

## **6.0 Fingerprinting Analysis of Sediment Data**

Screening-level fingerprinting evaluations for TPH, PAH, and dioxin/furan sediment data were conducted to determine if they could be used to differentiate between potential contaminant sources. This was done by evaluating the Oakland Bay investigation data set for quantity and quality of data and then comparing the appropriate values with known source data. A technical memo was developed to justify the fingerprinting process for each contaminant type based on data usability (Appendix K).

For this investigation, concentrations of all analytes reported between the method detection limit (MDL) and practical quantitation limit (PQL [also known as reporting limit]) have all been annotated with a “J” qualifier (estimated concentration), indicating a high level of uncertainty in the quantitative value. Statistical evaluations of data whose uncertainties are “high” can lead to erroneous conclusions, especially if the sample populations being compared are limited in size or are highly censored (high percentages of non-detect data). To determine the usefulness of the analytical data for differentiating between possible sources of contaminants, only un-qualified data measured at concentrations at least three times above the practical quantitation limit were evaluated.

Petroleum hydrocarbons were rarely detected, and when detected, had concentrations close to detection limits. No petroleum data met the minimum requirement for additional evaluation. Based on the inherent limitations in TPH analyses and the highly censored nature of these data, conducting a detailed fingerprinting analysis was determined not be practicable.

PAH data from Oakland Bay and Hammersley Inlet also were highly censored (a large number of non-detect data), with only a single non-qualified positive result greater than three times the PQL. In Shelton Harbor, 82 percent of surface sediment and 84 percent of subsurface sediment PAH data were determined to be of relatively high quantitative uncertainty (Taylor 1987). Assuming that a minimum of five individual PAHs must be present in a sample at concentrations greater than three times the PQL for fingerprint analysis, then approximately one-sixth of the stations would have sufficient data at one or more depth intervals to evaluate relative ratios of individual PAH concentrations. Even if the data set is restricted to only Shelton Harbor, more than three-quarters of the stations failed to meet the minimum requirement of five individual PAHs with un-qualified concentrations more than three times the PQL. Based on the small amount of viable data, fingerprinting PAHs in Oakland Bay, Hammersley Inlet, or Shelton Harbor would not provide reliable results.

Enough dioxin/furan data from Oakland Bay, Hammersley Inlet, and Shelton Harbor with un-qualified values at concentrations at least three times the PQL were available for fingerprinting analysis.

## 6.1 Fingerprinting Analysis of Dioxins and Furans

Dioxins and furans come from many sources such as waste incineration, power/energy generation, minimally controlled and uncontrolled combustion, chemical manufacturing, and natural sources. Each source generates its own specific mixture and concentrations of congeners that in some cases can be used as a “fingerprint” for source identification in environment samples.

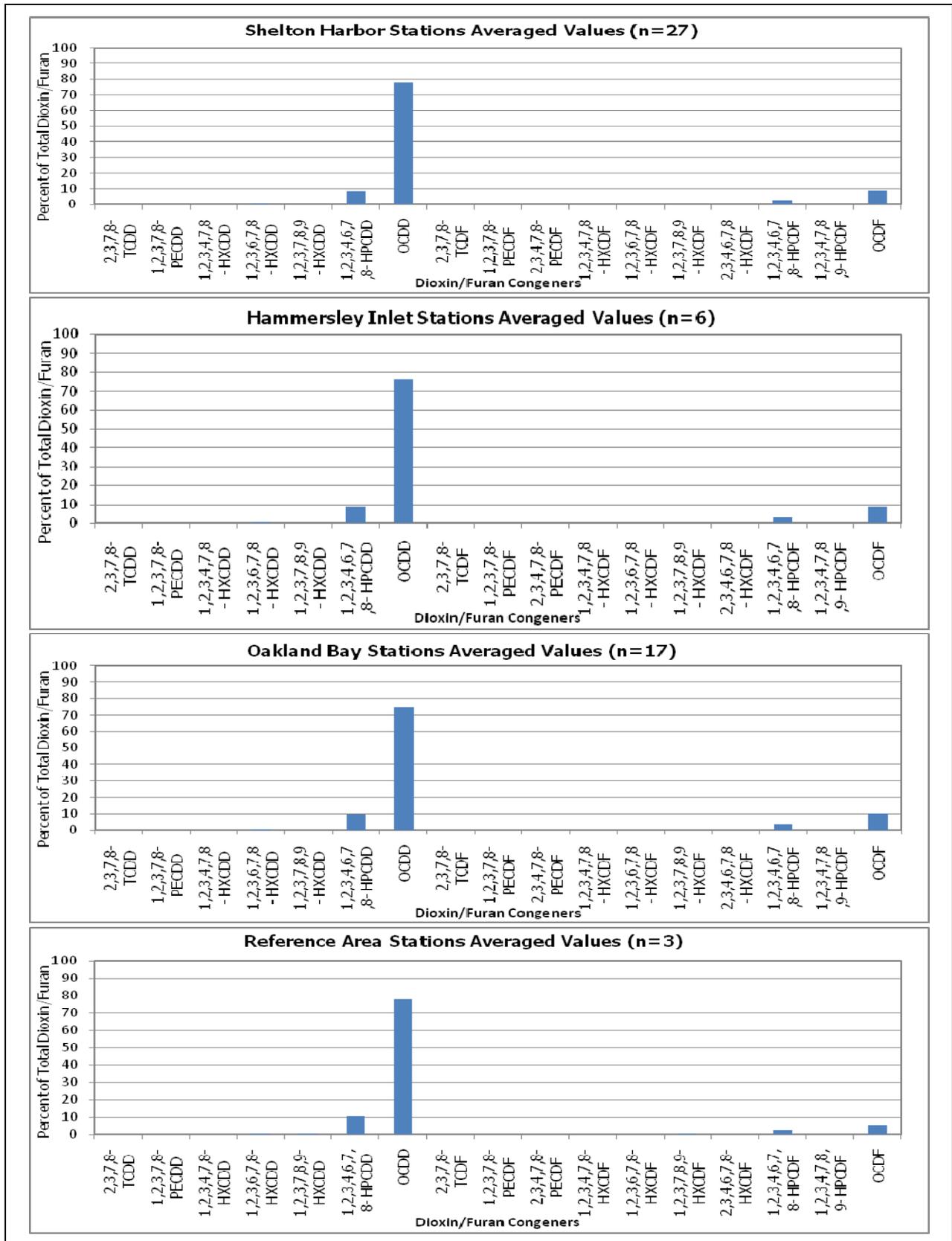
Dioxins and furans are families of related compounds with from 1 to 8 chlorine atoms located at various positions around a base carbon ring structure. Each unique compound is referred to as a congener. Congeners with the same number of chlorine atoms are referred to as homologues. There are 75 different dioxin congeners and 135 different furan congeners. Congeners vary significantly in their toxicity. Dioxin and furan congener source information has been used to generate visual profiles (bar graphs) in *An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States for the Years 1987, 1995, and 2000* (USEPA 2006).

The bar graphs show the proportion of each congener (17 congeners in all) to the total mass of the dioxin and furan congeners. These visual profiles can be compared to profiles from environmental samples to identify possible dioxin and furan sources in the environment. In comparing the profiles, the evaluator looks for the presence of similar congeners (bars) that are also at approximately the same proportion (graph height). The more congeners found in the samples that match a source type, the better the fit. In some cases, there are multiple chemical sources, which create a mixture of dioxins and furans; this requires advanced statistical analysis to determine possible source types. In some cases, more than one USEPA source profile may match the environmental samples and additional sampling or further site investigations may be needed.

In addition to USEPA source identification, dioxin and furan profiles of environmental samples can be used to compare different site areas, other nearby sites, and background/reference areas. Statistical analysis of the values used to create the graphs is often used to determine if samples are from different sources or from the same source. In this section, the dioxin and furan profiles from Oakland Bay are compared by sub-area (Oakland Bay, Shelton Harbor, Hammersley Inlet, and reference stations); and are compared to data from Goose Lake, background dioxin/furan data from sub-basins within Puget Sound, and to selected profiles from the USEPA source inventory.

## 6.2 Proportional Distribution of Dioxins/Furans Congener Concentrations

The proportion that each dioxin/furan congener contributes to the total concentration of congeners across the study area and for each sub-basin is shown on Figure 6-1. The visual analysis of the graphs from each of the three sub-basins indicates that the source of dioxins and furans are consistent throughout the study area. Note that the profile for the reference area stations is quite similar as well, although concentrations in the reference samples were significantly lower than that found in the study area. Table 6-1 provides a breakdown of the primary dioxin/furan congeners found across the Oakland Bay study area and reference area



**Figure 6-1. Relative percent of congeners (compared to total dioxin/furan congeners) from Shelton Harbor, Hammersley Inlet, Oakland Bay and Reference Area.**

samples based on the 53 samples collected. The remaining congeners represent less than 1 percent each of the total congener dioxin/furan mass.

**Table 6-1. Primary dioxin/furan congeners found across the Oakland Bay study area.**

| Study Area       | Congener            | Mean Total Dioxin/Furan Congeners by Mass (%) |
|------------------|---------------------|---|
| Hammersley Inlet | 1,2,3,4,6,7,8-HpCDD | 9.20  |
| Oakland Bay      |                     | 9.59  |
| Shelton Harbor   |                     | 8.35  |
| Total Study Area |                     | 8.96  |
| Hammersley Inlet | OCDD                | 76.4  |
| Oakland Bay      |                     | 74.8  |
| Shelton Harbor   |                     | 78.0  |
| Total Study Area |                     | 76.7  |
| Hammersley Inlet | 1,2,3,4,6,7,8-HpCDF | 3.20  |
| Oakland Bay      |                     | 3.60  |
| Shelton Harbor   |                     | 2.85  |
| Total Study Area |                     | 3.12  |
| Hammersley Inlet | OCDF                | 8.98  |
| Oakland Bay      |                     | 9.80  |
| Shelton Harbor   |                     | 9.05  |
| Total Study Area |                     | 9.09  |

### 6.3 Comparison of Oakland Bay Study Sediment Dioxins/Furans Congener Data to Goose Lake Congener Data

Sulfite liquor waste from the Rayonier pulp and paper mill was discharged to Goose Lake from the early 1930s to the mid-1940s. A comparison of dioxin and furan congener data from Goose Lake and its associated drainage ravine and Oakland Bay was conducted to determine if similarities exist between the two profiles. Goose Lake dioxin/furan data were obtained from Ecology’s Environmental Information Management (EIM) website.

The dioxin/furan congener proportional-distribution profiles of the Goose Lake dataset indicate greater variability than those of Oakland Bay, as determined by a comparison of coefficient of variation (CV); a greater CV indicates greater variability in the sample population. Specifically, the proportion of octachlorodibenzo-p-dioxin (OCDD) in sediment samples from Goose Lake has a mean percent value of 56.4, with a standard deviation of 17.8 (CV=0.32) compared to the entire set of Oakland Bay study samples, with a mean percent value of 76.7 and standard deviation of only 4.43 (CV=0.06). Figure 6-2a illustrates the variability in dioxin/furan congener

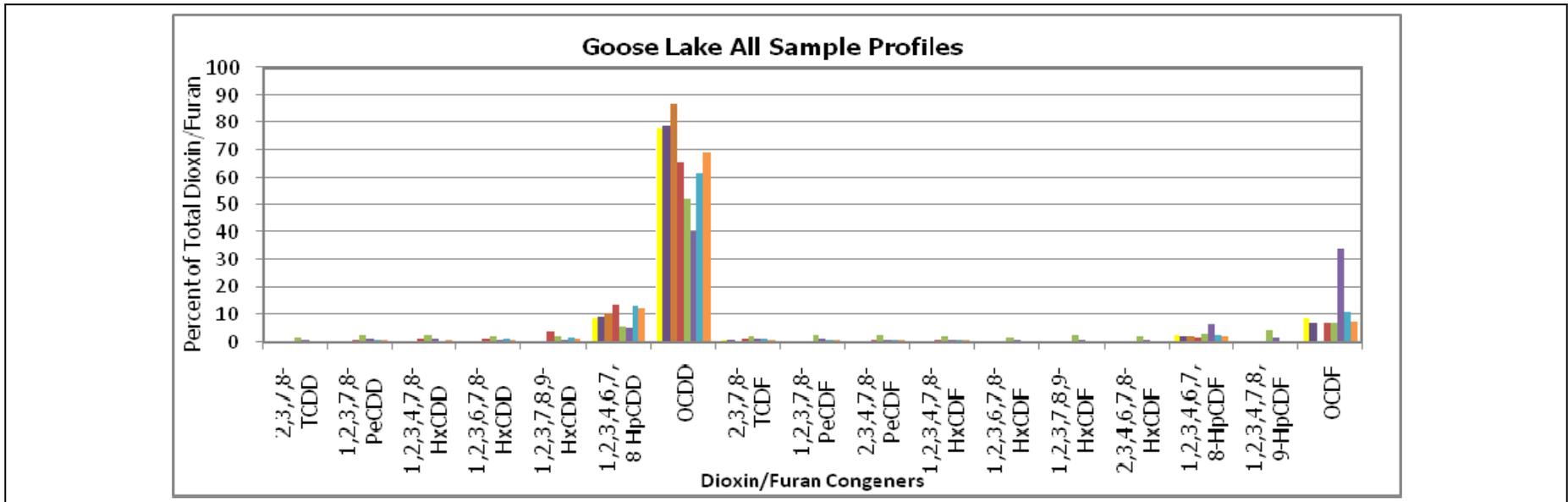


Figure 6-2a. Proportions of dioxin/furan congeners from *all* samples collected from Goose Lake data (n=8).

