Port Angeles Harbor
Sediment Dioxin Source Study
Port Angeles, WA

Final Report

Prepared for

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List of Acronyms

ALS	Alternating Least Squares
COPC	chemical of potential concern
CSO	combined sewer overflow
CSM	conceptual site model
dioxin	polychlorinated dibenzo-*p*-dioxin
DOI	Department of Interior
Ecology	Washington State Department of Ecology
EIA	environmental impact assessment
EIM	Environmental Information Management
EPA	Environmental Protection Agency
E & E	Ecology and Environment, Inc.
Fibreboard	Fibreboard Paper Products
FWEC	Foster Wheeler Environmental Corporation
furan	polychlorinated dibenzofuran
HCA	Hierarchical Cluster Analysis
HFB	hog fuel boiler
IDW	inverse distance weighted
MCDD	monochlorodibenzo-*p*-dioxin
MCDF	monochlorodibenzofuran
MCR	Multivariate Curve Resolution
M&R	Merrill & Ring Timber, Inc.
Na-PCP	sodium pentachlorophenol
NCASI	National Council for Air and Stream Improvement
Nippon	Nippon Paper Industries
ng/kg	nanograms per kilogram
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
OCDD	octachlorodibenzo-*p*-dioxin
OCDF	octachlorodibenzofuran
PAH	polycyclic aromatic hydrocarbon
PCA	principal components analysis
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
SAIC	Science Applications International Corporation
STA	sediment trend analysis
TCDD	tetrachlorodibenzo-*p*-dioxin
TEF	toxicity equivalency factor
TEQ	toxic equivalency
TOC	total organic carbon
WPCC	Water Pollution Control Commission
WWTP	wastewater treatment plant

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1.0 Introduction

Port Angeles Harbor was identified by the Washington State Department of Ecology (Ecology) as a priority cleanup and restoration site under the Puget Sound Initiative. Ecology is responsible for overseeing source control, cleanup, and restoration of the harbor. Recent investigations have identified polychlorinated dibenzo-*p*-dioxin (dioxin) and polychlorinated dibenzofuran (furan) congener toxic equivalency (TEQ) concentrations of surface sediments in excess of background concentrations across the entire harbor (NewFields 2012). The Port Angeles Harbor Sediment Dioxin Source Study was initiated by Ecology to increase understanding of dioxin/furan contamination in harbor sediments, with an objective of identifying potential upland sources.

Ecology contracted with Science Applications International Corporation (SAIC), with NewFields as their subcontractor, to provide technical support for sediment-related issues in Port Angeles Harbor. NewFields managed the investigation of potential dioxin/furan sources to harbor sediment through the use of chemometric analyses. Data analysis and interpretation were completed by NewFields and independent consultant Greg Glass. All chemometric analyses were conducted by Infometrix Inc.

The Port Angeles Harbor Sediment Dioxin Source Study documents the chemometric evaluation and interpretations of Port Angeles Harbor 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 surface sediments of the harbor.

1.1 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, as shown in Figure 1. There are 210 unique dioxin/furan compounds, each called a “congener” (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). Figure 1 shows each numbered carbon atom, corresponding to possible positions for the chlorine atoms.

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 to be the most toxic. These 17 congeners have chlorine atoms in the 2, 3, 7, and 8 positions shown in Figure 1. In this study, the terms “dioxins” and “furans” will be used to refer to the 17 congeners of primary interest, listed in Table 1. This report also will refer to these 17 congeners as the “2,3,7,8-substituted congeners” because chlorine has been substituted for hydrogen at the 2, 3, 7, and 8 positions.

Concentrations of the 17 dioxins/furans of primary interest are often expressed as a TEQ 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, such as 1.5 nanograms of 2,3,7,8-TCDD TEQ per kilogram of sediment (1.5 ng TEQ/kg). 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 most potent congeners, 2,3,7,8-TCDD and 1,2,3,7,8-PeCDD, are assigned a TEF of 1, while the least potent, OCDD and OCDF, have the smallest TEF, 0.0003.

Federal and state environmental regulatory and health agencies are interested in dioxins/furans because they are toxic to humans and wildlife. Once released into the environment, dioxins/furans resist degradation, do not dissolve in water, and attach strongly to particles such as soil, dust, and sediment. This means that they are persistent and can bioaccumulate in people and animals and can be measured in environmental media long after they have been released. Despite their persistence and ubiquitous presence, levels of dioxins/furans in the environment have been declining since the 1970s due to improvements in air pollution control technologies for combustion and incineration facilities and cleanup of dioxin-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. Instead, dioxins/furans are byproducts of chemical manufacturing and combustion or incineration processes involving chlorine compounds. For example, dioxins are most notorious for their presence as a contaminant in the herbicide 2,4,5-T and in Agent Orange. They can also be produced during incineration of wood, oil, and wastes. Major contributors of dioxins/furans 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.

Dioxins/furans are present at some level throughout the environment, in air, food, water, soils, and sediments. Dioxins/furans tend to be found in higher concentrations near industrial areas but are present in various concentrations throughout urban, rural, and even remote wilderness areas. Urban soil and sediment concentrations of dioxins/furans commonly represent the combined influences of multiple sources.

1.2 Study Objectives

The goal of the Port Angeles Sediment Dioxin Source Study is to increase the understanding of dioxin/furan sediment contamination throughout the harbor, including the magnitude and likely sources of contamination to surface sediments. Specific objectives of this study include:

- Identifying distinct dioxin/furan congener source signatures present in Port Angeles Harbor sediments;
- Determining the relative contribution of identified dioxin/furan sources to harbor-wide contamination; and
- Using the spatial patterns of sediment dioxin/furan sources, as well as characteristics of facilities in the Port Angeles area, to identify potential upland sources.

The results of this study are expected to guide Ecology in pursuing dioxin source control strategies for the harbor. It is not Ecology's intention to perform detailed quantitative allocations among potential point/nonpoint sources or to apportion liability to potentially liable parties.

2.0 Previous Investigation of Dioxins/Furans in Port Angeles Harbor Sediments

The Port Angeles Harbor Supplemental Data Evaluation to the Sediment Investigation Report (NewFields 2012) summarizes and evaluates sediment data from numerous studies performed in the harbor. The report contains analysis of the dominant sediment transport pathways, the spatial distribution of dioxin/furan congener TEQs and other contaminants of potential concern, and the likely upland locations of contaminant sources. This section presents findings and conclusions from NewFields (2012) relevant to understanding where in Port Angeles Harbor sediment dioxins/furans are found and their potential fate and transport.

2.1 Sediment Transport Pathways

An understanding of sediment transport processes in Port Angeles Harbor aids in interpreting sediment chemistry results when trying to identify point sources of dioxin/furans. In NewFields (2012), numerous studies of physical processes and geomorphology were integrated to construct conceptual site models (CSMs) for sediment transport in the harbor and identify the key sediment transport pathways. A single sediment transport CSM does not encompass the complex conditions likely responsible for sediment transport. Instead, CSMs for a range of low and high energy conditions were required to account for discrepancies in sediment transport pathways inferred by surface and subsurface currents, hydrodynamic modeling, particle size distributions of deposited sediment, and geomorphic evidence. Figure 2 depicts sediment transport pathways during conditions of both low energy (typical currents) and high energy (storm-induced waves and currents). Three very different, spatially segregated, transport pathways likely responsible for the movement of sediment from sources to sinks are apparent within the southern, western, and central harbor (Figure 2).

2.1.1 Southern Harbor Sediment Transport

The majority of chemicals of potential concern (COPCs) and sediment sources to Port Angeles Harbor (industrial outfalls, combined sewer overflows [CSOs], creeks, etc.) are located along the southern harbor shoreline or contribute to runoff that enters the harbor along the southern shoreline (Ecology and Environment, Inc. [E & E] 2008). Of particular importance to historical sediment and COPC loading in this region was discharge from the Rayonier Mill nearshore and deepwater outfalls. Five nearshore outfalls discharged untreated mill effluent between 1937 and 1972. After this period, treated effluent was discharged to the outer harbor through a deepwater outfall until the mill's closure in 1997. During operation, the former Rayonier Mill discharged approximately 35 million gallons of effluent per day, with a solids load of approximately 20 tons per day (EPA 1974; Foster Wheeler Environmental Corporation [FWEC] 1997). In comparison, total annual CSO discharge to Port Angeles Harbor between 2003 and 2008 averaged 32 million gallons (City of Port Angeles 2009), making daily discharge from Rayonier approximately equivalent to yearly CSO discharge.

Under low energy conditions, particles delivered to the harbor as effluent or runoff deposit in close proximity to the discharge point, with fine-grained material subject to limited, multi-directional transport by weak tidal currents. Much of the fine-grained material entering the southern harbor in the vicinity of the former Rayonier property has the potential to be transported eastward out of the harbor (Battelle 2004). Sediment deposition continues under this regime until the onset of a high energy storm event.

Large precipitation events efficiently deliver sediment to the harbor as runoff from both creeks and outfalls. This influx of sediment is subjected to wind- and wave-induced transport mechanisms that do not typically occur during low energy conditions. Waves produced by strong winds can induce bottom currents capable of resuspending surface sediments in the shallow southern harbor (Herrera 2011). These wind-induced waves can also act to enhance the bottom currents responsible for sediment transport in deeper areas of the harbor. Large wind-driven waves from the northeast, as well as refraction of the swell entering the harbor from the Strait of Juan de Fuca, result in westward longshore sediment transport along the southern harbor from Lees Creek to the western harbor (Figure 2).

2.1.2 Western Harbor Sediment Transport

Western Port Angeles Harbor serves as the long-term sink for depositional sediment within the harbor. The western harbor, extending from the western shoreline eastward approximately one mile, was one of only two regions of the harbor identified as being net depositional (GeoSea 2009). Under low energy conditions, the dominant sources of sediment to this region are nearby outfalls. Similar to the southern harbor, sediment deposition is likely to occur in close proximity to outfalls of the western harbor during low energy conditions. During high energy events, additional sediment sources to the western harbor potentially include creek and southern harbor outfall discharge delivered by longshore transport (Figure 2).

Because there is little wave energy in the western harbor, sediment is subject to current-driven transport on a day-to-day basis and also intermittent, density-driven mudflows. Results of both a current meter study (Evans-Hamilton 2008) and the sediment trend analysis (STA) (GeoSea 2009) suggest that sediment transport is predominantly eastward toward the central harbor. Mudflows are expected to travel downslope to the east. Both of these eastward transport mechanisms are likely to disperse fine-grained sediment away from the shoreline and across the entirety of the western harbor (Figure 2). However, sediment transport likely does not continue unimpeded in the easterly direction, as STA identified a transport front approximately one mile from the harbor’s western shoreline (Figure 2).

An intertidal lagoon located at the western end of the harbor also serves as a likely sediment sink, but also a possible source to the western harbor. The lagoon has historically been used for log rafting and the northeastern corner has previously been dredged (Exponent 2008). The lagoon connects to the harbor through a narrow, armored channel. Under low energy conditions, sediment delivered to the lagoon by either outfalls or flood tides is expected to deposit in the lagoon without the ability to be eroded during ebb tides. The narrowness of the channel and the steep bluff to the southwest of the lagoon likely prevent the lagoon from experiencing substantial wind- or wave-induced currents. Therefore, sediment introduced to the lagoon during high energy events is also likely to deposit there. This conceptualization of sediment deposition in the lagoon is supported by the STA, which identified the lagoon as being completely depositional (GeoSea 2009). Lagoon sediments may have the ability to be mobilized and transported to the western harbor if outfalls discharging to the lagoon scour the sediment bed. It is also possible that effluent discharging to the lagoon is transported directly to the western harbor during ebb tides without first depositing within the lagoon.

2.1.3 Central Harbor Sediment Transport

STA identified sediment parting zones, areas of sediment erosion from which sediment is transported away, in central Port Angeles Harbor approximately half a mile north of the former Rayonier Mill dock and also along the outer Ediz Hook (Figure 2). Because a parting zone clearly cannot be a continuous source of sediment without a replenishment mechanism, its presence implies both sediment loading and dispersion processes. Sediments throughout the central harbor were determined to be in a state of dynamic equilibrium (GeoSea 2009). Sediment loading to the parting zones likely occurs during extreme events, which can radically and rapidly replenish them with sediment. Sources of sediment to the parting zone closest to the former Rayonier property likely include sediment eroded by storm wave energy from the shallow southern harbor, as well as some new sediment delivered to the harbor by creeks during high runoff events.

After the parting zone has been recharged with sediment, typical day-to-day transport processes not associated with extreme events act to disperse sediment away from the parting zone. Based on currents measured during spring tides (Evans-Hamilton 2008), the strongest near-bed current at the locations of the parting zones is likely to the west. This bottom current is a combination of tidal current and the counterflow balance to the strong eastward surface currents within the harbor caused by westerly winds. This same westward bottom current may also transport fine-grained sediment emanating from the Rayonier deepwater outfall and City of Port Angeles wastewater treatment plant (WWTP) deepwater outfall, which discharge into the deep harbor east of the sediment parting zone (Figure 2). As was the case with sediment moving eastward from the western harbor, sediment being transported westward from the central harbor is unlikely to move across the transport front and upslope into the western harbor (Figure 2).

2.2 Spatial Patterns and Potential Sources of Dioxins/Furans

Interpolation of surface sediment dioxin/furan total TEQs results in distinct spatial patterns which, in conjunction with knowledge of sediment transport processes, can be used to infer likely upland source locations of dioxins/furans entering the harbor. However, it is assumed that every measure of sediment dioxin total TEQ is a composite of impacts from multiple sources. Therefore, while spatial patterns of total TEQ can identify the most impacted regions of the harbor, individual source contributions responsible for the magnitude and spatial pattern of total TEQ remain unresolved.

Dioxin/furan congener TEQs are greatest along the western harbor shoreline (maximum of 119 ng TEQ/kg), with concentrations decreasing with distance into the central and outer harbor (Figure 3). TEQs of the surface sediment samples collected within the lagoon were among the highest observed. Sediment transport to the western harbor from distant sources is unlikely to be the dominant mechanism responsible for the observed increasing east-west concentration gradient in the central and western harbor. Also, the transport of airborne dioxin to the western harbor from source locations along the southern harbor is unlikely as winds are predominantly from the west. Instead, upland sources along the western harbor shoreline are the likely driver of the surface sediment dioxin pattern in the western harbor. Western harbor facilities identified in

NewFields (2012) as being potential point sources for dioxins/furans include Nippon Paper Industries (Nippon) and previous operators (Daishowa and Crown Zellerbach), Merrill & Ring Timber, Inc. (M&R), Fibreboard Paper Products (Fibreboard), and City of Port Angeles CSOs.

Dioxin/furan TEQs of the former Rayonier Mill log pond and dock area are greater than those of the central and outer harbor, suggesting the former mill property as a potential dioxin source (Figure 3). The fact that a more extensive, plume-like dioxin footprint is not apparent adjacent to the property infers that sediment transport processes may act to diffuse the dioxin signal away from the property. Dioxin derived from the former Rayonier Mill property initially deposited in close vicinity to their nearshore outfalls is likely to have been subjected to high energy resuspension and subsequent transport by longshore and tidal currents, including multi-directional dispersion as it is winnowed away from the parting zone (Figure 2).

If the former Rayonier Mill property were the main source of dioxin to the western harbor, dioxin concentrations similar to those found in the western harbor would be expected along the clockwise longshore transport path in the areas that accumulate equally fine-grained sediment. Although elevated dioxin/furan TEQ concentrations exist for fine-grained sediments in the vicinity of the City of Port Angeles' active CSOs and east of Terminal 1, these concentrations are much less than those of the western harbor. These elevated concentrations may be due to localized CSO and Terminal 1 dioxin/furan sources rather than material transported from the vicinity of the former Rayonier Mill property. While the high energy location of the former Rayonier Mill property likely causes it to be a contributor of dispersed dioxins/furans throughout much of the harbor, it is likely not the predominant source responsible for the observed spatial pattern of dioxin/furan contamination in the western harbor.

2.3 Dioxin/Furan Chemical Fingerprinting

Chemical fingerprinting is a technique used to differentiate potential sources of chemical contaminants. Fingerprinting of dioxin/furan congeners found in Port Angeles Harbor sediments was pursued in the hope of identifying regions of the harbor influenced by specific industrial, municipal, or residential sources. Port Angeles Harbor sediment dioxin/furan congener data were initially evaluated for potential fingerprinting analysis by E & E (2012). Chemical fingerprinting methods applied by NewFields (2012) were unable to discern multiple dioxin/furan congener profiles for sediments of Port Angeles Harbor. As a result, a more intensive fingerprinting approach consisting of multivariate chemometric analyses (unmixing analyses) of the sediment dioxin/furan congener data was recommended to differentiate sources to harbor sediments (NewFields 2012). A similar approach of chemometric analysis was performed for Port Angeles soil dioxin/furan congener data as a part of the *Rayonier Mill Off-Property Soil Dioxin Study* (E & E and Glass 2011).

3.0 Methods

This section discusses the methodology used to accomplish the objectives of this study. This included the compilation of Port Angeles Harbor dioxin/furan congener data sets, chemical unmixing analysis of these data, and spatial interpolation and analysis of chemical unmixing results.

3.1 Data Sets

Port Angeles Harbor sediment dioxin/furan congener data from seven individual data sets were combined for use in the chemometric analysis. Table 2 provides the number of surface and subsurface sediment samples used in chemometric analysis from each of the following studies:

- Port Angeles Harbor Sediment Characterization Study (E & E 2012);
- National Park Service (NPS) Sediment Sampling for Nippon Paper Industries Outfall 002 Replacement (NPS 2010);
- Nippon Paper Industries USA Pulp and Paper Mill Environmental Baseline Investigation (Exponent 2008);
- Remedial Investigation for the Marine Environment Near the Former Rayonier Mill Site (Malcolm Pirnie 2007a);
- Lower Elwha Klallam Tribe Sediment Samples, Dioxins and Furans Analysis (Malcolm Pirnie 2007a, Appendix P);
- Phase 2 Addendum Remedial Investigation for the Marine Environment Near the Former Rayonier Mill Site (Malcolm Pirnie 2007b); and
- Summary of the Log Pond Survey Scoping Effort for the Remedial Investigation (FWEC 2001).

For this study, surface sediment samples are defined as having an upper limit of the sediment/water interface and a variable lower limit. This lower limit was generally 10 centimeters (95 percent of surface sediment samples), but extended as deep as 40 centimeters. Although sediment samples from the NPS (2010) study extended to a depth of 74 centimeters, these samples were removed from the combined data set as a result of data screening methods (see Section 3.2.1).

The compiled Port Angeles Harbor sediment dioxin/furan congener data set, including reported concentrations and calculated total TEQs, are presented in Appendix A. When available, data collected for the above studies were obtained from Ecology's Environmental Information Management (EIM) database. If not available in EIM, data were obtained directly from original project data reports. In all cases, data downloaded from EIM were verified using original project data reports.

3.2 Chemometric Analysis

Many sources of dioxins/furans contribute to measured concentrations in environmental samples, such as Port Angeles Harbor sediments. In general, each sample can be assumed to reflect the combined contributions from a number of potential sources. Therefore, a one-to-one match of an environmental sample to a known dioxin/furan profile from a single source should not be expected. An understanding of the sources that account for measured environmental concentrations of dioxins/furans requires a decomposition, or “unmixing,” of the bulk measured concentrations.

Chemometrics is the application of mathematical and statistical methods to chemical measurements. Multivariate analysis techniques were applied to the measured concentrations of seventeen 2,3,7,8-substituted dioxin/furan congeners in Port Angeles Harbor sediments to develop an “unmixing” model for the data set. The chemometric evaluations included two equally important parts:

- The mathematical decomposition of sample measurements into their components (“unmixing”); and
- Interpretation of the sources mathematically identified by the unmixing analysis.

It is notable that in the first part, development of the chemometric model, the data are treated purely as numbers stripped of all other attributes. No information on sampling locations, sediment characteristics (e.g., grain size or total organic carbon [TOC]), proximity to discharge points or upland facilities, or other sample or site characteristics influence the mathematical solution to the unmixing model. All of the non-numerical attributes of samples, however, are considered in the interpretation of the results of the mathematical analyses. Those interpretations also consider the similarity of modeled source profiles to the profiles documented for known source types. The consistency of the chemometric decomposition of the data set with the known characteristics of the samples and study area features is one important measure of the validity of data interpretations.

A brief description of the chemometric analysis methods is provided in this section. Additional details are found in Appendix B. Some exploratory analyses were performed including analytes other than dioxins/furans (e.g., metals and polycyclic aromatic hydrocarbons [PAHs]), but the results did not improve the resulting unmixing model. Only the analyses of dioxin/furan data are discussed here.

3.2.1 Data Set Screening

The cumulative Port Angeles Harbor sediments data set from the studies identified in Section 3.1 included 279 samples with results for 17 dioxin/furan congeners. Chemometric analyses use the patterns across samples in the profiles of these 17 congeners. Where samples have numerous undetected results among the 17 congeners, these dioxin/furan profiles become less well defined. The frequency of undetected results varied across the data set, becoming more pronounced for samples with very low total TEQ values. Samples with more than four undetected results were screened out of the data set before performing chemometric analyses, resulting in a reduction from 279 to 234 samples representing 181 locations across the harbor. Samples at more than one depth interval were included for some locations. Most of the omitted samples had total TEQ concentrations less than 2 ng TEQ/kg, and the spatial coverage of the harbor was not materially affected by the removal of these 45 samples. Further evaluations (using principal components analysis [PCA]; see below) noted three samples with somewhat atypical profiles, but these three samples were not screened out as potential outliers. In a few of the retained samples (with four or fewer undetected congener results), the contribution to total TEQ of undetected congeners assigned a value of one-half the detection limit was more than de minimis, but those samples were also retained for the chemometric analyses.

3.2.2 Metrics

Dioxin/furan sample results were reported from the lab as bulk congener concentrations, in nanograms per kilogram (ng/kg) dry weight. These bulk concentrations were scaled for relative toxicity using the current set of TEF values, and the TEF-scaled values were summed to obtain total TEQ concentrations. The data set included a large range of TEQ concentrations. Chemometric analyses are concerned with the patterns of dioxins/furans rather than the TEQ magnitudes across samples. Therefore, 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. The 234 TEF-scaled, normalized profiles were the input data set for chemometrics.

Human health and ecological risk evaluations are based on TEQ calculations rather than bulk measurements, as are regulatory decisions for cleanup criteria and actions. The “dioxin/furan sources” of greatest interest to meet the objectives of this study are those that contribute to a significant portion of the sample TEQ values and profiles. From the point of view of risk evaluations and cleanup decisions, the bulk dioxin/furan levels in a sample are of little importance if, after TEF scaling, they contribute almost nothing to TEQ concentrations. Even after screening of the initial sediments data set to remove samples with a higher frequency of undetected results, it is noted that some congeners have very small contributions to sample TEQs across the entire data set. Moreover, some of those congeners have relatively frequent undetected results but with substantially varying detection limits, which, after substitution of one-half the varying detection limits, means pseudo-variation in concentrations would be introduced into the analysis. Chemometric analyses based on a scaling of bulk congener concentrations without introducing TEFs may be inappropriately affected by such data set characteristics. Thus, even though there is a theoretical one-to-one relationship between bulk and TEF-scaled concentrations, chemometric analyses using these two metrics may not produce equivalent results. Chemometric analyses based on variance-scaling (instead of TEF-scaling) of bulk concentrations were also explored, but did not result in a more informative unmixing model (see Appendix B, Section 4.4). Only the primary evaluations using TEF-scaled, normalized profiles are discussed herein.

3.2.3 Unmixing Model

The mathematical model of the data set produces the following component results:

- The number of sources contributing to the sample measurements;
- The chemical patterns of model sources (dioxin/furan TEQ profiles);
- The source amounts (fractional contributions) of each model source 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 source amounts from 1 (non-closure deviations; see below).

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 sources, the analyses mathematically derive a model of the sources – conceptually "working backwards" from receptors to sources. There are several similar mathematical approaches used for unmixing evaluations. In this study, a combination of PCA and Multivariate Curve Resolution – Alternating Least Squares (MCR-ALS) methods was used.

With 17 2,3,7,8-substituted congeners defining the chemical patterns in the sample profiles, each sample can be visualized or mapped as a point in a 17-dimensional space. Samples with similar TEQ profiles would be located near one another in that 17-dimensional space. PCA attempts to reduce the number of dimensions required to map the data, while accounting for almost all of the variability in the data set. PCA factors, each representing some combination of the congener variables, are determined with each added factor accounting for successively less of the overall variance. A decision on how many factors to retain in the model of the data is made based on the cumulative fraction of the original variance accounted for, among other criteria.

The number of PCA factors required to account for nearly all of the data set variance is an indication of the number of sources to be included in the model. Diagnostic criteria can be used to evaluate the number of PCA factors, and models with different numbers of sources can be explored when the difference in total variance accounted for is small. It should be noted that the PCA factors or axes do not themselves define source profiles – the weights for some congener variables, for example, may be negative, which has no physical meaning for a source profile.

An MCR-ALS method was used for the unmixing analysis. The ALS method assumes the data set reflects the variable contributions from a fixed number of sources. Therefore, the measured values are assumed to be the product of the chemical patterns for the sources and the amounts contributed from each source to each sample. This product is calculated iteratively using matrix algebra, with one matrix of source 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 sources are allowed, because negative contributions lack physical meaning. When the iterative calculations converge, the unmixing model is complete. It provides in its two matrices solutions for the chemical profiles of sources 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. This is appropriate when it cannot be assumed or demonstrated that the model includes all possible sources contributing to the measurements. Deviations from 1 are generally small and are another indication of model goodness-of-fit.

The source amounts in the model are relative measures of the sample compositions – recall that the normalization of TEF-scaled profiles removed the effects of TEQ magnitude variations. Interpretations of the unmixing model results benefit from absolute measures of the impacts of sources. The contributions of sources to total sample TEQ, as contrasted to only the sample chemical pattern, are obtained by multiplying the source amounts by the total TEQ for the sample. The results are termed source TEQ increments. The sum of those model TEQ increments will differ from the measured sample TEQ to the degree that the sum of source amounts differs from 1 (non-closure analysis approach).

3.2.4 Model Interpretation

An inventory of comparison dioxin/furan profiles was compiled to support possible interpretations of the source profiles obtained through chemometric modeling. That inventory of source profiles included over 300 candidate profiles compiled from published literature and site-specific studies. Source types included air emissions, effluent discharges, ash, and various chemicals known to include dioxins/furans from their manufacture; several soil and sediment data sets from site-specific studies were also included. The initial inventory was reduced by removing redundant profiles that would impede in cluster analysis because of their high similarity, leaving over 150 profiles for a comparison set.

Two methods were used to compare source profiles from the unmixing model to those in the compiled inventory. Hierarchical Cluster Analysis (HCA) was the first method of evaluating similarity, with the results represented by a dendrogram. Correlation analyses were also performed against the entire inventory, with the highest ranking correlations listed for each model profile. These two approaches for interpreting chemical patterns are complementary and provide candidate source types for further evaluation based on Port Angeles history and the likely presence of actual sources or facilities matching the candidates. It should be noted that the comparisons of source 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 other factors than just chemical pattern.

The source TEQ increments calculated from chemometric modeling and measured total sample TEQs can be associated with specific sample locations to produce TEQ increment spatial maps. The resulting spatial patterns, matched to distinctly different chemical patterns (in contrast to total TEQ values), support further evaluations of specific physical sources with matching chemical patterns that may have contributed to the sediment dioxin/furan measurements.

3.2.5 Uncertainties

Chemometric pattern evaluations are subject to various sources of uncertainty, as is common to all modeling efforts. As previously noted, one common source of uncertainty, chemical patterns compromised by frequent not-detected results, was partially addressed during data screening. Some additional recognized potential sources of uncertainty are:

- 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 weathering effects (losses post-deposition); and
- Highly-correlated impacts from multiple sources that produce composite profiles, affecting comparisons to single source profiles from a source inventory (degraded similarity).

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.

3.3 Spatial Interpolation and Analysis

Spatial interpolation is the process of approximating data in unsampled locations by using known values at discrete locations. Results of the unmixing analysis (source TEQ increments) were used to create interpolated surfaces utilizing the geostatistical toolsets of ESRI ArcGIS version 10. Inverse distance weighted (IDW) interpolations provided an exact deterministic technique to model local spatial variation and determine the TEQ increment at unsampled locations. The aim of this method is to build a model that describes the major spatial features of the data set. The resulting data products are surfaces of dioxin/furan source TEQ increments across the extent of Port Angeles Harbor. These surfaces can be utilized to determine general spatial patterns and help infer underlying processes contributing to those patterns.

Spatial interpolation could not be applied to the entire Port Angeles Harbor sediment data set. Although both surface and subsurface sediments were used in unmixing analysis to identify dioxin/furan congener source profiles, data interpolation and analysis of spatial patterns was restricted to surface sediment results. Both the limited spatial coverage and varying depth intervals of subsurface dioxin/furan congener data prevent the interpolation of subsurface TEQ increments throughout the harbor. Also, the physical separation of the lagoon from the rest of the harbor prevents the use of lagoon samples in spatial interpolation. As a result, locations in the lagoon are shown as point features on figures displaying harbor-wide interpolated surfaces.

In addition to interpreting spatial pattern, interpolated TEQ increment surfaces were used to determine the fractional contribution of each source to total TEQ harbor-wide. While the fractional contribution of each source to all samples is informative (see Section 3.2.3), performing similar analysis on interpolated surfaces removes sampling bias caused by differences in sample density. When considering sample statistics instead of spatial models, sampling bias causes the dominant sources in densely sampled areas to appear to have a greater contribution to total TEQ harbor-wide, while dominant sources in more sparsely sampled areas are under-represented.

4.0 Results

The results of chemometric unmixing analyses are summarized in this section, with additional details provided in Appendix B. The interpretation of model results is provided in Section 5.0. Results for models with both 6 and 4 sources are discussed in this section, including source profiles, source amounts, and source TEQ increments for each model. The source TEQ increments, which provide a decomposition of measured total TEQ for the sediment samples, are further summarized in terms of their comparative magnitudes and spatial patterns.

4.1 Chemometrics

After data set screening, which resulted in 234 sediment samples retained for evaluation, a PCA analysis was performed. Based on the PCA results, cross-validation diagnostic criteria, and further examination of sample residuals for normalized TEQ profiles in the ALS unmixing analysis, an initial model based on 6 sources was developed. The results for the 6-source model are summarized in Section 4.1.1 below. After examining these results, a second model based on only 4 sources was developed. The reasons for considering a second unmixing model using only 4 sources are discussed in Section 4.1.2, and those results are summarized as well. The two unmixing models are compared in Section 4.1.3. After reviewing these unmixing results, the 4-source model was selected as the primary model for further evaluations. The magnitudes and spatial patterns for source TEQ increments in Sections 4.2 and 4.3, and the interpretations of model results in Section 5.0, address only the 4-source model.

4.1.1 6-Source Model

The normalized TEQ profiles for 6 sources are shown as line plots, with separate panels for each source profile, in Figure 4. Numerical values for these source profiles are provided in Appendix B, Table 9. The 6 source profiles are seen to reflect a variety of patterns. For 4 of the 6 profiles (Sources 1, 3, 4, and 6), the dioxin congeners are dominant, accounting for between 81 and 98 percent of the TEQ. The other 2 profiles (Sources 2 and 5) are dominated by the furan congeners, comprising 70 to 77 percent of the TEQ. Within each of these two subgroups, different congeners have the highest contributions to total TEQ.

The source amounts, or fractional contributions of each source to each of the 234 samples included after data screening, are listed as numerical values in Appendix B, Table 10. Some of the source amounts are zero; not every model source is found to contribute to every sample. Samples are shown, however, to be composed of varying contributions from multiple sources. The sum of the fractional source amounts is not equal to 1 because the unmixing model was run without a closure constraint. Only 15 of the 234 samples (6.4 percent) have summed source amounts differing from 1 by more than 5 percent. That result, as well as examination of the residuals for sample profiles, indicates good model fit to the original data set.

The source TEQ increments calculated from the source amounts and sample measured TEQs are listed in Table 3. The sum of source TEQ increments does not equal the sample measured TEQ because the model was run without a closure constraint on source amounts. Note that where the sample TEQ is relatively small, even the higher deviations from 1 for the sum of source amounts may result in only small differences between measured and modeled sample TEQs. Conversely, relatively small differences for source amounts may result in larger differences in sample TEQs when total TEQs are higher. Of the 234 samples included in the model, only 18 (7.7 percent) have differences in TEQ of more than 1 ng TEQ/kg. Thus, the 6-source model produces total TEQ values within 1 ng TEQ/kg for more than 92 percent of the 234 sediment samples.

4.1.2 4-Source Model

A detailed review of the results of the 6-source model showed that two pairs of source profiles each had a substantial degree of commonality, even though there were some differences in the ranking of congener contributions between the paired profiles. The two sources whose profiles were dominated by furan congeners, Sources 2 and 5, were both similar to PCB profiles for dioxins/furans (Figure 4). PCB profiles are notable for having almost no dioxin contributions, and are therefore not a surprising candidate for a furan-dominated source profile. The second pair of similar source profiles, for Sources 3 and 6, both had the largest contribution from 1,2,3,4,6,7,8-HpCDD, which is a diagnostic congener for PCP dioxin profiles; both source profiles also had modestly elevated contributions from 1,2,3,4,6,7,8-HpCDF, which is also noted for PCP profiles (Figure 4). Sources 3 and 6 differed mostly in contributions from other dioxin congeners.

When the spatial patterns of TEQ increments were examined for the 6-source model, each of these pairs of modeled sources showed a strong consistency and correlation in spatial pattern, with only a few exceptions. One possibility raised by these similarities in source profiles and spatial patterns of TEQ increments was the occurrence of subtle variations in batches of these chemicals (PCBs, PCP) used over time, or variations in fate (degradation) processes that slightly affected TEQ profiles over time since release.

The ALS unmixing model was therefore repeated for a 4-source model. The residuals plot showed slightly larger residuals than for the 6-source model, with three samples showing notably higher residuals for specific congeners (see Appendix B, Figure 14). These three samples with atypical TEQ profiles (EP-09-SD, LP-16, and CO03B) were previously noted during data set screening, but were not removed as outliers. Their patterns are seen to be drivers for one source in each of the two pairs of sources with similar profiles in the 6-source model (Sources 2 and 6), which thus appears to reflect the atypical patterns of only a few samples in the sediments data set.

These findings support the usefulness of the 4-source model as a more economical (parsimonious) model. The interpretations of source types and spatial patterns are practically equivalent for both the 6-source and 4-source models.

The normalized TEQ profiles for 4 sources are shown as line plots, with separate panels for each source profile, in Figure 5. Numerical values for these source profiles are provided in Appendix B, Table 11. As was the case for the 6-source model, the 4-source profiles are seen to reflect a variety of patterns. For 3 of the 4 profiles (Sources 1, 3, and 4), the dioxin congeners are dominant, accounting for between 80 and 97 percent of the TEQ (Figure 5). The fourth profile (Source 2) is dominated by the furan congeners, accounting for 75 percent of the TEQ.

The source amounts for the 4-source model are listed as numerical values in Appendix B, Table 12. As before, some of the source amounts are zero, with samples shown to be composed of varying contributions from multiple sources. Only 29 of the 234 samples (12.4 percent) have summed source amounts differing from 1 by more than 5 percent, approximately double the percentage from the 6-source model. With fewer sources, this model has somewhat higher residuals than the 6-source model, especially for the three samples noted above. Overall model fit is still judged to be good for the 4-source model.

The source TEQ increments calculated from the source amounts and sample measured TEQs are listed in Table 4. Of the 234 samples included in the model, only 25 (10.7 percent) have differences in TEQ of more than 1 ng TEQ/kg. Thus, the 4-source model still produces total TEQ values within 1 ng TEQ/kg for almost 90 percent of the 234 sediment samples.

4.1.3 Comparison of 6 and 4-Source Models

A comparison of the source profiles in the 6- and 4-source unmixing models shows a strong degree of correspondence between appropriately matched profiles. (Note: the numerical ordering of sources as determined in the ALS unmixing software does not necessarily match between model runs). Refer to Figures 4 and 5 for visual presentations, and Appendix B, Tables 9 and 11 for numerical values, for the source profiles in both models.

- Source 1 in the 6-source model and Source 1 in the 4-source model are close analogs, with dioxin congeners dominating in each (98 and 97 percent, respectively). The highest profile contributor in each case is 2,3,7,8-TCDD, with 77 and 69 percent contributions, respectively.
- Source 4 in the 6-source model and Source 4 in the 4-source model are also close analogs. Both source profiles are dominated by dioxin congeners (81 and 80 percent, respectively). The highest profile contributor in each case is 1,2,3,7,8-PeCDD, with 51 and 44 percent contributions, respectively. The next 5 highest contributing congeners are also very similar between these two source profiles.
- The two sources in the 6-source model with dominant furan congener contributions, Source 2 and Source 5, have an analog in Source 2 in the 4-source model. Total furan contributions of 70 and 77 percent in the 6-source model are closely matched by a 75 percent furan contribution in the 4-source model. Sources 2 and 5 in the 6-source model have different patterns of contributions among the furan congeners, with notable differences for at least 4 furan congeners between the two source profiles. Source 2 in the 4-source model appears to be a merging of furan contributions from these two profiles, with moderate dioxin contributions for the same congeners as in the 6-source model profiles.
- Finally, Source 3 and Source 6 in the 6-source model have an analog in Source 3 of the 4-source model. All three profiles are dominated by dioxin congeners (81 and 87 percent for the 6-source model profiles and 80 percent for the 4-source model profile). The highest profile contributor for all three profiles is the same, 1,2,3,4,6,7,8-HpCDD (35 and 46 percent in the 6-source model profiles and 42 percent for the 4-source model profile). The highest furan contributor, 1,2,3,4,6,7,8-HpCDD, is also the same for all three profiles. The secondary contributing congeners among dioxins differ in the two profiles from the 6-source model; Source 3 in the 4-source model appears to be a merging of these secondary contributors.

These pairings of source profiles between the two unmixing models have an obvious implication for the source amounts from the two models. The source amounts of Sources 1 and 4 were directly compared between models; the sum of amounts from Sources 2 and 5 in the 6-source model were compared to Source 2 amounts from the 4-source model, and the sum of amounts from Sources 3 and 6 in the 6-source model were compared to Source 3 amounts from the 4-source model (Table 5). Note that since the unmixing models were run without a closure constraint, the sum of source amounts for the same sample may vary slightly between the two models.

Sources 1 and 2 from the 4-source model, and their analogs in the 6-source model, generally had smaller source amounts across most of the sediment samples. The majority of source amounts compared across models for these sources were within 2 percentage points, or a fractional amount of 0.02 (196 samples for Source 1; 135 samples for Source 2). Nearly all of the 234 samples were within 5 percentage points, or a fractional amount of 0.05 (227 samples for Source 1; 218 samples for Source 2). Both models therefore resulted in very similar source amounts. It was noted that 6 samples had identical source amounts of zero in both unmixing models for Source 1, and the number of zero amounts was much larger for Source 2 in the 4-source model versus the sum of the two matched 6-source model profiles (17 samples versus 1).

Sources 3 and 4 from the 4-source model, and their analogs in the 6-source model, generally had higher source amounts across most of the sediment samples. For these two sources, the variations between models were larger. Only a few samples were within 2 percentage points (8 samples for Source 3; 13 samples for Source 4), and the numbers within 5 percent were still relatively small (51 samples for Source 3; 48 samples for Source 4). Compared to the 6-source model and paired profiles, source amounts for Source 3 were almost universally smaller in the 4-source model (232 samples), while amounts for Source 4 were nearly all larger (227 samples). The 4-source model therefore results in a general shift of a portion of source amounts from Source 3 to Source 4, compared to the initial 6-source model. It was noted that the number of zero source amounts was larger for Source 3 in the 4-source model versus the sum of the two matched 6-source model profiles (9 samples versus 1).

While some differences in source profiles and source amounts can be identified between the two unmixing models, a comparative evaluation indicates that these differences are relatively small. The two unmixing models lead to results that are not markedly different with respect to source profiles and spatial patterns of source contributions. The 4-source model was used as the basis for all further evaluations.

4.2 Source Increment Magnitudes

The magnitude of dioxins/furans in Port Angeles Harbor sediment samples can be determined in terms of the calculated source TEQ increments based on the 4-source model. Figure 6 provides box-and-whisker plots for the numerical distributions of surface sediment sample TEQ increments for each of the 4 sources. By inspection of this box-and-whisker plot and associated tabled values by sample (Table 6), it is apparent that Source 3 and 4 increments overall contribute more to harbor sediment samples than increments from Sources 1 or 2. The largest of four source increments can be determined for each of the 181 surface sediment samples (Table 4); the counts for number of samples with maximum increments by source are 2 samples for Source 1, 7 for Source 2, 49 for Source 3, and 123 for Source 4.

While the preceding discussion of source increment magnitudes identifies Sources 3 and 4 as the dominant source increments in harbor samples, spatial modeling is required to quantitatively determine the fractional contribution of each source increment to total TEQ harbor-wide. Spatial modeling accounts for sampling bias caused by differences in sample density. For example, despite the greatest number of sediment samples having Source 4 as their maximum TEQ increment, Source 4 may not be the dominant source to harbor-wide total TEQ if samples high in Source 4 were all collected in a relatively small region. Considering the spatial extent of Port Angeles Harbor shown in Figure 3, modeling results indicate that Sources 3 and 4 are the major contributors to harbor-wide total TEQ, comprising 40 and 44 percent of the total TEQ, respectively (Table 6). Sources 1 and 2 have much smaller contributions, respectively comprising 6 and 10 percent of harbor-wide total TEQ.

4.3 Source Increment Spatial Patterns

The unmixing analysis of the Port Angeles Harbor sediment data supports a more focused and useful evaluation of spatial patterns than an analysis based on total TEQ results (Section 2.2). The contribution to each sample from individual sources (source 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 sources illustrates the relative scale of impact of the separate sources and thereby provides more detailed information than that of total TEQs before unmixing (Figure 3).

Surface sediment TEQ increments for the individual sources derived from the 4-source unmixing model are presented in Figures 7 through 10. TEQ increments are shown using the same scale among the four sources such that the relative magnitude of sources can be visually compared. These figures also identify locations of samples removed from unmixing analysis based on data screening criteria (Section 3.2.1).

Surface sediment TEQ increment data displayed in Figures 7 through 10 are also presented as interpolated surfaces in Figure 11. In this figure it can be seen that both the magnitude and spatial pattern of the TEQ increments differ greatly among sources.

4.3.1 Source 1

The spatial extent of Source 1 is restricted almost entirely to the western harbor lagoon (Figure 7). The seven surface sediment samples, including three duplicates, with the highest Source 1 TEQ increment (11 to 63 ng TEQ/kg) are all located within the lagoon. Sediments outside of the lagoon all have Source 1 TEQ increments less than 6 ng TEQ/kg, with 94 percent of these samples having TEQ increments less than 2 ng TEQ/kg. There are only three samples, all within the lagoon, in which the Source 1 TEQ increment contributes more than 25 percent of the total TEQ. This suggests that the contribution of Source 1 to sediments harbor-wide is relatively insignificant and sediments outside the lagoon may not be impacted by the specific dioxin source causing elevated Source 1 values within the lagoon.

4.3.2 Source 2

The spatial extent of Source 2 is more extensive than Source 1 (Figure 8). Samples with the highest Source 2 TEQ increments are restricted to the former Rayonier Mill log pond, western harbor, and lagoon. Seven of the nine surface sediment samples with the highest Source 2 TEQ increments (9 to 23 ng TEQ/kg) are located within the former Rayonier Mill log pond. The only other locations with comparably high Source 2 TEQ increments are located along the western harbor shoreline in the vicinity of Terminal 5 (16 ng TEQ/kg) and Nippon (12 ng TEQ/kg). Locations in the central and outer harbor generally have Source 2 TEQ increments less than 2 ng

TEQ/kg. With the exception of one sample in the western harbor, all samples in which the Source 2 TEQ increment contributes more than 25 percent of the total TEQ are located within the former Rayonier Mill log pond. This suggests that Source 2 has a minimal contribution to total TEQ outside of the log pond.

4.3.3 Source 3

The spatial extent of Source 3 is concentrated to the western harbor and lagoon (Figure 9). Ten of the eleven locations with the greatest Source 3 TEQ increments (29 to 116 ng TEQ/kg) are located in the western harbor, with the four highest TEQ increments at locations in closest proximity to the Nippon property. While samples from the lagoon generally have elevated Source 3 TEQ increments compared to the rest of the harbor, all concentrations are less than 28 ng TEQ/kg. Three locations with Source 3 TEQ increments greater than 10 ng TEQ/kg occur in proximity to the former Rayonier Mill property; however, these elevated values appear to be outliers compared to neighboring samples (Figure 9). Source 3 generally contributes greater than 50 percent (maximum of 93 percent) to total TEQ for samples in the western harbor. Lagoon samples have a lower contribution from Source 3, averaging 35 percent.

4.3.4 Source 4

Source 4 has the most diffuse spatial pattern of those differentiated by the 4-source unmixing model (Figure 10). The eleven sample locations with the greatest Source 4 TEQ increments (19 to 68 ng TEQ/kg) are found either in the lagoon or former Rayonier log pond, with the four highest TEQ increments found in the log pond. All sample locations outside the lagoon and log pond have Source 4 TEQs less than 17 ng TEQ/kg. Source 4 TEQs greater than 6 ng TEQ/kg are common throughout the western harbor and along the southern harbor. Samples with the greatest Source 4 contribution to total TEQ (maximum of 83 percent) are located in the log pond, the remaining area surrounding the former Rayonier Mill property, the southern harbor, and the central harbor. Despite the lagoon samples having some of the highest Source 4 TEQ increments, equally high amounts of other sources cause lagoon samples to have a lower contribution to total TEQ from Source 4 than most other harbor samples.

5.0 Discussion

In this section each of the four dioxin sources to Port Angeles Harbor sediments identified through unmixing analysis are discussed separately. First, the distinctive chemical profiles of the identified dioxin sources are discussed, including evaluation of dioxin-containing materials with analogous profiles. Spatial patterns of the source are then described in relation to likely sediment transport pathways driving these patterns. Finally, a comprehensive interpretation of the source is presented, incorporating supplementary information regarding the history of upland industrial activities and locations of potential point sources.

5.1 Source 1

5.1.1 Chemical Profile

The Source 1 TEQ profile is dominated by the contribution of a single dioxin congener, 2,3,7,8-TCDD (Figure 5). One manufactured chemical is known to have a similar dioxin profile with almost all of its TEQ contributed by this single dioxin congener. That chemical, 2,4,5-T, was the primary component of a widely used commercial herbicide called Silvex, with both terrestrial and aquatic herbicide applications. Inquiries to obtain a full dioxin/furan profile for 2,4,5-T, including at EPA’s dioxin reassessment program, were not successful; such information may be viewed as proprietary by the chemical manufacturers. A study of soils near a 2,4,5-T manufacturing facility in New Zealand provided analyses of all 2,3,7,8-substituted congeners for a subset of soil samples. Although such soils would include contributions from other sources, most of their TEQs were determined to be from releases from the 2,4,5-T manufacturing facility. Those soil profiles were therefore used as a surrogate for the unavailable profiles of 2,4,5-T alone in the compilation of comparison profiles.

Correlation analyses of Source 1 and the inventory of comparison profiles showed that several of these New Zealand soil samples had the highest correlation coefficients (see Appendix B, Table 6). Profiles with this pattern of dominant 2,3,7,8-TCDD contributions to TEQ have been observed in scattered locations in several urban soil studies, including Denver and Port Angeles. Some Denver residential samples also show high correlations to Source 1, as do several wood ash profiles. The profiles for effluents from paper mills using chlorine bleaching, as documented in the 104 mill study (National Council for Air and Stream Improvement [NCASI] 1990), are dominated by 2,3,7,8-TCDD and 2,3,7,8-TCDF. Although several such effluent profiles appear on the ranked list of correlations for Source 1, that modeled profile has a zero contribution for 2,3,7,8-TCDF. Silvex, or manufactured 2,4,5-T, and possibly wood ash appear to be the most similar source types to Source 1.

5.1.2 Spatial Pattern

The spatial pattern of Source 1 is unlike the other sources in that it is almost entirely restricted to the lagoon (Figure 11). Unmixing results and spatial modeling suggest that 6 percent of harbor-wide total TEQ is composed of Source 1. However, Source 1 TEQ increments harbor-wide are less than 2 ng TEQ/kg and may be within the error of the unmixing model. Regardless, Source 1 is the most minimal contributor to harbor-wide dioxin contamination of the considered sources.

The spatial pattern suggests direct discharge of Source 1 to the lagoon from the nearby upland and relatively little input of Source 1 to the remaining harbor from other upland locations. Low Source 1 TEQ increments in the western harbor immediately outside of the lagoon support previous conclusions that the lagoon is depositional and its sediments are non-erosive (GeoSea 2009). The morphology of the lagoon, and most lagoons in general, cause them to act as sediment traps for any material discharged directly to their waters, as well as the finest-grained sediments transported to them when inundated at high tidal stages.

5.1.3 Interpretation

Knowledge of the lagoon's history aids in understanding possible mechanisms by which Source 1 dioxin became deposited there. The following information regarding the historical use of the lagoon are derived from environmental impact assessments (EIA) conducted by Crown Zellerbach Corporation (1980) and Daishowa (1989). The log pond was originally formed as a natural lagoon in accordance with the formation of Ediz Hook. Beginning with the establishment of the Whalen Brothers Mill in 1917 (later Crown Zellerbach [1920 – 1986], James River Company [1986 – 1988], Daishowa [1988 – 2003], and Nippon [2003 – present]), the lagoon served as a storage area for logs prior to the pulping process. By the 1940s the meandering channel connecting the lagoon to the western harbor had been replaced by a drive ditch to convey logs to the lagoon. The drive ditch was equipped with operating gates that isolated the water level in the lagoon from tidal fluctuations of the harbor.

Before the practice of log storage in the lagoon was abandoned in the mid-1970s, approximately 12 acres of the lagoon were filled. This included filling of the southeast corner of the lagoon and the creation of two dykes across the western lagoon, forming two small ponds that currently exist. The fill used included both sludge and boiler ash. In 1974 the U.S. Fish and Wildlife Service ordered an end to any further filling of the lagoon and the removal of material already present. The result of this action was a consent decree, which allowed material already deposited in the lagoon to remain and no additional fill of any kind to be placed in the lagoon. The operating gates for the drive ditch were subsequently removed in 1976, returning tidal fluctuations to the lagoon.

Regardless of what the exact source material is for Source 1 dioxin (2,4,5-T and/or wood ash), high TEQs of this source are restricted to the lagoon and are not likely to be mobilized to the harbor. The historic industrial uses of the lagoon suggest input of Source 1 dioxin from adjacent upland activities. Two outfalls from the Crown Zellerbach property discharged directly to the lagoon until the early 1970s (Shea et al. 1981). The documented filling of the lagoon with ash from the adjacent wood-fired boiler could explain the similarity of the Source 1 profile to wood ash.

It is also plausible that 2,4,5-T could be a source material for Source 1 dioxin. The herbicide 2,4,5-T may have been transported to the lagoon as runoff if it were applied for weed control purposes in the surrounding upland area. This chemical may have also been applied directly to the lagoon for the prevention of aquatic weeds (Gangstad 1983, 1984; Martin and Martin 1985). During the time that the lagoon served as a log pond, tide gates isolated it from the flushing effects of tides and currents. This would have created a relatively shallow, stagnant pond subject to algal blooms. Application of 2,4,5-T directly to the pond as an algaecide (Cowell 1965) may have been used to control such blooms and prevent the biological fouling of logs prior to processing.

5.2 Source 2

5.2.1 Chemical Profile

The Source 2 TEQ profile shows substantial contributions from several furan congeners, with lesser contributions overall from dioxin congeners (Figure 5). Correlation analyses show the highest ranking comparison profiles are for a number of (fresh, unweathered) manufactured PCBs (see Appendix B, Table 6). The correlation coefficients are not as high for the top-ranked comparison profiles for Source 2 versus the other 3 sources. The Source 2 profile has contributions of 25 percent to total TEQ from the dioxin congeners. PCB profiles, however, are known to have almost zero contribution from dioxin congeners. The Source 2 profile may reflect a degree of compound source types, with non-PCB sources contributing to the profile as well as PCBs. This could occur, for example, if widespread low concentrations of PCBs co-occurred with widespread low impacts from various combustion sources. Spatial co-occurrence of this type could result from similar stormwater release points to the harbor, and also could be influenced by sediment characteristics (e.g., grain size distributions, TOC). The pattern of furan congeners introduced through historic PCB releases may also have been changed somewhat over time through fate/degradation processes, reducing correlations from fresh PCB profiles.

While the contributions from dioxin congeners mean Source 2 cannot be a pure PCB profile, and the patterns of furan contributions vary somewhat from reference PCB profiles, PCBs provide the most similar pattern for Source 2 among comparison profiles.

5.2.2 Spatial Pattern

In contrast to Source 1, the spatial pattern of Source 2 dioxin suggests multiple physically separated point source locations. Interpolation of Source 2 TEQ (Figure 11) shows a distinct pattern, with clusters of high-TEQ increment values within the lagoon, close to the western harbor shoreline, and within the former Rayonier log pond. Although present in multiple areas of the harbor, Source 2 dioxin only contributes approximately 10 percent to total TEQ harbor-wide.

Spatial patterns suggest two primary source locations of Source 2 dioxin deposited in harbor sediments: the upland western harbor and the former Rayonier Mill property. Patterns of Source 2 in both the western harbor and lagoon are consistent with western harbor point sources subjected to the dominant sediment transport pathways depicted in Figure 2. Transport pathways in the western harbor act to disperse sediment from close to the western shoreline eastward throughout the western harbor under both high and low energy conditions. Additionally, western harbor sources may contribute to lagoon sediments, as fine-grained, suspended sediments of the western harbor are expected to be transported into the lagoon during flood tides. While sediment transport from the harbor into the lagoon would have been restricted before 1976 because of the existence of operating gates on the lagoon drive ditch (Section 5.1.3), the activity of moving logs into the lagoon may have allowed the introduction of harbor sediment. Whether Source 2 enters the lagoon directly from the upland or is transported from the western harbor, Source 2 is not likely to be removed from the lagoon by natural sediment transport processes.

The highest Source 2 TEQs in the vicinity of the former Rayonier Mill are confined to the log pond. As discussed in NewFields (2012) and summarized in Section 2.1, hydrodynamic conditions in the vicinity of the former Rayonier Mill property are extremely different from those of the western harbor. The location of the former mill at the mouth of the harbor potentially leads to dispersion and dilution of much of the property-sourced contaminants. High energy events appear to cause resuspension in the shallow area surrounding the property, dispersing sediment deposited during more typical conditions and resulting in little net deposition. In contrast, the rock jetty that forms the northern boundary of the log pond has historically protected the log pond by blocking and dispersing surface wave energy. The result of wave protection has been the trapping of relatively fine-grained sediments behind the jetty within the log pond. For these reasons it is expected that Source 2 dioxin originating from the former Rayonier Mill upland may dominantly be found in log pond surface sediments and not the remaining sediment in close proximity to the property.

5.2.3 Interpretation

Ancillary sediment data support the theory that Source 2 dioxin is at least partially derived from PCBs. Figure 12 displays the spatial patterns of both Source 2 TEQ and PCB Aroclors, as well as a scatter plot of these surface sediment data. PCB Aroclors were frequently not detected in sediments of the harbor (shown in Figure 12 as red circles). When detected, the greatest total PCB Aroclor concentrations were contained to a relatively small region near the former Rayonier Mill property, particularly the log pond. The only other regions where PCB Aroclors were frequently detected were the western harbor, lagoon, and the southern harbor near Peabody Creek (Figure 12). PCBs Aroclors were not detected in surface sediments of either the central or outer harbor. Locations where PCB Aroclors were not detected generally have Source 2 TEQ values less than 2 ng TEQ/kg. While the scatter plot of Source 2 TEQ versus total PCB Aroclors is not a clear linear relationship, it is apparent that the highest Source 2 TEQs occur where PCB Aroclors are detected (Figure 12). A possible reason for the poor correlation between Source 2 TEQ and PCB Aroclor concentrations is the presence of multiple PCB Aroclor mixtures (potentially from different upland sources) and their differing rates of volatilization and degradation.

The co-occurrence of PCBs and Source 2 in Port Angeles Harbor sediments, as well as the dioxin profile of Source 2, suggests that Source 2 dioxin is a chemical component of PCBs and they are transported and deposited in a similar manner. As with PCBs, the spatial distribution of Source 2 suggests the former Rayonier Mill property and western harbor industries are the primary sources to harbor sediment. The high PCB and Source 2 concentrations observed within the log pond indicate that this area traps these contaminants when released from the upland property, likely due to the wave energy protection provided by the rock jetty. Although sediment transport processes may have dispersed PCBs and Source 2 derived from the former Rayonier property throughout much of the harbor, they are found in such low levels as not to be significant in the central and outer harbor.

There is a high likelihood that PCBs were extensively used at both the former Rayonier Mill property and western harbor industrial properties. PCBs have historically been used as coolants and lubricants in electrical equipment such as transformers and capacitors, and they are 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). PCBs were identified as contaminants of concern for the marine environment near the former Rayonier Mill property because of their possible presence in process wastewater effluent and from incidents of leaking transformers (E & E 2008). Similar concerns regarding PCB discharge also exist for other pulp and paper mills and wood treatment facilities of the western harbor. Additionally, PCBs were extensively used in ship manufacturing as a fire retardant and may be introduced into waters through ship building, maintenance, and decommissioning activities. This may be relevant as portions of the M&R property were once a shipyard (E & E 2008).

5.3 Source 3

5.3.1 Chemical Profile

The Source 3 TEQ profile has the largest contribution from one dioxin congener, 1,2,3,4,6,7,8-HpCDD (42 percent), with additional contributions of 12 and 17 percent from two additional dioxin congeners. One furan congener, 1,2,3,4,6,7,8-HpCDF, accounts for most of the furan contributions (Figure 5). Correlation analyses identify numerous PCP-related profiles as highest ranked (see Appendix B, Table 6). Those comparison profiles with high correlation coefficients include profiles for manufactured PCP (both oil and water soluble forms), PCP-treated utility poles, and sediment samples from Budd Inlet near a former wood treating facility that used PCP. Multiple available profiles for manufactured PCP are included in the inventory of comparison profiles, and those PCP profiles show some variation, but the largest contributing congeners are a good match to the Source 3 modeled profile. PCP is notable for having among the highest dioxin/furan TEQ content among manufactured chemicals.

5.3.2 Spatial Pattern

The spatial pattern of Source 3 in harbor sediments is dominated by a likely point source in the western harbor (Figure 11). The highest Source 3 TEQs occur in close proximity to the current Nippon facility, with slightly lower concentrations found throughout the western-most harbor, including the lagoon. While Source 3 was found to contribute 40 percent to total TEQ harbor-wide, virtually all Source 3 dioxin is found in the western harbor and lagoon. Lower levels of Source 3 dioxin also exist in small, isolated pockets in close proximity to the former Rayonier Mill property. A single location west of the former Rayonier log pond with a relatively high Source 3 TEQ is a likely outlier, as no neighboring locations have elevated levels of Source 3 (Figure 11).

The Source 3 pattern is consistent with originating from a point source along the Nippon shoreline and subsequently dispersing along the major sediment transport pathways (Figure 2). As was mentioned regarding Source 2 (Section 5.2.2), transport pathways in the western harbor act to disperse sediment from close to the western shoreline eastward throughout the western harbor and westward into the lagoon. It appears that Source 3 follows the eastward dispersion transport pathway of the western harbor, as Source 3 TEQ increments decrease as an inverse of distance from the western shoreline. This pattern also implies that sediment transport from the southern harbor to the western harbor under high energy conditions (Figure 2) does not significantly introduce Source 3 to the western harbor.

5.3.3 Interpretation

As discussed in Section 5.3.1, the chemical pattern of Source 3 dioxin is most similar to that of PCP. Approximately 80 percent of PCP production in the United States has been used for commercial wood treatment, 6 percent for slime control in pulp and paper production, and 3 percent for non-industrial purposes (Institute of Environmental Protection [IEP] 2008). The remaining 11 percent was converted to Na-PCP, the sodium salt of PCP, also commonly used as a wood preservative and slimicide.

