Assessment, Olympia, WA. Agreed Order # DE-08-TCP SR-5415	FS94656838Ph2	Level 1	8-Feb-07	9-Feb-07	--	--	--	--	--	--	3*
West Bay Marina Remedial Investigation, Olympia, WA	AODE5272/Hart Crowser 2011; 2012	Level 4	19-Aug-09	28-Feb-12		--	--	--	7	4	--
Phase II Environmental Site Assessment at Washington Department of Fish and Wildlife Parcel A, B, and C in Olympia (600 Capitol Way North)	G1300114 - Parcel A	Level 2	17-Dec-12	17-Dec-12	--	--	--	--	--	15	--
	G1300114 - Parcel B	Level 2	24-Oct-12	24-Oct-12	--	--	--	--	--	17	--
	G1300114 - Parcel C	Level 2	23-Oct-12	24-Oct-12	--	--	--	--	--	16	--
Infrastructure Interim Action Report for East Bay Redevelopment Site	Pioneer Technologies 2010	Level 2 (QA1)	8-Jun-09	7-Aug-09	--	--	--	--	--	--	13¥
Port of Olympia Source Control Investigations	Anchor QEA 2012; personal comm. see notes	Level 2 (QA1)	9-Aug-10	23-Dec-13	--	--	--	--	8◊	--	--
City of Olympia Catch Basin Solids	Personal comm. see notes	Level 2 (QA1)	13-Feb-14	13-Feb-14	--	--	--	--	8◊	--	--
Cascade Pole Supplemental Site Investigation Report	Landau 1993	Level 4	13-Dec-90	1-Aug-91	8¤	5¤	--	--	--	--	--

Notes:

†represents the start and end date output from EIM, not necessarily the time period for dioxin sampling

*sample depth not defined

¥only samples that exceeded the interim action cleanup level (IACL) were included.

◊ storm drain solids

¤only the highest TEQ samples (>50 ng TEQ/kg) were taken from ESE 1992

Level 1 - Data neither Verified nor Assessed for Usability

Level 2 - Data Verified (also referred to as QA1)

Level 3 - Data Verified and Assessed for Usability

Level 4 - Data Verified and Assessed for Usability in a Formal Study Report

Level 5 - Data Verified and Assessed for Usability in a Peer-Reviewed Study Report

References:

Anchor QEA. 2009. Completion Report Berths 2 and 3 Interim Action Cleanup. Prepared for the Port of Olympia, Olympia, WA. by Anchor QEA. June 2009.

Anchor QEA. 2013. Draft Investigation Report Port of Olympia Budd Inlet Sediment Site. Prepared for the Port of Olympia, Olympia, WA. by Anchor QEA. December 2013.

Anchor QEA. 2012. Port of Olympia Source Control Investigations. Prepared for the Port of Olympia, Olympia, WA. by Anchor QEA. June 2012.

Hart Crowser 2011. Remedial Investigation Westbay Marina. Prepared for the Washington State Department of Ecology, Lacey, WA. by Hart Crowser. June 2011.

Hart Crowser 2012. Remedial Investigation Addendum Westbay Marina. Prepared for the Washington State Department of Ecology, Lacey, WA. by Hart Crowser. May 2012.

Landau Associates. 1993. Remedial Investigation Report Sediments Operable Unit Cascade Pole Site, Olympia, WA. Prepared for Cascade Pole Company, Olympia, WA. by Landau Associates. January 1993.

Pioneer Technologies. 2010. Infrastructure Interim Action Report for East Bay Redevelopment Site. Prepared for the Port of Olympia, Olympia, WA. by Pioneer Technologies. June 2010.

SAIC. 2008. Sediment Characterization Study, Budd Inlet, Olympia, WA. Prepared for the Washington State Department of Ecology, Lacey, WA. by SAIC. March 2008.

Thurston County. 2010. Field Sampling Report Priest Point Park Sediment Sampling Project. Prepared for the Washington Department of Ecology, Lacey, WA. by Thurston County Public Health and Social Services. November 2010.

J. Dunay, personal communication, August 19, 2014

Table 3. Outliers Removed During the Data Screening Step

EIM StudyID or Reference	Sample_Name	TEQ	Percent Contribution from NDs	Number of NDs
Anchor 2013a	POBI-SC-47-3-4	1.42	47	5
Anchor 2013a	POBI-SS-32SG	5.03	3	1
BUDD07	BI-C2-2-3 FT	0.377	36	7
BUDD07	BI-C7-2-3 FT	0.768	38	5
BuddOakDioxins	BI-43216	0.645	11	5
BuddOakDioxins	BI-140	3.33	7	6
BuddOakDioxins	BI-268	3.62	14	6
Thurston County 2010	CC102-01	0.67	6	4
Thurston County 2010	U73-01	0.747	4	5
Thurston County 2010	OOOO123-01	0.867	14	5
Thurston County 2010	N44-01	1.43	28	7
Thurston County 2010	LLLL121-01	1.59	17	4
Thurston County 2010	RRR181-01	2.13	15	6
WB1577RIFS	SD24	8.04	0	1
Anchor 2013a	POBI-SC-19-8-10	25.6	1	1
Anchor 2013a	POBI-SC-19-10-12	61.4	0	1
Anchor 2013a	POBI-SC-20-15-16	113	0	0
BuddOakDioxins	BI-556	41.8	0	1
OHPSD06	OHPSD0224-S29-Z	3.19	0	2
PERLA08	C1-01A	3.23	0	0
BUDD07	BI-C5-6-7 FT*	4210	0	1

ND = non-detects
TEQ = toxcity equivalency
*sample was added to source library due to the high concentration

Table 4. Source Library Matches to the 3- and 4-Factor Models

4-Factor Model	Profile Description		3-Factor Model
1	**Source Library** - Matched to profiles from effluent and hog fuel boiler ash. **Local Library** - Matched to an ash sample from Oakland Bay (low pressure boiler baghouse) and one soil pile sample from the East Bay Redevelopment Site.		**1**
2	**Source Library** - Matched to profiles from PCP wood preserving formulations, PCP treated utility poles, and water soluble (Na-PCP) treatment formulations **Local Library** - Matched to five upland soil samples from West Bay Marina. Matched 11 of 12 samples collected prior to sediment remediation at Cascade Pole. Matched to one soil pile sample from the East Bay Redevelopment Site. Matched with storm drain solids samples collected from the Port.		**2**
3	**Source Library** - clustered with and weak correlation (>0.75) to Aroclors 1254, 1260, and 1268. **Local Library** - Matched to sample BI-C5-6-7-FT	**Source Library** - weak correlation (>0.75) to Aroclor 1268.	**3**
4	**Source Library** - clustered with and weak correlation (>0.75) to burn barrel emissions.	**Local Library** - weak correlation (>0.75) to BI-C5-6-7-FT and clustered with one upland soil sample from West Bay Marina and two soil pile samples from the East Bay Redevelopment Site.	

Table 5. Summary Statistics for the Upper Quintiles of Surface Sediment Data for Each Factor

			Total Dioxin/Furan TEQ (ng TEQ/kg)			
Factor	**Color**	**Count**	**Minimum**	**Maximum**	**Mean**	**St. Dev.**
1	Blue	41	1.3	48.6	12.2	10.8
2	Red	44	1.7	98.9	24.7	17.3
3	Yellow	39	2.3	318	24.6	48.6
Mixed Samples	Black	77	2.7	62.5	21.3	13
Total		**196**	**1.2**	**318**	**21.1**	**25.4**

Table 6. Fractional Contribution of Factors 1, 2, and 3 in Port and City of Olympia Storm Drain Solids

Sample ID			Date	TEQ	Factor 1	Factor 2	Factor 3
City of Olympia	East Bay	CB 8515	2/13/2014	12.1	44%	56%	0%
		CB 7937	2/13/2014	53.1	51%	49%	0%
		CB 7812	2/13/2014	39.2	32%	65%	4%
		CB 12461	2/13/2014	20	42%	55%	3%
		CB 8755	2/13/2014	855	44%	56%	0%
	West Bay	CB 10163	2/13/2014	29.1	50%	50%	0%
		CB 10171	2/13/2014	22.4	47%	44%	9%
		CB 10906	2/13/2014	20.8	49%	51%	0%
Port of Olympia		A08CB	8/9/2010	164	42%	58%	0%
			1/26/2012	157	50%	50%	0%
			12/23/2013	54.8	43%	57%	0%
		A02CB	8/9/2010	1960	17%	83%	0%
			1/26/2012	257	33%	67%	0%
			12/23/2013	1530	30%	70%	0%
		B27CB	8/9/2010	2020	22%	75%	3%
			1/26/2012	438	36%	61%	3%

Appendix A

Budd Inlet
Technical Memorandum

Technical Memorandum

To: Washington State Department of Ecology
300 Desmond Drive SE
Lacey, WA 98503

From: NewFields
115 2nd Ave N, Suite 100
Edmonds, WA 98020

Date: January 17, 2014

Subject: Budd Inlet Sediment Chemometrics - Data Screening

In preparation for performing a chemometric assessment of Budd Inlet sediment dioxin/furan congener data, the usability of available and relevant site data was evaluated. This memo describes the data selection criteria, the data screening process, and the identification of any data anomalies. With the exception of one study (Anchor 2013a), all data evaluated were accessed through Ecology's Environmental Information Management (EIM) database, which was used as a tool to query and download existing data. While the data identified in this memo will be utilized for chemometric evaluation, further analysis may deem some of these data unfit for the chemometric process.

1.0 Existing Dioxin/Furan Data

Data evaluation required identifying all sample locations within Budd Inlet and the surrounding watershed that included dioxin/furan congener results. Samples collected within Capitol Lake were included, as well as nearby upland samples. Tissue samples were not included, as metabolism can alter the dioxin/furan congener profile between sediments and receptor organisms. Only one study (EIM Study_ID BERA0003) exclusively contained tissue samples.

The studies reviewed and their associated samples are listed in Table 1. Locations of these samples are displayed in Figures 1 through 4. Figures 1 and 2 present the dioxin/furan sampling locations by EIM Study_ID for the full spatial extent and a more detailed view of the southern portion of Budd Inlet, respectively. Figures 3 and 4 present the depth interval of sample collection for both the full spatial extent and detailed view of the southern portion of Budd Inlet, respectively.

Complete analytical results for these studies were downloaded from EIM and were subsequently reviewed relative to the dates of sample collection, sample depths, data validation levels, and detection limits. Short narratives of each study are presented below.

Investigation Report Port of Olympia Budd Inlet Sediment Site

In 2013, Anchor QEA conducted an investigation of sediment contamination profiles throughout Budd Inlet. This was the only study where chemistry data was not available from EIM. Instead, data was extracted from the tables in the draft investigation report (Anchor 2013a). A total of 65 surface and 132 subsurface sediment samples were collected throughout Budd Inlet for this investigation. These newly collected samples were combined with existing data to carry out a chemometric evaluation of dioxin/furan congeners (Anchor 2013b).

Relatively few congeners were qualified as non-detects, but many were qualified as estimated maximum possible concentration (EMPC) values. An EMPC qualifier indicates that the target congener did not meet all the criteria for a positive identification. EMPC results were typically elevated above the target method reporting limits (MRLs). A possible treatment for EMPC data is suggested below in Section 2.0. Approximately 50 percent of the collected samples were also analyzed for SMS chemicals of concern. All samples were analyzed for TOC and particle size.

Phase II Environmental Site Assessment at Washington Department of Fish and Wildlife (WDFW) Parcels A, B, and C

These three upland studies were submitted separately into EIM, but were collected using the same methodologies. All of the soil samples were collected between October 23 and December 17, 2012. Parcel A consists of 15 subsurface soil sample intervals from five discrete locations. Parcels B and C consists of 17 and 16 subsurface sample intervals, respectively, from six discrete locations. All non-detects were reported at the MRL at values less than 1 ng/kg. However, all "J" qualified results and some "B" qualified results were also reported at the MRL. For a given congener, the MRLs used for the J and B results were higher than the MRLs used for the non-detect results. TOC results were available for select sample intervals.

Budd Inlet and Oakland Bay Dioxin Study

This study includes sediment samples collected both within Budd Inlet and Oakland Bay during June 2011. Surface sediment samples were collected at 25 discrete locations. The 0-10 cm interval was sampled at all 25 locations. The 0-2 cm interval was sampled from collocated grabs at 6 of these locations, for a total sample count of 31. Dioxin/furan method detection limits (MDLs) were less than 1 ng/kg for all non-detected congeners. In addition to dioxin/furan congener results, both grain size and total organic carbon (TOC) results were available for all samples.

West Bay Marina Remedial Investigation

The West Bay Marina RI included results from a wide range of matrices including upland soil, groundwater, marine sediment, and marine sediment porewater. However, dioxin/furan congeners were only analyzed in 2 sediment and 13 soil samples. The soil samples consisted of seven surface samples collected from either 0-7.6 cm or 0-0.25 ft, and four subsurface samples collected no deeper than 2.1 ft. Depth intervals were not included for the two samples collected from January 2010. The sediment samples were collected from the top 0-10 cm. TOC and grain size results were available for the sediment sample, along with many other SMS chemicals of concern.

Non-detects for the sediment and soil samples collected in 2011 and 2012 were reported at values below the listed MRL for each result. It is unclear what these values represent. Non-detects for the two soil samples collected in 2010 were reported at the practical quantitation limit (PQL), which was as high as 5 ng/kg for some congeners. Of these two samples, only WB-018 had any non-detect results.

Port of Olympia Berth 2 & 3 Interim Action Cleanup Sampling

Sediment samples in this study were collected during three sampling periods. Sixteen collocated surface and subsurface samples collected in September 2008 were classified as pre-dredge sampling. Surface sample intervals range from 0-12 inches to 0-24 inches for this sampling period. Surface sediment samples from 0-10 cm were collected in February and March of 2009. The four samples from February were classified as post-dredge sampling, and the eleven samples from March were classified as post-cover sampling. Though further evaluation is needed, it is possible that only the pre-dredge samples will be used as reference conditions for the chemometric analysis.

It is not clear whether the non-detects were the MRLs or the MDLs. Identical MRL and MDL values were listed for non-detects in the EIM download. None of the reported values for non-detects exceeded 0.3 ng/kg. Non-detects may be an issue with four of the post-cover samples. TOC and particle size were also analyzed with each of the samples.

Percival Landing Redevelopment Project

This dredged material characterization consists of collocated surface and subsurface samples collected at three locations. The depth intervals were not consistent. Only three congeners were non-detects, and all non-detect results were less than 0.3 ng/kg. It is unknown whether these values were reported at the MDL or MRL.

West Bay of Budd Inlet Sediment Characterization Study: Berths 2 & 3

This 2007 sediment characterization includes 13 surface and 10 subsurface sediment samples. Surface and subsurface samples are often collocated. Surface sample depths were most commonly collected from the 0-2 ft interval, but some samples were collected as deep as 0-3 ft or 0-4 ft. TOC and particle size were reported for all but three of the surface samples. Non-detects were reported at the PQL, and the majority of non-detect values were below 0.5 ng/kg. It is likely that sampling locations for this study were resampled and subsequently dredged as part of the *Port of Olympia Berth 2 & 3 Interim Action Cleanup Sampling* conducted in 2008 and 2009.

Hardel Plywood Contaminated Site Investigation (C396_Hardel EIM Results)

Three surface sediment samples (0-10 cm) were analyzed for dioxin/furan congeners and a wide range of SMS chemicals of concern from nearshore sediments at the Hardel site. No results were qualified as non-detects. However, PQL values were listed with each of the reported results. Results from several dioxin/furan congeners matched the reported PQLs suggesting that these results were non-detects. TOC and particle size were reported for each sample.

Budd Inlet Sediment Characterization

The Budd Inlet baywide sediment investigation was conducted by Ecology to determine the nature, extent, and possible sources of dioxin/furan contamination in sediments. Samples collected during this study were used to evaluate the vertical and spatial extent of dioxin/furan congeners in the federal navigation channel and Port of Olympia berthing area, as well as measuring uptake by ecological receptors. In addition to the dioxin/furan chemical evaluation, SMS chemicals of concern were measured in sediments near potential source areas. TOC and particle size data is available for all samples.

A total of 52 marine surface sediment samples were collected and analyzed for dioxin/furan congeners from the 0-10 cm interval, and an additional two were collected from 0 to 1 ft. Forty five subsurface core intervals were analyzed. All cores were split into one foot increments prior to analysis. Two freshwater samples from Capitol Lake were also analyzed. Though it was listed that non-detects were reported at the MRL, the values were low, suggesting MDLs were instead used. Tissue data from clams, crabs, and flatfish were also collected during this characterization but were excluded from the current data summary.

Solid Wood Inc. (West Bay Park) RI/FS

Data from this EIM download included dioxin/furan congener results from three sampling periods. Four soil samples were collected in February and March of 2008. These were subsurface samples, but the same number is listed for the upper and lower depth in EIM so the exact interval is not known. Non-detects were reported at the PQL and were high, with a minimum of 4.6 ng/kg. Ten marine sediment samples were collected in June 2008. As with the soil samples the same number was reported for the upper and lower depth. TOC and particle size results were available for these samples. Non-detects were reported at a PQL less than 1 ng/kg. Eleven more soil samples were collected in September 2009. No upper or lower depth is listed for these samples. All non-detect results were less than 1.2 ng/kg.

Solid Wood Inc. (West Bay Park) Rail Spur Phase II Environmental Site Assessment

This site assessment includes results for seven sediment and three soil samples which were collected and analyzed for dioxin/furan congeners in February 2007. No value was included for the upper or lower depth interval for any of the samples. Every congener result for this study was qualified, most as non-detects. Only some of the non-detect data were accompanied by a MRL value. It was assumed that any non-detect result that had an associated MRL was an actual non-detect, and that the remaining results were not intended to have qualifiers. MRLs for this study were high.

East Bay Redevelopment Site

This study included results for seven groundwater samples from two locations collected between July 2008 and December 2009. Nearly all reported results for each sample were non-detects, therefore this study is not listed in Table 1.

Olympia Harbor Supplemental Dioxin Study

This supplemental investigation was conducted to characterize nearly 460,000 cubic yards of material for potential open water disposal. Twenty-four surface and 17 subsurface cores were collected and analyzed to characterize the navigational channel. Non-detect results were all less than 0.65 ng/kg. TOC and particle size results were available for most samples.

Cascade Pole Longterm Groundwater Compliance Monitoring and Sediment Sampling

This dataset includes the first two rounds of post-remedy monitoring conducted at the Cascade Pole Facility. Depth intervals were not included for the 20 samples collected in 2007. Also, all non-detect results from 2007 were reported at the listed PQL. The 2012 monitoring included five surface and 15 subsurface samples. Non-detects in the 2012 data were reported below the listed MRL. All reported non-detect values were below 1.6 ng/kg, but most were below 0.4 ng/kg.

Cascade Pole Sediment Confirmation Monitoring

Only one sample collected in September 2003 was reported for this study. The sample was collected from a 0-4.3 ft interval. Most of the reported congeners were non-detects.

Budd Inlet Dioxin & Tissue Monitoring – Post Sediment Remediation – Cascade Pole

This study included nine surface sediment samples ranging to a maximum lower depth of 30 cm. The samples were collected in 2002, and the data was included in EIM as a legacy to the SEDQUAL database. It is unclear whether the non-detects were reported as MRLs or MDLs. The non-detect values were high, suggesting MRLs. Most of the congeners from these samples were non-detects.

Cascade Pole Remedial Investigation, Sediment Toxicity Assessment

The Cascade Pole RI includes samples collected in 1990 and 1991 from the Cascade Pole Site and reference locations within Budd Inlet. Samples were labeled surface or subsurface, but no upper or lower depth information was provided. Fifteen surface and subsurface samples were collected and analyzed. Two congeners, 1,2,3,7,8-PeCDD and 1,2,3,4,6,7,8-HpCDF, were not included in the analysis. Even without these congeners, the TEQ concentrations in many of these samples would be considered high by current standards. It is likely that much of this sampled area has been remediated in the last 2 decades.

2.0 Data Screening

Results of the above studies constitute the relevant and available dioxin/furan congener data for Budd Inlet, Capitol Lake, and their watersheds. Dioxin/furan data from the reviewed studies were mostly recent, with all but one study having been conducted since 2002. The only exception was the samples collected from sediments near the Cascade Pole facility in 1990 and 1990 (Study_ID CASCADRI).

At a minimum, data from all but one study reviewed underwent a Level 2 QA assessment (Table 1). The Level 2, or QA1 data validation is a summary of laboratory performance based on its quality control forms but includes no, or minimal, raw data review.

Data from the *Solid Wood Inc. (West Bay Park) Rail Spur Phase II Environmental Site Assessment* study (Study_ID FS94656838Ph2) only underwent a Level 1 QA assessment. The depth intervals of the sediment samples from this study were not specified, and more recent samples appear to have been collected in the vicinity. This study may be excluded from analysis.

Review of the data did not indicate that any additional studies summarized in this memorandum should be screened from further evaluation. However, further analysis may demonstrate that individual samples do not adequately

represent the distribution of dioxin/furan contamination in Budd Inlet. Some possible reasons why samples may be excluded from chemometric analysis include:

- Elevated MDLs/MRLs that skew the congener profile towards non-detected congeners.
- Samples located in areas that have undergone maintenance dredging or cleanup remedies. Samples from the following Study_IDs may be affected: OlyMarineTerminal08, PERLA08, Budd Inlet W Bay 07, OHPSDO6, and CASCADRI.
- Samples with an Unknown Interval from Table 1
- Samples from CACADRI which only have 15 reported congeners.

Although some of the above criteria may remove data from the chemometric un-mixing analysis, the results can still be further evaluated for comparison purposes (see Section 3.0). The same is true of any soil samples present in Table 1.

MDLs and MRLs for dioxin/furan congeners are generally low for non-detected congeners, and therefore are not likely to drive pattern identification. However, steps will be taken early in the chemometric process to determine the importance of non-detects to a sample's toxic equivalency (TEQ) and its congener profile. This may be evaluated by looking at both the maximum number of non-detected congeners per sample and the minimum acceptable dioxin/furan TEQ.

EMPC values will be evaluated in the same manner as non-detects. EMPCs were commonly reported in the data from Anchor 2013a. In most other studies, EMPCs are given a K qualifier, which is considered a non-detect during most Level 3/4 data validations.

Determination of these screening limits will require further evaluation of the data using chemometric software.

3.0 Data Utilization

Dioxin/furan data from the reviewed studies will be used for one of two purposes in the chemometric process, either for sediment profile "un-mixing" (source identification) or as profiles in a comparison library. Only marine and intertidal sediment samples, both surface and subsurface, will be used for chemometric source analysis and identification. While surface sediment data generally consists of the 0-10 cm interval, deeper depth intervals may also be considered.

Currently, the total dioxin/furan congener dataset consists of 256 surface and 247 subsurface sediment samples (Table 1). These numbers will change as samples are removed for QA reasons, samples with larger surface depth intervals (0-3 ft) are reclassified as subsurface, and some samples from the dataset are found to be representative of source profiles for the comparison library.

These sediment data will be compiled into a project database with a single coordinate system and consistent concentration units. Additional sample parameters such as grain size and TOC will also be maintained in the database.

The remaining usable dioxin/furan data from upland samples will be added to NewFields' existing library of congener profiles. Comparison between data-derived Budd Inlet sediment profiles with library profiles will aid in the identification of potential dioxin/furan sources.

The library currently consists of dioxin/furan congener profiles from a wide range of potential source materials, industrial samples, and environmental samples. In addition, prior chemometric analysis of Budd Inlet sediments by Anchor QEA has already identified 14 samples that were believed to be representative of congener profiles from four distinct sources within Budd Inlet (Anchor 2013b). Eight samples were considered representative of the East Bay Redevelopment Site, four samples were representative of Cascade Pole, and one sample each was representative of Hardel Mutual Plywood and Reliable Steel. Congener profiles from these four sources will be added to the library as part of the chemometric evaluation.

4.0 References

Anchor. 2013a. Draft Investigation Report Port of Olympia Budd Inlet Sediment Site, Prepared for the Port of Olympia, Olympia, WA. Prepared by Anchor QEA, Seattle, WA. December 2013.

Anchor. 2013b. Chemometric Source Investigation Port of Olympia Budd Inlet Sediment Site, Prepared for the Port of Olympia, Olympia, WA. Prepared by Anchor QEA, Portland, OR. December 2013.

Table 1. Summary of Existing Dioxin/Furan Congener Data in Budd Inlet.

Study Name	EIM Study ID	EIM Data Entry Review Status	Study QA Level Assessment	Field Collection Start Date†	Field Collection End Date†	Marine/Intertidal Sediment			Freshwater Sediment	Upland Soil		
						Surface Samples	Subsurface Samples	Unknown Interval	Surface Samples	Surface Samples	Subsurface Samples	Unknown Interval
Investigation Report Port of Olympia Budd Inlet Sediment Site	Not in EIM	Not Reviewed	Level 4	25-Feb-13	14-Mar-13	65	132	--	--	--	--	--
Phase II Environmental Site Assessment at Washington Department of Fish and Wildlife Parcel A, B, and C in Olympia (600 Capitol Way North)	G1300114 - Parcel A	Not Reviewed	Level 2	17-Dec-12	17-Dec-12	--	--	--	--	--	15	--
	G1300114 - Parcel B	Not Reviewed	Level 2	24-Oct-12	24-Oct-12	--	--	--	--	--	17	--
	G1300114 - Parcel C	Not Reviewed	Level 2	23-Oct-12	24-Oct-12	--	--	--	--	--	16	--
Budd Inlet and Oakland Bay Dioxin Study	BuddOakDioxins	Reviewed	Level 3	1-Jun-11	21-Jun-11	30	--	--	--	--	--	--
West Bay Marina Remedial Investigation, Olympia, WA	AODE5272	Not Reviewed	Level 4	19-Aug-09	28-Feb-12	2	--	--	--	9	4	--
Port of Olympia: Berth 2 & 3 Interim Action Cleanup Sampling to Characterize Pre-Dredge, Post-Dredge, and Post-Cover conditions.	OlyMarineTerminal08	Not Reviewed	Level 5	25-Sep-08	16-Mar-09	23	8	--	--	--	--	--
Percival Landing Redevelopment Project - Antidegradation Evaluation, DY10	PERLA08	Not Reviewed	Level 2 (QA1)	14-Feb-08	14-Feb-08	3	3	--	--	--	--	--
West Bay of Budd Inlet - Sediment Characterization Study: Berths 2 and 3 Interim Action Project.	Budd Inlet W Bay 07	Not Reviewed	Level 4	26-Aug-07	29-Aug-07	13	10	--	--	--	--	--
C396_Hardel EIM Results.	Budd Inlet Hardel 07	Not Reviewed	Level 2 (QA1)	13-Aug-07	13-Aug-07	3*	--	--	--	--	--	--
Budd Inlet Sediment Characterization	BUDD07	Not Reviewed	Level 4	2-Apr-07	15-Jun-07	54	45	--	2	--	--	--

Study Name	EIM Study ID	EIM Data Entry Review Status	Study QA Level Assessment	Field Collection Start Date†	Field Collection End Date†	Marine/Intertidal Sediment			Freshwater Sediment	Upland Soil		
						Surface Samples	Subsurface Samples	Unknown Interval	Surface Samples	Surface Samples	Subsurface Samples	Unknown Interval
Solid Wood Inc. (West Bay Park) RI/FS, Olympia, WA. Agreed Order # DE-08-TCP SR-5415	WB1577RIFS	Not Reviewed	Level 3	9-Feb-07	25-Oct-12	9*	2*	--	--	--	4*	11*
Solid Wood Inc. (West Bay Park) Rail Spur Phase II Environmental Site Assessment, Olympia, WA. Agreed Order # DE-08-TCP SR-5415	FS94656838Ph2	Not Reviewed	Level 1	8-Feb-07	9-Feb-07	--	--	6*	--	--	--	3*
Olympia Harbor - Supplemental Dioxin Study, DY07	OHPSD06	Not Reviewed	Level 2 (QA1)	7-Mar-06	10-Mar-06	24	17	--	--	--	--	--
Cascade Pole Longterm Groundwater Compliance Monitoring and Sediment Sampling, Olympia, WA	FS1385	Not Reviewed	Level 5	24-Jun-05	1-Oct-13	5	15	20*	--	--	--	--
Cascade Pole Sed Confirm Monitoring 2003	CASCON03	Not Reviewed	Level 4	10-Sep-03	10-Sep-03	1	--	--	--	--	--	--
Budd Inlet Dioxin & Tissue Mon-Post Sediment Remediation - Cascade Pole Company (CPC)	CASMON03	Not Reviewed	Level 2 (QA1)	11-Apr-02	10-Jun-02	9	--	--	--	--	--	--
Cascade Pole Remedial Investigation, Sediment Toxicity Assessment	CASCADRI	Not Reviewed	Level 4	6-Dec-90	14-Aug-91	15*	15*	--	--	--	--	--
Total						**256**	**247**	**26**	**2**	**9**	**56**	**14**

Notes:

†represents the start and end date output from EIM, not necessarily the time period for dioxin sampling

*sample depth not defined

Level 1 - Data neither Verified nor Assessed for Usability

Level 2 - Data Verified (also referred to as QA1)

Level 3 - Data Verified and Assessed for Usability

Level 4 - Data Verified and Assessed for Usability in a Formal Study Report

Level 5 - Data Verified and Assessed for Usability in a Peer-Reviewed Study Report