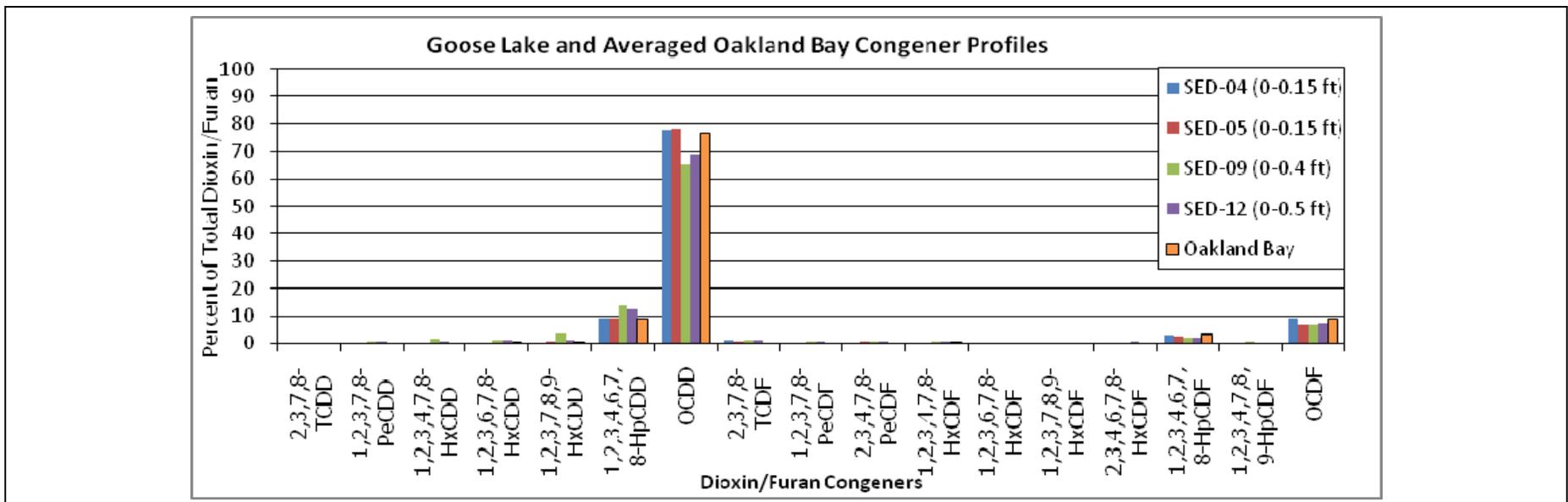


Figure 6-2b. Average proportions of dioxin/furan congeners in sediment from the Oakland Bay study area compared to four Goose Lake surface sediment samples having total congener concentrations greater than 150 parts per trillion dry weight.

proportional-distribution profiles among each of the eight sediment samples collected at Goose Lake. Surface sample results only are provided in Figure 6-2b, along with the average Oakland Bay profile. Table 6-2 presents Goose Lake sample results by location and depth. The subsurface samples, with lower dioxin/furan concentrations, introduce most of the variability to the Goose Lake dataset. The surface sediments exhibit congener profile patterns more similar to themselves and to those of Oakland Bay sediments than to the deeper Goose Lake sediments.

**Table 6-2. Goose Lake dioxin/furan sample results.**

| Location | Depth (feet) | Sum of Congeners (ng/kg) |
|----------|--------------|--------------------------|
| SED-04   | 0-0.15       | 407                      |
| SED-05   | 0-0.15       | 1,520                    |
| SED-08   | 0-0.15       | 134                      |
| SED-09   | 0-0.4        | 1,180                    |
| SED-10   | 0.5-2        | 6.28                     |
| SED-10   | 4-4.5        | 13.5                     |
| SED-11   | 0.75-1.25    | 95.1                     |
| SED-12   | 0-0.5        | 179                      |

Shaded samples used in Figure 6-2b.

Historical use and sedimentation studies were not conducted for Goose Lake, so no historical perspective can be established for the surface and subsurface sediments tested. Sulfite liquor discharges to the lake occurred between the early 1930s and the mid 1940s. It is probable that dioxin associated with that source would be found beneath the surface, assuming that some sedimentation has occurred since the 1940s. The difference between the surface and subsurface profiles indicate either different source types or the impacts of degradation over time.

## 6.4 Comparison of Oakland Bay Sediment Study Dioxins/Furans Congener Data to Background Puget Sound Surface Sediment Congener Data

In July 2008, the USEPA conducted a comprehensive survey of Puget Sound surface sediments, including the 17 dioxin/furan congeners and eight dioxin/furan homologues tested in Oakland Bay, to establish area-wide background conditions (samples were collected from the OSV Bold). The greater Puget Sound region was divided into 14 sub-basins to determine how geography may affect the distribution of contaminants of concern, and if one sub-basin would be best suited as a reference area for future study comparisons. Sub-basins included:

|                           |                                 |
|---------------------------|---------------------------------|
| Admiralty Inlet           | Port Susan and Possession Sound |
| Carr Inlet                | Samish Bay                      |
| Central Puget Sound       | San Juan Islands                |
| Dabob Bay                 | Saratoga Passage & Skagit Bay   |
| Holmes Harbor             | South Central Puget Sound       |
| Hood Canal                | South Puget Sound               |
| North Central Puget Sound | Strait of Juan de Fuca          |

Descriptive statistics of the Oakland Bay and OSV Bold survey surface sediment dioxin/furan profiles are presented in Table 6-3.

**Table 6-3. Comparison of Oakland Bay study and OSV Bold survey surface sediment dioxin/furan results.**

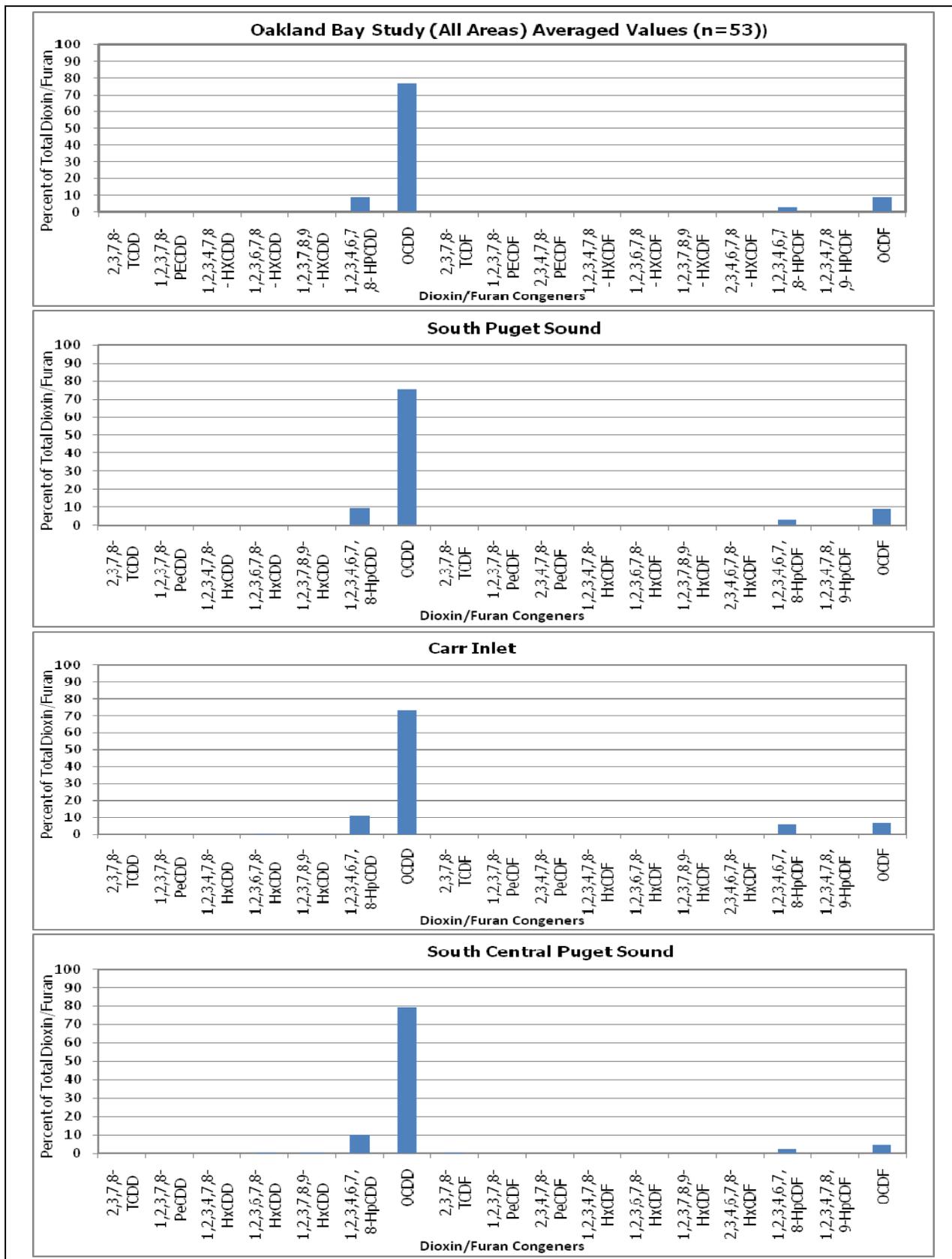
| Total Dioxin/Furan Congeners | Dioxin/Furan Concentration<br>Oakland Harbor Study<br>(ng/kg)<br>50 samples | Dioxin/Furan Concentration<br>OSV Bold Survey<br>(ng/kg)<br>75 samples |
|------------------------------|---|--|
| Mean                         | 9,390.0   | 186.6  |
| Median                       | 7,010.2   | 127.2  |
| Minimum                      | 37.4  | 5.8 (U)  |
| Maximum                      | 83,240.1  | 2,130.3  |