Throughout the history of the pulp and paper industry, slimicides have been used to prevent the uncontrolled growth of microorganisms that can result in slime deposits. When unchecked, slime can clog filters, screens, and pipelines, and result in spots and breaks in the paper sheet. The use of slimicides, in addition to good housekeeping, is the only practical way to prevent slime formation during the papermaking process (Sanborn 1965). The chemicals used as slimicides have varied over the past century and have often been implicated as highly toxic components of mill effluent and major sources of aquatic pollution (Ali and Sreekrishnan 2001).

It is expected that sediments of Port Angeles Harbor have a dioxin component derived from PCP because of the long-term existence of both lumber and pulp and paper mills along the harbor waterfront. Despite PCP being a likely source of dioxin in harbor sediments, PCP has not recently been detected in any surface sediments of the harbor (E & E 2012). This absence is likely due to the rapid degradation rate of PCP (Kao et al. 2004) compared to its associated dioxin. Additionally, the lack of PCP in harbor sediments may indicate that Source 3 dioxin is relatively old and not associated with modern upland activities.

The spatial pattern of Source 3 dioxin suggests that the industries responsible for the majority of Source 3 are located in the western harbor (Figure 11). Facilities of the western harbor that were likely to have used PCP as either a wood preservative or slimicide include Crown Zellerbach, M&R, and Fibreboard. Identifying the dominant mechanism by which Source 3 became deposited in the harbor is best understood by examining the relationships between Source 3 and metals in surface sediments and distinguishing upland industrial processes driving these relationships.

Relationship between Source 3 Dioxin and Mercury

The co-association of Source 3 dioxin and mercury in surface sediments implies that these chemicals may be derived from a common source. Source 3 TEQ and mercury concentration are spatially well-correlated, having their highest concentrations in close proximity to the Nippon property, an inverse distance decrease across the western harbor, moderate values in the lagoon, and low concentrations in the central and outer harbor (Figure 13). This visual pattern is reinforced by the direct relationship between surface sediment Source 3 TEQ increments and mercury concentration throughout the harbor, as shown in the scatter plot (Figure 13).

The independent and combined use of PCP and mercury as industrial slimicides may explain the spatial correlation of Source 3 and mercury in harbor sediments (Figure 13). The antimicrobial properties of mercury-containing compounds (mostly phenyl mercuries) played an important role in slime control for the pulp and paper industry between 1940 and 1970 (Sherbin 1979). These slimicides were often used in combination with chlorophenates (such as Na-PCP) for their synergistic value (Sanborn 1965). However, due to their severe environmental impact, the use of mercury-based compounds by the industry steadily declined until complete discontinuance in 1970. Mercury-containing compounds were generally replaced by a variety of cyanate, sulfur, and chlorinated phenol compounds for microbial control (EPA 1971; Wang et al. 2009).

The utility of Na-PCP as a slimicide was first recognized in 1938, when it was found to be toxic to many types of organisms that were resistant to chlorine and had been used in several cases where other biocides had failed (Carswell and Nason 1938). The advantages of using chlorophenates as slimicides include (Sanborn 1965):

- Compatibility with many different chemicals used in paper manufacturing;
- Dispersive and penetrative properties;
- Adaptability to many problems of pulp and paper mills and water systems;
- Less affected by organic matter than many other chemicals;
- Non-corrosive to metals; and
- Persistence in mill systems.

By 1980, the pulp and paper industry recognized the wastewater implications of PCP-containing slimicides (NCASI 2009). Significant concentrations of PCP found in pulp and paper mill wastewaters were traced to the use of slimicides containing Na-PCP (EPA 1978). Additionally, PCP was found to be as toxic to fish as previously used slimicides containing mercury (Norup 1972). Following inclusion of PCP on the EPA priority pollutant list and the detection of PCP in some mill effluents, its use by the pulp and paper industry was discontinued (Nitka et al. 1982).

Records of the specific slimicides used by Port Angeles pulp and paper mills are lacking. However, as of 1962 discharge permits for both Crown Zellerbach and Rayonier included the requirement that “a detailed report on the mill’s slime control program be submitted to the Washington Water Pollution Control Commission (WPCC)” (Shea et al. 1981). These slime control reports are not currently present in the Washington State Archive. It was documented that Crown Zellerbach discontinued the use of slimicide products manufactured by the Betz company in 1975, replacing them with the cyanate-containing CYTOX 3522 slimicide (Morgan 1976). Betz was known to have produced slime control products containing Na-PCP during the time that they were utilized by Crown Zellerbach (EPA 1971, 1976).

Relationship between Source 3 Dioxin and Zinc

In a similar manner as mercury, Source 3 TEQ and zinc concentration are co-associated in surface sediments throughout the harbor (Figure 14). Elevated concentrations of zinc found in western harbor and lagoon sediments can be traced to a unique industrial process that was utilized at the Crown Zellerbach pulp and paper mill, but not other mills of the harbor. While the Rayonier and Fibreboard mills both used sulfite pulping followed by chlorine-based bleaching processes, Crown Zellerbach performed mechanical pulping and zinc hydrosulfite bleaching. The differences in processes between mills were required for the different grades of paper being produced. Chlorine-based bleaching acts to fully remove pulp’s lignin component (source of color), where as zinc hydrosulfite bleaching preserves lignin while decolorizing it through the deactivation of chromophores.

Zinc hydrosulfite used by Crown Zellerbach was manufactured on site at the facility from powdered zinc and sulfur dioxide (Nippon 2000). In 1977, the process of zinc-based bleaching at

Crown Zellerbach was replaced by the zinc-free sodium hydrosulfite process in order to comply with zinc discharge levels (25.4 kg/day) stipulated in their National Pollutant Discharge Elimination System (NPDES) permit (Shea et al. 1981). Because high levels of zinc were characteristic of Crown Zellerbach discharge prior to discontinuation of zinc-based bleaching, the spatial distribution of elevated zinc concentrations in the harbor is a likely indication of the Crown Zellerbach effluent depositional footprint prior to 1977 (Figure 14). The co-association of Source 3 dioxin and zinc suggests that Source 3 may have been present in the zinc-rich effluent discharged from the Crown Zellerbach facility, and that this facility is the main contributor of Source 3 dioxin to the harbor.

Point Source Location Based on Spatial Pattern

The highest Source 3 TEQs, as well as the highest concentrations of mercury and zinc, occur immediately in front of an outfall on the current Nippon property (Figures 13 and 14). This outfall (identified as Outfall 021) was used by Crown Zellerbach to discharge effluent to the harbor between 1920 and 1978 (Shea et al. 1981). A mill effluent disposal map from 1957 shows that this same outfall (referred to in this document as Outfall 40) drained the machine and finishing rooms of the Crown Zellerbach facility (Exponent 2008). According to an effluent discharge table present on the map, this outfall discharged an average of 4,000 gallons per minute of pulp fiber and industrial waste, making it the facility’s highest volume outfall at the time. In the 1960s, the area immediately in front of this outfall was found to have the greatest thickness of sludge deposits harbor-wide, which were at the time attributed to discharge of paper mill wastes from Crown Zellerbach (U.S. Department of Interior [DOI] 1967).

Summary

When considered together, surface sediment chemistry, spatial pattern, and history of industrial operations imply that the former Crown Zellerbach facility was the dominant source of Source 3 dioxin to harbor sediments. Source 3 appears to be derived from PCP-containing slimicides used during papermaking, which were subsequently discharged to the harbor in process wastewater. These lines of evidence also suggest that Source 3 dioxin present in harbor sediments was primarily deposited before the 1980s. By the late 1970s it appears that Crown Zellerbach had terminated the use of PCP-containing slimicides, installed primary and secondary wastewater treatment facilities, and ceased the discharge of effluent to the harbor.

While Crown Zellerbach appears to be the major contributor of Source 3 dioxin to sediments of the western harbor, other western harbor facilities may also have lesser contributions. M&R is known to have applied PCP in the form of Permatox 180 to lumber as a wood preservative until approximately 1974 (CH2M Hill 1989). Preservatives were applied within a spray room with a recirculating distribution system. Investigations of the property in the late 1980s found low levels of PCP in soil and groundwater, with this contamination contained to a small upland footprint that did not require remedial action (Hart Crowser 1988; CH2M Hill 1989). Process wastewater from the property was not discharged to the harbor.

The Fibreboard pulp and paper mill may also have contributed to Source 3 dioxin of the western harbor. As mentioned previously, Fibreboard performed chlorine-based bleaching until closure in 1970. Both chlorine and chlorine dioxide used in conventional chlorine-based bleaching are effective biocides for the prevention of bacteria. Consequently the use of additional slime control agents at Fibreboard may have been limited. While Fibreboard may have utilized similar PCP-containing slimicides as Crown Zellerbach, there are no known records to substantiate this. The chlorine bleaching process is known to form dioxins/furans and other chlorinated compounds (Wang et al. 2009). However, Source 3 does not have the characteristic congener pattern created by the chlorine bleaching of paper pulp (NCASI 1990).

5.4 Source 4

5.4.1 Chemical Profile

The Source 4 TEQ profile has the largest contribution from one dioxin congener, 1,2,3,7,8-PeCDD (44 percent), with a “hump” of additional moderate contributions from several higher chlorinated dioxin congeners (Figure 5). Two furan congeners, 2,3,7,8-TCDF and 2,3,4,7,8-PeCDF, account for most of the furan contributions. The pattern of dominant 1,2,3,7,8-PeCDD contribution combined with the two primary contributing furan congeners was noted in the Port Angeles soil dioxins study as being characteristic of air emissions from burning salt-laden wood, based on a large number of stack tests at multiple facilities. Similar patterns were found in hog fuel boiler ash from burning salt-laden wood, and also in effluent samples from the former Rayonier mill. Residential wood burning and forest fires have somewhat similar patterns as well. The correlation analysis showed multiple stack tests at hog fuel boilers burning salt-laden wood were highly ranked, as were similar profiles from both Rayonier ash and effluent samples (see Appendix B, Table 6). One vehicle emissions-related profile, among several included in the inventory of comparison profiles, also occurs among the high-ranking patterns and has some contribution from higher-chlorinated dioxin congeners.

Like Source 2, Source 4 may represent a composite pattern to some degree. Based on the correlation analysis results, the most similar patterns are found to be air emissions from hog fuel boilers burning salt-laden wood and the related and similar patterns in effluent and ash samples. Additional diffuse source types such as vehicle emissions, forest fires, residential wood burning, and perhaps other common combustion sources may also contribute to a lesser extent in the Source 4 profile.

5.4.2 Spatial Pattern

The spatial pattern of Source 4 is much more dispersed than the other dioxin sources previously discussed (Figure 11). Source 4 contributes 44 percent to harbor-wide TEQ, making it the most abundant source of dioxin to sediments of the harbor. Additionally, Source 4 is the dominant contributor to total TEQ of the southern and central harbor, regions where the other sources generally have much lower contributions.

The Source 4 pattern appears to be influenced by all major sediment transport pathways in the harbor (Figure 2). Highest Source 4 TEQs (>20 ng TEQ/kg) are located in the most protected depositional regions; the log pond and lagoon. Slightly lower Source 4 TEQs (8 to 20 ng TEQ/kg) are found in a patchy nature throughout the western harbor. A plume-like feature of moderate Source 4 TEQs (4 to 8 ng TEQ/kg) exists along the southern harbor in the vicinity of active CSOs. Relatively low Source 4 TEQs (<4 ng TEQ/kg) are restricted to the central and outer harbor.

Intricacies of the Source 4 spatial pattern can be used to identify potential point source locations (Figure 11). Based on their proximity to the highest Source 4 TEQ samples, both the Nippon and former Rayonier Mill properties are likely sources of Source 4 dioxin to harbor sediments. These high Source 4 TEQs result because of the depositional character of the log pond and lagoon, which allow these features to trap Source 4 from the respective adjacent properties. The lack of a well-defined Source 4 spatial gradient in the western harbor (Figure 11) indicates that a single point source along the western shoreline may not be driving the spatial pattern (as was the case for Source 3). Instead, the western harbor pattern may be the result of multiple point sources with complex transport mechanisms.

Deposition of Rayonier-derived Source 4 is apparent in the log pond; however, similar deposition in close proximity to the property is not expected due to physical scouring and dispersive processes. The dominant sediment transport pathways suggest that Source 4 derived from the former Rayonier Mill property would eventually be dispersed in a multidirectional manner throughout the southern, central, and outer harbor (Figure 2). Source 4 deposited along the southern harbor may have a Rayonier-derived component, but also additional input from other source locations along the southern harbor.

5.4.3 Interpretation

The extensive spatial distribution of Source 4 dioxin and relatively high levels in many regions of the harbor make it the greatest contributor to total TEQ of sediments harbor-wide. As discussed in Section 5.4.1, the chemical pattern of Source 4 is most similar to that of emissions and ash from HFBs burning salt-laden wood, as well as effluent samples from one such facility. Locations of operational (Nippon) and historic (Fibreboard, K-Ply, and Rayonier) HFBs in Port Angeles, which utilized salt-laden wood as a fuel source, are shown in Figure 15. HFBs burning salt-laden wood were also identified in the Rayonier Mill Off-Property Soil Dioxin Study (E & E and Glass 2011) as being a major contributor to Port Angeles soil dioxin. Because of the widespread presence of HFB-derived dioxin in upland soils, it is important to consider the aerial transport of Source 4, subsequent deposition, remobilization, and delivery to the harbor when identifying likely point sources to sediments. Dioxins/furans produced in HFBs are not only associated with stack emissions, but also boiler ash that is handled as solid waste by the HFB operators.

Similarity between the dioxin chemical pattern of emissions and ash from HFBs burning salt-laden wood and former Rayonier Mill effluent samples collected between 1989 and 1992 (FWEC 1997) imply the presence of HFB ash in the mill’s effluent. The chemical pattern of these Rayonier effluent samples is not characteristic of the dioxin/furan congener pattern created during the chlorine bleaching process and what has typically been found in the effluent of pulp and paper mills utilizing elemental chlorine bleaching (NCASI 1990). During the time that the Rayonier effluent samples were collected, many pulp and paper mills were switching from elemental chlorine bleaching to elemental chlorine-free processes, known to produce far fewer dioxins (NCASI 2009). While effluent from the former Rayonier Mill may have had a different dioxin concentration and composition prior to the 1990s, HFB ash appears to be a candidate source of dioxin TEQ in the effluent samples analyzed. Similar comparisons between HFB ash and effluent from other Port Angeles facilities cannot be made, as these data do not exist.

Dioxin from Hog Fuels

Using salt-laden wood in HFBs can result in significantly higher emissions of dioxins/furans than can burning salt-free wood (Duo and Leclerc 2004; Lavric et al. 2004; Luthe et al. 1997; Luthe et al. 1998; Pandompatam et al. 1997; Preto et al. 2005; Uloth et al. 2005). Stack tests for dioxin air emissions from the former Rayonier Mill (1995) and the Nippon mill (2009) have previously been compared (E & E and Glass 2011). The estimated HFB emissions from the former Rayonier Mill based on the 1995 stack test, 0.077 grams TEQ/year, are more than 23 times greater than the estimate of 0.0033 grams TEQ/year calculated from the 2009 Nippon HFB stack test. However at the time of the Nippon stack test, and for many years prior, the Nippon mill was not burning salt-laden wood. Delivery of materials by water and storage of logs in the lagoon was standard during earlier operations at the property (then Crown Zellerbach), but are believed to have ceased by 1976. The comparison of estimated annual TEQ emissions from the Nippon and former Rayonier mills, with substantially higher emissions associated with burning salt-laden wood versus non-salt-laden wood, is consistent with literature reports associating salt-laden wood with higher emissions (see Das 2003; Pandompatam et al. 1997; Luthe and Prahacs 1993; Duo et al. [undated]; Duo and Leclerc 2007; EPA 2006; Van Oostdam and Ward 1995).

Data are also available for boiler ash dioxins for the Nippon and former Rayonier mills, presenting the same type of comparison between burning non-salt-laden wood and salt-laden wood. Yake et al. (1998) provide estimated loadings of dioxin from boiler ash for both mills. The result for Rayonier (22.2 mg TEQ/day) is 1,850 times greater than the value for Daishowa (currently Nippon) (0.012 mg TEQ/day). Daishowa HFB ash was disposed of at a Port Angeles-area landfill (Lawson Landfill) starting in 1983, reportedly well after use of the lagoon ended. Deep cores in the ash disposal area were collected and tested for dioxins/furans in 1998 (E & E 1998a). The TEQs for six ash samples from up to 17 feet below the surface ranged from 0.48 to 1.6 ng TEQ/kg. In contrast, results for Rayonier ash at times exceeded 10,000 ng TEQ/kg (FWEC 1997; see also E & E 1998b and 1998c for results of sampling at Rayonier ash disposal landfills).

Both HFB emissions and ash data thus confirm that burning salt-laden wood can substantially increase dioxin levels. The potential for Port Angeles HFBs to produce dioxin-rich emissions and ash associated with burning salt-laden wood, and not recent periods of burning relatively salt-free wood, are of greatest interest for understanding the presence of Source 4 in harbor sediments.

Port Angeles HFBs

Facilities in Port Angeles burning salt-laden wood wastes in HFBs are likely to have had similar emission and ash dioxin TEQ profiles. Due to the location of facilities on Port Angeles Harbor and the abundance of wood as a source of fuel for onsite burners, burning wood chips and wood wastes coming from logs floated in the harbor was a common practice. The former Rayonier Mill used wood chips, including salt-laden wood, in the onsite HFB (Integral 2006). Additionally, dewatered sludge from the mill’s wastewater treatment system was also burned in the Rayonier HFB.

Historically, the operations of several other facilities, including the Nippon, K-Ply (formerly Pen-Ply), and Fibreboard, involved marine delivery and storage of materials and therefore burning of salt-laden wood wastes (see Yake et al. 1998; Martin 1983; and Plywood Pioneers Association 2001). There are no direct measurements of air emissions from these facilities during the time that they were burning salt-laden wood from which to derive dioxin mass emissions. Cumulative dioxin emissions from these facilities would reflect the duration of operations, the annual amounts of salt-laden wood burned, boiler and pollution control system designs, and other factors. Given the size and operating histories of these other Port Angeles locations with HFBs, their combined (and in some cases individual) dioxin/furan TEQ air emissions may well have been similar in scale to the estimated cumulative emissions from the former Rayonier Mill (E & E and Glass 2011).

Residential wood burning in Port Angeles is not likely to have a significant contribution to Source 4 in harbor sediments. Although TEQ profiles for residential wood burning are fairly similar to that of Source 4, the former Rayonier Mill HFB annually burned many times more wood than total residential use (E & E and Glass 2011). Additionally, the use of relatively salt-free wood for residential applications would minimize the amount of dioxin produced as opposed to the use of salt-laden wood in HFBs.

Transport of HFB-Related Dioxin Prior to Entering the Marine Environment

Sediment Source 4 TEQs may reflect contributions from more than one HFB source and also mixtures of boiler ash and stack emissions. Additionally, Source 4 may be introduced to the harbor through a variety of transport pathways that are physically disconnected from the HFBs themselves. Prior to deposition in the harbor, transport of Source 4 dioxin may involve:

- Aerial deposition of HFB emissions onto the harbor surface;
- Aerial deposition of HFB emissions in the uplands and subsequent delivery to the harbor in 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; and
- Direct disposal of HFB ash into the harbor.

HFB emissions and ash may have a long and complex transport history before being introduced to the marine environment. Published studies have shown that impacts on nearby soils from dioxin in air emissions decrease relatively rapidly as distance from the source increases. Therefore the greatest amount of dioxin aerial deposition (both on-water and upland) is expected in close proximity to the HFB. This was the case for upland soils in the vicinity of the former Rayonier HFB (E & E and Glass 2011). Elevated HFB-sourced dioxin in Port Angeles soils was also identified far west of the Rayonier HFB, assumed to be derived from other HFBs located along the western and southern harbor. Once deposited on the land surface, emission-related dioxin is susceptible to transport in stormwater runoff. Such runoff is delivered to the harbor by local creeks, the City of Port Angeles WWTP deepwater outfall, and CSOs. Therefore creeks, the deepwater outfall, and CSOs may appear as point sources for Source 4 even though the dioxin is initially derived from HFBs.

In recent times, boiler ash produced at Port Angeles facilities was generally removed from the properties and disposed of in landfills. However, little is known about ash disposal procedures during the early history of industrial activities in the harbor. Unknown amounts of ash may have been used as fill at the properties, as was the case in the Crown Zellerbach lagoon (see Section

5.1.3). Prior to removal from a property, exposed boiler ash at a facility may be introduced to the marine environment through transport by wind and stormwater runoff. Additionally, boiler ash may have inadvertently been incorporated into process water or incorporated into wastewater effluent as a means of disposal.

Deposition of HFB-Related Dioxin in the Marine Environment

As discussed in Section 5.4.2, the overall Source 4 pattern in surface sediments appears to be influenced by all major sediment transport pathways in the harbor (Figure 15).

Lagoon

High Source 4 TEQs of the lagoon are inevitably because of proximity to the Nippon HFB and the depositional nature of the lagoon. The use of boiler ash as fill in the lagoon (Daishowa 1989), deposition of emissions from the adjacent HFB stack, and effluent containing HFB ash may have contributed to these high TEQs. Sediments of the lagoon are not expected to be a source to the rest of the harbor because the morphology and hydrologic conditions of the lagoon prevent erosion and transport of deposited material.

Western Harbor

Lack of a well-defined Source 4 spatial gradient in the western harbor suggests complex transport mechanisms prior to deposition (Figure 15). As was discussed regarding Source 3 dioxin (Section 5.3.2), a point source subjected to in-water transport processes of the western harbor is expected to produce a plume-like footprint with highest concentrations emanating from the point source. The patchy nature of moderately high Source 4 TEQs present throughout the western harbor may imply multiple sources and/or a combination of aerial and in-water transport processes.

The majority of western harbor Source 4 dioxin is likely derived from emissions, ash, and effluent from the closest HFBs (Nippon and Fibreboard). The downwind locations of the K-Ply and Rayonier HFBs suggest that these facilities would have very limited aerial contributions of Source 4 to the western harbor. Also, sediment transport processes are not expected to significantly transport Source 4 from the southern harbor to the western harbor. Conversely, in-water processes are not expected to significantly transport western harbor Source 4 eastward beyond the transport front and into the central harbor (Figure 15). However, prevailing westerly winds may aerially transport HFB-derived dioxin beyond this front prior to deposition, potentially causing western harbor HFBs to contribute to Source 4 of central harbor sediments.

Southern, Central, and Outer Harbor

The only other region of the harbor with equally high Source 4 TEQs as the lagoon is the former Rayonier log pond (Figure 15). In a similar manner as the lagoon, the log pond appears to have acted as a depositional zone for stack emissions, ash, and ash-containing effluent from the adjacent Rayonier HFB. Similar levels of Source 4 as in the log pond are expected to have been deposited in the remaining area surrounding the Rayonier HFB. However, as was discussed in regard to Source 2, the physical environment surrounding the former Rayonier property (outside of the log pond) prevents the long-term deposition of fine-grained material derived from upland sources. The location of the former mill at the mouth of the harbor leads to high energy resuspension and subsequent low energy dispersion of property-sourced contaminants throughout much of the southern, central, and outer harbor, as well as much of this material being transported outside the confines of the harbor (Figure 15). Both moderate Source 4 TEQs along the southern harbor between Peabody Creek and Tumwater Creek and relatively low Source 4 TEQs of the central and outer harbor are likely to have some contribution from sediments scoured from near the former Rayonier Mill property. Little Source 4 deposition is expected in the shoreline region between the western extent of the log pond and Peabody Creek (Figure 15), as the sediment bed here is composed of predominantly sand and gravel (GeoSea 2009).

Prevailing westerly winds of Port Angeles Harbor prevent the aerial deposition of the former Rayonier HFB emissions far into the western harbor. Instead, dioxin derived from Rayonier HFB emissions would deposit close to the property or on upland surfaces, as has previously been documented (E & E and Glass 2011). Any HFB emissions contributing to dioxin contamination in Port Angeles uplands may also contribute to the diffuse Source 4 spatial pattern found in the southern, central, and outer harbor. After being mobilized in stormwater runoff, HFB emissions can be transported to the harbor by creeks and in effluent from both the WWTP deepwater outfall and municipal CSOs. Creek and CSO stormwater delivery mechanisms are likely contributors to moderate Source 4 TEQs of the southern harbor between Peabody Creek and Tumwater Creek (Figure 15). Subsequent in-water sediment transport mechanisms may further spread this dioxin to the central harbor. Source 4 introduced to the harbor by the WWTP deepwater outfall may contribute to low Source 4 TEQ increments of the central and outer harbor. Overall, multiple HFB point sources and the complexity of possible transport mechanisms prior to deposition in sediments make the partitioning of Source 4 between the different HFBs challenging.

6.0 Conclusions

In an effort to increase the understanding of dioxin/furan sediment contamination throughout Port Angeles Harbor, specific objectives of the Port Angeles Sediment Dioxin Source Study included:

- Identifying distinct dioxin/furan congener source signatures present in harbor sediments;
- Determining the relative contribution of identified dioxin/furan sources to harbor-wide contamination; and
- Using the spatial patterns of sediment dioxin/furan sources, as well as characteristics of facilities in the Port Angeles area, to identify potential upland point source locations.

The results of this study are expected to guide Ecology in pursuing dioxin source control strategies for the harbor. It is not Ecology's intention to perform detailed quantitative allocations among potential point/nonpoint sources or to apportion liability to potentially liable parties.

The chemometric evaluation of Port Angeles Harbor dioxin/furan congeners identified four source patterns that provide a good model for measured TEQ values. Each of the four proposed source patterns has an analog in known dioxin-producing materials:

- Source 1 – 2,4,5-T or wood ash;
- Source 2 – PCBs;
- Source 3 – Pentachlorophenol; and
- Source 4 – Emissions, ash, and effluent related to the burning of salt-laden wood in HFBs.

Spatial interpolation of dioxin source TEQ increments allowed for the determination of the relative contribution of each source to harbor-wide dioxin contamination. Sources 3 and 4 are the major contributors to harbor-wide total TEQ, comprising 40 and 44 percent of the total TEQ, respectively. Sources 1 and 2 play a much smaller role in harbor-wide dioxin contamination, respectively contributing 6 and 10 percent to harbor-wide total TEQ.

Each of the dioxin sources has a unique spatial pattern in harbor sediments, which, along with supplemental data, can be used to identify potential upland source locations and understand mechanisms by which the dioxin became deposited:

Source 1 dioxin is confined almost entirely to the lagoon and is the likely result of either 2,4,5-T application or ash disposal in the lagoon by the former owner of the adjacent pulp and paper mill, Crown Zellerbach. Subsequent land use activities at this property (stormwater runoff, site-related construction activities, etc.) may have also contributed Source 1 to the lagoon.

Source 2 dioxin is likely derived primarily from PCBs, as it is concentrated in regions of the harbor where PCB Aroclors have been detected; the lagoon, western harbor, and the former Rayonier log pond. These patterns and the history of upland industrial activities suggest western harbor industries and the former Rayonier Mill property are the primary source locations. Introduction of PCBs and their associated dioxin to the harbor may be related to industrial process wastewater effluent, runoff related to leaking transformers, and possible in-water activities involving ship manufacturing and maintenance.

Source 3 dioxin is characteristic of PCP, a chemical used extensively by both lumber and pulp and paper mills. The co-association in sediments of Source 3 with both mercury and zinc implies that these components may have been delivered to the harbor from a common source. Mercury and PCP were commonly used, both independently and together, as slimicides in pulp and paper mills. Crown Zellerbach is believed to have used PCP-containing slimicides until the mid-1970s. Zinc can be used as a tracer for Crown Zellerbach wastewater discharged to the harbor because of their zinc hydrosulfite bleaching process, not used by other Port Angeles mills. The similar spatial patterns of Source 3, mercury, and zinc are indicative of a localized point source at the neck of Ediz Hook. This specific location was the site of a historic Crown Zellerbach outfall identified as discharging industrial waste from sectors of the mill most likely to have utilized slimicides. Ongoing western harbor activities (i.e., log handling tugboats) may result in continual mixing of the surface sediments, causing western harbor sediments to be both a sink for historical contamination and an ongoing source for current surface sediment contamination.

Source 4 dioxin, derived from emissions, ash, and effluent related to the burning of salt-laden wood in HFBs, is the most abundant and diffuse source of dioxin to harbor sediments. Its spatial pattern is indicative of multiple point sources and extensive dispersion by sediment transport pathways of the harbor. Source 4 found in sediments of the lagoon, western harbor, and former Rayonier log pond are most likely derived from the most proximal HFBs. Lower levels of Source 4 TEQ increments throughout the southern, central, and outer harbor have potential contributions from:

- Aerial deposition of HFB emissions onto the harbor surface;
- Scoured and dispersed sediment from the vicinity of the former Rayonier Mill; and
- HFB emissions first deposited in the uplands and subsequently delivered to the harbor in stormwater runoff and municipal effluent.

Chemometric unmixing and spatial analysis of Port Angeles Harbor sediment dioxin/furan congener data are consistent with the main conclusions from NewFields (2012) regarding dioxin contamination based on total TEQ:

- The former Rayonier Mill property and upland sources along the western harbor shoreline are the dominant contributors to sediment dioxin contamination.
- Local sources of dioxin contribute most to western harbor sediment contamination, not those transported from the southern harbor.
- Sediments of the lagoon are not a source to the harbor, but suspended material in the harbor may be transported to and deposited within the lagoon.
- Dioxin from the former Rayonier Mill has the potential to be dispersed throughout much of the harbor and contribute to low-level dioxin in the central harbor.

In addition to supporting these previous conclusions, a main deduction of this study is that the majority of dioxin contamination in harbor sediments appears to be derived from industrial practices no longer occurring. Much of the dioxin found in the harbor was associated with the use of PCP, PCBs, and possibly 2,4,5-T, chemicals currently banned from industrial use. Three of the four HFBs of the harbor have been decommissioned, and the remaining operational HFB is no longer fueled with salt-laden wood. However, dioxin derived from HFB emissions that are currently present in soil may continue to be transported to the harbor in stormwater runoff. Based on these conclusions, ongoing sources of dioxin are not expected to cause extensive recontamination of the harbor subsequent to cleanup.

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Figures

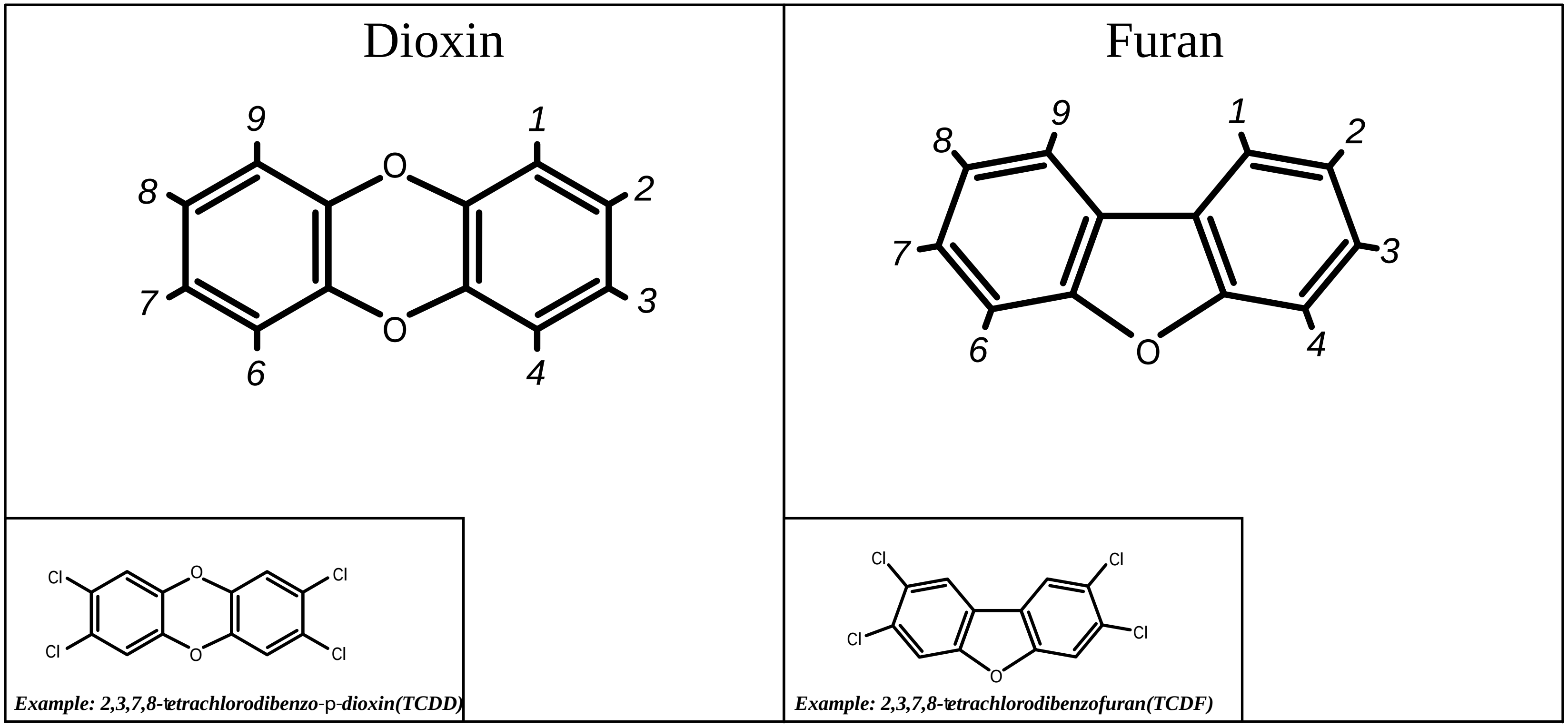

Figure 1. Structure and Chlorine Substitution Locations for Dioxins and Furans

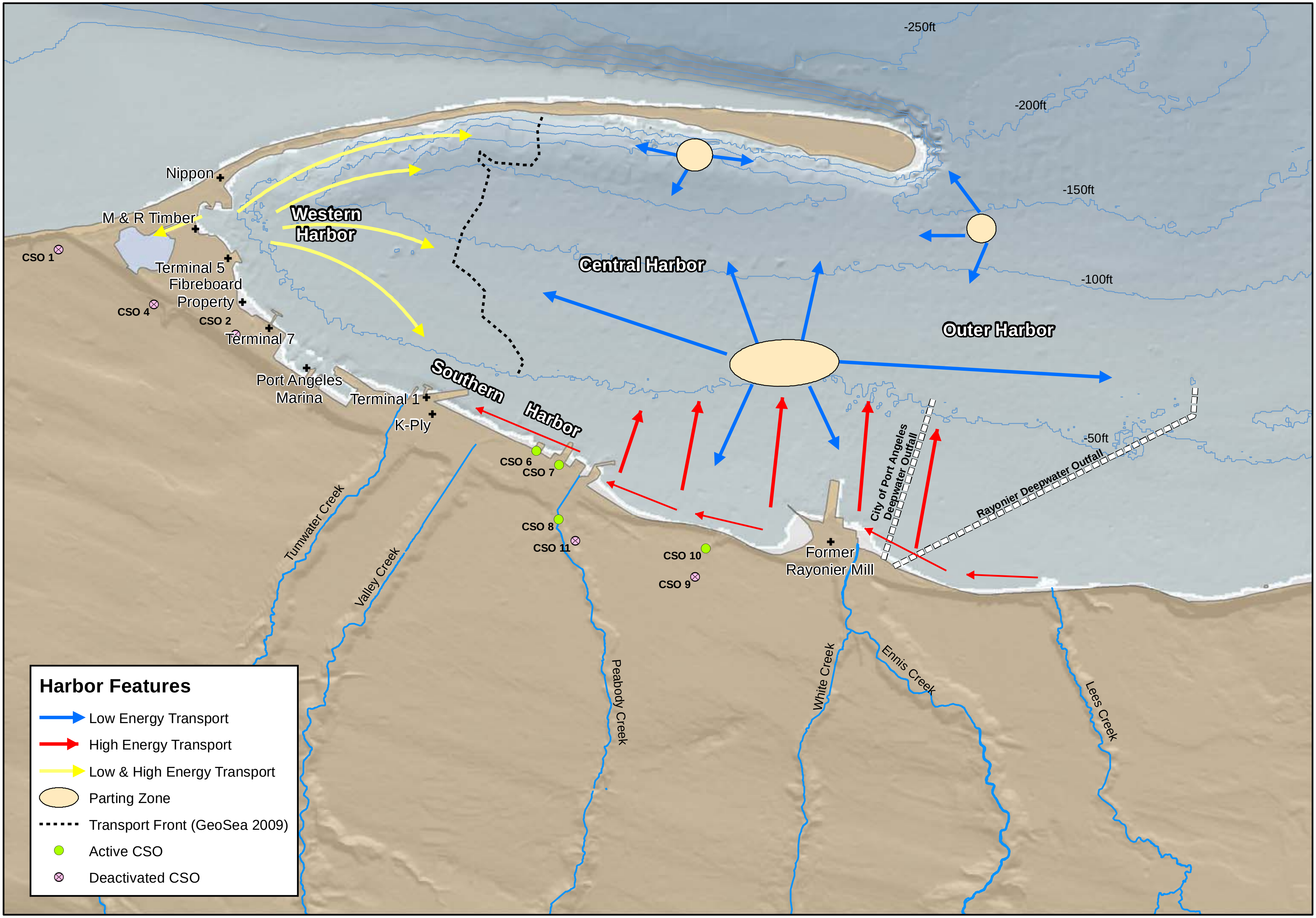

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Figure 2. Sediment Transport Pathways

NewFields

L. Delwiche, 2012
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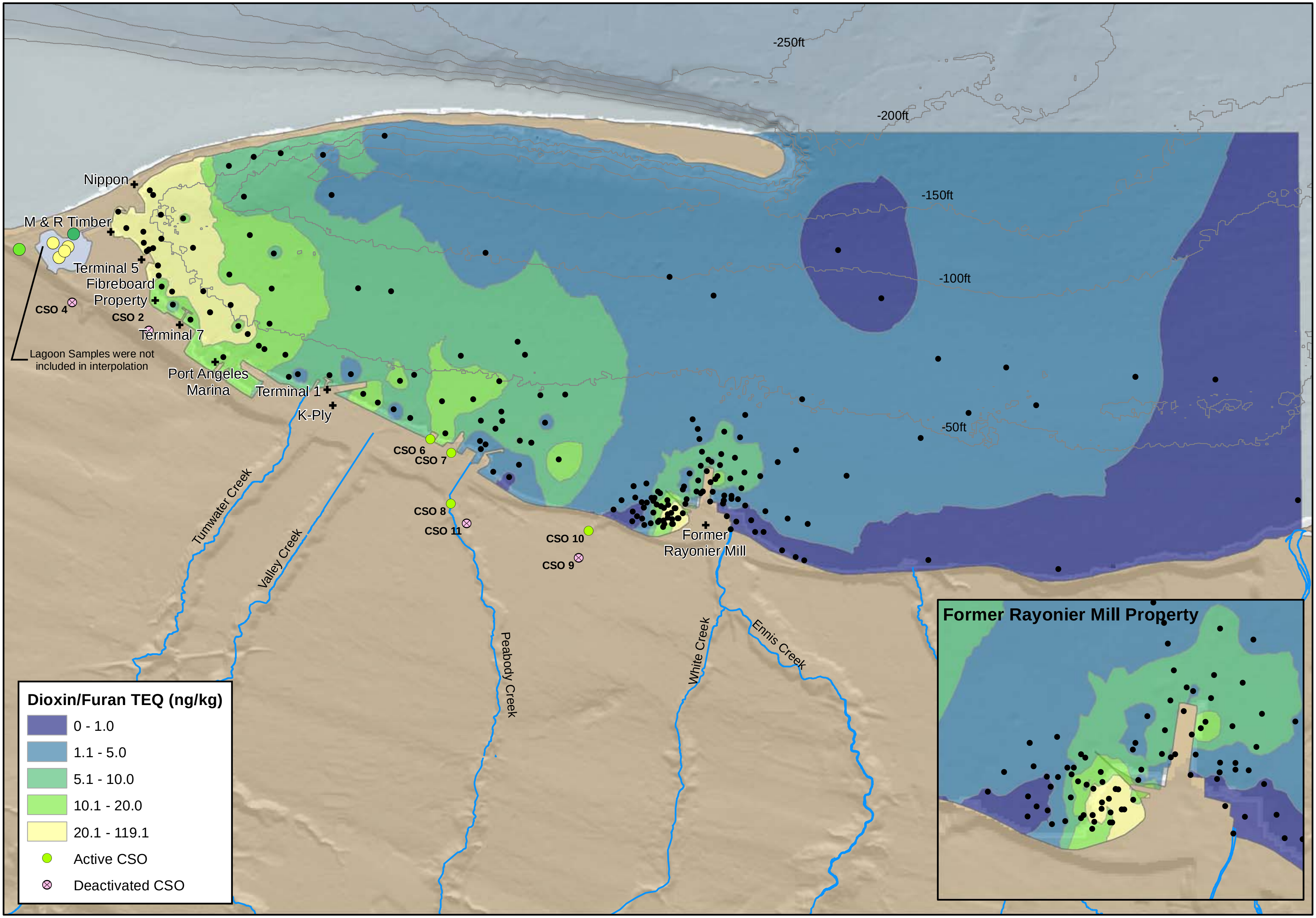

Figure 3. Interpolated Sediment Dioxin/Furan Total TEQs

N

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2013

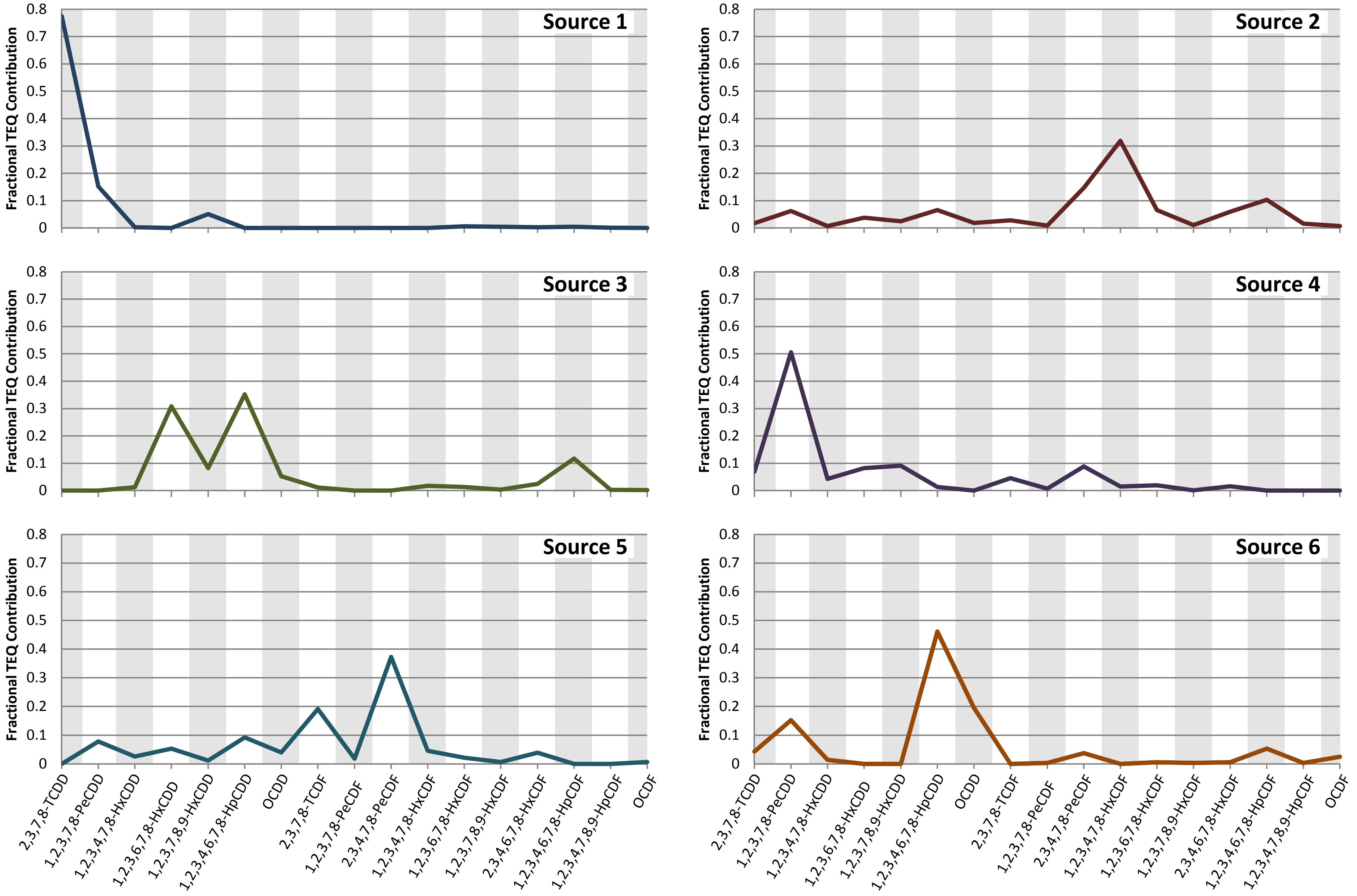

Figure 4. Dioxin/Furan Source Profiles derived from the 6-Source Model

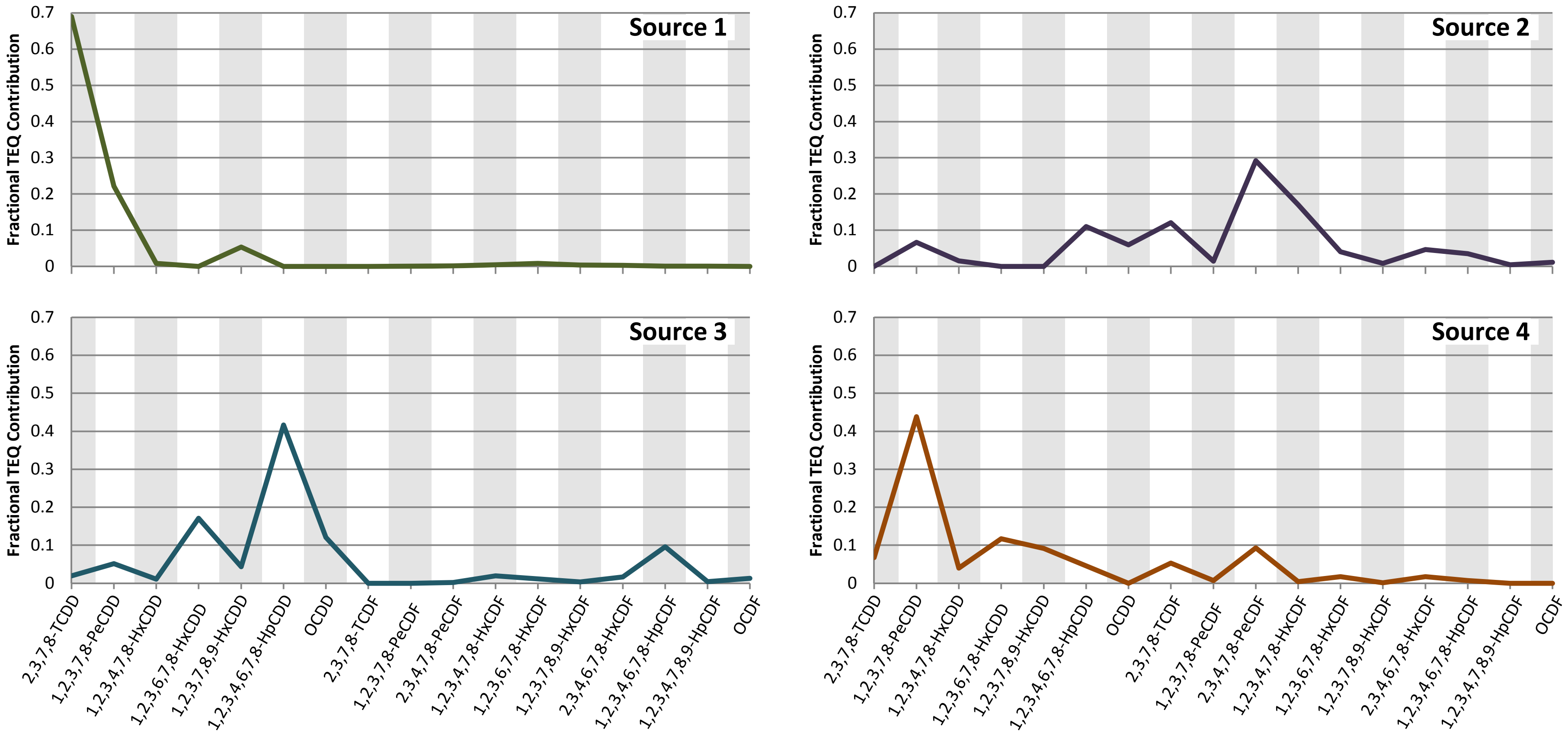

Figure 5. Dioxin/Furan Source Profiles derived from the 4-Source Model

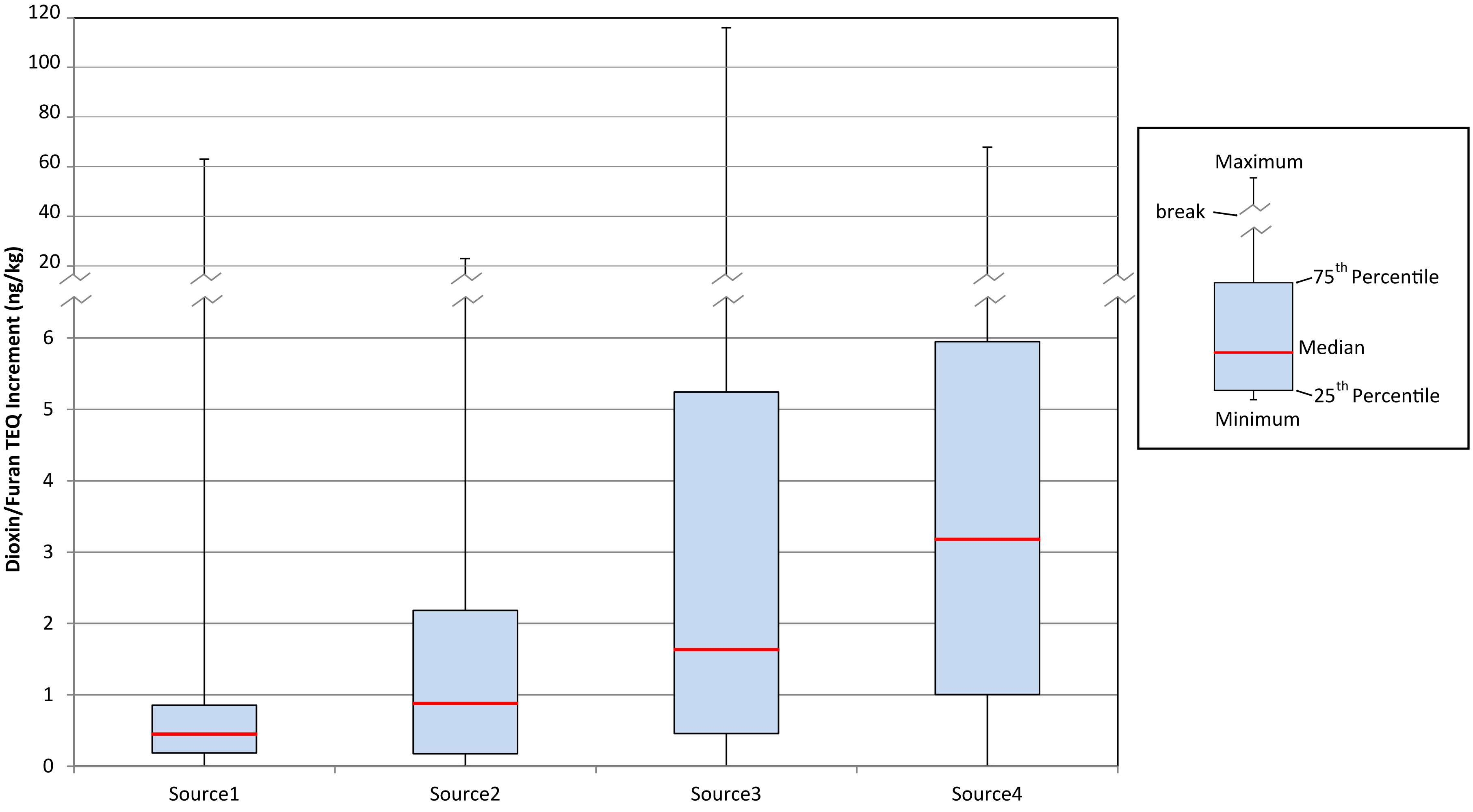

Figure 6. Comparison of Surface Sediment Sample Source Increments

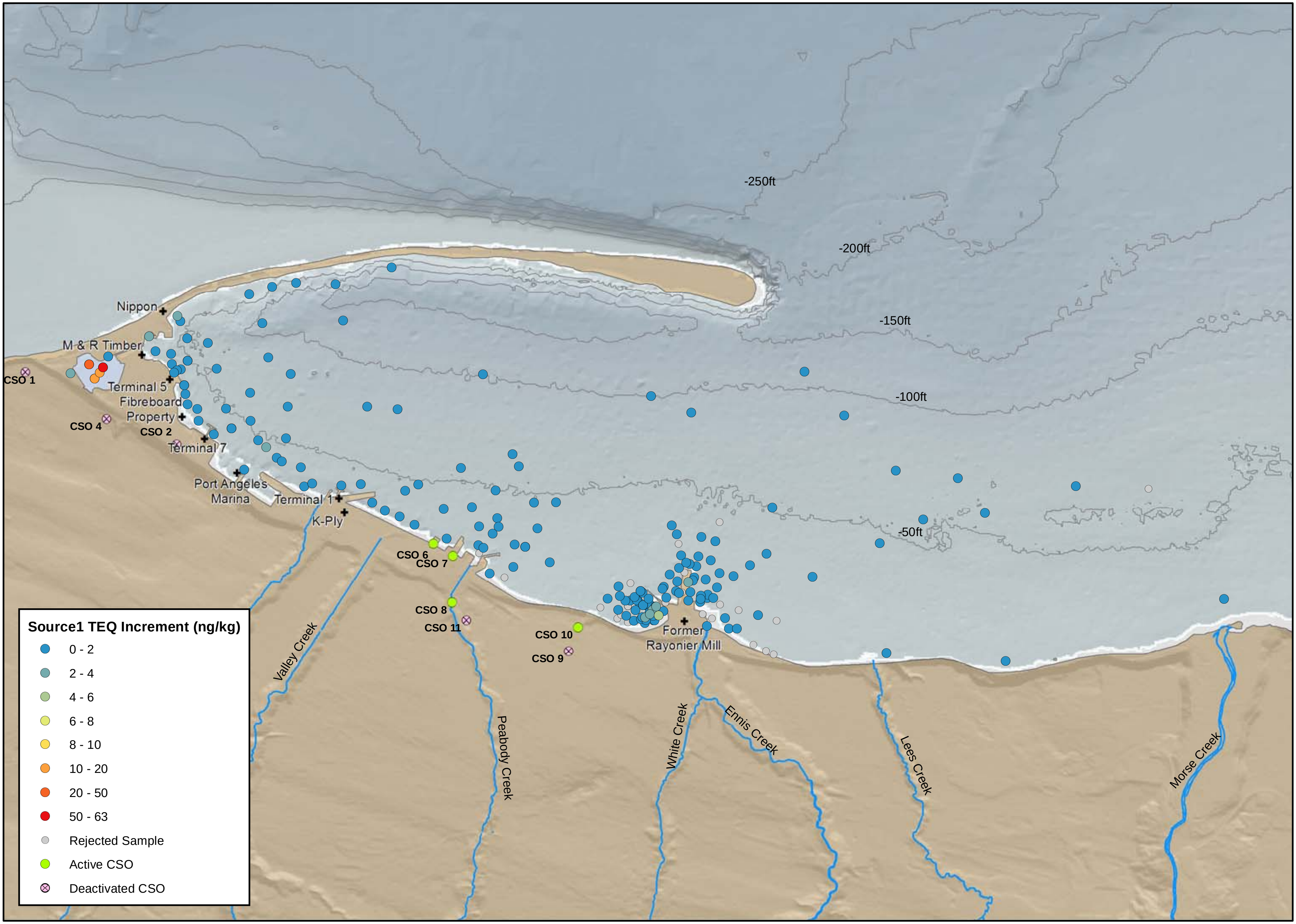

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Figure 7. Source 1 Dioxin TEQ Increments