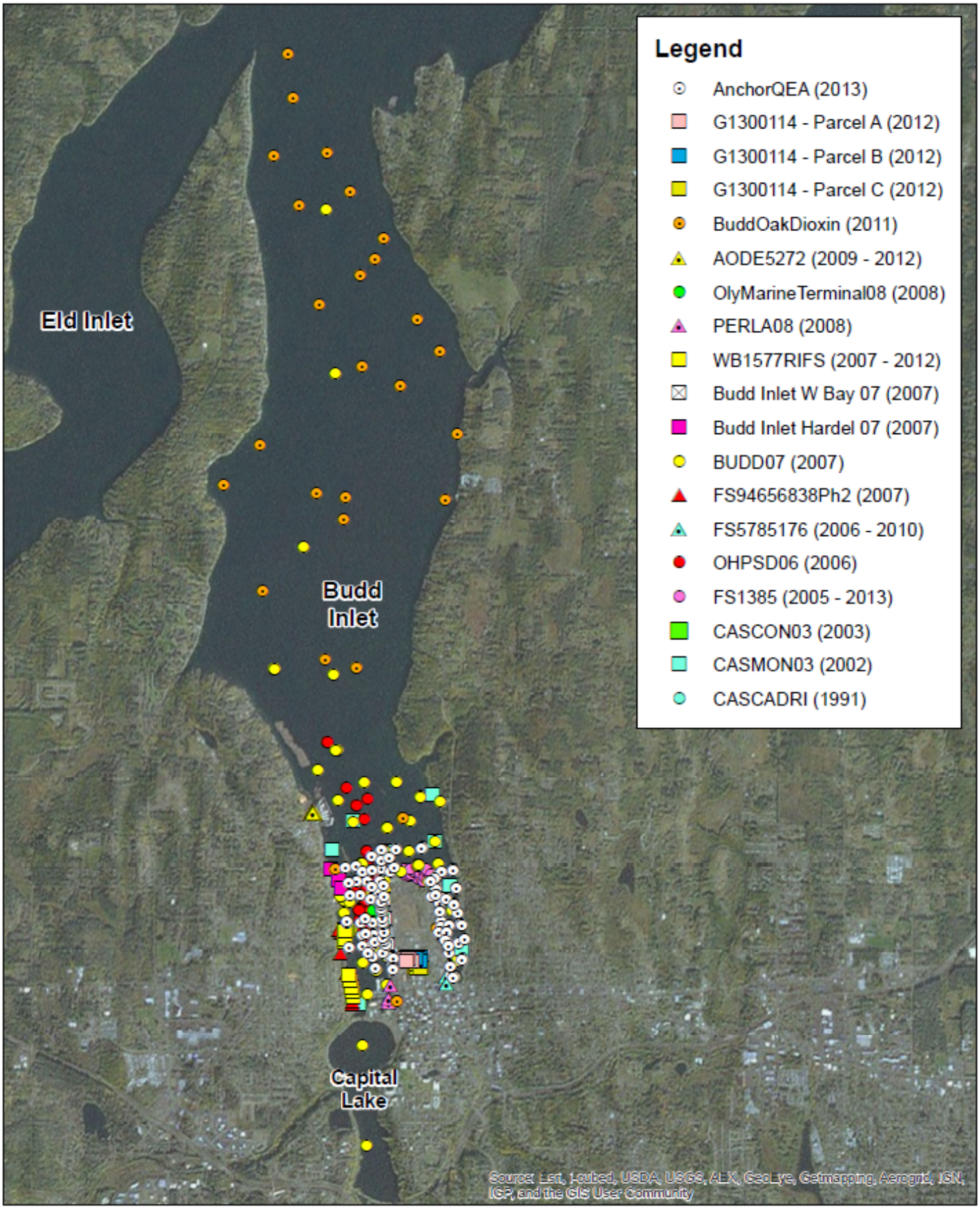

Figure 1. Budd Inlet Studies of Dioxins/Furans - Full Extent

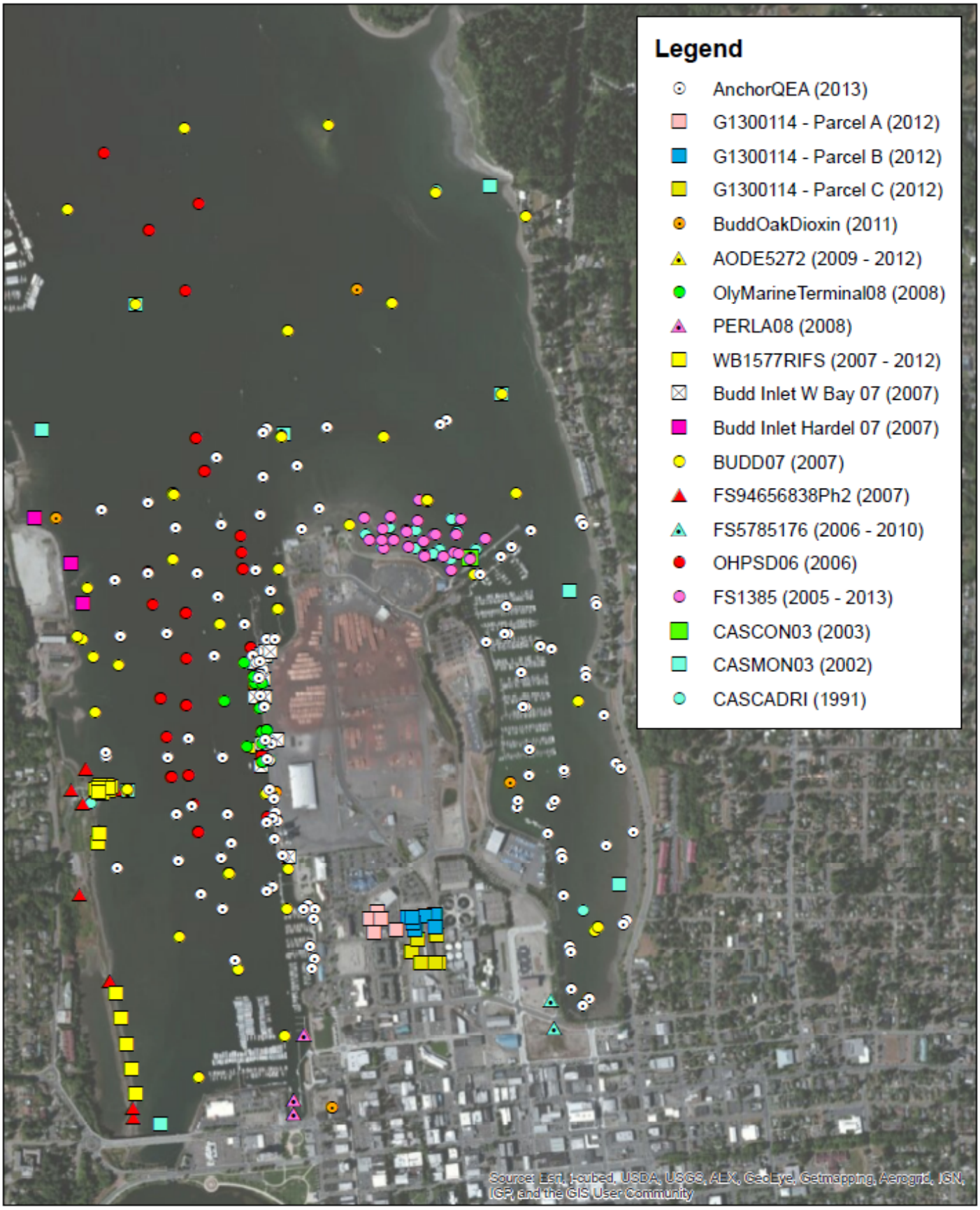

Figure 2. Budd Inlet Studies of Dioxins/Furans - Southern Inlet

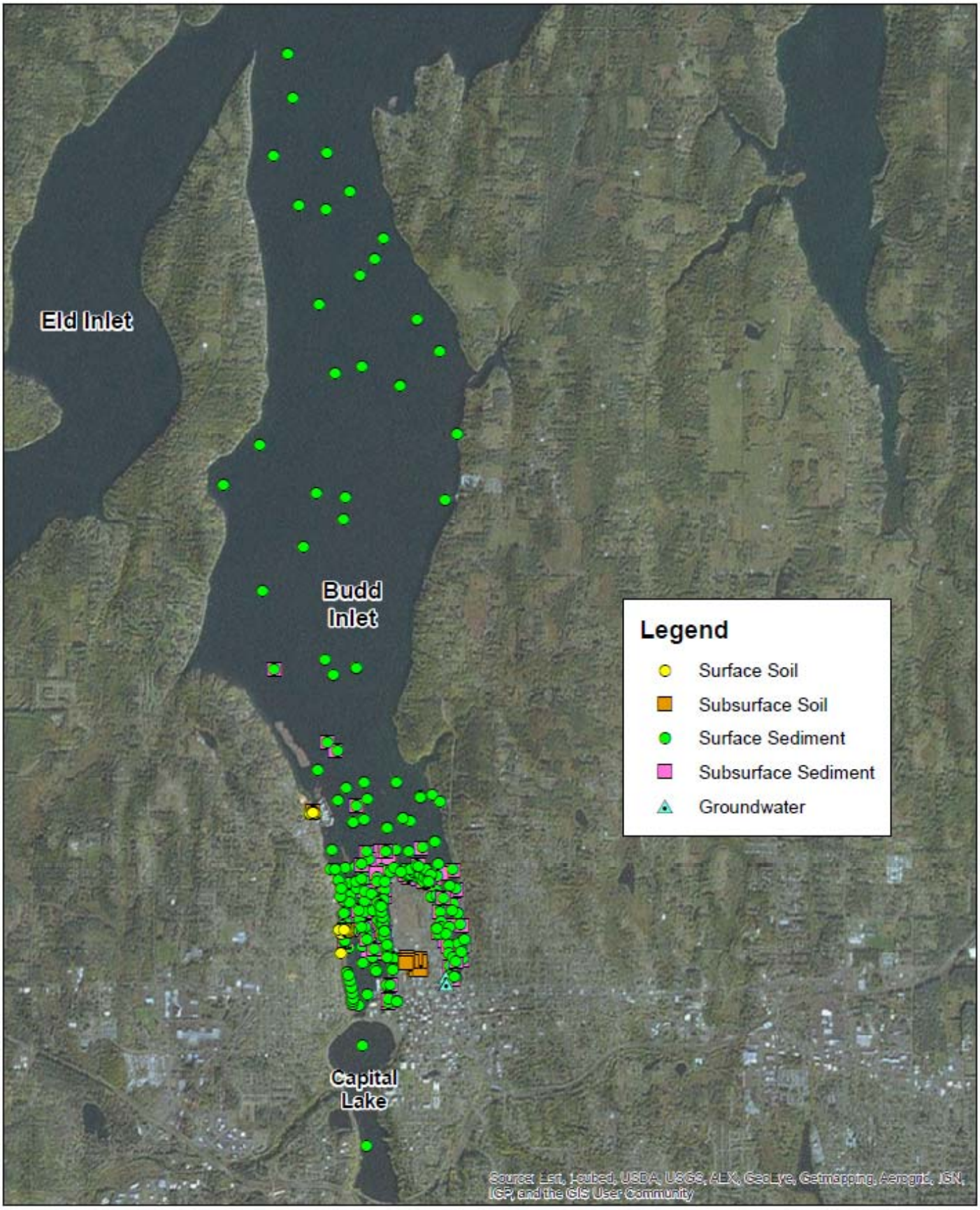

Figure 3. Budd Inlet Dioxin/Furan Samples - Full Extent

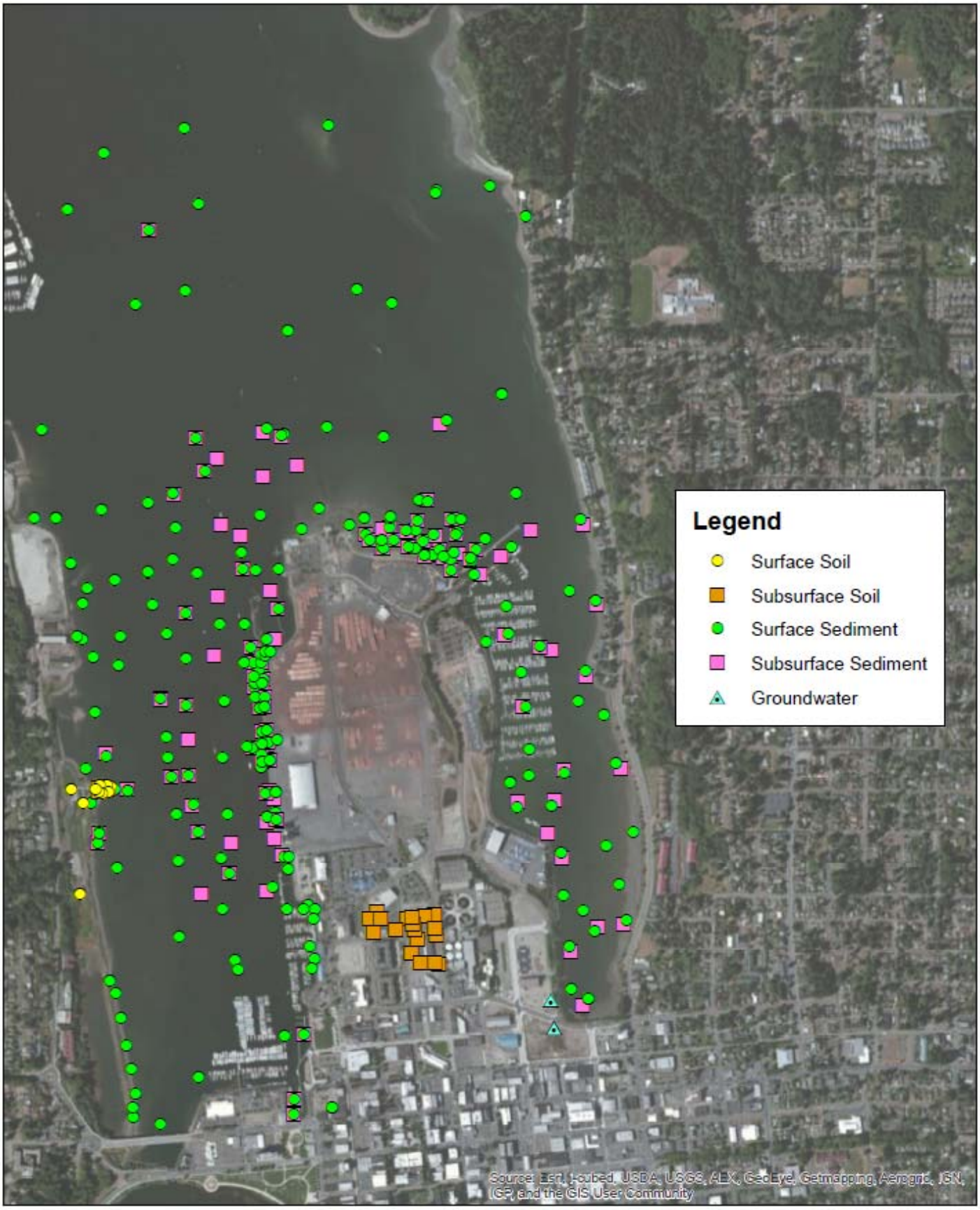

Figure 4. Budd Inlet Dioxin/Furan Samples - Southern Inlet

Appendix B

Chemometric Evaluation of Budd Inlet Dioxin/Furan Data

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Figures

Tables

List of Acronyms

ALS	Alternating Least Squares
dioxin	polychlorinated dibenzo-*p*-dioxin
DMMP	Dredged Material Management Program
EIM	Environmental Information Management
E & E	Ecology and Environment, Inc.
FWEC	Foster Wheeler Environmental Corporation
furan	polychlorinated dibenzofuran
HCA	Hierarchical Cluster Analysis
HFB	hog fuel boiler
ng/kg	nanograms per kilograms
OCDD	octaclorodibenzodioxin
PCA	principal components analysis
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
TEF	toxicity equivalency factor
TEQ	toxic equivalency

1.0 Introduction

The chemometric evaluation process involves extracting information from chemical systems by data-driven means, typically through the application of multivariate statistics. When a data analysis scenario includes the collection of more than one or two measurements, interpretation of the results in a univariate sense can become tedious, if not misleading. Often these measurements are correlated rather than being completely independent. Univariate analysis is incapable of detecting these correlations and can misrepresent trends and relationships that result from correlation. A multivariate approach utilizes tools and techniques from mathematics and statistics to guide interpretation of complex and potentially correlated data.

In this chemometric study, multivariate methods were applied to evaluate important patterns in the distribution of polychlorinated dibenzo-p-dioxins (dioxins) and dibenzofurans (furans) congeners obtained from the chemical analysis of Budd Inlet sediment samples. The chemometric process consisted of the following steps:

1. Data compilation and screening;
2. Data scaling;
3. Multivariate chemical source unmixing; and
4. Source interpretation.

This appendix provides a more detailed description of these chemometric analysis steps than is found in the report. The results of this evaluation revealed several patterns apparent in the sediments of Budd Inlet that suggest dioxin/furan contributions from specific source types.

2.0 Data Compilation and Screening

2.1 Data Compilation

The data used for the chemometric evaluation consisted of analytical results for the 17 priority dioxin/furan congeners from samples collected within Budd Inlet and the surrounding watershed. Tissue samples were not included for evaluation, as metabolism can alter the dioxin/furan profile between sediments and receptor organisms.

The majority of the evaluated dioxin/furan data were accessed through Ecology's Environmental Information Management (EIM) database, which was used as a tool to query and download existing data. Complete analytical results for these studies were downloaded from EIM and were subsequently reviewed relative to the dates of sample collection, sample depths, data validation levels, and detection limits (see Appendix D of the study report). The relevant studies used in the analysis are presented in Table 2 of the study report.

The following data not present in EIM were also evaluated due to their potential importance in understanding dioxin/furan sources to Budd Inlet:

- Priest Point Park Sediment Sampling Project (Thurston County 2010) – this report presented the analytical results of a series of intertidal sediment samples collected in the vicinity of Priest Point Park. The study was conducted with the intent of determining whether human health risks due to dioxin/furan contamination were present in nearshore sediments.
- Infrastructure Interim Action Report for East Bay Redevelopment Site (Pioneer Technologies 2010) – This document includes a summary of recent excavation activities at the East Bay Redevelopment Site. Subsamples of the excavated soil were analyzed for dioxin/furan contamination.
- Port of Olympia Source Control Investigations (Anchor QEA 2012) – This investigation was conducted to evaluate concentrations of dioxin/furan congeners in storm drain solids collected from Port of Olympia storm drains near Berths 1 and 2. Additional Port and City of Olympia storm drain solids data were obtained from Anchor QEA via personal communications.
- Cascade Pole Supplemental Site Investigation Report (Landau Associates 1993) – Some sediment data from the Cascade Pole site was available in EIM as Study ID CASCADRI. However, this data was limited to 15 congeners. The Supplemental Site Investigation Report included data from the early 1990's for all 17 congeners.

Dioxin/furan data from all of the above studies were segregated into two data sets, each used for different purposes during evaluation:

1. *Unmixing Data Set* – consisted of intertidal and subtidal sediment samples from most of the above referenced data. Surface and subsurface samples were included in the data set. This data set was used for dioxin/furan congener unmixing to derive unique chemical profiles. Historical sediment sampling results from the Cascade Pole site were not included for unmixing, but were part of the *Comparison Data Set*.

2. *Comparison Data Set* – consisted of the upland soil samples and historical sediments from Cascade Pole (all samples that may represent sources to Budd Inlet sediments). This data set was added as a subset to the existing dioxin/furan source library used for comparative purposes in the *Port Angeles Harbor Sediment Dioxin Source Study* (NewFields 2013). The combined source library was used to evaluate the likely source types contributing to profiles of the *Unmixing Data Set*.

2.2 Data Screening

The congener profile is a representation of the abundance of each dioxin/furan congener in a sample relative to the total for that sample. Chemometric analysis is used to simultaneously evaluate and compare congener profiles across all samples in a given data set.

When samples have numerous non-detected congeners, or when non-detected congeners contribute to a large percentage of the dioxin/furan toxic equivalency (TEQ), these profiles become less defined and can skew the analysis. For these reasons it is important to screen samples from chemometric analysis whose profiles are biased by non-detects. In addition, samples with known biases, such as those collected during post cleanup monitoring, should not be included in the unmixing analysis.

Dredging along the Port of Olympia Berths 2 & 3 was conducted in February 2009 for the first time in nearly 30 years (Anchor QEA 2009; EIM Study ID OlyMarineTerminal08). Samples collected prior to dredging were included in the data set, as they represented the historical record of deposition along the berths that likely represented a unique source or pathway. Post dredge samples, collected prior to the placement of a clean sand cover over the dredged area, were also included as they were found to contain elevated dioxin/furan concentrations. Since this cover represented known non-native material, no post-cover samples were used in the chemometric analysis.

Similarly, samples collected as part of the sediment cap monitoring at the Cascade Pole site were not incorporated into the analysis (Landau Associates 2014; EIM Study ID FS1385). These samples were collected from the clean, non-native fill, placed within the Cascade Pole cleanup area.

Excluding post cover sampling, the original *Unmixing Data Set* contained 486 samples. The distribution of non-detects across all samples is shown in Figure 1. 2,3,7,8-TCDD was the most frequently non-detected congener, while OCDD was detected in nearly all samples. Samples with frequent non-detected congeners were screened from the *Unmixing Data Set* based on the following criteria:

- Eight or more non-detected congeners; or

- Non-detected congeners contributing to more than 50 percent of the total dioxin/furan TEQ concentration, when non-detected congeners are assigned a value of one-half the detection limit.

Prior to the full chemometric analysis, the congener profiles for samples close to, but not exceeding, the above thresholds were viewed in Excel. Congener profiles of 14 samples showed obvious differences in that they had congener peaks that were not typically present in the remaining samples. Most of these samples had low TEQ concentrations and 4-7 non-detected congeners. These samples were considered to have undue influence from non-detects and were removed as outliers.

A total of 115 samples were removed from the full data set as a result of the non-detect screening. TEQ values for the removed samples were typically low, with an average of 1.25 ng TEQ/kg. Figure 2 shows the distribution of non-detects within the screened *Unmixing Data Set*. The three congeners for which non-detects were most frequent were 2,3,7,8-TCDD (155 samples),1,2,3,7,8,9-HxCDF (49 samples), and 2,3,7,8-TCDF (45 samples).

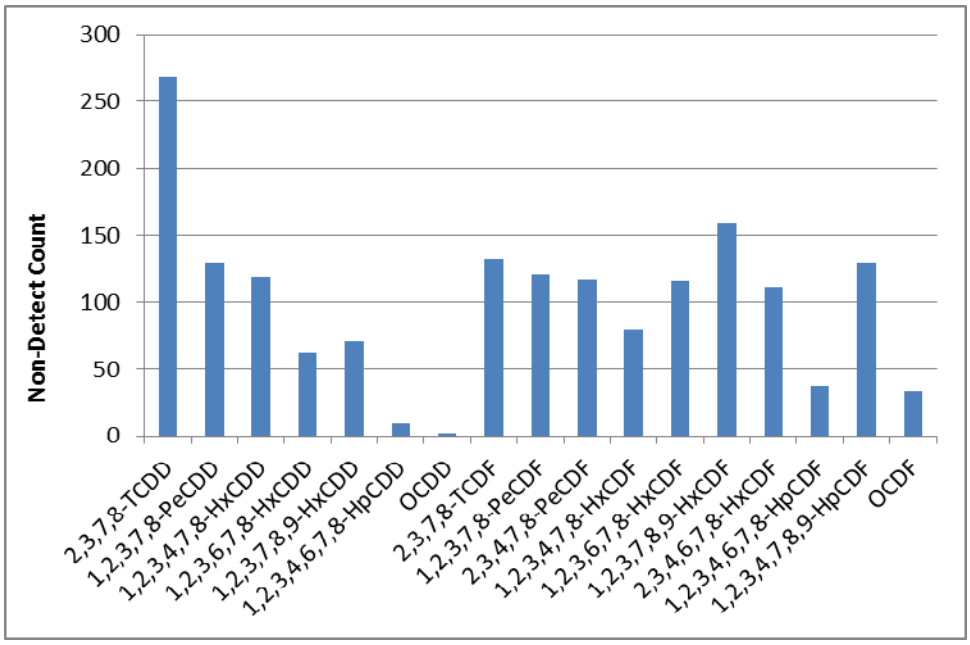

Figure 1. Distribution of Non-detected Congeners within the Complete *Unmixing Data Set.*

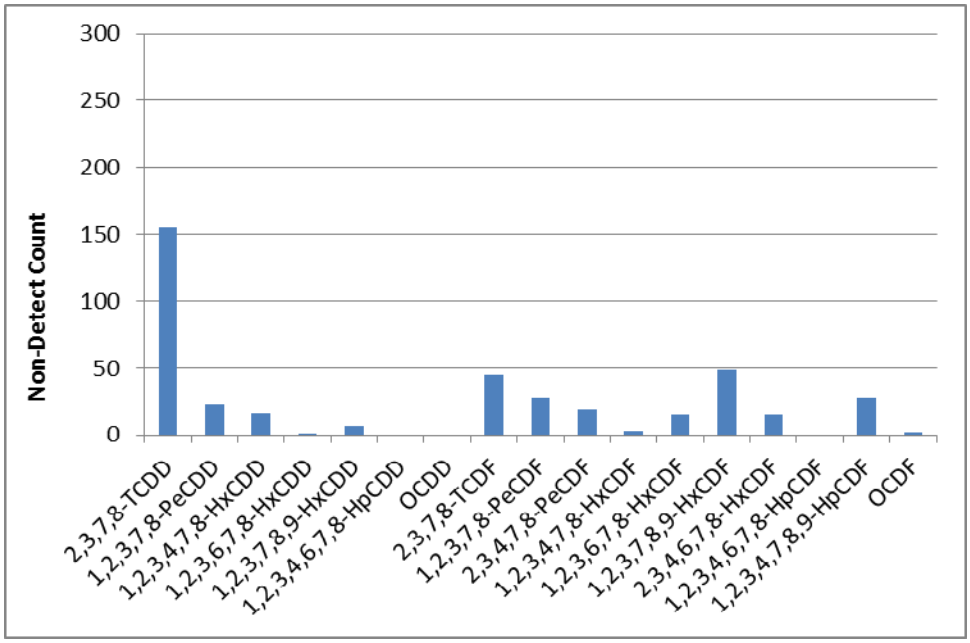

Figure 2. Distribution of Non-detected Congeners within the Screened *Unmixing Data Set*.

3.0 Data Scaling and Normalization

Dioxin/furan sample results were reported from the lab as bulk congener concentrations, in nanograms per kilogram (ng/kg) dry weight. It was typical for certain congeners, such as OCDD, to be present at concentrations many of orders of magnitude greater than other congeners. It was also common for some samples to have concentrations that were orders of magnitude greater than other samples. If multivariate analysis were to be performed on this raw data in which the concentration measurements varied by such large amounts, those samples and congeners with the greatest concentrations would drive the analysis. To allow interpretation of the differences in congener fingerprints, it is customary to transform the variables such that they are all roughly the same order of magnitude. Data scaling controls for the effect of congener specific concentration differences within a sample, and data normalization controls for the effect of differing concentrations between samples.

A subset of the bulk congener data is shown as a line plot in Figure 3. This figure shows the dioxin/furan data of 25 randomly selected samples from the screened *Unmixing Data Set* without any scaling of the congener concentrations. Each trace in this figure presents one sample plotted as a function of congener. Plotted in this way, it is clear that some samples have much higher concentrations than others and that the overwhelming contribution of intensity to each sample comes from OCDD. In this figure the lesser-chlorinated dioxins and furans contribute relatively little intensity. For this reason, concentrations for many of the congeners are not even apparent in Figure 3.

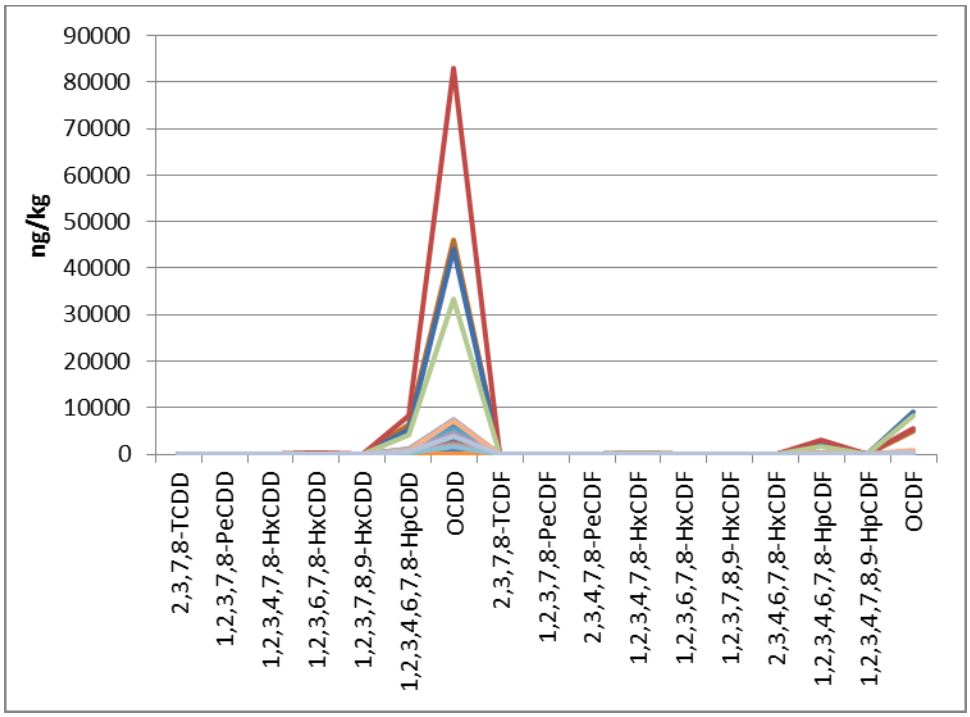

Figure 3. Bulk Congener Profiles of the *Unmixing Data Set* (25 sample subset).