Values not converted to TEQ

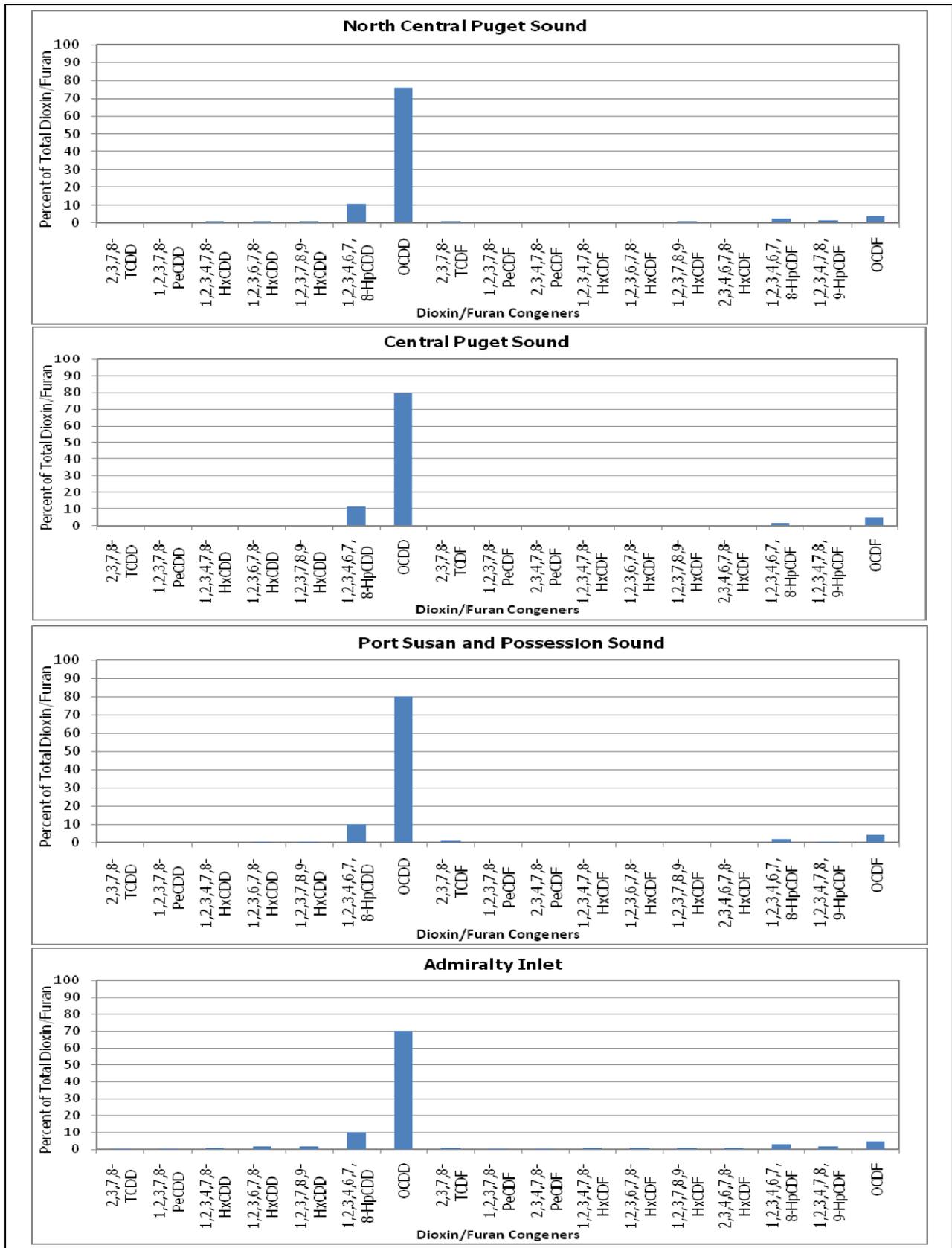
ng/kg – nanogram per kilogram

U – undetected, value to left indicates the detection limit.

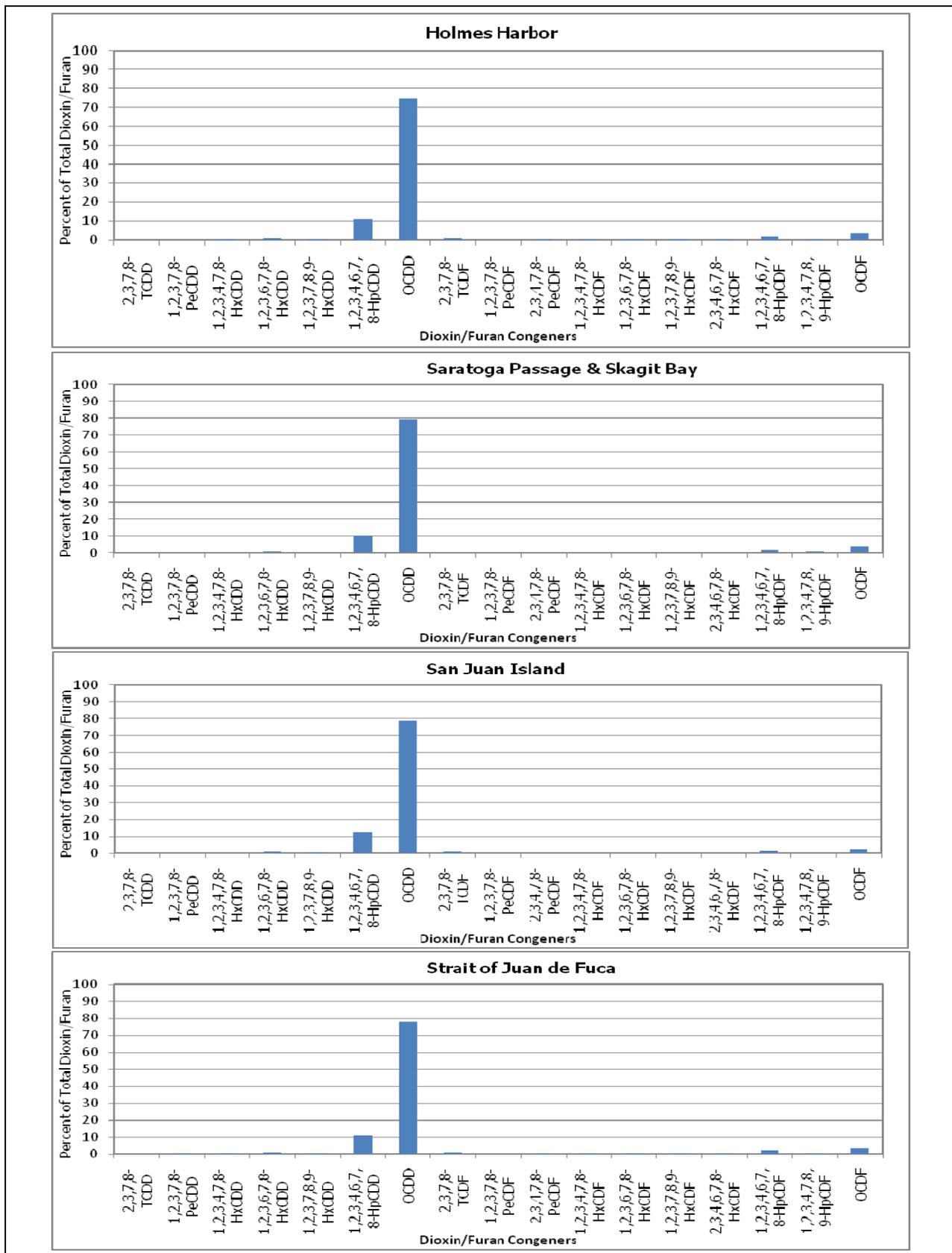
Table 6-3 indicates clear differences between the two surveys in total concentrations of dioxins/furans, with Oakland Bay having higher values in all categories. However, the congener proportional-distribution found in Oakland Bay, Shelton Harbor, and Hammersley Inlet sub-basins are very similar to the Puget Sound sub-basins (Figures 6-3 a-c). As with the Oakland Bay Study, OCDD contributed the greatest amount to the sum total of dioxin/furan congeners (70 to 80 percent), with 1,2,3,4,6,7,8- heptachlorodibenzo-p-dioxin (HpCDD) at 10 percent and 1,2,3,4,6,7,8-heptachlorodibenzo-furan (HpCDF) and octochlorodibenzo-furan (OCDF) at roughly 5 percent or less. In addition, there appears to be a geographic trend in the Puget Sound profiles, with a slight reduction of percent contribution of 1,2,3,4,6,7,8-HpCDF and OCDF moving from the South Puget Sound/Carr Inlet sub-basin to South Central Puget Sound.



**Figure 6-3a. Average proportional distribution profiles of congener concentrations to the total concentration of congeners from the OSV Bold survey and Oakland Bay study.**



**Figure 6-3b. Average proportional distribution profiles of congener concentrations to the total concentration of congeners from the OSV Bold survey.**



**Figure 6-3c. Average proportional distribution profiles of congener concentrations to the total concentration of congeners from the OSV Bold survey.**

## 6.5 Comparison of Congener Distributions in Oakland Bay Study Sediments to EPA Source Inventory Profile

Congener profiles from several sources in the United States were compiled by the USEPA National Center for Environment Assessment (USEPA 2006). Of the many source profiles compiled by the USEPA, 15 have been presented in Figures 6-4 a-d and listed in Table 6-4. The profiles illustrate the proportional distribution of 17 congeners from various natural and industrial sources. Figures 6-4 a-d depict the proportional-distribution congener profiles from the study area, along with source profiles from automotive emission, industrial wood burning, pulp paper process, forest fire, industrial oil-fired boiler, and pentachlorophenol sources. Several congener proportional-distribution profiles provided in Figure 6-4 a-d show general qualitative similarities between Oakland Bay area findings and source types. Congener profile data for other potential sources relevant to Oakland Bay, such as ash from burning of salt-laden wood, sulfite liquor waste, and sulfite liquor recovery boiler emissions, were not available in the EPA source inventory for comparison.

**Table 6-4. USEPA source congener profiles presented in Figures 6-4 a-d.**

| USEPA Source Congener Profiles                  |   |   |
|---|---|---|
| Diesel Fuel Truck                               | Electrostatic Precipitator Waste Ash                | Pulp and Paper Mill Bleached Pulp (mid 1990s) |
| Unleaded Fueled Automobile                      | Forest Fires  | Technical Grade PCP (1987)                    |
| Unleaded Fueled Automobile w/ Catalytic Convert | Black Liquor Recovery Boiler                        | Technical Grade PCP (1985-1987)               |
| Industrial Wood Combustor                       | Pulp and Paper Mill Wastewater Effluent (mid 1990s) | PCP (NA from Closed Paper Mill in California) |
| Combustion of Bleach-Kraft Mill Sludge          | Pulp and Paper Mill Wastewater Sludge (mid 1990s)   | Oil-Fired Utility/Industrial Boilers          |

Five of the 15 USEPA-provided congener profiles were similar to those found in Oakland Bay sediments, including technical grade PCP (1987) (Figure 6-4d), black liquor recovery boiler stack emissions (Figure 6-4c), forest fires (Figure 6-4b), combustion of Bleach-Kraft mill sludge in wood residue boilers (Figure 6-4b), and unleaded fueled automobiles with catalytic converters (Figure 6-4a). PCP (1987) and black liquor recovery boiler emissions appear to match the closest, with all four primary congener compositions within two standard deviations of the mean found in Oakland Bay sediments. Black liquor is formed from the Kraft pulping process that converts wood into paper pulp (accounting for roughly 95 percent of the Oakland Bay study results). Table 6-5 provides dioxin/furan congener proportional-distribution profiles of the five source types (shaded values within two standard deviations of the Oakland Bay study means). PCP use and sulfite liquor (similar to black liquor) incineration are linked to activities within the study area (Herrera 2008a, Ecology 2000). Sulfite liquor also was burned in boilers from the mid-1940s to 1957.

**Table 6-5. Comparison of possible source congener compositions with Oakland Bay study sediments.**

| Primary Dioxin and Furan Congeners in Oakland Bay | Oakland Bay Congener Composition Range (%) <sup>a</sup> | Technical Grade PCP (1987) (%) | Black Liquor Boiler Emissions (%) | Bleach-Kraft Mill Sludge (%) | Forest Fires (%) | Automobiles w/ Catalytic Converters (%) |
|---|---|--------------------------------|-----------------------------------|------------------------------|------------------|---|
| 1,2,3,4,6,7,8- HpCDD                              | 6.22-11.7   | 9.5                            | 7.6                               | 12.3                         | 17.0             | 6.5                                     |
| OCDD  | 67.8-85.6   | 75.4                           | 72.5                              | 48.8                         | 68.7             | 51.1                                    |
| 1,2,3,4,6,7,8- HpCDF                              | 1.53-4.71   | 1.9                            | 1.7                               | 11.2                         | 2.6              | 1.5                                     |
| OCDF  | 3.89-14.29  | 13.1                           | 7.9                               | 7.7                          | 1.0              | 13.2                                    |

<sup>a</sup> Range represents two standard deviations from the mean of Oakland Bay sediment samples (approximately 95 percent of all Oakland Bay samples fall within this range).