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L. Delwiche, 2013

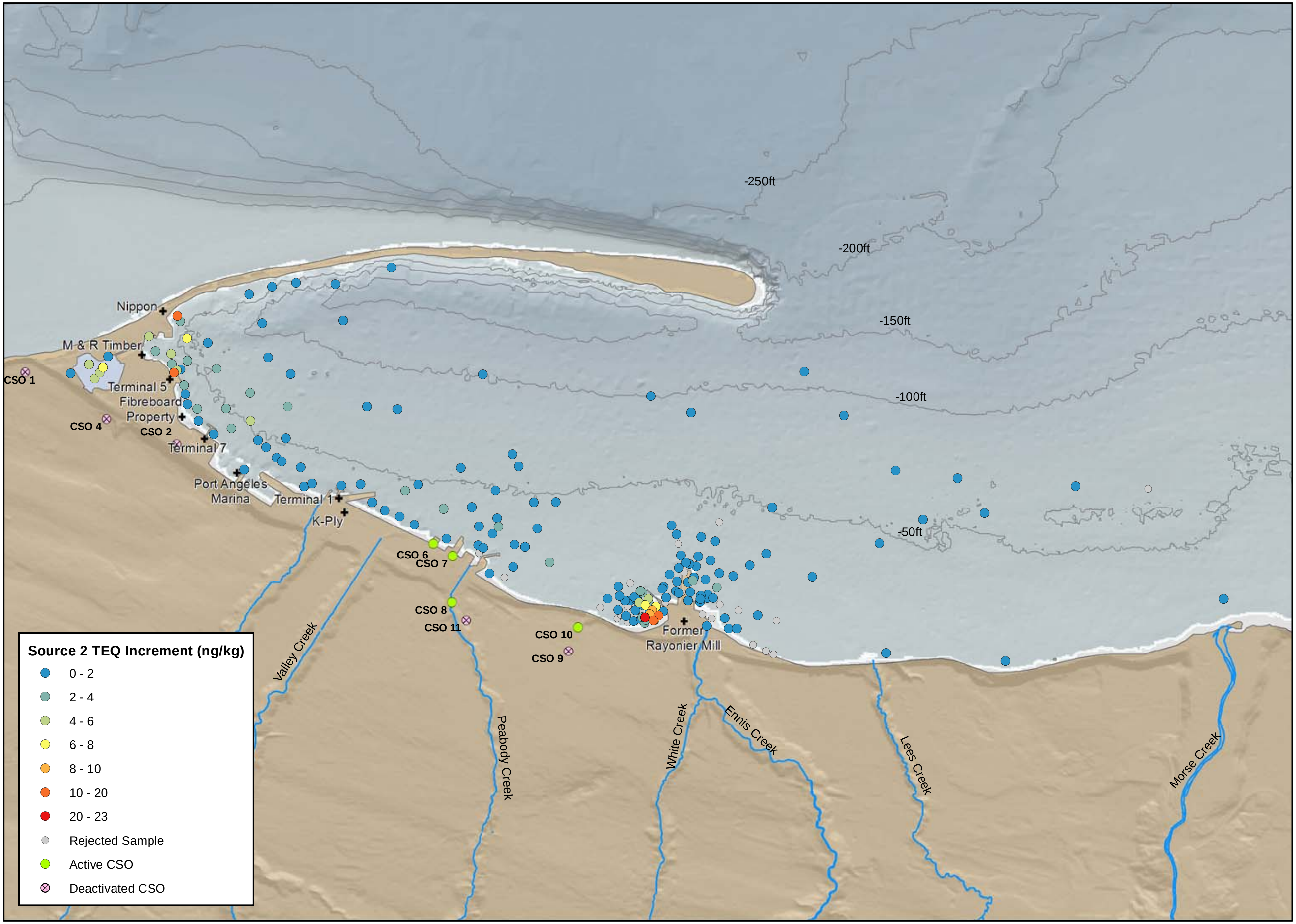

Figure 8. Source 2 Dioxin TEQ Increments

L. Delwiche, 2013

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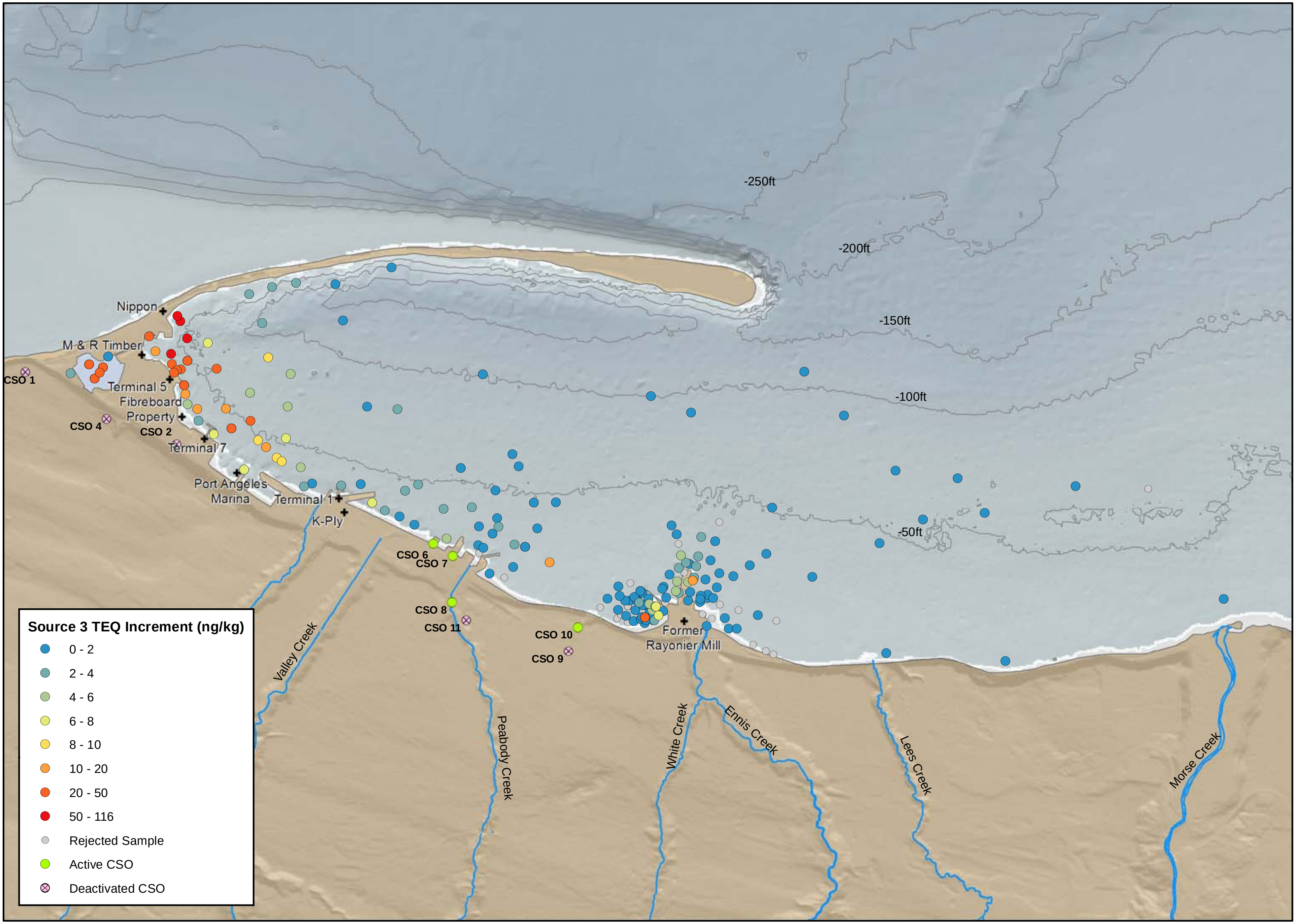

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Figure 9. Source 3 Dioxin TEQ Increments

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L. Delwiche, 2013

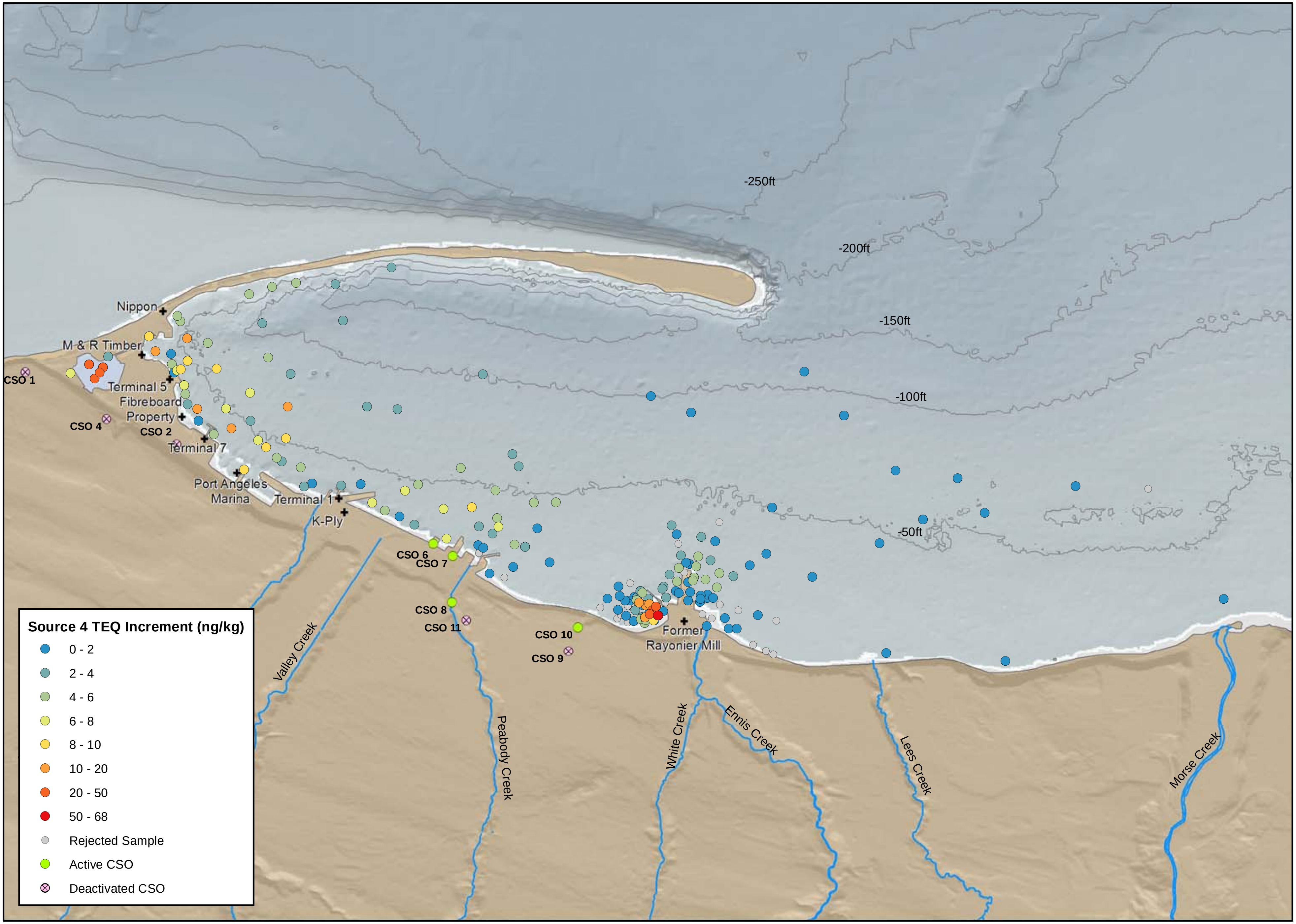

Figure 10. Source 4 Dioxin TEQ Increments

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L. Delwiche, 2013

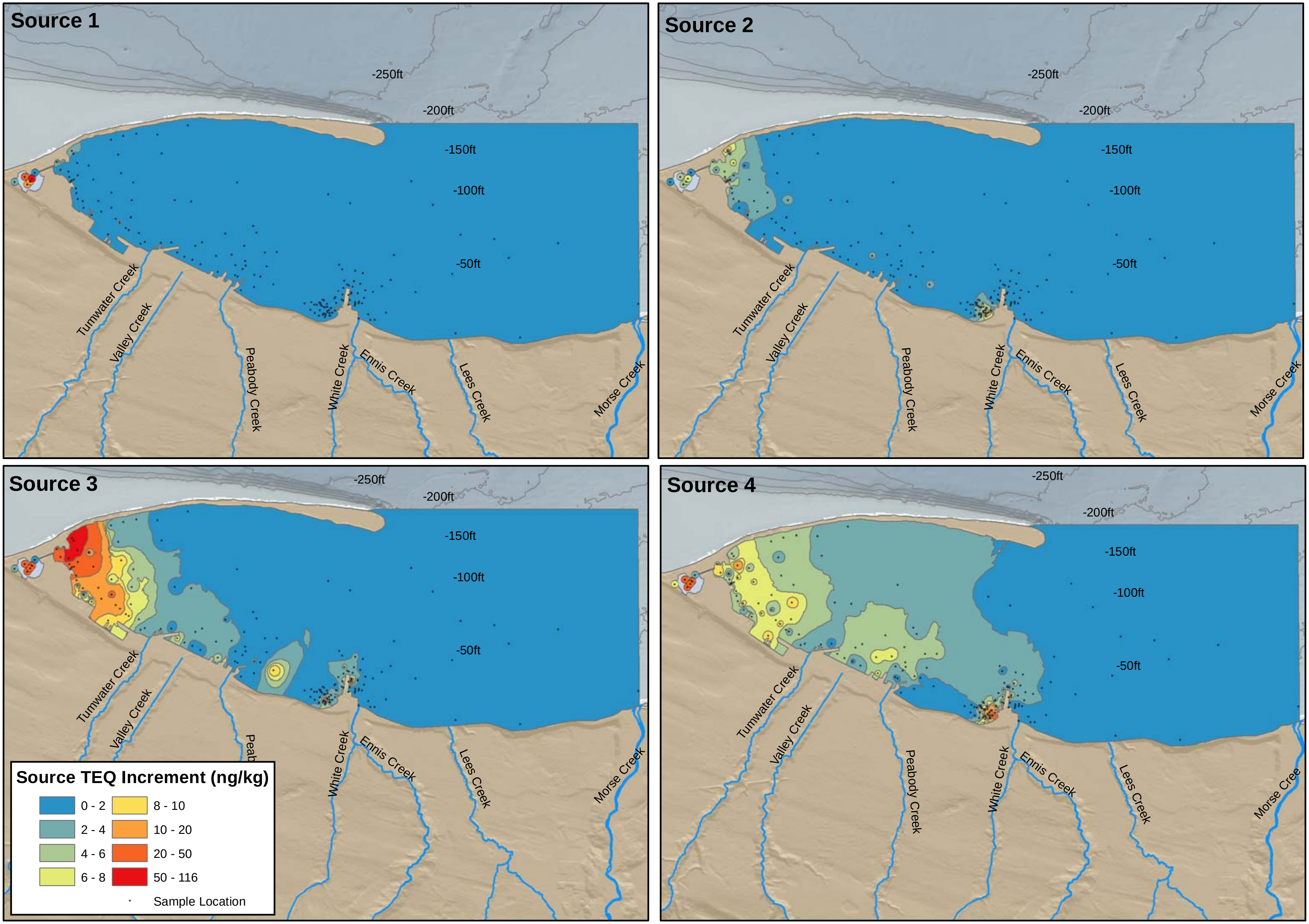

Figure 11. Interpolated TEQ Increments

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L. Delwiche, 2013

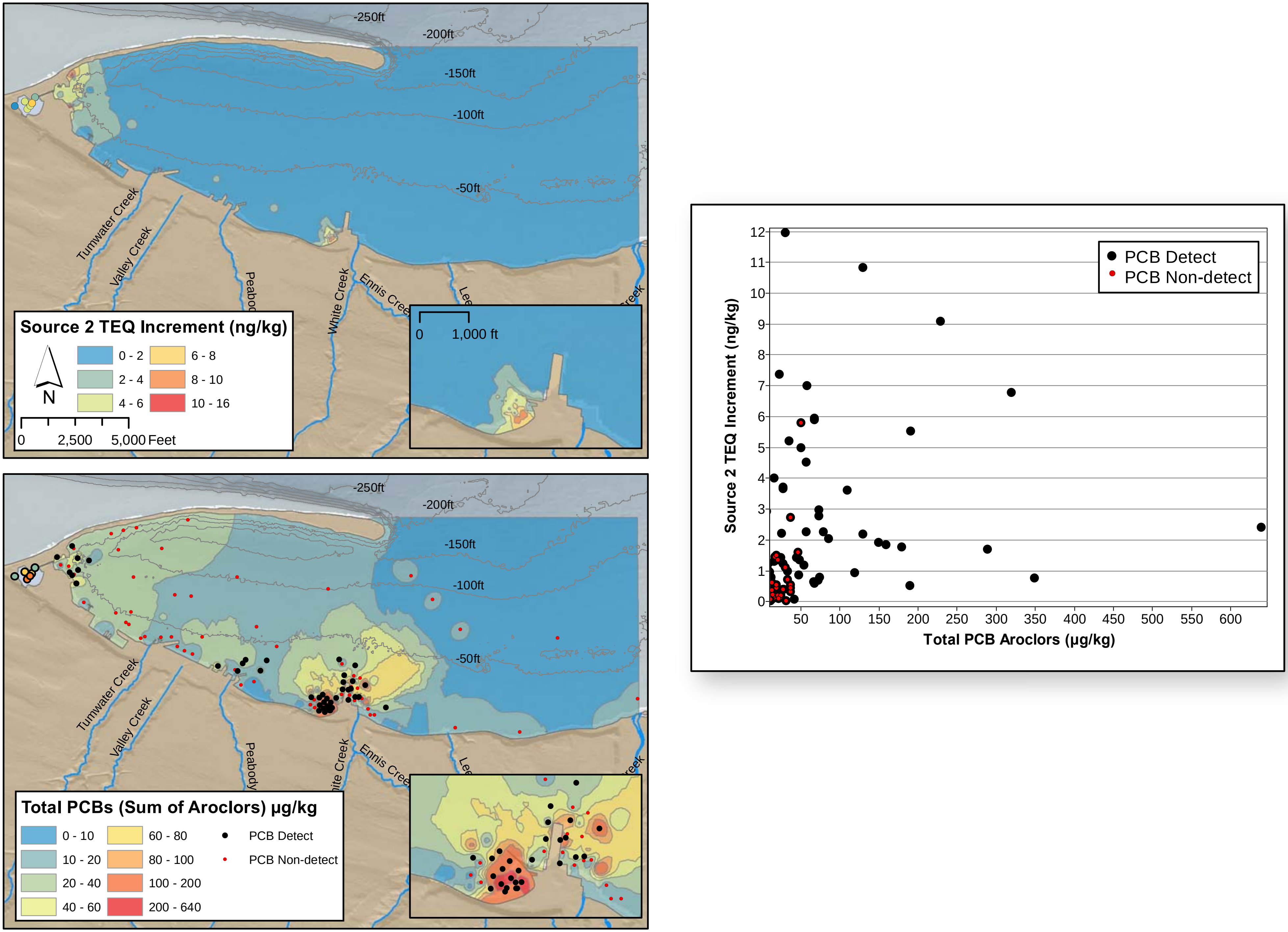

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Figure 12. Interpolated Source 2 TEQ Increments and Total PCB Aroclor Concentrations

L. Delwiche, 2013

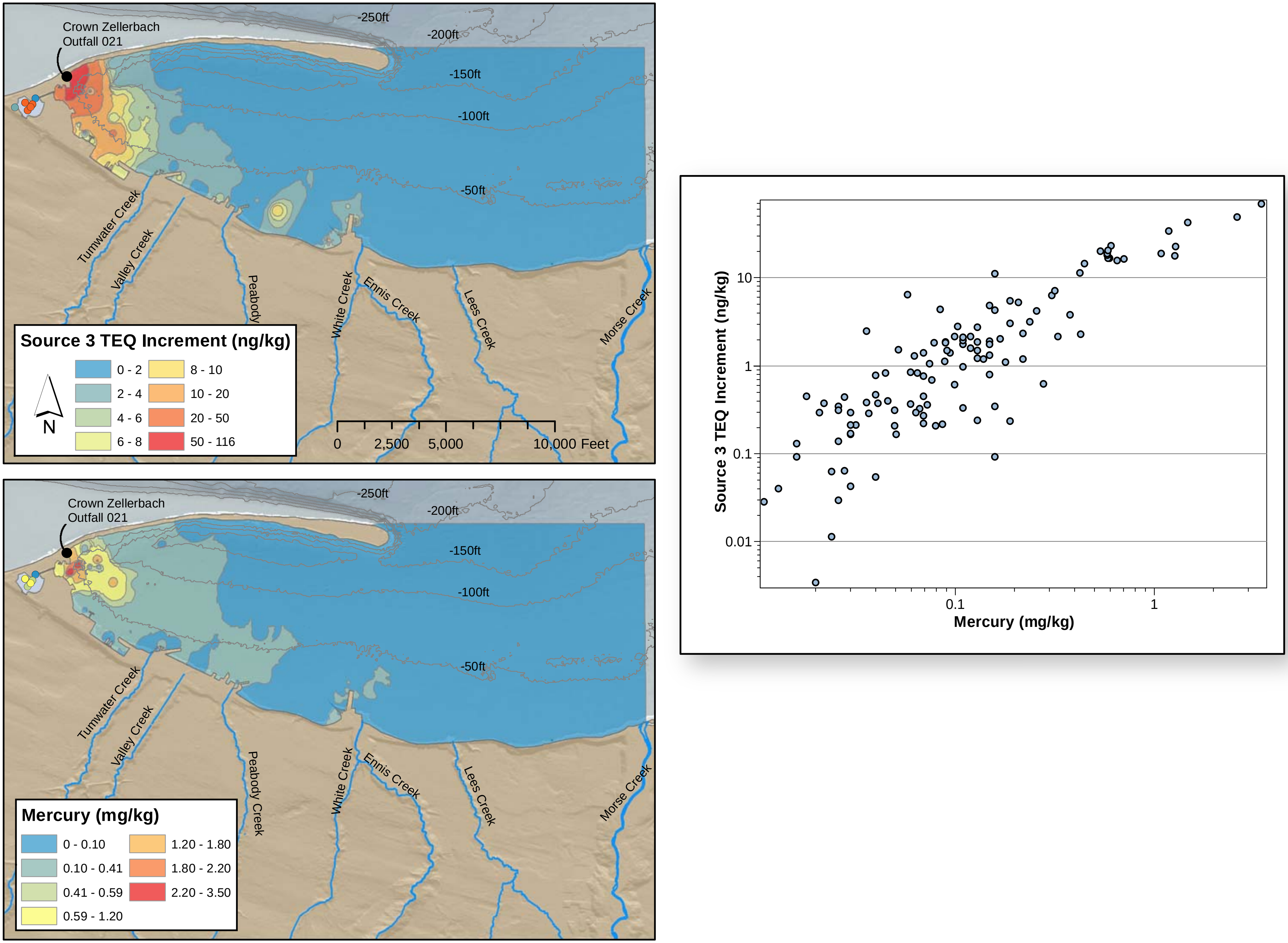

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Figure 13. Interpolated Source 3 TEQ Increments and Mercury Concentrations

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L. Delwiche, 2013

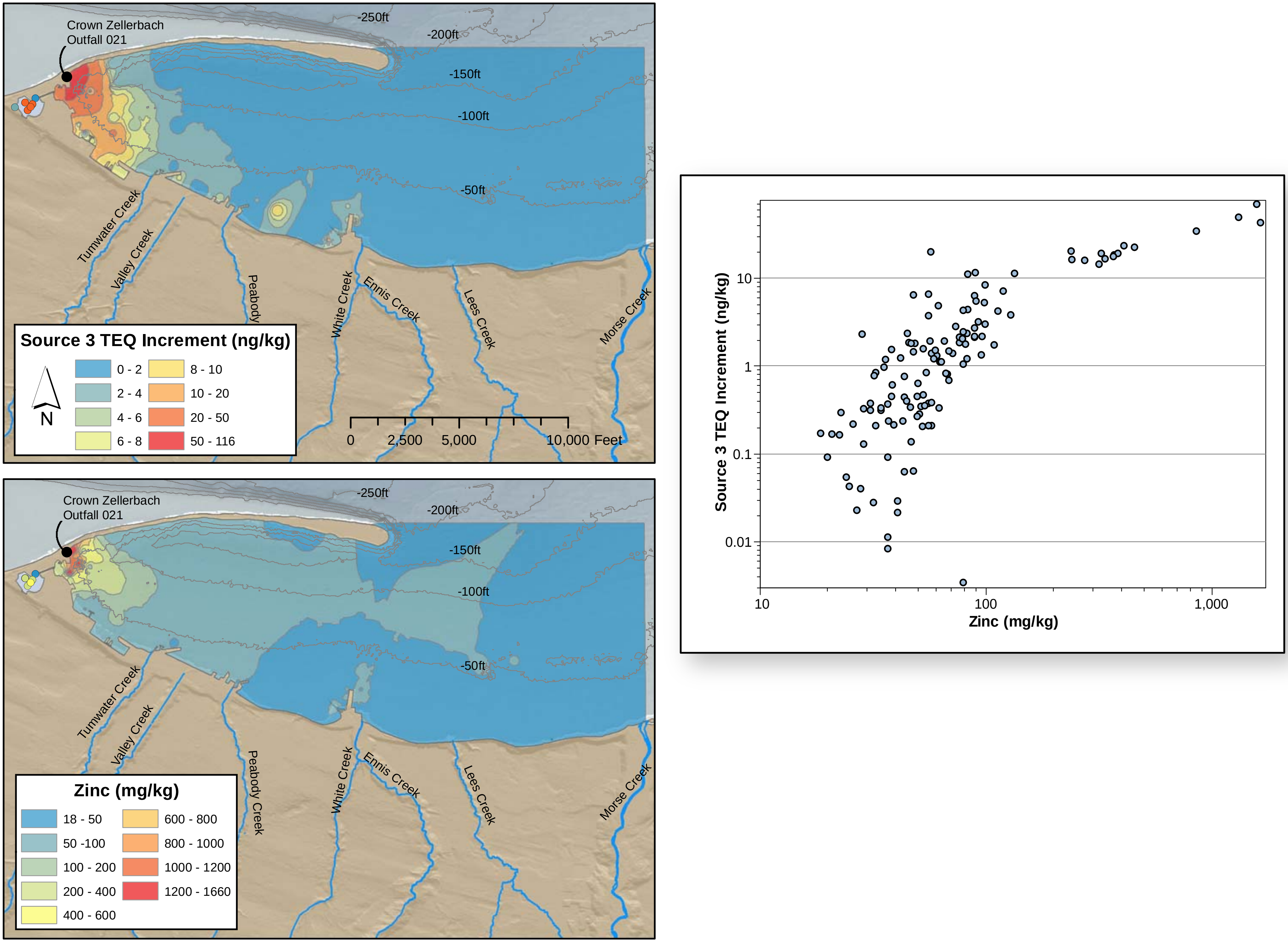

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Figure 14. Interpolated Source 3 TEQ Increments and Zinc Concentrations

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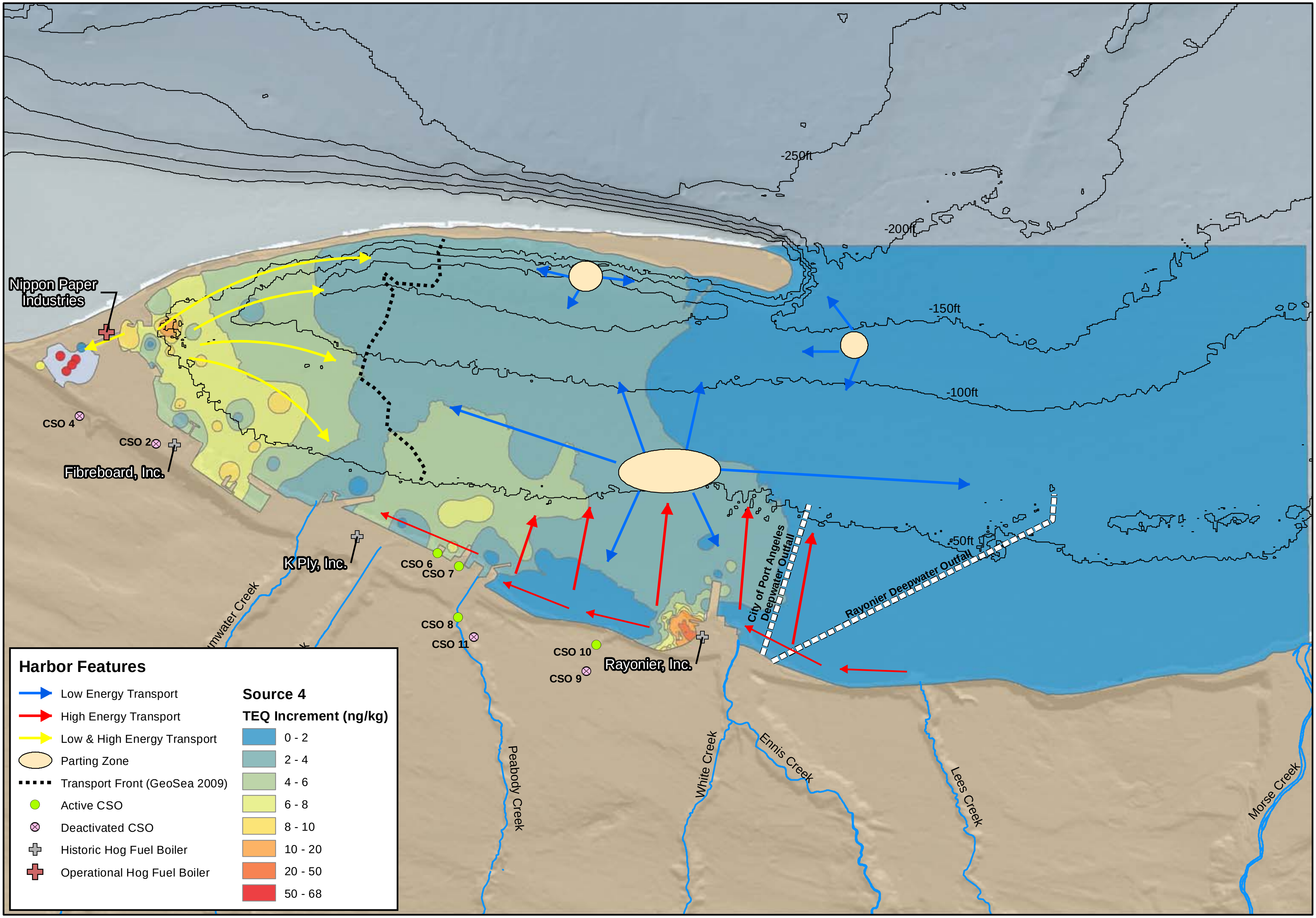

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Figure 15. Interpolated Source 4 TEQ Increments and Sediment Transport Pathways

N

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2013

Tables

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

Notes:

TEF - toxicity equivalency factor

Table 2. Port Angeles Harbor Dioxin/Furan Congener Sediment Samples

Study	Surface Samples	Subsurface Samples
E & E 2012	83	58
NPS 2010	2	0
Exponent 2008	17	4
Malcolm Pirnie 2007a	45	7
Malcolm Pirnie 2007a, Appendix P	4	0
Malcolm Pirnie 2007b	53	0
Foster Wheeler 2001	5	1
Total	**209**	**70**

Table 3. TEQ Increments derived from the 6-Source Model

Location ID	TEQ Increment (ng/kg)						Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6			
Surface Samples									
BL01A	0.28	0.15	1.78	1.98	0.02	1.05	5.25	5.25	0.00
BL02A	0.29	0.09	1.28	1.28	0.05	0.88	3.88	3.85	-0.03
BL03A	0.81	0.19	2.13	1.98	0.19	2.14	7.43	7.47	0.04
BL04A	0.18	0.04	0.36	0.42	0.05	0.18	1.23	1.23	-0.01
BL06A	0.48	0.20	1.73	3.01	0.18	0.31	5.90	5.92	0.02
BL08A	0.46	0.20	1.82	2.99	0.14	0.63	6.22	6.30	0.08
CO01A	0.13	0.05	0.09	0.74	0.16	0.13	1.31	1.29	-0.01
CO02A	0.63	0.79	0.83	2.45	0.74	1.07	6.51	6.44	-0.07
CO03A	0.07	0.04	0.03	0.12	0.02	0.04	0.32	0.31	-0.01
CO04A	0.07	0.00	0.01	0.09	0.02	0.05	0.23	0.22	-0.01
CO05A	0.13	0.07	0.06	0.59	0.08	0.12	1.05	1.04	-0.01
DO01A	0.11	0.10	0.13	0.78	0.10	0.08	1.29	1.29	0.00
DO02A	0.17	0.00	0.43	1.07	0.12	0.02	1.81	1.76	-0.05
DO03A	0.19	0.02	0.46	0.81	0.08	0.33	1.89	1.92	0.03
DO04A	0.18	0.02	0.44	0.85	0.12	0.05	1.67	1.70	0.03
DO05A	0.20	0.02	0.34	0.80	0.08	0.00	1.44	1.40	-0.04
EC01A	0.10	0.01	0.00	0.21	0.00	0.04	0.35	0.33	-0.02
EC03A	0.45	0.70	0.39	1.31	0.58	0.50	3.94	3.98	0.04
EC04A	0.11	0.03	0.14	0.42	0.06	0.24	0.99	0.99	0.00
ED01A	0.53	0.03	1.37	2.43	0.68	1.32	6.35	6.35	0.00
ED02A	0.98	0.34	1.89	4.54	1.20	1.23	10.18	10.17	0.00
ED03A	0.61	0.23	1.37	3.60	0.66	1.75	8.22	8.19	-0.03
ED04A	1.10	0.29	2.28	4.31	0.79	2.37	11.14	10.93	-0.22
ED05A	0.21	0.16	0.28	0.61	0.17	0.33	1.75	1.74	-0.02
EE01A	0.05	0.00	0.01	0.06	0.01	0.01	0.15	0.15	0.00
EE02A	0.09	0.00	0.02	0.25	0.00	0.04	0.41	0.40	-0.01
EE03A	0.08	0.01	0.03	0.15	0.02	0.02	0.31	0.30	0.00
EI02A	0.09	0.00	0.04	0.11	0.01	0.01	0.26	0.26	0.00
EI04A	0.04	0.00	0.02	0.15	0.01	0.02	0.24	0.24	0.00
EI07A	0.09	0.00	0.06	0.27	0.03	0.02	0.48	0.47	-0.01
EP-01-SD	0.49	0.16	0.82	2.45	0.98	0.70	5.61	5.55	-0.05
EP-02-SD	0.88	0.32	2.82	7.71	1.89	1.41	15.03	15.07	0.03
EP-03-SD	0.72	0.20	1.30	5.08	1.50	0.84	9.65	9.55	-0.09
EP-04-SD	0.68	0.31	1.08	4.94	1.62	2.01	10.65	10.62	-0.03
EP-05-SD	0.87	0.20	2.00	5.06	1.62	0.56	10.32	10.25	-0.07
EP-06-SD	0.89	0.34	2.78	6.75	2.26	1.20	14.22	14.14	-0.08
EP-07-SD	0.60	0.22	2.05	4.30	1.23	0.52	8.92	8.94	0.02
EP-08-SD	0.69	0.15	1.64	3.96	1.39	0.85	8.68	8.66	-0.03
EP-09-SD	0.17	0.50	1.03	0.33	0.81	10.58	13.43	14.91	1.48
EP-10-SD	0.34	0.11	1.15	2.70	0.69	0.57	5.56	5.56	0.00
EP-11-SD	0.58	0.35	2.09	4.99	1.84	1.83	11.67	11.58	-0.09
FT01A	0.63	0.39	3.12	5.42	0.53	2.58	12.66	12.55	-0.11
FT04A	0.27	0.04	0.67	1.38	0.13	0.82	3.31	3.27	-0.04
FT06A	0.34	0.12	1.47	2.99	0.16	0.22	5.29	5.32	0.03
FT10A	0.47	0.12	1.43	4.22	0.23	0.09	6.56	6.59	0.03
FT12A	0.19	0.06	0.29	0.89	0.11	0.04	1.57	1.56	0.00
FT13A	0.25	0.06	0.37	1.16	0.07	0.08	1.99	1.97	-0.01
FWX1	5.89	1.70	11.26	58.01	15.16	2.62	94.64	95.91	1.27
FWX2	2.54	2.18	6.46	22.23	7.55	1.56	42.52	42.88	0.36
FWX3	1.42	1.55	2.30	13.29	6.02	1.29	25.87	25.94	0.07
FWX4	0.99	1.31	3.64	8.56	4.94	0.43	19.86	20.21	0.35
FWX5	0.00	0.67	19.39	4.61	9.23	25.18	59.09	56.21	-2.88
FWX6	3.13	7.15	8.30	14.48	16.42	10.80	60.28	60.90	0.62
HS-02	0.33	0.13	0.62	1.09	0.37	0.71	3.25	3.26	0.01
HS-03	0.27	0.40	1.17	3.00	0.93	0.78	6.56	6.55	-0.01
HS-04	0.68	0.56	1.87	5.33	1.81	1.16	11.42	11.34	-0.09
HS-06	0.00	0.24	0.31	0.72	0.30	0.36	1.94	1.95	0.01

Table 3. TEQ Increments derived from the 6-Source Model

Location ID	TEQ Increment (ng/kg)						Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6			
HS-07	0.09	0.10	0.23	0.31	0.01	0.08	0.82	0.86	0.04
HS-07_d	0.47	0.02	0.78	2.47	0.81	0.26	4.81	4.96	0.14
HS-08	0.20	0.24	0.60	1.66	0.59	0.43	3.72	3.75	0.03
IE03A	0.33	0.07	1.03	2.86	0.04	0.30	4.63	4.63	0.00
IE04A	0.36	0.06	1.19	2.86	0.00	0.16	4.62	4.62	0.00
IE05A	0.61	0.29	2.67	4.75	0.44	1.12	9.87	9.94	0.07
IE06A	0.40	0.35	2.96	5.04	0.29	0.53	9.57	9.63	0.06
IE07A	0.52	0.51	2.09	4.28	0.10	0.75	8.26	8.33	0.07
IE09A	1.75	4.59	33.82	1.80	0.00	23.87	65.83	62.94	-2.89
IE12A	0.35	0.18	1.71	2.37	0.09	0.86	5.57	5.61	0.04
IE14A	0.29	0.15	1.30	2.07	0.08	0.32	4.22	4.26	0.04
IE15A	0.47	0.34	3.74	3.27	0.08	1.38	9.28	9.35	0.06
IH01A	1.93	10.25	68.31	0.00	0.00	52.28	132.77	119.13	-13.64
IH02A	0.91	2.78	22.15	6.16	0.00	13.35	45.35	43.66	-1.69
IH03A	0.60	0.43	10.96	4.73	0.24	2.52	19.47	19.40	-0.08
IH04A	0.32	0.36	4.73	3.27	0.00	1.04	9.72	9.79	0.07
IH05A	0.16	0.10	1.78	1.32	0.00	1.11	4.48	4.46	-0.01
IH06A	0.38	0.30	5.42	3.45	0.00	2.19	11.73	11.62	-0.11
IT-06	0.00	5.52	1.16	6.57	6.47	1.25	20.97	20.54	-0.43
IT-07	0.34	2.02	0.23	0.76	6.94	4.06	14.34	14.36	0.02
IT-08	0.64	0.76	0.95	4.29	2.97	1.19	10.80	10.75	-0.05
KP01A	0.97	0.62	4.23	5.34	0.93	3.66	15.74	15.44	-0.31
KP02A	0.78	0.32	2.07	4.66	1.01	2.19	11.03	11.10	0.07
KP03A	0.43	0.07	0.37	1.14	0.30	0.24	2.56	2.52	-0.04
KP04A	0.55	0.23	1.09	2.43	0.35	0.52	5.17	5.17	0.00
KP05A	0.45	0.29	2.12	3.96	0.37	1.27	8.46	8.46	0.00
KP07A	0.38	0.10	0.81	1.85	0.20	0.19	3.52	3.51	-0.01
LA01A	25.04	2.78	14.28	12.54	0.00	6.78	61.42	61.56	0.14
LA01A-01	18.81	3.16	16.48	19.67	2.10	13.54	73.76	74.29	0.53
LA02A	11.42	2.16	16.47	20.07	0.00	5.28	55.41	55.24	-0.17
LA02A-01	11.29	7.26	18.00	25.12	1.92	11.55	75.13	77.01	1.87
LA03A	55.98	1.66	20.02	8.94	0.88	6.36	93.85	93.22	-0.63
LA03A-01	10.26	2.56	18.76	21.54	4.01	11.33	68.46	68.61	0.15
LP01A	0.12	0.01	0.29	0.66	0.13	0.45	1.65	1.63	-0.02
LP-02	0.39	0.34	0.32	1.20	0.73	0.04	3.02	3.02	0.00
LP-02-SD	0.11	0.21	0.93	3.97	1.42	0.64	7.27	7.07	-0.21
LP-03	0.37	0.94	0.21	3.87	1.49	0.71	7.58	7.35	-0.23
LP03A	0.07	0.04	0.09	0.58	0.15	0.16	1.10	1.09	0.00
LP-03-SD	3.36	1.07	1.50	31.80	8.34	3.78	49.85	49.02	-0.83
LP-04	0.10	0.04	0.04	0.28	0.09	0.14	0.69	0.71	0.02
LP04A	0.31	0.28	0.31	2.12	0.71	0.35	4.07	4.03	-0.04
LP-04-SD	1.98	1.63	1.81	25.23	4.76	7.72	43.13	42.52	-0.61
LP-05	0.68	1.11	0.76	2.64	1.48	0.86	7.53	7.61	0.08
LP05A	0.69	1.06	2.42	8.54	1.97	3.88	18.56	18.51	-0.05
LP-06	1.66	2.83	2.24	45.63	4.83	5.18	62.37	59.36	-3.01
LP-07-SD	0.78	0.23	0.00	4.73	1.68	0.88	8.31	8.08	-0.23
LP-08	0.11	0.06	0.17	0.26	0.19	0.07	0.86	0.86	0.00
LP-08-SD	0.73	0.63	0.11	4.61	2.93	1.11	10.13	9.86	-0.27
LP-09	0.62	0.22	0.44	2.42	1.52	0.90	6.12	6.04	-0.08
LP-10	0.21	0.17	0.33	1.06	0.60	0.36	2.71	2.71	-0.01
LP-11	0.14	0.01	0.16	0.01	0.26	0.04	0.62	0.65	0.02
LP-12	0.00	0.14	0.36	0.65	0.40	0.70	2.25	2.34	0.08
LP-12_d	0.00	0.15	0.32	1.10	0.45	0.08	2.11	2.11	0.00
LP-13	0.64	0.55	1.98	7.27	1.27	3.13	14.83	14.57	-0.27
LP-13_d	0.15	0.39	0.93	4.63	0.71	1.16	7.96	7.91	-0.05
LP-14	0.00	0.17	0.20	0.90	0.24	0.14	1.66	1.63	-0.03
LP-15	0.15	0.24	0.05	0.74	0.58	0.10	1.87	1.82	-0.05
LP-16	0.52	5.88	0.26	3.10	0.96	0.07	10.78	10.74	-0.04

Table 3. TEQ Increments derived from the 6-Source Model

Location ID	TEQ Increment (ng/kg)						Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6			
LP-17_d	0.18	0.00	0.34	0.68	0.35	0.00	1.55	1.53	-0.02
LP-18	0.41	1.14	0.75	2.27	1.12	0.80	6.50	6.52	0.03
LP-18	0.28	1.81	1.21	0.15	1.59	0.51	5.55	5.54	0.00
LP-20	0.64	0.50	0.78	1.83	1.87	0.43	6.05	5.99	-0.06
MA01A	0.00	0.17	6.28	7.93	0.00	2.33	16.71	15.16	-1.55
MA02A	0.27	0.41	5.21	3.37	0.00	5.37	14.65	14.76	0.11
MA03A	0.62	0.77	6.96	5.74	0.00	3.03	17.12	17.17	0.05
MA04A	0.14	0.25	4.30	2.01	0.00	4.69	11.38	11.48	0.10
MA05A	0.72	0.62	6.23	7.06	0.10	0.83	15.57	15.63	0.06
MD01A	0.21	0.08	1.82	1.48	0.35	2.68	6.62	6.54	-0.08
MD-02	0.34	0.19	0.34	1.73	0.92	0.88	4.40	4.34	-0.06
MD02A	0.52	0.34	1.46	4.10	0.81	3.36	10.59	10.67	0.08
MD-03	0.15	0.23	0.20	0.63	0.41	0.45	2.07	2.08	0.01
MD03A	0.47	0.40	1.08	4.60	0.84	2.20	9.60	9.67	0.07
MD04A	0.40	0.60	1.54	2.18	0.55	4.07	9.35	9.71	0.36
MD-04-SD	0.34	0.00	0.38	1.18	0.52	0.83	3.26	3.02	-0.24
MD05A	0.11	0.03	0.22	0.80	0.10	0.06	1.32	1.31	0.00
MD-07-SD	0.23	0.11	0.00	1.16	0.20	0.34	2.04	1.98	-0.06
MD-08	0.01	0.32	0.82	0.67	0.36	1.03	3.20	3.09	-0.11
MD-08-SD	0.26	0.10	0.58	0.65	0.83	0.00	2.42	2.46	0.04
MD-09-SD	0.35	0.13	0.50	2.68	0.80	0.42	4.88	4.86	-0.02
MD-10	1.35	0.00	1.10	3.63	2.01	0.43	8.51	8.66	0.15
MD-10-SD	0.04	0.01	0.28	3.52	2.25	0.92	7.02	7.05	0.03
MD-12-SD	0.27	0.00	0.52	1.56	0.45	0.82	3.63	3.51	-0.12
MD-13-SD	0.69	0.16	0.45	3.17	1.35	0.55	6.37	6.35	-0.01
MD-14-SD	0.47	0.40	0.92	4.23	0.77	0.64	7.42	7.39	-0.04
MD-15-SD	0.36	0.08	0.14	2.25	0.61	0.29	3.73	3.65	-0.08
MD-17	3.18	0.54	2.28	0.00	0.82	3.83	10.65	10.57	-0.07
MD-17-SD	0.70	0.21	1.23	0.77	1.51	1.83	6.25	6.27	0.02
MD-18-SD	0.68	0.00	3.83	4.05	1.15	13.26	22.96	21.50	-1.46
MD-21-SD	0.24	0.07	0.00	1.86	0.64	0.25	3.06	2.92	-0.13
MD-22-SD	0.35	0.15	0.27	2.25	0.15	0.45	3.61	3.68	0.07
MD-23-SD	0.11	0.69	0.69	0.69	0.29	2.16	4.62	4.45	-0.17
MD-24-SD	0.19	0.07	0.14	0.67	0.01	0.22	1.30	1.28	-0.02
NPI-L1	14.82	2.95	22.93	24.03	3.44	8.28	76.46	75.90	-0.56
NPI-L2	0.51	0.26	1.51	2.04	0.21	0.40	4.95	4.93	-0.02
NPI-L3	2.44	0.80	2.77	6.09	0.64	1.83	14.58	14.69	0.11
NPI-PA1	2.46	2.42	19.94	6.95	2.91	21.63	56.31	56.31	0.00
NPI-PA10	0.94	1.26	15.52	4.42	1.70	12.41	36.25	35.17	-1.08
NPI-PA10_d	0.96	1.30	14.94	4.36	1.40	12.44	35.40	34.88	-0.52
NPI-PA2	1.33	1.46	11.20	8.33	2.18	4.72	29.21	28.65	-0.56
NPI-PA3	2.41	7.22	41.82	1.36	4.63	39.24	96.68	94.06	-2.62
NPI-PA4	1.98	5.81	48.48	11.12	1.51	39.70	108.61	105.16	-3.45
NPI-PA5	0.58	0.53	4.12	4.01	0.53	3.05	12.81	12.58	-0.23
NPI-PA6	1.01	2.47	17.38	6.53	1.16	16.23	44.76	44.16	-0.61
NPI-PA6_d	1.38	2.50	17.41	5.92	1.54	13.20	41.95	40.90	-1.06
NPI-PA8	1.02	1.38	16.06	3.13	1.98	17.46	41.04	40.21	-0.83
NPI-PA9	1.25	2.58	18.64	4.93	1.61	18.95	47.96	47.44	-0.51
OF-05_d	0.14	0.00	0.24	0.63	0.14	0.00	1.16	1.15	-0.01
OH01A-R	0.15	0.04	0.35	0.74	0.07	0.00	1.34	1.31	-0.03
OH02A	0.08	0.02	0.21	0.46	0.05	0.00	0.82	0.82	0.00
OH03A	0.11	0.04	0.21	0.42	0.05	0.00	0.83	0.83	0.00
RL01A	0.06	0.02	0.16	0.58	0.03	0.10	0.97	0.97	-0.01
WP-01-SD	1.37	1.51	14.26	7.11	1.66	6.40	32.31	32.37	0.07
WP-01-SD_	1.64	1.12	19.42	9.42	1.74	7.12	40.45	40.94	0.49
WP-02-SD	0.95	1.48	10.44	5.73	1.24	5.10	24.95	24.84	-0.10
WP-03-SD	0.66	1.96	8.50	1.52	1.20	16.77	30.61	32.24	1.63
WP-04-SD	2.39	0.99	9.76	8.13	1.50	3.61	26.39	26.43	0.04

Table 3. TEQ Increments derived from the 6-Source Model

Location ID	TEQ Increment (ng/kg)						Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6			
WP-05-SD	0.12	0.96	3.57	5.23	1.55	2.43	13.86	13.86	0.00
WP-06-SD	1.14	1.25	14.09	8.46	1.78	5.03	31.76	31.66	-0.09
WP-07-SD	1.32	1.85	15.46	6.52	1.93	11.07	38.15	37.53	-0.63
WP-08-SD	1.24	1.43	4.24	8.63	1.80	1.22	18.55	18.60	0.05
WP-09-SD	0.60	0.25	3.53	4.50	1.15	1.98	12.01	11.97	-0.04
WP-10-SD	0.04	0.74	5.25	3.44	0.74	4.46	14.66	14.62	-0.04
WP-11-SD	0.55	18.74	10.20	0.00	0.61	12.77	42.86	46.27	3.40
WW01A	0.14	0.04	0.29	0.81	0.08	0.04	1.40	1.38	-0.01
Suburface Samples									
LP-20	0.00	5.21	3.20	3.01	13.17	3.32	27.92	26.69	-1.24
MD05B	0.11	0.03	0.14	0.52	0.05	0.04	0.87	0.87	0.00
CO02B	0.14	0.06	0.10	0.84	0.19	0.25	1.58	1.57	-0.01
DO04B	0.19	0.06	0.55	1.98	0.03	0.06	2.86	2.83	-0.02
DO05B	0.13	0.03	0.38	0.78	0.09	0.00	1.41	1.36	-0.05
EC03B	0.69	4.57	2.10	3.59	3.73	7.33	22.01	22.87	0.86
ED03B	0.71	0.38	2.12	3.36	1.08	1.50	9.15	9.04	-0.11
EE03B	0.14	0.10	0.07	0.28	0.06	0.08	0.73	0.72	-0.01
MA02B	0.43	0.00	10.61	9.98	0.00	0.30	21.32	20.74	-0.58
MD01B	0.18	0.15	0.59	1.37	0.26	0.78	3.34	3.44	0.10
MD04B	0.99	0.52	1.59	3.45	0.92	1.63	9.10	9.26	0.16
MD05C	0.08	0.02	0.11	0.37	0.04	0.03	0.65	0.65	0.00
BL08B	0.17	0.03	0.23	0.62	0.03	0.08	1.16	1.14	-0.01
DO04C	0.08	0.01	0.04	0.14	0.02	0.00	0.29	0.29	0.00
DO05C	0.06	0.01	0.05	0.15	0.00	0.00	0.27	0.27	0.00
EC03C	0.34	4.45	0.83	2.80	1.73	1.63	11.77	12.25	0.48
EC04B	0.33	0.76	0.50	1.93	0.65	0.23	4.41	4.40	-0.01
ED02B	0.17	0.05	0.13	0.60	0.10	0.09	1.14	1.14	0.00
ED05B	0.29	0.68	1.62	1.52	0.79	0.77	5.68	5.71	0.03
EE02B	0.10	0.10	0.03	0.50	0.04	0.07	0.84	0.84	0.00
EE03C	0.14	0.02	0.00	0.45	0.20	0.03	0.83	0.82	-0.01
IE05B	1.28	1.77	4.45	13.31	1.25	2.16	24.23	24.09	-0.14
IE12B	0.36	0.15	4.96	5.09	0.31	0.32	11.20	11.17	-0.03
IE14B	0.42	0.00	4.20	6.67	0.12	0.00	11.40	10.60	-0.80
IE16B	0.12	0.00	0.02	0.17	0.03	0.01	0.35	0.35	0.00
IH02B	2.79	11.31	40.80	14.62	0.00	23.21	92.73	89.65	-3.08
IH06B	4.45	2.85	36.52	14.90	0.00	16.21	74.93	74.13	-0.80
KP02B	0.86	1.77	5.53	7.88	0.00	3.61	19.64	19.03	-0.61
KP07B	0.09	0.03	0.07	0.28	0.02	0.02	0.51	0.51	0.00
MA02C	1.01	1.69	11.71	8.07	0.00	6.75	29.23	28.72	-0.51
MD02B	0.83	1.66	2.28	9.12	2.23	1.89	18.02	18.19	0.17
CO03B	0.13	3.33	0.00	0.12	0.86	0.00	4.44	4.17	-0.27
CO05B	0.57	3.27	1.38	2.03	1.31	0.35	8.90	8.88	-0.02
ED01B	0.24	0.04	0.06	0.35	0.01	0.05	0.75	0.74	0.00
KP03B	0.38	0.31	3.04	2.09	0.21	1.14	7.17	7.01	-0.16
LA02B	0.34	0.02	0.00	1.61	0.48	0.05	2.51	2.48	-0.04
IE01B	1.15	0.61	0.00	5.77	0.93	0.29	8.75	8.66	-0.09
ED03C	0.09	0.02	0.12	0.32	0.07	0.12	0.74	0.74	0.00
MD03C	1.52	0.61	1.07	6.83	1.10	0.53	11.67	11.75	0.09
BL02B	0.53	1.06	7.08	6.93	0.00	3.27	18.86	18.30	-0.57
ED02C	0.46	0.04	0.36	1.50	0.16	0.00	2.52	2.56	0.05
ED04B	0.98	0.30	3.98	9.29	1.02	1.82	17.38	17.25	-0.14
IE09B	0.55	0.54	3.12	0.75	0.15	6.50	11.62	12.12	0.50
KP08B	0.23	0.04	0.09	0.45	0.00	0.08	0.89	0.84	-0.05
LA02C	0.17	0.01	0.00	0.33	0.11	0.01	0.62	0.59	-0.03
NPI-L2	9.46	1.42	48.33	41.24	3.94	14.42	118.81	117.94	-0.87
NPI-PA9	0.25	0.27	1.40	0.52	0.06	0.41	2.92	2.91	-0.02
MD02C	0.13	0.00	0.02	0.85	0.27	0.00	1.27	1.27	0.00
MD03B	1.19	0.49	1.00	7.19	1.26	0.70	11.84	11.88	0.05

Table 3. TEQ Increments derived from the 6-Source Model

Location ID	TEQ Increment (ng/kg)						Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6			
BL02C	0.12	0.05	0.13	0.27	0.02	0.05	0.64	0.63	0.00
IH02C	0.14	0.02	0.00	0.24	0.00	0.02	0.42	0.39	-0.03
ED01C	0.19	0.01	0.00	0.19	0.00	0.02	0.40	0.37	-0.03
IH06C	0.13	0.00	0.00	0.18	0.02	0.02	0.35	0.34	-0.02

Notes:
Δ TEQ = (Measured TEQ) - (Sum of TEQ Increments)

Table 4. TEQ Increments derived from the 4-Source Model

Location ID	TEQ Increment (ng/kg)				Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4			
Surface Samples							
BL01A	0.28	0.10	2.50	2.33	5.22	5.25	0.04
BL02A	0.31	0.12	1.94	1.51	3.88	3.85	-0.03
BL03A	0.91	0.43	3.87	2.32	7.53	7.47	-0.06
BL04A	0.20	0.07	0.48	0.47	1.22	1.23	0.01
BL06A	0.47	0.19	1.65	3.44	5.75	5.92	0.17
BL08A	0.45	0.18	2.05	3.44	6.12	6.30	0.18
CO01A	0.14	0.21	0.13	0.85	1.33	1.29	-0.03
CO02A	0.73	1.41	1.54	2.85	6.52	6.44	-0.08
CO03A	0.08	0.06	0.06	0.13	0.32	0.31	-0.01
CO04A	0.08	0.02	0.05	0.09	0.24	0.22	-0.01
CO05A	0.15	0.14	0.11	0.67	1.06	1.04	-0.02
DO01A	0.12	0.17	0.11	0.88	1.28	1.29	0.01
DO02A	0.16	0.03	0.31	1.22	1.73	1.76	0.03
DO03A	0.21	0.09	0.67	0.93	1.90	1.92	0.02
DO04A	0.19	0.09	0.39	0.97	1.64	1.70	0.06
DO05A	0.20	0.06	0.22	0.89	1.37	1.40	0.02
EC01A	0.11	0.00	0.02	0.22	0.35	0.33	-0.02
EC03A	0.52	1.16	0.71	1.51	3.90	3.98	0.08
EC04A	0.13	0.09	0.31	0.49	1.02	0.99	-0.03
ED01A	0.57	0.74	2.27	2.88	6.46	6.35	-0.11
ED02A	1.05	1.42	2.46	5.28	10.21	10.17	-0.03
ED03A	0.69	0.91	2.56	4.23	8.39	8.19	-0.20
ED04A	1.23	1.09	3.96	5.02	11.31	10.93	-0.38
ED05A	0.24	0.31	0.51	0.70	1.76	1.74	-0.03
EE01A	0.06	0.02	0.01	0.06	0.15	0.15	0.00
EE02A	0.11	0.01	0.03	0.27	0.42	0.40	-0.01
EE03A	0.09	0.02	0.03	0.16	0.31	0.30	0.00
EI02A	0.10	0.01	0.03	0.11	0.26	0.26	0.00
EI04A	0.05	0.01	0.02	0.16	0.25	0.24	-0.01
EI07A	0.10	0.02	0.05	0.30	0.48	0.47	-0.01
EP-01-SD	0.52	1.11	1.15	2.89	5.67	5.55	-0.12
EP-02-SD	0.87	2.00	3.14	9.06	15.06	15.07	0.00
EP-03-SD	0.75	1.60	1.43	5.95	9.73	9.55	-0.18
EP-04-SD	0.78	1.98	2.32	5.88	10.94	10.62	-0.33
EP-05-SD	0.87	1.63	1.85	5.92	10.27	10.25	-0.02
EP-06-SD	0.86	2.38	2.99	7.99	14.22	14.14	-0.08
EP-07-SD	0.57	1.25	1.96	5.05	8.83	8.94	0.11
EP-08-SD	0.70	1.44	1.89	4.68	8.71	8.66	-0.06
EP-09-SD	0.67	2.51	10.78	1.12	15.07	14.91	-0.16
EP-10-SD	0.34	0.72	1.33	3.18	5.57	5.56	0.00
EP-11-SD	0.59	2.12	3.11	6.00	11.82	11.58	-0.24
FT01A	0.67	0.84	4.84	6.40	12.75	12.55	-0.21
FT04A	0.31	0.20	1.26	1.61	3.39	3.27	-0.12
FT06A	0.31	0.11	1.32	3.43	5.17	5.32	0.15
FT10A	0.45	0.16	1.03	4.81	6.44	6.59	0.15
FT12A	0.19	0.13	0.22	1.01	1.55	1.56	0.02
FT13A	0.27	0.08	0.31	1.30	1.96	1.97	0.01
FWX1	5.71	15.05	6.49	67.63	94.88	95.91	1.03
FWX2	2.44	8.60	5.07	26.16	42.26	42.88	0.62
FWX3	1.40	7.03	1.75	15.82	26.01	25.94	-0.07
FWX4	0.85	5.62	2.80	10.36	19.62	20.21	0.59
FWX5	0.00	11.36	41.24	8.90	61.50	56.21	-5.29

Table 4. TEQ Increments derived from the 4-Source Model

Location ID	TEQ Increment (ng/kg)				Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4			
FWX6	3.44	22.65	15.93	18.86	60.88	60.90	0.03
HS-02	0.37	0.51	1.13	1.29	3.30	3.26	-0.04
HS-03	0.27	1.21	1.51	3.58	6.56	6.55	-0.02
HS-04	0.69	2.18	2.26	6.31	11.45	11.34	-0.11
HS-06	0.00	0.50	0.55	0.90	1.96	1.95	0.00
HS-07	0.10	0.07	0.27	0.35	0.79	0.86	0.07
HS-07_d	0.48	0.76	0.71	2.87	4.83	4.96	0.13
HS-08	0.21	0.76	0.78	1.98	3.73	3.75	0.02
IE03A	0.33	0.01	0.98	3.25	4.58	4.63	0.05
IE04A	0.35	0.00	1.01	3.24	4.60	4.62	0.02
IE05A	0.60	0.53	3.13	5.51	9.77	9.94	0.17
IE06A	0.33	0.31	2.83	5.85	9.32	9.63	0.31
IE07A	0.53	0.37	2.30	4.90	8.10	8.33	0.23
IE09A	1.71	2.71	55.28	4.10	63.80	62.94	-0.86
IE12A	0.35	0.17	2.22	2.76	5.51	5.61	0.10
IE14A	0.28	0.11	1.35	2.38	4.12	4.26	0.14
IE15A	0.41	0.18	4.59	3.86	9.05	9.35	0.30
IH01A	1.91	5.77	116.30	0.49	124.47	119.13	-5.34
IH02A	0.72	0.70	33.57	8.22	43.21	43.66	0.45
IH03A	0.26	0.00	12.52	5.84	18.62	19.40	0.78
IH04A	0.19	0.00	5.24	3.89	9.31	9.79	0.48
IH05A	0.15	0.05	2.63	1.60	4.44	4.46	0.03
IH06A	0.27	0.00	6.97	4.16	11.41	11.62	0.21
IT-06	0.00	10.80	1.37	8.38	20.55	20.54	-0.02
IT-07	0.45	9.07	3.57	1.91	15.01	14.36	-0.65
IT-08	0.67	3.60	1.44	5.25	10.95	10.75	-0.21
KP01A	1.05	1.48	6.94	6.39	15.86	15.44	-0.42
KP02A	0.86	1.32	3.52	5.50	11.20	11.10	-0.11
KP03A	0.48	0.35	0.46	1.28	2.56	2.52	-0.05
KP04A	0.59	0.48	1.29	2.77	5.13	5.17	0.04
KP05A	0.46	0.53	2.82	4.63	8.44	8.46	0.02
KP07A	0.39	0.22	0.77	2.09	3.47	3.51	0.04
LA01A	28.20	1.57	19.78	9.78	59.32	61.56	2.23
LA01A-01	21.26	5.19	27.08	20.14	73.66	74.29	0.62
LA02A	12.48	0.07	19.28	21.27	53.09	55.24	2.15
LA02A-01	12.66	7.34	26.13	27.75	73.89	77.01	3.12
LA03A	63.02	2.95	26.14	0.00	92.11	93.22	1.11
LA03A-01	11.22	5.89	26.64	24.29	68.04	68.61	0.57
LP01A	0.14	0.16	0.62	0.78	1.70	1.63	-0.07
LP-02	0.41	0.98	0.20	1.39	2.98	3.02	0.04
LP-02-SD	0.07	1.54	0.99	4.77	7.36	7.07	-0.29
LP-03	0.42	2.25	0.40	4.57	7.64	7.35	-0.29
LP03A	0.08	0.19	0.17	0.68	1.12	1.09	-0.03
LP-03-SD	3.64	9.09	1.16	37.02	50.92	49.02	-1.89
LP-04	0.12	0.13	0.13	0.32	0.71	0.71	0.00
LP04A	0.34	0.92	0.37	2.48	4.11	4.03	-0.08
LP-04-SD	2.39	6.50	6.04	29.56	44.49	42.52	-1.97
LP-05	0.77	2.38	1.23	3.13	7.51	7.61	0.10
LP05A	0.81	2.98	4.98	10.18	18.95	18.51	-0.44
LP-06	1.89	6.75	1.93	52.79	63.36	59.36	-4.00
LP-07-SD	0.88	1.93	0.18	5.51	8.50	8.08	-0.42
LP-08	0.12	0.23	0.19	0.31	0.86	0.86	0.01
LP-08-SD	0.80	3.51	0.51	5.56	10.39	9.86	-0.53