Prior to chemometric analysis, the congener profiles must be transformed through scaling and normalization as to maximize the influence of each sample and each congener. Scaling is done prior to normalization. There are different approaches to accomplish variable scaling; however different methods may not produce equivalent results. Two methods of variable scaling were explored in the Budd Inlet chemometric analysis:

1. Variance-Scaling – each congener is scaled by the standard deviation of the measure across all samples.

2. TEF-Scaling – congener concentrations are scaled to the congener-specific toxicity equivalency factor (TEF) values.

3.1 Variance-Scaling

In Figure 4, the data from Figure 3 have been scaled by the standard deviations of the individual congeners across the set of samples. This is done by calculating the standard deviation for one congener across all samples, and dividing all results for that congener by the standard deviation. The result is that each scaled congener has a variance of 1. There remains variation in magnitude for the different congeners but patterns become more discernible.

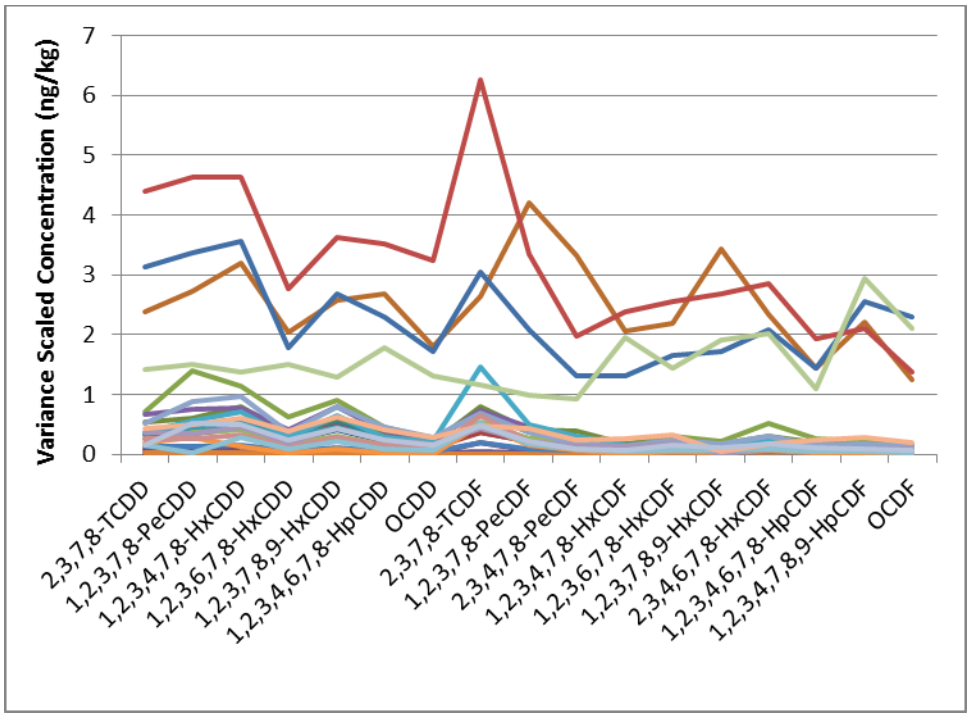

Figure 4. Variance-scaled profiles of the *Unmixing Data Set* (25 sample subset).

It is customary to normalize the data so that variation in absolute concentration between samples is minimized. Although various methods of normalization are used in multivariate statistics, area percent normalization is typical for chromatography data and was used in this study. Normalizing the data involves calculating the sum of all congeners for a given sample, and dividing individual results by this sum. Once normalized, the sum of all congeners for a sample equals 1. Normalization removes the influence of high or low concentration samples from the analysis.

For example, Figure 5 shows area percent normalized data from Figure 4. Scaled and normalized data was used as the input for chemometric analysis.

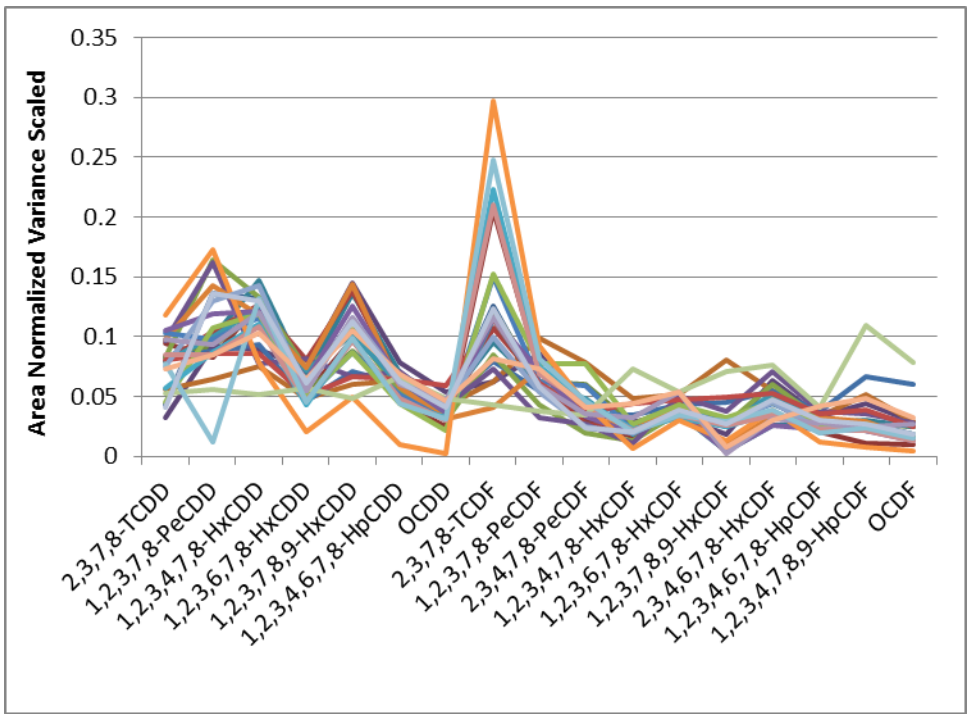

Figure 5. Area-normalized Variance-scaled Profiles of the *Unmixing Data Set* (25 sample subset).

In Figure 5 it can be seen that one of the congeners with the most variability among sample profiles is 2,3,7,8-TCDD. This is one of the congeners most frequently not detected in the data set (Figure 1). This highlights the first of three major drawbacks of variance-scaling:

1. There is a risk that a variable of little importance and of intensities in the noise level will be magnified to the same importance as variables with real, diagnostic signals.
2. The scaling factor is a function of the samples that are included in the calculation and would therefore change if different samples were processed.
3. Because the scaling factors are specific to the data set being scaled, the resulting congener profiles cannot be directly compared to profiles outside of the data set, such as a profile library.

3.2 TEF-Scaling

Because of these variance-scaling shortcomings, the alternative method of TEF-scaling for dioxin/furan congener data has frequently been applied (Lohmann and Jones 1998; Alcock et al. 2002; Hilscherova et al. 2003; E & E and Glass 2011; NewFields 2013). This method of scaling based on congener toxicity relative to 2,3,7,8-TCDD has three distinct advantages over variance-scaling:

1. Scaling factors (congener-specific TEFs) are independent of the samples in the data set being processed.

2. Because the scaling factors can be applied universally to dioxin/furan congener data, analysis results can be compared to profile libraries scaled by the same means.

3. Chemometic analysis of TEF-scaled data identifies dioxin/furan profiles that contribute to a significant portion of sample TEQ. This is useful for decision making, as human health risk, ecological risk, and cleanup criteria are all based on TEQ.

In Figure 6, the data from Figure 3 have been scaled by the TEFs (Table 1). OCDD is no longer the dominant peak due to its low TEF of 0.0003 (Table 1). As with variance-scaling, this initial scaling of the raw concentration data reveals pattern among the different congeners, however there is considerable variation in magnitude between samples due to concentration.

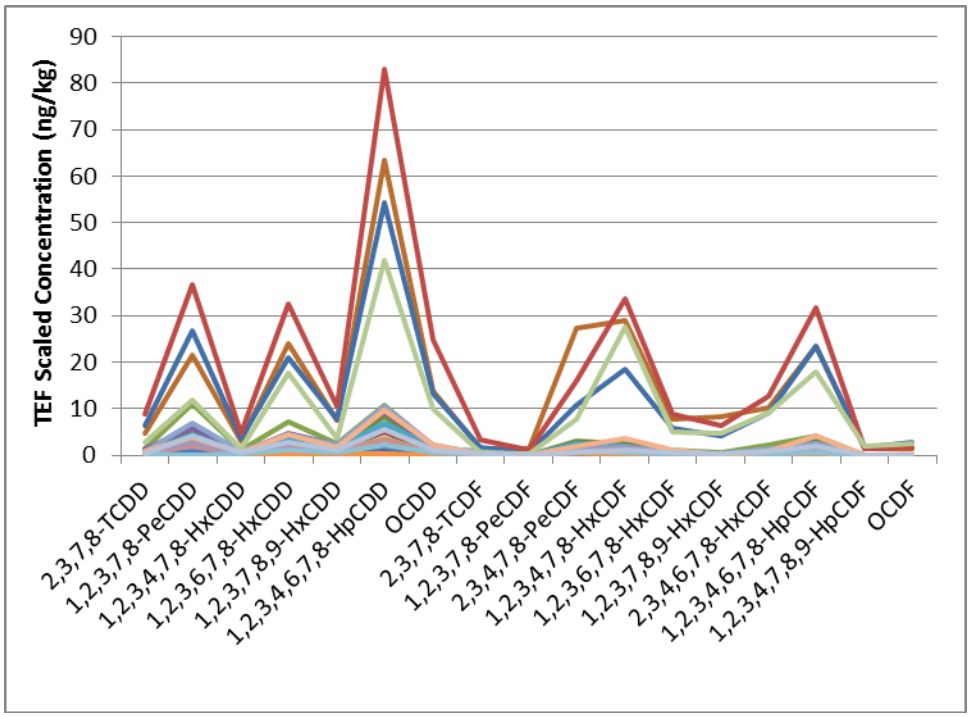

Figure 6. TEF-scaled Profiles of the *Unmixing Data Set* (25 sample subset).

As with the variance-scaled results, further normalization by percent area is performed so that each sample profile has a congener sum of 1 (Figure 7). Because the results in Figure 7 were TEF-scaled and normalized, the values for each congener is a sample's profile is the congener's fractional contribution the sample's total dioxin/furan TEQ. Unlike Figure 5 where sample profile variation was most apparent for frequently non-detected congeners, profile variation in Figure 7 is dominated by frequently detected congeners.

Table 1. Dioxin/Furan Homologue Groups and 17 Congeners of Greatest Concern.

Homologue Group	Congener	Abbreviation	TEF
Dioxins			
Tetrachlorodibenzo-p-dioxins		TCDD	--
	2,3,7,8-tetrachlorodibenzo-p-dioxin	2,3,7,8-TCDD	1
Pentachlorodibenzo-p-dioxins		PeCDD	--
	1,2,3,7,8-pentachlorodibenzo-p-dioxin	1,2,3,7,8-PeCDD	1
Hexachlorodibenzo-p-dioxins		HxCDD	--
	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	1,2,3,4,7,8-HxCDD	0.1
	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	1,2,3,6,7,8-HxCDD	0.1
	1,2,3,7,8,9-hexachlorodibenzo-p-dioxin	1,2,3,7,8,9-HxCDD	0.1
Heptachlorodibenzo-p-dioxins		HpCDD	--
	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	1,2,3,4,6,7,8-HpCDD	0.01
Octachlorodibenzo-p-dioxin	Octachlorodibenzo-p-dioxin	OCDD	0.0003
Furans			
Tetrachlorodibenzofurans		TCDF	--
	2,3,7,8-tetrachlorodibenzofuran	2,3,7,8-TCDF	0.1
Pentachlorodibenzofurans		PeCDF	--
	1,2,3,7,8-pentachlorodibenzofuran	1,2,3,7,8-PeCDF	0.03
	2,3,4,7,8-pentachlorodibenzofuran	2,3,4,7,8-PeCDF	0.3
Hexachlorodibenzofurans		HxCDF	--
	1,2,3,4,7,8-hexachlorodibenzofuran	1,2,3,4,7,8-HxCDF	0.1
	1,2,3,6,7,8-hexachlorodibenzofuran	1,2,3,6,7,8-HxCDF	0.1
	1,2,3,7,8,9-hexachlorodibenzofuran	1,2,3,7,8,9-HxCDF	0.1
	2,3,4,6,7,8-hexachlorodibenzofuran	2,3,4,6,7,8-HxCDF	0.1
Heptachlorodibenzofurans		HpCDF	--
	1,2,3,4,6,7,8-heptachlorodibenzofuran	1,2,3,4,6,7,8-HpCDF	0.01
	1,2,3,4,7,8,9-heptachlorodibenzofuran	1,2,3,4,7,8,9-HpCDF	0.01
Octachlorodibenzofuran	Octachlorodibenzofuran	OCDF	0.0003

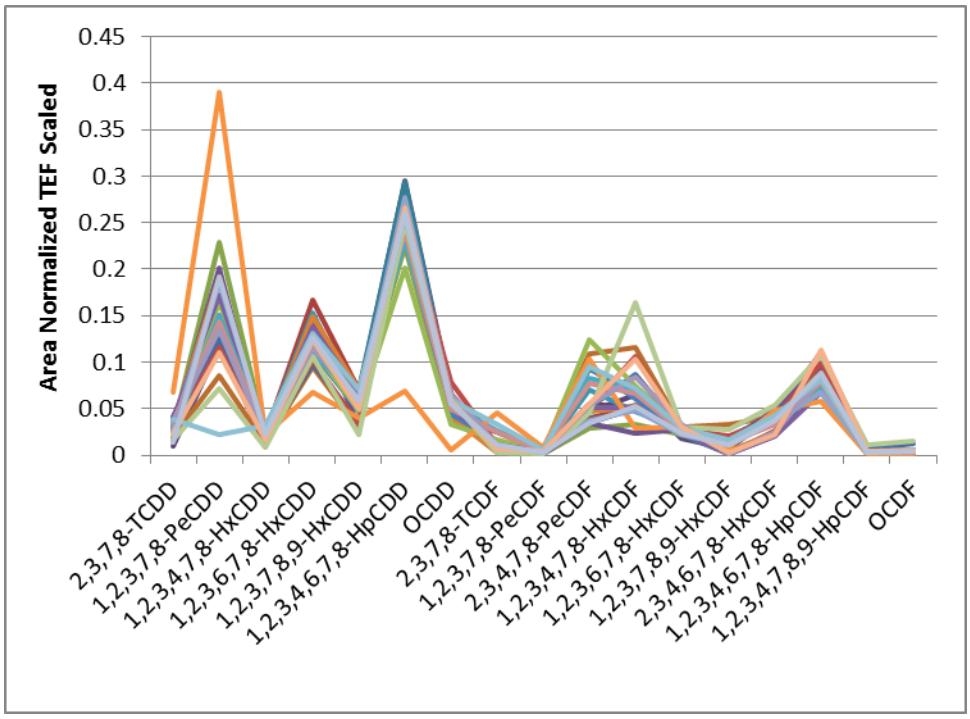

Figure 7. Area-normalized TEF-scaled Profiles of the *Unmixing Data Set* (25 sample subset).

4.0 Unmixing Model

Pirouette (Infometrix, Bothell, WA) software was used for the application of chemometric modeling. This software contains a full suite of multivariate statistical tools. The mathematical output for the *Unmixing Data Set* as modeled in Pirouette includes the following results:

- The number of significant factors contributing to the sample measurements;
- The congener profiless of the modeled factors (dioxin/furan TEQ profiles);
- The fractional contribution of each modeled factor to each sample as well as the contribution to each sample's total TEQ; and
- A characterization of the model's goodness-of-fit through residuals (congener-by-congener differences between modeled and measured values for every sample) and deviations of summed factor fractional contributions from 1 (non-closure deviations; see below).

Chemometric analyses are a form of receptor-oriented modeling. Starting from the receptor measurements (in this case sediment samples), and without any prior assumptions about the number or patterns of potential factors, the analyses mathematically derive a model of the factors – conceptually working backwards from receptors to sources. There are several similar multivariate approaches used for unmixing evaluations. A combination of Principal Component Analysis (PCA) and Alternating Least Squares (ALS) methods was used in this study.

4.1 Principal Component Analysis

The 17 dioxin/furan congeners for each sample could hypothetically be plotted on a 17-dimentional space. Samples with similar TEQ profiles would be located near one another in that 17-dimensional space. Viewing data in this manner is not possible. Instead, PCA attempts to reduce the number of dimensions required to plot the data, while accounting for almost all of the variability in the data set. PCA factors, each representing some combination of the congeners, are determined with each added factor accounting for successively less of the overall variance.

4.1.1 Variance-Scaled PCA

Three factors provided a good fit in PCA. Figure 8 is a 3-dimensional representation of the variance-scaled data. In Figure 8a, the vast majority of data set variability is explained by Factor 1 at 86.6 percent, followed by Factor 2 at 6.5 percent. Factor 3 only contributes an additional 2.1 percent. Figure 8b shows that Factor 1 has the high congener loadings for 2,3,7,8-TCDF, a congener with frequent non-detects. However, the non-detects did not appear to have undue influence on the unmixing results.

4.1.2 TEF-Scaled PCA

Figure 9 is a 3-dimensional representation of PCA results of the TEF-scaled data. The cumulative variability explained by the 3-factor model for the TEF-scaled data was similar to that of the variance-scaled data. Factor 1 accounts for 89.4 percent, Factor 2 accounts for 6.4 percent, and Factor 3 for 2.2 percent (Figure 9a). Congeners that have the most influence in differentiating the profiles are farthest from the axes (Figure 9b). Congeners 1,2,3,7,8-PeCDD

and 1,2,3,4,6,7,8-HpCDD are key peaks in the congener profiles for Factors 1 and 2, respectively.

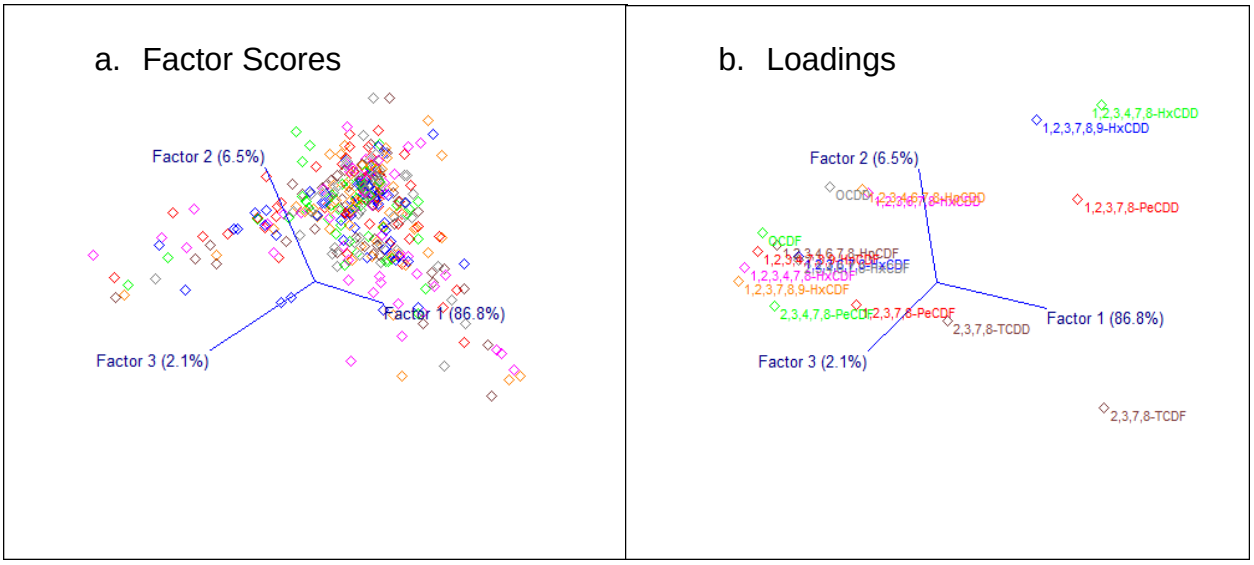

Figure 8. PCA Factor Scores (a) and Loadings (b) of Variance-scaled *Unmixing Data Set*.

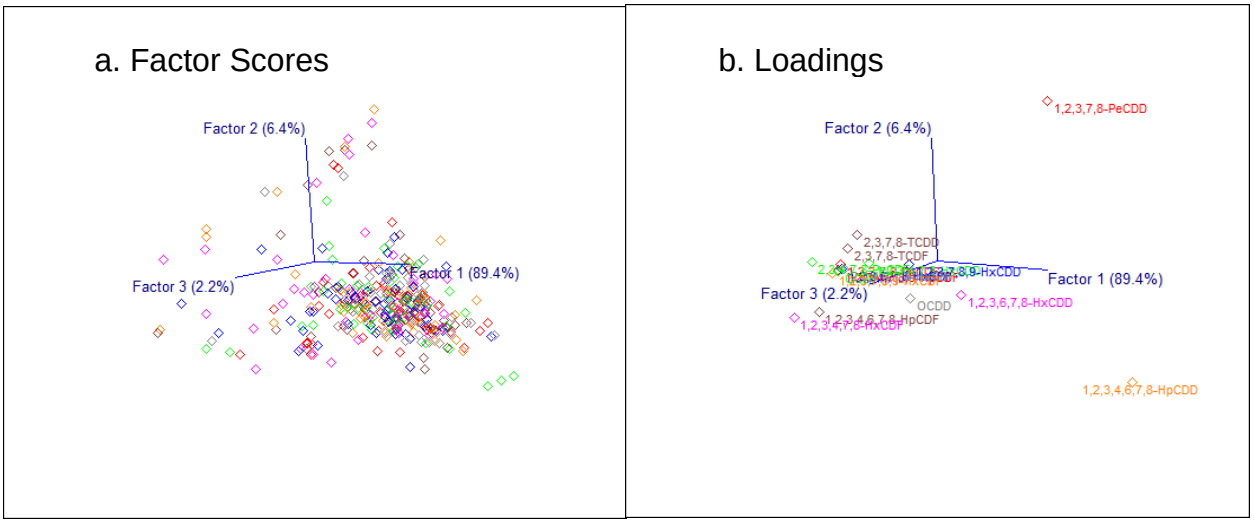

Figure 9. PCA Factor Scores (a) and Loadings (b) of TEF-scaled *Unmixing Data Set*.

4.2 Alternating Least Squares

Mixture analysis algorithms are designed to extract the patterns from which sample mixtures are composed. For this study an ALS method was used for the unmixing analysis. One assumption of the ALS method is that the entire data set can be reproduced from variable contributions from a fixed number of factors such that the congener profile for each factor can be reproduced from differing amounts of Factors 1, 2, and 3. This product is calculated iteratively using matrix algebra, with one matrix of factor profiles and a second matrix of factor contributions to samples. Starting values are assigned to both matrices to begin the calculations. As the iteration proceeds,

constraints are applied; for example, one constraint is that no negative contributions from factors are allowed, because negative contributions lack physical meaning. When the iterative calculations converge, the unmixing model is complete. The solution provided consists of the chemical profiles of factors and their contributions to each sample (i.e., sample composition). The residuals of the resulting model illustrate the goodness-of-fit.

The number of PCA factors required to account for nearly all of the data set variance is an indication of the number of factors to be included in the ALS unmixing model. For the TEF-scaled data, three factors accounted for 98 percent of the total data set profile variability, while four factors accounted for 98.9 percent of the variability. Therefore, both a 4-factor and a 3-factor ALS model using TEF-scaling are explored and compared in this section. A 3-factor variance-scaled model is also included in this section for comparison.

4.2.1 4-Factor TEF-scaled Model

The normalized TEQ profiles for the 4-factor model are shown as line plots in Figure 10, with separate panels for each factor profile. Numerical values for these factor profiles are provided in Table 2. Dioxin congeners dominate in the profiles for Factors 1 and 2, comprising 75 percent and 88 percent of the total, respectively. Factor 3 had the greatest furan contribution to TEQ, at 75 percent (Table 2). Factor 4 was also dominated by furans at 71 percent of the total.

Table 2. Factor Profiles Derived from the 3-Factor TEF-scaled Model.

	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
4-Factor TEF-scaled Model																	
Factor 1	0.10	0.50	0.03	0.06	0.05	0.01	0.00	0.06	0.01	0.11	0.00	0.03	0.01	0.04	0.00	0.00	0.00
Factor 2	0.00	0.07	0.03	0.16	0.07	0.43	0.11	0.00	0.00	0.00	0.03	0.01	0.01	0.02	0.04	0.00	0.00
Factor 3	0.04	0.00	0.00	0.05	0.00	0.13	0.03	0.02	0.01	0.23	0.26	0.05	0.05	0.06	0.07	0.01	0.01
Factor 4	0.04	0.09	0.00	0.10	0.02	0.04	0.00	0.00	0.00	0.01	0.07	0.04	0.00	0.06	0.50	0.01	0.01
3-Factor TEF-scaled Model																	
Factor 1	0.10	0.48	0.03	0.06	0.05	0.01	0.00	0.05	0.01	0.10	0.00	0.03	0.00	0.04	0.03	0.00	0.00
Factor 2	0.00	0.06	0.03	0.16	0.07	0.43	0.11	0.00	0.00	0.00	0.04	0.01	0.01	0.02	0.06	0.00	0.01
Factor 3	0.04	0.02	0.00	0.06	0.01	0.10	0.02	0.01	0.00	0.16	0.20	0.05	0.03	0.06	0.21	0.01	0.01
3-Factor Variance-scaled Model (profiles converted to TEF)																	
Factor 1	0.02	0.00	0.00	0.08	0.00	0.22	0.05	0.00	0.00	0.12	0.19	0.04	0.04	0.05	0.16	0.01	0.01
Factor 2	0.12	0.39	0.02	0.04	0.03	0.00	0.00	0.07	0.01	0.15	0.03	0.03	0.01	0.05	0.06	0.00	0.00
Factor 3	0.01	0.15	0.03	0.15	0.08	0.35	0.08	0.00	0.00	0.01	0.03	0.02	0.00	0.02	0.06	0.00	0.00

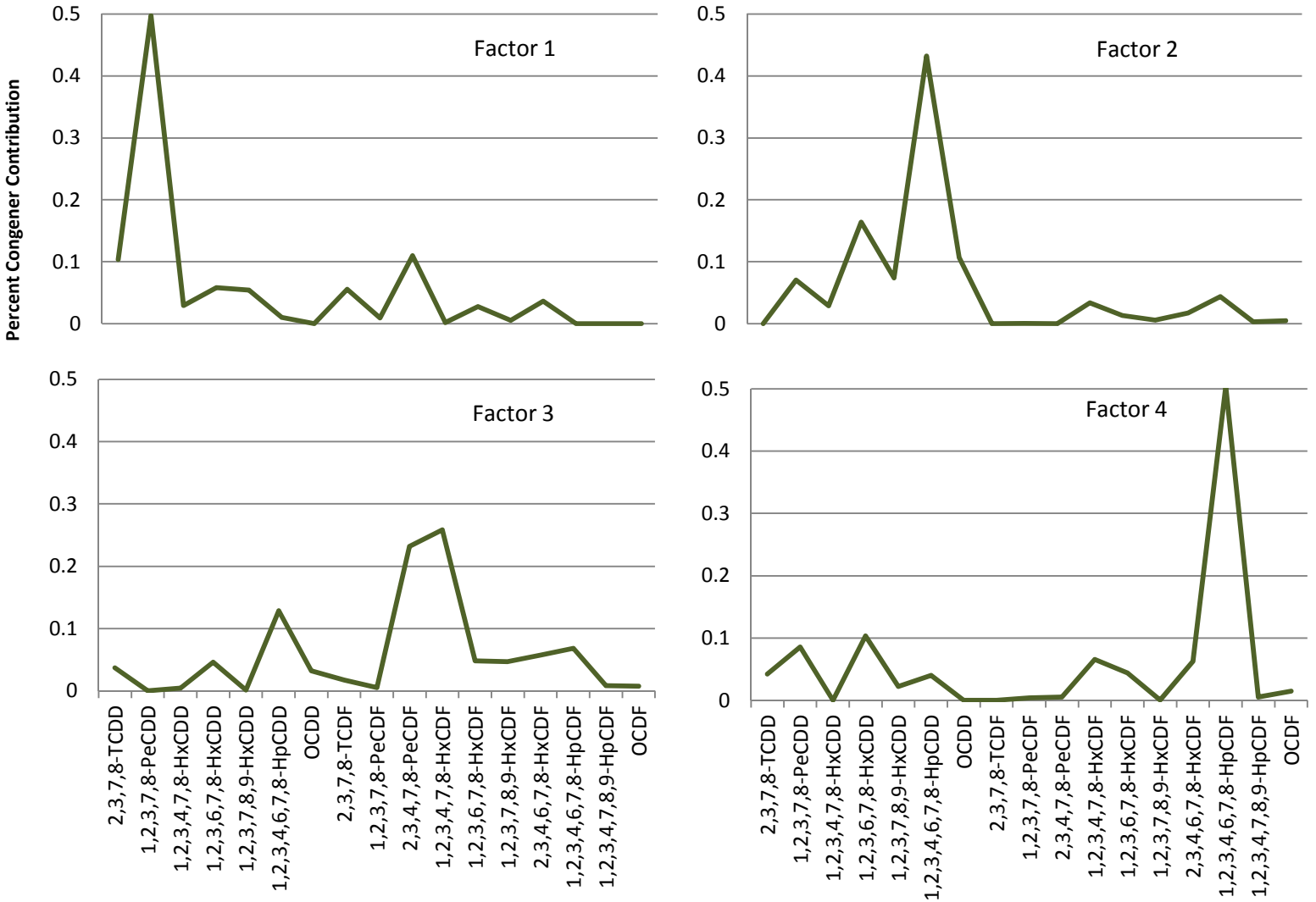

Figure 10. Dioxin/Furan Congener Profiles for the 4-Factor TEF-Scaled Model.