Shaded values are within two standard deviations of the Oakland Bay study mean value.

Although an USEPA source profile may match well with an environmental sample, the three PCP congener profiles in Figure 6-4d illustrate that matching source profiles with environmental samples is not exact; there is variability within source types – the three PCP-reference profiles have significant differences in proportional distributions. The PCP (NA from Closed Paper Mill in California) and the PCP (1985-87) profiles do not match well with the Oakland Bay profiles, whereas the PCP (1987) does match well. Before making any determination as to the exact source of dioxins and furans, additional sampling and analyses may be required to match specific sources.

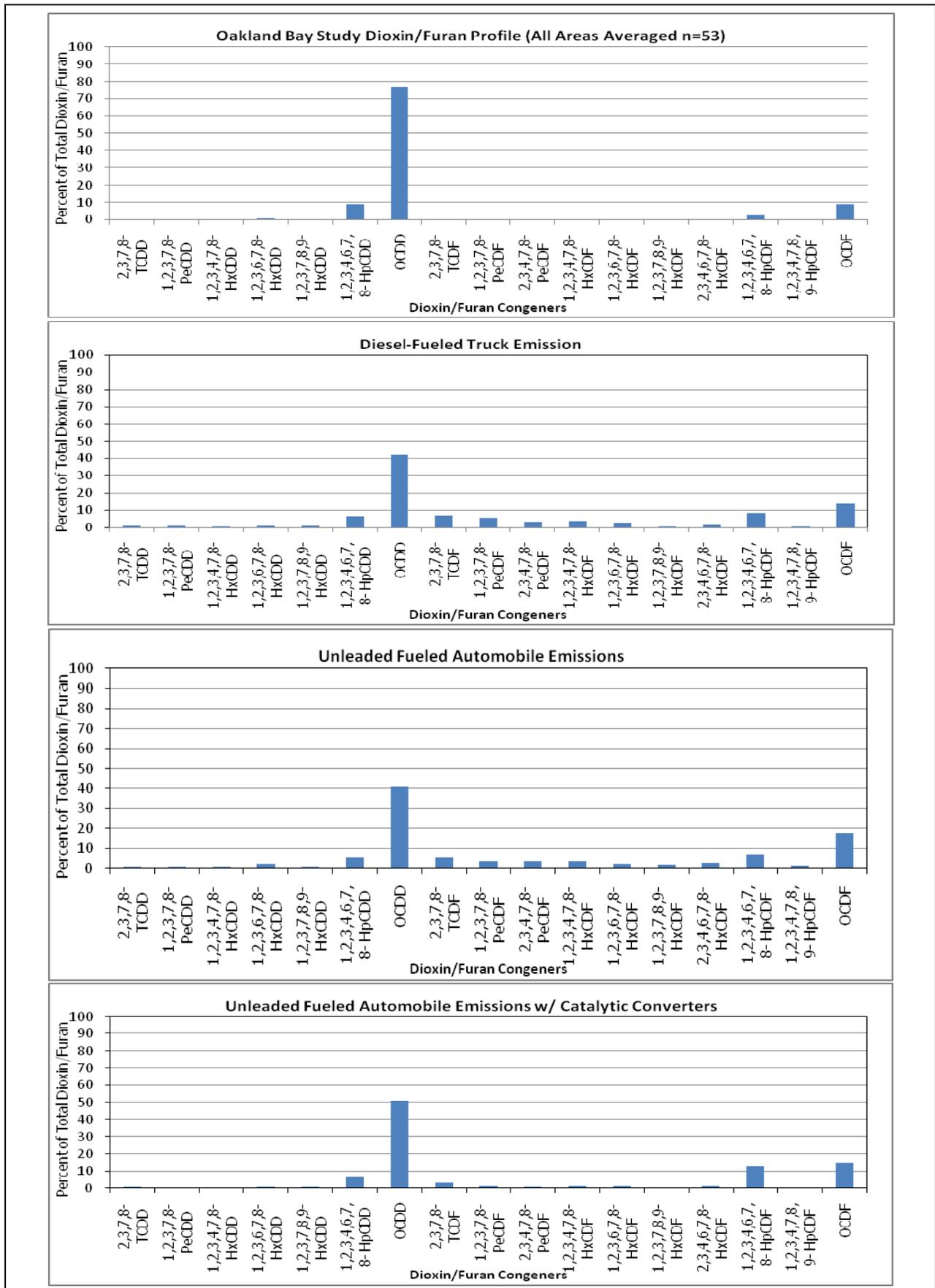
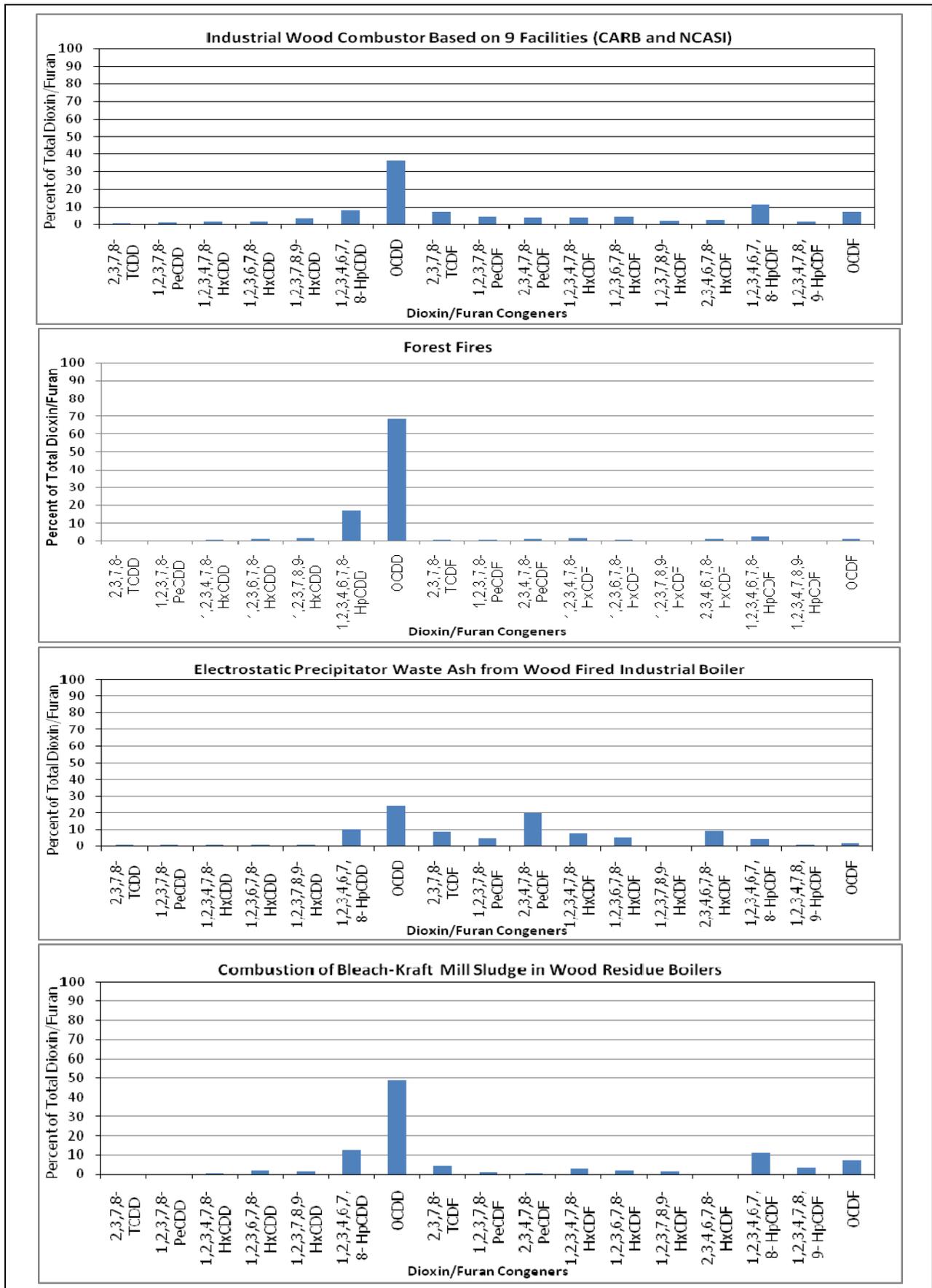


Figure 6-4a. Relative percent profiles of congener concentrations to the total concentration of congeners from various sources (USEPA 2006) and Oakland Bay study.



**Figure 6-4b. Relative percent profiles of congener concentrations to the total concentration of congeners from various sources (USEPA 2006).**

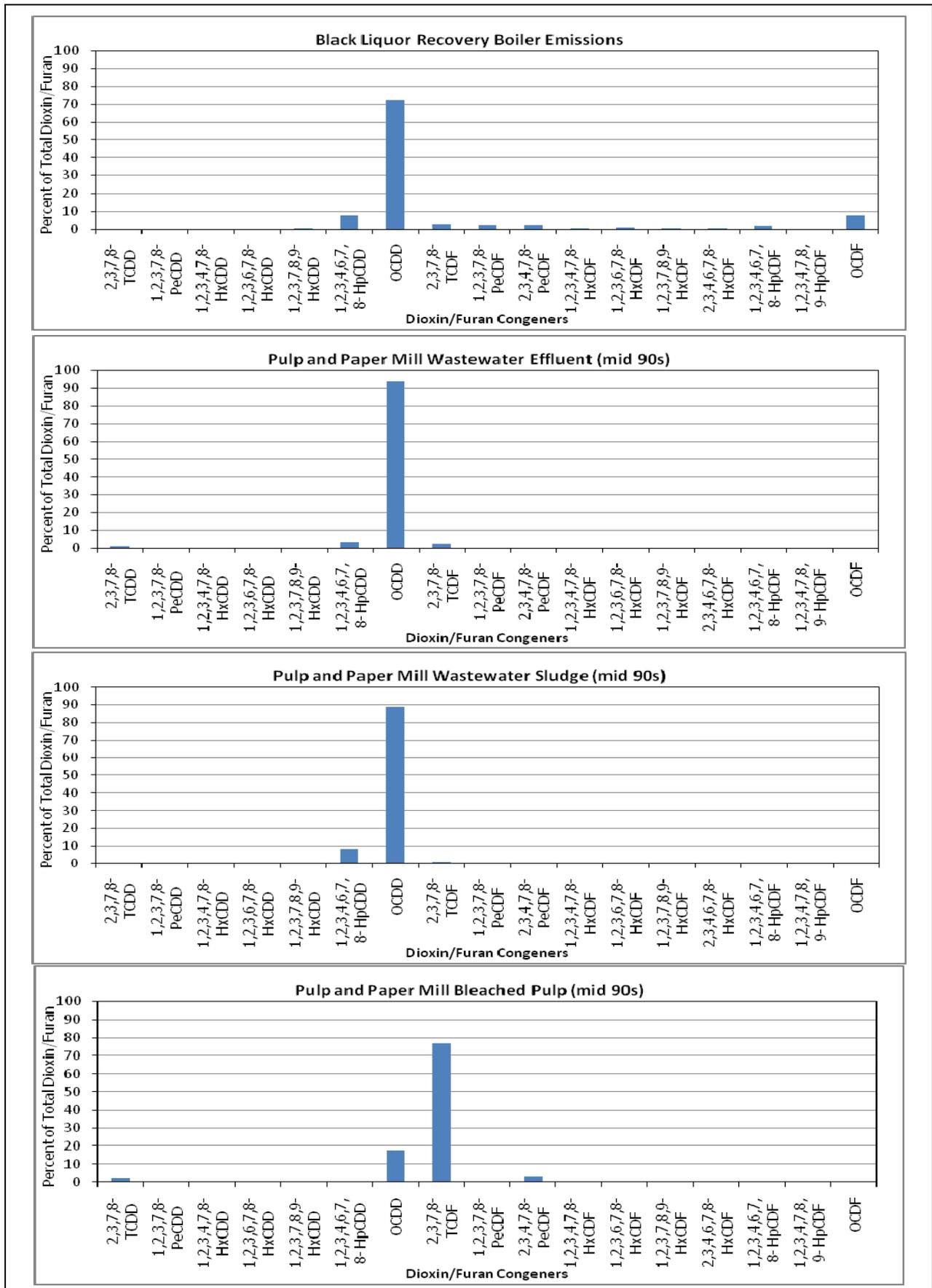


Figure 6-4c. Relative percent profiles of congener concentrations to the total concentration of congeners from various sources (USEPA2006).