Table 4. TEQ Increments derived from the 4-Source Model

Location ID	TEQ Increment (ng/kg)				Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ^1 (ng/kg)
	Source 1	Source 2	Source 3	Source 4			
LP-09	0.69	1.75	0.94	2.90	6.28	6.04	-0.24
LP-10	0.23	0.73	0.51	1.27	2.75	2.71	-0.04
LP-11	0.15	0.26	0.18	0.02	0.62	0.65	0.03
LP-12	0.01	0.56	0.91	0.85	2.33	2.34	0.01
LP-12_d	0.00	0.53	0.25	1.34	2.12	2.11	-0.01
LP-13	0.74	1.84	4.02	8.60	15.19	14.57	-0.62
LP-13_d	0.16	1.01	1.46	5.45	8.07	7.91	-0.16
LP-14	0.00	0.36	0.23	1.07	1.66	1.63	-0.03
LP-15	0.16	0.77	0.04	0.90	1.88	1.82	-0.06
LP-16	0.76	5.51	0.17	3.44	9.88	10.74	0.86
LP-17_d	0.17	0.28	0.20	0.80	1.45	1.53	0.08
LP-18	0.48	2.03	1.22	2.70	6.43	6.52	0.09
LP-18	0.30	2.99	1.61	0.36	5.26	5.54	0.28
LP-20	0.67	2.25	0.89	2.24	6.05	5.99	-0.07
MA01A	0.00	0.00	7.50	9.32	16.82	15.16	-1.66
MA02A	0.33	0.38	9.75	4.29	14.74	14.76	0.02
MA03A	0.53	0.17	9.04	6.82	16.56	17.17	0.61
MA04A	0.18	0.42	8.34	2.71	11.64	11.48	-0.16
MA05A	0.54	0.08	6.12	8.19	14.94	15.63	0.69
MD01A	0.26	0.59	4.09	1.93	6.88	6.54	-0.33
MD-02	0.39	1.14	0.92	2.09	4.54	4.34	-0.20
MD02A	0.67	1.34	4.08	4.94	11.02	10.67	-0.35
MD-03	0.18	0.62	0.53	0.77	2.11	2.08	-0.03
MD03A	0.56	1.28	2.59	5.44	9.87	9.67	-0.21
MD04A	0.58	1.40	5.06	2.78	9.81	9.71	-0.10
MD-04-SD	0.39	0.51	0.99	1.42	3.31	3.02	-0.29
MD05A	0.11	0.10	0.18	0.92	1.31	1.31	0.00
MD-07-SD	0.27	0.32	0.16	1.32	2.08	1.98	-0.10
MD-08	0.02	0.67	1.67	0.89	3.25	3.09	-0.16
MD-08-SD	0.25	0.86	0.45	0.81	2.38	2.46	0.08
MD-09-SD	0.36	0.88	0.56	3.14	4.94	4.86	-0.08
MD-10	1.43	1.89	1.00	4.19	8.51	8.66	0.15
MD-10-SD	0.01	2.29	0.62	4.38	7.29	7.05	-0.24
MD-12-SD	0.30	0.43	1.07	1.86	3.67	3.51	-0.16
MD-13-SD	0.75	1.47	0.55	3.71	6.48	6.35	-0.12
MD-14-SD	0.50	1.03	1.02	4.90	7.44	7.39	-0.06
MD-15-SD	0.40	0.68	0.13	2.60	3.81	3.65	-0.15
MD-17	3.69	1.67	5.86	0.00	11.21	10.57	-0.64
MD-17-SD	0.79	1.83	2.75	1.08	6.45	6.27	-0.19
MD-18-SD	1.18	2.16	15.55	5.62	24.51	21.50	-3.01
MD-21-SD	0.27	0.70	0.00	2.17	3.14	2.92	-0.22
MD-22-SD	0.40	0.26	0.45	2.55	3.66	3.68	0.02
MD-23-SD	0.21	1.04	2.62	0.95	4.82	4.45	-0.37
MD-24-SD	0.22	0.08	0.27	0.74	1.32	1.28	-0.04
NPI-L1	16.08	4.97	27.80	26.03	74.88	75.90	1.02
NPI-L2	0.53	0.33	1.64	2.33	4.82	4.93	0.11
NPI-L3	2.73	1.24	3.81	6.73	14.50	14.69	0.19
NPI-PA1	2.87	5.93	38.78	9.80	57.38	56.31	-1.07
NPI-PA10	0.91	2.96	26.16	6.37	36.39	35.17	-1.23
NPI-PA10_d	0.97	2.75	25.65	6.23	35.60	34.88	-0.72
NPI-PA2	1.16	2.91	14.36	10.17	28.60	28.65	0.05
NPI-PA3	2.77	11.94	77.17	5.39	97.27	94.06	-3.21
NPI-PA4	1.98	6.97	83.18	16.53	108.67	105.16	-3.51

Table 4. TEQ Increments derived from the 4-Source Model

Location ID	TEQ Increment (ng/kg)				Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4			
NPI-PA5	0.60	0.94	6.42	4.85	12.82	12.58	-0.23
NPI-PA6	1.14	3.65	31.38	8.96	45.12	44.16	-0.97
NPI-PA6_d	1.40	3.68	28.66	8.05	41.79	40.90	-0.89
NPI-PA8	1.23	3.99	31.51	5.23	41.96	40.21	-1.75
NPI-PA9	1.49	4.49	35.29	7.34	48.61	47.44	-1.17
OF-05_d	0.14	0.12	0.14	0.72	1.12	1.15	0.03
OH01A-R	0.14	0.06	0.23	0.83	1.26	1.31	0.05
OH02A	0.08	0.04	0.15	0.53	0.80	0.82	0.02
OH03A	0.11	0.06	0.16	0.47	0.80	0.83	0.03
RL01A	0.07	0.04	0.19	0.67	0.97	0.97	-0.01
WP-01-SD	1.16	2.41	19.08	8.92	31.56	32.37	0.81
WP-01-SD_	1.21	1.85	24.51	11.73	39.31	40.94	1.63
WP-02-SD	0.82	2.12	14.31	7.16	24.42	24.84	0.43
WP-03-SD	1.20	4.20	23.74	3.04	32.17	32.24	0.07
WP-04-SD	2.39	1.88	12.00	9.53	25.80	26.43	0.63
WP-05-SD	0.06	2.23	5.12	6.41	13.82	13.86	0.04
WP-06-SD	0.82	2.15	17.47	10.44	30.88	31.66	0.79
WP-07-SD	1.29	3.45	24.66	8.61	38.00	37.53	-0.47
WP-08-SD	1.24	2.61	4.31	10.03	18.19	18.60	0.41
WP-09-SD	0.56	1.26	4.75	5.41	11.98	11.97	-0.01
WP-10-SD	0.00	1.40	8.87	4.46	14.74	14.62	-0.12
WP-11-SD	1.44	16.06	22.56	0.52	40.58	46.27	5.69
WW01A	0.14	0.08	0.23	0.91	1.37	1.38	0.01
Suburface Samples							
LP-20	0.00	17.46	5.25	5.40	28.11	26.69	-1.43
MD05B	0.11	0.06	0.12	0.58	0.87	0.87	0.01
CO02B	0.16	0.25	0.23	0.97	1.62	1.57	-0.05
DO04B	0.18	0.00	0.38	2.25	2.82	2.83	0.02
DO05B	0.13	0.06	0.23	0.89	1.31	1.36	0.05
EC03B	1.09	8.05	8.46	4.87	22.47	22.87	0.40
ED03B	0.75	1.36	3.07	4.00	9.18	9.04	-0.13
EE03B	0.16	0.14	0.12	0.31	0.72	0.72	-0.01
MA02B	0.00	0.00	9.54	11.70	21.24	20.74	-0.50
MD01B	0.21	0.41	1.15	1.64	3.41	3.44	0.03
MD04B	1.11	1.38	2.68	4.01	9.17	9.26	0.09
MD05C	0.09	0.05	0.09	0.42	0.65	0.65	0.00
BL08B	0.18	0.04	0.23	0.70	1.15	1.14	0.00
DO04C	0.09	0.02	0.03	0.14	0.28	0.29	0.01
DO05C	0.06	0.01	0.04	0.16	0.26	0.27	0.00
EC03C	0.53	5.30	2.11	3.39	11.33	12.25	0.92
EC04B	0.37	1.21	0.50	2.24	4.32	4.40	0.08
ED02B	0.18	0.14	0.15	0.67	1.15	1.14	0.00
ED05B	0.29	1.28	2.12	1.87	5.56	5.71	0.15
EE02B	0.12	0.12	0.04	0.56	0.84	0.84	0.00
EE03C	0.15	0.21	0.00	0.52	0.88	0.82	-0.06
IE05B	1.33	2.35	4.94	15.36	23.98	24.09	0.11
IE12B	0.16	0.00	4.58	5.97	10.71	11.17	0.46
IE14B	0.20	0.00	2.91	7.67	10.79	10.60	-0.19
IE16B	0.13	0.03	0.01	0.17	0.35	0.35	0.00
IH02B	2.81	4.35	60.56	18.14	85.86	89.65	3.79
IH06B	4.15	0.12	49.37	18.15	71.78	74.13	2.34
KP02B	0.93	0.78	8.02	9.14	18.87	19.03	0.17
KP07B	0.10	0.03	0.06	0.31	0.50	0.51	0.01

Table 4. TEQ Increments derived from the 4-Source Model

Location ID	TEQ Increment (ng/kg)				Sum of TEQ Increments (ng/kg)	Measured TEQ (ng/kg)	Δ TEQ[1] (ng/kg)
	Source 1	Source 2	Source 3	Source 4			
MA02C	0.96	0.35	16.96	9.70	27.98	28.72	0.74
MD02B	0.89	3.45	2.95	10.71	18.00	18.19	0.19
CO03B	0.24	3.48	0.02	0.15	3.88	4.17	0.29
CO05B	0.67	3.78	1.52	2.37	8.34	8.88	0.54
ED01B	0.27	0.04	0.07	0.36	0.74	0.74	0.00
KP03B	0.34	0.33	3.80	2.51	6.98	7.01	0.03
LA02B	0.38	0.49	0.00	1.84	2.71	2.48	-0.23
IE01B	1.30	1.38	0.00	6.48	9.16	8.66	-0.50
ED03C	0.10	0.09	0.19	0.37	0.75	0.74	-0.01
MD03C	1.67	1.49	0.79	7.70	11.65	11.75	0.10
BL02B	0.45	0.00	9.29	8.15	17.89	18.30	0.41
ED02C	0.50	0.14	0.17	1.65	2.46	2.56	0.10
ED04B	0.96	1.03	4.54	10.79	17.33	17.25	-0.08
IE09B	0.81	1.17	9.03	1.26	12.27	12.12	-0.15
KP08B	0.26	0.00	0.12	0.47	0.86	0.84	-0.02
LA02C	0.19	0.12	0.00	0.35	0.66	0.59	-0.06
NPI-L2	8.89	2.59	56.11	48.22	115.81	117.94	2.13
NPI-PA9	0.24	0.21	1.71	0.62	2.78	2.91	0.12
MD02C	0.13	0.25	0.00	0.99	1.37	1.27	-0.10
MD03B	1.30	1.57	0.82	8.20	11.89	11.88	-0.01
BL02C	0.13	0.06	0.15	0.29	0.62	0.63	0.01
IH02C	0.16	0.02	0.00	0.24	0.42	0.39	-0.03
ED01C	0.21	0.00	0.00	0.18	0.39	0.37	-0.02
IH06C	0.15	0.02	0.00	0.19	0.36	0.34	-0.02

Notes:
Δ TEQ = (Measured TEQ) - (Sum of TEQ Increments)

Table 5. Unmixing Model Comparison Matrix

4-Source Model	6-Source Model
Source 1	Source 1
Source 2	Source 2
	Source 5
Source 3	Source 3
	Source 6
Source 4	Source 4

Table 6. Dioxin Source Contributions to Harbor-wide Surface Sediment Total TEQ

Dioxin Source	Model Data	Sample Data				
	Contribution to Harbor-wide Dioxin Total TEQ[1] (%)	Number of Samples with Dioxin TEQ increment:				
		< 2 ng/kg	2 - 10 ng/kg	10 - 20 ng/kg	20 - 50 ng/kg	> 50 ng/kg
1	6	153	17	7	3	1
2	10	123	51	6	1	0
3	40	40	82	33	22	4
4	44	35	115	19	10	2

Notes:

1. Percent contribution derived from spatial interpolation models of surface sediment data.

Appendix A

Port Angeles Harbor
Sediment Dioxin/Furan Congener Data Set

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Study ID	Location	Latitude	Longitude	Upper Depth (cm)	Lower Depth (cm)	Total TEQ[1] (ng/kg)
E & E 2012	PASED08	BL01A	48.1252	-123.4472	0	10	5.25
E & E 2012	PASED08	BL02A	48.1254	-123.4464	0	10	3.85
E & E 2012	PASED08	BL02B	48.1254	-123.4464	91	122	18.3
E & E 2012	PASED08	BL02C	48.1254	-123.4464	152	198	0.63
E & E 2012	PASED08	BL03A	48.1254	-123.4434	0	10	7.47
E & E 2012	PASED08	BL04A	48.1255	-123.4414	0	10	1.23
E & E 2012	PASED08	BL06A	48.1309	-123.4410	0	10	5.92
E & E 2012	PASED08	BL08A	48.1308	-123.4379	0	10	6.3
E & E 2012	PASED08	BL08B	48.1308	-123.4378	30	61	1.14
E & E 2012	PASED08	BL08C	48.1308	-123.4378	91	122	0.2
E & E 2012	PASED08	CO01A	48.1175	-123.4099	0	10	1.29
E & E 2012	PASED08	CO02A	48.1184	-123.4096	0	10	6.44
E & E 2012	PASED08	CO02B	48.1185	-123.4095	15	30	1.57
E & E 2012	PASED08	CO03A	48.1183	-123.4074	0	10	0.31
E & E 2012	PASED08	CO03B	48.1183	-123.4074	61	91	4.17
E & E 2012	PASED08	CO04A	48.1182	-123.4062	0	10	0.22
E & E 2012	PASED08	CO04B	48.1182	-123.4061	30	61	0.33
E & E 2012	PASED08	CO05A	48.1185	-123.4054	0	10	1.04
E & E 2012	PASED08	CO05B	48.1185	-123.4054	61	91	8.88
E & E 2012	PASED08	DO01A	48.1202	-123.3947	0	10	1.29
E & E 2012	PASED08	DO02A	48.1227	-123.3879	0	10	1.76
E & E 2012	PASED08	DO03A	48.1244	-123.3835	0	10	1.92
E & E 2012	PASED08	DO04A	48.1273	-123.3801	0	10	1.7
E & E 2012	PASED08	DO04B	48.1273	-123.3801	15	30	2.83
E & E 2012	PASED08	DO04C	48.1273	-123.3801	30	61	0.29
E & E 2012	PASED08	DO04D	48.1273	-123.3801	61	81	0.12
E & E 2012	PASED08	DO05A	48.1250	-123.3772	0	10	1.4
E & E 2012	PASED08	DO05B	48.1250	-123.3772	15	30	1.36
E & E 2012	PASED08	DO05C	48.1250	-123.3772	30	41	0.27
E & E 2012	PASED08	EC01A	48.1166	-123.4054	0	10	0.33
E & E 2012	PASED08	EC02A	48.1174	-123.4058	0	10	0.13
E & E 2012	PASED08	EC03A	48.1187	-123.4054	0	10	3.98
E & E 2012	PASED08	EC03B	48.1187	-123.4054	15	30	22.9
E & E 2012	PASED08	EC03C	48.1187	-123.4054	30	61	12.2
E & E 2012	PASED08	EC04A	48.1185	-123.4048	0	10	0.99
E & E 2012	PASED08	EC04B	48.1185	-123.4050	30	61	4.4
E & E 2012	PASED08	EC05A	48.1171	-123.4049	0	10	0.26
E & E 2012	PASED08	ED01A	48.1227	-123.4063	0	10	6.35
E & E 2012	PASED08	ED01B	48.1227	-123.4063	61	91	0.74
E & E 2012	PASED08	ED01C	48.1227	-123.4063	183	213	0.37
E & E 2012	PASED08	ED02A	48.1213	-123.4065	0	10	10.2
E & E 2012	PASED08	ED02B	48.1213	-123.4065	30	61	1.14
E & E 2012	PASED08	ED02C	48.1213	-123.4065	91	122	2.56
E & E 2012	PASED08	ED03A	48.1206	-123.4066	0	10	8.19
E & E 2012	PASED08	ED03B	48.1206	-123.4066	15	46	9.04
E & E 2012	PASED08	ED03C	48.1206	-123.4066	84	114	0.74
E & E 2012	PASED08	ED04A	48.1199	-123.4068	0	10	10.9
E & E 2012	PASED08	ED04B	48.1199	-123.4069	91	122	17.2
E & E 2012	PASED08	ED05A	48.1189	-123.4072	0	10	1.74
E & E 2012	PASED08	ED05B	48.1189	-123.4072	30	61	5.71
E & E 2012	PASED08	EE01A	48.1172	-123.4035	0	10	0.15
E & E 2012	PASED08	EE01B	48.1172	-123.4035	15	30	0.1
E & E 2012	PASED08	EE02A	48.1165	-123.4031	0	10	0.4
E & E 2012	PASED08	EE02B	48.1166	-123.4031	30	61	0.84
E & E 2012	PASED08	EE02C	48.1166	-123.4031	61	91	0.2
E & E 2012	PASED08	EE03A	48.1165	-123.4023	0	10	0.3
E & E 2012	PASED08	EE03B	48.1165	-123.4023	15	30	0.72
E & E 2012	PASED08	EE03C	48.1165	-123.4023	30	61	0.82
E & E 2012	PASED08	EE04A	48.1154	-123.4005	0	10	0.13
E & E 2012	PASED08	EE04B	48.1154	-123.4005	15	30	0.39
E & E 2012	PASED08	EE04C	48.1154	-123.4005	30	61	0.15
E & E 2012	PASED08	EE05A	48.1150	-123.3992	0	10	0.13
E & E 2012	PASED08	EI02A	48.1151	-123.3868	0	10	0.26
E & E 2012	PASED08	EI04A	48.1148	-123.3746	0	10	0.24
E & E 2012	PASED08	EI07A	48.1196	-123.3524	0	10	0.47
E & E 2012	PASED08	FT01A	48.1220	-123.4324	0	10	12.5
E & E 2012	PASED08	FT04A	48.1216	-123.4291	0	10	3.27
E & E 2012	PASED08	FT06A	48.1271	-123.4252	0	10	5.32
E & E 2012	PASED08	FT10A	48.1247	-123.4213	0	10	6.59
E & E 2012	PASED08	FT12A	48.1312	-123.4077	0	10	1.56
E & E 2012	PASED08	FT13A	48.1323	-123.4119	0	10	1.97

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Study ID	Location	Latitude	Longitude	Upper Depth (cm)	Lower Depth (cm)	Total TEQ[1] (ng/kg)
E & E 2012	PASED08	IE01B	48.1406	-123.4332	76	107	8.66
E & E 2012	PASED08	IE03A	48.1405	-123.4390	0	10	4.63
E & E 2012	PASED08	IE04A	48.1392	-123.4447	0	10	4.62
E & E 2012	PASED08	IE05A	48.1392	-123.4487	0	10	9.94
E & E 2012	PASED08	IE05B	48.1391	-123.4487	30	61	24.1
E & E 2012	PASED08	IE06A	48.1389	-123.4512	0	10	9.63
E & E 2012	PASED08	IE07A	48.1383	-123.4535	0	10	8.33
E & E 2012	PASED08	IE09A	48.1363	-123.4605	0	10	62.9
E & E 2012	PASED08	IE09B	48.1363	-123.4605	91	122	12.1
E & E 2012	PASED08	IE12A	48.1364	-123.4520	0	10	5.61
E & E 2012	PASED08	IE12B	48.1364	-123.4521	30	61	11.2
E & E 2012	PASED08	IE14A	48.1367	-123.4438	0	10	4.26
E & E 2012	PASED08	IE14B	48.1367	-123.4438	30	61	10.6
E & E 2012	PASED08	IE15A	48.1329	-123.4490	0	10	9.35
E & E 2012	PASED08	IE16B	48.1331	-123.4531	30	61	0.35
E & E 2012	PASED08	IH01A	48.1340	-123.4613	0	10	119
E & E 2012	PASED08	IH02A	48.1330	-123.4603	0	10	43.7
E & E 2012	PASED08	IH02B	48.1330	-123.4603	30	61	89.7
E & E 2012	PASED08	IH02C	48.1330	-123.4603	178	208	0.39
E & E 2012	PASED08	IH03A	48.1313	-123.4597	0	10	19.4
E & E 2012	PASED08	IH04A	48.1306	-123.4594	0	10	9.79
E & E 2012	PASED08	IH05A	48.1295	-123.4583	0	10	4.46
E & E 2012	PASED08	IH06A	48.1286	-123.4566	0	10	11.6
E & E 2012	PASED08	IH06B	48.1286	-123.4566	30	61	74.1
E & E 2012	PASED08	IH06C	48.1286	-123.4566	249	279	0.34
E & E 2012	PASED08	KP01A	48.1243	-123.4402	0	10	15.4
E & E 2012	PASED08	KP02A	48.1238	-123.4388	0	10	11.1
E & E 2012	PASED08	KP02B	48.1238	-123.4388	30	61	19
E & E 2012	PASED08	KP03A	48.1234	-123.4373	0	10	2.52
E & E 2012	PASED08	KP03B	48.1234	-123.4373	61	91	7.01
E & E 2012	PASED08	KP04A	48.1229	-123.4357	0	10	5.17
E & E 2012	PASED08	KP05A	48.1256	-123.4355	0	10	8.46
E & E 2012	PASED08	KP07A	48.1334	-123.4292	0	10	3.51
E & E 2012	PASED08	KP07B	48.1334	-123.4292	30	61	0.51
E & E 2012	PASED08	KP08B	48.1259	-123.4382	91	122	0.84
E & E 2012	PASED08	LA01A	48.1331	-123.4697	0	10	61.6
E & E 2012	PASED08	LA02A	48.1322	-123.4691	0	10	55.2
E & E 2012	PASED08	LA02B	48.1322	-123.4691	61	91	2.48
E & E 2012	PASED08	LA02C	48.1322	-123.4691	91	122	0.59
E & E 2012	PASED08	LA03A	48.1329	-123.4683	0	10	93.2
E & E 2012	PASED08	LP01A	48.1182	-123.4157	0	10	1.63
E & E 2012	PASED08	LP03A	48.1181	-123.4133	0	10	1.09
E & E 2012	PASED08	LP04A	48.1184	-123.4126	0	10	4.03
E & E 2012	PASED08	LP05A	48.1180	-123.4113	0	10	18.5
E & E 2012	PASED08	MA01A	48.1263	-123.4534	0	10	15.2
E & E 2012	PASED08	MA02A	48.1271	-123.4501	0	10	14.8
E & E 2012	PASED08	MA02B	48.1272	-123.4501	15	30	20.7
E & E 2012	PASED08	MA02C	48.1272	-123.4501	30	61	28.7
E & E 2012	PASED08	MA03A	48.1283	-123.4521	0	10	17.2
E & E 2012	PASED08	MA04A	48.1269	-123.4496	0	10	11.5
E & E 2012	PASED08	MA05A	48.1285	-123.4492	0	10	15.6
E & E 2012	PASED08	MD01A	48.1189	-123.4087	0	10	6.54
E & E 2012	PASED08	MD01B	48.1190	-123.4088	15	30	3.44
E & E 2012	PASED08	MD01C	48.1190	-123.4088	30	61	0.18
E & E 2012	PASED08	MD02A	48.1196	-123.4086	0	10	10.7
E & E 2012	PASED08	MD02B	48.1196	-123.4096	30	61	18.2
E & E 2012	PASED08	MD02C	48.1196	-123.4096	122	152	1.27
E & E 2012	PASED08	MD03A	48.1205	-123.4084	0	10	9.67
E & E 2012	PASED08	MD03B	48.1205	-123.4084	122	152	11.9
E & E 2012	PASED08	MD03C	48.1205	-123.4084	89	119	11.8
E & E 2012	PASED08	MD04A	48.1214	-123.4083	0	10	9.71
E & E 2012	PASED08	MD04B	48.1214	-123.4083	15	46	9.26
E & E 2012	PASED08	MD05A	48.1228	-123.4088	0	10	1.31
E & E 2012	PASED08	MD05B	48.1228	-123.4087	10	25	0.87
E & E 2012	PASED08	MD05C	48.1228	-123.4087	25	56	0.65
E & E 2012	PASED08	OH01A-R	48.1277	-123.3865	0	10	1.31
E & E 2012	PASED08	OH02A	48.1314	-123.3920	0	10	0.82
E & E 2012	PASED08	OH03A	48.1343	-123.3962	0	10	0.83
E & E 2012	PASED08	RL01A	48.1197	-123.4278	0	10	0.97
E & E 2012	PASED08	WW01A	48.1249	-123.3991	0	10	1.38
NPS 2010	NPI_PA_002_2010	NPI_PA_002-150	48.1356	-123.4684	0	73.7	0.1

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Study ID	Location	Latitude	Longitude	Upper Depth (cm)	Lower Depth (cm)	Total TEQ[1] (ng/kg)
NPS 2010	NPI_PA_002_2010	NPI_PA_002-150_d	48.1356	-123.4684	0	73.7	0.06
Exponent 2008	PORT ANGELES DNR08	LA01A-01	48.1331	-123.4697	0	10	74.3
Exponent 2008	PORT ANGELES DNR08	LA02A-01	48.1329	-123.4683	0	10	77
Exponent 2008	PORT ANGELES DNR08	LA03A-01	48.1322	-123.4691	0	10	68.6
Exponent 2008	PORT ANGELES DNR08	NPI-L1	48.1326	-123.4686	0	10	75.9
Exponent 2008	PORT ANGELES DNR08	NPI-L2	48.1337	-123.4678	0	10	4.93
Exponent 2008	PORT ANGELES DNR08	NPI-L2	48.1337	-123.4678	93.98	124.46	118
Exponent 2008	PORT ANGELES DNR08	NPI-L3	48.1325	-123.4756	0	10	14.7
Exponent 2008	PORT ANGELES DNR08	NPI-PA1	48.1352	-123.4637	88.9	116.84	0.33
Exponent 2008	PORT ANGELES DNR08	NPI-PA1	48.1352	-123.4637	0	10	56.3
Exponent 2008	PORT ANGELES DNR08	NPI-PA10	48.1319	-123.4598	0	10	35.2
Exponent 2008	PORT ANGELES DNR08	NPI-PA10_d	48.1319	-123.4598	0	10	34.9
Exponent 2008	PORT ANGELES DNR08	NPI-PA2	48.1342	-123.4629	73.66	101.6	0.22
Exponent 2008	PORT ANGELES DNR08	NPI-PA2	48.1342	-123.4629	0	10	28.7
Exponent 2008	PORT ANGELES DNR08	NPI-PA3	48.1366	-123.4608	0	10	94.1
Exponent 2008	PORT ANGELES DNR08	NPI-PA4	48.1351	-123.4597	0	10	105
Exponent 2008	PORT ANGELES DNR08	NPI-PA5	48.1349	-123.4576	0	10	12.6
Exponent 2008	PORT ANGELES DNR08	NPI-PA6	48.1336	-123.4596	0	10	44.2
Exponent 2008	PORT ANGELES DNR08	NPI-PA6_d	48.1336	-123.4596	0	10	40.9
Exponent 2008	PORT ANGELES DNR08	NPI-PA8	48.1333	-123.4612	0	10	40.2
Exponent 2008	PORT ANGELES DNR08	NPI-PA9	48.1329	-123.4607	104.14	132.08	2.91
Exponent 2008	PORT ANGELES DNR08	NPI-PA9	48.1329	-123.4607	0	10	47.4
Malcolm Pirnie 2007a	RAYONR05	HS-01	48.1211	-123.4290	0	10	0.53
Malcolm Pirnie 2007a	RAYONR05	HS-02	48.1214	-123.4286	0	10	3.26
Malcolm Pirnie 2007a	RAYONR05	HS-03	48.1224	-123.4277	0	10	6.55
Malcolm Pirnie 2007a	RAYONR05	HS-04	48.1229	-123.4271	0	10	11.3
Malcolm Pirnie 2007a	RAYONR05	HS-05	48.1194	-123.4263	0	10	0.42
Malcolm Pirnie 2007a	RAYONR05	HS-06	48.1202	-123.4254	0	10	1.95
Malcolm Pirnie 2007a	RAYONR05	HS-07	48.1216	-123.4243	0	10	0.86
Malcolm Pirnie 2007a	RAYONR05	HS-08	48.1229	-123.4231	0	10	3.75
Malcolm Pirnie 2007a	RAYONR05	IT-04	48.1181	-123.4097	0	10	0.33
Malcolm Pirnie 2007a	RAYONR05	IT-05	48.1148	-123.3984	0	10	0.31
Malcolm Pirnie 2007a	RAYONR05	IT-06	48.1168	-123.4109	0	10	20.5
Malcolm Pirnie 2007a	RAYONR05	IT-07	48.1168	-123.4108	0	10	14.4
Malcolm Pirnie 2007a	RAYONR05	IT-08	48.1166	-123.4117	0	10	10.7
Malcolm Pirnie 2007a	RAYONR05	LP-01	48.1169	-123.4146	0	10	0.47
Malcolm Pirnie 2007a	RAYONR05	LP-02	48.1168	-123.4129	0	10	3.02
Malcolm Pirnie 2007a	RAYONR05	LP-03	48.1168	-123.4116	0	10	7.35
Malcolm Pirnie 2007a	RAYONR05	LP-04	48.1171	-123.4137	0	10	0.71
Malcolm Pirnie 2007a	RAYONR05	LP-05	48.1170	-123.4121	0	10	7.61
Malcolm Pirnie 2007a	RAYONR05	LP-06	48.1172	-123.4104	0	10	59.4
Malcolm Pirnie 2007a	RAYONR05	LP-07	48.1176	-123.4164	0	10	0.97
Malcolm Pirnie 2007a	RAYONR05	LP-08	48.1175	-123.4146	0	10	0.86
Malcolm Pirnie 2007a	RAYONR05	LP-09	48.1175	-123.4127	6.1	76.25	7.24
Malcolm Pirnie 2007a	RAYONR05	LP-09	48.1175	-123.4127	0	10	6.04
Malcolm Pirnie 2007a	RAYONR05	LP-10	48.1174	-123.4113	0	10	2.71
Malcolm Pirnie 2007a	RAYONR05	LP-11	48.1181	-123.4138	0	10	0.65
Malcolm Pirnie 2007a	RAYONR05	LP-12	48.1179	-123.4120	9.15	45.75	5.87
Malcolm Pirnie 2007a	RAYONR05	LP-12	48.1179	-123.4120	0	10	2.34
Malcolm Pirnie 2007a	RAYONR05	LP-12_d	48.1179	-123.4120	0	10	2.11
Malcolm Pirnie 2007a	RAYONR05	LP-13	48.1178	-123.4107	9.15	45.75	6.28
Malcolm Pirnie 2007a	RAYONR05	LP-13	48.1178	-123.4107	0	27.45	3.82
Malcolm Pirnie 2007a	RAYONR05	LP-13	48.1178	-123.4107	0	10	14.6
Malcolm Pirnie 2007a	RAYONR05	LP-13	48.1178	-123.4107	27.4	61	0.88
Malcolm Pirnie 2007a	RAYONR05	LP-13_d	48.1178	-123.4107	0	10	7.91
Malcolm Pirnie 2007a	RAYONR05	LP-14	48.1184	-123.4144	0	10	1.63
Malcolm Pirnie 2007a	RAYONR05	LP-15	48.1184	-123.4129	0	10	1.82
Malcolm Pirnie 2007a	RAYONR05	LP-16	48.1183	-123.4114	0	10	10.7
Malcolm Pirnie 2007a	RAYONR05	LP-17	48.1191	-123.4146	0	10	0.51
Malcolm Pirnie 2007a	RAYONR05	LP-18	48.1188	-123.4123	0	39.65	5.54
Malcolm Pirnie 2007a	RAYONR05	LP-18	48.1188	-123.4123	39.65	45.75	0.92
Malcolm Pirnie 2007a	RAYONR05	LP-18	48.1188	-123.4123	0	10	6.52
Malcolm Pirnie 2007a	RAYONR05	LP-19	48.1193	-123.4134	0	10	1.2
Malcolm Pirnie 2007a	RAYONR05	LP-20	48.1171	-123.4109	9.15	56.425	26.7
Malcolm Pirnie 2007a	RAYONR05	LP-20	48.1171	-123.4109	0	10	5.99
Malcolm Pirnie 2007a	RAYONR05	LP-20	48.1171	-123.4109	56.425	91.5	1.11
Malcolm Pirnie 2007a	RAYONR05	MD-02	48.1192	-123.4099	0	10	4.34
Malcolm Pirnie 2007a	RAYONR05	MD-03	48.1187	-123.4061	0	10	2.08
Malcolm Pirnie 2007a	RAYONR05	MD-08	48.1208	-123.4074	0	10	3.09
Malcolm Pirnie 2007a	RAYONR05	MD-16	48.1189	-123.4081	0	10	3.35
Malcolm Pirnie 2007a	RAYONR05	MD-17	48.1195	-123.4074	0	10	10.6

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Study ID	Location	Latitude	Longitude	Upper Depth (cm)	Lower Depth (cm)	Total TEQ[1] (ng/kg)
Malcolm Pirnie 2007a	RAYONR05	MD-18	48.1202	-123.4078	0	10	1.66
Malcolm Pirnie 2007a	RAYONR05	OF-05	48.1270	-123.3680	0	10	0.35
Malcolm Pirnie 2007a	RAYONR05	OF-06	48.1270	-123.3605	0	10	0.29
Malcolm Pirnie 2007a, Appendix P	LEKT_RAYONR05	HS-07_d	48.1216	-123.4243	0	10	4.96
Malcolm Pirnie 2007a, Appendix P	LEKT_RAYONR05	LP-17_d	48.1191	-123.4146	0	10	1.53
Malcolm Pirnie 2007a, Appendix P	LEKT_RAYONR05	MD-10	48.1202	-123.4043	0	10	8.66
Malcolm Pirnie 2007a, Appendix P	LEKT_RAYONR05	OF-05_d	48.1270	-123.3680	0	10	1.15
Malcolm Pirnie 2007b	PAMILLRI	EP-01-SD	48.1229	-123.4291	0	10	5.55
Malcolm Pirnie 2007b	PAMILLRI	EP-02-SD	48.1242	-123.4299	0	10	15.1
Malcolm Pirnie 2007b	PAMILLRI	EP-03-SD	48.1235	-123.4272	0	10	9.55
Malcolm Pirnie 2007b	PAMILLRI	EP-04-SD	48.1217	-123.4254	0	10	10.6
Malcolm Pirnie 2007b	PAMILLRI	EP-05-SD	48.1254	-123.4275	0	10	10.3
Malcolm Pirnie 2007b	PAMILLRI	EP-06-SD	48.1240	-123.4328	0	10	14.1
Malcolm Pirnie 2007b	PAMILLRI	EP-07-SD	48.1269	-123.4312	0	10	8.94
Malcolm Pirnie 2007b	PAMILLRI	EP-08-SD	48.1246	-123.4236	0	10	8.66
Malcolm Pirnie 2007b	PAMILLRI	EP-09-SD	48.1206	-123.4217	0	10	14.9
Malcolm Pirnie 2007b	PAMILLRI	EP-10-SD	48.1279	-123.4259	0	10	5.56
Malcolm Pirnie 2007b	PAMILLRI	EP-11-SD	48.1252	-123.4368	0	10	11.6
Malcolm Pirnie 2007b	PAMILLRI	LP-01-SD	48.1167	-123.4135	0	10	0.76
Malcolm Pirnie 2007b	PAMILLRI	LP-02-SD	48.1169	-123.4122	0	10	7.07
Malcolm Pirnie 2007b	PAMILLRI	LP-03-SD	48.1172	-123.4113	0	10	49
Malcolm Pirnie 2007b	PAMILLRI	LP-04-SD	48.1178	-123.4106	0	10	42.5
Malcolm Pirnie 2007b	PAMILLRI	LP-05-SD	48.1172	-123.4142	0	10	0.55
Malcolm Pirnie 2007b	PAMILLRI	LP-06-SD	48.1178	-123.4136	0	10	0.36
Malcolm Pirnie 2007b	PAMILLRI	LP-06-SD_d	48.1178	-123.4136	0	10	0.42
Malcolm Pirnie 2007b	PAMILLRI	LP-07-SD	48.1182	-123.4127	0	10	8.08
Malcolm Pirnie 2007b	PAMILLRI	LP-08-SD	48.1187	-123.4121	0	10	9.86
Malcolm Pirnie 2007b	PAMILLRI	MD-03-SD	48.1171	-123.3982	0	10	2.07
Malcolm Pirnie 2007b	PAMILLRI	MD-04-SD	48.1174	-123.4001	0	10	3.02
Malcolm Pirnie 2007b	PAMILLRI	MD-05-SD	48.1178	-123.4022	0	10	1.97
Malcolm Pirnie 2007b	PAMILLRI	MD-06-SD	48.1181	-123.4041	0	10	0.61
Malcolm Pirnie 2007b	PAMILLRI	MD-07-SD	48.1217	-123.3995	0	10	1.98
Malcolm Pirnie 2007b	PAMILLRI	MD-08-SD	48.1209	-123.4012	0	10	2.46
Malcolm Pirnie 2007b	PAMILLRI	MD-09-SD	48.1200	-123.4028	0	10	4.86
Malcolm Pirnie 2007b	PAMILLRI	MD-10-SD	48.1192	-123.4045	0	10	7.05
Malcolm Pirnie 2007b	PAMILLRI	MD-11-SD	48.1238	-123.4044	0	10	2.75
Malcolm Pirnie 2007b	PAMILLRI	MD-12-SD	48.1224	-123.4048	0	10	3.51
Malcolm Pirnie 2007b	PAMILLRI	MD-13-SD	48.1211	-123.4052	0	10	6.35
Malcolm Pirnie 2007b	PAMILLRI	MD-14-SD	48.1198	-123.4056	0	10	7.39
Malcolm Pirnie 2007b	PAMILLRI	MD-15-SD	48.1234	-123.4093	0	10	3.65
Malcolm Pirnie 2007b	PAMILLRI	MD-16-SD	48.1222	-123.4086	0	10	0.67
Malcolm Pirnie 2007b	PAMILLRI	MD-17-SD	48.1209	-123.4077	0	10	6.27
Malcolm Pirnie 2007b	PAMILLRI	MD-18-SD	48.1197	-123.4070	0	10	21.5
Malcolm Pirnie 2007b	PAMILLRI	MD-21-SD	48.1200	-123.4094	0	10	2.92
Malcolm Pirnie 2007b	PAMILLRI	MD-22-SD	48.1190	-123.4100	0	10	3.68
Malcolm Pirnie 2007b	PAMILLRI	MD-23-SD	48.1188	-123.4083	0	10	4.45
Malcolm Pirnie 2007b	PAMILLRI	MD-24-SD	48.1184	-123.4061	0	10	1.28
Malcolm Pirnie 2007b	PAMILLRI	MD-24-SD_d	48.1184	-123.4061	0	10	1.37
Malcolm Pirnie 2007b	PAMILLRI	WP-01-SD	48.1291	-123.4548	0	10	32.4
Malcolm Pirnie 2007b	PAMILLRI	WP-01-SD_d	48.1291	-123.4548	0	10	40.9
Malcolm Pirnie 2007b	PAMILLRI	WP-02-SD	48.1304	-123.4555	0	10	24.8
Malcolm Pirnie 2007b	PAMILLRI	WP-03-SD	48.1296	-123.4529	0	10	32.2
Malcolm Pirnie 2007b	PAMILLRI	WP-04-SD	48.1278	-123.4512	0	10	26.4
Malcolm Pirnie 2007b	PAMILLRI	WP-05-SD	48.1315	-123.4531	0	10	13.9
Malcolm Pirnie 2007b	PAMILLRI	WP-06-SD	48.1303	-123.4584	0	10	31.7
Malcolm Pirnie 2007b	PAMILLRI	WP-07-SD	48.1331	-123.4566	0	10	37.5
Malcolm Pirnie 2007b	PAMILLRI	WP-08-SD	48.1307	-123.4491	0	10	18.6
Malcolm Pirnie 2007b	PAMILLRI	WP-09-SD	48.1266	-123.4476	0	10	12
Malcolm Pirnie 2007b	PAMILLRI	WP-10-SD	48.1340	-123.4513	0	10	14.6
Malcolm Pirnie 2007b	PAMILLRI	WP-11-SD	48.1328	-123.4609	0	10	46.3
Foster Wheeler 2001	LOG_POND_2001	FWX1	48.1172	-123.4103	0	15.2	95.9
Foster Wheeler 2001	LOG_POND_2001	FWX2	48.1175	-123.4110	0	15.2	42.9
Foster Wheeler 2001	LOG_POND_2001	FWX3	48.1178	-123.4117	0	15.2	25.9
Foster Wheeler 2001	LOG_POND_2001	FWX4	48.1180	-123.4124	0	15.2	20.2
Foster Wheeler 2001	LOG_POND_2001	FWX5	48.1170	-123.4117	0	15.2	56.2
Foster Wheeler 2001	LOG_POND_2001	FWX6	48.1170	-123.4117	0	15.2	60.9

Notes:
1. Total TEQ to 2,3,7,8-TCDD, with non-detected congeners equal to 0.5*MDL
2. Non-detected congeners are listed as negative values equivalent to the MDL

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Dioxin Congeners[2] (ng/kg)						
	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
E & E 2012	0.4	1.2	1.43	7.14	4.01	116	1040
E & E 2012	0.35	0.83	0.99	4.9	2.9	90.7	723
E & E 2012	1.05	4.09	4.41	26.7	12.9	417	2820
E & E 2012	0.11	0.17	0.14	0.59	0.41	7.96	38.9
E & E 2012	0.85	1.45	1.56	8.4	5.39	179	2060
E & E 2012	0.18	0.27	0.26	1.47	0.96	22.8	177
E & E 2012	0.6	1.66	1.56	7.89	4.87	81.9	602
E & E 2012	0.59	1.68	2.1	8.1	5.34	99.8	850
E & E 2012	0.17	0.36	0.31	1.25	0.84	13	88.7
E & E 2012	0.07	0.07	0.03	0.07	0.19	0.76	5.73
E & E 2012	0.16	0.43	0.48	0.98	0.92	12.5	112
E & E 2012	0.72	1.6	1.76	5.29	3.75	95.9	949
E & E 2012	0.18	0.5	0.5	1.12	0.94	18.6	199
E & E 2012	0.07	0.08	0.06	0.21	0.2	3.65	31.3
E & E 2012	0.17	0.35	0.42	1.91	1.1	30.9	199
E & E 2012	0.06	0.06	0.04	0.11	0.13	2.87	28.3
E & E 2012	0.08	0.12	0.1	0.2	0.2	2.6	22.9
E & E 2012	0.15	0.35	0.3	0.73	0.69	10.1	75.6
E & E 2012	0.65	1.47	1.97	7.74	4.4	104	815
E & E 2012	0.14	0.43	0.35	1.11	0.95	10.9	82.7
E & E 2012	0.2	0.58	0.46	2.2	1.44	17.8	102
E & E 2012	0.22	0.49	0.49	2.21	1.61	32.5	438
E & E 2012	0.2	0.47	0.39	2.14	1.51	20.1	201
E & E 2012	0.28	1.04	0.85	3.34	2.51	26	141
E & E 2012	0.07	0.08	0.07	0.25	0.24	1.93	13.7
E & E 2012	0	0.05	0.03	0.09	0.14	0.68	4.54
E & E 2012	0.21	0.44	0.34	1.79	1.17	12.8	64.7
E & E 2012	0.16	0.41	0.41	1.86	1.28	13	68.8
E & E 2012	0.06	0.08	0.06	0.29	0.23	2.16	13.9
E & E 2012	0.09	0.12	0.08	0.17	0.26	2.1	14.7
E & E 2012	0.04	0.04	0	0.07	0.07	0.75	5.2
E & E 2012	0.47	0.89	0.95	2.85	2.26	48.6	607
E & E 2012	1.17	3.58	4.03	12.6	9.63	465	7320
E & E 2012	0.6	2.13	2.38	6.4	5.63	147	2080
E & E 2012	0.13	0.27	0.27	0.82	0.61	17.1	200
E & E 2012	0.42	1.16	1.11	3.69	2.72	43	344
E & E 2012	0.1	0.07	0.04	0.11	0.16	1.52	10.6
E & E 2012	0.63	1.54	1.68	6.23	5.19	122	1120
E & E 2012	0.21	0.23	0.19	0.48	0.5	5.28	44.5
E & E 2012	0.16	0.13	0.06	0.14	0.23	0.91	3.56
E & E 2012	1.13	2.72	3.21	9.95	7.86	147	1200
E & E 2012	0.17	0.35	0.35	0.98	0.76	11.1	96.5
E & E 2012	0.46	0.83	1.59	2.32	2.29	15.8	59.9
E & E 2012	0.8	2.23	2.64	7.32	5.62	145	1340
E & E 2012	0.85	2.14	2.07	9.97	5.63	164	1410
E & E 2012	0.1	0.2	0.21	0.66	0.5	11.1	110
E & E 2012	1.26	2.78	3.06	10.9	6.84	212	1680
E & E 2012	1.49	5.2	4.99	20.8	13.1	252	2080
E & E 2012	0.22	0.41	0.43	1.47	1.13	29.5	263
E & E 2012	0.38	1.03	1.32	6.76	3.47	108	935
E & E 2012	0.05	0.04	0.03	0.08	0.1	1.1	7.85
E & E 2012	0.04	0.03	0.03	0.04	0.07	-0.3	1.43
E & E 2012	0.09	0.15	0.1	0.27	0.27	3.13	22.3
E & E 2012	0.12	0.29	0.26	0.55	0.56	5.97	54.8
E & E 2012	0.06	0.09	0.04	0.09	0.12	0.34	1.31
E & E 2012	0.07	0.09	0.06	0.22	0.21	2.44	13.5
E & E 2012	0.13	0.19	0.14	0.53	0.41	8.07	56.7
E & E 2012	0.14	0.27	0.25	0.44	0.43	3.65	20.3
E & E 2012	0.04	0.04	0	0.08	0.07	0.75	6.08
E & E 2012	0.08	0.13	0.13	0.34	0.27	3.22	23.4
E & E 2012	0.06	0.05	0.03	0.06	0.1	0.72	5.04
E & E 2012	0.04	0.05	0	0.09	0.08	0.42	1.68
E & E 2012	0.08	0.07	0.04	0.23	0.19	1.94	13.7
E & E 2012	0.04	0.09	0.05	0.2	0.16	1.93	14.1
E & E 2012	0.09	0.16	0.13	0.43	0.35	3.96	26.1
E & E 2012	0.98	3.27	3.11	14.4	9.26	248	2260
E & E 2012	0.34	0.87	0.85	3.17	2.42	66.8	589
E & E 2012	0.48	1.6	1.68	7.1	4.84	68.1	536
E & E 2012	0.66	2.23	2.18	7.98	5.96	63.7	408
E & E 2012	0.21	0.5	0.45	1.7	1.2	14.6	95.5
E & E 2012	0.28	0.64	0.55	2.15	1.57	19.4	122

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Dioxin Congeners[2] (ng/kg)						
	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
E & E 2012	1.31	3.26	2.81	4.95	5.37	31.2	132
E & E 2012	0.47	1.54	1.23	5.56	4.07	55.2	436
E & E 2012	0.48	1.52	1.21	6.08	4.17	53.5	404
E & E 2012	0.85	2.69	2.56	12.4	8.28	158	1480
E & E 2012	2.04	7.48	6.26	25.7	15.9	298	2210
E & E 2012	0.69	2.72	3.03	13.7	7.74	140	1110
E & E 2012	0.74	2.39	2.68	10.1	6.16	118	950
E & E 2012	2.61	5.19	6.18	103	23.8	2360	17300
E & E 2012	0.77	1.5	1.43	11.6	3.28	393	6480
E & E 2012	0.47	1.39	1.19	7.28	4.6	104	1070
E & E 2012	0.65	2.7	2.23	20.2	9.28	199	1530
E & E 2012	0.38	1.15	1	5.78	3.65	64.5	583
E & E 2012	0.76	3.34	2.45	18.9	10.2	134	740
E & E 2012	0.65	1.96	1.61	14.4	6.71	200	1830
E & E 2012	0.1	0.11	0.05	0.17	0.28	1.69	14.7
E & E 2012	3.72	7.44	11.9	191	31.9	5090	24300
E & E 2012	1.76	5.44	5.63	72.1	21.5	1420	11500
E & E 2012	4.46	12.1	8.21	149	26.8	2420	31200
E & E 2012	0.12	0.14	0.06	0.12	0.33	0.86	4.97
E & E 2012	0.92	2.91	3.69	38.9	12.9	511	4160
E & E 2012	0.53	1.88	1.73	17.9	6.78	217	1950
E & E 2012	0.27	0.85	0.95	6.58	3.4	117	1110
E & E 2012	0.63	2.12	2.39	19.6	8.91	297	2640
E & E 2012	5.25	10.8	12.2	128	42.8	2030	20000
E & E 2012	0.12	0.12	0.07	0.13	0.22	0.91	4.12
E & E 2012	1.28	3.48	3.32	17.4	11.4	350	2700
E & E 2012	1.02	2.88	2.61	10.9	8.09	190	2250
E & E 2012	1.4	4.74	4.27	24.1	11.8	378	3440
E & E 2012	0.43	0.7	0.59	2.28	1.67	29.7	226
E & E 2012	0.5	1.33	1.22	11.9	3.9	167	1430
E & E 2012	0.62	1.42	1.55	5.44	4.07	72.3	510
E & E 2012	0.68	2.29	2.09	9.92	6.92	145	1350
E & E 2012	0.43	1.04	1	4.17	2.59	42.4	303
E & E 2012	0.09	0.16	0.11	0.44	0.39	4.06	30
E & E 2012	0.21	0.28	0.14	0.66	0.58	7.55	52.8
E & E 2012	20.6	11.3	14.2	56.5	32.9	820	8780
E & E 2012	10.5	12.7	17.6	67	38.5	854	6750
E & E 2012	0.38	0.92	0.94	1.3	1.46	7.82	15.9
E & E 2012	0.15	0.2	0.18	0.25	0.28	1.16	2.04
E & E 2012	44.3	14.4	15.3	76.1	37.2	1020	8750
E & E 2012	0.16	0.42	0.45	1.45	1.13	34	323
E & E 2012	0.11	0.34	0.31	0.88	0.63	12.8	166
E & E 2012	0.41	1.25	1.01	3.12	2.4	39	329
E & E 2012	1.31	5.21	5.12	15.9	11.8	298	3540
E & E 2012	0.43	4.14	6.1	24.6	16.2	336	2410
E & E 2012	0.68	2.54	2.72	18.8	9.84	433	5000
E & E 2012	1.05	5.14	4.47	43	16	393	2930
E & E 2012	1.66	5.31	5.26	42.5	18	732	6900
E & E 2012	1.02	3.47	4	26.1	12.5	393	3590
E & E 2012	0.45	1.71	2.27	14.6	8.72	374	4090
E & E 2012	1.09	3.84	3.98	25.4	12.5	271	1960
E & E 2012	0.37	1.18	1.73	6.16	5.7	203	1690
E & E 2012	0.27	0.86	1.06	2.91	2.52	64.2	588
E & E 2012	0.04	0.04	0.05	0.15	0.15	2.64	23.4
E & E 2012	0.84	2.72	2.76	8.19	7.17	222	2750
E & E 2012	1.38	5.29	5.91	15.6	12.2	211	2030
E & E 2012	0.16	0.47	0.5	0.86	0.93	4.68	6.41
E & E 2012	0.78	2.81	3.12	7.55	6.13	157	1810
E & E 2012	1.46	4.04	4.65	9.38	8.65	95.3	539
E & E 2012	1.68	3.87	4.36	9.04	9.4	88.3	494
E & E 2012	0.65	1.85	1.84	7.25	4.58	245	3750
E & E 2012	1.08	2.23	2.46	8.24	6.27	145	1740
E & E 2012	0.14	0.44	0.47	1.38	1.02	12.9	82.3
E & E 2012	0.12	0.29	0.26	0.89	0.7	8.12	53.2
E & E 2012	0.09	0.21	0.2	0.67	0.5	6.23	39
E & E 2012	0.16	0.39	0.37	1.73	1.23	12.5	69.6
E & E 2012	0.1	0.25	0.17	1.03	0.79	8.71	56.5
E & E 2012	0.11	0.23	0.19	1	0.78	8.82	58.8
E & E 2012	0.09	0.32	0.33	0.99	0.78	12.1	93.8
E & E 2012	0.17	0.44	0.36	1.62	1.14	14.4	91.7
NPS 2010	0	0	0	0.2	0.11	1.31	8.6

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Dioxin Congeners[2] (ng/kg)						
	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
NPS 2010	0	0	0	0.1	0	0.73	4.6
Exponent 2008	16.6	15.3	21.9	70.8	32.6	1270	11900
Exponent 2008	11.1	17.1	22.1	71.1	31.5	1230	8660
Exponent 2008	10	14.7	21	79.9	33.6	1270	10800
Exponent 2008	13.6	16.3	19	95.7	34.5	1280	8770
Exponent 2008	0.56	1.21	1.31	6.68	2.94	79.2	504
Exponent 2008	10.9	24.9	33.9	191	71.3	2490	18100
Exponent 2008	2.41	3.84	4.81	13.7	8.21	206	1300
Exponent 2008	-0.2	-0.1	-0.2	0.46	-0.2	5.78	45.5
Exponent 2008	3.38	7.56	12	70.1	22.3	1760	17900
Exponent 2008	1.61	4.56	5.51	52	13.1	1180	8720
Exponent 2008	1.62	4.5	5.29	50.7	13.1	1140	9930
Exponent 2008	-0.1	-0.1	-0.2	-0.2	-0.2	0.79	4.15
Exponent 2008	1.86	5.51	5.7	44.3	10	651	4940
Exponent 2008	3.83	8.16	9.14	133	23.1	3420	29000
Exponent 2008	4.18	12.9	11.7	157	30.6	3680	26900
Exponent 2008	0.88	2.68	2.55	16.2	6.16	305	2280
Exponent 2008	2	6.31	5.99	60	14	1400	12700
Exponent 2008	2.11	5.65	5.41	58.8	13.2	1280	9580
Exponent 2008	1.81	4.71	5.5	54.5	12	1410	14000
Exponent 2008	0.25	0.4	0.43	4.75	1.11	71.5	419
Exponent 2008	2.2	5.98	6.57	63.2	14	1570	15100
Malcolm Pirnie 2007a	-0.1	0.21	-0.1	0.56	0.52	8.94	76
Malcolm Pirnie 2007a	0.36	0.74	0.76	2.97	2.1	61.3	604
Malcolm Pirnie 2007a	0.46	1.77	1.7	6.57	4.4	93.3	824
Malcolm Pirnie 2007a	0.95	3.15	2.62	11.2	7.38	149	1270
Malcolm Pirnie 2007a	-0.1	-0.1	-0.1	0.59	0.37	7.38	68.9
Malcolm Pirnie 2007a	-0.1	0.45	0.52	1.85	1	32.2	420
Malcolm Pirnie 2007a	0.1	0.19	0.22	1	0.49	12.8	100
Malcolm Pirnie 2007a	0.29	1	0.78	3.58	2.26	49	540
Malcolm Pirnie 2007a	-0.1	-0.2	-0.4	-0.4	-0.4	1.71	23.7
Malcolm Pirnie 2007a	-0.1	-0.2	-0.3	-0.3	-0.3	-1.2	13
Malcolm Pirnie 2007a	0.52	4.24	6.78	14.8	14.4	203	2640
Malcolm Pirnie 2007a	0.52	1.7	1.58	6.63	4.17	256	4990
Malcolm Pirnie 2007a	0.86	2.71	2.77	8.58	6.51	123	1760
Malcolm Pirnie 2007a	-0.1	-0.1	-0.1	0.69	-0.1	16	160
Malcolm Pirnie 2007a	0.39	0.75	0.82	2.49	1.67	24	186
Malcolm Pirnie 2007a	0.6	2.3	1.8	5.29	3.9	65.5	720
Malcolm Pirnie 2007a	0.1	0.19	0.33	0.44	0.33	8.96	120
Malcolm Pirnie 2007a	0.77	1.75	2	5.6	4.1	93	920
Malcolm Pirnie 2007a	4.91	25.2	27.5	61	-0.3	448	2390
Malcolm Pirnie 2007a	-0.2	-0.2	-0.2	0.5	-0.2	32	523
Malcolm Pirnie 2007a	0.11	0.18	0.24	0.83	0.55	12.1	87
Malcolm Pirnie 2007a	-0.6	-1.2	-1.1	4.63	-1.1	155	2250
Malcolm Pirnie 2007a	0.69	1.6	0.98	4.38	2.6	75.1	943
Malcolm Pirnie 2007a	0.26	0.68	0.53	2.21	1.54	36	378
Malcolm Pirnie 2007a	0.11	-0.1	0.15	0.62	0.35	9.93	106
Malcolm Pirnie 2007a	-0.5	-1.3	-1	5.21	-1	188	2590
Malcolm Pirnie 2007a	-0.1	0.47	0.35	1.87	1.28	47.9	733
Malcolm Pirnie 2007a	-0.1	0.61	0.8	2.14	1.52	22.2	174
Malcolm Pirnie 2007a	-0.7	-2	-1.8	8.46	-1.8	102	899
Malcolm Pirnie 2007a	-0.6	-0.9	1.2	5.42	2.14	61.8	482
Malcolm Pirnie 2007a	1.14	4.36	4.1	12.9	9.96	243	2480
Malcolm Pirnie 2007a	-0.4	-0.6	-0.6	-0.7	-0.6	5.42	36.2
Malcolm Pirnie 2007a	0.49	2.61	2.43	7.33	5.36	101	1130
Malcolm Pirnie 2007a	-0.1	0.5	0.44	1.6	1.18	18	190
Malcolm Pirnie 2007a	0.18	0.48	0.3	1.24	0.7	14.8	144
Malcolm Pirnie 2007a	0.73	2.09	2.51	6.26	4.93	67.8	510
Malcolm Pirnie 2007a	-0.1	-0.1	-0.1	0.65	0.46	7.28	72.3
Malcolm Pirnie 2007a	-0.5	-0.8	-0.8	5.19	3.26	94.1	915
Malcolm Pirnie 2007a	-0.4	-0.8	-0.5	-0.6	-0.5	-1	5.46
Malcolm Pirnie 2007a	0.53	1.5	1.25	5.13	3.1	80	1030
Malcolm Pirnie 2007a	-0.1	-0.1	0.31	1	0.76	42.4	585
Malcolm Pirnie 2007a	-0.7	3.37	3.8	22.4	8.61	420	4960
Malcolm Pirnie 2007a	0.65	1.27	1.35	5.19	2.69	70.9	681
Malcolm Pirnie 2007a	-0.2	-0.3	-0.3	-0.3	-0.3	16.1	218
Malcolm Pirnie 2007a	0.42	1.15	0.87	3	2.1	65.9	698
Malcolm Pirnie 2007a	0.19	0.47	0.37	1.67	0.15	33.6	404
Malcolm Pirnie 2007a	-0.2	0.55	-0.3	3.5	0.96	82.4	874
Malcolm Pirnie 2007a	-0.4	-0.5	-1.7	-1.7	-1.6	163	1450
Malcolm Pirnie 2007a	2.63	1.1	1.22	8.51	4.5	263	3830