Each of the four profiles in the 4-factor model is unique (Figure 10). The TEQ profile of Factor 1 is dominated by 1,2,3,7,8-PeCDD at 50 percent. Factor 2 is dominated by 1,2,3,4,6,7,8-HpCDD at 43 percent. 2,3,4,7,8-PeCDF and 1,2,3,4,7,8-HxDCF were present in Factor 3 at 23 and 26 percent, respectively. 1,2,3,4,6,7,8- HpCDF was the dominant congener in Factor 4 at 50 percent (Table 2; Figure 10).

Fractional contributions to each of the samples in the *Unmixing Data Set* were calculated as part of the ALS model run. Some of the factor fractional contributions are zero, as not every model factor is found to contribute to every sample. Most samples, however, were composed of varying contributions from multiple factors. The sum of the fractional contributions for each sample does not necessarily have to equal 1 because the ALS unmixing model was run without a closure constraint. Only 23 samples (~6.4 percent of the total) have summed factor fractions differing from 1 by more than 5 percent. This result, as well as examination of the residuals for sample profiles, indicates good model fit to the *Unmixing Data Set*.

Just as the sum of the fractional contributions does not always equal 1, the sum of the TEQ increments does not always equal the sample measured TEQ. Where the sample TEQ is relatively small, even the higher deviations from a combined fractional contribution of 1 will result in only small differences between measured and modeled sample TEQs. Conversely, relatively small differences from 1 for fractional contributions may result in larger differences in sample TEQs when total TEQs are higher. Of the nearly 360 samples included in the model, only 18 have differences in TEQ of more than 2 ng TEQ/kg. Thus, the 4-factor model produces total TEQ values within 2 ng TEQ/kg for almost 95 percent of Budd Inlet samples.

4.2.2 3-Factor TEF-scaled Model

A detailed review of the results of the 3-factor model shows that two of the factor profiles are very similar to profiles from the 4-factor model. The normalized TEF profiles for the 3 factors are shown as line plots in Figure 11. Numerical values for the three factor profiles are provided in Table 2. Factors 1 and 2 are nearly identical between the 3- and 4- factor model runs. Differences are apparent for Factor 3. Factor 3 of the 3-factor model is a composite of Factors 3 and 4 of the 4-factor model. Factor 3 includes congener peaks for 2,3,4,7,8-PeCDF (16 percent) 1,2,3,4,7,8-HxDCF (20 percent) and 1,2,3,4,6,7,8- HpCDF (21 percent).

The fractional contributions for the 3-factor model are listed as numerical values in Appendix D. Twenty four of the samples (~6.7 percent) have summed factor fractions differing from 1 by more than 5 percent. This demonstrates that the overall fit is still good for the 3-factor model.

The sums of the TEQ increments calculated from the fractional contributions for each sample were comparable to the total TEQ. Of the nearly 360 samples included in the model, 15 had differences in TEQ of more than 2 ng TEQ/kg. Thus, the 3-factor model recreates the TEQ to values within 2 ng TEQ/kg for almost 96 percent of the *Unmixing Data Set*.

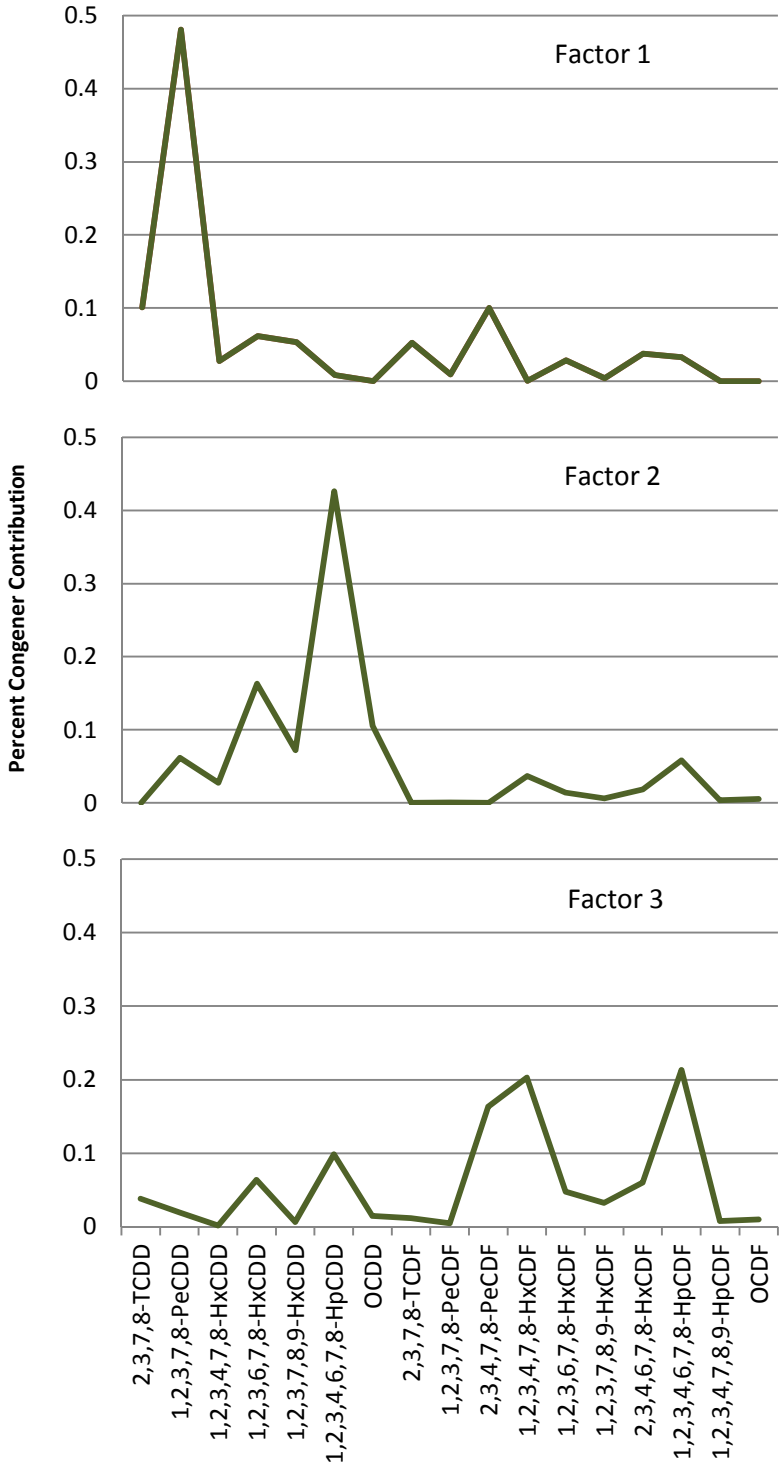

Figure 11. Dioxin/Furan Congener Profiles for the 3-Factor TEF-Scaled Model.

4.2.3 3-Factor Variance-scaled Model

As mentioned earlier, factor profiles from a variance-scaled model output cannot be directly compared to TEF-scaled profiles. To make this comparison, the variance-scaled profiles from the ALS output were multiplied by the respective congener standard deviations (Section 3.1) and then multiplied by the TEF (Table 1). The TEF corrected variance scaled profiles for the 3 factors are shown as line plots in Figure 12. Numerical values for the 3 factor profiles are provided in Table 2.

There are some differences in the congener profiles between the TEF-scaled and variance-scaled models. Variance-scaled Factor 1 has 10 percent less 1,2,3,7,8-PeCDD than TEF-scaled Factor 1, while variance-scaled Factor 2 has 9 percent more 1,2,3,7,8-PeCDD than TEF-scaled Factor 2. A similar pattern exists for 1,2,3,4,6,7,8-HpCDD, which is lower in TEF-scaled Factor 2 and higher in variance-scaled Factor 3.

As with the TEF-scaled data, the fractional contributions were calculated for the variance-scaled results and compared to a total value of 1. Thirteen samples (~3.6 percent) had summed factor fractions differing from 1 by more than 5 percent.

The sums of the TEQ increments calculated from the fractional contributions for each sample were comparable to the total TEQ. Of the nearly 360 samples included in the model, 11 had differences in TEQ of more than 2 ng TEQ/kg. Thus, the 3-factor model recreates the TEQ to values within 2 ng TEQ/kg for almost 97 percent of the *Unmixing Data Set*.

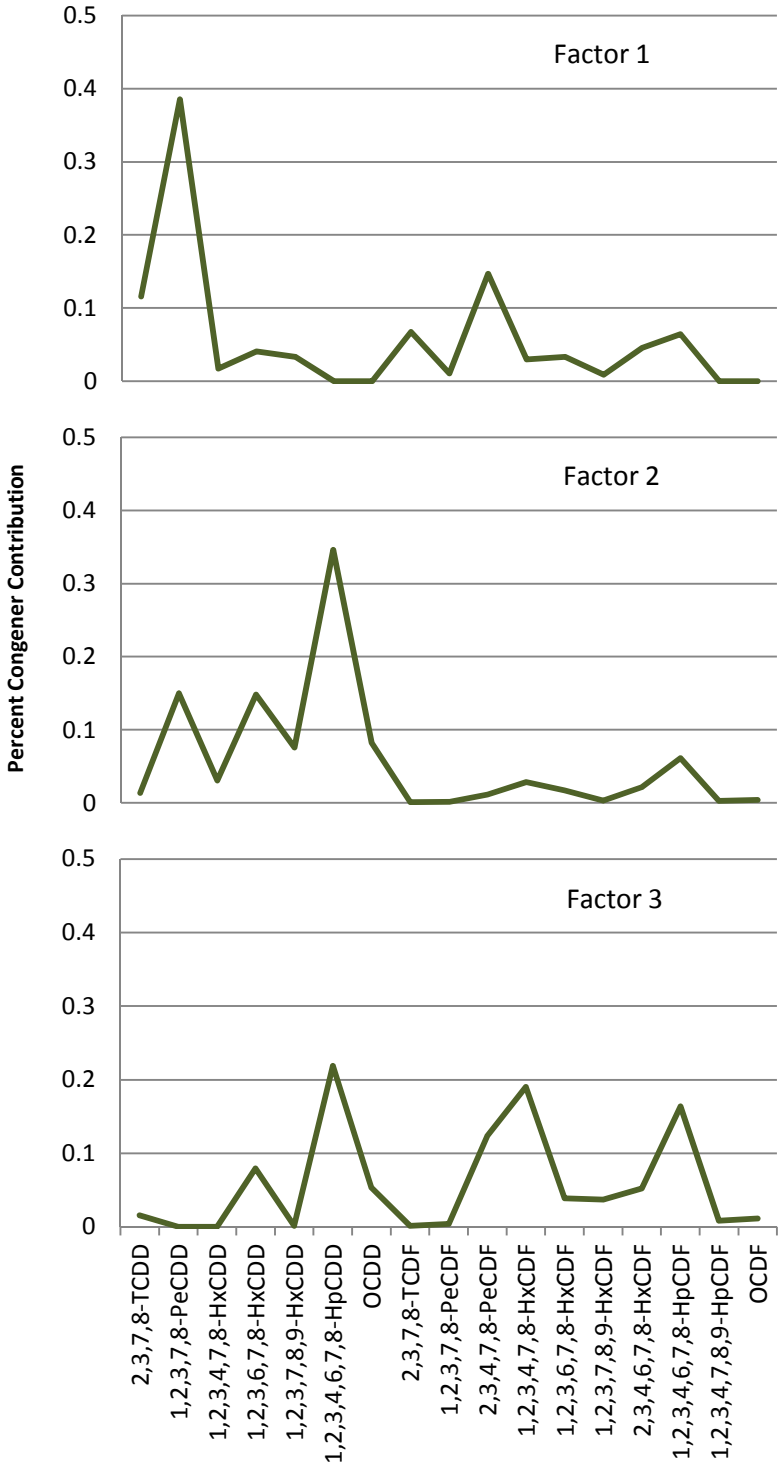

Figure 12. Dioxin/Furan Congener Profiles for the 3-Factor Variance-Scaled Model.

5.0 Source Library Comparison

A library of comparison dioxin/furan profiles was compiled to support interpretations of the factor profiles obtained through chemometric modeling. The *Comparison Data Set* included over 300 candidate profiles compiled from published literature, regional environmental samples, and site-specific studies (Section 2.1). Examples of source types present in the source library include air emissions, effluent discharges, ash, and various chemicals known to include dioxins/furans as part of their manufacturing.

Comparisons of factor profiles from the ALS model to those in the compiled source library were made by two means:

1. Hierarchical Cluster Analysis (HCA); and
2. Tabulation of correlation coefficients.

As the name implies, HCA is a method of evaluating similarity by organizing data into a hierarchy of clusters. The results of HCA are best represented graphically by a dendrogram (or similarity tree). This manner of representation displays highly similar sample pairs with relatively small separation distances. Simply stated, similar congener profiles (and presumably similar pathways or sources) will cluster together. As applied to this study, HCA was used to identify library profiles with high similarity to the ALS-derived factor profiles.

A correlation coefficient (r-value) can be calculated for sample pairs as a measure of the strength and direction of their relationship. Correlation between two samples can be either positive or negative, with perfect positive correlation having a value of 1. Correlation analyses were performed for ALS-derived profiles against the entire source library.

The HCA dendrogram is presented in Figure 13, and includes the locations of the factors for each of the three model runs (3-factor TEF, 4-factor TEF, 3-factor variance). Regardless of the model run, each factor clusters on a different branch of the dendrogram indicating different source types. Figures 15, 17, and 19 allow closer inspection of the dendrogram branches containing factor profiles, including which samples from the *Comparison Data Set* fall within a cluster based on profile similarity. The HCA analysis was considered a qualitative match to the profiles from the *Comparison Data Set*.

The correlations were a more quantitaive match to the *Comparison Data Set*. Modeled factor profiles were considered a significant match to that of a source library profile when the correlation coefficient was greater than or equal to 0.95. Examples of the correlations are provided in Figures 14, 16, and 18.

5.1 Comparison of the Model Outputs

The dendrogram in Figure 13 shows that there were several similarities between the model runs:

- Factor 3 from the 3-factor variance model and Factor 2 from the 3- and 4-factor TEF models clustered on proximal branches of the dendrogram;

- Factor 2 from the 3-factor variance model and Factor 1 from the 3- and 4-factor TEF models clustered on proximal branches of the dendrogram; and
- Factor 1 from the 3-factor variance model and Factors 3 from the 3- and 4-factor TEF models clustered on proximal branches of the dendrogram.

Factor 1 of the TEF-scaled models clustered with or correlated to several hog fuel boiler emissions or effluent source profiles. Factor 1 of the variance-scaled model was similar to these same profiles, but with weaker correlation coefficients. Factor 2 of the TEF-scaled models correlated strongly to pentachlorophenol (PCP) based sources, including treated utility poles and historical sediment samples from Cascade Pole. Factor 2 from the variance-scaled model had much weaker (often less than 0.95) correlations to these same sources. For these reasons the decision was made to abandon the variance-scaled model in favor of TEF-scaling.

The decision was also made to abandon the 4-factor TEF-scaled model in favor of the 3-factor model. During HCA, Factor 4 was isolated in a small cluster (Figure 13), indicating it was not a good match to any profiles in the source library. Rather than include a profile that could not be explained, it was decided to use the 3-factor model and acknowledge that Factor 3 may contain some unexplained variance in its 1,2,3,4,6,7,8-HpCDF peak. The remainder of source discussion focuses on the 3-factor TEF-scaled model. Table 3 includes some of the best profile matches to the *Comparison Data Set* for each of the factors and associated references.

Table 3. Factor Profile Matches to the Source Library

Budd Inlet Sediment Profile	Source Library Match		Correlation Coefficient (r-value)
	Description	Reference	
Factor 1	Hog Fuel Boiler Sludge (Port Angeles)	FWEC 1997	0.988
	Effluent (Port Angeles)	Malcolm Pirnie 2007	0.988
	Low Pressure Boiler Baghouse (Shelton Timber Company)	CH2M Hill 1987	0.981
	HFB Stack Emission (CANST50)	DeAbreu 2009	0.956
	Wood Filter Ash-Sample 3	Oehme and Muller 1995	0.955
Factor 2	Pre-cleanup Cascade Pole Sediment (CP1-M-D1A-0-10)	Landau Associates 1993	0.993
	PCP wood preserving formulation	Christman et al. 1989	0.979
	Port of Olympia Storm Drain Solids (A02CB)	Anchor QEA 2012	0.985
	PCP Treated Utility Pole	Lorber et al. 2002	0.991
	West Bay Marina Soil (HC-WB-US-009)	Hart Crowser 2011a; 2012	0.976
Factor 3	Berth 3 Sediment Sample (BI-C5-6-7 FT)	SAIC 2008	0.814
	Aroclor 1268 Chem Fal-1268	NA	0.777
	Aroclor 1260 Chem Wak-1260	NA	0.707
	Aroclor 1254	Johnson et al. 2008	0.707

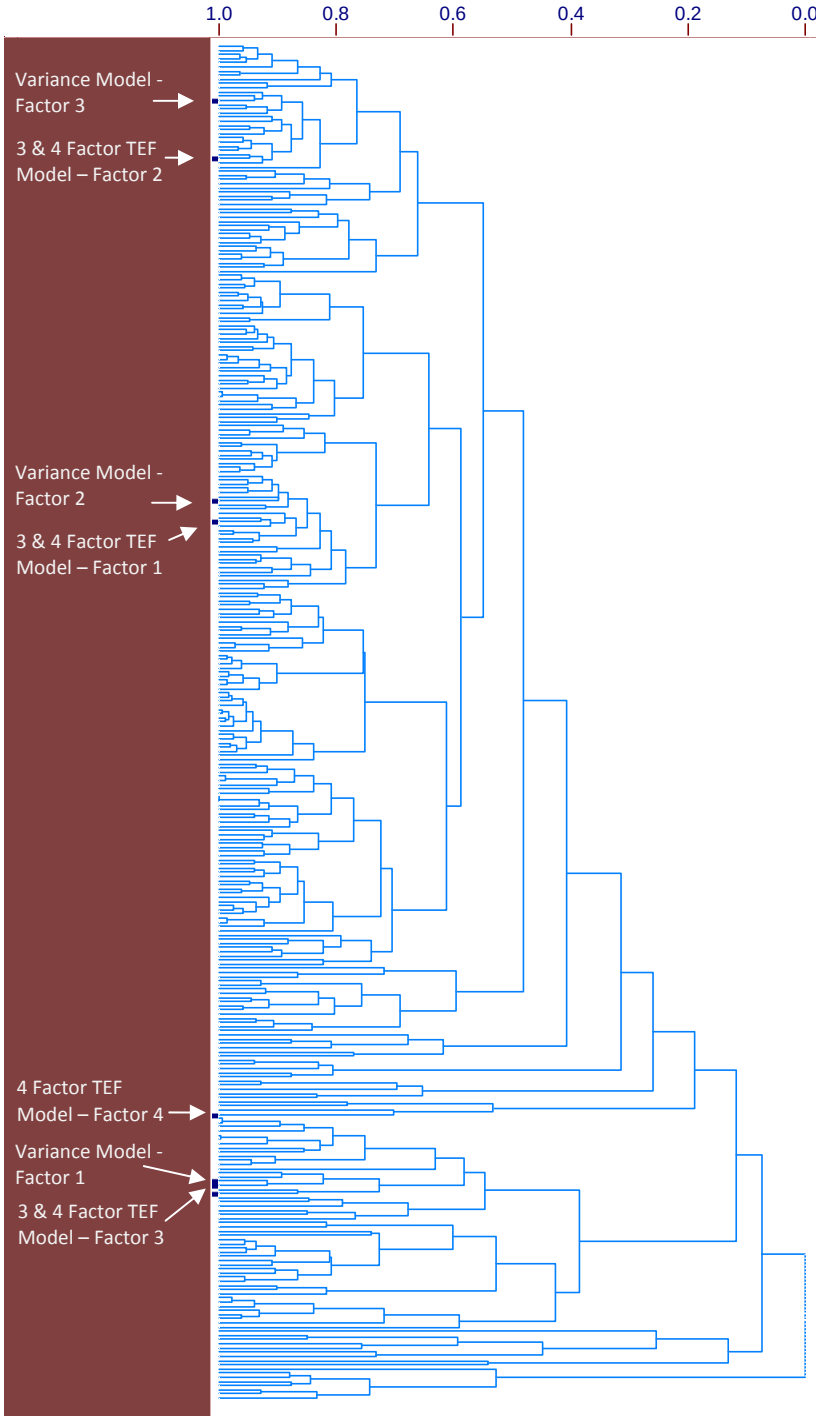

Figure 13. HCA Dendrogram Showing the Profiles for the 3- and 4-Factor TEF-Scaled Model and the 3-Factor Variance-Scaled Model.

5.2 Factor 1 Comparison

Dioxin/furan profiles of the *Comparison Data Set* that best match Factor 1 are represented by the green branch of the dendrogram in Figure 15. Nearly all of the profiles on this branch are related to wood combustion with an emphasis on hog fuel boiler (HFB) sources, including effluent, emissions, and ash. This same profile was also present in soils at several rural Washington State Parks (WA Rural Soils; Hart Crowser 2011) indicating the potential diffuse nature of this profile.

Five library matched samples, their correlation coefficients, and associated references are provided in Table 3. These matches include:

- Hog fuel boiler sludge from Port Angeles, WA paper mill;
- Effluent samples from Port Angeles, WA paper mill;
- Emissions from Canadian HFBs;
- Ash from Shelton Timber Company boiler; and
- Wood filter ash.

Figure 14 is included as an example of a correlation fit. It shows the plot of Hog Fuel Boiler Sludge 1 versus Factor 1 (r-value = 0.988). This particular sludge sample was collected from the Rayonier Mill in Port Angeles, WA (FWEC 1997).

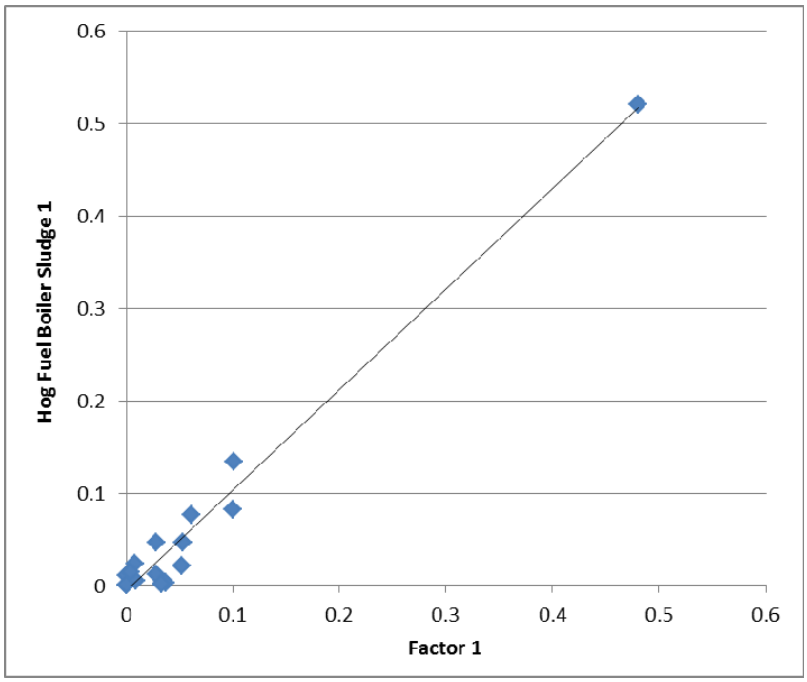

Figure 14. Example of a Correlation Match from the *Comparison Data Set* to Factor 1.

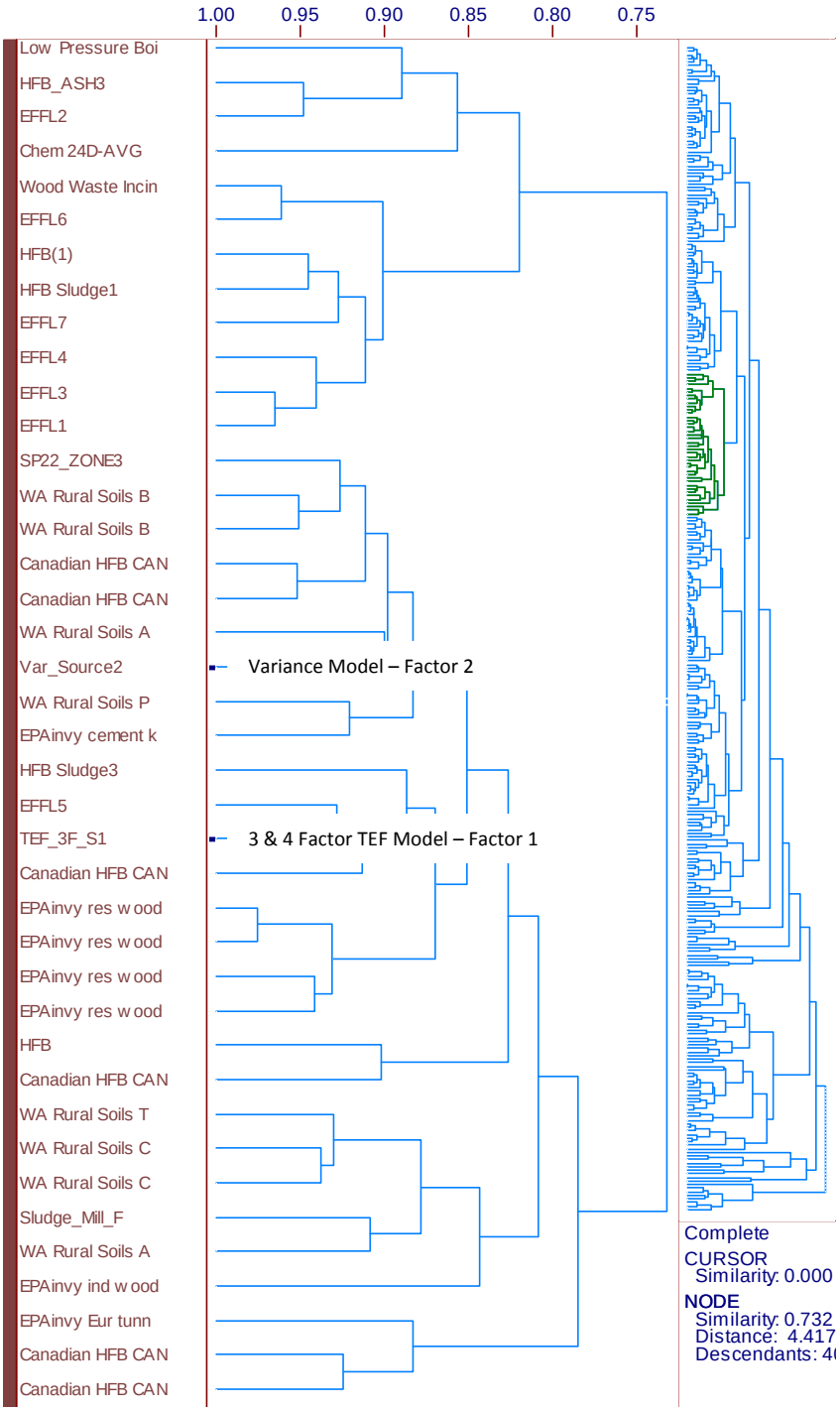

Figure 15. Branch of the *Comparison Data Set* Dendrogram Containing Factor 1.

5.3 Factor 2 Comparison

Dioxin/furan profiles of the *Comparison Data Set* that best match Factor 2 are represented by the green branch of the dendrogram in Figure 17. Many of the profiles in this branch are related to PCP treated poles or sediments with known PCP contamination including samples with the prefix CP1 or CP2 from the historical Cascade Pole site. Samples with the prefix A02CB or B22CB are storm drain samples from Port of Olympia property adjacent to the shipping berths.

Five library matched samples, their correlation coefficients, and associated references are provided in Table 3. These matches include:

- Pre-cleanup sediments from Cascade Pole;
- PCP wood preservatives;
- Storm drain solids from the Port of Olympia;
- PCP treated utility poles; and
- Soils from West Bay Marina (it is unclear whether West Bay Marina constitutes a source of this profile or if the profile was present in contaminated fill).

Figure 16 is included as an example of a correlation fit. It shows the plot of dioxin in a PCP treated utility pole four years after treatment versus Factor 2 (r-value = 0.993).