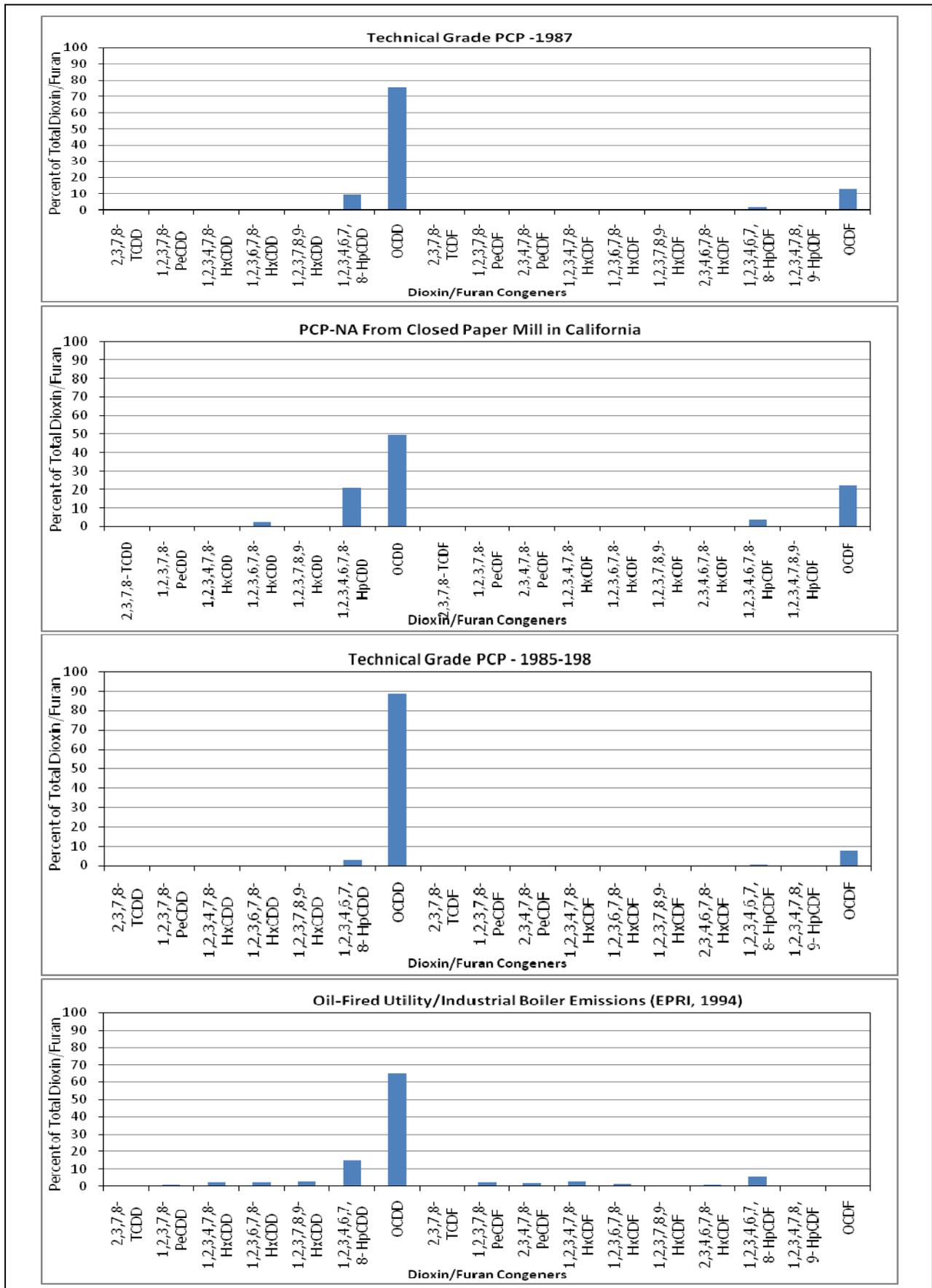


Figure 6-4d. Relative percent profiles of congener concentrations to the total concentration of congeners from various sources (USEPA 2006).

## **7.0 Sediment Quality Trends**

This section summarizes sediment transport and accumulation across the Oakland Bay study area, the distribution of wood waste, and chemical and bioassay testing results. The chemical testing results also are compared to those of the 2000 Ecology Shelton Harbor investigation.

### **7.1 Sediment Transport and Accumulation**

A sediment budget was developed by estimating accumulation rates determined from sediment core dating and a common sediment production model (Syvitski et al. 2005). The budget confirms that nearly all sediment deposited within the study area stays within the confines of greater Oakland Bay (including Shelton Harbor and Chapman Cove). While there is some transport of fine-grained sediment (silt and clay) from Shelton Harbor to central Oakland Bay, most sediment discharged to the bay remains close to where it first enters marine waters.

The pattern of circulation and sediment transport in Oakland Bay primarily results from tidal motion. First documented by Ecology (2004a), strong flows near the bed occur as marine water enters the study area from Hammersley Inlet on a rising or flood tide. Once high tide is reached and water begins to flow out of the study area, most flow leaves near the water surface. The strong bottom flows associated with flood tides are highly constrained within the narrow inlet bottom, preventing deposition in this area. The sediment accumulation that does occur in Hammersley Inlet and at the transition into Oakland Bay generally consists of coarse-grained material derived from eroded areas along Hammersley Inlet and Puget Sound shorelines; these volumes are small with respect to creek input to the bay. The strong bottom flow during flood tides pushes some sediment into Shelton Harbor and along the northern shore of Oakland Bay. Sediment transport is flood-dominated along the seabed; the ebb tide is dominated by flow at the surface, containing relatively small amounts of fine grain sediment. As such, very little sediment moves out of the system.

There are several consequences of this sediment transport relative to the pattern of COPCs found in the study area. Because sediment in Hammersley Inlet is either non-existent or derived from erosion input from the east, the seabed accumulates little chemical input from Shelton Harbor and greater Oakland Bay. The Oakland Bay system primarily receives sediment derived from Shelton Harbor and, to a lesser extent, Oakland Bay creeks. It can be assumed that COPCs found in Oakland Bay that are transported with sediment likely originate in Shelton Harbor (since no contaminants were identified at any of the Oakland Bay creeks). However, this study did not find evidence that significant concentrations of industrial COPCs, other than dioxins, exist in either the harbor or bay (COPCs associated with wood waste were found across both locations).

Dioxins were analyzed in multiple core sections at five locations across Oakland Bay (separate from Shelton Harbor). At all five stations, relatively higher dioxin concentrations were found in the 1-2 foot core section than in the surface grab sample (Figure 5-11 and Appendix G). This vertical distribution indicates that dioxin input has diminished over the last 30 to 60 years (based on the deposition rate range of 0.25 to 0.50 cm/yr [0.1 to 0.2 in/year] estimated for the bay). This

corresponds to the time period when sulfite liquor waste and hog fuel burning was discontinued in the late 1950s and a salt-free wood burning power plant was installed by Simpson in 1986 (Herrera 2008a).

Sediment accumulation rates are variable, with faster accumulation occurring near the creek outlets, resulting in thicker depositional blankets in these areas. Higher dioxin concentration with depth can also be seen at SH-04 and SH-10, adjacent to Shelton and Goldsborough Creek discharges into the harbor. Cores collected at other locations in the harbor that do not indicate the same concentration profile may reflect near-surface sediment disturbances or more recent localized inputs.

## **7.2 Wood Waste Distribution**

The pattern of sediment transport across the study area has resulted in accumulation of wood waste according to two primary modes: low concentrations spread across deeper portions of Oakland Bay by tidal flows near the sediment bed, and significant accumulations (greater than 20 percent by volume) near historical and current log rafting and wood processing activities. These distributions are illustrated in Figures 5-1 and 5-2. The general distribution of low concentration wood across the main portion of the study area is intermixed with the recent depositional layer, defined by the geophysical surveys (refer to Section 5.2.3 for an interpretive explanation regarding definition of the wood-containing sediment layer).

Wood waste observed in the cores has primarily originated from wood processing and rafting activities in Shelton Harbor and other isolated milling and rafting areas. The shedding of bark and chips associated with rafting has contributed to wood waste at low concentrations across the entire study area, including the northern end of Oakland Bay. Current log rafting and mill activity continue to be sources of wood waste.

- **Bark:** Wood waste was most prevalent as bark, found at 70 percent of sampling stations. The primary source of bark has likely been from log rafts historically stored across much of Shelton Harbor and the perimeter of Oakland Bay. The majority of bark was found in Shelton Harbor, where logs were delivered to the water by train and tugboat. Concentrated log handling activities along the shoreline where logs have been transferred in and out of storage have resulted in the largest accumulations of bark.
- **Chips:** Wood waste was found as chips at 26 percent of the sampling stations, primarily in Shelton Harbor, and mostly with less than 5 percent wood present. The primary source of chips is likely from wood processing operations.
- **Fibers:** Wood waste was found as fibers at 23 percent of the sampling stations, primarily in Shelton Harbor and mostly with less than 5 percent wood present. The primary source of fibers is likely from wood processing operations. Fibers were likely discharged as part of the sulfite liquor waste

associated with historical paper production (which ended in the late 1950s) and from fiberboard manufacturing (conducted from the 1940s to 1974). The presence of fibers appears to be restricted to Shelton Harbor and, to a limited extent, along the southern shore of lower Oakland Bay.

- **Sawdust:** Wood waste was found as sawdust at 6 percent of the sampling stations. Sawdust was found at two Shelton Harbor locations and one Oakland Bay location, each with significant accumulations. The primary source of sawdust is likely from wood milling operations located at the west end of Shelton Harbor and at the head of Oakland Bay.

Most of the wood mass exists in sediment as a widespread, low-concentration deposit situated in the recently deposited marine bed surface associated with the onset of wood industry operations. Wood waste is often covered with a thin layer of cleaner sediment that has accumulated after the largest wood-waste-producing activities have stopped on a local basis. This is particularly true for wood deposited in the deeper sediments of Oakland Bay. The persistence of both significant wood accumulation on a local basis and the low-concentrations seen across both Shelton Harbor and Oakland Bay, support indications that the wood waste, like sediment, is relatively immobile.

Areas of concentrated wood waste are present within Shelton Harbor (Figure 4-3) and at one location in Oakland Bay. Areas of significant wood waste accumulation in Shelton Harbor include:

- The pond saw area (primarily sawdust at least 6.7 feet deep)
- The railway log dump to the south of the channelized mouth of Goldsborough Creek (fibers, chips, and bark 5 or more feet deep)
- Former sawmill #4 (primarily fibers and sawdust at least 10.5 feet deep)

The one area of significant wood waste accumulation in Oakland Bay was near the head of the bay, represented by core OB-12 (primarily sawdust at least 9.5 feet deep). The source of the Oakland Bay deposit is unknown, but may be an historical sawmill.