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Dioxin Congeners[2] (ng/kg)						
	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
Malcolm Pirnie 2007a	-0.3	-0.4	-0.7	2.19	-0.7	55	589
Malcolm Pirnie 2007a	-0.1	-0.1	-0.1	0.74	-0.1	5.32	29.4
Malcolm Pirnie 2007a	-0.1	-0.1	-0.1	0.48	-0.1	3.7	20.7
Malcolm Pirnie 2007a, Appendix P	0.55	1.43	1.36	4.51	3.13	51.8	335
Malcolm Pirnie 2007a, Appendix P	0.18	0.39	0.42	1.65	1.32	14.1	101
Malcolm Pirnie 2007a, Appendix P	1.31	2.26	2.43	6.82	5.23	84.1	645
Malcolm Pirnie 2007a, Appendix P	0.15	0.35	0.28	1.31	0.89	9.97	47.4
Malcolm Pirnie 2007b	0.58	1.51	1.67	5.27	2.78	75.4	670
Malcolm Pirnie 2007b	1.29	4.42	5.24	16.7	8.72	192	1780
Malcolm Pirnie 2007b	0.96	2.95	3.18	9.31	5.04	107	844
Malcolm Pirnie 2007b	0.97	3.05	3.6	8.63	5.58	155	1690
Malcolm Pirnie 2007b	1.06	2.93	2.93	11.6	5.81	119	903
Malcolm Pirnie 2007b	1.22	3.93	4.89	15.6	8.3	188	1340
Malcolm Pirnie 2007b	0.79	2.45	3.02	10.7	5.81	115	858
Malcolm Pirnie 2007b	0.85	2.36	2.62	9.28	4.96	116	997
Malcolm Pirnie 2007b	0.62	1.85	1.9	6.75	2.98	484	11100
Malcolm Pirnie 2007b	0.48	1.57	1.57	6.38	3.25	76.4	732
Malcolm Pirnie 2007b	0.88	3.06	3.16	11.8	6.12	185	1670
Malcolm Pirnie 2007b	-0.1	0.45	-0.3	0.58	-0.2	5.27	32.5
Malcolm Pirnie 2007b	0.4	2.25	2.35	7.48	3.83	82.4	742
Malcolm Pirnie 2007b	5.02	18	17.3	37	24.1	366	2320
Malcolm Pirnie 2007b	3.67	14.8	13.8	31	18.8	510	5240
Malcolm Pirnie 2007b	-0.2	-0.2	-0.4	-0.6	-0.4	5.38	27.8
Malcolm Pirnie 2007b	-0.2	-0.2	-0.4	-0.3	-0.4	3.64	25.5
Malcolm Pirnie 2007b	-0.2	-0.2	-0.2	0.47	-0.3	4.22	27.8
Malcolm Pirnie 2007b	0.98	2.82	2.31	5	2.95	63.8	539
Malcolm Pirnie 2007b	0.95	2.91	2.54	6.09	3.46	95.2	793
Malcolm Pirnie 2007b	0.41	0.75	0.77	-1.5	1.17	21.7	152
Malcolm Pirnie 2007b	0.38	0.81	1.09	2.24	1.49	62.7	310
Malcolm Pirnie 2007b	-0.3	0.84	-0.7	1.36	-1.1	22.4	168
Malcolm Pirnie 2007b	-0.1	0.27	-0.3	0.51	0.34	5.32	35.6
Malcolm Pirnie 2007b	0.27	0.7	0.71	-1.8	1.13	20.2	127
Malcolm Pirnie 2007b	0.25	-0.9	1.04	2.76	1.47	29.9	194
Malcolm Pirnie 2007b	0.48	1.55	1.63	4.24	2.63	50.7	321
Malcolm Pirnie 2007b	-0.6	2.14	2.06	4.97	-2.7	81.9	617
Malcolm Pirnie 2007b	-0.3	1.08	1.03	2.96	-1.6	26.3	142
Malcolm Pirnie 2007b	0.35	0.99	1.13	3.1	1.72	63.2	578
Malcolm Pirnie 2007b	0.78	1.92	2.01	4.73	3	61	420
Malcolm Pirnie 2007b	0.69	2.39	3.08	6.89	4.55	79.9	512
Malcolm Pirnie 2007b	0.45	1.3	1.11	2.78	1.65	28.1	192
Malcolm Pirnie 2007b	-0.1	-0.2	-0.3	0.94	-0.5	11.7	76.5
Malcolm Pirnie 2007b	0.68	-1.8	1.87	5.2	2.63	147	1500
Malcolm Pirnie 2007b	1.38	4.22	5.2	15.4	7.03	793	7680
Malcolm Pirnie 2007b	0.33	1.08	-0.9	1.92	1.28	20.6	129
Malcolm Pirnie 2007b	0.45	1.29	1.22	2.84	1.67	37.2	258
Malcolm Pirnie 2007b	0.24	0.76	1.01	2.91	1.15	140	1150
Malcolm Pirnie 2007b	0.21	0.41	-0.4	1.02	0.64	17	135
Malcolm Pirnie 2007b	-0.3	-0.5	0.52	1.18	0.91	20.2	159
Malcolm Pirnie 2007b	1.86	5.03	6.06	50.1	18.2	841	6200
Malcolm Pirnie 2007b	2.26	6.32	8.18	70.3	23.2	1030	9830
Malcolm Pirnie 2007b	1.39	4.06	5.33	37.5	11.7	635	4780
Malcolm Pirnie 2007b	1.37	3.64	3.92	29.1	9.54	1060	15000
Malcolm Pirnie 2007b	2.6	5.23	6.89	38.1	14.5	544	4010
Malcolm Pirnie 2007b	-1.2	3.25	3.16	16.6	5.8	262	2430
Malcolm Pirnie 2007b	1.73	5.5	6.81	52.6	15.4	761	6080
Malcolm Pirnie 2007b	2	5.56	6.13	53.7	14.5	1100	8890
Malcolm Pirnie 2007b	1.65	5.01	5.89	22.2	8.61	241	1650
Malcolm Pirnie 2007b	0.87	2.77	3.62	15.7	6.65	235	2070
Malcolm Pirnie 2007b	-1	2.56	2.65	19.8	5.71	403	4020
Malcolm Pirnie 2007b	1.31	3.15	9.73	37.4	10.1	1100	9530
Foster Wheeler 2001	8.7	31.8	36.9	86.3	73.7	776	4920
Foster Wheeler 2001	3.6	12.6	13.9	40.3	27.6	421	2550
Foster Wheeler 2001	2.1	7.7	8.2	21	16	232	1830
Foster Wheeler 2001	1.4	5	5.4	21.3	12.8	212	2180
Foster Wheeler 2001	-1.8	6.5	10.6	58.5	46.5	2080	14000
Foster Wheeler 2001	4	11.1	13	47.1	31.7	998	12400

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Furan Congeners^2 (ng/kg)									
	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
E & E 2012	1.26	0.63	0.78	1.34	0.86	-0.1	0.8	20.8	0.99	60.3
E & E 2012	0.76	0.42	0.61	0.83	0.61	0.05	0.58	16.1	0.75	54.3
E & E 2012	2.77	1.5	2.27	4.78	3.65	0.24	3.19	121	23.7	340
E & E 2012	0.16	0.1	0.15	0.19	0.12	0	0.13	3.7	0.36	5.07
E & E 2012	1.54	0.83	1.14	1.73	1.17	0.1	1.13	24.7	1.52	89
E & E 2012	0.34	0.16	0.22	0.32	0.19	0	0.2	4.2	0.2	9.79
E & E 2012	2.16	0.89	1.22	1.51	1.03	0.1	0.92	23.8	1.2	51.1
E & E 2012	2.03	0.88	1.2	1.61	0.98	0.1	0.93	23	1.4	108
E & E 2012	0.31	0.18	0.26	0.25	0.17	0	0.17	3.55	0.17	7.14
E & E 2012	-0.1	0	0.03	0.05	0	0	0	-0.1	0	-0.2
E & E 2012	0.51	0.31	0.5	0.36	0.2	-0.1	0.19	2.2	-0.2	9.11
E & E 2012	2.91	1.25	2.14	3.63	1.22	0.16	1.38	16	0.84	72.9
E & E 2012	0.8	0.37	0.54	0.43	0.28	0.04	0.24	2.6	-0.2	14.1
E & E 2012	0.12	0.05	0.09	0.16	0.05	0	0.04	0.72	0	1.41
E & E 2012	2.23	0.98	2.79	11.3	1.92	0.07	2.82	22.4	1.17	18.7
E & E 2012	-0.1	0.03	0.06	-0.1	0.04	0	0.03	0.32	0.04	0.78
E & E 2012	0.12	-0.1	-0.1	-0.1	-0.1	0	-0.1	-0.5	-0.1	-1.1
E & E 2012	0.47	0.27	0.32	0.38	0.23	0.04	0.18	1.81	0.15	3.5
E & E 2012	6.34	1.7	3.55	12.1	2.63	0.16	2.99	45.3	4.45	100
E & E 2012	0.5	0.34	0.42	0.47	0.4	0.04	0.32	2.73	0.18	9.59
E & E 2012	0.73	0.33	0.46	0	0.3	0.03	0.28	7	0.24	9.9
E & E 2012	0.71	0.26	0.36	0.45	0.23	0.03	0.27	3.49	0.22	8.5
E & E 2012	1.02	0.27	0.35	0.45	0.25	0.03	0.25	3.88	0.23	16.7
E & E 2012	1.14	0.47	0.64	0.67	0.41	0.06	0.39	5.71	0.34	9.35
E & E 2012	0.11	0.05	0.07	0.06	0.04	0	0.04	0.48	0.03	0.86
E & E 2012	0.03	0	0.03	0.03	0	0	0	0.09	0	-0.1
E & E 2012	0.6	0.21	0.34	0.34	0.2	0	0.22	2.5	0.16	4.4
E & E 2012	0.58	0.23	0.35	0.35	0.23	0	0.23	3.4	-0.2	4.71
E & E 2012	0.06	0	0.06	0.06	0.04	0	0.04	0.53	0.03	0.76
E & E 2012	0.05	0.03	0.06	0.04	0.03	0	0.03	0.33	0	-0.8
E & E 2012	0	0	0.03	0	0	0	0	0.1	0	-0.2
E & E 2012	2.56	0.78	1.4	2.94	0.84	0.06	1.16	11.7	0.98	60.6
E & E 2012	17	4.07	7.76	17.7	4.64	0.29	4.55	132	8.15	1260
E & E 2012	11.4	2.03	4.56	15.4	3.97	0.13	2.7	98.1	8.06	438
E & E 2012	0.36	0.15	0.23	0.23	0.14	0	0.13	2.47	0.13	26.8
E & E 2012	2.88	1.02	1.71	3.2	1.1	0.08	1.02	13.8	1.32	43.6
E & E 2012	0	0	0.05	0.12	0.04	0	0.03	0.44	-0.1	-0.7
E & E 2012	2.88	1.14	1.68	1.39	0.88	0.07	0.81	13.2	0.74	108
E & E 2012	0.19	0.11	0.14	0.19	0.11	0	0.09	1.61	0.1	5.8
E & E 2012	0.04	0.03	0.04	0.04	0.04	0	0.03	0.25	0.03	0.43
E & E 2012	5.17	2.14	3.06	3.09	1.67	0.16	1.55	21	1.13	84.2
E & E 2012	0.51	0.23	0.34	0.32	0.2	0	0.2	2.55	0.16	11.2
E & E 2012	0.99	0.47	0.66	0.53	0.4	0.03	0.3	3.35	0.24	9.75
E & E 2012	3.52	1.4	2.15	2.09	1.24	0.09	1.11	22	1.05	75.9
E & E 2012	4.36	1.73	2.63	2.95	1.5	0.12	1.52	28.8	1.38	98.3
E & E 2012	0.33	0.16	0.2	0.19	0.11	0	0.12	1.87	0.09	10.9
E & E 2012	3.66	1.81	2.71	2.71	1.62	0.17	1.5	31.1	1.62	78.8
E & E 2012	7.45	3.05	4.23	4.42	2.58	0.31	2.49	37.9	2.1	122
E & E 2012	0.94	0.31	0.47	0.88	0.31	0	0.28	3.6	0.35	9.26
E & E 2012	3.82	1.11	1.65	3.4	1.24	0.12	1.15	25.9	1.23	48.7
E & E 2012	0.05	0.03	0.04	-0.1	0.03	0	0	-0.2	0.04	0.39
E & E 2012	0	0	0	0	0	0	0	-0.1	0	-0.1
E & E 2012	0.11	0.06	0.09	-0.1	0.05	0	0.05	0.68	0.05	1.21
E & E 2012	0.3	0.2	0.26	0.4	0.28	0.03	0.21	1.32	-0.1	2.75
E & E 2012	0	0	-0.1	-0.1	0	0	0	-0.2	-0.1	-0.3
E & E 2012	0.08	0.06	0.08	-0.1	0.06	0	0.05	0.49	0.04	0.89
E & E 2012	0.27	0.16	0.22	0.41	-0.2	0	0.16	1.9	0.33	6.71
E & E 2012	0.53	0.26	0.4	-0.3	0.25	0	0.21	1.04	-0.1	2.24
E & E 2012	0.03	0	0.03	0	0	0	0	0.18	0	0.43
E & E 2012	0.2	-0.1	-0.1	-0.1	-0.1	0	-0.1	-0.8	-0.1	1.95
E & E 2012	0.03	0	0	0	0	0	0	-0.2	0	-0.3
E & E 2012	0	0	0.03	0	0	0	0	-0.1	0	-0.1
E & E 2012	0.07	0.03	0.05	0.04	0.03	0	0	0.41	0.04	0.88
E & E 2012	0.08	0.04	0.07	-0.1	0.04	0	0.04	0.41	0.05	0.84
E & E 2012	0.18	0.07	0.12	-0.1	0.07	0	0.07	0.79	0.06	2.05
E & E 2012	3.95	1.86	2.75	3.37	2.16	0.21	2.06	35.5	2.1	111
E & E 2012	0.96	0.45	0.69	0.66	0.51	0.04	0.47	7.26	0.44	21
E & E 2012	1.84	0.8	1.16	1.29	0.86	0.09	0.86	15.1	0.89	43.5
E & E 2012	2.69	1.25	1.59	1.48	1.1	0.1	1.07	15.3	0.88	36.4
E & E 2012	0.69	0.29	0.43	0.44	0.28	0.03	0.27	3.71	0.21	7.21
E & E 2012	0.73	0.32	0.47	0.47	0.3	0.04	0.31	4.84	0.29	9.12

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Furan Congeners^2 (ng/kg)									
	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
E & E 2012	4.07	2.53	3.34	2.45	2.05	0.17	2.05	25.8	0.47	13.8
E & E 2012	1.91	0.69	0.9	1.02	0.7	0.06	0.64	11	0.6	32.7
E & E 2012	1.9	0.64	0.81	1.05	0.63	0.07	0.62	11.4	0.6	27.3
E & E 2012	3.61	1.54	2.17	2.55	1.75	0.15	1.96	31.3	1.48	79.1
E & E 2012	8.05	4.38	6.97	7.64	5.88	0.31	5.66	107	2.94	216
E & E 2012	3.48	1.37	2.02	2.77	1.82	0.16	1.98	33.1	1.57	77.1
E & E 2012	2.85	1.23	1.69	2.61	1.64	0.15	1.67	36.5	1.54	74
E & E 2012	5.03	3.55	4.52	18.7	8.85	1.05	8.7	651	19	2190
E & E 2012	2.12	1.19	1.32	2.17	1.14	-0.2	1.03	97.5	3.75	801
E & E 2012	1.77	0.7	0.97	1.39	0.72	0.08	0.89	24.5	0.94	88.7
E & E 2012	4.3	1.3	1.84	2.94	1.72	0.15	1.95	46.3	1.56	78.2
E & E 2012	1.64	0.54	0.78	1.17	0.68	0.07	0.65	16.9	0.78	60.7
E & E 2012	5	1.32	1.68	1.99	1.26	0.14	1.21	25.3	1.21	59.8
E & E 2012	2.68	0.98	1.35	2.31	1.35	0.15	1.33	58.5	2.55	284
E & E 2012	0.21	0	0.08	-0.1	0.05	0	0.03	0.94	0.04	0.57
E & E 2012	7.18	5.96	7.18	37.3	15.1	1.25	15.9	1430	36.7	5420
E & E 2012	5.34	2.96	3.25	11.9	6.31	1.88	5.8	420	13.2	1220
E & E 2012	8.81	6.62	7.96	37.1	16.5	0.86	13.4	996	22.4	2310
E & E 2012	0.09	0.07	0.1	0.08	0.06	0	0.07	0.21	0.03	-0.2
E & E 2012	3.95	1.59	2.15	4.84	3.07	0.34	3.42	128	4.58	282
E & E 2012	2.34	0.99	1.2	2.65	1.69	0.24	1.81	61.2	2.61	278
E & E 2012	0.92	0.44	0.53	1.07	0.64	0.08	0.59	21.2	0.92	66.4
E & E 2012	2.39	0.91	1.19	2.79	1.71	0.14	1.69	67.8	2.66	188
E & E 2012	15.3	3.87	5.51	18.9	9.52	0.85	8.01	565	15.1	2170
E & E 2012	0.11	0.07	0.08	-0.1	0.04	0	0.04	0.18	0.03	0.17
E & E 2012	4.04	2.27	3.63	4.42	2.71	0.27	2.69	52.1	2.57	123
E & E 2012	3.6	2	3.18	2.57	1.99	0.26	2.2	30.6	1.88	204
E & E 2012	3.6	2.03	3.09	7.36	3.69	0.17	3.29	109	4.3	440
E & E 2012	0.86	0.5	0.82	0.59	0.49	0.05	0.54	4.65	0.31	11.4
E & E 2012	1.28	0.85	1.22	2.28	1.3	0.18	1.25	33	1.43	61
E & E 2012	1.62	0.88	1.39	1.4	1.07	0.1	1.03	15.9	0.88	41.2
E & E 2012	2.89	1.26	1.92	2.28	1.34	0.15	1.42	27.4	1.65	92.3
E & E 2012	1.48	0.56	0.84	0.9	0.58	0.06	0.57	10.9	0.5	24.8
E & E 2012	0.18	0.09	0.12	0.14	0.09	0	0.09	1.58	0.1	2.4
E & E 2012	0.13	0.1	0.13	0.17	0.1	0.04	0.09	2.31	0.12	6.13
E & E 2012	6.69	3.41	4.57	11.7	10.5	0.77	11.4	262	8.42	594
E & E 2012	10.7	5.04	6.25	11.9	9.19	0.7	10.1	259	10.4	615
E & E 2012	2.16	0.88	1.02	0.49	0.49	0.04	0.4	3.28	0.11	1.8
E & E 2012	0.43	0.18	0.22	0.12	0.11	0	0.1	0.56	0	0.29
E & E 2012	8.36	4.17	4.91	12.5	9.25	0.97	10.7	278	9.65	610
E & E 2012	0.63	0.28	0.4	0.34	0.22	0.03	0.21	3.24	0.23	15.6
E & E 2012	0.63	0.25	0.39	0.32	0.19	0	0.16	2.32	0.16	14.7
E & E 2012	2.72	1.11	1.65	1.61	0.81	0.08	0.78	9.11	0.55	24.6
E & E 2012	7.23	3.56	6.21	5.86	2.75	0.31	2.86	63.4	2.95	450
E & E 2012	0.95	1.05	1.09	3.11	2.19	0.19	2.3	52.5	2.44	107
E & E 2012	2.87	1.15	1.49	3.1	1.73	0.15	1.82	86	3.76	760
E & E 2012	4.57	1.93	2.78	3.94	3.12	0.22	3.18	88.7	3.07	267
E & E 2012	5.18	2.23	3.02	7.63	4.81	0.5	4.33	220	9.01	922
E & E 2012	4.37	1.53	2.09	4.51	2.62	0.29	2.6	112	5.15	420
E & E 2012	1.78	0.98	1.19	2.6	1.43	0.2	1.51	53.8	2.38	336
E & E 2012	4.8	1.92	2.55	4.4	2.7	0.25	2.54	82	3.8	212
E & E 2012	1.87	0.92	1.18	1.59	0.77	0.1	0.81	16.4	0.89	82.9
E & E 2012	1.27	0.63	0.84	0.87	0.52	0.06	2.28	5.99	0.43	25.7
E & E 2012	0.08	0	-0.1	-0.1	-0.1	0	0	-0.4	-0.1	-0.9
E & E 2012	4.49	1.9	2.66	2.82	1.37	0.15	1.32	28.3	1.51	291
E & E 2012	10.4	3.54	6.38	7.73	3.58	0.27	3.85	70.8	4.69	236
E & E 2012	0.73	0.45	0.62	-0.3	0.36	0.06	0.31	-0.8	-0.1	-0.7
E & E 2012	4.77	1.9	2.74	2.74	1.56	0.16	1.44	26.9	1.47	172
E & E 2012	5.82	3.15	4.08	3.16	2.45	0.23	2.13	25.8	1.27	105
E & E 2012	5.44	2.78	3.82	3.41	2.37	0.25	2.02	27.7	1.57	77
E & E 2012	3.53	1.3	1.94	2.81	1.13	0.1	1.24	52.3	2.36	736
E & E 2012	3.87	1.66	2.6	2.79	1.62	0.13	1.46	36.2	1.68	282
E & E 2012	0.56	0.27	0.38	0.3	0.23	0.03	0.23	2.62	0.16	7.43
E & E 2012	0.37	0.16	0.23	0.22	0.16	0	0.16	1.58	0.12	5.12
E & E 2012	0.23	0.13	0.18	0.17	0.12	0	0.12	1.07	0.09	3.5
E & E 2012	0.56	0.22	0.31	0.38	0.23	0.03	0.23	2.82	0.17	4.36
E & E 2012	0.39	0.12	0.2	0.24	0.13	-0.1	0.13	2.03	0.09	3.24
E & E 2012	0.36	0.13	0.2	0.27	0.14	0	0.13	2.22	0.14	3.87
E & E 2012	0.39	0.15	0.24	0.23	0.15	0	-0.1	2.51	0.21	8.3
E & E 2012	0.53	0.24	0.37	0.37	0.23	0	0.23	3.26	0.19	6.73
NPS 2010	-0.1	0	0.05	0.12	0	0	0	0.32	0	0.38

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Furan Congeners[2] (ng/kg)									
	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
NPS 2010	-0.1	0	0	0.09	0.07	0	0.05	0.25	-0.1	0.02
Exponent 2008	11	6.53	12.1	14.3	13.5	2.94	19.5	324	9.58	1000
Exponent 2008	19.4	9.28	16.1	15.4	12.2	3.18	18.3	842	11.9	3140
Exponent 2008	14.2	7.52	14.8	14.4	12.2	3.3	18.7	319	10.6	922
Exponent 2008	13.6	7.26	14.9	15.4	13.4	3.62	21.9	385	12.4	661
Exponent 2008	0.92	0.56	1.14	1.35	1.04	0.42	1.61	20.4	0.95	36
Exponent 2008	18.2	10.8	21.2	21.9	19.7	6.44	30.9	532	15.1	1070
Exponent 2008	3.59	2.03	3.36	3.29	3.25	0.76	4.7	63.1	2.63	114
Exponent 2008	-0.1	-0.1	-0.1	0	0	-0.1	0	1.41	-0.2	2.65
Exponent 2008	8.09	4.25	9.86	13.1	8.87	3.26	15.3	346	15.3	1330
Exponent 2008	5.73	2.68	5.85	8.11	5.12	2.15	7.84	252	7.3	650
Exponent 2008	5.65	2.59	5.38	7.59	4.82	1.77	7.95	262	8.15	1000
Exponent 2008	0.09	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	-0.4
Exponent 2008	6.09	3.99	7.12	7.03	5.12	1.48	7.84	212	4.37	378
Exponent 2008	8.86	6.46	16.2	28.5	13	5.61	20.7	879	29.3	2810
Exponent 2008	11	6.67	14.3	24	13.5	4.51	21.1	1010	28.5	3300
Exponent 2008	2.88	1.47	2.61	2.89	1.75	0.73	2.81	78.1	2.7	214
Exponent 2008	6.29	3.44	7.07	10.1	5.66	1.88	8.63	390	11.1	1820
Exponent 2008	6.6	3.62	7.09	10.2	5.6	1.66	8.65	376	11	1150
Exponent 2008	4.59	2.83	6.64	8.26	5.15	1.96	8.74	292	8.5	782
Exponent 2008	0.37	-0.2	0.48	0.82	0.55	-0.2	0.98	32.4	1.04	64.6
Exponent 2008	5.51	3.39	7.65	10.6	6.45	2.26	10.4	409	12.1	1760
Malcolm Pirnie 2007a	-0.4	0	0	0.16	-0.1	-0.1	-0.1	1.59	-0.2	3.1
Malcolm Pirnie 2007a	1.33	0.53	0.92	0.89	0.87	-0.2	0.84	7.57	0.54	20.3
Malcolm Pirnie 2007a	2.87	1.4	2.43	2.16	1.2	-0.4	1.98	23	0.98	66
Malcolm Pirnie 2007a	5.68	2.69	4.36	3.59	1.9	-0.6	3.2	33	2.1	108
Malcolm Pirnie 2007a	0.47	0	0.22	0.2	-0.1	-0.1	-0.1	1.82	-0.2	5.17
Malcolm Pirnie 2007a	1.1	0.46	0.73	1.06	0.54	-0.2	0.59	7.77	0.55	58.4
Malcolm Pirnie 2007a	0.42	0.13	0.12	0.39	0.23	0.17	0.26	4.58	0.28	13.1
Malcolm Pirnie 2007a	1.95	0.81	1.42	1.19	0.62	-0.3	1.1	16.2	0.86	74.4
Malcolm Pirnie 2007a	-0.1	-0.1	-0.1	-0.3	-0.3	-0.7	-0.4	-0.5	-1	-3
Malcolm Pirnie 2007a	-0.1	-0.1	-0.1	-0.3	-0.3	-0.6	-0.4	-0.7	-1.6	-3.6
Malcolm Pirnie 2007a	8.64	8.5	14.3	21.7	5.95	-1.3	5.79	38	-5.3	440
Malcolm Pirnie 2007a	10.8	5.48	11	9.3	2.1	-0.4	3.28	52.1	1.34	941
Malcolm Pirnie 2007a	7.2	3.4	5.63	4.78	1.45	-0.2	2.03	21.4	1.34	203
Malcolm Pirnie 2007a	-0.4	-0.1	-0.1	0.23	-0.1	-0.1	-0.1	2.1	-0.5	15
Malcolm Pirnie 2007a	2.1	0.97	1.44	1.69	0.58	-0.3	0.76	7.41	0.96	23.8
Malcolm Pirnie 2007a	3.54	2.45	3.8	4.21	1.37	-0.2	1.68	14	0.7	82.8
Malcolm Pirnie 2007a	-0.4	0.2	0.25	0.18	0.19	-0.2	-0.1	2	-0.3	22.9
Malcolm Pirnie 2007a	5.41	1.9	3.1	5	1.99	0.7	1.71	20.1	2.1	98.1
Malcolm Pirnie 2007a	23.6	19.3	22.4	18.6	12	2.2	11.8	93	6.4	240
Malcolm Pirnie 2007a	-0.3	-0.2	-0.2	0.2	-0.1	-0.2	-0.1	7.2	-0.3	127
Malcolm Pirnie 2007a	0.59	0.2	0.34	0.39	0.17	-0.1	0.18	1.82	-0.3	12.5
Malcolm Pirnie 2007a	5.57	3.21	5.68	4.92	-0.9	-1	0.94	34.3	-1.8	487
Malcolm Pirnie 2007a	4.8	1.64	2.72	1.95	0.78	-0.2	1.2	14	-0.8	80.4
Malcolm Pirnie 2007a	1.74	0.63	1.18	1	0.43	-0.4	0.64	8	-1	39.8
Malcolm Pirnie 2007a	0.74	0.21	0.3	0.24	0.08	-0.1	0.12	1.64	-0.2	11
Malcolm Pirnie 2007a	2.59	-1	1.95	1.98	1.01	-0.8	-0.8	31.4	-2	492
Malcolm Pirnie 2007a	1.3	0.6	0.85	0.7	0.3	-0.3	-0.2	14.7	-0.8	203
Malcolm Pirnie 2007a	1.59	0.69	0.94	0.94	0.46	-0.2	0.64	4.44	-0.4	13.7
Malcolm Pirnie 2007a	4.55	-1.2	4.03	3.54	-1.5	-1.7	-1.4	28.4	-2.9	103
Malcolm Pirnie 2007a	2.29	-0.7	2.2	1.46	0.98	-0.7	-0.7	20.9	-1	56.2
Malcolm Pirnie 2007a	4.86	0.9	4.61	3.95	2	-0.5	2.8	33.7	1.1	180
Malcolm Pirnie 2007a	-0.7	-0.5	-0.5	-0.3	-0.3	-0.4	-0.3	1.52	-0.6	3.12
Malcolm Pirnie 2007a	3.09	1.86	2.69	2.36	1.16	-0.4	1.74	20.4	-1.1	80
Malcolm Pirnie 2007a	-0.8	0.58	0.76	0.75	0.37	-0.1	0.34	4.8	-0.2	66.1
Malcolm Pirnie 2007a	1.42	0.67	1.1	1.12	0.47	-0.2	0.44	3.79	-0.5	15.9
Malcolm Pirnie 2007a	6	3.61	4.83	20.3	4.71	1.13	2.95	51.8	10.3	117
Malcolm Pirnie 2007a	0.5	-0.1	0.26	0.29	0.17	-0.1	0.24	1.63	-0.3	10.9
Malcolm Pirnie 2007a	3.23	1.8	3.06	6.77	2.32	-0.5	1.99	26.6	2.33	111
Malcolm Pirnie 2007a	-0.3	-0.5	-0.5	-0.4	-0.4	-0.4	-0.4	-0.5	-0.6	4.89
Malcolm Pirnie 2007a	2.79	1.94	2.92	3.94	1.41	-0.3	1.82	42.3	1.19	197
Malcolm Pirnie 2007a	-0.5	0.29	0.29	0.29	0.15	-0.2	-0.2	5.7	0.21	84.9
Malcolm Pirnie 2007a	16.8	11.5	22.4	22.4	5.07	-2.5	8.27	109	-2.9	866
Malcolm Pirnie 2007a	5.1	1.9	3.1	3.1	0.89	-0.7	1.04	15.8	-1.8	86.6
Malcolm Pirnie 2007a	0.77	-0.2	0.99	0.83	-0.2	-0.2	0.24	4.48	-0.4	40.7
Malcolm Pirnie 2007a	2.89	1.53	1.82	1.44	0.75	-0.2	0.73	9.61	-0.7	57.8
Malcolm Pirnie 2007a	1.35	0.67	0.81	1	1	-0.3	0.43	6.9	-0.5	67.2
Malcolm Pirnie 2007a	1.14	0.63	0.96	1.43	0.67	-0.3	-0.3	20.2	0.56	47.4
Malcolm Pirnie 2007a	1.5	-0.3	-0.4	-0.8	-0.8	-1.3	-1.1	12.3	-6.2	45
Malcolm Pirnie 2007a	2.1	0.9	1.6	3.47	1	-0.3	1.31	26.7	1.6	160

Appendix A:
Port Angeles Harbor Sediment Dioxin/Furan Congener Data Set

Study	Furan Congeners[2] (ng/kg)									
	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
Malcolm Pirnie 2007a	0.95	-0.3	-0.3	-0.4	-0.4	-0.5	-0.5	5.44	-1.7	25.7
Malcolm Pirnie 2007a	0.5	-0.1	-0.1	0.25	-0.1	-0.1	-0.1	1.3	-0.3	1.99
Malcolm Pirnie 2007a	-0.1	-0.1	-0.1	0.22	0.19	-0.1	-0.1	0.83	-0.3	1.46
Malcolm Pirnie 2007a, Appendix P	4.96	0.99	1.41	1.06	1.11	0.08	1	16	1.07	46.4
Malcolm Pirnie 2007a, Appendix P	1.69	0.32	0.49	0.26	0.29	-0.1	0.33	2.89	0.23	13.3
Malcolm Pirnie 2007a, Appendix P	9.95	1.81	2.84	1.99	1.5	0.14	1.33	18	1.13	74
Malcolm Pirnie 2007a, Appendix P	0.89	0.2	0.31	0.27	0.19	0.05	0.21	2.53	0.15	2.79
Malcolm Pirnie 2007b	2.23	1.26	2.26	1.28	1.07	0.36	1.44	15.5	0.94	47.9
Malcolm Pirnie 2007b	5.54	3.18	5.28	3.06	2.75	0.94	3.76	46.4	2.49	211
Malcolm Pirnie 2007b	4.2	2.14	3.78	1.99	1.67	0.6	2.36	25.3	1.52	59
Malcolm Pirnie 2007b	3.93	2.57	4.13	2.38	2.16	0.75	2.6	22.7	1.4	77.8
Malcolm Pirnie 2007b	4.53	2.28	3.88	2.18	1.81	0.69	2.56	31.4	1.64	87.1
Malcolm Pirnie 2007b	5.46	3.13	5.51	3.14	2.59	1.05	3.8	42.6	2.31	98.7
Malcolm Pirnie 2007b	3.76	1.87	3.1	2.14	1.53	0.66	2.26	27.6	1.57	67.2
Malcolm Pirnie 2007b	3.65	1.9	3.25	1.78	1.45	0.6	2.15	26.1	1.4	105
Malcolm Pirnie 2007b	2.84	1.4	2.41	1.84	1.09	-0.3	1.49	92.5	4.81	2080
Malcolm Pirnie 2007b	2.12	1.12	1.87	1.13	0.97	0.38	1.44	18	1.01	67.2
Malcolm Pirnie 2007b	4.23	2.43	4.48	2.59	2.15	0.9	3.27	38.5	2.11	131
Malcolm Pirnie 2007b	0.28	-0.2	-0.2	-0.1	-0.1	-0.1	-0.3	1.04	-0.2	3.84
Malcolm Pirnie 2007b	3.11	2.1	3.39	2.14	1.02	0.31	1.29	10.5	-0.5	107
Malcolm Pirnie 2007b	26.4	14.7	21.6	10.7	8.98	3.14	11.2	74	4.16	209
Malcolm Pirnie 2007b	16	10.7	16.1	9.61	7.17	2.29	9.39	112	4.89	835
Malcolm Pirnie 2007b	0.57	-0.3	0.42	-0.1	-0.1	-0.2	-0.2	0.91	-0.2	-2.1
Malcolm Pirnie 2007b	0.35	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1	0.75	-0.2	2.35
Malcolm Pirnie 2007b	0.22	-0.2	0.21	-0.1	-0.1	-0.2	-0.2	0.78	-0.2	2.53
Malcolm Pirnie 2007b	5.13	2.79	3.78	1.99	1.47	0.46	1.87	12.1	0.72	68.5
Malcolm Pirnie 2007b	6.32	3.42	5.77	3.53	1.96	0.55	2.58	23.2	1.24	107
Malcolm Pirnie 2007b	1.01	0.56	-0.8	-0.4	-0.3	-0.1	0.52	4.12	-0.1	17.3
Malcolm Pirnie 2007b	1.13	0.79	1.12	-0.6	0.52	-0.3	-0.5	2.97	-0.2	7.32
Malcolm Pirnie 2007b	0.96	0.43	0.74	-0.4	0.4	-0.2	0.5	2.92	-0.1	9.7
Malcolm Pirnie 2007b	0.33	-0.2	-0.2	-0.2	-0.1	-0.1	-0.2	0.82	-0.1	2.02
Malcolm Pirnie 2007b	0.85	0.42	0.72	0.54	0.45	-0.1	-0.6	4.47	-0.4	11.5
Malcolm Pirnie 2007b	1.49	0.93	1.34	0.82	0.73	-0.1	0.89	5.53	0.36	17.7
Malcolm Pirnie 2007b	2.9	1.3	1.89	1.24	0.97	0.34	1.18	9.86	-0.6	45.8
Malcolm Pirnie 2007b	9.64	2.16	3.3	2.06	1.67	0.4	1.74	11.9	0.91	30.8
Malcolm Pirnie 2007b	1.48	0.87	1.18	0.8	-0.5	-0.1	-0.7	5.74	0.37	13.2
Malcolm Pirnie 2007b	1.62	-0.8	1.08	-0.6	0.55	-0.1	0.67	8.4	0.54	84.4
Malcolm Pirnie 2007b	4.53	1.81	2.69	1.64	1.19	0.48	1.52	12.1	0.79	43.7
Malcolm Pirnie 2007b	3.33	1.59	2.52	2.43	1.33	-0.4	1.69	16.6	1.38	61.1
Malcolm Pirnie 2007b	1.94	1.06	1.56	0.8	0.67	-0.2	0.88	5.85	0.4	23.8
Malcolm Pirnie 2007b	0.46	0.28	0.39	-0.3	0.26	-0.1	-0.2	2.32	-0.2	7.55
Malcolm Pirnie 2007b	3.12	1.6	2.45	1.84	1.23	0.45	1.51	17.5	1.04	64.1
Malcolm Pirnie 2007b	4.71	2.41	3.81	2.97	1.85	0.78	2.57	34.2	1.52	142
Malcolm Pirnie 2007b	1.81	0.89	1.47	0.66	0.59	-0.2	0.73	3.83	-0.2	10.5
Malcolm Pirnie 2007b	2.65	1.1	-1.5	1.03	0.9	0.27	0.96	7.35	0.52	12.4
Malcolm Pirnie 2007b	2.27	0.49	0.94	3.15	0.69	-0.3	1.08	13.3	1.59	53.2
Malcolm Pirnie 2007b	0.63	0.33	-0.5	0.42	-0.2	-0.1	0.31	3.11	0.32	6.29
Malcolm Pirnie 2007b	0.65	-0.4	0.67	0.84	0.37	-0.1	0.5	3.35	-0.3	13.1
Malcolm Pirnie 2007b	8.23	3.04	5.75	8.14	4.89	2.3	9.2	236	10.5	724
Malcolm Pirnie 2007b	9.82	3.22	6.35	8.69	5.45	2.23	9.67	294	11.4	1000
Malcolm Pirnie 2007b	5.63	2.29	4.84	6.6	3.87	1.46	6.43	202	7.06	486
Malcolm Pirnie 2007b	6.02	2.63	4.78	6.24	3.53	2.1	6.92	281	12.4	3150
Malcolm Pirnie 2007b	6.22	2.77	5.47	6.03	4.24	1.88	6.95	154	7.18	483
Malcolm Pirnie 2007b	5.19	2.26	4.44	4.07	2.8	1.03	3.92	91.6	3.33	239
Malcolm Pirnie 2007b	7.87	3	6.17	7.61	4.89	2.11	7.97	229	7.48	553
Malcolm Pirnie 2007b	7.65	3.76	7.17	8.5	5.26	-1.6	-7.9	337	12.1	1650
Malcolm Pirnie 2007b	5.85	3.41	6.04	5.93	4.67	1.44	6.11	94.2	4.29	214
Malcolm Pirnie 2007b	3.24	1.67	3.33	2.5	2.1	0.76	3.18	47.1	2.13	150
Malcolm Pirnie 2007b	3.45	1.51	2.95	3.43	2.09	0.64	3.25	115	3.6	415
Malcolm Pirnie 2007b	5.41	15.9	11.5	57.7	26.8	16.6	20	363	154	1590
Foster Wheeler 2001	82.4	-0.9	32.9	27.3	15.8	3	19.7	152	7.6	618
Foster Wheeler 2001	37.6	-0.5	15.4	15.1	7.8	-1.5	9.3	160	5.2	381
Foster Wheeler 2001	24.4	-0.3	11.3	11.1	5.4	0.73	6.3	45.8	2.5	267
Foster Wheeler 2001	19.3	-0.2	8.4	9.3	4.1	0.65	6.9	45.1	3.3	191
Foster Wheeler 2001	25.6	-0.3	15.5	17.9	8	1.5	10.9	112	4.7	157
Foster Wheeler 2001	47.9	-0.5	28.5	34.6	11.8	1.8	15.9	238	12.7	2240

Appendix B

Chemometric Evaluation of Port Angeles Harbor Data

CHEMOMETRIC EVALUATION OF PORT ANGELES HARBOR DATA

Source Apportionment Investigations

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1. INTRODUCTION

Port Angeles Harbor was identified by the Washington State Department of Ecology as a priority cleanup and restoration site under the Puget Sound Initiative. Infometrix was contracted as part of an effort aimed at providing continuing technical support for completion of the Port Angeles Harbor Supplemental Data Evaluation to the Sediment Investigation Report.

In particular, Infometrix was requested to perform chemometric evaluation of Port Angeles Harbor data. The request was to include application of multivariate methods for the evaluation of important congeners of polychlorinated dibenzo-p-dioxins (dioxins) and dibenzofurans (furans) obtained from chemical analysis of sediment samples collected in the harbor. Specific tasks included: evaluation of analyses of sediment samples from the harbor as to suitability, chemometric processing of dioxin compounds found in these sediments, and interpretation of the underlying patterns of dioxins found in the chemometric studies as to their possible sources.

The relative concentrations of dioxin and furan congeners measured in Port Angeles Harbor sediments reveal several patterns[1] that suggest contributions from ubiquitous chemical formulations.

This report provides a brief introduction to the multivariate tools used in the study. A detailed description of the data analysis steps is included. Finally, some conclusions are drawn from the results and include the following.

- It appears that at least 4 distinct sources of dioxins/furans can be described in the harbor sediments
- Each of the proposed 4 source patterns has an analog in known dioxin-producing materials:
    - 2,4,5-T or wood ash
    - PCBs
    - Pentachlorophenol
    - Emissions, ash, and effluent from hog fuel boiler facilities processing salt-laden wood

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[1] Pattern here refers to TEF-scaled amounts; see later text for details

2. MULTIVARIATE APPROACH

When a data analysis scenario includes the collection of more than one or two measurements, interpretation of results in a univariate sense (one variable at a time) can become tedious if not misleading. It is rare that measurements are completely independent (that is, selective); they are more commonly correlated. Univariate analysis cannot detect correlations and will misrepresent trends and relationships that result from correlation. Multivariate analysis uses tools and techniques from mathematics and statistics to guide interpretation of multichannel information, and the approach has been used in this study.

Among the multivariate tools used in the environmental field, factor-based and mixture analysis methods are the most common. Factor and principal component analysis are exploratory methods (Sharaf et al. 1986.; Beebe et al. 1998) that seek to find and understand relationships among samples, locate potential outliers or aberrant samples, and describe differences and similarities among measurements. Particularly suited to studies of source apportionment, mixture analysis algorithms (Johnson et al. 2007) such as target factor analysis, polytopic vector analysis and alternating least squares can reveal underlying patterns of chemical constituents and then assign contributions of these patterns to sample mixtures.

Data for multivariate analysis are usually composed in a rectangular matrix, with rows representing samples and columns representing measurements on these samples. This approach can be used for presenting for analysis the results of spectroscopic measurements, tables of chromatographic peak areas, or collections of discrete wet chemistry measurements. The patterns exhibited by the collection of measurements for each sample are like fingerprints, and the objective of environmental analysis is often to characterize the patterns in a collection of measured samples.

The dioxin and furan measurements in this study originate from chromatographic analyses. Although the chromatography used for the analyses is capable of resolving the vast majority of the 200-plus isomers of chlorinated homologs, it is customary in studies of these classes of compounds to focus on the 2,3,7,8-chloro isomers (Ecology 2007). This group of 17 compounds includes 7 dioxin and 10 furan isomers (see Section 3 on Data description and setup).

Detectors in chromatography do not respond in the same way to all compounds, thus peak intensities may vary considerably even when compounds are present in the same amounts. In addition, natural abundances of compounds that derive from a common source are expected to vary. As a result, the range of intensities of congeners can vary over several orders of magnitude. Finally, the actual concentration of material injected into the gas chromatograph cannot be perfectly controlled.

If a multivariate analysis were to be performed on raw patterns of data in which the measurements vary by such large amounts, those compounds with the largest intensity would drive the analysis. In other words, the analysis would reflect only the information in the most abundant measures. To allow interpretation of the differences in chromatographic fingerprints, it is customary to scale the data to put all measurements on common ground.

The first step in standardizing data is to scale the individual measurements to be of similar magnitude. In most chemometric studies in which the measurements are discrete and not continuous, each measurement is scaled by either the range or the standard deviation of the measure across all samples.

The result is that each scaled variable will either have a range of 0 to 1 or a variance of 1. There are two drawbacks to these scaling methods: (1) the scaling factor is a function of the samples that are included in the calculation and would therefore change if different samples were processed, and (2) 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 signal.

One method frequently used in studies of dioxins (see, for example, Lohmann and Jones 1998; Alcock et al. 2002; and Hilscherova et al. 2003), and used here, is to scale by a toxic equivalency factor (TEF; see Table 4), based on toxicities relative to 2,3,7,8-TCDD. An advantage of TEF scaling not shared by the other methods is that the result is not dependent on the particular data set because the scaling is done for each sample independently. The scaling factors for range and variance scaling are derived from calculations using all of the data; changing what data are included will change the scale factors.

The second step is to normalize by area percent (divide each value in a sample by the sum of the TEF-scaled values in that sample). Relative differences in amount of material entering the chromatogram are thus removed, allowing comparison of patterns without complications of sample amount.

Factor analysis (FA) and principal component analysis (PCA) are two exploratory algorithms that share code and objectives, differing very little in use (Massart et al. 1988). The essence of each is the concept that the number of measured variables determines the dimensionality of a data set. If there are two variables measured, data can be plotted on an X-Y plot and relationships can easily be visualized. A 3-dimensional plot with X, Y, and Z axes can present data from three measurements. But, beyond three measurements, it rapidly becomes cumbersome to visualize data in plots.

It is possible to rotate the axes: instead of using the measurements to define the axes, we can take advantage of correlation among the variables and use different combinations of variables to force the axes into different positions. The axes remain orthogonal to each other but there are still as many 'new' axes as there were before. A special way of choosing which directions these new axes take is based on results from PCA: the first new axis is oriented in the direction of maximum spread in the data on the original measurement axes. Thus, a linear regression through the data points will result in a line that would become the first "eigenvector", the name often used to designate the new axis. After removing the effect of this first new direction (by projecting all points onto this line and looking at what is left), another regression is done to find the next new direction of maximum spread, forming the second eigenvector. This is repeated until a whole new set of axes is defined.

Because each step of the matrix decomposition finds the variance in the current matrix, each eigenvector has associated with it the amount of variance it describes. And, because each successive step has less variance to work with, the variance explained in the eigenvectors decreases monotonically. Depending on the data set, the amount of variance described in just the first few eigenvectors will rapidly approach 100%. Thus, a data set with many dimensions (for example, a data matrix measured on the 17 congeners is a 17-dimensional set) can be reduced to what is practically a redefined set of much reduced dimensionality, perhaps as little as 3 or 4 eigenvectors, and we can safely ignore the remaining directions which represent only a fraction of the total variance, say less than 1% or 0.1%.

Relationships among the samples do not change when axes are rotated. However, their positions on the new axes, referred to as scores, will be different. The relationships among the samples will usually become much more understandable by reducing the complexity of the data to just a few coordinates.

Unfortunately, the eigenvectors do not have physical meaning; they are abstract vectors derived only from variation in the data. Observation of the scores can help guide an interpretation such as that there may be groups of similar samples, or even that there are samples that are located in positions intermediate between others, implying that they might be mixtures. But, to do source apportionment, we need a tool to find those patterns that appear to underlie all of the mixed samples and have physical meaning.

Mixture analysis algorithms are designed to find those patterns. Although there are many different algorithms for doing mixture analysis, their objectives are similar: extract the patterns from which the sample mixtures are composed. The multivariate curve resolution-alternating least squares (ALS) approach used in this study may differ some from the mathematical approach used in other publications (Johnson et al. 2007), but results are comparable.

First, we assume that a matrix of data (whose dimension is number of samples down the rows by number of measurements across the columns) derived from a single material can be built by multiplying the vector (or list) containing the amounts of this material in the different samples by the vector that represents the pattern of measurements for that material. If there are two materials, then the data would be formed by multiplying a table of compositions (of size number of samples by the two columns of compositions of the two materials) by the table containing the two patterns (one row of numbers for each material). Data originating from more than two sources would come from similarly larger composition and profile tables.

The ALS algorithm (Tauler et al. 1993) works by trying to discover these two matrices of compositions and patterns. This can be restated as solving a single equation with two unknowns, which of course cannot be solved directly. Instead, one matrix, say that of the patterns, is estimated first and, using matrix algebra, an estimate is then derived for the other matrix, that of the compositions. This estimated matrix of compositions is then used to deduce a matrix of the patterns. If no other intervention was done, we would be back where we started.

To assure that we get closer to a meaningful solution, before the two estimation steps are repeated, constraints are applied to the newly estimated data. There are many forms the constraints can take, but the most common are to apply non-negativity to both matrices: we assume that the intensities in the measurements cannot be less than zero, and we also assume that the proportions of the two patterns that make up the compositions must also be zero or positive. By applying these constraints, the iterations through the steps of estimating first the patterns matrix and then the compositions matrix will eventually converge to a solution where the patterns and compositions are meaningful.

3. DATA DESCRIPTION AND SETUP

Data were submitted to Infometrix in the form of an Excel spreadsheet that collected results from several studies that had been performed on Port Angeles Harbor sediments over the past years. Data sources included:

Table 1. Sources of data analyses for the study

Study	Study ID	Surface Samples	Subsurface Samples
E & E 2012	PASED08	83	58
NPS 2010	NPI_PA_002_2010	2	0
Exponent 2008	PORT ANGLELES DNR08	17	4
Malcolm Pirnie 2007a	RAYONR05	45	7
Malcolm Pirnie 2007a, Appendix P	LEKT_RAYONR05	4	0
Malcolm Pirnie 2007b	PAMILLRI	53	0
Foster Wheeler 2001	LOG_POND_2001	5	1
Total		209	70

The main focus of the chemometric studies is the collection of 2,3,7,8-chlorinated congeners of dioxins and furans (17 compounds). Dioxin/furan measurements are available for all 279 samples listed above.

However, other chemical compounds were included in the data set as supporting information, including:

- Total Homologs (8 values)
- Metals (9)
- Polynuclear Aromatic Hydrocarbons (PAHs) (18)

Unfortunately, because the data originated from many different surveys, not all compounds were measured in every study (see Table 2). Therefore, when considering combinations of different classes of chemical compounds, smaller subsets must be used.

Table 2. Metal and PAH compounds; number of locations with data

Compound	No.	Compound	No.
Arsenic	204	2-Methylnaphthalene	201
Cadmium	207	Acenaphthene	201
Chromium	168	Acenaphthylene	201
Copper	195	Anthracene	201
Lead	179	Benz[a]anthracene	201
Mercury	195	Benzo(a)pyrene	201
Nickel	139	Benzo(b)fluoranthene	201
Silver	168	Benzo(ghi)perylene	201
Zinc	207	Benzo(k)fluoranthene	201
		Chrysene	201
		Dibenzo(a,h)anthracene	201
		Dibenzofuran	187
		Fluoranthene	201
		Fluorene	201
		Indeno(1,2,3-cd)pyrene	201

Compound	No.	Compound	No.
		Naphthalene	201
		Phenanthrene	201
		Pyrene	201

Finally, other physical and chemical parameters of the samples were included in the spreadsheet:

- Latitude and longitude (NAD83HARN)
- Upper and lower depth (cm) from which the sample was obtained
- Particle/Grain Size, Fines (%) and Total Organic Carbon (%)
- TEQs (ng/Kg)

To facilitate quick visualization of the data source and location when preparing data plots, the origin of every sample was coded by study and category/location within each study. The list of these studies is tabulated in Table 3.

Table 3. Sample source categories (as Region ID)

Study	Sample group prefix	Region ID
PASED08	BL	1
PASED08	CO	2
PASED08	DO	3
PASED08	EC	4
PASED08	ED	5
PASED08	EE	6
PASED08	EI	7
PAMILLRI	EP	8
PASED08	FT	9
LOG_POND_2001	FW	10
RAYONR05	HS	11
PASED08	IE	12
PASED08	IH	13
RAYONR05	IT	14
PASED08	KP	15
PASED08	LA	16
PASED08, PAMILLRI, RAYONR05	LP	17
RAYONR05	MA	18
PASED08, PAMILLRI, RAYONR05	MD	19
PORT ANGELES DNR08	NP	20
RAYONR05	OF	21
PASED08	OH	22
PASED08	RL	23
PAMILLRI	WP	24
PASED08	WW	25

The order of presentation of the 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 4. Also included in this table are the Toxic Equivalency Factors (TEF; see Glossary) used for scaling the data prior to chemometric analysis.

Table 4. Congener names and toxic equivalency factors

Index	Congener	TEF
1	2,3,7,8-TCDD	1
2	1,2,3,7,8-PECDD	1
3	1,2,3,4,7,8-HXCDD	0.1
4	1,2,3,6,7,8-HXCDD	0.1
5	1,2,3,7,8,9-HXCDD	0.1
6	1,2,3,4,6,7,8-HPCDD	0.01
7	OCDD	0.0003
8	2,3,7,8-TCDF	0.1
9	1,2,3,7,8-PECDF	0.03
10	2,3,4,7,8-PECDF	0.3
11	1,2,3,4,7,8-HXCDF	0.1
12	1,2,3,6,7,8-HXCDF	0.1
13	1,2,3,7,8,9-HXCDF	0.1
14	2,3,4,6,7,8-HXCDF	0.1
15	1,2,3,4,6,7,8-HPCDF	0.01
16	1,2,3,4,7,8,9-HPCDF	0.01
17	OCDF	0.0003

Data preparation for the dioxin/furan measures included the following steps.

- Variable sorting – dioxins (see Table 4) and homologs (ordered by increasing chlorination)
- Sample sorting – by Study location, by Upper depth, Lower depth
- Censoring – create fields for
    - Count of number of NDs on dioxins
    - Count of number of NDs on metals
- Replace all ND values (stored as negative numbers) with ND = 0.5 of MDL
- Add _d suffix to duplicate Study Location names

After data preparation was complete, the resulting spreadsheet was imported into the Pirouette software (Infometrix, Bothell, WA) for subsequent chemometrics analysis. The Region ID variable was made into a categorical variable as was a variable holding the non-detect counts. Latitude and longitude, upper and lower depth, and TOC and TEQ columns were made into dependent variables. Colors were assigned to the category values such that any sample-oriented plots could be evaluated on the basis of sample location/study. In Table 8 (see Appendix), a summary of this information is presented for the 279 samples in the study.

For the primary analyses, only the 17 dioxin and furan congeners were retained as the block of independent variables. Exploratory analyses of the metals and of the PAHs were performed separately. Finally, the metals data were combined with the dioxins data for a secondary analysis (data not shown).

4. DATA ANALYSIS

The samples provided for this study of Port Angeles harbor sediments represent a wide range of TEQ, from values less than 0.5 ppt in the outer harbor to values exceeding 40 ppt, and as high as 120 ppt, in the vicinity of major wood processing facilities in the east and west ends of the harbor. The map in Figure 1 illustrates this range.

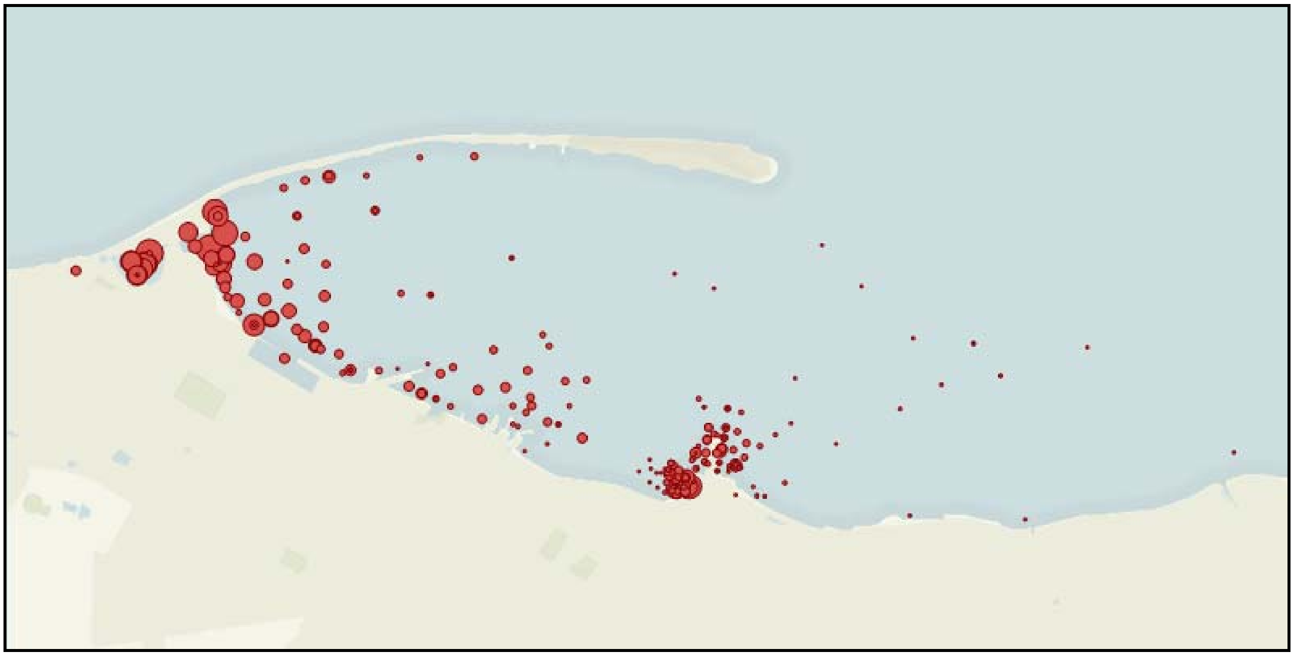


Figure 1. TEQ values in samples from Port Angeles harbor; point size proportional to TEQ

Samples with highest TEQ values are located nearest the Rayonier facility on the south edge of the harbor, the Nippon facility at the western bight inside the spit, and in the lagoon inland from the Nippon site. In addition, several locations along the harbor shoreline between these two facilities show TEQs which are of moderate intensity. Samples nearer the harbor mouth exhibit the lowest TEQs. Based on this evidence it can be assumed that dioxins in the harbor are not uniformly distributed, rather they are highest in areas of likely contamination and decrease in magnitude with distance from these potential sources.

4.1. DATA PRETREATMENTS

Preliminary evaluation of the appropriateness of the data was conducted by examining line plots and by principal component analysis (PCA). These steps often allow identification of unusual or aberrant samples that should be excluded from processing; retaining outlier samples can influence subsequent interpretation.

For example, the bulk congener data can be shown (see Figure 2) as a line plot. This graphic shows the dioxin/furan data without any scaling of the response values. Each trace in this figure presents one sample plotted as a function of congener.

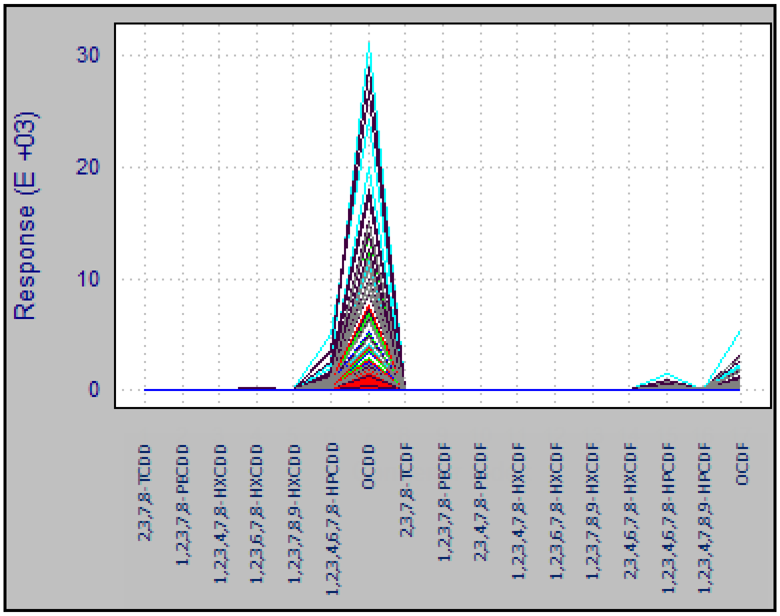


Figure 2. Bulk congener profiles of all study samples; traces colored by Region ID (see Table 3)

Plotted in this way, it is clear that the overwhelming contribution to overall intensity comes from the octa-chloro dioxin congener, while the lesser-chlorinated dioxins and furans contribute relatively little intensity. In a multivariate analysis, it is desirable that most variables be allowed to “participate” in the analysis, thus, it is customary to scale the different variables such that they are all roughly in the same order of magnitude. As discussed in the background section (see Multivariate Approach), there are different approaches to accomplish variable scaling. For this study, two approaches were applied to investigate whether conclusions would differ: scaling by the TEF and scaling by the standard deviation (also called variance scaling).