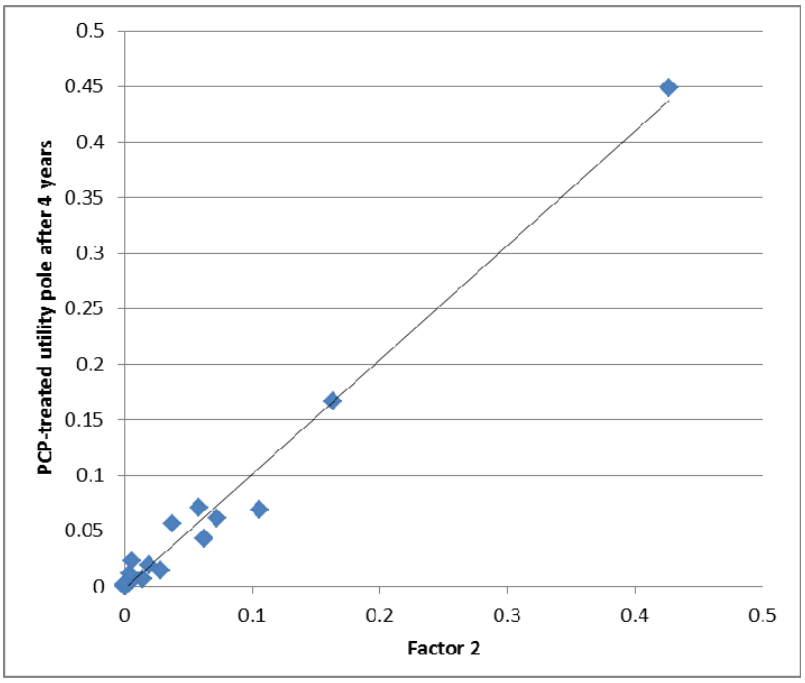

Figure 16. Example of a Correlation Match from the *Comparison Data Set* to Factor 2.

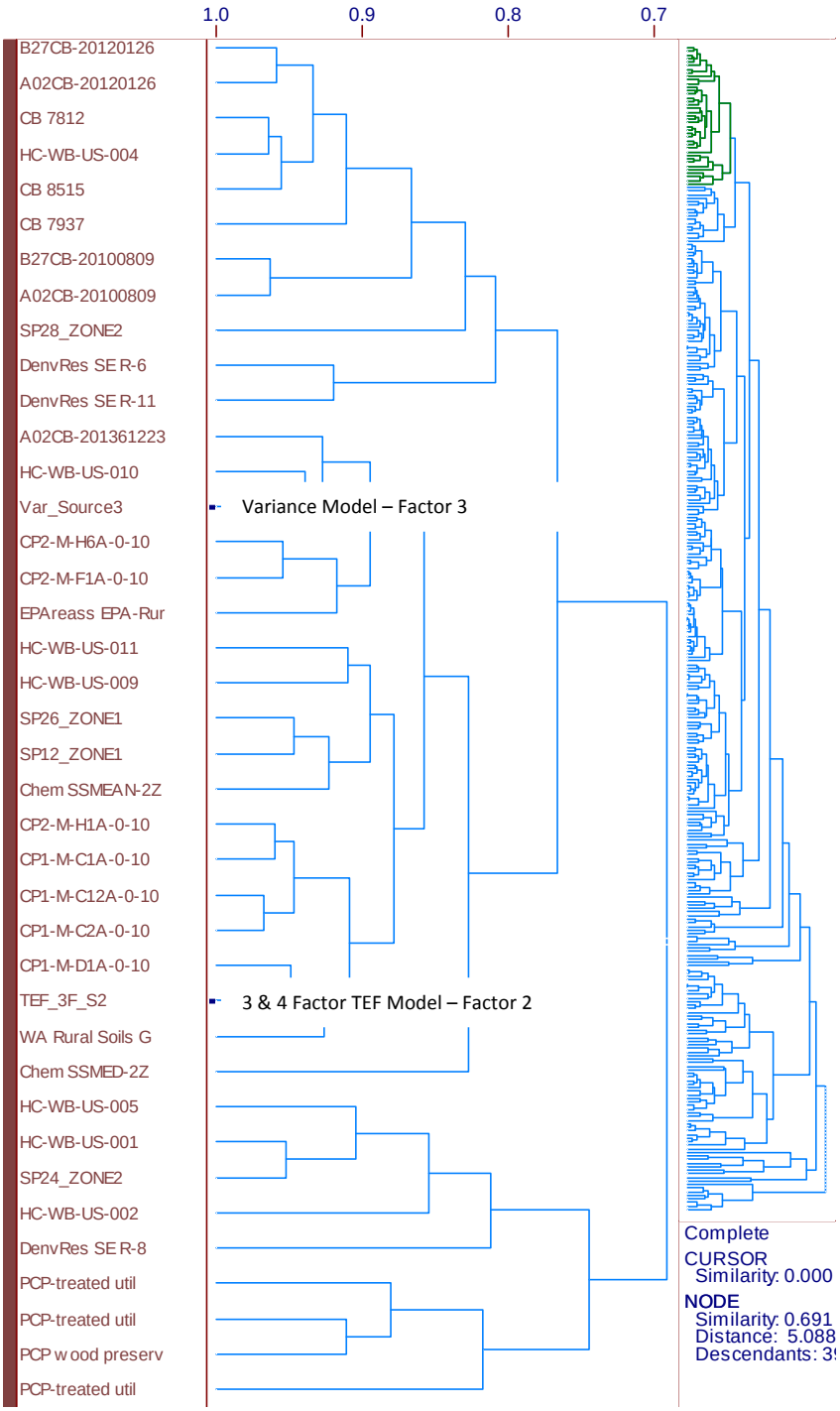

Figure 17. Branch of the *Comparison Data Set* Dendrogram Containing Factor 2.

5.4 Factor 3 Comparison

Dioxin/furan profiles of the *Comparison Data Set* that best match Factor 3 are represented by the green branch of the dendrogram in Figure 19. Profiles clustered with Factor 3 include polychlorinated biphenyl (PCB) Aroclors, wood waste, and medical incinerators.

The best source library correlation matches for Factor 3 are presented in Table 3. None of these matches correlated above the 0.95 threshold. The best correlation was a sediment sample (BI-C5-6-7 FT) collected during the 2007 Budd Inlet Baywide Investigation (SAIC 2008). Aside from this sample, Factor 3 was a weak ($r > 0.70$) match to several PCB profiles (example in Figure 18). Correlations to the wood waste and medical incinerators were weaker still.

The best match for Factor 3 was considered to be PCBs. PCBs are dominated by furan congeners as is Factor 3. However, Factor 3 has some additional peaks suggesting a mixed profile. Various lines of evidence linking Factor 3 to PCBs are provided in the report.

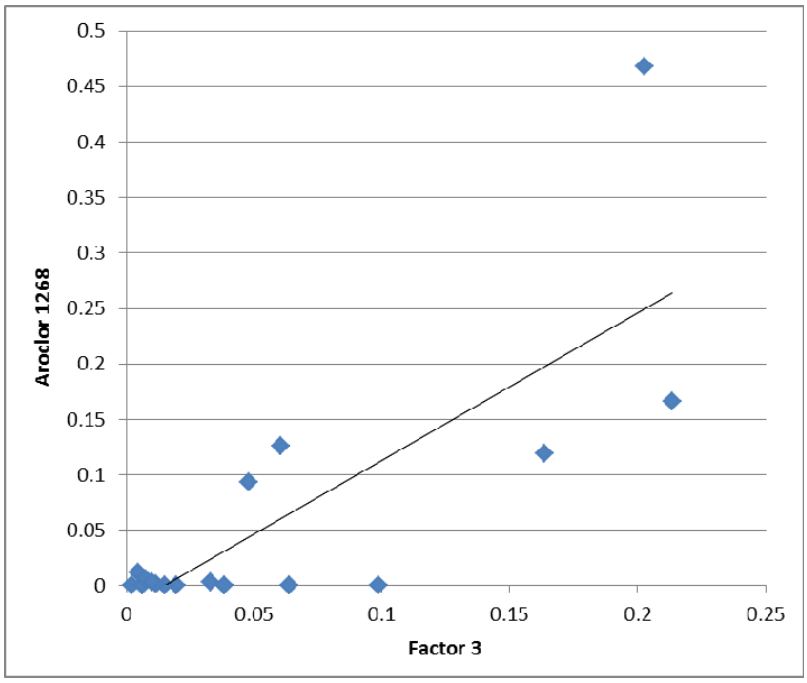

Figure 18. Example of a Correlation Match from the *Comparison Data Set* to Factor 3.

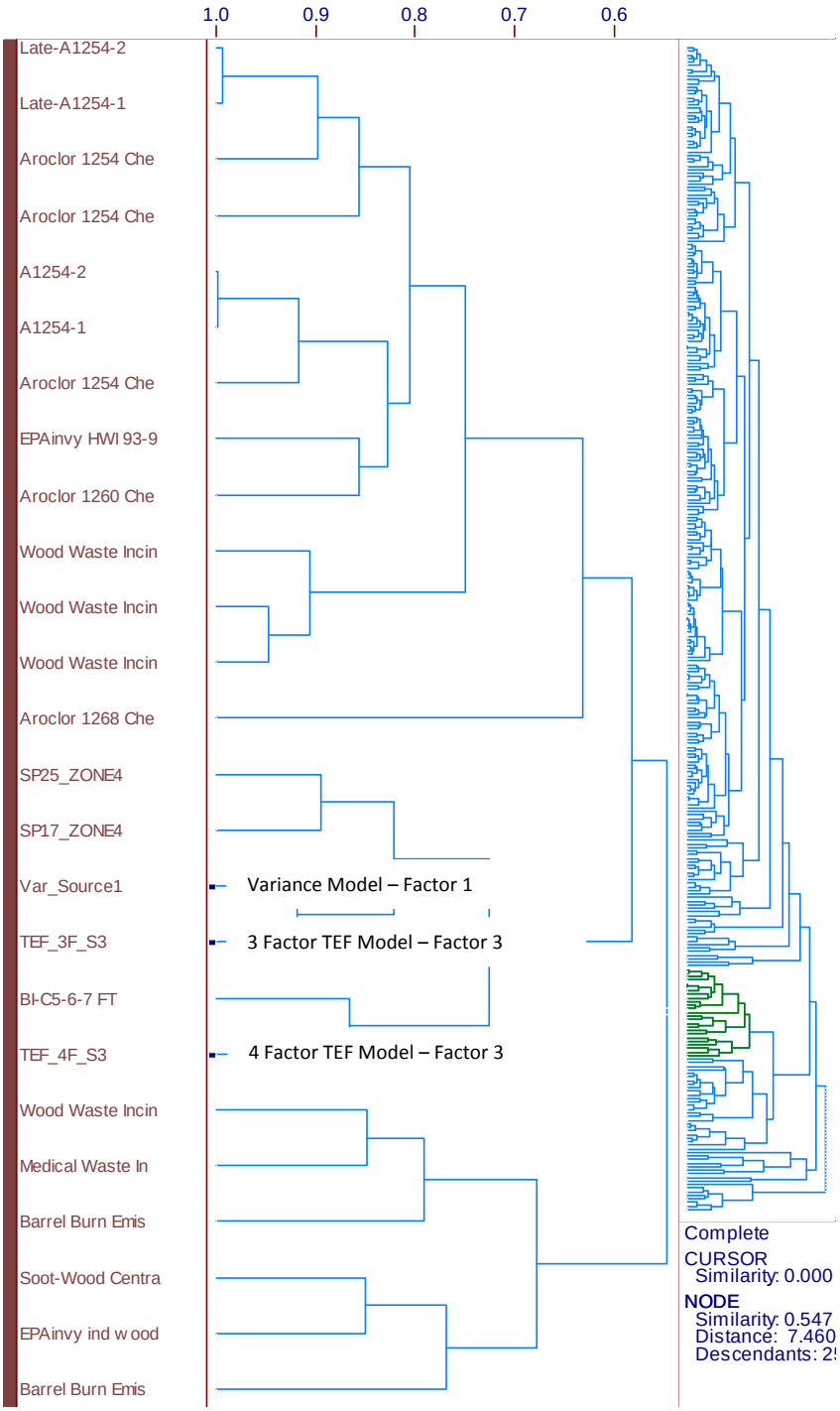

Figure 19. Branch of the *Comparison Data Set* Dendrogram Containing Factor 3.

6.0 Summary

Chemometric analysis of dioxin/furan congeners was conducted on nearly 360 sediment samples from Budd Inlet. Data from these analyses were collectively processed with several algorithms to look for underlying patterns that might explain their distribution in bay sediments.

Multiple model runs were evaluated using a variety of scaling and normalization techniques. A 3-factor TEF-scaled model was ultimately selected as the best fit for Budd Inlet as it was the simplest model that explained the variability in the data set and provided the best matches to the source library.

The 3 source patterns that were discovered in this process appear to be correlated to materials commonly found in harbors of this type, particularly where wood processing historically occurred. These include the following:

1. A source that has a pattern similar to those found in stack emissions and ash from HFBs which utilized salt-laden wood,

2. A source that strongly resembles that from PCP which was used for wood treatment, and

3. A source that resembles the furan dominated profiles of PCBs, which would have been used historically at most industrial sites.

7.0 References

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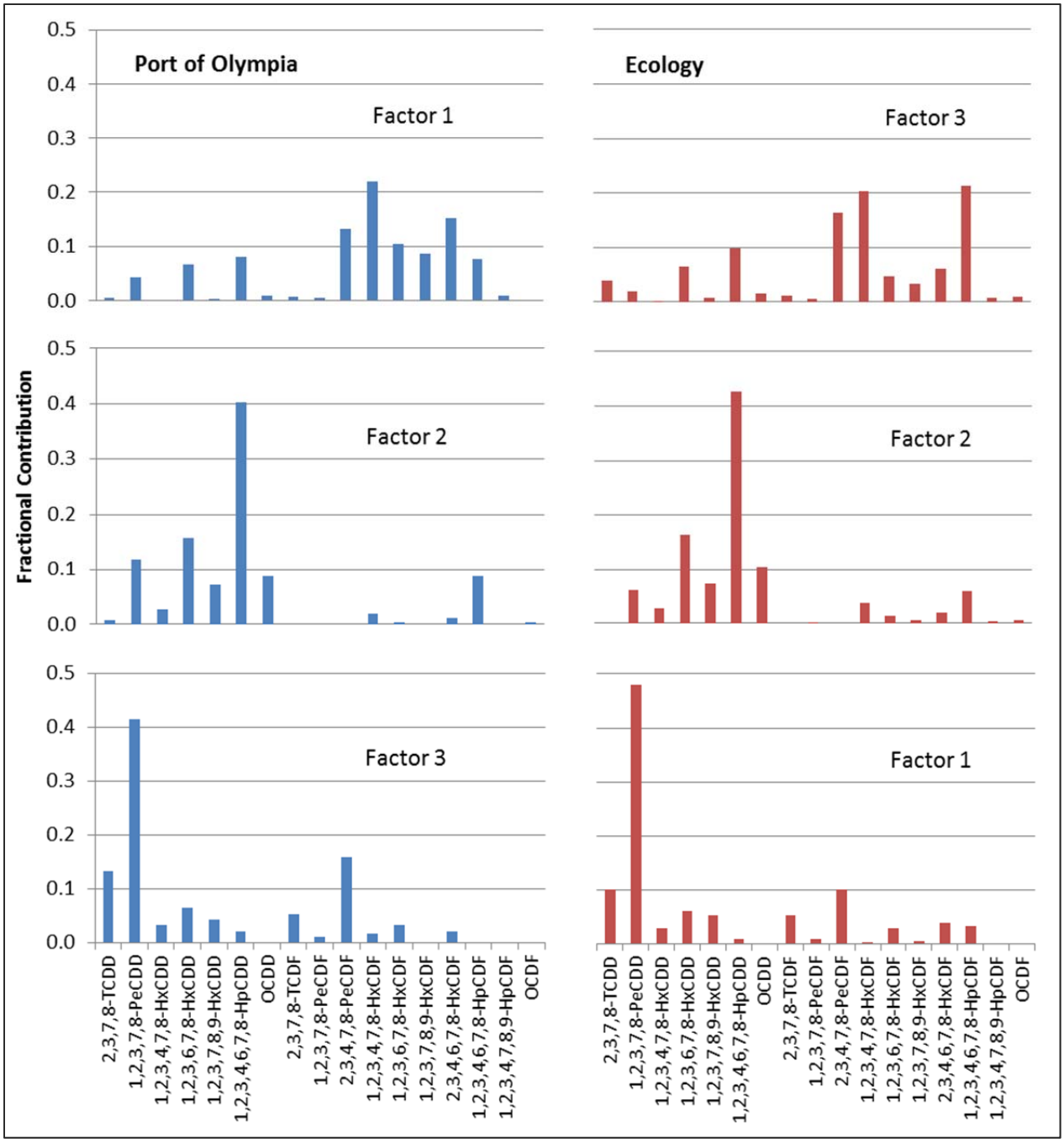
Appendix C

Profile Comparison between Ecology and Port of Olympia Chemometric Studies



This figure represents a comparison of the TEQ-normalized factor profiles from the Ecology and Port of Olympia (Anchor QEA's 2015) chemometric evalutations. Despite the fact that both studies used different unmixing models and slightly different data-sets, both converged on 3 factors with similar profiles to describe the overall variability.

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Appendix D

Unmixing Data Set and Fractional Contributions

Table 1. Sample Information, Congener Data, and Fractional Contributions using the 3-Factor TEF-Scaled Model for the 358 Samples in the Unmixing Data Set.

Study ID	Sample Name	Year	Point_X*	Point_Y*	Upper Depth	Lower Depth	UOM	Total TEQ	Factor 1 Contribution	Factor 2 Contribution	Factor 3 Contribution	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
Anchor	POBI-SC-01-0.5-1	2013	1040209.0	635257.2	0.5	1	ft	8.47	0.402	0.548	0.050	0.227	2	2.34	11.5	5.67	205	1180	1.11	0.4995	0.985	3.32	1.75	1.12	2.95	51.6	2.1	66.6
Anchor	POBI-SC-01-0-0.5	2013	1040209.0	635257.2	0	0.5	ft	8.99	0.215	0.644	0.140	0.215	1.235	2.52	12.3	6.29	246	1780	1.29	1.21	0.939	4.25	2.51	1.62	4.03	68.3	3.06	115
Anchor	POBI-SC-01-1-1.5	2013	1040209.0	635257.2	1	1.5	ft	4.37	0.259	0.542	0.199	0.1845	0.635	1.24	6	2.76	103	622	1.1	0.746	0.816	2.22	1.22	0.682	2	32.6	0.665	38.4
Anchor	POBI-SC-02-1-2	2013	1040783.0	635268.8	1	2	ft	48.8	0.188	0.723	0.089	1.38	6.85	8.33	60.1	22.8	1570	16100	3.92	4.28	4.46	22.1	9.97	5.65	14.8	348	13.3	624
Anchor	POBI-SC-02-4-5	2013	1040783.0	635268.8	4	5	ft	3.56	0.941	0.019	0.040	0.2795	1.63	0.875	1.77	1.46	10.6	33.9	2.3	1.42	1.49	0.927	1.05	0.314	1.3	3.92	0.238	2.39
Anchor	POBI-SC-02-5-6	2013	1040783.0	635268.8	5	6	ft	2.67	0.973	0.027	0.000	0.264	1.33	0.3595	1.23	1.11	8.02	26.4	1.86	0.974	0.966	0.575	0.692	0.097	0.567	1.68	0.072	1.03
Anchor	POBI-SC-04-9-11	2013	1040861.7	635714.9	9	11	ft	25.9	0.187	0.623	0.190	0.949	3.52	4.95	32	10.5	769	5020	2.17	2.85	3.29	16.8	6.42	3.88	10.2	223	9.84	372
Anchor	POBI-SC-05-2-3	2013	1040485.9	635689.0	2	3	ft	21.2	0.326	0.331	0.343	0.91	4.15	4.04	18.9	8.38	386	2490	3.39	2.79	3.61	14.4	6.18	3.55	10.4	323	7.83	413
Anchor	POBI-SC-05-3-4	2013	1040485.9	635689.0	3	4	ft	15.7	0.340	0.235	0.425	0.4345	3.31	2.75	11.9	5.6	237	1510	2.84	2.11	2.86	10.6	4.8	2.17	7.8	322	5.74	365
Anchor	POBI-SC-05-4-5	2013	1040485.9	635689.0	4	5	ft	17.7	0.332	0.375	0.293	0.897	3.53	3.49	15.5	7.75	356	2420	2.94	2.32	3.49	14.8	5.45	2.3	3.79	201	7.52	504
Anchor	POBI-SC-06-0-0.5	2013	1040892.2	635867.3	0	0.5	ft	11.6	0.295	0.637	0.068	0.2085	2.18	3.37	14	7.57	326	2630	1.19	1.07	1.12	4.51	2.44	1.15	3.61	84.9	4.18	239
Anchor	POBI-SC-06-1-1.5	2013	1040892.2	635867.3	1	1.5	ft	4.52	0.259	0.666	0.075	0.128	0.776	1.16	5.3	2.44	136	1090	0.485	0.462	0.447	1.88	0.875	0.642	1.54	31.4	1.4	60.3
Anchor	POBI-SC-07-14-16	2013	1040854.4	635891.0	14	16	ft	58.6	0.213	0.612	0.175	0.86	9.04	13.3	73.8	25.7	1710	11100	4.27	6.15	7.62	40.4	14.2	9.37	24.3	477	21.4	894
Anchor	POBI-SC-08-3-5	2013	1040801.1	635860.9	3	5	ft	26.9	0.253	0.628	0.119	0.432	4.69	5.78	38.2	14.2	778	5680	2.97	2.94	3.15	15.1	6.7	3.12	2.51	218	8.95	337
Anchor	POBI-SC-08-5-6	2013	1040801.1	635860.9	5	6	ft	46.5	0.237	0.636	0.127	1.43	7.57	9.68	63.4	23.7	1370	9400	4.44	5.3	5.31	26.1	10.8	5.99	8.27	366	15.3	695
Anchor	POBI-SC-08-7-8	2013	1040801.1	635860.9	7	8	ft	3.64	0.202	0.391	0.407	0.1035	0.441	0.2475	3.75	1.39	80.4	530	0.669	0.697	1.84	2.96	1.17	0.689	1.57	28.4	1.49	51.6
Anchor	POBI-SC-09-6-7	2013	1040152.0	636022.9	6	7	ft	52	0.268	0.441	0.291	1.47	8.95	10.9	52.4	24.6	1160	7690	4.97	5.73	8.19	46	15.5	9.46	24.7	557	26	1160
Anchor	POBI-SC-09-7-8	2013	1040152.0	636022.9	7	8	ft	68.5	0.223	0.438	0.339	0.69	10.7	14.8	71.6	31.4	1560	10100	5.31	6.35	11	67.2	21	9.53	34.1	856	35.3	2030
Anchor	POBI-SC-09-8-9	2013	1040152.0	636022.9	8	9	ft	13.4	0.431	0.106	0.463	0.928	3.11	1.9	8.68	4.59	127	797	3.63	2.39	3.49	8.19	4.32	1.5	7.41	262	2.85	160
Anchor	POBI-SC-09-9-10	2013	1040152.0	636022.9	9	10	ft	6	0.774	0.103	0.122	0.4055	2.34	1.34	4.08	2.43	41.3	130	2.78	1.68	2.07	1.73	1.83	0.549	2.92	34.5	0.815	32.2
Anchor	POBI-SC-10-11-13	2013	1040828.1	636141.9	11	13	ft	36.5	0.179	0.491	0.330	0.53	4.89	6.7	41.1	14.7	896	6430	2.98	4.63	5.09	36.6	11.3	6.78	18.5	418	19.2	808
Anchor	POBI-SC-10-13-14	2013	1040828.1	636141.9	13	14	ft	2.75	0.213	0.497	0.290	0.0885	0.435	0.479	3.05	1.22	69	509	0.26	0.2095	0.202	3.08	0.4795	0.657	0.379	32.5	1.53	67.7
Anchor	POBI-SC-11-2-4	2013	1040867.5	636065.9	2	4	ft	28	0.204	0.697	0.099	0.354	4.25	5.8	35.7	13.6	900	7100	2.85	2.91	3.25	14.1	6.64	3.09	8.95	196	7.15	269
Anchor	POBI-SC-11-6-8	2013	1040867.5	636065.9	6	8	ft	11.6	0.233	0.617	0.150	0.2475	1.86	2.55	13.8	6.03	337	2320	1.47	1.52	1.55	7.58	2.88	1.85	4.24	83.4	3.9	164
Anchor	POBI-SC-11-8-10	2013	1040867.5	636065.9	8	10	ft	10	0.244	0.547	0.209	0.2	1.69	2.15	11.5	4.8	268	1850	0.997	1.21	1.5	8.95	2.94	1.79	2.16	79.3	4.72	167
Anchor	POBI-SC-12-2-4	2013	1040841.9	636402.8	2	4	ft	38.3	0.229	0.711	0.061	0.483	6.23	10.6	46	23.5	1230	10100	3.54	3.89	4	18.4	7.82	3.55	10.4	232	9	426
Anchor	POBI-SC-12-6-8	2013	1040841.9	636402.8	6	8	ft	5.74	0.260	0.576	0.164	0.14	1.01	1.27	6.93	2.7	158	1110	0.316	0.704	0.729	3.66	1.39	0.748	1.97	49.7	1.9	80.3
Anchor	POBI-SC-12-8-10	2013	1040841.9	636402.8	8	10	ft	1.57	0.893	0.038	0.069	0.1095	0.7	0.581	0.761	0.598	5.94	42.8	0.197	0.666	0.577	0.73	0.586	0.579	0.664	1.98	0.584	3.2
Anchor	POBI-SC-13-6-8	2013	1040819.3	636407.0	6	8	ft	50.8	0.149	0.422	0.429	0.939	6.07	9.3	49.1	16.5	1170	8580	3.37	5.4	9.6	62.2	15.4	9.99	25.7	657	32	1520
Anchor	POBI-SC-13-8-9	2013	1040819.3	636407.0	8	9	ft	10.9	0.156	0.486	0.357	0.1775	1.39	2.04	11.5	4.4	278	2050	0.743	1.24	1.8	11.5	3.43	1.81	2.67	142	6.26	348
Anchor	POBI-SC-14-1-2	2013	1039419.2	636507.3	1	2	ft	24.7	0.558	0.309	0.133	1.94	7.15	6.13	21.1	11.8	384	2240	7.63	4.41	5.69	10.7	6.4	2.08	9.43	162	6.29	290
Anchor	POBI-SC-14-2-3	2013	1039419.2	636507.3	2	3	ft	1.92	1.000	0.000	0.000	0.2085	1.01	0.245	0.696	0.639	3.45	12.9	1.36	0.635	0.688	0.444	0.225	0.161	0.516	0.71	0.02975	0.498
Anchor	POBI-SC-16-4-5	2013	1040140.8	636605.4	4	5	ft	56.7	0.247	0.435	0.319	1.51	9.2	11.9	58	26.7	1260	8870	4.79	5.65	9.21	52.9	17	8.64	26.8	653	26.6	1250
Anchor	POBI-SC-16-5-6	2013	1040140.8	636605.4	5	6	ft	15.6	0.395	0.165	0.440	0.935	3.46	2.3	10.5	5.39	187	1240	3.5	2.55	3.57	9.16	5	1.76	8.37	309	1.85	227
Anchor	POBI-SC-16-6-7	2013	1040140.8	636605.4	6	7	ft	1.35	0.799	0.071	0.130	0.1395	0.542	0.317	0.879	0.252	7.83	31.3	0.67	0.465	0.421	0.413	0.423	0.169	0.281	9.34	0.223	5.62
Anchor	POBI-SC-17-2-4	2013	1040809.1	636860.2	2	4	ft	24.8	0.201	0.636	0.163	0.341	3.71	5.11	28.3	12.1	749	5920	2.59	2.88	3.12	15.2	5.72	3.12	8.38	218	9.41	462
Anchor	POBI-SC-18-6-8	2013	1040779.7	636968.3	6	8	ft	65.9	0.025	0.490	0.485	0.737	4.28	7.72	68.7	16.5	1760	12500	1.345	4.9	10.2	83.3	19.2	13.2	35.8	1030	52.3	3200
Anchor	POBI-SC-18-8-9	2013	1040779.7	636968.3	8	9	ft	6.38	0.072	0.448	0.480	0.1245	0.58	0.834	6.18	1.75	159	1170	0.435	0.668	0.69	9.24	2.33	1.61	1.45	101	4.45	241
Anchor	POBI-SC-19-2-4	2013	1040783.5	637141.3	2	4	ft	584	0.000	0.252	0.748	3.53	20.9	31.4	477	86.5	11200	84900	38.9	76.6	287	1390	219	237	307	4550	405	16600
Anchor	POBI-SC-19-6-8	2013	1040783.5	637141.3	6	8	ft	77.3	0.027	0.705	0.268	1.12	5.66	10.2	88.3	20.6	2880	15500	5.06	5.26	11.5	49.3	12.5	10.1	21.8	1050	32.4	2700
Anchor	POBI-SC-20-13-15	2013	1040769.4	637116.7	13	15	ft	131	0.065	0.478	0.457	1.67	10.6	14.1	140	36.5	3370	25200	7.55	14	28.8	201	40.3	36.2	67.6	1270	98.5	2960
Anchor	POBI-SC-21-1-2	2013	1040388.7	637320.2	1	2	ft	4.99	0.467	0.236	0.297	0.226	1.34	1.04	4.2	1.9	70.4	394	1.48	0.915	1.1	2.2	1.52	0.596	1.11	82.3	0.57	52.4
Anchor	POBI-SC-22-7-8	2013	1040750.8	637244.9	7	8	ft	316	0.037	0.223	0.740	4.76	20.1	7.7	230	52.9	5510	47100	21.2	30.3	81.9	450	92.7	86.7	176	7860	231	12400
Anchor	POBI-SC-22-8-8.5	2013	1040750.8	637244.9	8	8.5	ft	357	0.000	0.338	0.662	3.17	15	8	310	51.7	7730	67800	18.6	39.5	114	684	117	141	191	4540	347	14500
Anchor	POBI-SC-23-6-8	2013	1040785.4	637260.9	6	8	ft	885	0.002	0.566	0.432	9.76	42.4	57.8	1410	276	23300	250000	38.4	30.9	50.8	276	121	71.2	435	21600	589	60400
Anchor	POBI-SC-24-2-3	2013	1040918.3	637452.3	2	3	ft	76.7	0.140	0.155	0.705	0.439	8.08	9.21	56.1	23.3	1080	7030	3.94	9.76	31.7	169	31.6	28.3	46.7	782	49.3	1020
Anchor	POBI-SC-25-1-2	2013	1040434.3	637835.3	1	2	ft	1.88	0.402	0.448	0.150	0.126	0.44	0.334	2.37	0.939	39.6	253	0.354	0.382	0.181	0.925	0.2735	0.178	0.2585	20.1	0.573	22.2
Anchor	POBI-SC-26-1-2	2013	1040894.5	637870.5	1	2	ft	5.32	0.272	0.525	0.203	0.1505	0.958	0.987	6.76	2.66	136	908	0.562	0.322	0.784	3.28	1.43	0.5	1.06	57.5	1.52	68.4
Anchor	POBI-SC-27-3-4	2013	1040482.5	638459.9	3	4	ft	7.41	0.290	0.351	0.359	0.1935	1.37	1.41	6.12	3.47	144	963	1.01	0.81	1.24	6.44	2.02	1.23	3.77	109	3.13	177
Anchor	POBI-SC-27-4-5	2013	1040482.5	638459.9	4	5	ft	4.71	0.229	0.380	0.390	0.126	0.727	0.919	4.57	2.22	99	620	0.2285	0.461	1.12	5.67	1.48	1.01	1.35	52.5	2.5	120
Anchor	POBI-SC-28-1-2	2013	1040463.1	639036.5	1	2	ft	10.8	0.270	0.433	0.297	0.2435	2.01	2.32	10.7	5.35	244	1520	1.36	1.19	0.755	8.66	3.31	1.54	2.63	171	4.7	292
Anchor	POBI-SC-29-0-1	2013	1040857.6	638858.1	0	1	ft	2.15	0.175	0.588	0.237	0.111	0.2515	0.495	2.73	1.37	57.1	387	0.153	0.287	0.239	1.22	0.342	0.341	1.03	23.3	0.846	22.6