Figures 5-3 and 5-4 depict estimated wood waste present across the study area based on geophysical results and core sample descriptions. The figures denote thickness of material found above the predevelopment surface in areas where wood waste is known to occur from geomorphic evidence and core observations (it excludes the head of the bay not sampled as part of the geophysical survey, Hammersley Inlet where no sediment accumulation was found, and creek delta portions of Shelton Harbor that are covered with large-grain material). A total of 335,000 cubic yards (256,000 cubic meters) of wood waste was estimated to exist in the surveyed area, based on the volumetric content of the mapped recent deposition deposit and average visible wood waste concentrations obtained from the cores. Of this estimated total, approximately 240,000 cubic yards (183,500 cubic meters), or 72 percent of it, resides at low concentrations across the majority of Oakland Bay and Shelton Harbor. Approximately 95,000 cubic yards (73,000 cubic meters), or 28 percent, was estimated in the concentrated wood deposits (not including the area identified at the head of the bay). These numbers are rough

estimates based on limited data, indicating the general distribution of wood waste across the entire study area.

### **7.3 Dioxins and Furans**

Fifty surface sediment and 14 subsurface sediment samples across Shelton Harbor, Oakland Bay, and Hammersley Inlet were analyzed for seventeen dioxin/furan congeners and eight dioxin/furan homologues. Dioxins/furans were found in every sample, at concentrations ranging from 1 to 902 ng/kg TEQ. The five highest concentrations (180 to 902 ng/kg TEQ) were found at widely-spread subsurface locations along and near the western Shelton Harbor shoreline, within the Goldsborough Creek delta, and along the Oakland Bay shoreline south of Chapman Cove. The five samples collected from Hammersley Inlet were among the lowest dioxin/furan concentrations (1.77 to 9.74 ng/kg TEQ); flows through the central deep portion of Hammersley Inlet as it extends into Oakland Bay do not allow for a buildup of sediment and samples were collected along the fringes of the channel. The lowest dioxin TEQ concentrations were found in the three reference area samples (0.245 to 0.692 ng/kg TEQ).

Dioxins/furans were identified in surface sediment at all 50 locations sampled, ranging from 1 to 175 ng/kg TEQ. The five highest concentrations, represented as pink and orange in Figure 5-10, were found along the western edge of Shelton Harbor. Aside from the contrast of higher levels in Shelton Harbor and lower levels in Oakland Bay, no clear concentration gradient within the bay is apparent – concentrations among the Oakland Bay samples is relatively consistent. This suggests a generalized, widespread source to bay sediments, such as aerial deposition or a well mixed plume carried by water. Burning of waste material known to produce dioxins/furans occurred historically at five known locations near the southern shoreline of Shelton Harbor (Herrera, 2008a). Historical discharges of sulfite liquor waste and pulp mill process wastewater to Shelton Harbor and Hammersley Inlet may have contributed to dioxin/furan presence in bay sediments; however, probably not to surface sediments, based on the time of discharge and sedimentation that has occurred since. Discharge of slurries from the hog fuel boiler air pollution control system to the municipal wastewater treatment plant during the late 1970s – early 1980s may explain some dioxin found closer to the surface. The continued presence of dioxin in surface sediments indicates that there is either a continuing source of dioxin, or that mixing of deeper with shallower sediments has occurred through human or natural processes.

Subsurface sediment was sampled at 12 stations in Shelton Harbor and Oakland Bay, based on relatively high concentrations found in surface samples analyzed first (Figure 5-11). Samples were analyzed from either the 1-2 foot or 2-3 foot core sections to evaluate the effects of sediment accumulation over the last 60 years (samples were collected from both 1-2 and 2-3 foot core sections at two locations in Shelton Harbor along the western shore). The full depth of the sediments containing elevated dioxin was not identified. Higher dioxin/furan concentrations found at depth at nine of the 12 stations sampled indicates that burying of this sediment has taken place since the time of higher dioxin inputs, either by natural sedimentation or mixing associated with human activities. The 2-3 foot interval within Shelton Harbor (at estimated 1 cm/yr accumulation rate) can be roughly interpreted to represent the years 1920 – 1950. It is likely that

dioxins/furans have been disbursed over a long period of time, through aerial and fluvial processes. Once incorporated into sediments, there has been little movement across or out of the Oakland Bay system.

Dioxin/furan fingerprint analysis compared congener proportional-distribution profiles for specific sources compiled by USEPA to Oakland Bay study profiles. Similar profiles were identified for PCP, black liquor boiler recovery emissions, automobiles with catalytic converters, forest fires, and combustion of bleach-Kraft mill sludge (certain PCP and black liquor boiler recovery stack emissions most closely match Oakland Bay sediment profiles). Congener profile data for other potential sources relevant to Oakland bay, such as burning of salt-laden wood, sulfite liquor waste, and sulfite liquor recovery boiler emissions, were not available for comparison. The dioxin/furan congeners found in Oakland Bay sediment appear similar to those found throughout Puget Sound. Goose Lake, known to have received Rayonier pulp and paper mill sulfite waste liquor, had dioxin/furan congener proportional-distribution profiles in surface sediments similar to the Oakland Bay study samples. Dioxin and furan congener compositions in deeper sediments did not match Oakland Bay as closely as the surface sediments. It appears that older dioxin/furan inputs to the lake were different than more recent inputs (e.g., older sulfite liquor waste discharged as a liquid versus more recent aerial deposition associated with combustion processes).

## **7.4 Relationship between Sediment Toxicity Tests and Chemical and Conventional Sediment Parameters**

This section compares surface sediment chemistry results with results from the four separate sediment toxicity tests. The analysis was limited to analytes detected in more than 15 percent of collected samples, because the utility of statistical analysis is greatly reduced if a majority of the sample population is at or below detection limits. The analytes used in this analysis were:

- Wood content (visual)
- Percent fines
- TVS
- Ammonia
- Sulfides
- TOC
- Antimony
- Arsenic
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Nickel
- Silver

- Zinc
- Total LPAHs
- Total HPAHs
- Resin acids
- Dioxins/furans

In this study, relationships between sediment chemistry/physical properties and sediment toxicity were investigated using correlation analyses and hypothesis testing. The correlation analyses were used to screen the data and identify any strong relationships between toxicity and sediment chemistry. The Pearson's  $r$  correlation coefficient was initially considered for use in these analyses; however, the primary drawback to Pearson's  $r$  is that it assumes that the relationship between toxicity and sediment chemistry is linear. In this study, it is likely that varying pollutant concentration will not have an effect on toxicity until a certain threshold is achieved; consequently, a linear fit will not model the relationship well. A second drawback of the Pearson's  $r$  correlation coefficient is that it assumes that both the toxicity and sediment chemistry data follow a normal distribution (evenly distributed about the average value) (Helsel and Hirsch 1992). This assumption was determined not to be consistently true, based on results of a Kolmogorov-Smirnov test for normality.

As a result of these considerations, the Kendall's Tau ( $\tau$ ) correlation coefficient was used instead of the Pearson's  $r$ . The Kendall's  $\tau$  correlation coefficient offers the following specific advantages given the characteristics of the data in this study:

- It measures the strength of all monotonic relationships (e.g., linear, exponential, etc.) between variables, as opposed to just linear relationships.
- No assumptions are required regarding distribution of the data.
- It can be used with censored data having non-detect values.
- It is resistant to the effects of outliers.

The results from the analyses with Kendall's  $\tau$  correlation coefficients are presented in Tables 7-1 and 7-2, which provide  $\tau$  values measuring correlations between toxicity and chemical and physical parameter results (graphs of all the correlations are presented in Appendix L). A  $\tau$  of +1 indicates a perfect positive relationship between the two variables, a  $\tau$  of -1 indicates a perfect negative relationship, while a  $\tau$  of 0 indicates no relationship between the variables. **Positive  $\tau$  values for the amphipod test and negative  $\tau$  values for all other toxicity tests indicate increasing toxicity with increasing concentration – this is because the amphipod test measures mortality and the other three tests measure survivorship.**

Table 7-1 indicates that amphipod test results indicated no significant correlation between mortality and most constituent concentrations; however, mortality results were negatively correlated with percent fines, antimony, silver, and dioxins/furans. In other words, as these concentrations increased, amphipod mortality decreased. This negative correlation cannot be

**Table 7-1. Kendall's Tau ( $\tau$ ) correlation matrix of sediment toxicity and chemistry from all Oakland Bay study monitoring stations.**