In Figure 3, the data from Figure 2 have been scaled by the TEFs. There remains variation in magnitude for the different congeners but patterns are easily discernible and the intensities are more directly correlated to risk assessment.

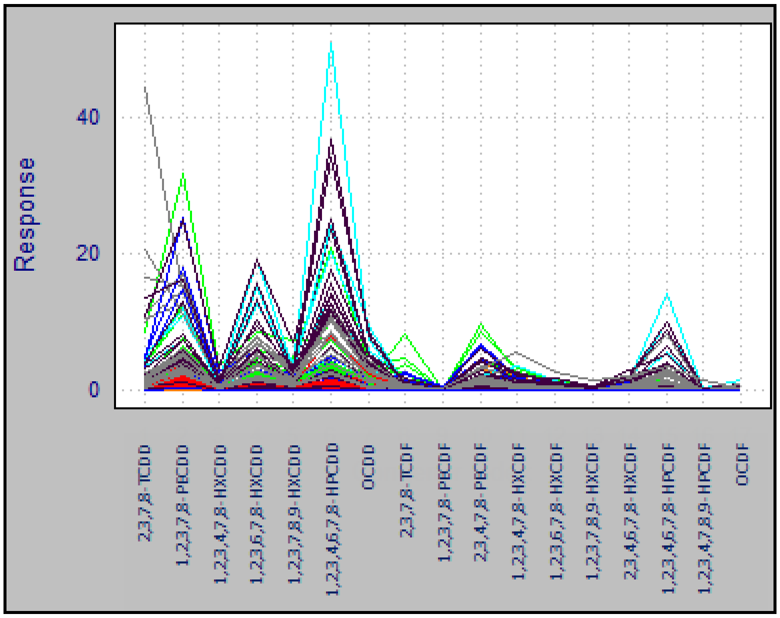


Figure 3. TEF-scaled profiles of all study samples; traces colored by Region ID (see Table 3)

In Figure 4, each variable was scaled by the standard deviation across the set of samples. This form of scaling results in a variance of 1 for each variable but runs the risk of inflating noisy variables to the same importance of other variables.

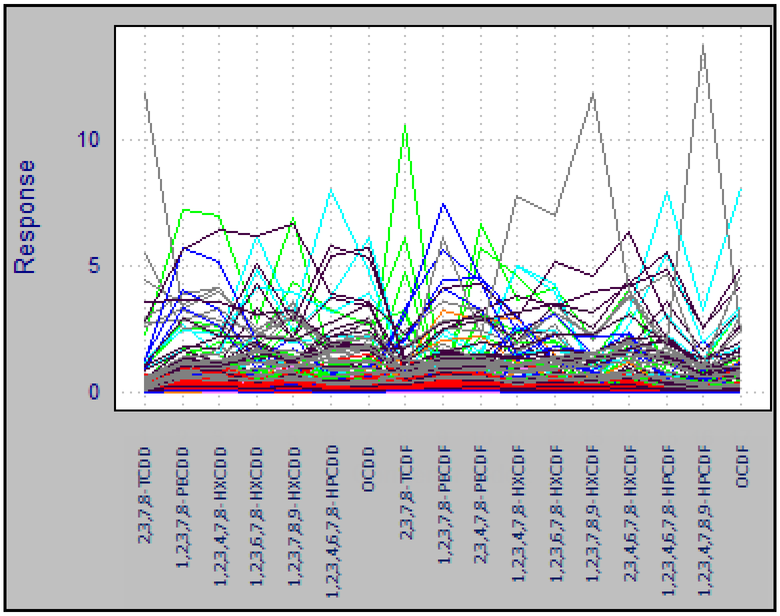


Figure 4. Variance-scaled profiles of study samples; traces colored by Region ID (see Table 3)

It is customary to further normalize the data to account for different sample sizes such that variation in absolute concentration is minimized. Although various methods of normalization are used in the multivariate field, area % normalization is typical for chromatography data and was used in this study. For example, Figure 5 shows area % normalized TEQ data.

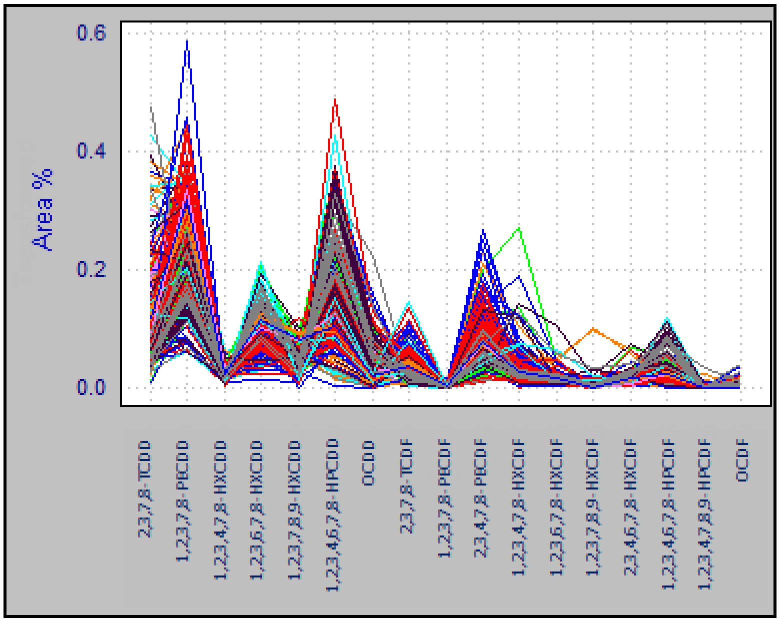


Figure 5. Normalized TEF-scaled profiles; traces colored by Region ID (see Table 3)

And Figure 6 shows the equivalent normalized profiles for variance-scaled data.

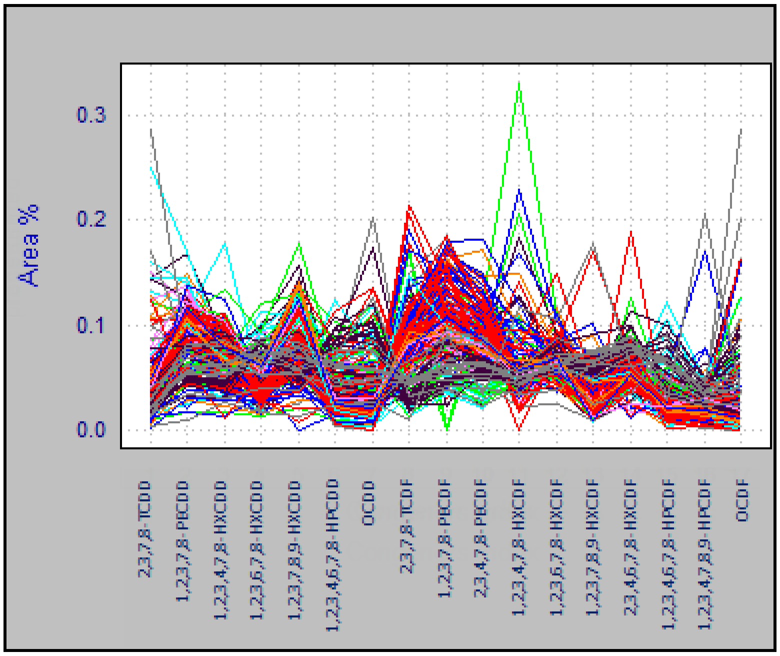


Figure 6. Normalized variance-scaled profiles; traces colored by Region ID (see Table 3)

Before any processing was done, data were censored to exclude those samples for which there were too many non-detect (ND) congener measurements. Excluding non-detects should not be done lightly as this can create an upward bias in statistics based on the included data (Helsel, 2012). On the other hand, substituting a value for the non-detect can also lead to biases, and this fabrication of data may lead to misleading conclusions about structure in the data. For this study, a middle ground was sought: exclude samples for which a large number of non-detects were present while for samples that were included, substitute the non-detect values with half the detection limit.

Of the 279 study samples for which 17 congeners were measured, there were a total of 597 non-detect values, approximately 13%. However, these non-detects were not uniformly distributed; for example, the two congeners for which non-detects were the highest included 1,2,3,7,8,9-HxCDF (127 samples; 46%) and 1,2,3,4,7,8,9-HpCDF (72 samples; 26%). Nine congeners exceeded 10% non-detects. The distribution of non-detects is shown in Figure 7.

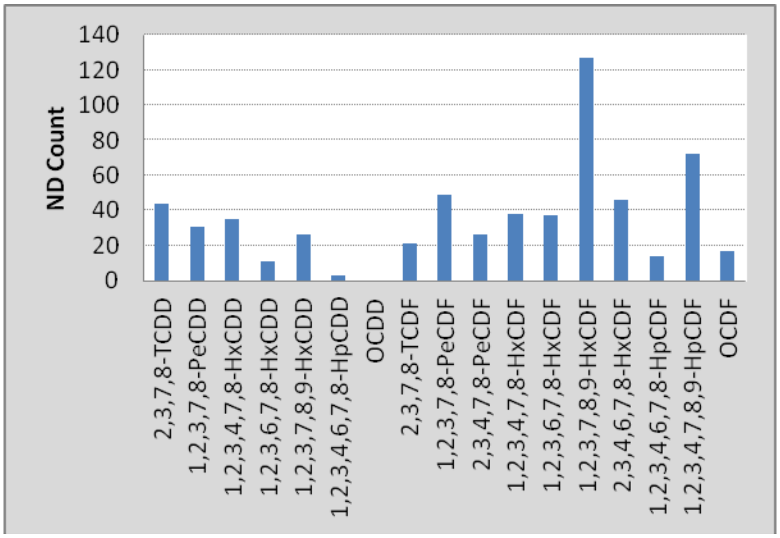


Figure 7. Distribution of non-detects across congeners

The frequency of non-detects within samples is skewed in an expected way, as shown in Figure 8. The frequency curve flattens after about 4 non-detects. Using this as a threshold, that is, excluding samples for which more than 4 congeners were non-detects, 234 samples (84%) were retained. Of the 45 samples excluded in this manner, none had a TEQ over 8 and most were below 2 ppt.

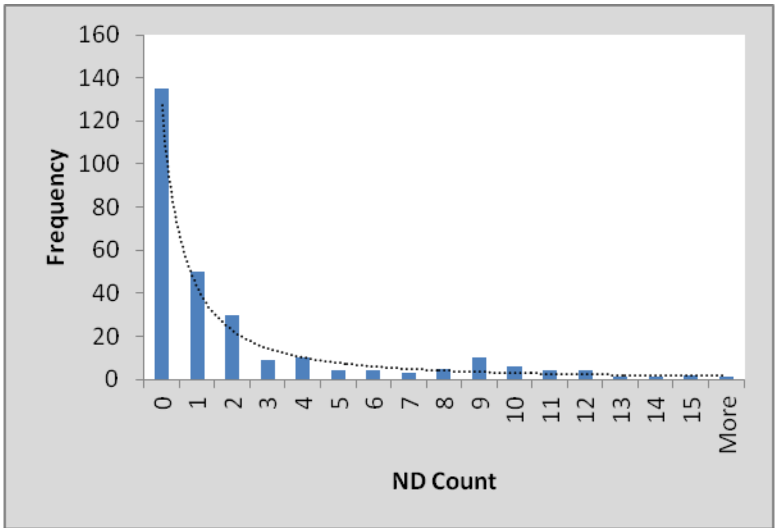


Figure 8. Frequency of non-detects in study samples

After excluding samples, the distribution of non-detects in the remaining included samples is more uniform. The highest number of remaining non-detects was 45 (19%), as shown in Figure 9.

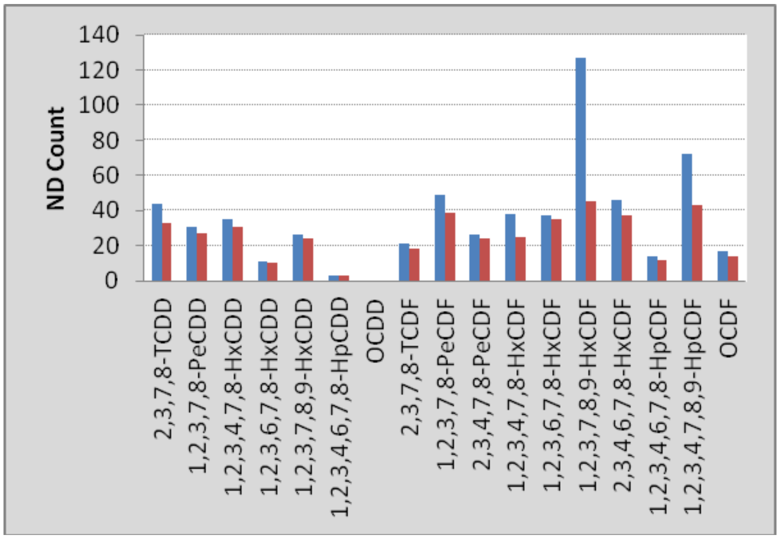


Figure 9. Distribution of non-detects across congeners before (blue) and after (red) exclusions

4.2. PCA ANALYSIS OF DIOXINS/FURANS

After censoring and pre-treating, data were processed by Principal Component Analysis (PCA). This algorithm re-orients the measurement domain into abstract factors. These factors, which are mutually orthogonal, are ranked by how much of information from the input data is described; each subsequent factor describes less information than the previous factor. Each factor (sometimes called eigenvector) has contributions from each measured variable; these contributions vary in each factor.

The sample coordinates are similarly transformed to coefficients on the factors. These coefficients are called scores, and the scores are often reviewed for trends and groupings among samples.

The normalized, TEF-scaled data from Figure 5 were processed with PCA, and the resulting scores (Factors 1-3) are shown in Figure 10. Cross-validation was used during the processing (Eastment, 1982). The prediction residual error sum of squares (of cross-validation, PRESS) can be used to help understand how many underlying components may be present in the data set and is also shown in Figure 10.

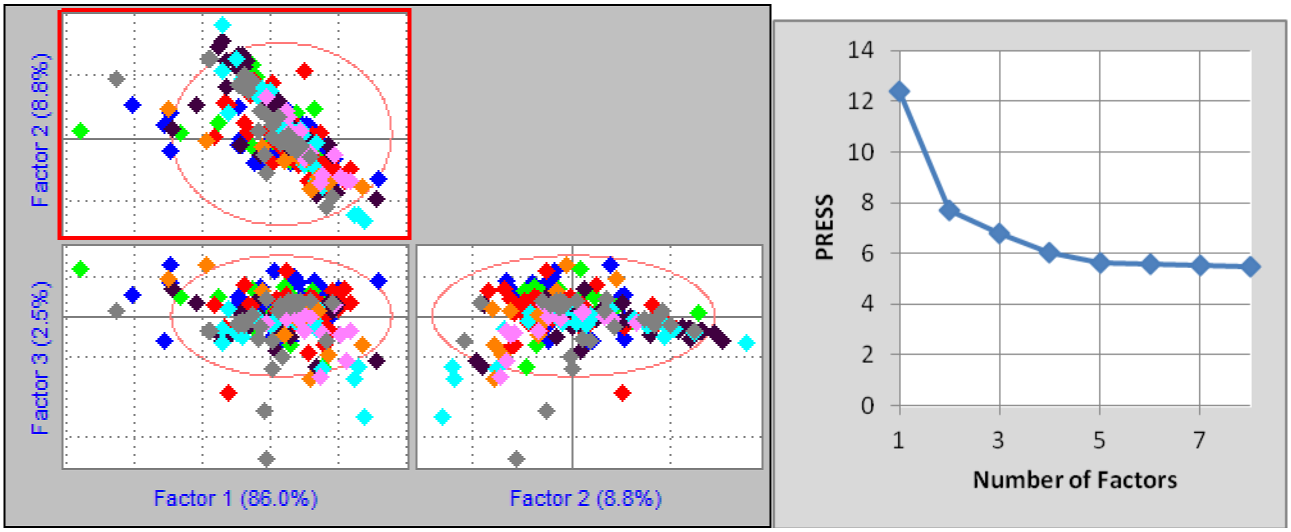


Figure 10. PCA scores and PRESS of TEF-scaled data; points colored by Region ID (see Table 3)

Thus, a reasonable representation of this data can be found between 4 and 6 factors (where the curve flattens). In the views of scores in the first 3 factor directions, which represents more than 97% of the information in this data set, most of the samples are congregated along a line defined in the space of Factor 1 vs. Factor 2, with a few samples extending beyond the ellipse of the 95% confidence limit.

In addition, the normalized, variance-scaled data (Figure 6) were also processed with PCA; the corresponding scores are shown in Figure 11. The cross-validation PRESS values for this computation is also shown in this figure.

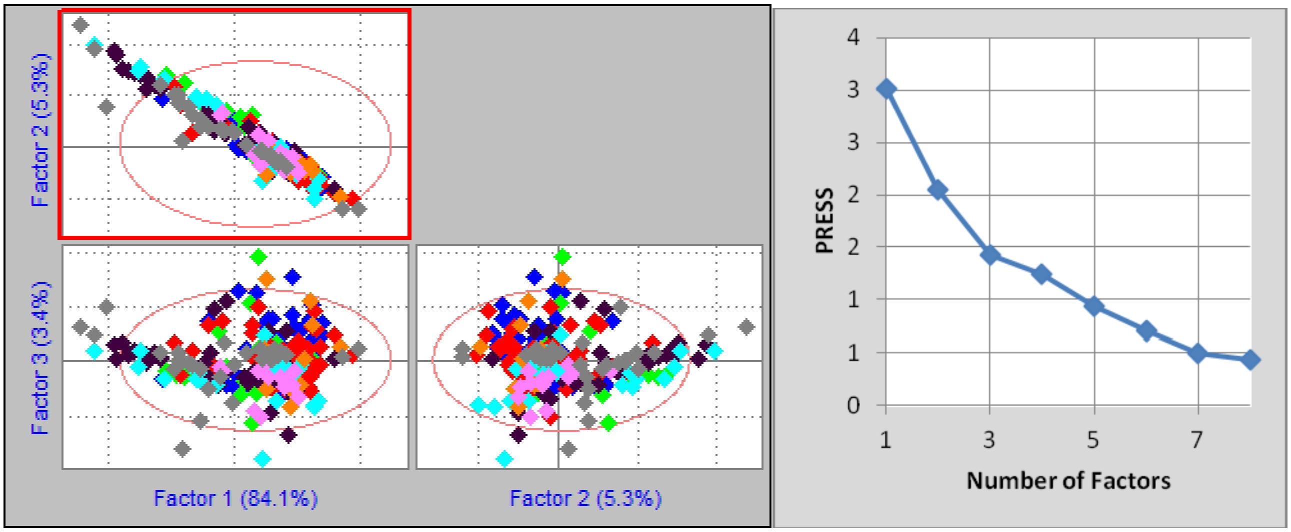


Figure 11. PCA scores and PRESS of variance-scaled data; points colored by Region ID (see Table 3)

In this case, the number of factors required to adequately describe the data is not as clear-cut. There is a partial leveling of the curve between 3 and 4 factors, but another leveling occurs at 7 factors. Although a strong linear trend in the Factor 1 vs Factor 2 plot is exhibited, additional factors spread the data into other groups. Mixture analysis (below) will help to understand the nature of these groups.

4.3. MIXTURE ANALYSIS OF DIOXINS/FURANS - TEF-SCALED DATA

Next, a mixture analysis was run with the MCR-ALS algorithm, in which up to 8 possible sources were considered. Based on the non-random structure in the first six PCA factors and on the quality of fit diagnostic for the ALS results, it was decided that 6 sources would be a good estimate (see Figure 12).

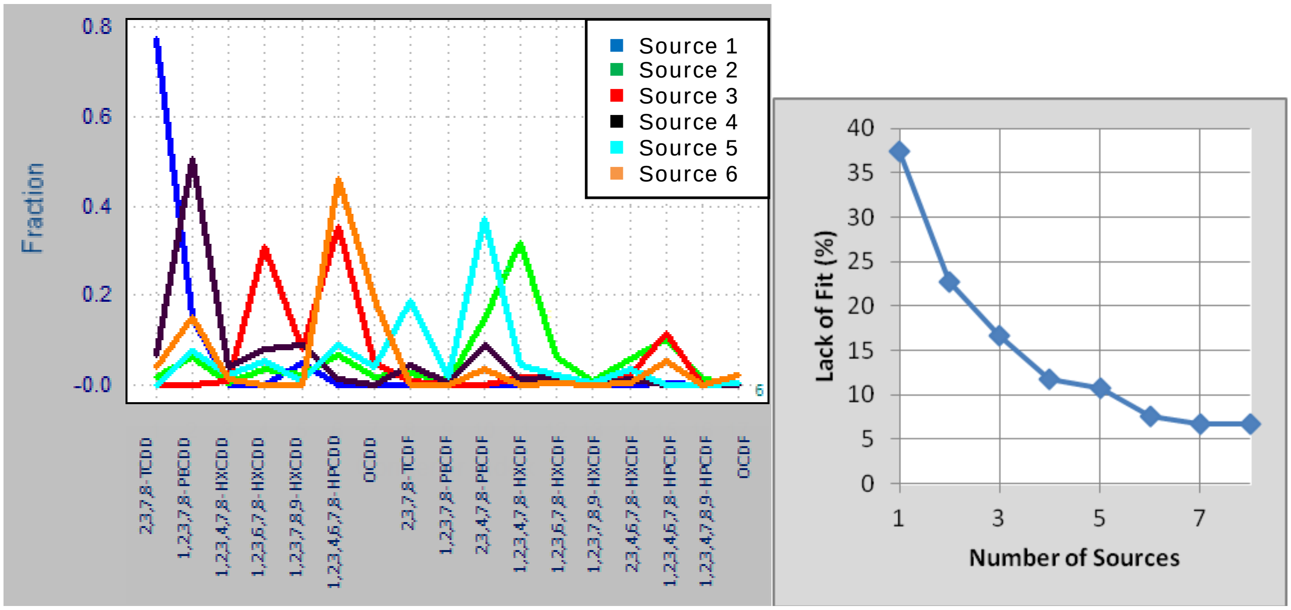


Figure 12. Source profiles and lack of fit metric determined by ALS; TEF-scaled data

The patterns of dioxins in these source profiles are estimates of the patterns of materials that may have been deposited in the harbor sediments. Tabular values for these six source profiles are shown in the Appendix as Table 9.

However, in such a mixed environment, it is likely that every sample location has some contribution from most, if not all, of these underlying source materials. In Figure 13, the relative contributions from each source are displayed graphically. The portions that the source profiles contribute to each sample are shown as source amounts, in Table 10.

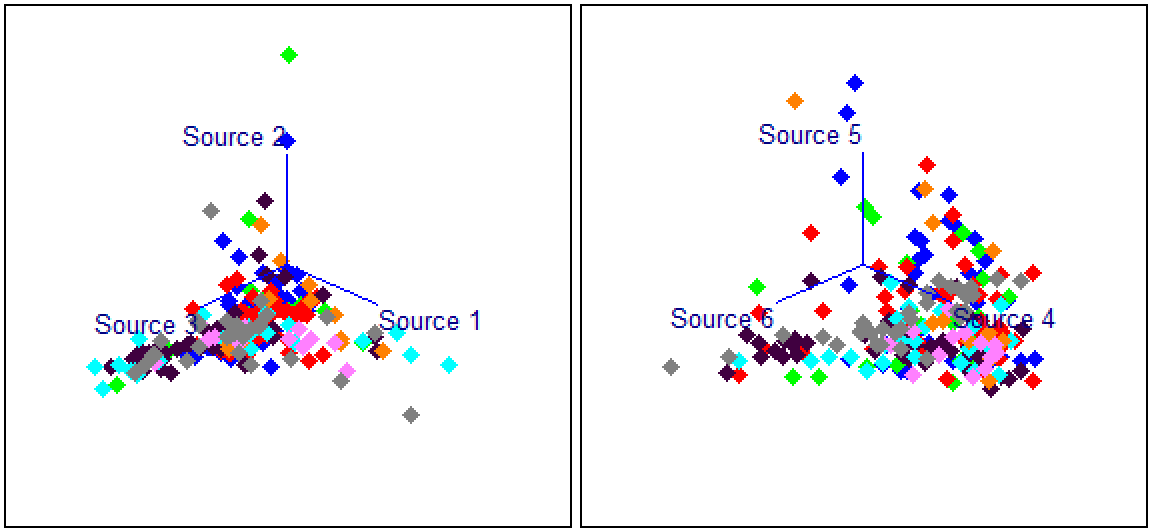


Figure 13. Contributions to samples from sources 1-3 and sources 4-6; TEF-scaled data; points colored by Region ID (see Table 3)

From these plots, it appears that major contributions to most of the sample locations come from sources 3 and 4, with somewhat lesser contributions from sources 1 and 6. Sources 2 and 5 seem to contribute to the fewest samples.

Two of the six sources appear to be related to dioxins that originate from pentachlorophenol and two others appear related to patterns that are similar to those from degradation of PCBs (see later in Discussion). Thus, it was considered interesting to restrict the number of sources from the ALS algorithm to only 4. When this is done, the residual profiles, which show features not contained in the ALS model, indicate that only a few samples are not completely modeled. In particular, in Figure 14, three samples show more deviation than other samples and are highlighted in the plot with thicker lines.

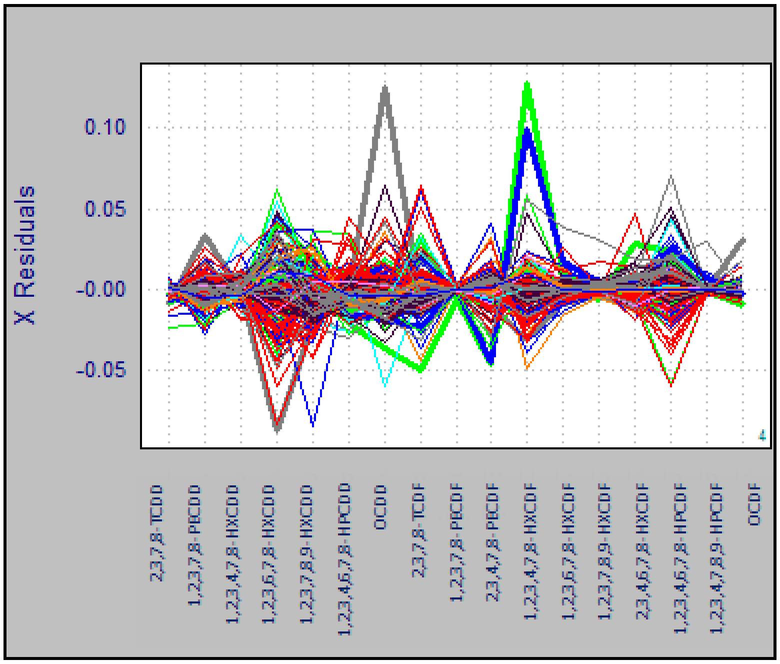


Figure 14. Residuals from 4-source ALS model; TEF-scaled data; traces colored by Region ID (see Table 3)

By making a model with more sources, these residuals would diminish. On the other hand, it is these samples that largely drive the 6-source ALS model. In fact, observing the normalized profiles of Figure 5 again, where the traces for these 3 samples are highlighted (Figure 15),

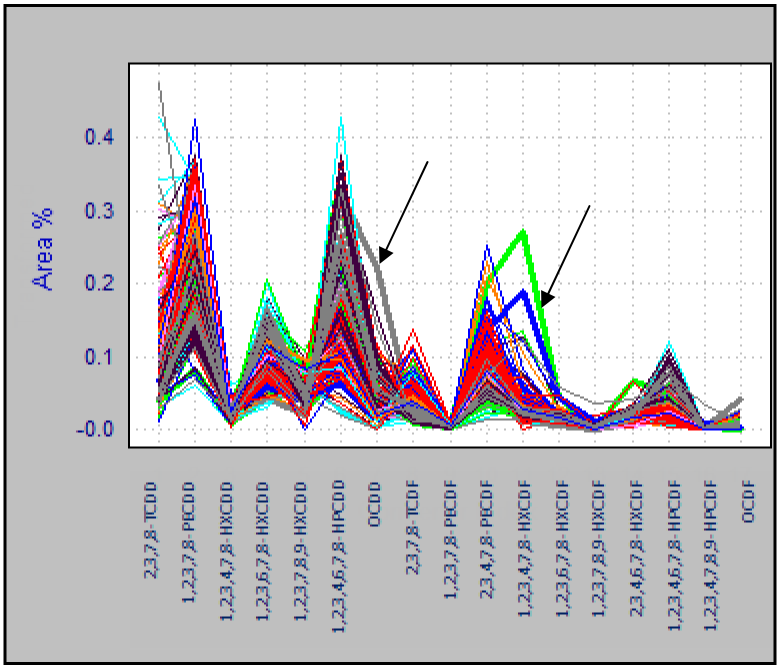


Figure 15. Normalized TEF-scaled profiles with 3 samples highlighted (marked with arrows); traces colored by Region ID (see Table 3)

we can see that:

- the extra intensity in the highlighted gray trace of Figure 15 occurs in the OCDD congener and is represented by Source 6 of Figure 12
- the extra intensity in the highlighted blue and green traces occurs in the 1,2,3,4,7,8-HxCDF congener and is represented by Source 2 of Figure 12

With only three outlier samples, it is not clear if they represent true sources that need to be incorporated into the evaluation or if they represent inconsistencies in either the sampling or in the instrumental analysis. The fact that two of the samples show much the same pattern (in particular the relatively high 1,2,3,4,7,8 HXCDF content) implies that these samples cannot be completely dismissed from consideration. It is instructive, however, to look at a 4-source model and compare results.

When a 4-source mixture analysis is computed (see Figure 16), sources 1 and 4 change only a little from their shapes in the 6-source model (recall Figure 12).

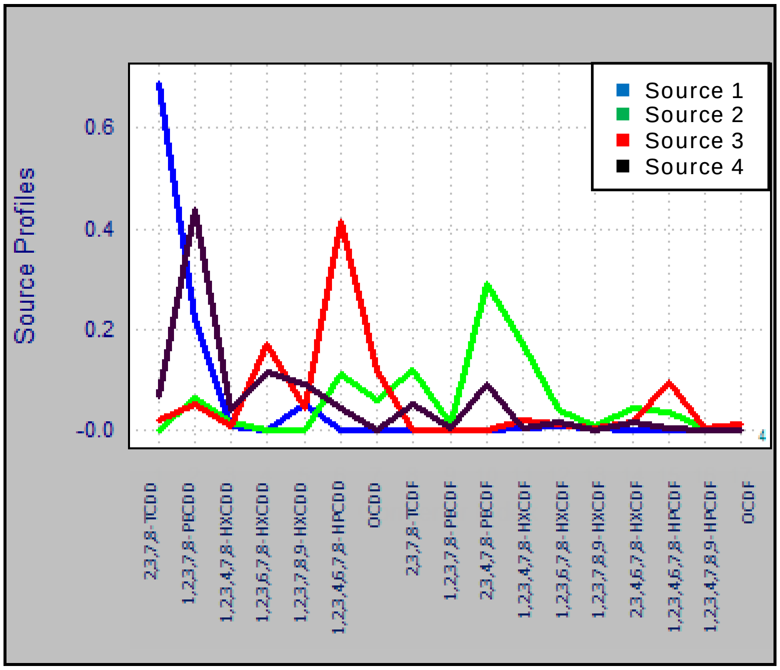


Figure 16. Source profiles from a 4-source ALS model; TEF-scaled data

In addition, Source 2 in the 4-source model appears to be a composite of sources 2 and 5 in the 6-source model, and Source 3 in the 4-source model appears to be a composite of sources 3 and 6 in the 6-source model.

The contributions from each source to the samples are shown in Figure 17. The major contributions derive from sources 3 and 4, as shown by the greater cluster of points in the upper end of their axes.

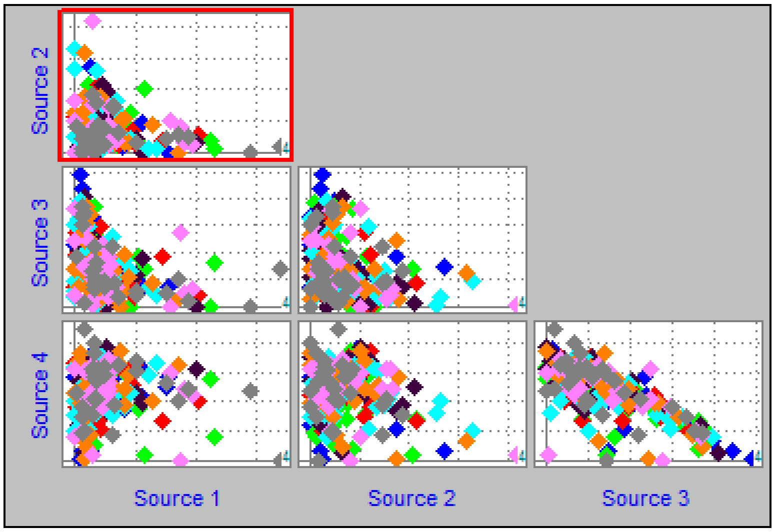


Figure 17. Source amounts from a 4-source model; TEF-scaled data; points colored by Region ID (see Table 3)

Tabular values for these four source profiles are shown in the Appendix as Table 11, and the portions that the source profiles contribute to each sample are shown as source amounts, in Table 12.

Mixture analysis of normalized TEF-scaled dioxin congeners performed with the MCR-ALS algorithm indicated a 6-source model, with the patterns of those six sources shown in Figure 12. Although these sources seem to contribute to the sample composition at every location, their relative contributions vary among the samples and, to some extent, by geography.

The pattern suggested for Source 1 is dominated by the 2,3,7,8-TCDD congener, as shown in Figure 18.

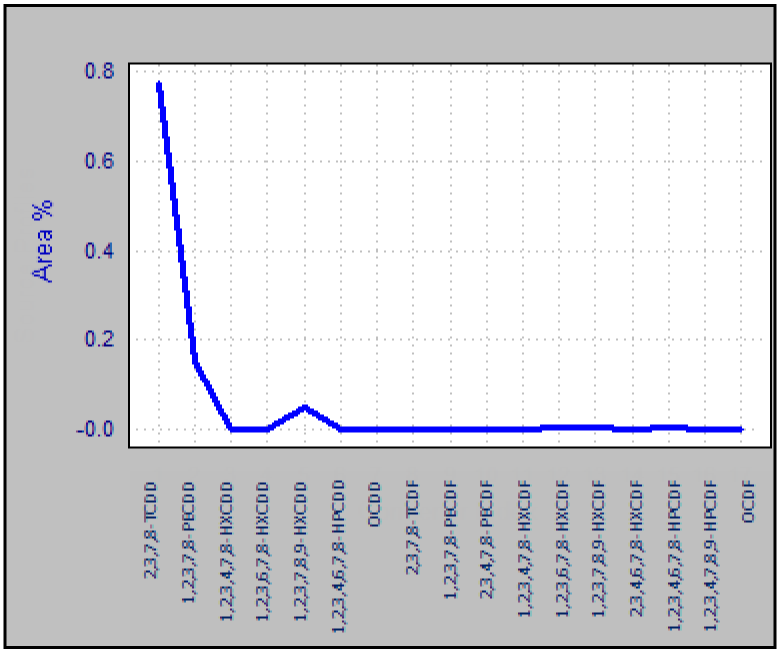
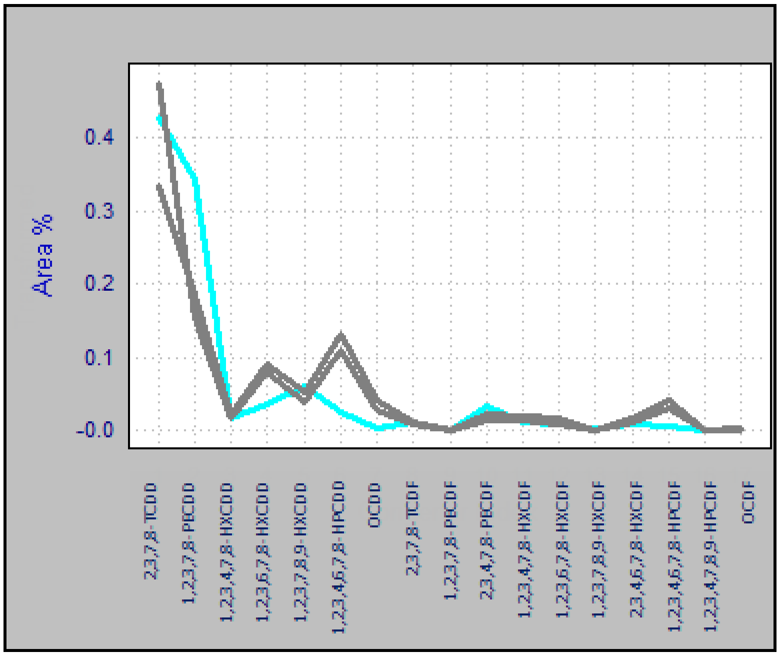


Figure 18. Source 1 pattern derived from mixture analysis, 6-source model

Only a few samples exhibited a pattern like that of Source 1; even those samples (see Figure 19) show contributions from other sources as well.



Sample IDs for the traces in this figure:

Index	**Location**
40	ED01C
138	LA01A
144	LA03A

Figure 19. Sample profiles most similar to Source 1

The pattern in Source 2 (see Figure 20) is dominated by 1,2,3,4,7,8-HxCDF, and to a lesser extent 2,3,4,7,8-PeCDF, with other furans also important.

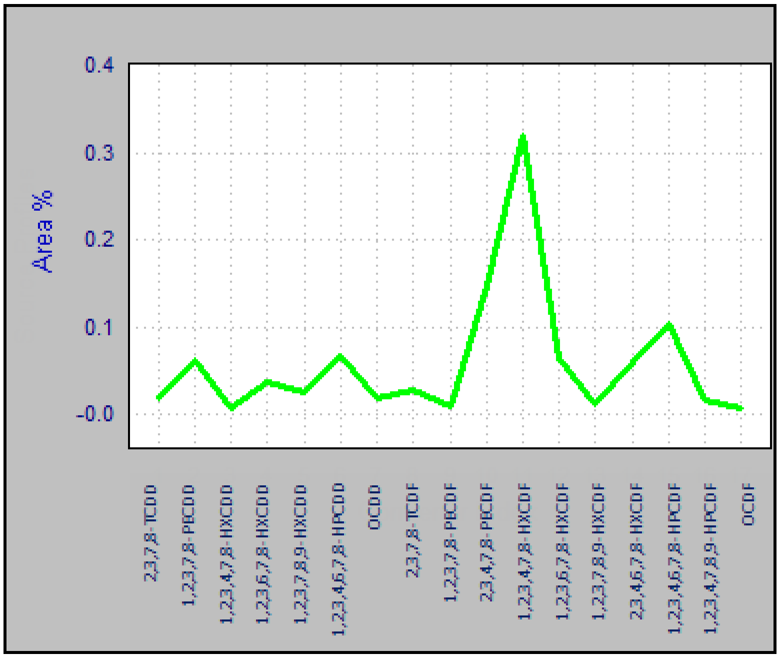
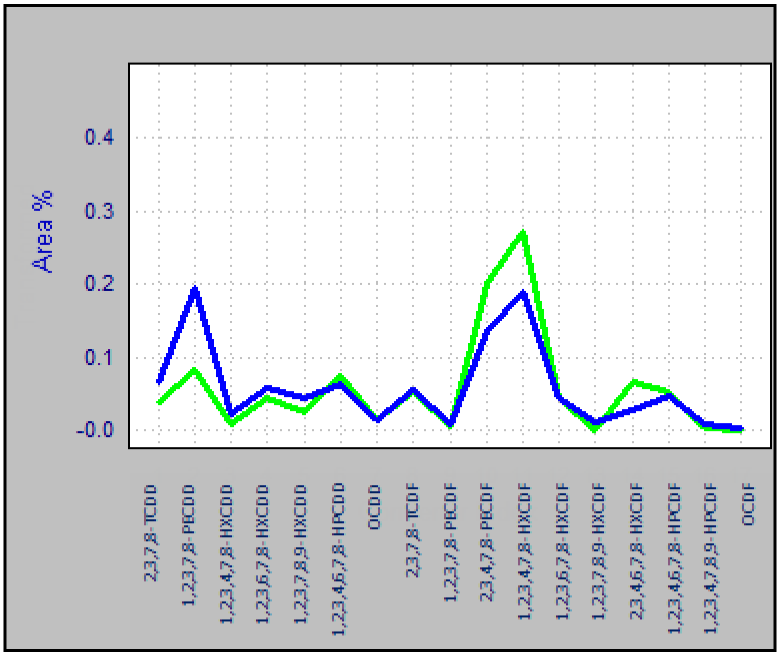


Figure 20. Source 2 pattern derived from mixture analysis, 6-source model

A few sample profiles show a pattern in which this congener is primary, for example, those in Figure 21.



Sample IDs for the traces in this figure:

Index	Location
15	CO03B
181	LP-16

Figure 21. Sample profiles most similar to Source 2

The pattern in Source 3 (see Figure 22) is dominated by 1,2,3,6,7,8-HXCDD, 1,2,3,4,6,7,8-HPCDD and 1,2,3,4,6,7,8-HPCDF.

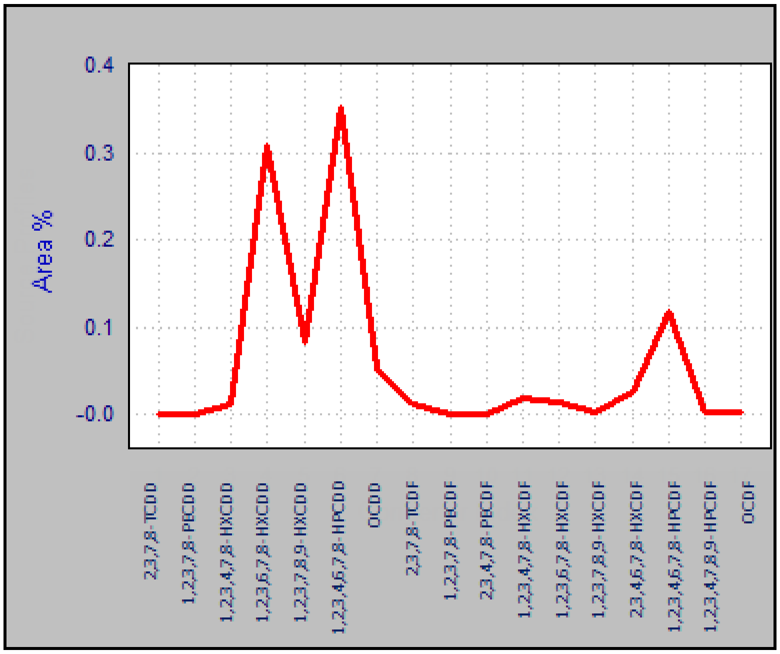
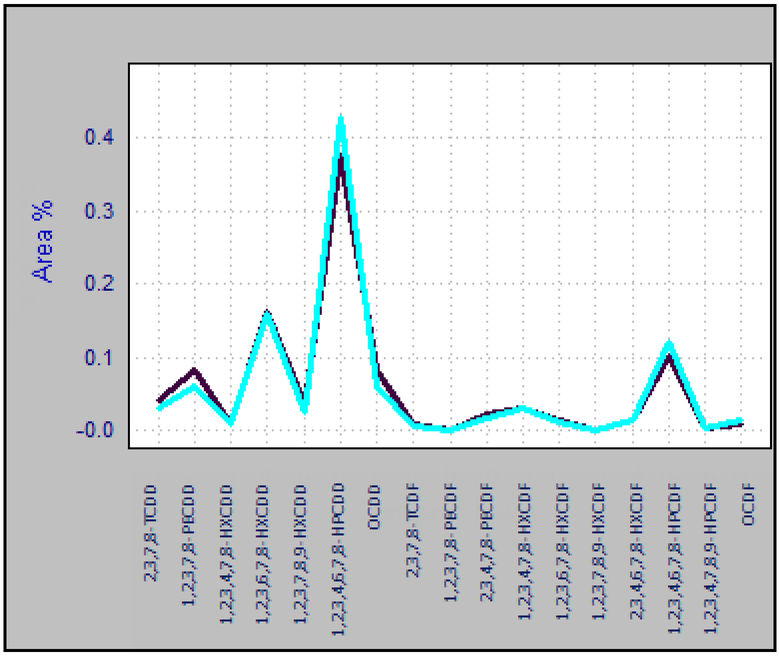


Figure 22. Source 3 pattern derived from mixture analysis, 6-source model

Many sample profiles show a pattern in which this source is primary; two are shown in Figure 23.



Sample IDs for the traces in this figure:

Index	Location
95	IE09A
113	IH01A

Figure 23. Sample profiles most similar to Source 3

The pattern for Source 4 (see Figure 24) is predominantly composed of 1,2,3,7,8-PECDD with minor intensity in the other chlorinated dioxins.

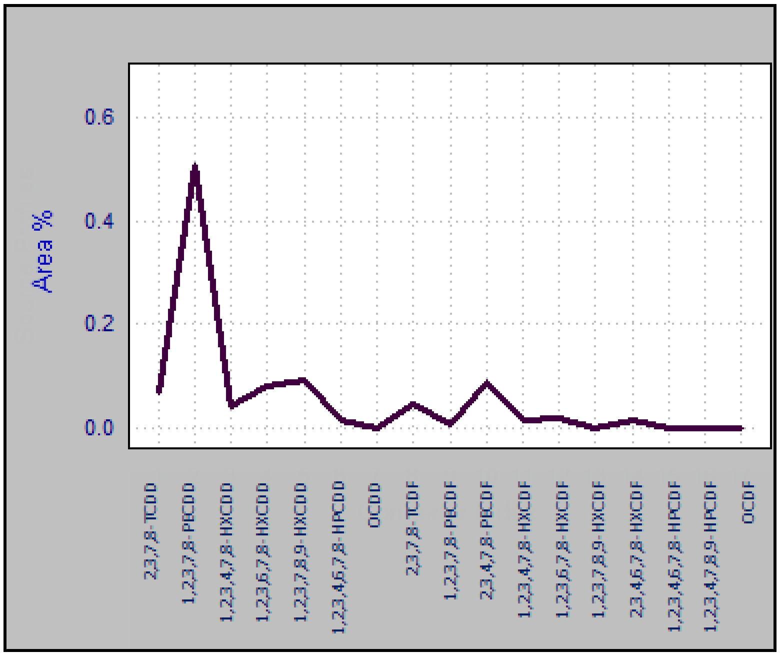
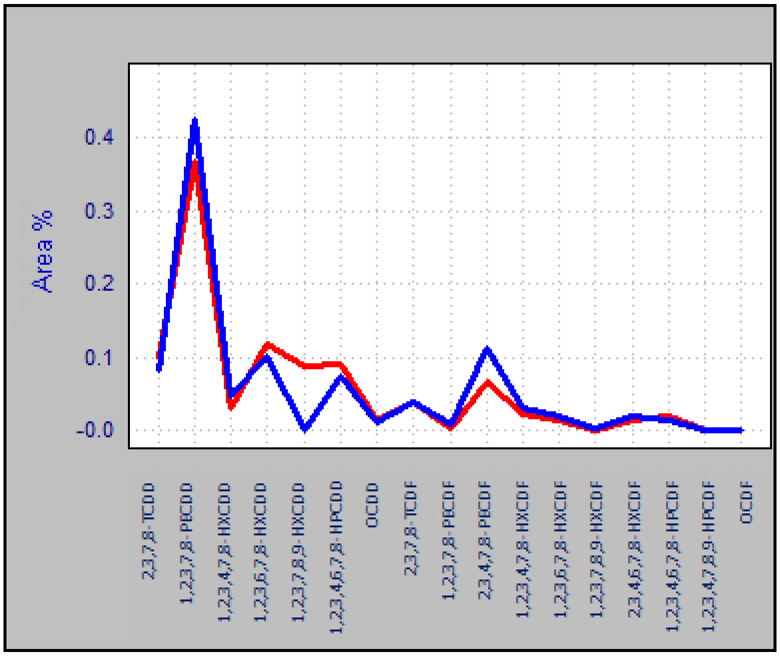


Figure 24. Source 4 pattern derived from mixture analysis, 6-source model

Many sample profiles show a pattern which resemble Source 4, for example, those in Figure 25



Sample IDs for the traces in this figure:

Index	Location
24	DO04B
160	LP-06

Figure 25. Sample profiles most similar to Source 4

The pattern for Source 5 (see Figure 26) has more of a furan nature, with two congeners dominant, 2,3,4,7,8-PECDF and 2,3,7,8-TCDF.

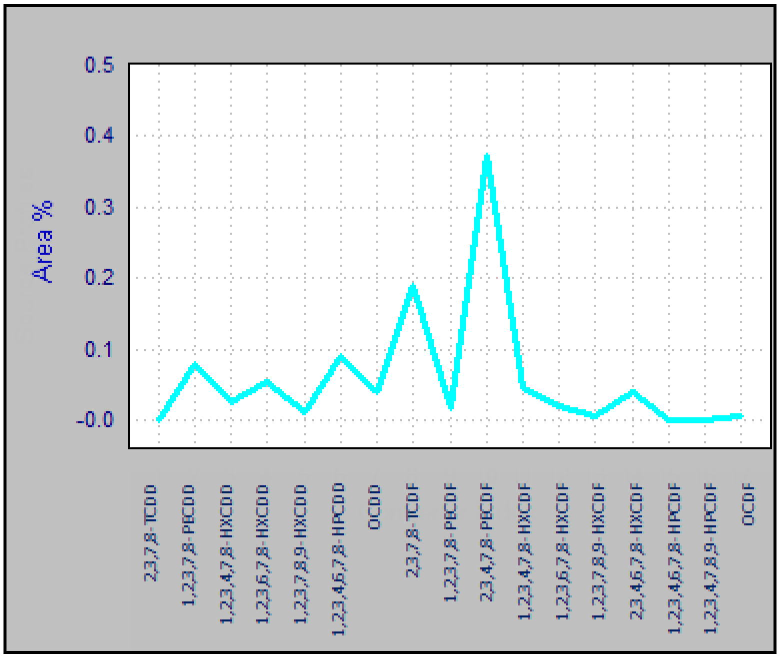
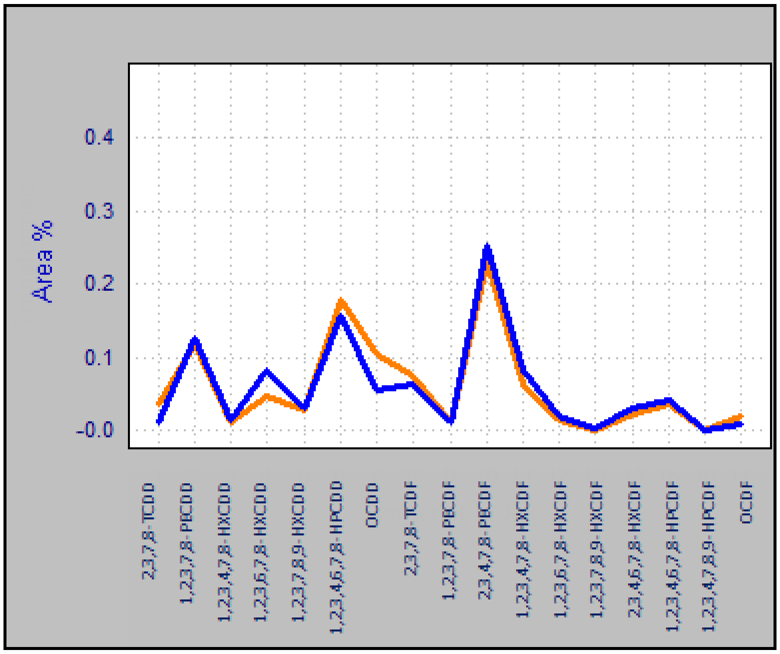


Figure 26. Source 5 pattern derived from mixture analysis, 6-source model

Only a few samples show a pattern which has features of Source 4, however, and even the best matches, for example, those in Figure 27, show contributions from other sources.



Sample IDs for the traces in this figure:

Index	Location
126	IT-07
189	LP-20

Figure 27. Sample profiles most similar to Source 5

The Source 6 pattern (see Figure 28) is dominated by 1,2,3,4,6,7,8-HPCDD with a smaller feature at 1,2,3,7,8-PECDD.

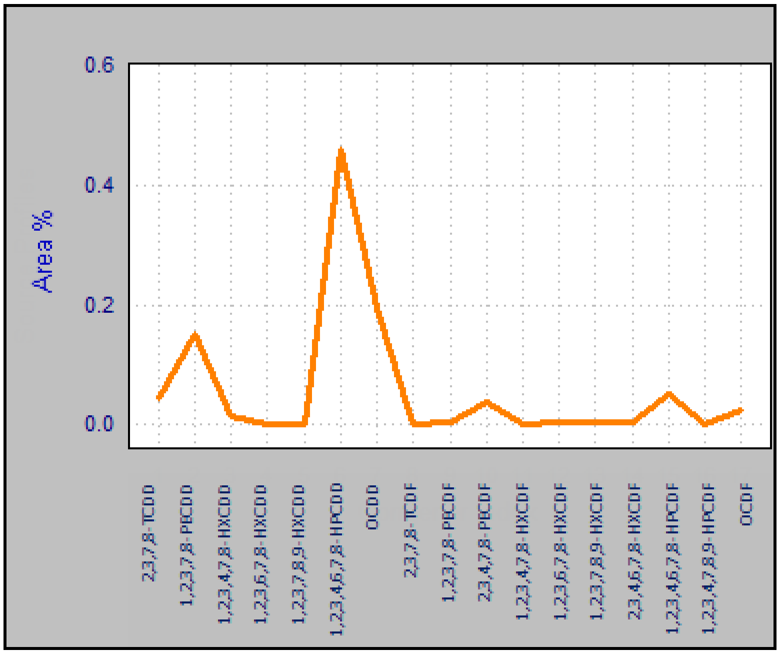
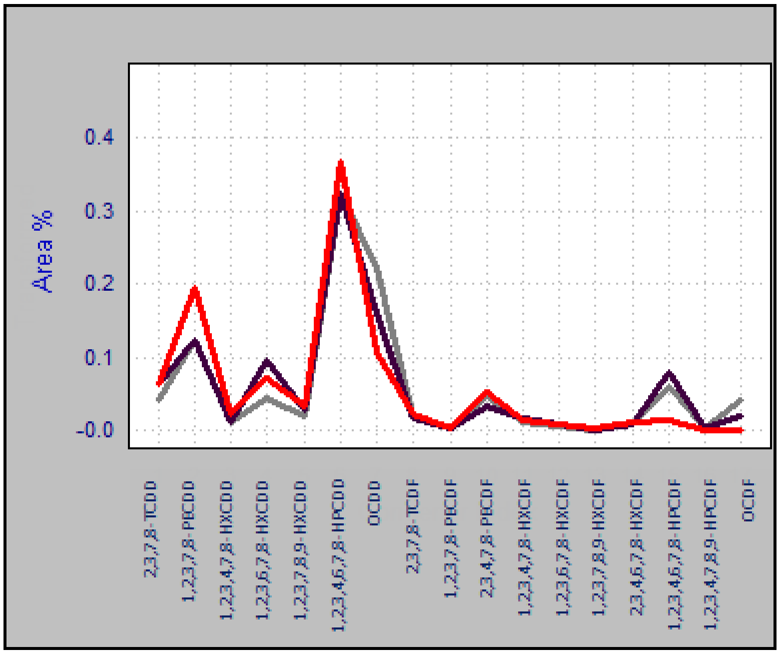


Figure 28. Source 6 pattern derived from mixture analysis, 6-source model

Many samples share a pattern showing the features of Source 6; a few of these are shown in Figure 29.



Sample IDs for the traces in this figure:

Index	**Location**
74	EP-09-SD
106	IE09B
234	MD-18-SD

Figure 29. Sample profiles most similar to Source 6

When the mixture analysis is done with only 4 sources for the model, the dioxin patterns change only for some of the sources, as mentioned earlier. However, sources 3 and 4 continue to be dominant. The following discussion summarizes the results from the 4-source model.

The pattern suggested for Source 1 is dominated by the 2,3,7,8-TCDD congener, as shown in Figure 18.

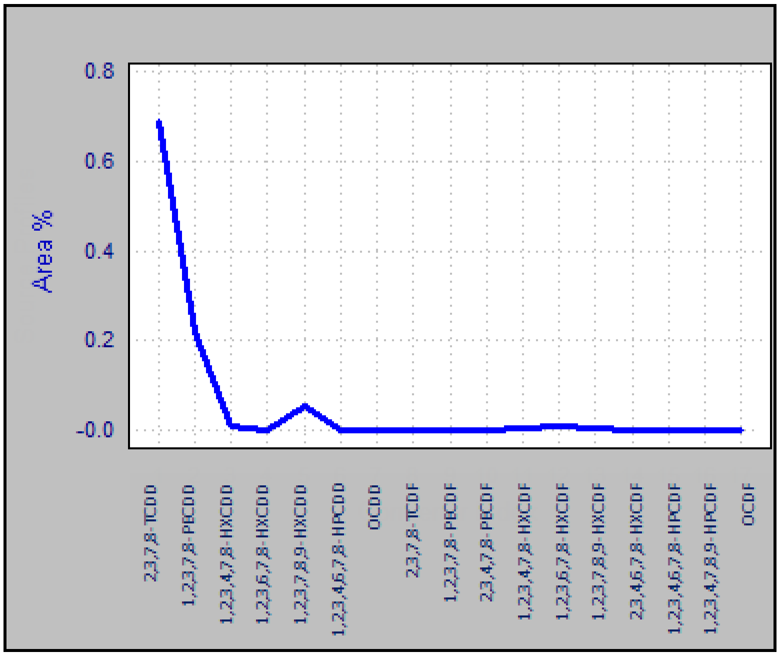


Figure 30. Source 1 pattern derived from a 4-source mixture model

Only a few samples exhibited a pattern like that of Source 1; because there is little difference in the shape of Source 1 from this model and from the 6-source model, the contributions of this source to samples also varies little (see Figure 19).

The pattern in Source 2 (see Figure 31) is dominated by 2,3,4,7,8-PeCDF and 1,2,3,4,7,8-HxCDF, with other furans also important. Note that the penta-chloro dioxin congener is more intense than the hexachloro isomer, the reverse for Source 2 in the 6-source model.