Study ID	Sample Name	Year	Point_X*	Point_Y*	Upper Depth	Lower Depth	UOM	Total TEQ	Factor 1 Contribution	Factor 2 Contribution	Factor 3 Contribution	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
Anchor	POBI-SC-30-0-1	2013	1041156.4	638944.1	0	1	ft	2.55	0.378	0.375	0.246	0.1065	0.558	0.554	2.55	1.25	48.8	315	0.523	0.382	0.479	1.08	0.644	0.32	1.1	33.7	0.558	17.9
Anchor	POBI-SC-31-1-2	2013	1040869.7	639241.6	1	2	ft	1.32	0.350	0.632	0.018	0.0328	0.292	0.31	1.84	0.761	37.4	247	0.203	0.1115	0.0955	0.557	0.304	0.163	0.266	7.49	0.0795	7.66
Anchor	POBI-SC-32-0-1	2013	1042409.2	639263.4	0	1	ft	20.5	0.341	0.330	0.328	1.21	4.05	3.55	18.9	7.82	368	2670	4.58	3.43	3.84	8.8	5.49	2.18	8.98	341	3.81	187
Anchor	POBI-SC-32-1-2	2013	1042409.2	639263.4	1	2	ft	5.21	0.870	0.060	0.070	0.4575	2.26	1.16	2.69	1.88	25.3	123	3.33	1.77	1.6	1.15	1.37	0.371	1.9	28.4	0.1605	11.4
Anchor	POBI-SC-33-1-2	2013	1043624.8	638363.0	1	2	ft	7.47	0.479	0.403	0.118	0.281	2	2.31	7.37	4.96	144	879	0.805	1.35	1.56	3.84	2.25	0.867	1.88	49.3	2.42	92.6
Anchor	POBI-SC-34-0-1	2013	1043169.6	638319.9	0	1	ft	7.6	0.307	0.622	0.071	0.2415	1.47	1.9	9.09	4.35	213	1520	2.07	1.1	0.58	3.85	1.69	0.908	1.51	51.4	2.12	84.9
Anchor	POBI-SC-35-0-1	2013	1042902.9	638103.5	0	1	ft	5.37	0.257	0.719	0.024	0.148	0.921	1.33	7.14	3.12	173	1330	0.641	0.2985	0.673	1.26	1.2	0.752	0.53	33.6	0.725	55.2
Anchor	POBI-SC-35-1-2	2013	1042902.9	638103.5	1	2	ft	2.38	0.130	0.721	0.149	0.095	0.2715	0.484	3.18	0.7	81.1	585	0.146	0.366	0.229	1.52	0.3095	0.185	0.981	18	0.863	27.9
Anchor	POBI-SC-36-3-4	2013	1042718.4	637958.8	3	4	ft	5.66	0.184	0.716	0.100	0.158	0.809	0.993	6.63	2.66	188	1470	0.3105	0.694	0.4045	3.36	1.27	0.83	1.94	38.4	1.9	79.8
Anchor	POBI-SC-36-4-5	2013	1042718.4	637958.8	4	5	ft	2.41	0.068	0.770	0.162	0.1045	0.1935	0.52	3	1.17	87	678	0.118	0.316	0.395	1.49	0.274	0.401	0.2225	17.3	0.812	32.7
Anchor	POBI-SC-37-1-2	2013	1042912.2	637428.8	1	2	ft	1.21	0.399	0.588	0.013	0.0312	0.3	0.322	1.48	0.768	32.1	238	0.1055	0.187	0.0865	0.581	0.253	0.162	0.0935	7.04	0.285	11
Anchor	POBI-SC-39-1-2	2013	1043316.5	637284.3	1	2	ft	3.53	0.906	0.031	0.063	0.376	1.55	0.631	1.5	1.21	14.1	86.5	2.7	1.5	1.29	0.716	0.79	0.0347	1.01	13.7	0.246	6.12
Anchor	POBI-SC-42-1-2	2013	1043891.8	636237.5	1	2	ft	4.78	0.274	0.453	0.273	0.244	0.695	1.66	5.36	3.24	101	618	1.4	1.08	1.41	3.43	1.68	0.594	1.03	31.9	0.97	69.9
Anchor	POBI-SC-44-1-2	2013	1042989.3	635979.2	1	2	ft	15.1	0.676	0.137	0.187	1.43	5.04	2.83	9.35	4.84	139	830	4.9	3.23	5.34	4.67	5.17	1.53	8.99	103	2.27	189
Anchor	POBI-SC-44-2-3	2013	1042989.3	635979.2	2	3	ft	8.69	0.728	0.047	0.225	0.471	3.13	1.51	4.86	2.5	48.6	265	3.46	2.08	3.74	2.53	3.64	1.07	6.97	62.6	1.41	148
Anchor	POBI-SC-44-3-4	2013	1042989.3	635979.2	3	4	ft	11.4	0.814	0.049	0.137	0.675	4.68	2.42	6.34	3.96	55.1	288	4.27	2.67	4.35	3.19	4.21	1.29	7.34	63.8	1.49	154
Anchor	POBI-SC-45-1-2	2013	1043304.1	635974.5	1	2	ft	57.9	0.199	0.742	0.059	0.715	8.6	14.1	74.2	33.2	1940	15300	4.28	4.9	6.29	27.7	11.2	6.89	18	318	22.5	761
Anchor	POBI-SC-45-2-3	2013	1043304.1	635974.5	2	3	ft	1.08	0.516	0.385	0.100	0.1	0.307	0.255	0.896	0.724	19.4	157	0.0655	0.129	0.0257	0.396	0.1245	0.0732	0.342	12.3	0.1215	12.3
Anchor	POBI-SC-47-0-1	2013	1043355.4	635468.7	0	1	ft	15.5	0.429	0.496	0.074	0.739	3.82	3.68	17.3	8.02	354	2320	2.95	2.27	1.735	8.51	4.42	0.905	6.77	83.3	3.26	104
Anchor	POBI-SC-47-1-2	2013	1043355.4	635468.7	1	2	ft	9.2	0.895	0.081	0.024	0.545	4.25	1.125	5.43	4.09	51.1	280	4.97	2.81	3.68	2.78	3.12	0.808	2.545	12	0.796	13.7
Anchor	POBI-SC-47-2-3	2013	1043355.4	635468.7	2	3	ft	6.12	0.908	0.019	0.074	1.08	2.52	0.65	1.5	1.93	27.1	153	4.62	2.3	2.21	2	1.35	0.439	1.01	10.4	0.659	27.1
Anchor	POBI-SC-48-1-2	2013	1043869.6	634887.9	1	2	ft	2.13	0.331	0.559	0.110	0.118	0.435	0.653	2.26	0.69	58.3	436	0.1695	0.1555	0.449	1.15	0.571	0.194	0.2435	11.7	0.2945	23.8
Anchor	POBI-SC-49-0-1	2013	1043407.6	634656.3	0	1	ft	319	0.144	0.526	0.330	8.83	36.8	46.2	326	105	8300	83000	34.3	35.8	53.9	337	89.4	65.3	127	3170	136	5510
Anchor	POBI-SC-49-10.5-11.4	2013	1043407.6	634656.3	10.5	11.4	ft	212	0.170	0.513	0.317	6.29	26.7	35.5	209	77.8	5440	44200	16.7	22.2	36	185	57.9	42.1	92.9	2350	165	9220
Anchor	POBI-SC-49-1-2	2013	1043407.6	634656.3	1	2	ft	1280	0.117	0.434	0.448	33	126	151	1410	411	27800	366000	67.5	155	232	1450	404	239	543	17900	633	31300
Anchor	POBI-SC-49-2-3	2013	1043407.6	634656.3	2	3	ft	144	0.165	0.628	0.208	3.26	18.2	27	189	66	4210	34900	12.5	16.7	23.8	126	37.3	29.6	23.1	981	59.4	2250
Anchor	POBI-SC-49-3-4	2013	1043407.6	634656.3	3	4	ft	99.8	0.213	0.701	0.086	5.03	13.4	21	142	55.4	2980	24400	19.4	10.8	13.4	42	18.9	12.4	30.7	500	32.9	1190
Anchor	POBI-SC-49-4-6	2013	1043407.6	634656.3	4	6	ft	26.8	0.193	0.725	0.082	1.42	3.51	4.99	34.5	13.3	876	5840	5.19	2.63	3.61	11.7	5.17	3.31	8.36	133	9.82	446
Anchor	POBI-SC-49-6-8	2013	1043407.6	634656.3	6	8	ft	50.9	0.193	0.744	0.062	1.27	6.92	9.28	70.7	28	1700	10900	15.4	5.73	7.49	19.9	8.19	5.48	13.9	250	16.2	755
Anchor	POBI-SC-50-1-2	2013	1043495.9	634188.4	1	2	ft	28.4	0.302	0.438	0.259	1.96	4.79	5.79	27.6	12.8	607	4310	3.88	4.23	5.95	22.9	8.61	5.65	13.4	199	12.3	522
Anchor	POBI-SC-50-12.4-13	2013	1043495.9	634188.4	12.4	13	ft	12.4	0.729	0.061	0.210	0.655	4.63	2.19	6.44	4	75.5	499	4.47	2.96	4.81	3.72	4.87	1.32	8.7	105	2.12	233
Anchor	POBI-SC-50-2-3	2013	1043495.9	634188.4	2	3	ft	21.9	0.033	0.471	0.495	0.3945	1.46	1.56	19.4	4.44	557	5290	0.85	2.02	4.12	33.2	6.8	6.68	12.5	254	18.8	941
Anchor	POBI-SC-50-3-4	2013	1043495.9	634188.4	3	4	ft	37	0.139	0.339	0.522	1.12	3.93	4.5	32.2	10.8	756	5630	2.72	4.74	12.2	63	14.7	12.1	10	317	31.7	1470
Anchor	POBI-SC-50-4-6	2013	1043495.9	634188.4	4	6	ft	225	0.051	0.101	0.848	2.86	12.5	11.9	147	31.6	2960	26900	14.7	29	126	599	100	118	140	1420	174	4550
Anchor	POBI-SC-50-6-8	2013	1043495.9	634188.4	6	8	ft	122	0.032	0.110	0.858	1.59	5.97	5.81	77.7	15.7	1630	15200	7.89	18	60.9	333	57	70.2	84.2	809	99.6	2380
Anchor	POBI-SC-50-8-10	2013	1043495.9	634188.4	8	10	ft	167	0.041	0.473	0.487	2.84	11.9	13.8	178	37.2	4190	33500	6.37	10.7	25.5	275	50.2	46.6	90.5	1810	190	8410
Anchor	POBI-SS-01SG	2013	1040484.7	634671.4	0	10	cm	10.8	0.151	0.678	0.170	0.2285	1.18	3.03	15.5	7.09	315	2430	1.48	1.31	1.4	5.52	2.92	1.32	4.4	86.6	3.48	155
Anchor	POBI-SS-02SG	2013	1041142.3	634772.6	0	10	cm	36.8	0.267	0.733	0.000	0.946	6.7	11.3	38.9	24.8	1200	12300	2.28	2.37	2.26	9.28	5.66	2.59	9.96	187	12.9	707
Anchor	POBI-SS-03SG	2013	1041136.4	635129.2	0	10	cm	17.7	0.258	0.706	0.036	0.387	3.06	4.99	21.2	10.4	551	4980	2.14	1.76	1.51	5.77	3.55	1.81	4.72	118	2.82	416
Anchor	POBI-SS-04SG	2013	1040836.9	635301.2	0	10	cm	15.5	0.292	0.620	0.088	0.3205	2.93	3.6	17.9	8.38	433	3900	0.92	1.88	1.7	7.7	3.49	2.47	5.59	104	5.46	225
Anchor	POBI-SS-05SG	2013	1040389.3	635122.7	0	10	cm	7.61	0.365	0.540	0.095	0.1675	1.69	1.87	9.35	4.26	188	1360	0.585	0.96	1.05	3.42	1.87	0.932	2.98	54.3	2.21	87.6
Anchor	POBI-SS-06SG	2013	1040940.2	635558.6	0	10	cm	1.96	0.150	0.644	0.206	0.02025	0.2305	0.2775	2.73	1.31	57.9	433	0.107	0.286	0.313	1.29	0.366	0.1405	0.879	17.2	0.899	36
Anchor	POBI-SS-07SG	2013	1040394.8	635565.0	0	10	cm	9.61	0.302	0.568	0.130	0.202	1.8	2.37	12.6	5.76	246	1770	1.23	1.13	1.27	4.74	2.34	1.2	3.64	76.1	1.56	129
Anchor	POBI-SS-08SG	2013	1040020.3	635552.9	0	10	cm	14.5	0.468	0.496	0.036	0.2735	3.93	3.36	21.9	10.1	305	2160	1.51	1.42	1.5	5.45	3.01	1.4	4.47	94.5	3.62	149
Anchor	POBI-SS-09SG	2013	1039485.4	635506.2	0	10	cm	4.52	0.536	0.464	0.000	0.156	1.41	1.53	5.41	3.12	94.9	596	0.4065	0.2465	0.567	1.31	0.826	0.412	1.22	20.7	0.388	32.5
Anchor	POBI-SS-10SG	2013	1040879.8	635945.0	0	10	cm	20.5	0.325	0.607	0.069	0.283	4.13	7.01	23.8	15.2	545	4380	1.76	1.52	1.74	7.73	4.36	1.89	6.86	164	8.69	563
Anchor	POBI-SS-11SG	2013	1040461.1	635941.3	0	10	cm	21	0.291	0.570	0.139	0.327	3.93	4.94	27.2	11.7	546	4080	2.57	2.38	2.39	10.7	5	2.43	7.86	187	6.51	286
Anchor	POBI-SS-12SG	2013	1040018.8	635950.7	0	10	cm	13.7	0.161	0.640	0.198	0.2755	1.54	3.67	20.5	9.04	378	2710	1.89	1.66	1.84	7.21	3.63	1.74	5.75	123	4.69	195
Anchor	POBI-SS-13SG	2013	1040860.2	636545.0	0	10	cm	24.8	0.272	0.529	0.199	0.3525	4.48	6.53	26.3	15	623	5320	2.5	3.25	3.18	22.2	6.65	2.39	7.48	201	7.75	466
Anchor	POBI-SS-14SG	2013	1040435.6	636439.0	0	10	cm	21.4	0.298	0.565	0.137	0.3115	4.1	4.9	27.2	12.4	557	3930	2.56	2.33	2.51	11.2	5.1	2.52	8.04	188	6.5	284
Anchor	POBI-SS-15SG	2013	1039959.3	636454.5	0	10	cm	14.8	0.157	0.632	0.211	0.3365	1.6	3.93	21.8	10	400	3100	2.09	0.97	2.08	7.95	3.76	1.71	6.84	134	5.19	215
Anchor	POBI-SS-16SG	2013	1039420.6	636473.8	0	10	cm	24.2	0.438	0.490	0.072	1.05	5.96	6.84	30.9	14.5	525	3280	3.6	2.7	3.05	8.88	5.47	2.27	9.56	164	5.88	223
Anchor	POBI-SS-17SG	2013	1040806.8	637183.8	0	10	cm	23.2	0.249	0.617	0.134	0.307	3.96	5.32	27	13	667	5220	2.29	2.39	2.93	14.1	5.03	3.04	8.22	176	8.55	453

Study ID	Sample Name	Year	Point_X*	Point_Y*	Upper Depth	Lower Depth	UOM	Total TEQ	Factor 1 Contribution	Factor 2 Contribution	Factor 3 Contribution	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
Anchor	POBI-SS-18SG	2013	1040724.1	637306.7	0	10	cm	19.7	0.288	0.571	0.141	0.2975	3.63	4.47	26.1	12.3	509	3700	2.15	2.09	2.31	10.8	4.57	2.3	7.39	167	6.44	334
Anchor	POBI-SS-19SG	2013	1040849.8	637446.3	0	10	cm	31	0.189	0.633	0.178	0.787	4.18	7.19	37.2	17.2	903	7050	2.33	3.23	4.64	22.3	7.32	5.2	11.6	212	10.9	471
Anchor	POBI-SS-20SG	2013	1040661.9	637584.7	0	10	cm	20.3	0.306	0.563	0.131	0.3175	3.93	4.76	26	12	521	3750	2.49	2.22	2.36	10.5	4.71	2.21	7.93	172	6.49	266
Anchor	POBI-SS-21SG	2013	1039983.6	637530.4	0	10	cm	3.88	0.319	0.568	0.113	0.1185	0.782	0.4665	5.82	1.17	102	656	0.2425	0.2115	0.449	0.915	1.07	0.558	1.92	37.5	1.4	68
Anchor	POBI-SS-22SG	2013	1039580.9	637517.5	0	10	cm	19.1	0.405	0.475	0.120	0.729	4.33	4.9	26.5	11.1	395	2530	2.96	2.18	2.3	7.91	4.83	2.57	8.6	153	5.29	189
Anchor	POBI-SS-23SG	2013	1040768.9	638055.3	0	10	cm	5.71	0.306	0.587	0.107	0.127	1.13	0.67	6.94	3.37	155	1210	0.589	0.605	0.609	2.91	1.23	0.704	2.11	45.1	1.75	64.8
Anchor	POBI-SS-24SG	2013	1040260.6	638042.0	0	10	cm	19.2	0.329	0.538	0.133	0.357	3.82	4.32	28.4	13.2	450	3100	2.35	2.06	1.98	9.32	4.58	2.2	6.97	171	5.85	248
Anchor	POBI-SS-25SG	2013	1039836.1	638053.5	0	10	cm	23.4	0.307	0.542	0.151	0.354	4.51	5.47	34.1	12.9	572	3640	2.52	2.42	2.46	10.9	6.06	2.56	10.6	229	7.5	283
Anchor	POBI-SS-26SG	2013	1039545.3	638001.1	0	10	cm	19.4	0.385	0.488	0.126	0.478	4.33	4.63	28.3	10.7	416	2850	2.95	2.08	2.57	7.69	4.74	2.06	8.45	168	5.84	244
Anchor	POBI-SS-27SG	2013	1039444.7	638610.9	0	10	cm	48.6	0.388	0.511	0.101	1.42	11.1	11.3	73.2	26.3	1090	6600	3.96	3.93	4.65	16.4	10.9	5.56	22.8	433	13.8	638
Anchor	POBI-SS-28SG	2013	1039851.8	638669.9	0	10	cm	17.3	0.147	0.623	0.230	0.354	1.82	4.25	28	10.5	463	3100	2.28	1.015	1.94	8.95	4.7	2.23	8.51	184	6.27	246
Anchor	POBI-SS-29SG	2013	1040084.0	638438.5	0	10	cm	10.9	0.348	0.543	0.109	0.227	2.34	2.42	15.8	5.99	261	1720	0.67	1.2	0.605	5.03	2.7	1.45	4.86	99.3	3.4	131
Anchor	POBI-SS-30SG	2013	1040825.5	638532.8	0	10	cm	9.71	0.407	0.427	0.166	0.317	2.26	1.93	11.2	4.72	198	1420	2.14	1.53	2.05	5.17	2.27	1.18	4.05	75	2.36	86.9
Anchor	POBI-SS-31SG	2013	1040904.9	639271.0	0	10	cm	11.8	0.303	0.502	0.196	0.2655	2.29	2.54	14	7.03	284	1910	0.815	1.32	1.41	5.52	2.62	1.48	4.29	147	3.29	140
Anchor	POBI-SS-33SG	2013	1041335.8	638567.8	0	10	cm	2.34	0.429	0.461	0.109	0.11	0.575	0.587	2.49	1.48	50.7	332	0.273	0.31	0.357	1.25	0.526	0.098	0.946	15.8	0.465	17.6
Anchor	POBI-SS-34SG	2013	1041426.5	639272.6	0	10	cm	2.33	0.348	0.501	0.151	0.134	0.499	0.2965	2.86	0.705	57.3	399	0.225	0.367	0.369	1.19	0.633	0.335	0.4775	20.2	0.63	21
Anchor	POBI-SS-35SG	2013	1042465.0	639296.3	0	10	cm	27.6	0.338	0.520	0.142	1.28	5.55	5.86	31.2	12.7	679	4700	5.53	4.11	4.56	13.7	6.08	3.26	10.2	210	6.33	254
Anchor	POBI-SS-36SG	2013	1042995.7	638191.5	0	10	cm	21.3	0.301	0.625	0.074	0.366	4.14	5.04	25.9	12.9	609	4430	2.71	2.48	2.59	9.74	4.82	1.275	7.72	138	6.18	251
Anchor	POBI-SS-37SG	2013	1043605.4	638407.7	0	10	cm	8.67	0.368	0.539	0.092	0.231	1.89	2.33	9.9	5.01	216	1470	1.54	1.36	1.56	4.03	2.13	0.97	3.11	49.7	2.02	70.3
Anchor	POBI-SS-38SG	2013	1042938.6	637674.3	0	10	cm	26.5	0.283	0.630	0.087	0.417	4.9	6.17	33.3	16.8	759	5530	3.17	3.01	3.03	12.4	6.01	1.625	9.5	187	7.24	304
Anchor	POBI-SS-39SG	2013	1043712.3	637698.6	0	10	cm	6.27	0.436	0.509	0.055	0.174	1.56	1.87	6.85	4.46	145	929	0.898	0.84	1.09	2.61	1.45	0.701	2.3	31.4	0.725	52.7
Anchor	POBI-SS-40SG	2013	1042751.9	637372.9	0	10	cm	22.9	0.261	0.642	0.096	0.3835	3.98	5.6	28.2	14.7	668	4860	2.36	1.18	2.59	10.5	4.88	2.82	8.18	170	6.73	283
Anchor	POBI-SS-41SG	2013	1042943.8	637429.9	0	10	cm	31.9	0.291	0.627	0.082	0.51	6.02	8.07	38.1	19.7	913	6630	3.63	3.11	3.79	14.8	7.24	3.8	11	217	8.65	346
Anchor	POBI-SS-42SG	2013	1043225.1	637313.2	0	10	cm	30.8	0.302	0.610	0.088	0.52	5.82	7.49	40.6	22.3	830	5810	3.44	3.3	3.32	14.5	6.72	3.48	11.2	215	8.76	384
Anchor	POBI-SS-43SG	2013	1043050.8	637092.0	0	10	cm	31.4	0.273	0.624	0.103	0.458	5.61	7.66	38.6	20	894	6410	3.55	3.57	3.95	15.1	7.19	3.83	11.4	228	9.14	364
Anchor	POBI-SS-44SG	2013	1043607.1	637095.7	0	10	cm	8.91	0.411	0.564	0.025	0.197	2.21	2.64	10.6	6.65	225	1480	0.64	0.59	0.75	4	1.145	1.02	3.45	51.8	1.22	85.4
Anchor	POBI-SS-45SG	2013	1043079.0	636797.0	0	10	cm	34.6	0.316	0.608	0.076	0.46	6.84	8.94	47.1	23.3	927	6720	3.55	3.66	3.97	15.6	7.75	3.65	11.9	230	10.1	433
Anchor	POBI-SS-46SG	2013	1043754.1	636698.6	0	10	cm	22.8	0.456	0.476	0.068	0.665	5.9	6.41	22.3	13.8	512	3260	4.59	3.8	4.82	10.3	5.56	2.63	8.86	102	5.4	172
Anchor	POBI-SS-47SG	2013	1043100.0	636427.0	0	10	cm	38.5	0.310	0.600	0.090	0.59	7.55	10.4	45.3	24.7	1050	7550	4.54	4.16	4.72	18.3	8.94	4.69	13.8	268	12.2	494
Anchor	POBI-SS-48SG	2013	1043089.4	636202.9	0	10	cm	37.9	0.295	0.606	0.099	1.04	7.07	9.74	44	23.1	1050	7520	3.75	3.94	4.73	18.6	8.71	4.49	13.8	258	11.7	497
Anchor	POBI-SS-49SG	2013	1043398.4	636212.7	0	10	cm	39.5	0.318	0.569	0.113	1.14	7.67	11.1	45.7	24.2	1030	7040	4.41	4.31	5.68	20.5	9.33	4.84	14.9	264	13.7	533
Anchor	POBI-SS-50SG	2013	1043846.5	636280.4	0	10	cm	14	0.465	0.457	0.079	0.403	3.68	4.09	14.3	9.26	299	1880	2.49	2.04	2.77	6.42	3.52	0.785	5.7	74.6	3.75	125
Anchor	POBI-SS-51SG	2013	1042976.6	635926.1	0	10	cm	34.3	0.291	0.600	0.109	0.487	6.48	9.2	39.4	20.4	952	7010	3.46	3.64	4.45	17.2	7.76	3.78	13.3	255	11.8	478
Anchor	POBI-SS-52SG	2013	1043274.4	635933.6	0	10	cm	40.9	0.289	0.592	0.119	0.645	7.61	10.7	48.1	24	1120	7870	4.2	4.4	5.82	22.5	10	4.62	16.8	282	14.5	646
Anchor	POBI-SS-53SG	2013	1043349.4	635519.0	0	10	cm	18.4	0.443	0.427	0.130	1.23	4.32	4.27	19.1	9.81	369	2350	4.32	2.93	4.14	9.08	4.37	2.17	7.02	95.7	5.11	194
Anchor	POBI-SS-54SG	2013	1043743.1	635569.7	0	10	cm	30.6	0.608	0.339	0.053	1.79	9.85	9.85	27.9	18.2	490	2900	6.82	4.97	6.62	11.9	7.32	2.79	10.8	137	7	233
Anchor	POBI-SS-55SG	2013	1043982.6	635686.7	0	10	cm	15.1	0.423	0.489	0.088	0.387	3.63	4.5	16	10.8	339	2140	2.44	2.06	2.77	7.08	3.85	1.77	6.32	83.8	4.3	161
Anchor	POBI-SS-56SG	2013	1043355.8	635149.3	0	10	cm	46.8	0.277	0.511	0.211	1.6	8.08	10.9	50.1	22	1160	8250	5.36	6.24	9.39	35.6	12.7	7.87	19.8	328	16.2	628
Anchor	POBI-SS-57SG	2013	1043899.3	634914.8	0	10	cm	9.82	0.370	0.587	0.043	0.235	2.16	3.14	11.4	7.14	253	1660	1.25	0.6	0.775	4.48	2.5	1.21	4.24	55.2	3.12	106
Anchor	POBI-SS-58SG	2013	1043393.6	634700.1	0	10	cm	49.9	0.289	0.545	0.166	1.86	8.82	11.9	55.9	26.5	1270	8820	5.8	5.69	8.24	32.8	12.3	8.57	21.1	330	21.1	838
Anchor	POBI-SS-59SG	2013	1043402.2	634334.9	0	10	cm	98	0.158	0.793	0.049	0.885	12.8	24.6	130	54.5	3490	27100	5.54	7.49	9.93	47.2	17.7	13.3	31.2	480	43.5	1480
Anchor	POBI-SS-60SG	2013	1043550.3	634240.0	0	10	cm	20.1	0.338	0.600	0.061	0.35	4.1	6.82	24.9	15	531	3680	1.69	1.9	2.71	8.61	4.89	1.23	7.5	114	7.77	364
Anchor	POBI-SS-61SG	2013	1041194.2	635095.8	0	10	cm	45.9	0.229	0.641	0.130	0.842	7.11	16.1	49.6	34.8	1300	10500	1.48	2.85	2.49	12.2	15.4	3.35	13.4	552	21	1900
Anchor	POBI-SS-62SG	2013	1041096.5	635090.6	0	10	cm	29.5	0.232	0.768	0.000	0.3375	4.9	8.15	35.5	18.8	1000	9170	1.99	2.14	2.28	9.02	5.07	2.72	8.15	161	8.52	384
Anchor	POBI-SS-63SG	2013	1041182.0	635008.0	0	10	cm	26.1	0.203	0.797	0.000	0.3285	4.12	6.82	32.1	15.1	942	9020	1.74	1.97	1.85	7.5	4.57	2.37	3.78	132	6.74	369
Anchor	POBI-SS-64SG	2013	1041176.8	634658.1	0	10	cm	15.4	0.186	0.814	0.000	0.215	2.38	3.8	18.3	8.58	585	5820	1.23	1.15	1.13	3.87	2.16	1.35	1.155	65.3	3.87	205
Anchor	POBI-SS-65SG	2013	1041151.8	634582.8	0	10	cm	35.7	0.229	0.771	0.000	0.415	6.26	9.44	43.3	23.2	1270	11900	1.88	2.18	1.215	9.53	5.49	2.86	8.95	161	8.81	396
AODE5272	HC-WB-SS-003	2011	1038363.0	640711.2	0	10	cm	13.2	0.245	0.709	0.047	0.1165	2.26	3.71	20.8	6.53	418	3030	1.03	1.45	1.45	4.93	2.77	1.49	2.78	82.5	3	84.9
AODE5272	HC-WB-SS-004	2011	1038362.3	640749.8	0	10	cm	10.9	0.311	0.689	0.000	0.12	2.29	4.46	14.6	6.88	340	3010	0.825	0.878	0.839	2.58	1.78	0.323	2.65	42.5	1.78	45.6
Budd Inlet Hardel 07	GS-01	2007	1038861.8	638563.6	0	10	cm	25.7	0.343	0.478	0.179	0.99	5	6.6	36	14	550	3800	1.3	5	5	8.4	7.5	5	8.4	250	9.4	410
Budd Inlet Hardel 07	GS-02	2007	1039167.0	638161.0	0	10	cm	43	0.445	0.498	0.057	1.6	11	11	59	24	950	6200	2.5	4.9	5.9	11	15	4.9	8.8	320	13	520
Budd Inlet Hardel 07	GS-03	2007	1039258.9	637808.1	0	10	cm	25.5	0.293	0.629	0.078	0.94	4.6	5.7	33	12	720	6200	2.3	4.6	4.6	4.6	5.7	4.6	5.1	190	7.3	390
Budd Inlet W Bay 07	POC-C10	2007	1040765.7	636346.2	0	2	ft	18.2	0.167	0.640	0.193	0.195	2.2	4.2	24	10	530	4500	1.9	2.5	4	9.7	5.2	2	6.5	140	6.3	240