|                       | Amphipod | Microtox    | Larval | Polychaete | Resin Acids | TVS          | Wood Content (visual) | Percent Fines | Ammonia      | Sulfide      | TOC          | Antimony     | Arsenic      | Cadmium      | Chromium     | Copper       | Lead         | Mercury      | Nickel       | Silver       | Zinc         | Total LPAHs  | Total HPAHs | Dioxins / Furans |
|-----------------------|----------|-------------|--------|------------|-------------|--------------|-----------------------|---------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|-------------|------------------|
| Amphipod              | 1.00     | <b>0.29</b> | 0.04   | -0.06      | -0.04       | -0.02        | -0.09                 | <b>-0.30</b>  | -0.06        | -0.07        | -0.13        | <b>-0.20</b> | -0.03        | -0.11        | -0.11        | -0.13        | -0.15        | -0.12        | -0.08        | <b>-0.23</b> | -0.14        | 0.04         | 0.16        | <b>-0.22</b>     |
| Microtox              |          | 1.00        | 0.09   | 0.02       | 0.06        | 0.01         | 0.03                  | <b>-0.23</b>  | 0.00         | -0.03        | -0.16        | -0.16        | 0.01         | -0.07        | -0.18        | -0.18        | -0.15        | -0.14        | -0.05        | <b>-0.21</b> | -0.16        | 0.09         | <b>0.23</b> | <b>-0.21</b>     |
| Larval                |          |             | 1.00   | 0.09       | -0.31       | <b>-0.26</b> | <b>-0.38</b>          | <b>-0.41</b>  | <b>-0.30</b> | <b>-0.30</b> | <b>-0.44</b> | <b>-0.30</b> | <b>-0.29</b> | <b>-0.27</b> | <b>-0.33</b> | <b>-0.35</b> | <b>-0.30</b> | <b>-0.28</b> | <b>-0.26</b> | <b>-0.39</b> | <b>-0.31</b> | <b>0.39</b>  | 0.05        | <b>-0.36</b>     |
| Polychaete            |          |             |        | 1.00       | -0.08       | 0.11         | -0.28                 | -0.07         | -0.15        | -0.04        | -0.09        | -0.05        | -0.04        | 0.01         | -0.12        | -0.09        | 0.00         | 0.00         | -0.14        | -0.08        | -0.04        | 0.12         | 0.07        | -0.02            |
| Resin acids           |          |             |        |            | 1.00        | <b>0.66</b>  | <b>0.54</b>           | 0.11          | 0.27         | 0.08         | <b>0.51</b>  | 0.25         | 0.36         | 0.30         | 0.17         | 0.15         | 0.25         | 0.35         | 0.08         | 0.24         | 0.22         | -0.16        | 0.31        | 0.33             |
| TVS                   |          |             |        |            |             | 1.00         | <b>0.46</b>           | 0.14          | <b>0.22</b>  | <b>0.20</b>  | <b>0.39</b>  | <b>0.31</b>  | <b>0.29</b>  | <b>0.31</b>  | <b>0.30</b>  | <b>0.37</b>  | <b>0.27</b>  | <b>0.33</b>  | <b>0.24</b>  | <b>0.25</b>  | <b>0.30</b>  | -0.07        | <b>0.31</b> | <b>0.27</b>      |
| Wood Content (visual) |          |             |        |            |             |              | 1.00                  | <b>0.45</b>   | <b>0.51</b>  | <b>0.42</b>  | <b>0.78</b>  | <b>0.67</b>  | <b>0.61</b>  | <b>0.56</b>  | <b>0.46</b>  | <b>0.56</b>  | <b>0.58</b>  | <b>0.62</b>  | <b>0.38</b>  | <b>0.59</b>  | <b>0.56</b>  | -0.31        | 0.22        | <b>0.70</b>      |
| Percent Fines         |          |             |        |            |             |              |                       | 1.00          | <b>0.34</b>  | <b>0.52</b>  | <b>0.54</b>  | <b>0.59</b>  | <b>0.46</b>  | <b>0.53</b>  | <b>0.57</b>  | <b>0.54</b>  | <b>0.61</b>  | <b>0.48</b>  | <b>0.46</b>  | <b>0.75</b>  | <b>0.63</b>  | <b>-0.38</b> | -0.15       | <b>0.63</b>      |
| Ammonia               |          |             |        |            |             |              |                       |               | 1.00         | <b>0.34</b>  | <b>0.41</b>  | <b>0.42</b>  | <b>0.40</b>  | <b>0.43</b>  | <b>0.36</b>  | <b>0.34</b>  | <b>0.35</b>  | <b>0.35</b>  | <b>0.32</b>  | <b>0.41</b>  | <b>0.44</b>  | <b>-0.25</b> | 0.10        | <b>0.32</b>      |
| Sulfide               |          |             |        |            |             |              |                       |               |              | 1.00         | <b>0.52</b>  | <b>0.45</b>  | <b>0.47</b>  | <b>0.51</b>  | <b>0.37</b>  | <b>0.40</b>  | <b>0.44</b>  | <b>0.40</b>  | <b>0.33</b>  | <b>0.50</b>  | <b>0.48</b>  | <b>-0.42</b> | -0.08       | <b>0.45</b>      |
| TOC                   |          |             |        |            |             |              |                       |               |              |              | 1.00         | <b>0.59</b>  | <b>0.49</b>  | <b>0.59</b>  | <b>0.47</b>  | <b>0.57</b>  | <b>0.56</b>  | <b>0.52</b>  | <b>0.35</b>  | <b>0.59</b>  | <b>0.58</b>  | <b>-0.48</b> | 0.03        | <b>0.60</b>      |
| Antimony              |          |             |        |            |             |              |                       |               |              |              |              | 1.00         | <b>0.66</b>  | <b>0.70</b>  | <b>0.62</b>  | <b>0.67</b>  | <b>0.78</b>  | <b>0.69</b>  | <b>0.53</b>  | <b>0.77</b>  | <b>0.78</b>  | <b>-0.23</b> | 0.13        | <b>0.65</b>      |
| Arsenic               |          |             |        |            |             |              |                       |               |              |              |              |              | 1.00         | <b>0.69</b>  | <b>0.53</b>  | <b>0.49</b>  | <b>0.64</b>  | <b>0.60</b>  | <b>0.49</b>  | <b>0.61</b>  | <b>0.68</b>  | <b>-0.22</b> | 0.14        | <b>0.55</b>      |
| Cadmium               |          |             |        |            |             |              |                       |               |              |              |              |              |              | 1.00         | <b>0.55</b>  | <b>0.60</b>  | <b>0.73</b>  | <b>0.70</b>  | <b>0.51</b>  | <b>0.68</b>  | <b>0.78</b>  | <b>-0.31</b> | 0.10        | <b>0.59</b>      |
| Chromium              |          |             |        |            |             |              |                       |               |              |              |              |              |              |              | 1.00         | <b>0.80</b>  | <b>0.66</b>  | <b>0.57</b>  | <b>0.79</b>  | <b>0.66</b>  | <b>0.75</b>  | <b>-0.27</b> | 0.09        | <b>0.53</b>      |
| Copper                |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              | 1.00         | <b>0.69</b>  | <b>0.61</b>  | <b>0.69</b>  | <b>0.66</b>  | <b>0.74</b>  | <b>-0.26</b> | 0.18        | <b>0.57</b>      |
| Lead                  |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              |              | 1.00         | <b>0.72</b>  | <b>0.55</b>  | <b>0.78</b>  | <b>0.84</b>  | <b>-0.27</b> | 0.11        | <b>0.72</b>      |
| Mercury               |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              |              |              | 1.00         | <b>0.48</b>  | <b>0.65</b>  | <b>0.74</b>  | <b>-0.23</b> | 0.17        | <b>0.67</b>      |
| Nickel                |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              |              |              |              | 1.00         | <b>0.55</b>  | <b>0.65</b>  | <b>-0.20</b> | 0.12        | <b>0.39</b>      |
| Silver                |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              |              |              |              |              | 1.00         | <b>0.80</b>  | <b>-0.32</b> | 0.02        | <b>0.73</b>      |
| Zinc                  |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              |              |              |              |              |              | 1.00         | <b>-0.28</b> | 0.11        | <b>0.65</b>      |
| Total LPAHs           |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              |              |              |              |              |              |              | 1.00         | <b>0.39</b> | <b>-0.26</b>     |
| Total HPAHs           |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              |              |              |              |              |              |              |              | 1.00        | 0.09             |
| Dioxins / Furans      |          |             |        |            |             |              |                       |               |              |              |              |              |              |              |              |              |              |              |              |              |              |              |             | 1.00             |

**Bold** values indicate significant relationships ( $\alpha=0.05$ ); values above 0.5 or below -0.5 indicate a strong linear relationship.

PAH data were OC-normalized.

$\tau$  values below and above the diagonal are mirror images; only one dataset is shown to make the table easier to read.



**Table 7-2. Kendall's Tau ( $\tau$ ) correlation matrix of sediment toxicity and chemistry for Shelton Harbor monitoring stations.**

|                       | Amphipod | Microtox    | Larval | Polychaete | Resin acids  | TVS          | Wood Content (visual) | Percent Fines | Ammonia      | Sulfide     | TOC          | Antimony     | Arsenic      | Cadmium     | Chromium     | Copper       | Lead        | Mercury      | Nickel      | Silver       | Zinc        | Total LPAHs  | Total HPAHs | Dioxins / Furans |
|-----------------------|----------|-------------|--------|------------|--------------|--------------|-----------------------|---------------|--------------|-------------|--------------|--------------|--------------|-------------|--------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|------------------|
| Amphipod              | 1.00     | <b>0.34</b> | -0.15  | -0.14      | -0.12        | -0.04        | -0.09                 | -0.27         | 0.05         | 0.02        | -0.11        | <b>-0.29</b> | -0.07        | -0.26       | -0.24        | <b>-0.30</b> | -0.26       | <b>-0.31</b> | -0.22       | -0.22        | -0.26       | -0.11        | 0.00        | -0.24            |
| Microtox              |          | 1.00        | 0.00   | 0.01       | 0.02         | 0.03         | -0.05                 | -0.13         | 0.12         | 0.14        | -0.10        | -0.12        | 0.10         | -0.11       | -0.25        | <b>-0.29</b> | -0.18       | -0.21        | -0.16       | -0.13        | -0.15       | 0.04         | 0.21        | -0.17            |
| Larval                |          |             | 1.00   | 0.13       | <b>-0.52</b> | <b>-0.36</b> | <b>-0.49</b>          | <b>-0.28</b>  | <b>-0.42</b> | -0.19       | <b>-0.32</b> | -0.23        | <b>-0.28</b> | -0.18       | <b>-0.27</b> | -0.24        | -0.21       | -0.16        | -0.25       | <b>-0.29</b> | -0.22       | <b>0.35</b>  | -0.11       | -0.23            |
| Polychaete            |          |             |        | 1.00       | -0.06        | 0.06         | -0.23                 | 0.13          | -0.07        | 0.03        | -0.09        | 0.13         | 0.06         | 0.12        | 0.13         | 0.13         | 0.17        | 0.16         | 0.13        | 0.14         | 0.16        | 0.12         | 0.12        | 0.10             |
| Resin acids           |          |             |        |            | 1.00         | <b>0.65</b>  | <b>0.61</b>           | 0.30          | 0.39         | 0.15        | <b>0.55</b>  | 0.33         | 0.39         | 0.35        | 0.21         | 0.18         | 0.34        | 0.32         | 0.18        | 0.33         | 0.29        | -0.18        | 0.15        | 0.33             |
| TVS                   |          |             |        |            |              | 1.00         | <b>0.55</b>           | <b>0.31</b>   | <b>0.28</b>  | <b>0.29</b> | <b>0.42</b>  | <b>0.33</b>  | <b>0.30</b>  | <b>0.27</b> | <b>0.31</b>  | <b>0.29</b>  | <b>0.30</b> | <b>0.30</b>  | 0.22        | <b>0.32</b>  | <b>0.30</b> | -0.14        | 0.13        | <b>0.29</b>      |
| Wood Content (visual) |          |             |        |            |              |              | 1.00                  | <b>0.59</b>   | <b>0.58</b>  | 0.41        | <b>0.74</b>  | <b>0.67</b>  | <b>0.50</b>  | <b>0.53</b> | 0.40         | <b>0.50</b>  | <b>0.55</b> | <b>0.55</b>  | 0.34        | <b>0.58</b>  | <b>0.50</b> | -0.21        | 0.21        | <b>0.72</b>      |
| Percent Fines         |          |             |        |            |              |              |                       | 1.00          | <b>0.46</b>  | <b>0.43</b> | <b>0.64</b>  | <b>0.72</b>  | <b>0.56</b>  | <b>0.71</b> | <b>0.66</b>  | <b>0.66</b>  | <b>0.72</b> | <b>0.60</b>  | <b>0.58</b> | <b>0.80</b>  | <b>0.79</b> | <b>-0.27</b> | 0.09        | <b>0.64</b>      |
| Ammonia               |          |             |        |            |              |              |                       |               | 1.00         | <b>0.43</b> | <b>0.48</b>  | <b>0.36</b>  | <b>0.51</b>  | <b>0.51</b> | <b>0.33</b>  | 0.24         | <b>0.34</b> | <b>0.34</b>  | <b>0.35</b> | <b>0.45</b>  | <b>0.46</b> | <b>-0.32</b> | 0.07        | <b>0.34</b>      |
| Sulfide               |          |             |        |            |              |              |                       |               |              | 1.00        | <b>0.46</b>  | <b>0.39</b>  | <b>0.46</b>  | <b>0.46</b> | <b>0.32</b>  | <b>0.35</b>  | <b>0.37</b> | <b>0.37</b>  | <b>0.31</b> | <b>0.40</b>  | <b>0.45</b> | -0.25        | 0.15        | <b>0.39</b>      |
| TOC                   |          |             |        |            |              |              |                       |               |              |             | 1.00         | <b>0.56</b>  | <b>0.42</b>  | <b>0.51</b> | <b>0.44</b>  | <b>0.51</b>  | <b>0.52</b> | <b>0.47</b>  | <b>0.33</b> | <b>0.58</b>  | <b>0.59</b> | <b>-0.29</b> | 0.17        | <b>0.60</b>      |
| Antimony              |          |             |        |            |              |              |                       |               |              |             |              | 1.00         | <b>0.62</b>  | <b>0.68</b> | <b>0.60</b>  | <b>0.65</b>  | <b>0.86</b> | <b>0.77</b>  | <b>0.50</b> | <b>0.77</b>  | <b>0.75</b> | -0.12        | 0.26        | <b>0.76</b>      |
| Arsenic               |          |             |        |            |              |              |                       |               |              |             |              |              | 1.00         | <b>0.66</b> | <b>0.42</b>  | <b>0.38</b>  | <b>0.61</b> | <b>0.56</b>  | <b>0.43</b> | <b>0.67</b>  | <b>0.65</b> | -0.15        | 0.24        | <b>0.57</b>      |
| Cadmium               |          |             |        |            |              |              |                       |               |              |             |              |              |              | 1.00        | <b>0.54</b>  | <b>0.55</b>  | <b>0.75</b> | <b>0.74</b>  | <b>0.51</b> | <b>0.78</b>  | <b>0.85</b> | -0.19        | 0.13        | <b>0.61</b>      |
| Chromium              |          |             |        |            |              |              |                       |               |              |             |              |              |              |             | 1.00         | <b>0.81</b>  | <b>0.63</b> | <b>0.51</b>  | <b>0.84</b> | <b>0.66</b>  | <b>0.69</b> | -0.19        | 0.07        | <b>0.46</b>      |
| Copper                |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              | 1.00         | <b>0.68</b> | <b>0.55</b>  | <b>0.72</b> | <b>0.65</b>  | <b>0.69</b> | -0.14        | 0.12        | <b>0.52</b>      |
| Lead                  |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              |              | 1.00        | <b>0.79</b>  | <b>0.54</b> | <b>0.81</b>  | <b>0.83</b> | -0.12        | 0.26        | <b>0.75</b>      |
| Mercury               |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              |              |             | 1.00         | <b>0.43</b> | <b>0.69</b>  | <b>0.73</b> | -0.10        | 0.18        | <b>0.68</b>      |
| Nickel                |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              |              |             |              | 1.00        | <b>0.59</b>  | <b>0.64</b> | -0.20        | 0.03        | <b>0.38</b>      |
| Silver                |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              |              |             |              |             | 1.00         | <b>0.88</b> | -0.17        | 0.24        | <b>0.74</b>      |
| Zinc                  |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              |              |             |              |             |              | 1.00        | -0.16        | 0.18        | <b>0.66</b>      |
| Total LPAHs           |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              |              |             |              |             |              |             | 1.00         | <b>0.39</b> | -0.11            |
| Total HPAHs           |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              |              |             |              |             |              |             |              | 1.00        | <b>0.34</b>      |
| Dioxins / Furans      |          |             |        |            |              |              |                       |               |              |             |              |              |              |             |              |              |             |              |             |              |             |              |             | 1.00             |

**Bold** values indicate significant relationships ( $\alpha=0.05$ ); values above 0.5 indicate a strong linear relationship.