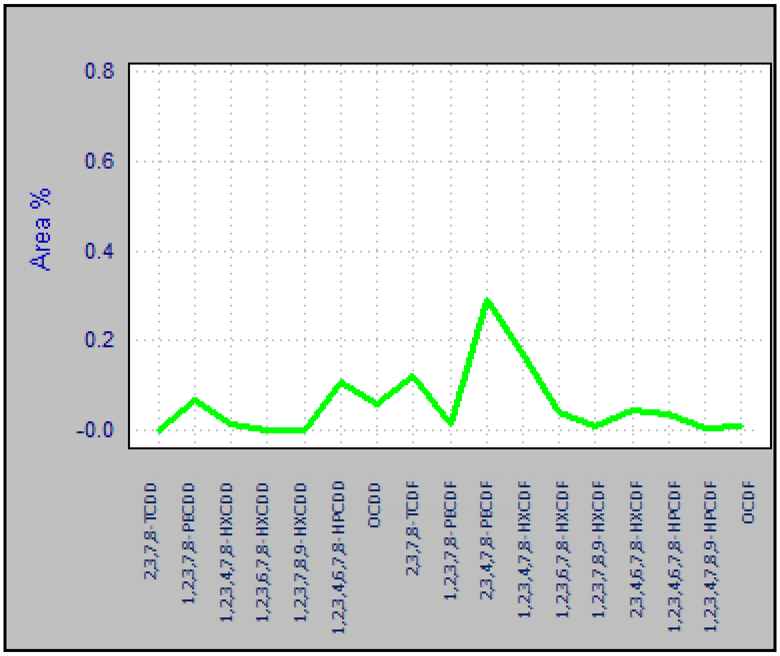
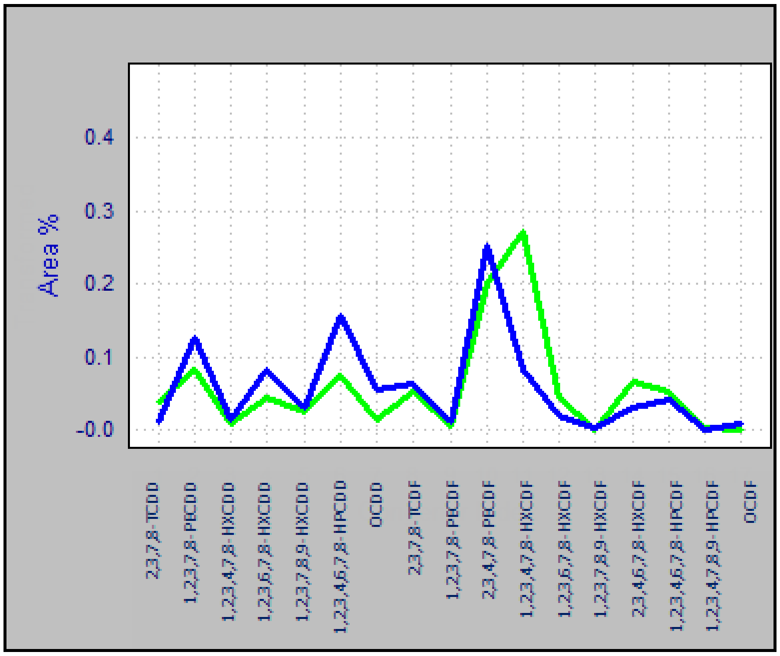


Figure 31. Source 2 pattern derived from a 4-source mixture model

As in the 6-source model, only a few sample profiles show a pattern in which this congener is primary, for example, those in Figure 32.



Sample IDs for the traces in this figure:

Index	Location
15	CO03B
189	LP-20

Figure 32. Sample profiles most similar to Source 2

The pattern in Source 3 (see Figure 33) is dominated by 1,2,3,4,6,7,8-HPCDD, with important intensity from 1,2,3,6,7,8-HXCDD and 1,2,3,4,6,7,8-HPCDF.

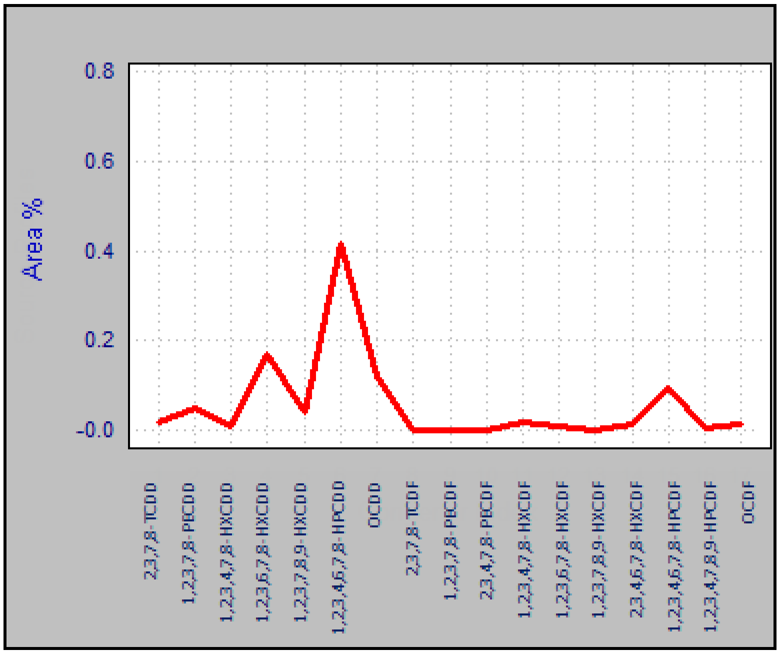


Figure 33. Source 3 pattern derived from a 4-source mixture model

Many sample profiles show a pattern in which this congener is primary as was the case for Source 3 from a 6-source model (for example, see Figure 23).

The pattern for Source 4 (see Figure 34) is predominantly composed of 1,2,3,7,8-PECDD with minor intensity in other chlorinated dioxins.

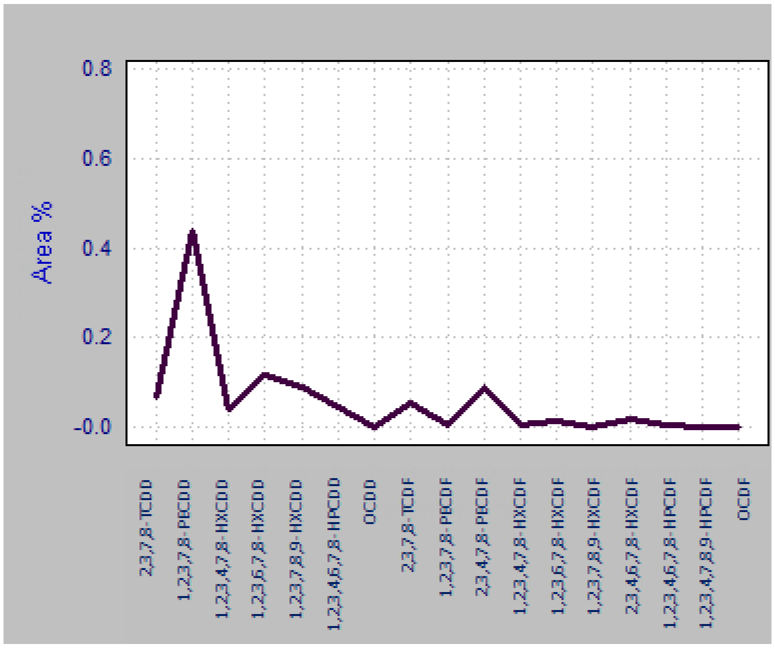


Figure 34. Source 4 pattern derived from a 4-source mixture model

Many sample profiles show a pattern which resemble Source 4 as was the case for Source 4 from a 6-source model (see Figure 25).

4.4. Mixture Analysis of Dioxins/Furans - Variance-scaled Data

To prepare variance-scaled data for mixture analysis requires an extra step. For the 234-sample data subset that was culled following non-detect censoring, the standard deviations of each of the 17 congeners were computed. Then, analogous to the TEF-scaling done in the prior effort, the values for each sample were scaled by (that is, divided by) the corresponding congener standard deviation. Note that this vector of scaling factors was retained for subsequent use in scaling the comparison profiles. The resulting profiles were already shown, in Figure 4.

In addition, the scaled profiles were area % normalized, and these profiles were also shown earlier (see Figure 6).

The MCR-ALS algorithm was then run on these normalized variance-scaled data, and the resulting source profiles are shown in Figure 35. The lack of fit metric in this figure does not indicate a clear distinction for choosing an optimal number of sources. To enable comparison to the results from TEF-scaling, 6 sources were chosen, and these source profiles are shown in the figure.

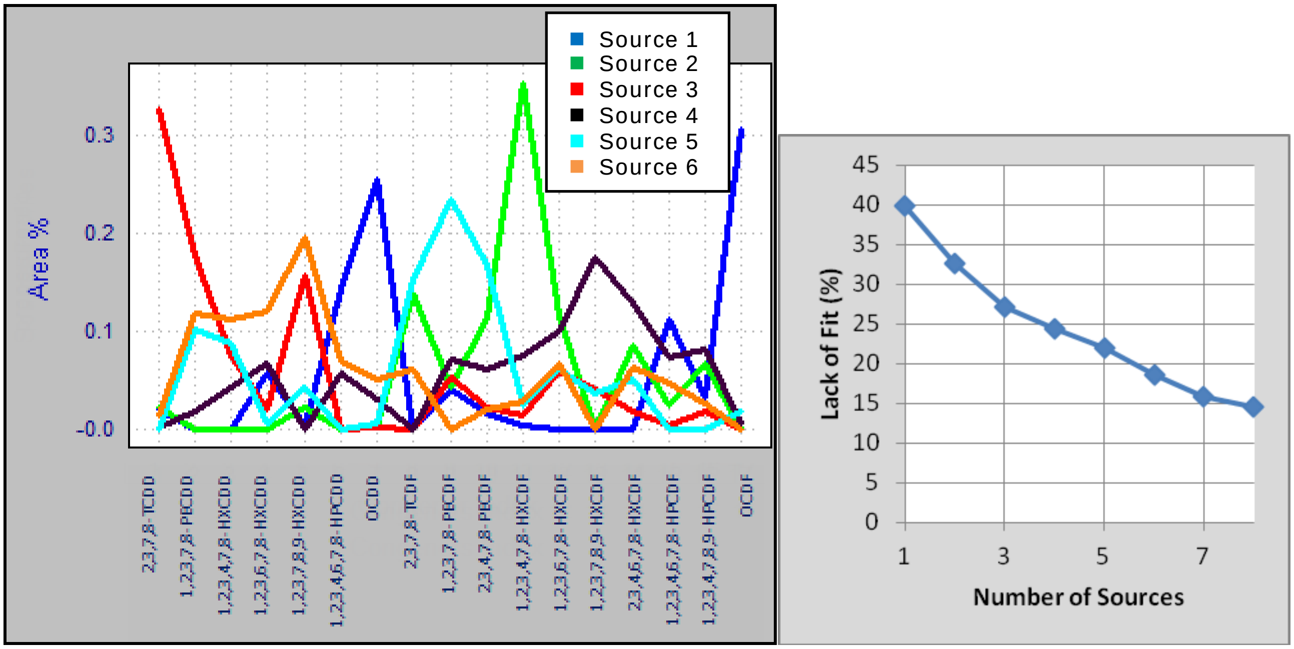


Figure 35. Source profiles and lack of fit metric determined by ALS; variance-scaled data

Note that the ordering of the sources is data-specific in the ALS algorithm thus there is no correlation in the numbering between this and other analyses.

The contributions from each of these 6 sources to the samples are shown in Figure 36.

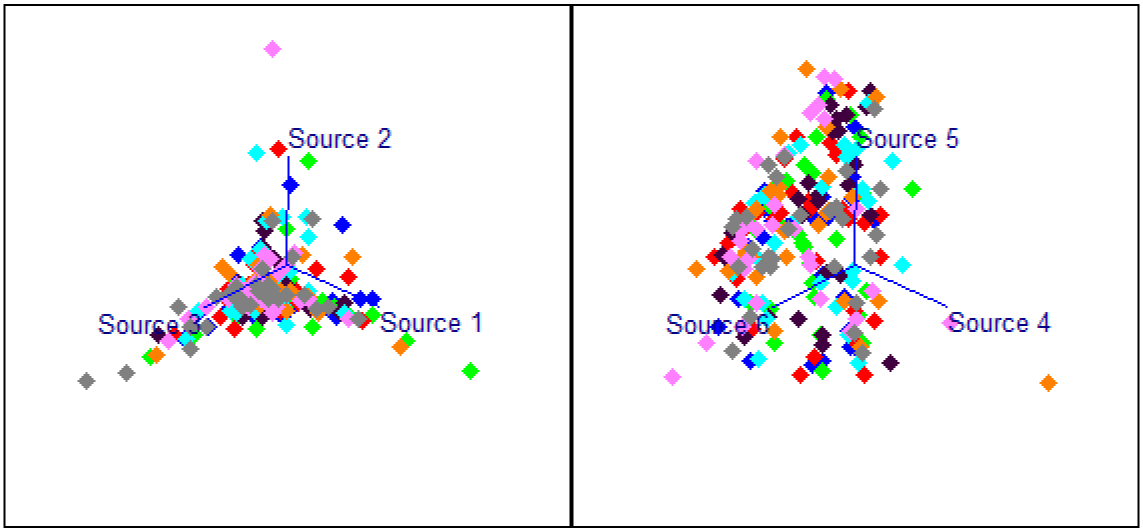


Figure 36. Contributions to samples from sources 1-3 and sources 4-6; variance-scaled data; points colored by Region ID (see Table 3)

From these plots of the source amounts, it appears that the major contribution derives from source 5 and perhaps source 6.

As was done with the TEF-scaled data, the mixture analysis was repeated, restricting the model to only 4 sources. The source profiles for this analysis are shown in Figure 37.

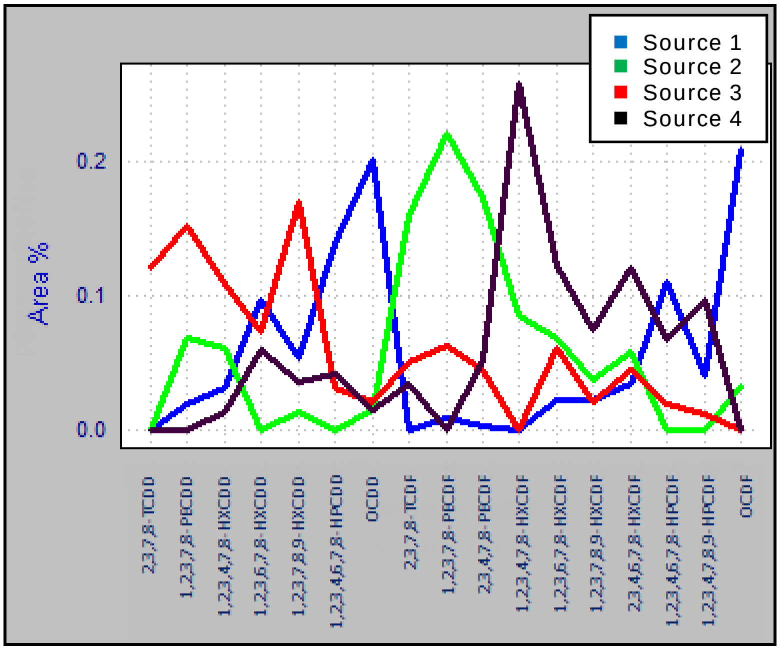


Figure 37. Source profiles from a 4-source ALS model; variance-scaled data

The corresponding source contributions to sample composition are shown in Figure 38.

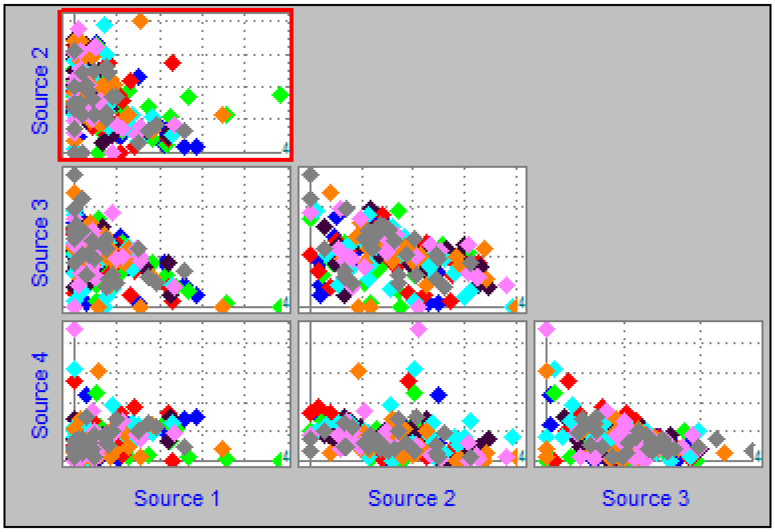


Figure 38. Source contributions from a 4-source ALS model; variance-scaled data; points colored by Region ID (see Table 3)

In this scenario, sources 2 and 3 appear to provide the major contributions to the samples. Unlike with the TEF-scaled data, the change from 6 to 4 sources did not simply merge profiles of a similar nature. In fact, source 3 from the 6-source model disappears in the 4-source model.

5. DISCUSSION

Mixture analysis of dioxins in the Port Angeles harbor has shown there to be distinguishable source profiles and varying contributions of these sources to the sample locations. This section will describe potential source patterns that correspond with the mixture analysis results and will display these contributions in terms of geography within the harbor.

5.1. COMPARISONS TO KNOWN SOURCE PATTERNS

To understand the nature of the source patterns determined via mixture analysis, a database of comparison patterns was constructed. The patterns for comparison were drawn from multiple sources, including:

- EPA Inventory of Sources and Environmental Releases
- Studies on Canadian hog fuel boilers
- Effluent samples from Rayonier
- Stack samples from Rayonier
- Study of treated utility poles
- EPA mill studies

The comparison patterns were compiled into a spreadsheet, TEF-scaled, then merged with a Pirouette table containing the 6 source profiles from mixture analysis on the TEF-scaled sample set. The combined data were analyzed in two complementary manners: first by hierarchical cluster analysis, then by a tabulation of correlation coefficients. These results are discussed below.

The first cluster analysis was performed on the 6 sources plus the 296 patterns from the sets of comparison data referenced above. Because many of the comparison patterns are redundant, this set was reduced to one containing only 154 comparison patterns by removing patterns which were essentially duplicate profiles.

The results from the cluster analysis are best viewed in the form of a dendrogram (see Figure 39), which shows samples in clusters according to their relative similarity. Each sample in the analysis is represented by a leaf node at the left edge of the graphic and those samples most similar to it are connected with a short branch line. The length of the line connecting samples is a measure of (dis)similarity.

In the figure, the leaf nodes for the 6 sources are shown as points, with corresponding labels. Thus, we can see in the dendrogram that the source patterns are distinguishable from each other and that there are comparison patterns that are similar to each source. The figures that follow the main dendrogram show the relationships of the most similar comparison patterns to each source pattern.

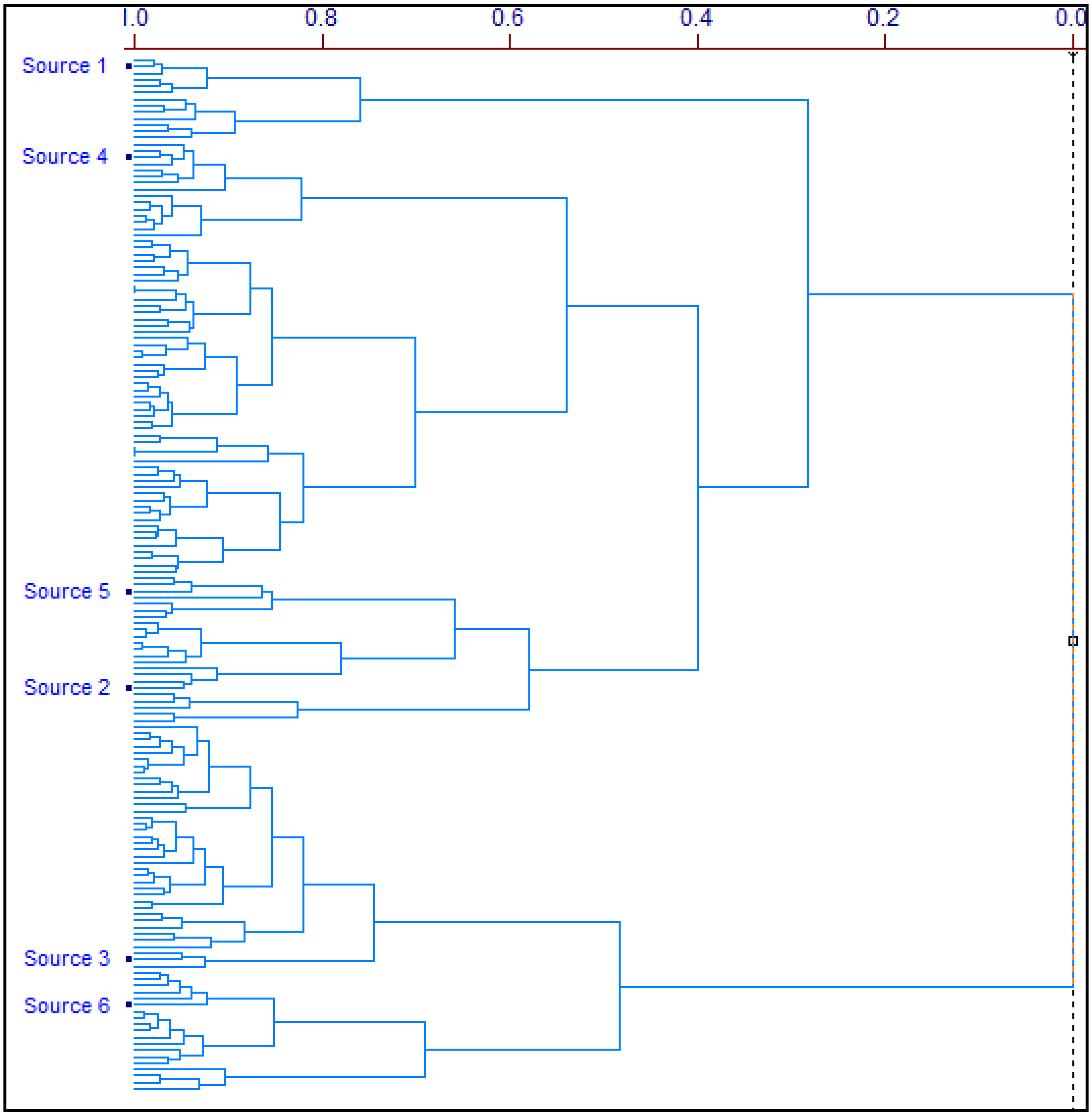


Figure 39. Dendrogram from cluster analysis of 6 sources and comparison patterns, based on TEF-scaled data

By zooming the dendrogram closer to a particular leaf node, it is easier to see the identities of its neighbors. For example, in Figure 40, the dendrogram is zoomed to show patterns similar to Source 1.

The pattern most similar to that of Source 1 comes from a study in New Zealand, which attributed dioxins to Silvex contamination and general urban background; other samples that derive from wood ash are also similar.

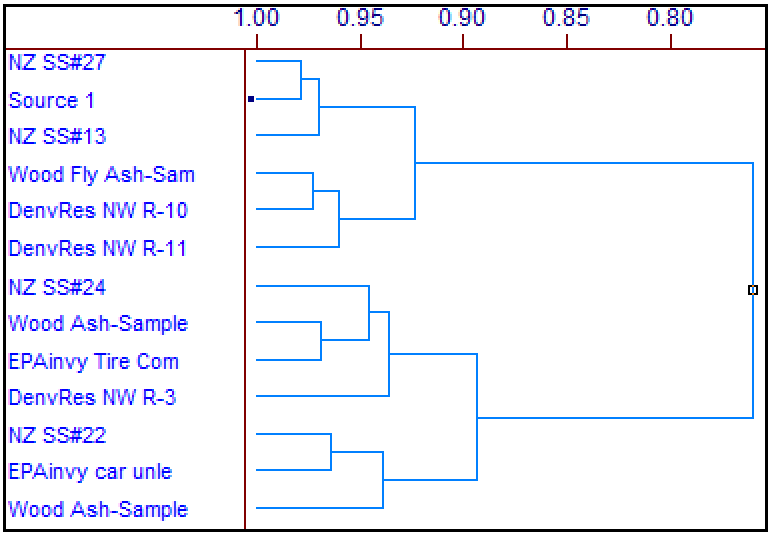


Figure 40. Dendrogram close-up around Source 1 and related comparison patterns

In Figure 41, the dendrogram is zoomed to focus on the patterns related to Source 2. Related patterns come from waste incineration and from heavily chlorinated PCB formulations.

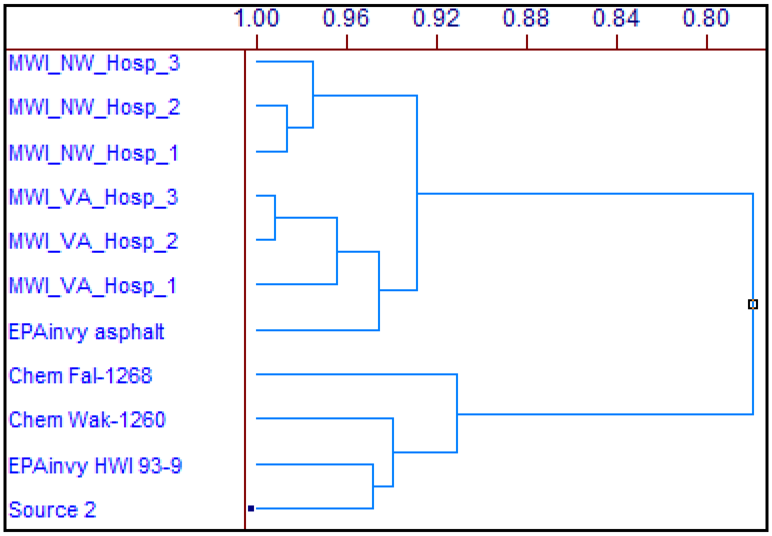


Figure 41. Dendrogram close-up around Source 2 and related comparison patterns

Two comparison patterns strongly resemble the pattern of Source 3, shown in Figure 42. Both of these patterns come from soluble formulations of PCP.

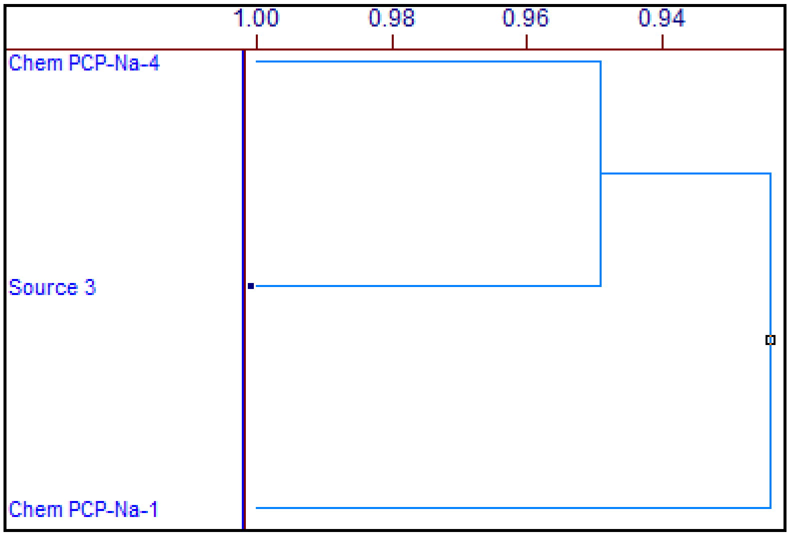


Figure 42. Dendrogram close-up around Source 3 and related comparison patterns

The Source 4 pattern, shown in Figure 43, is similar to patterns found in other studies of hog fuel boilers, as well as effluent samples from the Rayonier facility.

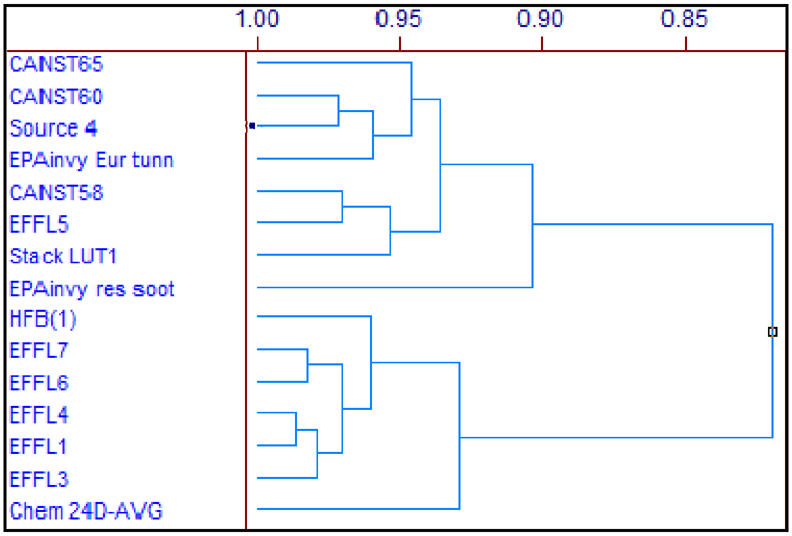


Figure 43. Dendrogram close-up around Source 4 and related comparison patterns

Patterns related to Source 5 are shown in Figure 44. These patterns include sources from soot derived from wood ovens as well as from other PCB formulations.

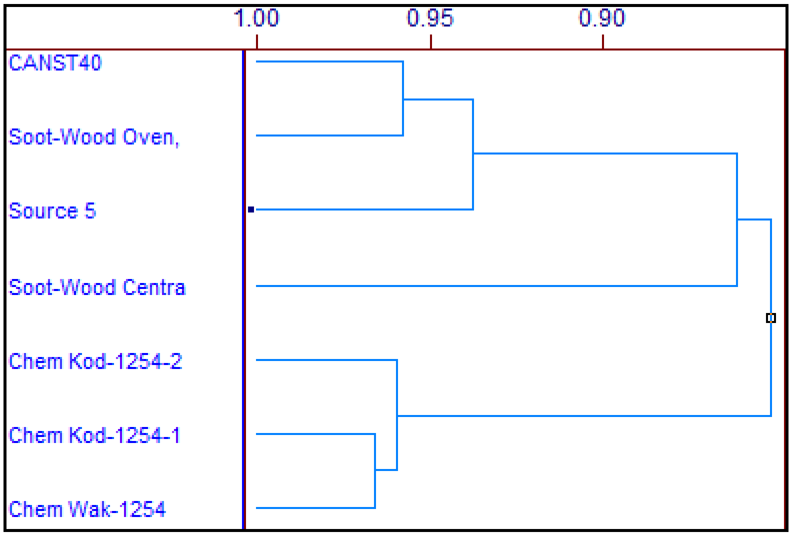


Figure 44. Dendrogram close-up around Source 5 and related comparison patterns

Finally, the Source 6 (Figure 45) appears to be similar to other PCP formulations as well as from wood treated with PCP.

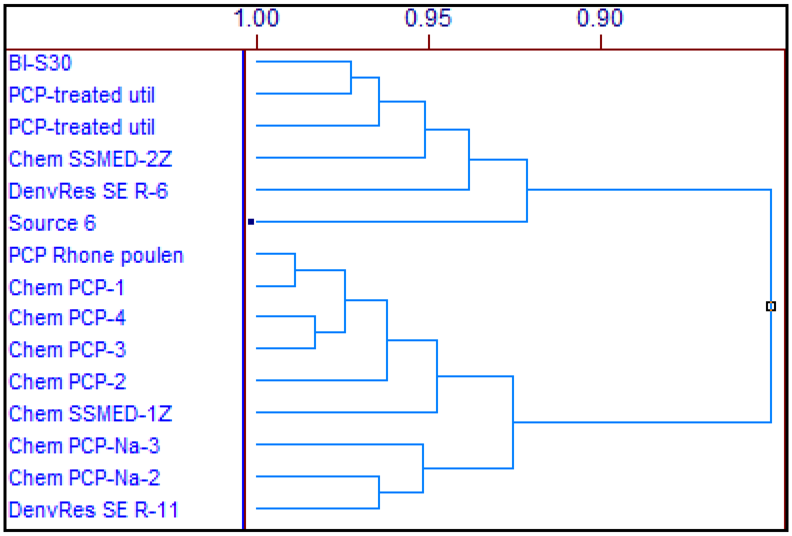


Figure 45. Dendrogram close-up around Source 6 and related comparison patterns

Complimenting these results are the cross-correlation values between each source and the whole set of comparison patterns. In the tables that follow, only those comparison patterns that produce a correlation over 0.90 are shown, for brevity.

Correlations were computed using the Excel built-in function that works on data from two arrays: the source profile and the comparison profile. The tables are sorted to show only the most-correlated patterns. Table 5 shows the correlations to the patterns derived from a 6-source mixture model.

Table 5. Correlations of comparison profiles to 6-source mixture model from TEF-scaled data

Correlation to Source 1		Correlation to Source 2		Correlation to Source 3	
Comparison Profile	**Corr.**	**Comparison Profile**	**Corr.**	**Comparison Profile**	**Corr.**
NZ SS#13	0.997	BI-C5-6-7 FT	0.953	Chem PCP-Na-4	0.925
NZ SS#27	0.996	Chem Fal-1268	0.946	PCP wood preserving forms	0.905
DenvRes NW R-10	0.983			PCP-treated utility poles	0.904
Wood Fly Ash-Sample 13	0.980				
NZ SS#24	0.977				
EPA/Paper-Mill B	0.972				
Wood Ash-Sample 12	0.969				
EPA/Paper-Mill G	0.969				
DenvRes NW R-11	0.967				
Wood Ash-Sample 11	0.963				
EPAinvy Tire Combust	0.961				
EPA/Paper-Mill C	0.961				

Correlation to Source 4		Correlation to Source 5		Correlation to Source 6	
Comparison Profile	**Corr.**	**Comparison Profile**	**Corr.**	**Comparison Profile**	**Corr.**
HFB(1)	0.989	Soot-Wood/Coal Oven 1	0.959	PCP-treated utility poles	0.956
CANST58	0.984	CANST40	0.940	Chem PCP-Na-2	0.944
EFFL3	0.983	Soot-Wood Central Heat, 3	0.929	Chem SSMED-1Z	0.935
CANST60	0.981	Soot-Wood Oven, 6	0.925	Chem PCP-3	0.932
EFFL1	0.979	Chem CH-56	0.924	PCP-treated utility poles	0.926
EFFL7	0.975	Chem Wak-1248	0.915	BI-TISSUE1B-SEDIMENT	0.925
EFFL4	0.972	Soot-Wood Oven, 3	0.914	BI-S30	0.924
EFFL6	0.972	Soot-Wood Central Heat, 4	0.910	DenvRes SE R-11	0.924
Chem 24D-AVG	0.971	Soot-Wood Oven, 7	0.908	Chem PCP-1	0.918
EFFL5	0.970	Soot-Wood Oven, 9	0.903	PCP-treated utility poles	0.917
				Chem PCP-4	0.914
				PCP Rhone poulenc	0.914
				Chem SSMEAN-2Z	0.913
				PCP-treated utility poles	0.912
				BI-C10-2-3 FT	0.910
				Chem PCP-2	0.906

Earlier discussion suggested that restricting the mixture model to only 4 sources had the effect of merging the shape of two source profiles into a new blended shape, for two different sets of profiles. A cluster analysis of a data set composed of the comparison patterns and these 4 source profiles is shown in Figure 46.

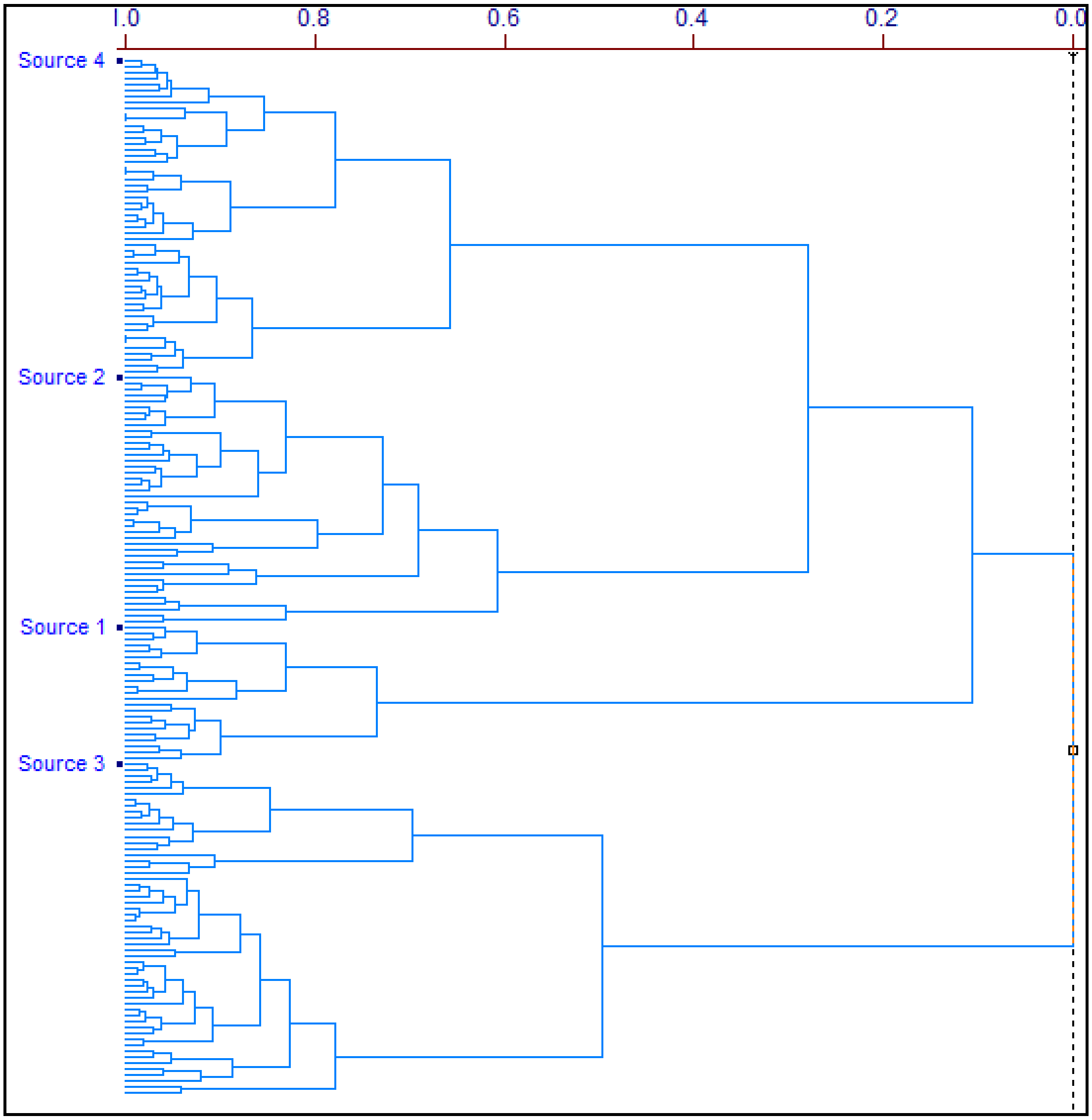


Figure 46. Dendrogram from cluster analysis of 4 sources and comparison patterns, based on TEF-scaled data

As before, the dendrogram has been zoomed in to the branches surrounding each of the proposed source profiles. For example, the branch including source 1 is shown in Figure 47.

The comparison patterns most similar to that of source 1 are those from the New Zealand study which describes the patterns as coming from contamination by 2,4,5-T and general urban background.

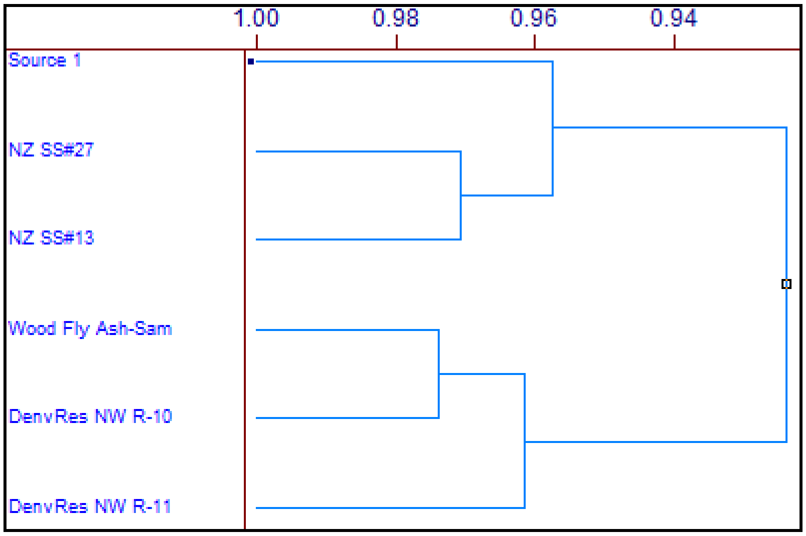


Figure 47. Dendrogram close-up around Source 1 and related comparison patterns; 4-source model

The comparison patterns most similar to that of source 2 are comprised of a variety of incineration sources (see Figure 48).

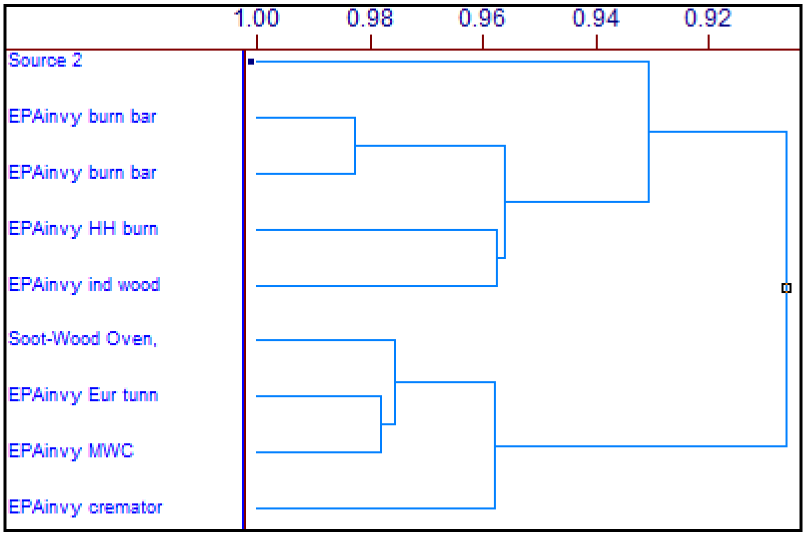


Figure 48. Dendrogram close-up around Source 2 and related comparison patterns; 4-source model

Source 3 (Figure 49) can be characterized as deriving from PCP as most of the most similar patterns come from pentachlorophenol sources.

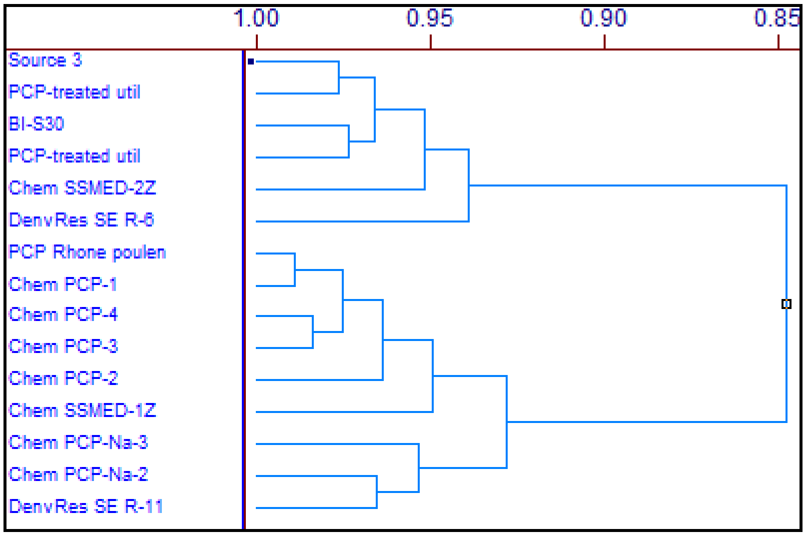


Figure 49. Dendrogram close-up around Source 3 and related comparison patterns; 4-source model

Finally, patterns resembling that of source 4 come from a variety of sources, but many originated from other hog fuel boilers.

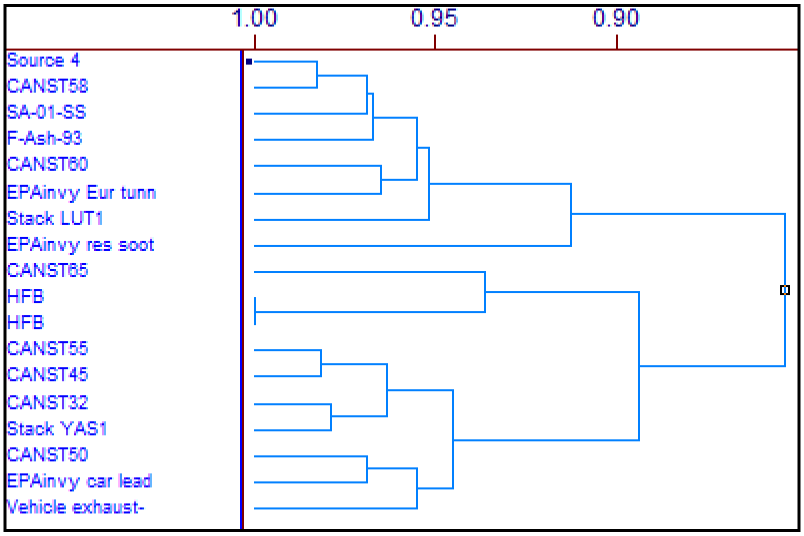


Figure 50. Dendrogram close-up around Source 4 and related comparison patterns; 4-source model

Correlation coefficient calculations were performed to compare the source profiles from the 4-source model and the same set of comparison patterns. The correlations do not change substantially for the two profiles that were not affected by the change in the model from 6 to 4 souces, and for those sources that resulted from this blending, the comparison patterns only shuffled some in the magnitude of their correlations. The correlations to the profiles in the 4-source model are shown in Table 6.

From these results of cluster and correlation analysis calculations, conclusions can be drawn about the nature of possible sources of dioxin contamination. It appears that four types of input are present:

- Wood ash and 2,4,5-T
- Polychlorinated biphenyls
- Pentachlorophenol
- Hog fuel boiler and wood processing effluent

Table 6. Correlations of comparison profiles to 4-source mixture model from TEF-scaled data

Correlation to Source 1		**Correlation to Source 2**	
Comparison Profile	**Corr.**	**Comparison Profile**	**Corr.**
NZ SS#24	0.991	Chem Wak-1254	0.906
NZ SS#13	0.989	Chem Kod-1254-1	0.863
NZ SS#27	0.983	Chem CH-56	0.856
DenvRes NW R-10	0.959	Chem Kod-1254-2	0.853
Wood Fly Ash-Sample 13	0.954	Soot-Wood Central Heat, 4	0.848
EPA/Paper-Mill C	0.954	EPAinvy ind wood 1	0.842
EPA/Paper-Mill G	0.953	Soot-Wood Central Heat, 3	0.840
Wood Ash-Sample 12	0.950		
EPA/Paper-Mill B	0.949		
EPA/Paper-Mill F	0.949		
Wood Ash-Sample 11	0.947		
EPAinvy Tire Combust	0.946		
DenvRes NW R-11	0.936		
Correlation to Source 3		**Correlation to Source 4**	
Comparison Profile	**Corr.**	**Comparison Profile**	**Corr.**
PCP-treated utility poles	0.983	CANST58	0.994
BI-S30	0.978	CANST60	0.975
BI-S11	0.976	EFFL5	0.974
PCP-treated utility poles	0.975	HFB(1)	0.974
PCP wood preserving forms	0.974	EPAinvy Eur tunnel a	0.972
PCP-treated utility poles	0.974	ASH5	0.970
Chem SSMED-2Z	0.971	EFFL7	0.965
PCP	0.971	EFFL3	0.963
Chem PCP-Na-3	0.970	EFFL1	0.963
Chem PCP-4	0.963	ASH2	0.960
Chem PCP-1	0.957	EFFL6	0.956
BI-C4-0-1 FT	0.956	Stack LUT1	0.954
BI-S1	0.955	EFFL4	0.951
PCP-treated utility poles	0.955	ASH4	0.948
Chem PCP-Na-2	0.955	CANST65	0.948
Chem PCP-2	0.955	CANST45	0.947

Similar data treatments were applied to the variance-scaled data. First, the comparison patterns were scaled by the same standard deviations used to scale the study data (the 234-sample censored data subset). Then, HCA was run on the comparison data combined with the source profiles from mixture analysis on the variance-scaled data (see, for example, Figure 35).

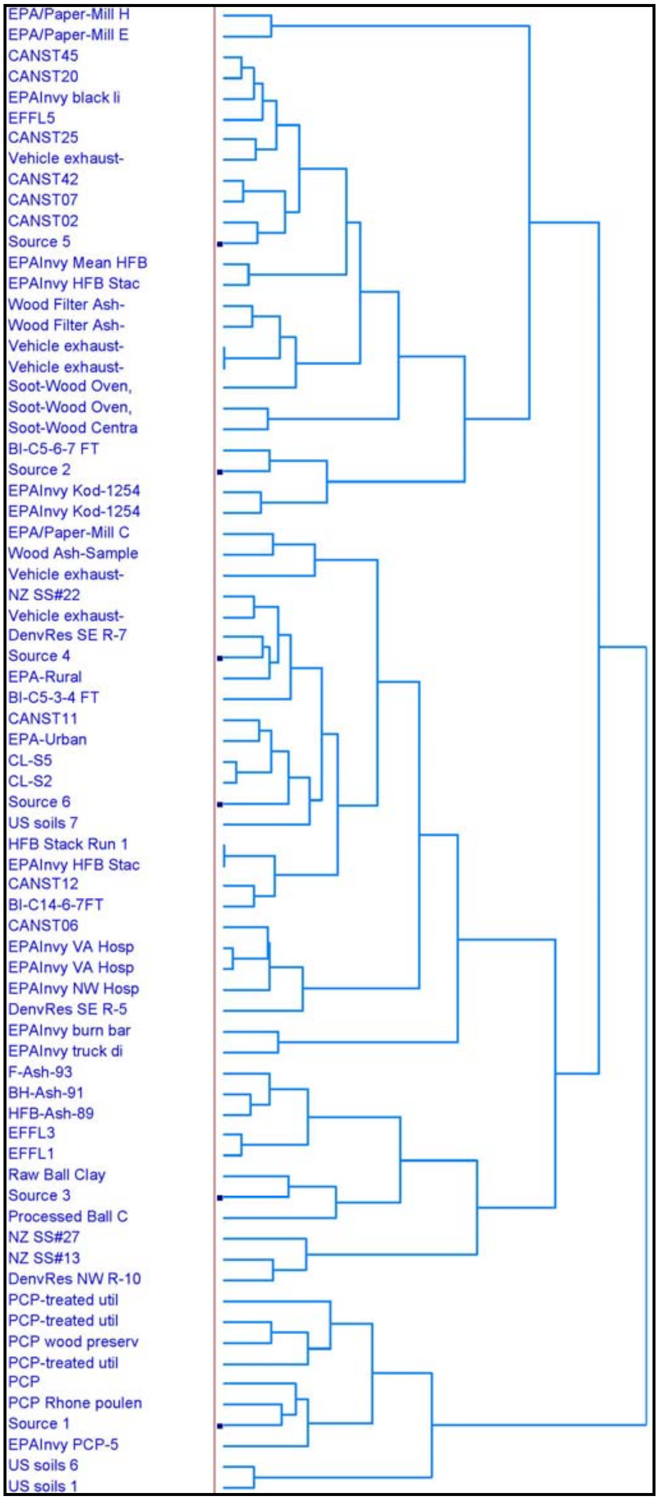


Figure 51. Dendrogram from cluster analysis of 6 sources and comparison patterns, based on variance-scaled data

A reduced set of comparison patterns was chosen (using the Kennard and Stone algorithm) to simplify interpretation of the dendrogram. Many of the same types of patterns appear related to the 6 source patterns obtained from mixture analysis on the variance-scaled data as were obtained from the TEF-scaled data, including PCP, PCB, incineration by products such as soot and ash, and hog fuel boiler effluent.

The comparisons were extended by including cross correlation computations with the mixture analysis source profiles and the comparison patterns. However, the correlations with this approach were not as strong as those from the TEF-scaled data. Only PCP and wood ash and hog fuel boiler effluent patterns matched the source profiles to an adequate degree. Some of these results are shown in Table 7.

Table 7. Correlations of comparison profiles to 6-source mixture model from variance-scaled data

Correlation to Source 1		Correlation to Source 2		Correlation to Source 3	
Comparison Profile	**Corr.**	**Comparison Profile**	**Corr.**	**Comparison Profile**	**Corr.**
EPAInvy PCP-3	0.956	BI-C5-6-7 FT	0.914	NZ SS#13	0.861
		EPAInvy Fal-1268	0.879		
Correlation to Source 4		**Correlation to Source 5**		**Correlation to Source 6**	
Comparison Profile	**Corr.**	**Comparison Profile**	**Corr.**	**Comparison Profile**	**Corr.**
EPAInvy NW Hosp 1	0.885	CANST22	0.937		
EPAInvy NW Hosp 3	0.878	CANST27	0.923		
CANST06	0.792	CANST32	0.922		
		CANST41	0.921		
		Wood Filter Ash-Sample 3	0.919		
		Soot-Wood Oven, 3	0.918		

The correlations against source 6 were too low to be considered a match and are not shown; the correlations for sources 3 and 4 are also too low to be accepted as matches.

Because the results from mixture analysis using TEF-scaled data and variance-scaled data give somewhat similar results both in terms of correlated dioxin patterns and geospatial distribution, the following mapping will be applied only to the TEF-scaled data.

5.2. GEOSPATIAL DISTRIBUTIONS OF SOURCE CONTRIBUTIONS

When the source amounts are re-scaled to their respective TEQ values, the result is called the Source Increment. A map plot of the source increments shows the relative importance of a source as a contribution to each sample but also the relative importance of a source in terms of geographic location. Figure 52 shows the source increment maps for the sources obtained from a 6-source mixture analysis model.

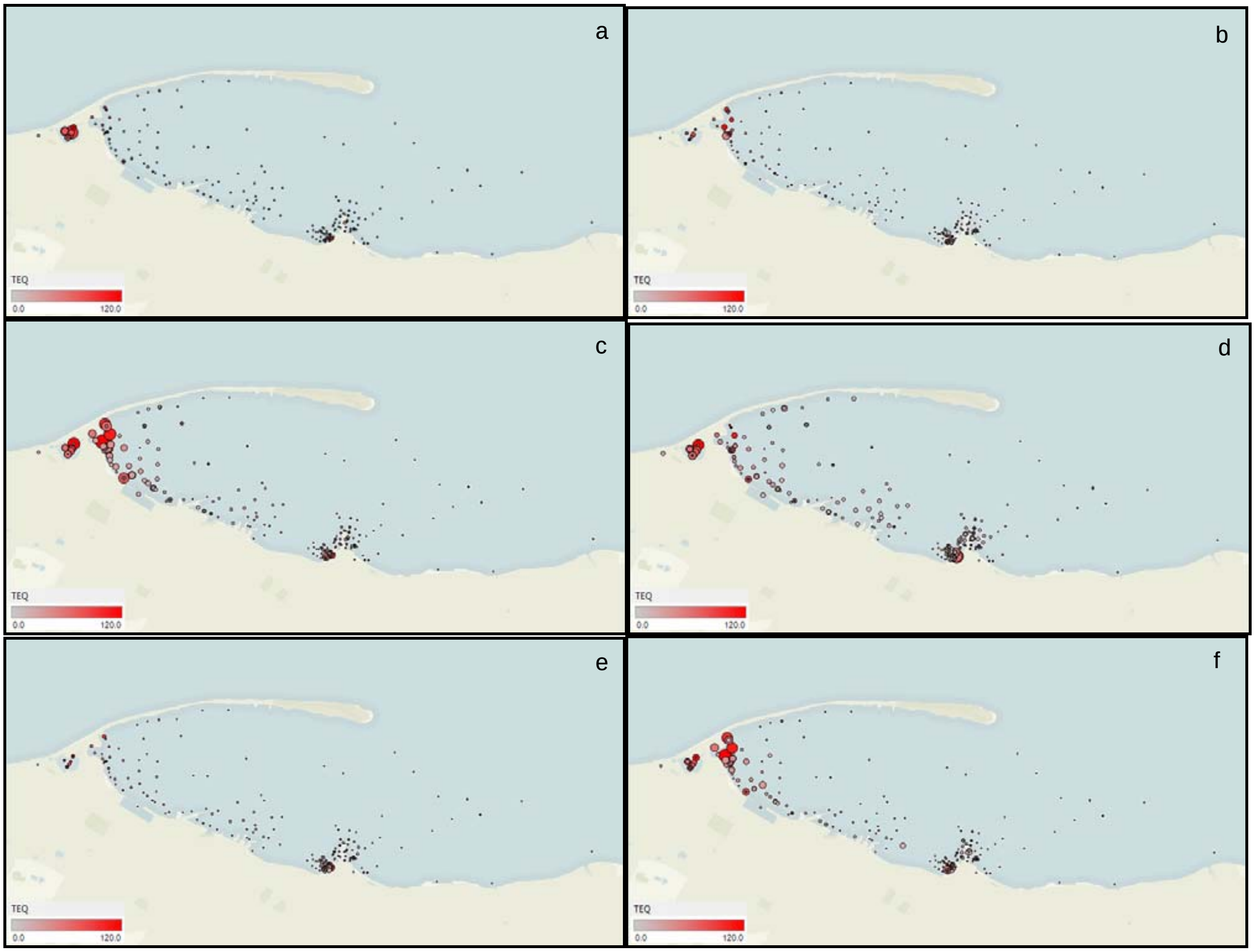


Figure 52. Source increment maps for 6-source model:
a) Source 1, related to 2,4,5-T and wood ash residue
b) Source 2, related to PCBs
c) Source 3, related to pentachlorophenol
d) Source 4, related to hog fuel boiler burning of salt-laden wood
e) Source 5, related to PCBs
f) Source 6, related to pentachlorophenol

Samples with high contributions from Source 1 are located primarily in the lagoon; a few samples in the west harbor and close to the Rayonier facility have low contributions from this source. Otherwise, Source 1 contributes only minimally to sample composition.

Sample contributions from Source 2 are relatively small and mostly appear in a few samples in the inner harbor at the west end and in the lagoon.

Significant contributions from Source 3 occur in samples in the inner harbor and lagoon with moderate input to samples along the waterfront at the west end of the harbor and adjacent the Rayonier site.

Sample locations for which Source 4 is a large contributor occur in the lagoon and adjacent the Rayonier site. Moderate contributions are also evident in many locations in the western and middle harbor. This dioxin profile has perhaps the most widespread occurrence.

Source 5 is a minor contributor to almost all locations, with a moderate contribution only to a few locations mostly near the Rayonier site.

Sample locations with high contributions from Source 6 are concentrated in the west end of the inner harbor. Other locations with moderate Source 6 contributions occur in the lagoon, in other near shore areas of the inner harbor and adjacent the Rayonier site.

Similar TEQ source increment maps were prepared for the 4-source mixture analysis model. Distribution of contributions from the sources mirrors that for the 6-source model, as shown in Figure 53.

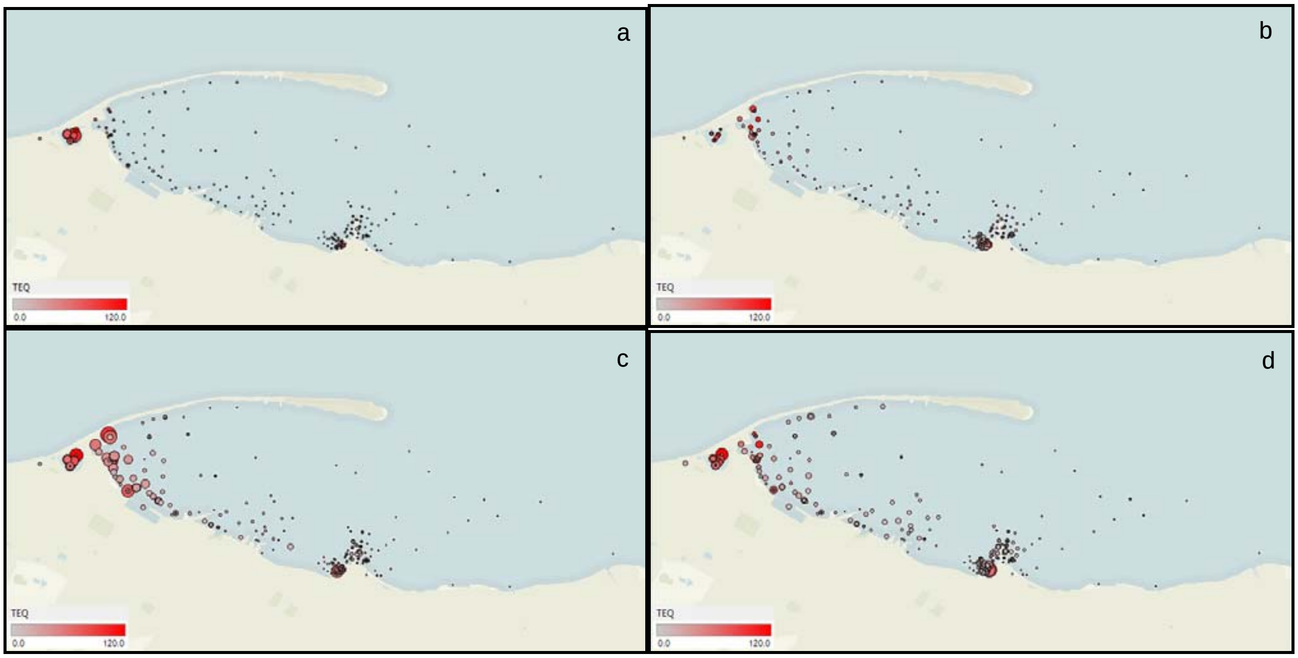


Figure 53. Source increment map for 4-source model:
a) Source 1, related to 2,4,5-T and wood ash residue
b) Source 2, related to PCBs
c) Source 3, related to pentachlorophenol
d) Source 4, related to hog fuel boiler burning of salt-laden wood

The majority of sample locations for which Source 1 is the dominant contribution occur in the lagoon. Low contributions also occur in the west harbor and near the Rayonier site.