Study ID	Sample Name	Year	Point_X*	Point_Y*	Upper Depth	Lower Depth	UOM	Total TEQ	Factor 1 Contribution	Factor 2 Contribution	Factor 3 Contribution	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
Budd Inlet W Bay 07	POC-C12	2007	1040733.2	636952.0	0	2	ft	30.4	0.193	0.614	0.193	0.77	3.9	8.2	40	15	840	7500	2.8	4.9	6.9	16	7.4	3.7	11	220	11	440
Budd Inlet W Bay 07	POC-C13	2007	1040732.3	637246.2	0	2	ft	25.7	0.200	0.595	0.205	0.58	3.4	7.9	31	14	700	6600	2.5	2.3	6.4	14	5.6	3.6	6.6	200	9.7	480
Budd Inlet W Bay 07	POC-C13-B	2007	1040732.3	637246.2	4	5.2	ft	63.5	0.157	0.569	0.274	1.3	7.6	15	75	26	1800	13000	5.2	5.5	17	50	16	12	13	550	29	1300
Budd Inlet W Bay 07	POC-C6	2007	1040815.1	636944.6	0	2	ft	20.5	0.158	0.630	0.213	0.5	2.6	3.6	22	8.1	640	4800	1.7	1.8	4	14	5.7	4.3	3.7	180	8.8	330
Budd Inlet W Bay 07	POC-C7	2007	1040808.7	637101.1	0	2	ft	28.1	0.131	0.662	0.208	0.39	3.6	4.4	32	9.5	970	6300	2.1	0.345	4.4	24	0.28	5	4.4	270	12	580
Budd Inlet W Bay 07	POC-C7-B	2007	1040808.7	637101.1	4	6	ft	8.4	0.016	0.821	0.163	0.075	0.53	1.4	12	2.7	310	1900	0.48	7.8	0.075	0.09	2.6	2.4	1.8	130	7.6	500
Budd Inlet W Bay 07	POC-C8	2007	1040793.6	637247.3	0	2	ft	15.9	0.071	0.669	0.260	0.34	1.3	2.4	14	4.6	500	7700	1.1	1.3	4.7	13	1.6	3.5	2.5	110	7.6	280
Budd Inlet W Bay 07	POC-C8-B	2007	1040793.6	637247.3	4	6	ft	703	0.000	0.379	0.621	1.8	12	34	650	87	18000	130000	18	29	290	1300	410	200	150	8600	560	19000
Budd Inlet W Bay 07	POC-C9	2007	1040800.0	637320.1	0	2	ft	20.6	0.064	0.489	0.447	0.45	1.4	3.3	23	7.6	550	4800	1.3	2.2	9.5	25	0.19	5.7	3.5	170	12	500
Budd Inlet W Bay 07	POC-S1	2007	1040984.0	635555.3	0	2	ft	5.77	0.228	0.772	0.000	0.05	0.96	2.3	5.9	4.5	200	1800	0.17	0.23	0.43	1.1	0.76	0.44	1.3	35	3.2	200
Budd Inlet W Bay 07	POC-S2	2007	1040912.5	636569.2	0	4	ft	0.71	0.398	0.564	0.038	0.0495	0.15	0.34	0.85	0.6	17	120	0.036	0.065	0.13	0.21	0.0315	0.0295	0.18	3.2	0.055	12
Budd Inlet W Bay 07	POC-S3	2007	1040830.1	637309.7	0	3	ft	4.54	0.223	0.395	0.383	0.15	0.6	1	4.2	1.9	97	700	0.35	0.62	1.9	4.2	1.3	1.4	2.1	32	2.4	97
Budd Inlet W Bay 07	POC-S4	2007	1040833.2	637344.6	0	3	ft	44.7	0.122	0.573	0.305	0.65	4.6	11	43	24	1300	11000	1.7	3.5	15	40	0.255	15	6.8	360	30	1600
Budd Inlet W Bay 07	POC-S5	2007	1040875.2	637334.4	0	4	ft	1.62	0.435	0.565	0.000	0.075	0.41	0.75	1.6	1.4	41	320	0.12	0.075	0.19	0.21	0.31	0.0405	0.44	6.6	0.6	27
BUDD07	BI-C1	2007	1040462.1	635422.7	0	10	cm	9.57	0.233	0.632	0.135	0.283	1.44	2.44	14	7.27	265	1890	0.631	1.02	1.28	4.79	2.42	0.1265	2.23	75.5	3.16	131
BUDD07	BI-C10	2007	1043219.3	637313.9	0	10	cm	30.6	0.206	0.698	0.096	0.848	4.36	7.34	40.7	21.9	948	7540	2.83	3.29	3.97	14.5	6.77	0.575	6.25	206	8.51	400
BUDD07	BI-C10-2-3 FT	2007	1043216.2	637311.4	2	3	ft	1.66	0.189	0.779	0.032	0.0405	0.231	0.411	2.06	1.18	55.6	641	0.0427	0.166	0.206	0.708	0.291	0.04465	0.133	8.26	0.437	14.6
BUDD07	BI-C12	2007	1036905.5	646413.8	0	10	cm	18.9	0.277	0.527	0.196	0.559	3.15	5.42	25	15.2	442	3210	2.7	2.16	2.95	13.6	4.73	0.427	4.63	155	6.69	287
BUDD07	BI-C1-2-3FT	2007	1040459.3	635427.6	2	3	ft	31.5	0.222	0.640	0.138	1.06	4.66	6.65	50	20.5	892	5930	2.74	3.15	3.47	17.4	7.91	0.631	7.02	252	8.76	314
BUDD07	BI-C13	2007	1042282.5	638604.2	0	10	cm	26.2	0.177	0.755	0.068	0.669	3.46	5.41	37.3	16.1	903	6410	2.5	3.57	4.78	12.3	4.4	0.459	4.49	114	4.71	173
BUDD07	BI-C13-1-2 FT	2007	1042275.9	638616.0	1	2	ft	14.8	0.171	0.501	0.328	0.55	1.84	2.52	16.7	7.53	380	2830	1.6	2.04	2.83	7.29	3.65	0.284	3.84	245	2.43	133
BUDD07	BI-C13-2-3 FT	2007	1042275.9	638616.0	2	3	ft	12.1	0.391	0.000	0.609	1.14	2.57	1.69	6.38	4.17	58.7	322	4.09	3.06	3.42	4.29	3.74	0.214	4.21	369	1.47	116
BUDD07	BI-C1-3-4FT	2007	1040459.3	635427.6	3	4	ft	21.6	0.245	0.504	0.251	0.845	3.35	5.03	28.1	13.7	515	3470	1.23	2.75	3.82	17.2	6.27	0.425	5.7	205	5.98	248
BUDD07	BI-C14	2007	1040957.7	637706.4	0	10	cm	13.8	0.168	0.663	0.169	0.4	1.78	2.96	17.5	10.2	428	3020	0.535	1.27	1.45	6	2.83	0.234	2.59	161	3.8	245
BUDD07	BI-C14-3-4FT	2007	1040951.2	637711.4	3	4	ft	6.68	0.201	0.421	0.377	0.0895	0.951	1.61	7.78	4.24	146	903	0.317	0.709	1.24	6.97	2.18	0.126	1.98	92.2	3.03	159
BUDD07	BI-C1-4-5 FT	2007	1040459.3	635427.6	4	5	ft	15.9	0.311	0.385	0.304	0.824	2.84	3.37	17.7	9.49	312	1840	2.67	2.54	3.88	11.5	5.17	0.351	4.77	176	4	147
BUDD07	BI-C15	2007	1040795.2	636115.0	0	10	cm	19	0.227	0.639	0.133	0.537	2.87	4.77	25.9	13.8	538	4220	1.57	1.91	2.25	9.48	4.59	0.423	4.01	161	6.88	340
BUDD07	BI-C15-2-3 FT	2007	1040802.2	636106.7	2	3	ft	33	0.169	0.622	0.209	0.788	4.24	8.03	43.3	22.2	954	7190	2.4	2.93	3.48	18.5	7.05	0.611	6.56	400	11.4	641
BUDD07	BI-C15-4-5 FT	2007	1040802.2	636106.7	4	5	ft	36.4	0.132	0.530	0.337	0.878	4	6.14	45.1	18.3	967	7140	2.66	4.65	6.66	37.7	11.3	1.16	7.94	414	18.9	771
BUDD07	BI-C15-6-7FT	2007	1040802.2	636106.7	6	7	ft	1.13	0.000	0.988	0.012	0.029	0.06	0.319	1.14	0.613	51	490	0.023	0.0437	0.04415	0.361	0.13	0.0428	0.132	7.23	0.923	44.2
BUDD07	BI-C16	2007	1040691.9	636511.5	0	10	cm	19.2	0.209	0.649	0.142	0.449	2.77	4.32	27.3	13.6	558	4110	1.62	2.02	2.47	10.2	4.48	0.387	4.3	160	6.25	280
BUDD07	BI-C16-1-2 FT	2007	1040693.7	636514.0	1	2	ft	4.6	0.154	0.344	0.501	0.174	0.541	0.727	4.66	1.95	93.9	627	0.1555	0.517	1.01	4.67	1.42	0.0535	1.12	89.8	2.43	146
BUDD07	BI-C1-6-7FT	2007	1040459.3	635427.6	6	7	ft	8.06	0.476	0.258	0.266	0.775	1.89	1.42	9.16	3.92	108	375	2.51	1.49	2.28	2.38	2.55	0.135	3.08	92	1.4	75.4
BUDD07	BI-C17	2007	1039284.6	643194.4	0	10	cm	29.3	0.209	0.592	0.199	0.766	4.11	7.28	41.5	20.2	780	5600	3.12	3.64	4.15	21	7.61	0.631	6.89	250	9.09	485
BUDD07	BI-C17-1-2FT	2007	1039208.8	643193.4	1	2	ft	0.764	0.316	0.470	0.214	0.0288	0.139	0.203	1.02	0.484	16.5	120	0.0595	0.048	0.175	0.462	0.209	0.04695	0.254	6.24	0.269	9.19
BUDD07	BI-C18	2007	1043619.0	634834.4	0	10	cm	18.8	0.250	0.646	0.105	0.689	2.96	5.37	24.4	14.6	542	3590	1.78	2.23	2.93	9.29	4.56	0.283	4.46	115	5.88	231
BUDD07	BI-C18-1-2- FT	2007	1043646.2	634866.0	1	2	ft	1.38	0.221	0.455	0.324	0.035	0.212	0.363	1.46	0.892	32.4	210	0.0615	0.157	0.201	0.637	0.338	0.0441	0.308	25.9	0.361	18.1
BUDD07	BI-C1-9-10 FT	2007	1040459.3	635427.6	9	10	ft	1.84	0.734	0.018	0.248	0.314	0.551	0.452	1.03	1.07	8.6	42	0.53	0.894	1.07	0.677	0.61	0.058	0.53	2.7	0.329	2.64
BUDD07	BI-C2	2007	1039601.7	636172.6	0	10	cm	14.5	0.348	0.512	0.141	0.78	2.76	4.08	21	10.3	320	2040	2.24	1.94	2.55	6.58	3.66	0.349	3.59	104	3.77	143
BUDD07	BI-C2-1-2 FT	2007	1039598.2	636182.6	1	2	ft	50.4	0.233	0.479	0.288	1.48	7.73	12.9	63	32.3	1190	6740	4.15	4.92	9	41.7	14.4	0.916	11.6	581	21.9	1000
BUDD07	BI-C3-0-1 FT	2007	1040885.9	635884.5	0	1	ft	17.1	0.197	0.711	0.092	0.484	2.38	4.16	23.6	12.1	535	4430	1.23	1.7	1.87	7.79	3.66	0.309	3.27	123	5.02	266
BUDD07	BI-C3-1-2 FT	2007	1040885.9	635884.5	1	2	ft	15.6	0.172	0.723	0.105	0.464	1.99	3.59	22.2	10.9	499	3770	0.705	1.58	1.68	7.5	3.51	0.356	3.13	114	4.49	166
BUDD07	BI-C3-2-3 FT	2007	1040885.9	635884.5	2	3	ft	12.7	0.198	0.689	0.114	0.36	1.74	2.69	19.2	9.02	385	2790	0.58	1.37	1.68	6.31	3	0.294	2.56	88.7	3.29	122
BUDD07	BI-C3-3-4FT	2007	1040885.9	635884.5	3	4	ft	4.48	0.204	0.673	0.123	0.0835	0.649	1.1	6.25	3.27	135	1000	0.38	0.478	0.515	2.6	1.08	0.105	0.989	33.4	1.3	26.95
BUDD07	BI-C4-0-1 FT	2007	1040832.2	636551.0	0	1	ft	29.1	0.161	0.731	0.108	0.547	3.65	7.62	36	21.4	944	8360	2.41	2.5	3.08	15.2	6.05	0.481	5.4	220	9.71	535
BUDD07	BI-C4-3-4 FT	2007	1040832.2	636551.0	3	4	ft	41.3	0.129	0.680	0.191	0.917	4.59	7.87	52.1	26.1	1300	10800	3.44	4.32	5.37	31.9	10.9	0.777	7.78	339	11.9	566
BUDD07	BI-C4-6-7 FT	2007	1040832.2	636551.0	6	7	ft	62.5	0.103	0.285	0.611	1.81	6.01	8.6	52.9	22	1190	8720	6.26	11.1	14.9	112	28.7	0.899	14.4	1020	23.9	1250
BUDD07	BI-C5	2007	1040767.2	637183.5	0	10	cm	21.6	0.204	0.654	0.142	0.64	3.02	5.6	29.6	15.2	635	4500	2	2.4	2.88	11.2	4.8	0.453	4.5	178	7.63	386
BUDD07	BI-C5-3-4 FT	2007	1040793.2	637242.5	3	4	ft	231	0.203	0.391	0.405	8.56	31.6	32.5	267	114	4800	31800	15	60.3	53.6	335	87.9	19.9	57.5	2020	128	2240
BUDD07	BI-C6	2007	1040069.2	638741.7	0	10	cm	14.1	0.244	0.598	0.158	0.438	2.19	3.27	23.1	9.41	370	2260	1.14	1.46	1.71	6.48	3.57	0.387	3.55	134	4.62	189
BUDD07	BI-C6-1-2 FT	2007	1040079.7	638733.0	1	2	ft	1.08	0.319	0.519	0.162	0.036	0.207	0.216	1.6	0.763	25.3	149	0.0408	0.143	0.171	0.562	0.278	0.0442	0.27	9.59	0.344	11
BUDD07	BI-C7	2007	1041027.3	639208.7	0	10	cm	8.18	0.241	0.594	0.165	0.292	1.26	1.88	11.2	5.68	222	1430	0.836	0.958	1.31	4.07	1.94	0.161	1.9	72.7	2.4	147
BUDD07	BI-C7-1-2 FT	2007	1041026.6	639203.3	1	2	ft	4.88	0.365	0.496	0.139	0.1735	1	1.16	6.6	3.43	109	730	1.09	0.855	1.15	2.35	1.14	0.099	1.13	31	1.05	35.1

Study ID	Sample Name	Year	Point_X*	Point_Y*	Upper Depth	Lower Depth	UOM	Total TEQ	Factor 1 Contribution	Factor 2 Contribution	Factor 3 Contribution	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
BUDD07	BI-C8	2007	1041915.6	639174.3	0	10	cm	5.8	0.388	0.465	0.146	0.523	1.12	1.74	6.97	4.29	118	801	1.65	1.13	1.31	2.38	1.14	0.0565	1.13	35.8	0.937	17.1
BUDD07	BI-C9	2007	1043052.0	638651.5	0	10	cm	25.7	0.210	0.659	0.131	0.632	3.66	7.23	35.7	19.7	750	5440	2.53	2.65	3.22	14	5.77	0.496	5.63	198	7.01	295
BUDD07	BI-S1	2007	1040139.9	633665.8	0	10	cm	19.2	0.176	0.738	0.086	0.456	2.5	4.61	26.7	13.7	619	5410	0.745	1.83	2.17	8.38	4.04	0.38	3.88	133	6.02	258
BUDD07	BI-S11	2007	1040899.0	633997.3	0	10	cm	32.5	0.126	0.838	0.036	0.723	3.63	5.62	48.9	20.7	1190	10500	1.98	2.71	3.03	12.2	5.47	0.499	5.42	183	7.94	429
BUDD07	BI-S12	2007	1042953.5	639512.4	0	10	cm	34.5	0.279	0.598	0.123	1.34	5.96	7.64	47.6	23.1	940	5950	4.04	4.77	5.83	17.6	8.06	0.75	7.27	234	9	344
BUDD07	BI-S13	2007	1042024.7	640332.1	0	10	cm	24.5	0.221	0.631	0.147	0.723	3.64	5.81	34	17.4	702	4760	1.18	3.07	3.64	13.4	6.14	0.522	5.39	195	7.44	300
BUDD07	BI-S14	2007	1041110.5	640122.8	0	10	cm	3.18	0.255	0.607	0.138	0.057	0.524	0.819	4.48	2.35	87.1	581	0.344	0.434	0.521	1.7	0.788	0.0469	0.708	24.3	1.05	36.8
BUDD07	BI-S15	2007	1042430.6	641282.3	0	10	cm	4.64	0.318	0.544	0.138	0.229	0.832	1.45	5.99	3.52	111	788	0.64	0.687	0.892	2.46	1.09	0.139	1.03	28.8	1.16	42.1
BUDD07	BI-S16	2007	1039798.0	640391.3	0	10	cm	15.9	0.260	0.571	0.169	0.42	2.56	4.17	25.7	11.5	390	2610	1.52	1.62	1.88	8.68	4.1	0.407	4.02	147	4.93	209
BUDD07	BI-S17	2007	1039232.0	641230.3	0	10	cm	14.7	0.248	0.584	0.169	0.399	2.31	3.29	23.9	10.2	379	2220	0.885	1.73	2	7.61	4.18	0.403	3.85	134	4.53	185
BUDD07	BI-S18	2007	1040268.5	641902.9	0	10	cm	26.4	0.196	0.621	0.183	0.609	3.6	6.14	37.8	18.5	747	4820	2.43	3.02	3.78	15.6	6.58	0.651	6.1	243	8.6	368
BUDD07	BI-S19	2007	1041521.4	641896.7	0	10	cm	2.94	0.282	0.577	0.141	0.0715	0.497	0.807	4.14	2.25	74.1	557	0.357	0.433	0.567	1.6	0.736	0.093	0.724	19	0.787	28.8
BUDD07	BI-S2	2007	1040511.9	634593.3	0	10	cm	10.3	0.212	0.679	0.109	0.317	1.48	2.64	14.2	7.42	309	2420	0.897	1.12	1.34	4.94	2.38	0.23	2.09	73.5	3.49	142
BUDD07	BI-S21	2007	1038478.1	642421.0	0	10	cm	19.3	0.231	0.593	0.176	0.547	2.83	4.31	32.2	13.7	498	3010	2.01	2.27	2.49	10.4	5.36	0.3295	5.09	176	5.96	231
BUDD07	BI-S23	2007	1039202.0	646130.6	0	10	cm	16.5	0.219	0.543	0.237	0.372	2.3	3.34	22.7	11.3	411	2750	4.24	2.91	3.36	10.6	4.05	0.377	3.87	157	5.75	258
BUDD07	BI-S26	2007	1038187.5	651115.1	0	10	cm	20.2	0.239	0.555	0.206	0.552	3.05	4.57	26.4	15.7	506	3620	2.53	2.64	3.37	14.3	5.06	0.471	4.83	171	8.25	456
BUDD07	BI-S28	2007	1039642.5	657798.5	0	10	cm	13.3	0.314	0.489	0.198	0.232	2.43	3.87	17.2	11.1	287	2210	2.42	1.95	2.53	10.1	3.45	0.285	3.22	97.7	4.86	242
BUDD07	BI-S29	2007	1039481.2	664186.5	0	10	cm	10.7	0.339	0.473	0.189	0.358	2.03	2.85	13.6	8.99	222	1690	2.02	1.36	2	7.46	2.65	0.24	2.59	78.5	3.67	198
BUDD07	BI-S3	2007	1040005.7	634885.0	0	10	cm	7.03	0.295	0.584	0.120	0.326	1.22	2.07	9.9	5.24	179	1210	0.414	0.782	1.02	3.03	1.74	0.171	1.8	52.3	2.04	80.7
BUDD07	BI-S30 SBI, Moxlie Creek	2007	1043546.4	634248.8	0	10	cm	60.3	0.038	0.962	0.000	0.977	5.06	10.4	77.1	30.3	2750	23800	2.19	2.75	4.01	20	7.22	0.613	6.57	228	32.1	943
BUDD07	BI-S31	2007	1042667.9	637951.7	0	10	cm	19.6	0.188	0.734	0.077	0.455	2.71	4.73	27.6	13.5	646	4470	1.61	1.97	2.26	8.85	4.18	0.366	4.06	127	5.04	224
BUDD07	BI-S32	2007	1039336.3	637344.7	0	10	cm	33.2	0.209	0.727	0.064	1.23	4.9	7.26	43	18.2	1100	8290	3.01	3.27	4.16	9.99	6.25	0.568	6.83	236	10.5	710
BUDD07	BI-S33	2007	1039552.8	637265.8	0	10	cm	16.7	0.291	0.548	0.161	0.668	2.86	4	27.9	11.1	395	2320	1.89	2.02	2.36	7.25	4.6	0.424	4.62	152	5.06	181
BUDD07	BI-S34	2007	1040976.7	635451.9	0	10	cm	5.24	0.217	0.773	0.009	0.062	0.791	2.09	6.89	4.91	171	1330	0.226	0.232	0.291	1.3	1.02	0.04465	0.859	37.7	2.73	162
BUDD07	BI-S35	2007	1040051.7	638167.6	0	10	cm	9.77	0.221	0.608	0.171	0.285	1.39	2.34	16.3	7.11	257	1570	0.715	1.1	1.17	4.73	2.69	0.222	2.54	93.5	3.23	131
BUDD07	BI-S36	2007	1040440.5	637589.0	0	10	cm	16.1	0.224	0.623	0.153	0.488	2.36	3.54	23.9	11.8	442	3080	1.31	1.69	2.05	8.61	3.82	0.35	3.82	137	5.36	222
BUDD07	BI-S37	2007	1040462.2	636928.3	0	10	cm	15.2	0.217	0.602	0.181	0.424	2.21	3.36	21.9	10.5	413	2940	1.4	1.64	2	8.23	3.82	0.373	3.38	151	4.98	221
BUDD07	BI-S38	2007	1040971.0	638058.5	0	10	cm	27	0.184	0.713	0.103	0.704	3.61	6.76	36.7	18.4	838	8430	1.055	2.67	3.23	12.8	4.8	0.482	4.97	200	6.74	334
BUDD07	BI-S4	2007	1040952.0	635106.0	0	10	cm	32	0.203	0.744	0.053	1.12	4.57	7.03	43.2	21.8	1060	8150	2.61	2.71	3.89	14.3	6.55	0.549	5.88	164	9.22	351
BUDD07	BI-S5	2007	1039335.4	636860.2	0	10	cm	18.5	0.406	0.476	0.119	1.04	3.99	5.1	27.7	13.1	370	2410	3.04	2.47	3.11	8.05	4.64	0.37	4.98	122	4.14	166
BUDD07	BI-S6	2007	1039302.2	637942.3	0	10	cm	32	0.296	0.607	0.097	1.05	5.81	9.29	48	23	838	5770	2.3	2.58	3.04	12.3	7.39	0.606	8.09	270	8.36	431
BUDD07	BI-S7-0-10cm SBI, near Hardel	2007	1039051.7	638556.5	0	10	cm	59.8	0.322	0.588	0.090	1.69	11.8	14.5	101	39.8	1530	8480	3.11	4.79	6.03	19.4	14	1.3	15.2	525	18.9	910
BUDD07	BI-S9	2007	1043535.6	636827.0	0	10	cm	15.8	0.326	0.554	0.119	0.738	2.92	4.41	20.4	11.7	393	2310	2.37	2.45	3.45	7.3	3.76	0.339	3.8	87.5	4.01	137
BUDD07	BI-TISSUE1B-SEDIMENT	2007	1039243.6	637493.5	0	10	cm	25.1	0.179	0.821	0.000	0.82	3.67	6.62	30	14.9	970	7930	1.37	1.3	1.71	4.38	3.32	0.275	3.4	142	5.6	416
BUDD07	BI-TISSUE1-SEDIMENT	2007	1039202.7	637519.2	0	10	cm	4.31	0.201	0.738	0.062	0.184	0.599	1	6.21	2.63	140	1080	0.1855	0.388	0.462	1.25	0.858	0.0449	0.991	30.2	1.42	63
BUDD07	BI-TISSUE2-SEDIMENT	2007	1043210.0	641044.0	0	10	cm	4.21	0.318	0.580	0.102	0.189	0.768	1.1	5.77	3.12	107	715	0.667	0.648	0.781	1.88	1.04	0.096	0.918	23.6	0.958	35.8
BUDD07	BI-TISSUE3-SEDIMENT	2007	1041595.3	638414.9	0	10	cm	9.5	0.285	0.619	0.096	0.429	1.64	2.25	11.8	6.21	266	2130	1.28	1.36	2	4.45	1.85	0.182	1.82	47.2	1.73	72.5
BUDD07	CL-S2	2007	1039928.0	627791.0	0	10	cm	2.04	0.360	0.585	0.055	0.083	0.408	0.674	2.72	1.87	49.6	377	0.1255	0.227	0.32	0.777	0.512	0.0515	0.415	10.3	1.06	26.5
BUDD07	CL-S5	2007	1039900.9	631665.5	0	10	cm	3.96	0.324	0.626	0.051	0.248	0.727	1.18	4.65	3.21	107	809	0.205	0.419	0.583	1.49	0.977	0.143	0.817	18.8	1.22	54.9
BuddOakDioxins	BI-116	2011	1040419.3	664831.8	0	10	cm	12.8	0.344	0.450	0.206	0.485	2.4	3.41	15.4	8	263	1940	3.12	2	3.25	7.84	2.94	1.68	4.8	83.9	4.59	217
BuddOakDioxins	BI-12	2011	1041302.0	662177.6	0	10	cm	15.2	0.309	0.455	0.236	0.533	2.59	3.68	18.3	9.9	317	2350	3.43	2.22	4.02	10	3.75	2.17	6.12	105	5.51	228
BuddOakDioxins	BI-148	2011	1039885.1	652981.7	0	10	cm	30	0.253	0.489	0.258	0.747	4.5	7.16	33	18.5	694	5470	7.98	5.25	8.35	21.1	7.4	3.99	10.8	226	10.9	478
BuddOakDioxins	BI-20	2011	1038916.3	646731.6	0	10	cm	20.1	0.234	0.490	0.276	0.646	2.81	4.66	24.8	11.6	468	3130	3.97	2.89	5.41	13.5	5.17	2.63	8.33	170	7.2	305
BuddOakDioxins	BI-236	2011	1043706.2	658517.4	0	10	cm	8.58	0.011	0.599	0.390	0.3305	0.194	2.79	11.3	6.08	221	1710	2.87	1.84	2.71	6.17	2.53	1.5	3.71	69.5	3.22	128
BuddOakDioxins	BI-241	2011	1039575.6	666390.2	0	10	cm	14	0.325	0.446	0.229	0.547	2.46	3.91	14.6	9.94	291	2180	3.92	2.19	3.88	9.24	3.44	1.85	5.19	90.8	4.63	224
BuddOakDioxins	BI-242	2011	1042923.9	636144.3	0	10	cm	12.8	0.238	0.600	0.162	0.414	1.93	3.13	14.9	7.1	360	2610	1.67	0.1015	3.14	6.44	2.96	1.61	4.35	79.9	3.38	138
BuddOakDioxins	BI-242-B	2011	1042923.9	636144.3	0	2	cm	53.7	0.215	0.620	0.165	1.52	7.42	17.4	60.6	31	1530	12200	6.07	5.77	12.8	26.6	12.6	6.25	20.3	339	14.8	549
BuddOakDioxins	BI-244	2011	1038164.6	670232.0	0	10	cm	7.07	0.031	0.565	0.404	0.321	0.2065	1.97	9.26	5.53	174	1310	2.07	0.1305	2.27	5.51	1.92	1.25	3.25	57.2	3.23	135
BuddOakDioxins	BI-268-B	2011	1042140.2	657236.9	0	2	cm	25.6	0.258	0.496	0.245	0.696	3.84	6.13	29.6	17.1	587	4540	6.77	4.32	6.77	17.5	6.33	3.4	9.85	184	8.38	371
BuddOakDioxins	BI-300	2011	1040888.0	636115.1	0	10	cm	26.4	0.224	0.621	0.154	0.825	3.79	8.36	30.4	16.7	730	6490	2.69	2.03	4.55	12.2	6.01	2.94	8.36	206	9.18	562
BuddOakDioxins	BI-300-B	2011	1040888.0	636115.1	0	2	cm	32.6	0.299	0.592	0.108	0.825	5.85	10.7	36.9	24.8	846	7490	2.92	2.23	5.31	12.1	6.68	2.81	10.5	245	11.2	940
BuddOakDioxins	BI-40056	2011	1041723.6	640457.3	0	10	cm	19	0.244	0.533	0.224	0.742	2.83	4.07	21.1	10.2	487	3500	2.99	2.37	5.16	11.2	4.6	2.47	6.71	140	5	197