Source 2 is a low contributor to locations in the lagoon, in the western harbor, and adjacent the Rayonier facility. It is not important elsewhere in the harbor.

Contributions from Source 3 are high in the western harbor, the lagoon and adjacent the Rayonier site; many near-shore locations in the western and middle harbor show moderate contributions as well.

Source 4 contributions are highest in the lagoon and at the Rayonier site. Moderate contributions can be seen from this source in the near and off shore regions of the western and middle harbor.

6. SUMMARY

Over 200 sediment samples from Port Angeles harbor were analyzed for polychlorinated dioxins and furans, as well as other compounds. Data from these analyses were collectively processed with several chemometrics algorithms to look for underlying patterns that might explain their distribution in the harbor.

Following principal component analysis to understand the complexity in the data set, mixture analysis was performed using a multivariate curve resolution method. Based on diagnostics from the two methods, it appears justified to describe 6 different source materials. However, the patterns for some of the source materials are similar to others, therefore, it was decided to select a 4-source model that was simpler to explain and visualize.

The 4 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 occurs. These include the following:

- A source that appears similar to patterns from 2,4,5-T and from incineration residue such as wood ash. This source occurs primarily in the lagoon at the west end of the harbor.
- A source that has similarity to the pattern from degradation of PCBs.
- A source that strongly resembles that from pentachlorophenol.
- A source that has a pattern similar to those found in stack emissions, ash, and effluent from wood processing facilities that use salt-laden wood, both in this harbor and in certain locations in western Canada.

7. GLOSSARY

ALS – Alternating Least Squares, a mixture analysis algorithm for uncovering source patterns in a mixture and the corresponding contributions (source amounts) of the source patterns to the mixture samples

Correlation – a measure of association between two data vectors

Eigenvalue - the variance in a set of variables explained by an eigenvector

Eigenvector - linear combination of variables that has the greatest variance

HCA – Hierarchical Cluster Analysis, a method of displaying sample similarity in a dendrogram

Matrix decomposition – linear algebra methods to transform a data matrix into its underlying eigenvectors

Mixture analysis – a family of methods that aim to resolve a mixture into contributing end-members

Normalization – method of removing variation in a data vector by dividing by a standard factor such as the sum of values

Outlier – a sample in a data set that appears not to conform to the patterns of other samples

PCA – Principal Component Analysis, an algorithm for converting a matrix of measurements on a set of samples by defining new components as linear combinations of the original measurements

Pirouette – a commercial software package with tools for performing chemometrics analyses

Scaling – a method of scaling a measure across a set of samples to a common scale, such as variance

Score – a coefficient or measure of distance from a vector's mean such as that from an eigenvector

Standardization – a form of scaling on the values in a vector in which the mean is subtracted from each value and the result is divided by the standard deviation

Source apportionment – use a mixture analysis algorithm to determine the contributions (also, source amounts) of underlying source patterns to samples

TEF - Toxic Equivalence Factor, used to scale the bulk dioxin/furan congener amounts relative to 2,3,7,8-tetrachlorodioxin

Variance - dispersion of a distribution about its mean

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9. APPENDIX

Table 8. Sample IDs and information

Index	Location	Region ID	TEQ	Latitude	Longitude
1	BL01A	1	5.25057	48.12522	-123.447
2	BL02A	1	3.85021	48.12544	-123.446
3	BL02B	1	18.2951	48.12543	-123.446
4	BL02C	1	0.633501	48.12543	-123.446
5	BL03A	1	7.47103	48.12541	-123.443
6	BL04A	1	1.225437	48.12552	-123.441
7	BL06A	1	5.91958	48.13086	-123.441
8	BL08A	1	6.30266	48.13076	-123.438
9	BL08B	1	1.143672	48.13077	-123.438
10	BL08C	1	0.204714	48.13077	-123.438
11	CO01A	2	1.292913	48.11749	-123.41
12	CO02A	2	6.4406	48.11843	-123.41
13	CO02B	2	1.56665	48.11852	-123.41
14	CO03A	2	0.312775	48.11828	-123.407
15	CO03B	2	4.16866	48.11828	-123.407
16	CO04A	2	0.223293	48.11821	-123.406
17	CO04B	2	0.333109	48.1182	-123.406
18	CO05A	2	1.04251	48.11848	-123.405
19	CO05B	2	8.8837	48.11848	-123.405
20	DO01A	3	1.290897	48.12019	-123.395
21	DO02A	3	1.758625	48.12267	-123.388
22	DO03A	3	1.91861	48.1244	-123.384
23	DO04A	3	1.7005	48.12732	-123.38
24	DO04B	3	2.834885	48.12732	-123.38
25	DO04C	3	0.288037	48.12732	-123.38
26	DO04D	3	0.119001	48.12732	-123.38
27	DO05A	3	1.395475	48.12499	-123.377
28	DO05B	3	1.364703	48.12504	-123.377
29	DO05C	3	0.268235	48.12504	-123.377
30	EC01A	4	0.33069	48.11658	-123.405
31	EC02A	4	0.130944	48.11738	-123.406
32	EC03A	4	3.98216	48.11872	-123.405
33	EC03B	4	22.8695	48.1187	-123.405
34	EC03C	4	12.246	48.1187	-123.405
35	EC04A	4	0.99237	48.1185	-123.405
36	EC04B	4	4.39738	48.1185	-123.405
37	EC05A	4	0.257093	48.1171	-123.405
38	ED01A	5	6.3487	48.1227	-123.406
39	ED01B	5	0.744205	48.12272	-123.406
40	ED01C	5	0.371527	48.12272	-123.406
41	ED02A	5	10.17436	48.12135	-123.406
42	ED02B	5	1.140815	48.12135	-123.406
43	ED02C	5	2.562425	48.12135	-123.406
44	ED03A	5	8.18567	48.12064	-123.407
45	ED03B	5	9.04239	48.12064	-123.407

Index	Location	Region ID	TEQ	Latitude	Longitude
46	ED03C	5	0.73721	48.12064	-123.407
47	ED04A	5	10.92814	48.11987	-123.407
48	ED04B	5	17.2451	48.11987	-123.407
49	ED05A	5	1.737118	48.11887	-123.407
50	ED05B	5	5.71081	48.11887	-123.407
51	EE01A	6	0.151256	48.11716	-123.404
52	EE01B	6	0.097645	48.11716	-123.404
53	EE02A	6	0.404218	48.11645	-123.403
54	EE02B	6	0.83828	48.11657	-123.403
55	EE02C	6	0.198116	48.11657	-123.403
56	EE03A	6	0.303276	48.11647	-123.402
57	EE03B	6	0.716388	48.11648	-123.402
58	EE03C	6	0.819407	48.11648	-123.402
59	EE04A	6	0.132845	48.11539	-123.401
60	EE04B	6	0.38662	48.11542	-123.401
61	EE04C	6	0.154711	48.11542	-123.401
62	EE05A	6	0.126725	48.11499	-123.399
63	EI02A	7	0.256105	48.11511	-123.387
64	EI04A	7	0.240697	48.11484	-123.375
65	EI07A	7	0.471815	48.1196	-123.352
66	EP-01-SD	8	5.5504	48.12289	-123.429
67	EP-02-SD	8	15.0667	48.12421	-123.43
68	EP-03-SD	8	9.5505	48.1235	-123.427
69	EP-04-SD	8	10.61804	48.12174	-123.425
70	EP-05-SD	8	10.25083	48.12541	-123.428
71	EP-06-SD	8	14.14061	48.12402	-123.433
72	EP-07-SD	8	8.93706	48.12685	-123.431
73	EP-08-SD	8	8.6584	48.12464	-123.424
74	EP-09-SD	8	14.9091	48.12061	-123.422
75	EP-10-SD	8	5.56496	48.12794	-123.426
76	EP-11-SD	8	11.5752	48.12517	-123.437
77	FT01A	9	12.548	48.12197	-123.432
78	FT04A	9	3.266	48.1216	-123.429
79	FT06A	9	5.32023	48.12713	-123.425
80	FT10A	9	6.58989	48.12472	-123.421
81	FT12A	9	1.563413	48.13121	-123.408
82	FT13A	9	1.972266	48.13226	-123.412
83	FWX1	10	95.9109	48.11719	-123.41
84	FWX2	10	42.8788	48.11752	-123.411
85	FWX3	10	25.9396	48.11785	-123.412
86	FWX4	10	20.2133	48.11803	-123.412
87	FWX5	10	56.2096	48.11702	-123.412
88	FWX6	10	60.9045	48.11702	-123.412
89	HS-01	11	0.534625	48.12107	-123.429
90	HS-02	11	3.26156	48.12144	-123.429
91	HS-03	11	6.54688	48.12243	-123.428
92	HS-04	11	11.33545	48.12291	-123.427
93	HS-05	11	0.415921	48.11944	-123.426
94	HS-06	11	1.95487	48.12019	-123.425

Index	Location	Region ID	TEQ	Latitude	Longitude
95	HS-07	11	0.85513	48.12158	-123.424
96	HS-07_d	11	4.95591	48.12158	-123.424
97	HS-08	11	3.74933	48.12289	-123.423
98	IE01B	12	8.65888	48.14057	-123.433
99	IE03A	12	4.62784	48.14049	-123.439
100	IE04A	12	4.62486	48.1392	-123.445
101	IE05A	12	9.94003	48.1392	-123.449
102	IE05B	12	24.0898	48.13914	-123.449
103	IE06A	12	9.62973	48.13888	-123.451
104	IE07A	12	8.3307	48.13835	-123.453
105	IE09A	12	62.9405	48.13632	-123.46
106	IE09B	12	12.11925	48.13633	-123.461
107	IE12A	12	5.61134	48.13637	-123.452
108	IE12B	12	11.17096	48.13635	-123.452
109	IE14A	12	4.2604	48.13673	-123.444
110	IE14B	12	10.60234	48.13674	-123.444
111	IE15A	12	9.34504	48.13294	-123.449
112	IE16B	12	0.349434	48.13314	-123.453
113	IH01A	13	119.1288	48.13403	-123.461
114	IH02A	13	43.6578	48.13301	-123.46
115	IH02B	13	89.6518	48.13301	-123.46
116	IH02C	13	0.393709	48.13301	-123.46
117	IH03A	13	19.3972	48.1313	-123.46
118	IH04A	13	9.79023	48.1306	-123.459
119	IH05A	13	4.46154	48.1295	-123.458
120	IH06A	13	11.61704	48.12862	-123.457
121	IH06B	13	74.1289	48.12863	-123.457
122	IH06C	13	0.337911	48.12863	-123.457
123	IT-04	14	0.326006	48.11811	-123.41
124	IT-05	14	0.314205	48.11478	-123.398
125	IT-06	14	20.53665	48.11684	-123.411
126	IT-07	14	14.36045	48.11684	-123.411
127	IT-08	14	10.7454	48.11664	-123.412
128	KP01A	15	15.4358	48.12428	-123.44
129	KP02A	15	11.0969	48.12377	-123.439
130	KP02B	15	19.0332	48.12377	-123.439
131	KP03A	15	2.51794	48.1234	-123.437
132	KP03B	15	7.01134	48.1234	-123.437
133	KP04A	15	5.16616	48.12286	-123.436
134	KP05A	15	8.45789	48.12563	-123.436
135	KP07A	15	3.51315	48.13337	-123.429
136	KP07B	15	0.50802	48.13337	-123.429
137	KP08B	15	0.841149	48.12588	-123.438
138	LA01A	16	61.5556	48.13312	-123.47
139	LA01A-01	16	74.2857	48.13312	-123.47
140	LA02A	16	55.2387	48.13217	-123.469
141	LA02A-01	16	77.0054	48.13294	-123.468
142	LA02B	16	2.47517	48.13218	-123.469
143	LA02C	16	0.592728	48.13218	-123.469

Index	Location	Region ID	TEQ	Latitude	Longitude
144	LA03A	16	93.2202	48.13294	-123.468
145	LA03A-01	16	68.6082	48.13217	-123.469
146	LP-01	17	0.46951	48.11689	-123.415
147	LP01A	17	1.63037	48.11824	-123.416
148	LP-01-SD	17	0.761027	48.11666	-123.414
149	LP-02	17	3.01841	48.11676	-123.413
150	LP-02-SD	17	7.066145	48.11688	-123.412
151	LP-03	17	7.34744	48.11684	-123.412
152	LP03A	17	1.093045	48.11814	-123.413
153	LP-03-SD	17	49.0233	48.11724	-123.411
154	LP-04	17	0.70827	48.1171	-123.414
155	LP04A	17	4.03138	48.11836	-123.413
156	LP-04-SD	17	42.5184	48.11779	-123.411
157	LP-05	17	7.61063	48.11705	-123.412
158	LP05A	17	18.5131	48.11796	-123.411
159	LP-05-SD	17	0.545098	48.11717	-123.414
160	LP-06	17	59.3571	48.11719	-123.41
161	LP-06-SD	17	0.364895	48.11777	-123.414
162	LP-06-SD_d	17	0.424584	48.11777	-123.414
163	LP-07	17	0.9745	48.11761	-123.416
164	LP-07-SD	17	8.08174	48.11818	-123.413
165	LP-08	17	0.86439	48.11747	-123.415
166	LP-08-SD	17	9.8588	48.11871	-123.412
167	LP-09	17	6.03937	48.11747	-123.413
168	LP-09	17	7.24243	48.11747	-123.413
169	LP-10	17	2.70717	48.11738	-123.411
170	LP-11	17	0.645661	48.11814	-123.414
171	LP-12	17	2.335295	48.11786	-123.412
172	LP-12	17	5.86888	48.11786	-123.412
173	LP-12_d	17	2.111854	48.11786	-123.412
174	LP-13	17	14.56757	48.1178	-123.411
175	LP-13	17	3.817724	48.1178	-123.411
176	LP-13	17	6.278222	48.1178	-123.411
177	LP-13	17	0.877928	48.1178	-123.411
178	LP-13_d	17	7.911721	48.1178	-123.411
179	LP-14	17	1.63126	48.11843	-123.414
180	LP-15	17	1.821785	48.11841	-123.413
181	LP-16	17	10.7404	48.11832	-123.411
182	LP-17	17	0.507915	48.11909	-123.415
183	LP-17_d	17	1.53055	48.11909	-123.415
184	LP-18	17	6.52495	48.11883	-123.412
185	LP-18	17	5.542553	48.11883	-123.412
186	LP-18	17	0.917305	48.11883	-123.412
187	LP-19	17	1.2028	48.11935	-123.413
188	LP-20	17	5.98623	48.11715	-123.411
189	LP-20	17	26.68519	48.11715	-123.411
190	LP-20	17	1.106493	48.11715	-123.411
191	MA01A	18	15.1572	48.12626	-123.453
192	MA02A	18	14.7593	48.12714	-123.45

Index	Location	Region ID	TEQ	Latitude	Longitude
193	MA02B	18	20.7383	48.12717	-123.45
194	MA02C	18	28.7207	48.12717	-123.45
195	MA03A	18	17.166	48.1283	-123.452
196	MA04A	18	11.48228	48.12692	-123.45
197	MA05A	18	15.6293	48.12849	-123.449
198	MD01A	19	6.54098	48.1189	-123.409
199	MD01B	19	3.44164	48.11897	-123.409
200	MD01C	19	0.18439	48.11897	-123.409
201	MD-02	19	4.33991	48.11918	-123.41
202	MD02A	19	10.6691	48.11957	-123.409
203	MD02B	19	18.1889	48.11956	-123.41
204	MD02C	19	1.268365	48.11956	-123.41
205	MD-03	19	2.0774	48.11865	-123.406
206	MD03A	19	9.6668	48.12049	-123.408
207	MD03B	19	11.8825	48.1205	-123.408
208	MD03C	19	11.7549	48.1205	-123.408
209	MD-03-SD	19	2.07202	48.1171	-123.398
210	MD04A	19	9.7076	48.12137	-123.408
211	MD04B	19	9.2596	48.12138	-123.408
212	MD-04-SD	19	3.020126	48.11744	-123.4
213	MD05A	19	1.314279	48.12281	-123.409
214	MD05B	19	0.873221	48.1228	-123.409
215	MD05C	19	0.647315	48.1228	-123.409
216	MD-05-SD	19	1.96586	48.11776	-123.402
217	MD-06-SD	19	0.613001	48.11808	-123.404
218	MD-07-SD	19	1.979775	48.12166	-123.4
219	MD-08	19	3.0874	48.12081	-123.407
220	MD-08-SD	19	2.458185	48.12085	-123.401
221	MD-09-SD	19	4.863915	48.12005	-123.403
222	MD-10	19	8.6633	48.12024	-123.404
223	MD-10-SD	19	7.04872	48.11924	-123.404
224	MD-11-SD	19	2.74892	48.12376	-123.404
225	MD-12-SD	19	3.51085	48.12244	-123.405
226	MD-13-SD	19	6.35239	48.12107	-123.405
227	MD-14-SD	19	7.38683	48.11978	-123.406
228	MD-15-SD	19	3.65344	48.1234	-123.409
229	MD-16	19	3.352395	48.11885	-123.408
230	MD-16-SD	19	0.66942	48.12216	-123.409
231	MD-17	19	10.57357	48.11954	-123.407
232	MD-17-SD	19	6.26893	48.12089	-123.408
233	MD-18	19	1.65835	48.12021	-123.408
234	MD-18-SD	19	21.5	48.11968	-123.407
235	MD-21-SD	19	2.92198	48.12004	-123.409
236	MD-22-SD	19	3.67889	48.11904	-123.41
237	MD-23-SD	19	4.45033	48.11878	-123.408
238	MD-24-SD	19	1.277787	48.11842	-123.406
239	MD-24-SD_d	19	1.36885	48.11842	-123.406
240	NPI_PA_002-150	20	0.103905	48.13564	-123.468
241	NPI_PA_002-150_d	20	0.063258	48.13564	-123.468

Index	Location	Region ID	TEQ	Latitude	Longitude
242	NPI-L1	20	75.9031	48.13259	-123.469
243	NPI-L2	20	4.92729	48.13372	-123.468
244	NPI-L2	20	117.94	48.13372	-123.468
245	NPI-L3	20	14.6916	48.13247	-123.476
246	NPI-PA1	20	56.3095	48.13521	-123.464
247	NPI-PA1	20	0.327633	48.13521	-123.464
248	NPI-PA10	20	35.1654	48.13191	-123.46
249	NPI-PA10_d	20	34.8792	48.13191	-123.46
250	NPI-PA2	20	28.6508	48.13419	-123.463
251	NPI-PA2	20	0.22484	48.13419	-123.463
252	NPI-PA3	20	94.0608	48.13665	-123.461
253	NPI-PA4	20	105.1561	48.13514	-123.46
254	NPI-PA5	20	12.5849	48.13488	-123.458
255	NPI-PA6	20	44.1562	48.1336	-123.46
256	NPI-PA6_d	20	40.8966	48.1336	-123.46
257	NPI-PA8	20	40.2065	48.13333	-123.461
258	NPI-PA9	20	47.4447	48.13292	-123.461
259	NPI-PA9	20	2.907655	48.13292	-123.461
260	OF-05	21	0.348377	48.12703	-123.368
261	OF-05_d	21	1.148787	48.12703	-123.368
262	OF-06	21	0.290653	48.12703	-123.361
263	OH01A-R	22	1.310408	48.12769	-123.387
264	OH02A	22	0.824917	48.13136	-123.392
265	OH03A	22	0.830351	48.13428	-123.396
266	RL01A	23	0.96608	48.11968	-123.428
267	WP-01-SD	24	32.3704	48.12907	-123.455
268	WP-01-SD_d	24	40.9386	48.12907	-123.455
269	WP-02-SD	24	24.8431	48.13042	-123.456
270	WP-03-SD	24	32.2389	48.12962	-123.453
271	WP-04-SD	24	26.4348	48.12783	-123.451
272	WP-05-SD	24	13.8618	48.13154	-123.453
273	WP-06-SD	24	31.6617	48.13033	-123.458
274	WP-07-SD	24	37.5268	48.13311	-123.457
275	WP-08-SD	24	18.5984	48.13067	-123.449
276	WP-09-SD	24	11.9715	48.12656	-123.448
277	WP-10-SD	24	14.6188	48.13404	-123.451
278	WP-11-SD	24	46.267	48.13275	-123.461
279	WW01A	25	1.382449	48.12485	-123.399

Table 9. Source Profiles, 6-source solution

Congener	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
2,3,7,8-TCDD	0.7744	0.0179	0.0000	0.0692	0.0000	0.0434
1,2,3,7,8-PeCDD	0.1525	0.0619	0.0000	0.5056	0.0783	0.1518
1,2,3,4,7,8-HxCDD	0.0031	0.0069	0.0121	0.0431	0.0254	0.0136
1,2,3,6,7,8-HxCDD	0.0000	0.0376	0.3080	0.0827	0.0531	0.0000

Congener	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
1,2,3,7,8,9-HxCDD	0.0508	0.0251	0.0822	0.0913	0.0111	0.0000
1,2,3,4,6,7,8-HpCDD	0.0000	0.0662	0.3524	0.0138	0.0924	0.4610
OCDD	0.0000	0.0188	0.0524	0.0000	0.0394	0.1954
2,3,7,8-TCDF	0.0000	0.0278	0.0112	0.0460	0.1909	0.0000
1,2,3,7,8-PeCDF	0.0000	0.0087	0.0000	0.0073	0.0179	0.0033
2,3,4,7,8-PeCDF	0.0000	0.1470	0.0000	0.0889	0.3729	0.0369
1,2,3,4,7,8-HxCDF	0.0000	0.3192	0.0177	0.0149	0.0454	0.0000
1,2,3,6,7,8-HxCDF	0.0065	0.0656	0.0132	0.0193	0.0215	0.0058
1,2,3,7,8,9-HxCDF	0.0045	0.0109	0.0034	0.0014	0.0061	0.0034
2,3,4,6,7,8-HxCDF	0.0025	0.0595	0.0246	0.0161	0.0390	0.0052
1,2,3,4,6,7,8-HpCDF	0.0049	0.1030	0.1173	0.0000	0.0000	0.0530
1,2,3,4,7,8,9-HpCDF	0.0008	0.0163	0.0032	0.0006	0.0000	0.0027
OCDF	0.0000	0.0077	0.0024	0.0000	0.0065	0.0245

Table 10. Source Amounts, 6-source solution; 234 samples

Location	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
BL01A	0.0533	0.0292	0.3385	0.3767	0.0031	0.1995
BL02A	0.0763	0.0226	0.3319	0.3336	0.0139	0.2293
BL02B	0.0291	0.0578	0.3868	0.3786	0.0000	0.1787
BL02C	0.1845	0.0849	0.1996	0.4194	0.0304	0.0847
BL03A	0.1081	0.0250	0.2848	0.2651	0.0251	0.2862
BL04A	0.1510	0.0328	0.2974	0.3409	0.0394	0.1448
BL06A	0.0816	0.0333	0.2917	0.5081	0.0297	0.0518
BL08A	0.0722	0.0310	0.2890	0.4739	0.0218	0.0994
BL08B	0.1443	0.0298	0.1993	0.5462	0.0263	0.0665
CO01A	0.0981	0.0417	0.0699	0.5706	0.1261	0.1042
CO02A	0.0975	0.1223	0.1282	0.3811	0.1148	0.1667
CO02B	0.0906	0.0359	0.0626	0.5342	0.1224	0.1607
CO03A	0.2249	0.1143	0.0915	0.3801	0.0773	0.1311
CO03B	0.0302	0.7989	0.0000	0.0285	0.2072	0.0000
CO04A	0.2952	0.0198	0.0496	0.3857	0.0685	0.2050
CO05A	0.1234	0.0707	0.0598	0.5671	0.0743	0.1137
CO05B	0.0636	0.3676	0.1559	0.2287	0.1470	0.0396
DO01A	0.0823	0.0808	0.0988	0.6007	0.0746	0.0603
DO02A	0.0966	0.0000	0.2444	0.6101	0.0695	0.0091
DO03A	0.1012	0.0090	0.2411	0.4217	0.0434	0.1695
DO04A	0.1087	0.0124	0.2614	0.5009	0.0686	0.0302
DO04B	0.0659	0.0196	0.1925	0.6971	0.0097	0.0225
DO04C	0.2715	0.0237	0.1451	0.4765	0.0791	0.0005
DO05A	0.1433	0.0142	0.2443	0.5704	0.0594	0.0000
DO05B	0.0974	0.0213	0.2770	0.5743	0.0652	0.0000
DO05C	0.2209	0.0304	0.1963	0.5418	0.0177	0.0007
EC01A	0.2937	0.0160	0.0101	0.6236	0.0000	0.1082
EC03A	0.1127	0.1765	0.0987	0.3287	0.1459	0.1263
EC03B	0.0300	0.2000	0.0919	0.1569	0.1631	0.3204
EC03C	0.0275	0.3631	0.0677	0.2289	0.1412	0.1327

Location	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
EC04A	0.1131	0.0260	0.1364	0.4255	0.0566	0.2416
EC04B	0.0760	0.1722	0.1135	0.4392	0.1487	0.0533
ED01A	0.0831	0.0053	0.2151	0.3823	0.1065	0.2078
ED01B	0.3187	0.0515	0.0743	0.4748	0.0117	0.0721
ED01C	0.5038	0.0188	0.0000	0.5086	0.0000	0.0542
ED02A	0.0965	0.0331	0.1856	0.4461	0.1179	0.1209
ED02B	0.1456	0.0417	0.1171	0.5254	0.0920	0.0800
ED02C	0.1815	0.0149	0.1392	0.5849	0.0614	0.0000
ED03A	0.0745	0.0281	0.1671	0.4396	0.0808	0.2141
ED03B	0.0786	0.0424	0.2345	0.3718	0.1191	0.1657
ED03C	0.1179	0.0292	0.1582	0.4330	0.0928	0.1664
ED04A	0.1009	0.0261	0.2091	0.3945	0.0721	0.2171
ED04B	0.0570	0.0172	0.2305	0.5385	0.0591	0.1056
ED05A	0.1191	0.0926	0.1609	0.3498	0.0989	0.1883
ED05B	0.0515	0.1198	0.2832	0.2663	0.1391	0.1348
EE01A	0.3610	0.0269	0.0540	0.4039	0.0809	0.0755
EE02A	0.2331	0.0063	0.0515	0.6132	0.0110	0.1027
EE02B	0.1211	0.1192	0.0308	0.5956	0.0468	0.0830
EE03A	0.2707	0.0286	0.0906	0.4988	0.0567	0.0675
EE03B	0.1932	0.1379	0.1037	0.3976	0.0812	0.1073
EE03C	0.1654	0.0213	0.0000	0.5544	0.2381	0.0343
EI02A	0.3483	0.0068	0.1529	0.4360	0.0509	0.0223
EI04A	0.1827	0.0026	0.0928	0.6098	0.0573	0.0710
EI07A	0.1947	0.0000	0.1299	0.5798	0.0631	0.0514
EP-01-SD	0.0875	0.0296	0.1484	0.4410	0.1767	0.1267
EP-02-SD	0.0585	0.0215	0.1869	0.5118	0.1255	0.0937
EP-03-SD	0.0759	0.0211	0.1357	0.5321	0.1575	0.0876
EP-04-SD	0.0645	0.0291	0.1021	0.4655	0.1528	0.1889
EP-05-SD	0.0854	0.0195	0.1953	0.4940	0.1583	0.0543
EP-06-SD	0.0630	0.0244	0.1965	0.4771	0.1598	0.0850
EP-07-SD	0.0676	0.0248	0.2290	0.4808	0.1375	0.0580
EP-08-SD	0.0799	0.0179	0.1893	0.4579	0.1603	0.0977
EP-09-SD	0.0114	0.0336	0.0691	0.0224	0.0544	0.7097
EP-10-SD	0.0620	0.0200	0.2063	0.4860	0.1234	0.1021
EP-11-SD	0.0498	0.0302	0.1803	0.4310	0.1591	0.1578
FT01A	0.0500	0.0307	0.2483	0.4321	0.0426	0.2053
FT04A	0.0841	0.0121	0.2048	0.4211	0.0410	0.2506
FT06A	0.0634	0.0217	0.2766	0.5615	0.0292	0.0411
FT10A	0.0706	0.0175	0.2173	0.6403	0.0356	0.0138
FT12A	0.1186	0.0368	0.1833	0.5702	0.0697	0.0245
FT13A	0.1281	0.0284	0.1877	0.5877	0.0367	0.0382
FWX1	0.0614	0.0177	0.1174	0.6049	0.1581	0.0273
FWX2	0.0592	0.0509	0.1506	0.5185	0.1761	0.0364
FWX3	0.0546	0.0599	0.0887	0.5125	0.2319	0.0498
FWX4	0.0489	0.0646	0.1799	0.4236	0.2445	0.0211
FWX5	0.0000	0.0118	0.3450	0.0820	0.1643	0.4480
FWX6	0.0514	0.1174	0.1362	0.2378	0.2697	0.1773
HS-02	0.1016	0.0394	0.1888	0.3346	0.1148	0.2166
HS-03	0.0411	0.0617	0.1793	0.4585	0.1416	0.1193

Location	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
HS-04	0.0599	0.0498	0.1653	0.4702	0.1599	0.1026
HS-06	0.0000	0.1247	0.1580	0.3707	0.1547	0.1857
HS-07	0.1060	0.1132	0.2726	0.3669	0.0073	0.0881
HS-07_d	0.0957	0.0046	0.1571	0.4982	0.1630	0.0530
HS-08	0.0536	0.0628	0.1604	0.4439	0.1574	0.1145
IE01B	0.1322	0.0708	0.0000	0.6665	0.1068	0.0337
IE03A	0.0721	0.0141	0.2234	0.6171	0.0095	0.0639
IE04A	0.0780	0.0122	0.2578	0.6179	0.0000	0.0336
IE05A	0.0614	0.0293	0.2691	0.4775	0.0438	0.1122
IE05B	0.0531	0.0735	0.1849	0.5526	0.0520	0.0897
IE06A	0.0420	0.0364	0.3070	0.5236	0.0296	0.0549
IE07A	0.0628	0.0613	0.2510	0.5137	0.0126	0.0897
IE09A	0.0278	0.0729	0.5373	0.0286	0.0000	0.3793
IE09B	0.0455	0.0448	0.2570	0.0621	0.0128	0.5367
IE12A	0.0628	0.0316	0.3049	0.4227	0.0169	0.1533
IE12B	0.0326	0.0135	0.4442	0.4554	0.0281	0.0287
IE14A	0.0680	0.0351	0.3048	0.4870	0.0198	0.0756
IE14B	0.0393	0.0000	0.3965	0.6287	0.0109	0.0000
IE15A	0.0499	0.0367	0.4001	0.3503	0.0090	0.1471
IE16B	0.3339	0.0113	0.0464	0.4738	0.0891	0.0365
IH01A	0.0162	0.0861	0.5734	0.0000	0.0000	0.4389
IH02A	0.0207	0.0636	0.5075	0.1411	0.0000	0.3059
IH02B	0.0311	0.1261	0.4551	0.1631	0.0000	0.2589
IH02C	0.3466	0.0510	0.0000	0.6009	0.0113	0.0559
IH03A	0.0308	0.0221	0.5648	0.2440	0.0123	0.1298
IH04A	0.0329	0.0371	0.4830	0.3337	0.0000	0.1058
IH05A	0.0368	0.0230	0.3993	0.2955	0.0000	0.2486
IH06A	0.0324	0.0254	0.4665	0.2968	0.0000	0.1882
IH06B	0.0600	0.0385	0.4927	0.2009	0.0000	0.2186
IH06C	0.3920	0.0005	0.0000	0.5464	0.0555	0.0510
IT-06	0.0000	0.2687	0.0566	0.3201	0.3149	0.0607
IT-07	0.0235	0.1406	0.0160	0.0528	0.4830	0.2827
IT-08	0.0594	0.0706	0.0888	0.3991	0.2764	0.1108
KP01A	0.0626	0.0400	0.2742	0.3458	0.0602	0.2371
KP02A	0.0699	0.0289	0.1868	0.4202	0.0908	0.1974
KP02B	0.0450	0.0930	0.2905	0.4138	0.0000	0.1897
KP03A	0.1727	0.0290	0.1482	0.4522	0.1182	0.0949
KP03B	0.0538	0.0447	0.4330	0.2982	0.0297	0.1633
KP04A	0.1066	0.0446	0.2119	0.4694	0.0674	0.1007
KP05A	0.0533	0.0345	0.2503	0.4679	0.0435	0.1505
KP07A	0.1081	0.0294	0.2304	0.5253	0.0563	0.0531
KP07B	0.1835	0.0562	0.1298	0.5546	0.0312	0.0440
KP08B	0.2712	0.0417	0.1114	0.5398	0.0000	0.0923
LA01A	0.4068	0.0452	0.2319	0.2036	0.0000	0.1102
LA01A-01	0.2532	0.0425	0.2218	0.2648	0.0283	0.1823
LA02A	0.2068	0.0391	0.2981	0.3634	0.0000	0.0957
LA02A-01	0.1466	0.0942	0.2338	0.3263	0.0249	0.1499
LA02B	0.1385	0.0079	0.0000	0.6513	0.1957	0.0217
LA02C	0.2803	0.0192	0.0000	0.5491	0.1794	0.0163

Location	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
LA03A	0.6005	0.0179	0.2148	0.0959	0.0095	0.0682
LA03A-01	0.1495	0.0373	0.2735	0.3140	0.0585	0.1651
LP01A	0.0716	0.0078	0.1771	0.4029	0.0772	0.2749
LP-02	0.1282	0.1141	0.1051	0.3980	0.2428	0.0134
LP-02-SD	0.0156	0.0297	0.1312	0.5617	0.2012	0.0901
LP-03	0.0498	0.1273	0.0288	0.5265	0.2029	0.0964
LP03A	0.0685	0.0370	0.0820	0.5295	0.1378	0.1476
LP-03-SD	0.0685	0.0217	0.0307	0.6487	0.1702	0.0771
LP-04	0.1397	0.0550	0.0585	0.3987	0.1274	0.1918
LP04A	0.0768	0.0692	0.0757	0.5270	0.1752	0.0866
LP-04-SD	0.0465	0.0384	0.0426	0.5933	0.1118	0.1816
LP-05	0.0892	0.1460	0.0996	0.3471	0.1947	0.1134
LP05A	0.0373	0.0572	0.1309	0.4611	0.1066	0.2095
LP-06	0.0279	0.0476	0.0378	0.7687	0.0813	0.0873
LP-07-SD	0.0961	0.0287	0.0000	0.5852	0.2085	0.1094
LP-08	0.1316	0.0681	0.1940	0.3017	0.2216	0.0809
LP-08-SD	0.0736	0.0643	0.0116	0.4678	0.2972	0.1131
LP-09	0.1027	0.0356	0.0725	0.4005	0.2518	0.1498
LP-10	0.0787	0.0610	0.1201	0.3909	0.2200	0.1318
LP-11	0.2198	0.0167	0.2514	0.0159	0.4009	0.0579
LP-12	0.0000	0.0610	0.1541	0.2779	0.1725	0.2990
LP-12_d	0.0000	0.0708	0.1530	0.5232	0.2132	0.0382
LP-13	0.0437	0.0374	0.1362	0.4989	0.0872	0.2148
LP-13_d	0.0186	0.0491	0.1178	0.5846	0.0896	0.1462
LP-14	0.0000	0.1058	0.1248	0.5515	0.1460	0.0881
LP-15	0.0815	0.1293	0.0290	0.4089	0.3207	0.0569
LP-16	0.0483	0.5472	0.0245	0.2883	0.0891	0.0064
LP-17_d	0.1172	0.0000	0.2227	0.4450	0.2309	0.0000
LP-18	0.0632	0.1744	0.1150	0.3480	0.1719	0.1233
LP-18	0.0498	0.3271	0.2180	0.0278	0.2865	0.0917
LP-20	0.1072	0.0833	0.1311	0.3051	0.3128	0.0712
LP-20	0.0000	0.1952	0.1201	0.1130	0.4935	0.1245
MA01A	0.0000	0.0110	0.4145	0.5234	0.0000	0.1537
MA02A	0.0185	0.0280	0.3532	0.2286	0.0000	0.3641
MA02B	0.0208	0.0000	0.5115	0.4813	0.0000	0.0145
MA02C	0.0351	0.0589	0.4076	0.2811	0.0000	0.2351
MA03A	0.0362	0.0449	0.4057	0.3341	0.0000	0.1763
MA04A	0.0120	0.0216	0.3741	0.1750	0.0000	0.4082
MA05A	0.0458	0.0398	0.3988	0.4519	0.0066	0.0531
MD01A	0.0314	0.0129	0.2782	0.2266	0.0534	0.4092
MD01B	0.0530	0.0439	0.1724	0.3994	0.0761	0.2262
MD-02	0.0780	0.0441	0.0774	0.3996	0.2112	0.2037
MD02A	0.0491	0.0322	0.1364	0.3845	0.0760	0.3147
MD02B	0.0454	0.0914	0.1255	0.5016	0.1225	0.1040
MD02C	0.0989	0.0000	0.0141	0.6727	0.2125	0.0015
MD-03	0.0740	0.1092	0.0972	0.3034	0.1962	0.2161
MD03A	0.0485	0.0412	0.1122	0.4760	0.0872	0.2279
MD03B	0.1005	0.0416	0.0840	0.6050	0.1064	0.0586
MD03C	0.1294	0.0523	0.0907	0.5814	0.0939	0.0449

Location	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
MD04A	0.0412	0.0620	0.1587	0.2250	0.0567	0.4196
MD04B	0.1067	0.0561	0.1720	0.3730	0.0990	0.1757
MD-04-SD	0.1137	0.0000	0.1271	0.3917	0.1708	0.2754
MD05A	0.0845	0.0208	0.1637	0.6122	0.0729	0.0477
MD05B	0.1218	0.0297	0.1608	0.5908	0.0576	0.0412
MD05C	0.1294	0.0307	0.1662	0.5721	0.0674	0.0417
MD-07-SD	0.1142	0.0575	0.0000	0.5848	0.1031	0.1725
MD-08	0.0026	0.1040	0.2644	0.2160	0.1170	0.3330
MD-08-SD	0.1074	0.0409	0.2348	0.2639	0.3382	0.0000
MD-09-SD	0.0714	0.0274	0.1037	0.5517	0.1642	0.0859
MD-10	0.1557	0.0000	0.1266	0.4185	0.2317	0.0497
MD-10-SD	0.0060	0.0013	0.0397	0.4991	0.3192	0.1302
MD-12-SD	0.0770	0.0000	0.1471	0.4457	0.1294	0.2340
MD-13-SD	0.1086	0.0251	0.0702	0.4996	0.2123	0.0864
MD-14-SD	0.0633	0.0541	0.1246	0.5723	0.1042	0.0864
MD-15-SD	0.0984	0.0231	0.0377	0.6156	0.1681	0.0787
MD-17	0.3006	0.0507	0.2155	0.0000	0.0776	0.3626
MD-17-SD	0.1123	0.0336	0.1962	0.1228	0.2409	0.2916
MD-18-SD	0.0315	0.0000	0.1780	0.1884	0.0536	0.6167
MD-21-SD	0.0830	0.0238	0.0000	0.6351	0.2187	0.0855
MD-22-SD	0.0946	0.0398	0.0736	0.6115	0.0400	0.1221
MD-23-SD	0.0245	0.1545	0.1544	0.1541	0.0658	0.4853
MD-24-SD	0.1502	0.0556	0.1070	0.5216	0.0111	0.1709
NPI-L1	0.1953	0.0389	0.3021	0.3165	0.0453	0.1091
NPI-L2	0.1044	0.0527	0.3062	0.4149	0.0435	0.0820
NPI-L2	0.0802	0.0120	0.4098	0.3497	0.0334	0.1222
NPI-L3	0.1664	0.0545	0.1888	0.4147	0.0437	0.1244
NPI-PA1	0.0436	0.0430	0.3542	0.1235	0.0516	0.3842
NPI-PA10	0.0268	0.0357	0.4414	0.1258	0.0484	0.3528
NPI-PA10_d	0.0275	0.0373	0.4284	0.1249	0.0402	0.3567
NPI-PA2	0.0463	0.0509	0.3908	0.2907	0.0761	0.1647
NPI-PA3	0.0256	0.0767	0.4446	0.0145	0.0493	0.4172
NPI-PA4	0.0188	0.0553	0.4610	0.1058	0.0143	0.3776
NPI-PA5	0.0464	0.0418	0.3270	0.3186	0.0420	0.2424
NPI-PA6	0.0229	0.0559	0.3935	0.1478	0.0262	0.3675
NPI-PA6_d	0.0336	0.0612	0.4257	0.1447	0.0377	0.3229
NPI-PA8	0.0254	0.0342	0.3995	0.0778	0.0494	0.4343
NPI-PA9	0.0265	0.0545	0.3928	0.1039	0.0340	0.3993
NPI-PA9	0.0856	0.0944	0.4825	0.1804	0.0202	0.1425
OF-05_d	0.1219	0.0043	0.2098	0.5482	0.1225	0.0000
OH01A-R	0.1119	0.0305	0.2668	0.5615	0.0549	0.0000
OH02A	0.0985	0.0297	0.2507	0.5611	0.0553	0.0030
OH03A	0.1300	0.0457	0.2492	0.5072	0.0600	0.0042
RL01A	0.0639	0.0258	0.1700	0.6039	0.0347	0.1080
WP-01-SD	0.0424	0.0465	0.4405	0.2198	0.0512	0.1976
WP-01-SD_d	0.0400	0.0274	0.4743	0.2301	0.0424	0.1740
WP-02-SD	0.0384	0.0596	0.4203	0.2307	0.0501	0.2052
WP-03-SD	0.0204	0.0609	0.2637	0.0471	0.0373	0.5202
WP-04-SD	0.0906	0.0376	0.3692	0.3076	0.0569	0.1364

Location	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
WP-05-SD	0.0088	0.0691	0.2578	0.3771	0.1119	0.1753
WP-06-SD	0.0362	0.0395	0.4449	0.2672	0.0562	0.1590
WP-07-SD	0.0353	0.0493	0.4121	0.1737	0.0515	0.2949
WP-08-SD	0.0667	0.0767	0.2279	0.4638	0.0968	0.0655
WP-09-SD	0.0499	0.0208	0.2953	0.3755	0.0963	0.1653
WP-10-SD	0.0026	0.0509	0.3590	0.2353	0.0504	0.3048
WP-11-SD	0.0119	0.4050	0.2204	0.0000	0.0131	0.2761
WW01A	0.0998	0.0321	0.2101	0.5828	0.0566	0.0292

Table 11. Source Profiles, 4-source solution

Congener	Source 1	Source 2	Source 3	Source 4
2,3,7,8-TCDD	0.6895	0.0000	0.0196	0.0678
1,2,3,7,8-PeCDD	0.2215	0.0666	0.0515	0.4383
1,2,3,4,7,8-HxCDD	0.0088	0.0158	0.0111	0.0401
1,2,3,6,7,8-HxCDD	0.0000	0.0000	0.1712	0.1174
1,2,3,7,8,9-HxCDD	0.0537	0.0000	0.0433	0.0916
1,2,3,4,6,7,8-HpCDD	0.0000	0.1106	0.4162	0.0457
OCDD	0.0006	0.0600	0.1210	0.0000
2,3,7,8-TCDF	0.0000	0.1210	0.0000	0.0531
1,2,3,7,8-PeCDF	0.0010	0.0151	0.0000	0.0067
2,3,4,7,8-PeCDF	0.0017	0.2919	0.0019	0.0928
1,2,3,4,7,8-HxCDF	0.0047	0.1709	0.0195	0.0041
1,2,3,6,7,8-HxCDF	0.0087	0.0406	0.0113	0.0170
1,2,3,7,8,9-HxCDF	0.0041	0.0087	0.0036	0.0015
2,3,4,6,7,8-HxCDF	0.0032	0.0466	0.0167	0.0172
1,2,3,4,6,7,8-HpCDF	0.0012	0.0355	0.0962	0.0068
1,2,3,4,7,8,9-HpCDF	0.0012	0.0051	0.0039	0.0000
OCDF	0.0000	0.0117	0.0130	0.0000

Table 12. Source Amounts, 4-source solution; 234 samples

Location	Source 1	Source 2	Source 3	Source 4
BL01A	0.0535	0.0192	0.4770	0.4436
BL02A	0.0811	0.0305	0.5027	0.3927
BL02B	0.0247	0.0000	0.5076	0.4455
BL02C	0.2052	0.0887	0.2351	0.4549
BL03A	0.1223	0.0576	0.5174	0.3109
BL04A	0.1631	0.0583	0.3907	0.3819
BL06A	0.0796	0.0321	0.2794	0.5803
BL08A	0.0716	0.0292	0.3247	0.5452
BL08B	0.1562	0.0366	0.2007	0.6080
CO01A	0.1094	0.1599	0.0998	0.6565
CO02A	0.1129	0.2183	0.2392	0.4425

Location	Source 1	Source 2	Source 3	Source 4
CO02B	0.1042	0.1596	0.1492	0.6193
CO03A	0.2586	0.1765	0.1763	0.4063
CO03B	0.0582	0.8338	0.0045	0.0349
CO04A	0.3412	0.1090	0.2022	0.4018
CO05A	0.1418	0.1328	0.1045	0.6400
CO05B	0.0754	0.4252	0.1716	0.2671
DO01A	0.0906	0.1295	0.0882	0.6848
DO02A	0.0929	0.0163	0.1779	0.6962
DO03A	0.1092	0.0493	0.3474	0.4853
DO04A	0.1090	0.0557	0.2283	0.5696
DO04B	0.0646	0.0016	0.1351	0.7923
DO04C	0.2987	0.0862	0.0943	0.5025
DO05A	0.1468	0.0426	0.1575	0.6367
DO05B	0.0921	0.0476	0.1716	0.6515
DO05C	0.2404	0.0230	0.1398	0.5814
EC01A	0.3384	0.0000	0.0540	0.6541
EC03A	0.1310	0.2904	0.1795	0.3786
EC03B	0.0479	0.3518	0.3698	0.2130
EC03C	0.0434	0.4328	0.1722	0.2767
EC04A	0.1320	0.0931	0.3124	0.4894
EC04B	0.0842	0.2759	0.1127	0.5092
ED01A	0.0901	0.1163	0.3573	0.4543
ED01B	0.3625	0.0562	0.0989	0.4831
ED01C	0.5771	0.0000	0.0000	0.4714
ED02A	0.1029	0.1398	0.2419	0.5187
ED02B	0.1611	0.1207	0.1320	0.5903
ED02C	0.1958	0.0558	0.0663	0.6428
ED03A	0.0845	0.1112	0.3127	0.5163
ED03B	0.0831	0.1508	0.3390	0.4419
ED03C	0.1316	0.1204	0.2610	0.4978
ED04A	0.1128	0.0997	0.3624	0.4598
ED04B	0.0559	0.0599	0.2632	0.6259
ED05A	0.1364	0.1802	0.2952	0.4034
ED05B	0.0509	0.2244	0.3706	0.3275
EE01A	0.4091	0.1115	0.0858	0.4024
EE02A	0.2657	0.0206	0.0858	0.6615
EE02B	0.1416	0.1413	0.0480	0.6654
EE03A	0.3047	0.0799	0.1027	0.5275
EE03B	0.2215	0.1935	0.1640	0.4318
EE03C	0.1827	0.2559	0.0000	0.6316
EI02A	0.3871	0.0500	0.1299	0.4382
EI04A	0.2033	0.0556	0.0924	0.6739
EI07A	0.2135	0.0463	0.1131	0.6382
EP-01-SD	0.0932	0.1998	0.2074	0.5214
EP-02-SD	0.0575	0.1326	0.2085	0.6011
EP-03-SD	0.0786	0.1677	0.1494	0.6228
EP-04-SD	0.0730	0.1862	0.2182	0.5534
EP-05-SD	0.0848	0.1593	0.1808	0.5773
EP-06-SD	0.0610	0.1681	0.2116	0.5648

Location	Source 1	Source 2	Source 3	Source 4
EP-07-SD	0.0639	0.1400	0.2194	0.5646
EP-08-SD	0.0810	0.1666	0.2188	0.5400
EP-09-SD	0.0446	0.1684	0.7229	0.0751
EP-10-SD	0.0611	0.1294	0.2383	0.5718
EP-11-SD	0.0508	0.1830	0.2684	0.5186
FT01A	0.0533	0.0670	0.3859	0.5101
FT04A	0.0959	0.0613	0.3873	0.4920
FT06A	0.0584	0.0212	0.2478	0.6444
FT10A	0.0677	0.0242	0.1558	0.7301
FT12A	0.1246	0.0804	0.1403	0.6433
FT13A	0.1364	0.0420	0.1574	0.6582
FWX1	0.0595	0.1569	0.0677	0.7051
FWX2	0.0568	0.2005	0.1181	0.6101
FWX3	0.0541	0.2709	0.0675	0.6100
FWX4	0.0418	0.2781	0.1385	0.5124
FWX5	0.0000	0.2021	0.7336	0.1583
FWX6	0.0565	0.3719	0.2616	0.3096
HS-02	0.1141	0.1560	0.3465	0.3956
HS-03	0.0406	0.1843	0.2309	0.5466
HS-04	0.0608	0.1927	0.1994	0.5571
HS-06	0.0000	0.2571	0.2815	0.4618
HS-07	0.1143	0.0808	0.3156	0.4106
HS-07_d	0.0976	0.1539	0.1425	0.5797
HS-08	0.0551	0.2025	0.2092	0.5282
IE01B	0.1500	0.1589	0.0000	0.7484
IE03A	0.0723	0.0016	0.2124	0.7033
IE04A	0.0759	0.0000	0.2184	0.7011
IE05A	0.0602	0.0530	0.3150	0.5546
IE05B	0.0552	0.0975	0.2051	0.6378
IE06A	0.0340	0.0324	0.2943	0.6071
IE07A	0.0637	0.0441	0.2760	0.5888
IE09A	0.0271	0.0431	0.8783	0.0652
IE09B	0.0669	0.0968	0.7453	0.1037
IE12A	0.0631	0.0311	0.3959	0.4917
IE12B	0.0146	0.0000	0.4100	0.5345
IE14A	0.0650	0.0257	0.3169	0.5597
IE14B	0.0193	0.0000	0.2746	0.7236
IE15A	0.0441	0.0193	0.4913	0.4133
IE16B	0.3755	0.1000	0.0333	0.4866
IH01A	0.0161	0.0484	0.9763	0.0041
IH02A	0.0164	0.0161	0.7688	0.1883
IH02B	0.0313	0.0485	0.6755	0.2024
IH02C	0.3994	0.0624	0.0000	0.6161
IH03A	0.0132	0.0000	0.6456	0.3013
IH04A	0.0191	0.0000	0.5354	0.3969
IH05A	0.0343	0.0109	0.5903	0.3588
IH06A	0.0232	0.0000	0.6000	0.3585
IH06B	0.0559	0.0017	0.6660	0.2448
IH06C	0.4468	0.0671	0.0000	0.5514

Location	Source 1	Source 2	Source 3	Source 4
IT-06	0.0000	0.5258	0.0669	0.4081
IT-07	0.0314	0.6319	0.2486	0.1333
IT-08	0.0622	0.3354	0.1336	0.4884
KP01A	0.0680	0.0958	0.4497	0.4138
KP02A	0.0772	0.1192	0.3174	0.4958
KP02B	0.0491	0.0408	0.4213	0.4800
KP03A	0.1901	0.1390	0.1825	0.5067
KP03B	0.0478	0.0476	0.5427	0.3577
KP04A	0.1139	0.0932	0.2500	0.5359
KP05A	0.0541	0.0630	0.3333	0.5470
KP07A	0.1120	0.0615	0.2179	0.5960
KP07B	0.2039	0.0657	0.1133	0.6055
KP08B	0.3085	0.0000	0.1479	0.5638
LA01A	0.4581	0.0255	0.3213	0.1588
LA01A-01	0.2861	0.0699	0.3645	0.2711
LA02A	0.2259	0.0012	0.3489	0.3851
LA02A-01	0.1644	0.0954	0.3394	0.3603
LA02B	0.1525	0.1989	0.0000	0.7417
LA02C	0.3157	0.1986	0.0000	0.5915
LA03A	0.6760	0.0316	0.2804	0.0000
LA03A-01	0.1635	0.0858	0.3883	0.3541
LP01A	0.0831	0.0997	0.3821	0.4793
LP-02	0.1374	0.3232	0.0652	0.4618
LP-02-SD	0.0094	0.2174	0.1396	0.6749
LP-03	0.0574	0.3060	0.0543	0.6223
LP03A	0.0770	0.1723	0.1549	0.6203
LP-03-SD	0.0743	0.1855	0.0237	0.7552
LP-04	0.1628	0.1882	0.1905	0.4558
LP04A	0.0838	0.2276	0.0917	0.6160
LP-04-SD	0.0563	0.1528	0.1421	0.6952
LP-05	0.1009	0.3127	0.1615	0.4111
LP05A	0.0439	0.1611	0.2691	0.5497
LP-06	0.0318	0.1138	0.0325	0.8893
LP-07-SD	0.1086	0.2386	0.0224	0.6821
LP-08	0.1394	0.2694	0.2246	0.3568
LP-08-SD	0.0814	0.3562	0.0521	0.5644
LP-09	0.1136	0.2901	0.1557	0.4803
LP-10	0.0849	0.2713	0.1885	0.4702
LP-11	0.2295	0.4096	0.2801	0.0364
LP-12	0.0026	0.2419	0.3901	0.3629
LP-12_d	0.0000	0.2523	0.1174	0.6354
LP-13	0.0510	0.1260	0.2756	0.5901
LP-13_d	0.0200	0.1279	0.1842	0.6884
LP-14	0.0000	0.2214	0.1381	0.6584
LP-15	0.0887	0.4237	0.0247	0.4941
LP-16	0.0710	0.5126	0.0162	0.3202
LP-17_d	0.1115	0.1803	0.1317	0.5215
LP-18	0.0728	0.3111	0.1873	0.4146
LP-18	0.0543	0.5398	0.2910	0.0648

Location	Source 1	Source 2	Source 3	Source 4
LP-20	0.1123	0.3759	0.1483	0.3744
LP-20	0.0000	0.6543	0.1969	0.2023
MA01A	0.0000	0.0000	0.4951	0.6147
MA02A	0.0221	0.0256	0.6603	0.2904
MA02B	0.0000	0.0000	0.4601	0.5639
MA02C	0.0334	0.0123	0.5906	0.3379
MA03A	0.0306	0.0100	0.5267	0.3972
MA04A	0.0155	0.0365	0.7261	0.2356
MA05A	0.0346	0.0054	0.3916	0.5242
MD01A	0.0404	0.0907	0.6249	0.2951
MD01B	0.0611	0.1203	0.3336	0.4751
MD-02	0.0894	0.2618	0.2127	0.4827
MD02A	0.0626	0.1256	0.3820	0.4631
MD02B	0.0489	0.1896	0.1624	0.5889
MD02C	0.1035	0.1999	0.0000	0.7771
MD-03	0.0880	0.2991	0.2575	0.3713
MD03A	0.0584	0.1328	0.2675	0.5628
MD03B	0.1096	0.1319	0.0690	0.6904
MD03C	0.1423	0.1267	0.0673	0.6548
MD04A	0.0599	0.1440	0.5208	0.2860
MD04B	0.1196	0.1486	0.2900	0.4326
MD-04-SD	0.1296	0.1687	0.3288	0.4692
MD05A	0.0871	0.0739	0.1364	0.7001
MD05B	0.1302	0.0664	0.1322	0.6651
MD05C	0.1383	0.0774	0.1396	0.6436
MD-07-SD	0.1366	0.1640	0.0820	0.6674
MD-08	0.0065	0.2164	0.5409	0.2892
MD-08-SD	0.1015	0.3518	0.1824	0.3306
MD-09-SD	0.0750	0.1808	0.1144	0.6459
MD-10	0.1649	0.2178	0.1153	0.4841
MD-10-SD	0.0010	0.3248	0.0876	0.6211
MD-12-SD	0.0860	0.1230	0.3062	0.5309
MD-13-SD	0.1178	0.2321	0.0860	0.5836
MD-14-SD	0.0674	0.1393	0.1374	0.6634
MD-15-SD	0.1083	0.1857	0.0368	0.7109
MD-17	0.3490	0.1575	0.5539	0.0000
MD-17-SD	0.1266	0.2916	0.4387	0.1728
MD-18-SD	0.0550	0.1005	0.7230	0.2615
MD-21-SD	0.0918	0.2408	0.0000	0.7420
MD-22-SD	0.1085	0.0715	0.1217	0.6941
MD-23-SD	0.0480	0.2339	0.5880	0.2125
MD-24-SD	0.1742	0.0624	0.2132	0.5795
NPI-L1	0.2118	0.0655	0.3662	0.3430
NPI-L2	0.1070	0.0664	0.3320	0.4727
NPI-L2	0.0754	0.0220	0.4757	0.4089
NPI-L3	0.1856	0.0842	0.2593	0.4579
NPI-PA1	0.0510	0.1053	0.6887	0.1740
NPI-PA10	0.0258	0.0841	0.7438	0.1812
NPI-PA10_d	0.0277	0.0790	0.7355	0.1786

Location	Source 1	Source 2	Source 3	Source 4
NPI-PA2	0.0404	0.1016	0.5013	0.3550
NPI-PA3	0.0295	0.1269	0.8205	0.0573
NPI-PA4	0.0189	0.0663	0.7910	0.1572
NPI-PA5	0.0481	0.0746	0.5101	0.3857
NPI-PA6	0.0258	0.0826	0.7107	0.2028
NPI-PA6_d	0.0341	0.0901	0.7008	0.1968
NPI-PA8	0.0305	0.0991	0.7837	0.1301
NPI-PA9	0.0314	0.0946	0.7438	0.1548
NPI-PA9	0.0830	0.0713	0.5887	0.2141
OF-05_d	0.1222	0.1004	0.1253	0.6235
OH01A-R	0.1101	0.0470	0.1718	0.6325
OH02A	0.0973	0.0519	0.1871	0.6365
OH03A	0.1339	0.0714	0.1938	0.5684
RL01A	0.0676	0.0460	0.2015	0.6939
WP-01-SD	0.0358	0.0744	0.5893	0.2756
WP-01-SD_d	0.0297	0.0452	0.5987	0.2866
WP-02-SD	0.0331	0.0855	0.5760	0.2882
WP-03-SD	0.0371	0.1302	0.7365	0.0942
WP-04-SD	0.0903	0.0712	0.4540	0.3606
WP-05-SD	0.0042	0.1611	0.3697	0.4621
WP-06-SD	0.0260	0.0678	0.5517	0.3296
WP-07-SD	0.0343	0.0919	0.6570	0.2294
WP-08-SD	0.0666	0.1406	0.2319	0.5391
WP-09-SD	0.0472	0.1054	0.3969	0.4516
WP-10-SD	0.0001	0.0959	0.6069	0.3052
WP-11-SD	0.0312	0.3470	0.4875	0.0113
WW01A	0.1022	0.0613	0.1694	0.6612