Study ID	Sample Name	Year	Point_X*	Point_Y*	Upper Depth	Lower Depth	UOM	Total TEQ	Factor 1 Contribution	Factor 2 Contribution	Factor 3 Contribution	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
BuddOakDioxins	BI-40056-B	2011	1041723.6	640457.3	0	2	cm	33.3	0.230	0.577	0.194	1.17	4.82	6.91	39.1	19.1	903	6660	4.72	3.91	8.13	18	7.91	4.73	11.3	238	9.69	301
BuddOakDioxins	BI-40216	2011	1038769.6	653169.1	0	10	cm	7.04	0.386	0.398	0.215	0.268	1.46	1.97	8.63	5.09	131	904	2.39	1.17	2.14	5.12	1.91	0.417	0.3095	42.8	2.13	78.1
BuddOakDioxins	BI-40272	2011	1041660.6	662991.3	0	10	cm	8.59	0.295	0.482	0.223	0.307	1.45	2.09	9.11	5.88	194	1410	1.93	1.07	2.02	5.68	2.13	1.11	3.34	63.6	3.39	120
BuddOakDioxins	BI-40528	2011	1039088.7	660497.4	0	10	cm	11.2	0.290	0.482	0.228	0.438	1.81	3.18	12.6	7.41	246	1920	2.54	1.54	2.74	7.02	2.79	1.4	4.36	81.1	4.38	175
BuddOakDioxins	BI-40984	2011	1040114.3	646377.5	0	10	cm	35.5	0.201	0.540	0.259	0.933	4.57	8.09	41.3	19.6	908	6790	8.11	5.83	9.12	23.7	9.8	4.6	13.5	289	11.2	457
BuddOakDioxins	BI-40984-B	2011	1040114.3	646377.5	0	2	cm	14.3	0.240	0.511	0.250	0.522	2.05	3.31	16.7	8.51	346	2380	3.52	2.26	3.69	9.51	3.74	1.95	4.71	112	4.27	163
BuddOakDioxins	BI-41040	2011	1044294.0	655314.1	0	10	cm	15.9	0.257	0.513	0.229	0.519	2.42	3.59	19.1	10.2	383	2590	3.1	2.29	4.21	9.88	3.94	1.93	6.04	116	4.48	148
BuddOakDioxins	BI-41240	2011	1039769.3	652127.8	0	10	cm	26.1	0.274	0.487	0.240	0.756	4.18	5.46	30.8	16	590	4850	6.03	4.1	6.55	18.5	6.18	3.51	10	190	9.25	378
BuddOakDioxins	BI-41296	2011	1043758.6	652783.4	0	10	cm	21.3	0.210	0.568	0.223	0.595	2.84	4.82	25.4	12.9	560	4310	3.97	2.87	5.08	13.1	6.02	2.78	7.63	160	5.68	216
BuddOakDioxins	BI-41552	2011	1042879.1	659823.4	0	10	cm	24.5	0.277	0.506	0.218	0.766	3.89	6.7	29.2	17	562	4230	4.93	3.11	5.85	16	5.92	3.46	9.47	168	8.44	320
BuddOakDioxins	BI-41680	2011	1037494.0	666311.7	0	10	cm	3.8	0.298	0.484	0.218	0.03835	0.663	0.919	4.42	2.77	84.6	647	0.798	0.482	0.961	2.4	0.999	0.501	1.52	28.5	1.65	68.1
BuddOakDioxins	BI-41752	2011	1036623.8	655099.6	0	10	cm	8.54	0.266	0.509	0.225	0.312	1.34	2.18	10.4	5.92	200	1550	1.56	1.06	2.04	5.82	0.098	1.04	3.51	64.6	3.52	136
BuddOakDioxins	BI-42704	2011	1038420.3	664363.9	0	10	cm	11.2	0.310	0.456	0.234	0.477	1.9	2.85	12.4	7.71	235	1820	2.83	1.38	2.76	7.68	2.93	1.36	4.52	77	4.19	163
BuddOakDioxins	BI-42776	2011	1036545.0	649460.8	0	10	cm	21.1	0.242	0.527	0.231	0.559	3.1	4.76	27.1	14.9	505	3570	3.63	2.33	4.51	14.3	4.88	2.74	8.06	167	7.67	356
BuddOakDioxins	BI-556-B	2011	1041290.7	633373.4	0	2	cm	25.7	0.134	0.806	0.060	0.109	2.81	9.89	31.5	14.2	876	10300	1.91	2.01	4.72	7.9	4.39	2.42	7.85	126	6.19	324
BuddOakDioxins	BI-84	2011	1035160.2	653612.1	0	10	cm	22.5	0.312	0.475	0.213	0.754	3.94	5.84	27.2	14.8	488	3500	4.5	3.2	5.4	14.4	5.66	3.13	9.34	154	8.26	321
BuddOakDioxins	BI-S30	2011	1043546.4	634248.8	0	10	cm	13.3	0.333	0.542	0.125	0.536	2.39	6.12	18.1	9.22	310	1920	1.22	0.0785	3.39	6.18	2.8	1.92	4.68	53.4	3.65	133
BuddOakDioxins	BI-S7	2011	1039051.7	638556.5	0	10	cm	62.5	0.329	0.484	0.187	2.58	11.3	22.1	100	27.6	1310	7890	5.8	6.62	12.6	21	16.5	6.28	34.7	542	17.5	740
CASMON03	CP-23-S	2002	1038947.6	639327.5	0	0.8	ft	10.7	0.198	0.559	0.243	0.5	1.25	2.6	19	6.7	250	1300	1.1	1.25	1.25	4.3	2.8	1.25	6.3	120	3.7	130
CASMON03	CP-25-S	2002	1042950.6	639510.6	0	0.9	ft	20.9	0.253	0.568	0.179	0.5	3.3	4.8	28	15	530	4300	2.9	2.9	3.9	13	5	1.25	4.9	160	8.4	240
CASMON03	CP-26-S	2002	1043489.8	637792.0	0	0.9	ft	8.58	0.269	0.625	0.106	0.5	1.25	2.9	12	7.4	220	1300	1.9	1.25	1.25	4.2	1.25	1.25	3.2	39	1.25	53
FS1385	CP-16-M2	2012	1041728.0	638476.0	0	10	cm	13.1	0.314	0.521	0.165	0.664	2.46	3.28	12.6	7.32	326	2290	1.36	1.32	2.16	8.55	3.43	1.64	5.49	89	4.17	123
FS1385	CP-17-M2	2012	1041955.0	638479.0	0	10	cm	11.2	0.116	0.812	0.073	0.335	1.28	1.85	11.5	4.64	437	3490	1.02	1.12	1.39	4.78	1.73	1.3	1.87	74.4	2.52	138
FS1385	CP-18-M2	2012	1042208.0	638623.0	0	10	cm	18.4	0.296	0.674	0.030	0.782	3.33	4.65	24.6	9.42	549	4130	2.98	2.3	2.89	6.83	3.22	2.46	5.3	65.1	2.99	71
FS1385	CP-19-M2	2012	1042565.0	638444.0	0	10	cm	1.71	0.250	0.668	0.081	0.2	0.246	0.304	1.93	0.826	50.8	371	0.206	0.17	0.16	0.692	0.282	0.136	0.546	9.03	0.226	13.6
FS1385	CP-20-M2	2012	1042772.0	638259.0	0	10	cm	19.2	0.283	0.651	0.065	0.629	3.57	4.46	23.5	9.88	579	4120	2.38	2.23	2.4	8.83	3.6	2.56	4.06	115	4.82	159
OHPSD06	OHPSD0224-S1	2006	1040806.9	635908.5	0	4	ft	1.87	0.064	0.503	0.433	0.065	0.115	0.42	2.11	0.75	46.2	326	0.15	0.23	0.48	2.15	1.38	0.29	0.76	15.9	0.75	29.5
OHPSD06	OHPSD0224-S10	2006	1038885.1	643533.2	0	2.4	ft	32	0.197	0.601	0.201	0.83	4.18	6.95	43.6	18.9	892	5710	4.2	3.72	7.52	18.6	7.88	3.65	10.8	230	8.61	375
OHPSD06	OHPSD0224-S11	2006	1039562.1	641711.0	0	1.8	ft	6.17	0.266	0.436	0.299	0.115	0.99	1.46	7.45	2.95	136	796	1.06	0.86	1.96	3.99	1.75	0.87	2.65	59.1	1.95	76.1
OHPSD06	OHPSD0224-S12	2006	1039866.8	637781.3	0	9	cm	19.4	0.269	0.504	0.227	0.66	3.01	4.44	29.2	9.99	448	2560	2.57	2.56	5.3	9.71	5.56	2.46	8.4	147	5.36	193
OHPSD06	OHPSD0224-S13	2006	1039835.5	638062.5	0	9	cm	24.2	0.233	0.561	0.206	0.7	3.47	5.43	37.2	12.9	619	3600	2.76	2.77	5.75	11.5	6.64	2.71	10.2	192	6.85	252
OHPSD06	OHPSD0224-S16	2006	1039981.2	636277.8	4	9.2	ft	1.45	0.688	0.000	0.312	0.22	0.44	0.25	0.74	0.46	6.04	23.2	0.75	0.42	0.87	0.41	0.4	0.05	0.51	8.73	0.18	4.92
OHPSD06	OHPSD0224-S18	2006	1040644.7	638350.5	1.2	2.2	ft	8.7	0.194	0.295	0.511	0.29	1.06	1.5	7.39	2.99	165	985	0.99	1.21	3.88	9.34	2.65	1.63	4.05	105	4.01	201
OHPSD06	OHPSD0224-S19	2006	1040659.5	638065.1	0	0.7	ft	30.2	0.181	0.552	0.267	0.84	3.68	6.19	39	15.8	806	5170	3.36	3.66	8.16	18.1	7.69	3.86	10.5	280	9.01	413
OHPSD06	OHPSD0224-S19-Z	2006	1040659.5	638065.1	0.4	1.4	ft	1.44	0.203	0.430	0.367	0.025	0.19	0.31	1.62	0.59	32.6	235	0.17	0.2	0.5	0.94	0.41	0.22	0.61	17.4	0.42	21.9
OHPSD06	OHPSD0224-S2	2006	1040772.7	636448.4	0	4	ft	54.2	0.079	0.720	0.201	2.08	4.49	8.4	53.9	20.4	1820	19700	3.58	4.83	11.1	32.9	14	5.75	15.3	399	22.3	1390
OHPSD06	OHPSD0224-S20	2006	1040154.2	637695.9	0	3.9	ft	18.1	0.286	0.378	0.336	0.32	3	4.19	20.7	8.89	365	2000	2.95	2.92	7.46	13.6	5.38	2.8	7.2	149	6.13	244
OHPSD06	OHPSD0224-S20-Z	2006	1040154.2	637695.9	3.9	4.9	ft	0.349	0.285	0.401	0.314	0.04	0.045	0.085	0.42	0.22	6.51	42.6	0.035	0.04	0.12	0.18	0.11	0.02	0.15	2.47	0.1	3.05
OHPSD06	OHPSD0224-S21	2006	1040132.1	636898.6	0	2.8	ft	14.4	0.307	0.325	0.368	0.68	2.44	2.78	14.8	6.1	264	1530	2.48	2.14	5.94	9.85	3.92	2.03	5.92	144	4.45	200
OHPSD06	OHPSD0224-S22	2006	1040133.2	636291.0	0	3.6	ft	15.8	0.310	0.341	0.348	0.81	2.59	2.9	19.1	6.31	289	1590	3.22	2.59	6.98	9.93	4.45	2.59	6.72	127	4.63	169
OHPSD06	OHPSD0224-S22-Z	2006	1040133.2	636291.0	3.6	4.6	ft	1.84	0.462	0.000	0.538	0.22	0.42	0.13	0.82	0.47	7.76	36.8	0.79	0.47	1.12	0.56	0.51	0.14	0.72	34.6	0.2	13.4
OHPSD06	OHPSD0224-S23	2006	1040202.6	635792.6	0	4.7	ft	20.9	0.288	0.372	0.340	0.93	3.26	4.9	24.7	9.51	406	1940	3.32	3.21	8.42	16.4	6.3	3.56	9.38	142	7.99	298
OHPSD06	OHPSD0224-S23-Z	2006	1040202.6	635792.6	4.7	5.7	ft	0.708	0.135	0.436	0.429	0.04	0.06	0.16	0.71	0.41	15.9	115	0.045	0.055	0.25	0.58	0.22	0.12	0.3	7.56	0.29	14.9
OHPSD06	OHPSD0224-S28	2006	1039909.2	636958.7	0	4	ft	5.05	0.306	0.402	0.292	0.12	0.88	1.24	6.27	2.35	103	556	0.95	0.81	1.86	3.39	1.41	0.81	2.17	38.4	1.45	61.2
OHPSD06	OHPSD0224-S29	2006	1039985.5	636278.0	0	4	ft	35.1	0.217	0.469	0.314	1.1	4.78	7.92	41	16.7	833	5180	4.37	4.35	10.8	25.2	9.99	4.58	14.1	330	12	647
OHPSD06	OHPSD0224-S3	2006	1040728.9	637039.4	0	4	ft	36	0.155	0.485	0.360	1.05	3.9	6.33	42.5	14.7	918	5890	3.7	4.79	13.2	31	10.2	1.81	13.9	324	14.2	639
OHPSD06	OHPSD0224-S3-B	2006	1040728.9	637039.4	4	9.8	ft	1.93	0.000	0.296	0.704	0.075	0.06	0.23	1.58	0.215	40.8	313	0.06	0.105	0.82	2.03	0.55	0.39	0.8	43	1.08	67.1
OHPSD06	OHPSD0224-S4	2006	1040707.1	637378.7	0	4	ft	48.9	0.110	0.357	0.533	1.15	3.98	5.53	48	13.3	1080	6700	3.96	6.37	25.8	61	15.1	13.1	21.5	431	25.9	1160
OHPSD06	OHPSD0224-S4-B	2006	1040707.1	637378.7	4	13.3	ft	4.28	0.067	0.226	0.706	0.17	0.26	0.175	3.04	0.9	77.4	585	0.31	0.43	2.08	4.92	1.28	0.95	1.88	84.9	2.45	132
OHPSD06	OHPSD0224-S5	2006	1040356.5	638924.1	0	2.2	ft	30.6	0.207	0.531	0.263	0.95	4.11	6.97	37.5	14.9	792	4880	3.32	3.54	8.04	20.9	8.8	4.13	11.9	254	9.65	440
OHPSD06	OHPSD0224-S6	2006	1040286.1	639215.3	0	4	ft	20	0.317	0.362	0.321	0.9	3.5	4.51	22	8.99	390	2060	3.5	2.91	8.08	15.3	5.76	0.93	8.98	143	6.78	280
OHPSD06	OHPSD0224-S6-B	2006	1040286.1	639215.3	4	15.6	ft	0.684	0.173	0.074	0.753	0.07	0.06	0.065	0.42	0.23	7.49	48.3	0.075	0.08	0.32	0.47	0.3	0.04	0.3	17.2	0.075	10.4
OHPSD06	OHPSD0224-S7	2006	1040230.0	640494.1	0	6.9	ft	3.03	0.277	0.314	0.409	0.07	0.5	0.63	2.99	1.23	55.6	330	0.58	0.48	1.15	2.06	0.86	0.42	1.3	41.5	0.93	45.3

Study ID	Sample Name	Year	Point_X*	Point_Y*	Upper Depth	Lower Depth	UOM	Total TEQ	Factor 1 Contribution	Factor 2 Contribution	Factor 3 Contribution	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
OHPSD06	OHPSD0224-S9	2006	1040371.6	641246.6	0	3.1	ft	6.7	0.252	0.476	0.272	0.27	1.01	1.5	7.44	3.27	160	1000	1.07	0.87	2.11	4.05	1.67	0.93	2.55	56.8	1.85	77.4
OlyMarineTerminal08	Post-Dredge_PO-BA-24	2009	1040781.0	636384.0	0	10	cm	48.3	0.120	0.798	0.083	0.836	5.36	10.5	52.6	21.8	1770	18000	3.76	3.93	7.95	18.9	8.5	3.7	12.6	298	12.5	673
OlyMarineTerminal08	Post-Dredge_PO-BA-25	2009	1040778.0	636648.0	0	10	cm	44.5	0.137	0.700	0.163	0.998	4.88	9.72	55	21.7	1420	13600	3.86	4.22	8.94	21.1	9.06	4.35	13.6	335	12.7	686
OlyMarineTerminal08	Post-Dredge_PO-BA-26	2009	1040772.0	636849.0	0	10	cm	47.5	0.134	0.733	0.133	0.979	5.43	9.67	56.8	20.7	1640	13800	3.71	4.25	9.24	23.3	8.94	4.58	13.7	315	12.8	690
OlyMarineTerminal08	Post-Dredge_PO-BA-27B	2009	1040737.0	637066.0	0	10	cm	32.1	0.189	0.624	0.187	0.739	4.16	7.97	43	16.3	922	7340	3.31	3.55	7.3	16.1	7.12	3.91	10.5	247	8.66	433
OlyMarineTerminal08	Pre-Dredge_PO-BA-24	2008	1040776.0	636383.0	0	1	ft	21.6	0.233	0.592	0.175	0.711	3.21	5.53	25.9	11.9	586	4600	2.54	2.72	4.11	10.7	5.09	2.38	8	172	6.42	323
OlyMarineTerminal08	Pre-Dredge_PO-BA-24-B	2008	1040776.0	636383.0	4	5	ft	51.2	0.172	0.626	0.202	1.44	6.38	9.96	67.5	23.6	1520	10900	4.6	5.08	10.8	27.8	10.8	5.92	17.7	434	14.8	648
OlyMarineTerminal08	Pre-Dredge_PO-BA-25	2008	1040782.0	636648.0	0	0.7	ft	23.6	0.239	0.608	0.152	0.724	3.68	6.27	27.5	12.3	667	5070	2.6	2.52	4.22	11.1	5.2	2.42	8.79	184	7.62	403
OlyMarineTerminal08	Pre-Dredge_PO-BA-25-B	2008	1040782.0	636648.0	3	3.7	ft	67.2	0.151	0.607	0.242	1.95	7.82	11.1	85.7	26.8	1990	14400	4.47	6.59	15.3	44.2	14.8	8.95	23.9	595	22.8	998
OlyMarineTerminal08	Pre-Dredge_PO-BA-26	2008	1040769.0	636853.0	0	1	ft	21.8	0.245	0.574	0.181	0.921	3.31	5.53	25.3	12.1	578	4490	2.45	2.59	4.23	11.1	4.97	2.44	8.17	173	6.56	375
OlyMarineTerminal08	Pre-Dredge_PO-BA-26-B	2008	1040769.0	636853.0	4	5	ft	57.4	0.157	0.661	0.182	1.56	6.84	11.5	74.7	26.3	1790	13400	4.74	5.71	12	30.7	11.7	6.75	19	441	15.8	673
OlyMarineTerminal08	Pre-Dredge_PO-BA-27	2008	1040728.0	637127.0	0	0.8	ft	22.5	0.217	0.583	0.201	0.714	3.16	5.86	27.9	11.7	609	4490	2.62	2.5	4.58	11.4	5.28	2.65	8.59	194	6.55	345
OlyMarineTerminal08	Pre-Dredge_PO-BA-27-B	2008	1040728.0	637127.0	3.3	4.2	ft	59.4	0.135	0.636	0.229	1.5	6.36	10.9	73.7	24.7	1770	16600	5.09	5.94	13.1	38.4	12.9	7.97	20.8	485	19	844
OlyMarineTerminal08	Pre-Dredge_PO-UP-20	2008	1040845.0	636401.0	0	2	ft	39.2	0.249	0.659	0.093	1.03	6.37	11.9	46.7	23.4	1170	9610	3.46	3.91	6.84	16.5	7.66	3.5	10.7	240	9.79	555
OlyMarineTerminal08	Pre-Dredge_PO-UP-20-B	2008	1040845.0	636401.0	2	4	ft	54.1	0.117	0.788	0.095	1.14	5.94	10.6	61.7	22.9	2020	17100	4.7	5.01	9.92	21.8	9.12	4.55	13.1	338	11.4	637
OlyMarineTerminal08	Pre-Dredge_PO-UP-21	2008	1040823.0	636659.0	0	2	ft	32.9	0.214	0.658	0.128	0.842	4.87	9.73	34.6	19.8	999	8410	2.59	3	5.18	13.9	6.81	2.8	10.2	267	11.5	814
OlyMarineTerminal08	Pre-Dredge_PO-UP-21-B	2008	1040823.0	636659.0	2	4	ft	44	0.143	0.747	0.110	0.985	5.28	10.1	47.9	19.5	1530	14500	3.42	3.89	7.62	20.1	7.73	3.94	12.8	287	10.9	564
OlyMarineTerminal08	Pre-Dredge_PO-UP-22	2008	1040809.0	636862.0	0	1.5	ft	40	0.015	0.985	0.000	0.518	3	7.66	34.3	12.8	1840	20700	1.94	2.45	4.59	11.2	4.61	2.47	7.98	182	8.96	556
OlyMarineTerminal08	Pre-Dredge_PO-UP-22-B	2008	1040809.0	636862.0	1.5	3	ft	28.2	0.158	0.695	0.147	0.617	3.49	6.39	33.5	13.1	920	7610	2.44	2.77	5.31	14.3	5.81	2.97	8.73	202	7.72	372
OlyMarineTerminal08	Pre-Dredge_PO-UP-23	2008	1040794.0	637071.0	0	2	ft	57.8	0.109	0.564	0.327	1.19	5.48	9.22	64.1	20.8	1680	12500	4.21	6.68	18.7	51.6	14.3	10.6	20.1	477	20.2	857
OlyMarineTerminal08	Pre-Dredge_PO-UP-23-B	2008	1040794.0	637071.0	2	4	ft	251	0.097	0.458	0.445	4.77	21.6	31.9	240	74.5	6350	46100	14.5	44.9	91.2	291	76.6	83.7	104	2360	143	4950
PERLA08	C1-01	2008	1040955.8	633326.0	0	2.3	ft	4.26	0.236	0.698	0.066	0.203	0.619	1.1	4.47	2.95	126	1470	0.8	0.565	0.678	1.57	0.901	0.0555	0.676	22.4	0.931	98.1
PERLA08	C2-01	2008	1040964.5	633448.3	0	3.1	ft	21.1	0.201	0.554	0.246	0.749	2.84	4.56	24.6	12.8	547	4640	2.42	2.42	3.76	17.7	7.17	0.232	5.38	177	6.09	406
PERLA08	C2-01A	2008	1040964.5	633448.3	3.1	5.6	ft	8.61	0.329	0.000	0.671	0.577	1.46	0.902	3.73	2.44	36	171	3.63	3.35	4.27	12	6.7	0.429	4.21	128	6.73	87.7
PERLA08	C3-01	2008	1041067.5	634012.2	0	3.4	ft	9.94	0.226	0.689	0.086	0.338	1.47	2.25	14.4	6.77	298	2460	1.13	1.07	1.48	4.89	2.42	0.116	1.54	53.4	2.11	112
PERLA08	C3-01A	2008	1041067.5	634012.2	3.4	5.5	ft	4.64	0.336	0.435	0.230	0.241	0.875	0.897	4.84	2.7	98	660	1	0.603	1.02	2.95	1.32	0.0735	2.17	39	1.05	72
PriestPoint	CCCC131-01	2010	1042490.5	642585.8	0	10	cm	2.19	0.478	0.430	0.092	0.09	0.57	0.66	2.3	1.1	44	330	0.74	0.51	0.56	1	0.63	0.33	0.225	10	0.24	16
PriestPoint	II118-01	2010	1041742.0	642798.5	0	10	cm	1.89	0.397	0.485	0.118	0.07	0.42	0.38	2.1	1	42	350	0.73	0.4	0.39	0.94	0.41	0.065	0.63	11	0.085	18
PriestPoint	IIII142-01	2010	1042584.5	642405.2	0	10	cm	2.78	0.559	0.394	0.047	0.125	0.81	0.87	2.6	1.9	50	340	0.95	0.55	0.7	1	0.79	0.175	0.9	9.3	0.28	13
PriestPoint	KKKK159-01	2010	1042615.9	642134.7	0	10	cm	1.89	0.569	0.394	0.037	0.09	0.57	0.4	1.6	1.2	35	260	0.71	0.29	0.47	0.67	0.51	0.19	0.62	6.1	0.245	10
PriestPoint	N57-01	2010	1041389.9	643799.0	0	10	cm	1.27	0.420	0.429	0.151	0.075	0.28	0.43	1.2	0.53	26	200	0.5	0.1	0.36	0.53	0.155	0.29	0.43	7.1	0.19	12
PriestPoint	OOO148-01	2010	1042260.6	642308.0	0	10	cm	3.92	0.453	0.401	0.146	0.25	0.9	1.2	3.9	2.2	73	540	1.2	0.81	1.1	1.8	1.4	0.215	1.4	18	0.245	29
PriestPoint	RRR181-02	2010	1042307.1	641772.6	0	10	cm	2.48	0.376	0.472	0.153	0.16	0.54	0.335	2.7	0.65	58	460	0.29	0.59	0.62	1.3	1.1	0.235	0.33	15	0.165	26
PriestPoint	V91-01	2010	1041345.6	643579.0	0	10	cm	4.84	0.355	0.479	0.166	0.08	1	1.1	5.8	2.4	110	860	1.3	1	1.4	2.6	0.89	0.6	1.6	29	1.8	43
PriestPoint	VVVV200-01	2010	1042801.6	641460.0	0	10	cm	2.76	0.333	0.553	0.114	0.13	0.5	1.1	2.8	1.8	68	510	0.77	0.4	0.62	1.1	0.88	0.15	0.92	14	0.15	25
PriestPoint	ZZZ157-01	2010	1042434.6	642166.6	0	10	cm	2.38	0.489	0.368	0.143	0.095	0.67	0.64	2	0.98	45	360	0.14	0.46	0.57	1	0.64	0.51	0.68	20	0.235	23
WB1577RIFS	SD19	2008	1039559.7	633757.0	0	0	cm	3.97	0.245	0.519	0.236	0.28	0.495	1.1	5	2.6	89	810	0.59	0.99	1.2	2	0.99	0.495	1.4	23	1.3	33
WB1577RIFS	SD20	2008	1039524.7	633966.0	0	0	cm	6.24	0.377	0.482	0.141	0.31	1.3	1.7	7.4	3.3	140	1100	0.86	0.99	1.8	3	0.99	0.495	2.3	30	0.99	45
WB1577RIFS	SD21	2008	1039480.9	634202.3	0	0	cm	6.87	0.318	0.529	0.153	0.36	1.2	1.8	8.6	3.9	160	1400	0.75	0.98	1.6	2.7	2.4	0.49	2.4	43	2.3	63
WB1577RIFS	SD23	2008	1039327.0	635727.2	0	0	cm	6.57	0.261	0.614	0.124	0.37	0.99	2.2	9.5	4.3	170	1400	1.4	0.99	0.99	3.2	0.99	0.495	0.99	42	2.1	59
WB1577RIFS	SD23-B	2008	1039327.0	635727.2	2	2	ft	3.73	0.299	0.346	0.355	0.36	0.485	1.1	3.8	2.2	64	420	1.3	0.97	1.6	1.8	0.97	0.485	1.5	27	1	38
WB1577RIFS	SD24-B	2008	1039342.1	635811.8	2	2	ft	8.86	0.503	0.115	0.383	0.67	2.3	4	4.7	0.98	98	600	2.8	0.98	4.7	8.4	3.1	1.2	1.2	62	1.9	61

*Washington State Plane South

UOM - Units of Measure