PAH data were OC-normalized.

$\tau$  values below and above the diagonal are mirror images; only one dataset is shown to make the table easier to read.



explained, given that these constituents were found to be positively correlated with toxicity in other bioassay tests, discussed below. The opposite pattern was observed with the Microtox test results, where percent fines, silver, and dioxins/furans were negatively correlated with increasing survivorship. The juvenile polychaete test results were not correlated with any of the sediment chemistry parameters. The larval development test results were correlated with the largest number of analytes, including percent fines, visible wood content, TOC, TVS, ammonia, sulfide, all metals, and dioxins/furans. Of these parameters, percent fines and TOC had the strongest correlations to larval survivorship ( $\tau = -0.41$  and  $-0.44$ , respectively). To investigate these relationships further, the statistics were re-analyzed reducing the sample population to only those samples collected from Shelton Harbor, the most highly impacted area (Table 7-2). In this case, resin acids, visible wood content, and ammonia showed the strongest correlations with larval survivorship ( $\tau = -0.52$ ,  $-0.49$ , and  $-0.42$ , respectively).

TOC, percent fines, resin acids, and visible wood content were the most highly correlated parameters with larval toxicity when considering both the entire study area dataset and the Shelton Harbor dataset. This suggests that these parameters play a role in larval toxicity. TOC and percent fines were also correlated with ammonia, sulfide, and all of the metals. So, it is possible that these other constituents associated with fine organic material also may contribute to larval mortality. Table 7-3 provides a graphical representation of the relationships among the combined bioassay test results at each station for all four tests, and the relative abundance of these wood waste-related parameters at each sample location. This table indicates that, on average, wood content and resin acids are both greater in those samples that failed toxicity tests (compare the relative length of colored bars in the pass-test category to the bars in the two fail-test categories).

In addition to environmental factors, the laboratory test method for larval toxicity should be considered. Standard protocol for the test requires that the sediment sample be thoroughly mixed with water in the test vessel and allowed to settle for 4 hours before the addition of larvae. If the sample contains significant amounts of organic fines, then those fines that settle after the 4-hour wait period may partially bury larvae and contribute to mortality, that is, mortality may be an artifact of the test method.

After performing the correlation analyses, hypothesis testing was performed to determine if there was a significant difference between pollutant concentrations in samples that failed toxicity tests and those that passed toxicity tests. In its simplest form, hypothesis testing addresses differences between data separated into two bins. In this case, the bins are toxicity test ‘pass’ and ‘fail’ categories. Significance is measured using a p-value with a threshold traditionally set at 0.05 (95 percent probability that there is a significant difference). If the test result has a p-value less than 0.05, then the difference between the datasets is deemed significant.

The benefit of this test is that there is a clear delineation between the chemistries of sediments that pass and fail a toxicity test; the chemistries are either significantly different or they are not. With correlation, the strength of the relationship between the dependent and independent variable is more difficult to interpret than with hypothesis testing; that is, there is no clear distinction between a strong relationship and a weak relationship.

If the data exhibit a normal distribution, then a parametric test is more appropriate for use in the analyses; if the data do not exhibit a normal distribution, then a non-parametric test is more appropriate. Using a parametric test on data that do not have a normal distribution violates a primary assumption of the test and produces spurious results. Non-parametric tests do not require any assumptions about the data's distribution and can be used equally well on normal and non-normal data (a parametric test will have slightly more power for detecting differences in the data if the data do in fact exhibit a normal distribution).

Based on the Kolmogorov-Smirnov normality test applied to the data, as discussed above, the non-parametric Mann Whitney U-Test was chosen instead of the parametric t-test (some of the data were normally distributed and some were non-normally distributed – because the t-test is invalid for non-normal data and because we did not want to exclude any data from the analysis, the Mann-Whitney U-test was applied to all the data in this study). This is a widely used and powerful test and the one most appropriate for this analysis.

Before running the Mann Whitney U-Test, data from all of the toxicity tests were combined. If a sample failed any of the tests, it was labeled a “fail”, if a sample passed all the tests, it was labeled a “pass”. The test results, based on these two bins, are presented in Table 7.4. It should be noted that if this test were to be applied to each toxicity measure individually, the results would be different.

Of the 50 surface sediment samples tested, 25 samples passed and 25 samples failed toxicity tests (except for resin acids and TVS, for which only 24 and 16 samples were analyzed, respectively). The sediment chemistries of these two data populations were compared using an alpha level of 0.05. That is to say, if the Mann-Whitney p-value was greater than 0.05, then no significant difference between data populations was determined. If sediment chemistry was significantly different in the toxicity-pass and toxicity-fail groups, the p-values were bolded in Table 7-4. The “direction of difference” column in the table indicates whether sediment chemistry concentrations were significantly higher in the toxicity-fail group than in the toxicity-pass group of samples. For most analytes, this was noted as Fail>Pass; only total LPAHs indicated that concentrations were higher for the toxicity-pass group.

As can be seen from Table 7-4, samples that failed the toxicity tests exhibited significantly higher levels of the following:

- Percent fines
- Ammonia
- Sulfide
- TOC
- Antimony
- Chromium
- Copper
- Nickel
- Silver
- Dioxins/furans

**Table 7-3. Results of wood waste constituents and visual observations of wood waste in surface sediment samples, based on toxicity testing results.**

| Sample ID  | Observed Wood (percent) | TOC (percent) | TVS (percent) | Ammonia (mg/kg) | Sulfides (mg/kg) | Total Resin Acids (µg/kg) |
|--|-------------------------|---------------|---------------|-----------------|------------------|---------------------------|
| <b>Sample stations failing CSL criteria for toxicity tests</b>         |                         |               |               |                 |                  |                           |
| SH-02  | 7.5                     | 2.46          | --            | 14.8            | 548              | --                        |
| SH-03  | 5                       | 3.8           | --            | 11.2            | 155              | --                        |
| SH-04  | 5                       | 4.13          | --            | 14.8            | 550              | --                        |
| SH-05  | 5                       | 3.2           | --            | 6.33            | 391              | --                        |
| SH-07  | 0.5                     | 1.59          | --            | 8.21            | 158              | --                        |
| SH-19  | 7.5                     | 4.44          | 17.72         | 17.1            | 916              | 4,200                     |
| SH-21  | 5                       | 5.59          | 16.64         | 18.6            | 1,890 J          | 5,700                     |
| SH-22  | 50                      | 5.77          | 19.68         | 30.5            | 969              | 7,400                     |
| SH-24  | 50                      | 4.97          | 14.17         | 17.2            | 148              | 9,000                     |
| OB-05  | 0                       | 2.35          | --            | 11.6            | 761              | 1,000                     |
| OB-06  | 2.5                     | 4.68          | --            | 9.47            | 1,190            | 1,200                     |
| OB-10  | 0                       | 2.62          | --            | 8.26            | 955              | 920                       |
| OB-13  | 0                       | 3.53          | --            | 10.4            | 255              | 1,100                     |
| OB-14  | 0                       | 1.71          | --            | 4.28            | 204              | --                        |
| OB-18  | 0                       | 2.86          | 9.35          | 22.4            | 1,110            | 450                       |
| OB-19  | 0                       | 2.6           | 9.25          | 6.83            | 823              | 1,500                     |
| <b>Sample stations failing SQS criteria for toxicity tests</b>         |                         |               |               |                 |                  |                           |
| SH-13  | 0.5                     | 11            | --            | 7.34            | 518              | --                        |
| SH-14  | 10                      | 3.1           | --            | 18.7            | 1350             | --                        |
| SH-26  | 0                       | 1.92          | 2.62          | 8.77            | 510              | 270                       |
| SH-28  | 0                       | 1.24          | 5.47          | 12              | 338              | 300                       |
| OB-03  | 0                       | 2.79          | --            | 11.7            | 1,240            | --                        |
| OB-04  | 5                       | 3.45          | --            | 8.52            | 599              | --                        |
| OB-09  | 0                       | 2.69          | --            | 10.8            | 1,530            | --                        |
| OB-12  | 0                       | 2.26          | --            | 10.1            | 908              | 1,800                     |
| HI-02  | 0                       | 0.571         | --            | 6.75            | 4.18             | 1,400                     |
| <b>Sample stations passing CSL and SQS criteria for toxicity tests</b> |                         |               |               |                 |                  |                           |
| SH-01  | 0                       | 1.59          | --            | 12.9            | 283              | --                        |
| SH-09  | 0                       | 2.17          | --            | 7.91            | 192              | --                        |
| SH-10  | 2.5                     | 2.03          | --            | 9.69            | 159              | --                        |
| SH-11  | 10                      | 2.32          | --            | 4.96            | 541              | --                        |
| SH-12  | 5                       | 4.79          | --            | 10.7            | 1070             | --                        |
| SH-15  | 0                       | 0.542         | --            | 4.3             | 5.01             | --                        |
| SH-16  | 0                       | 0.511         | --            | 2.76            | 1.19 U           | --                        |
| SH-18  | 0                       | 4.79          | 14.3          | 32.4            | 1,710            | 3,300                     |
| SH-20  | 5                       | 5.15          | 12.81         | 17.8            | 1,810            | 2,100                     |
| SH-23  | 2.5                     | 3.33          | 10.26         | 21.4            | 1,760            | 2,500                     |
| SH-25  | 0                       | 2.6           | 10.77         | 8.45            | 950              | 530                       |
| SH-27  | 5                       | 1.38          | 3.52          | 6.97            | 15.8             | 1,900                     |
| SH-29  | 0                       | 0.594         | 1.55          | 6.67            | 1.42             | 2,000                     |
| SH-30  | 0                       | 1.99          | 8.31          | 17.1            | 896              | 3,300                     |
| OB-01  | 0                       | 0.878         | --            | 15.1            | 6.83             | --                        |
| OB-02  | 0                       | 1.4           | --            | 4.79            | 489              | 3,200                     |
| OB-07  | 0                       | 0.995         | --            | 9.34            | 2.25 U           | --                        |
| OB-08  | 0.5                     | 1.36          | --            | 8.22            | 167              | --                        |
| OB-11  | 0                       | 2.32          | --            | 10.3            | 685              | --                        |
| OB-17  | 2.5                     | 2.39          | 4.41          | 4.72            | 363              | 1,900                     |
| HI-03  | 0                       | 1.45          | --            | 6.55            | 203              | --                        |
| HI-04  | 5                       | 0.625         | --            | 10.1            | 17.7             | 2,800                     |
| HI-05  | 0                       | 0.799         | --            | 7.82            | 9.65             | --                        |
| HI-06  | 0                       | 2.43          | --            | 5.68            | 258              | --                        |
| HI-07  | 0                       | 0.68          | --            | 5.83            | 1.3              | --                        |

Blue bar: Relative magnitude within the set of values for each parameter, allowing for quick inter-parameter comparisons.

CSL Cleanup screening level – combined results for all four toxicity tests  
 SQS Sediment quality guidelines – combined results for all four toxicity tests  
 mg/kg Milligrams per kilogram  
 µg/kg Micrograms per kilogram  
 -- Not analyzed  
 U Not detected  
 J Estimated value



**Table 7-4. Sediment chemistry toxicity test pass - fail comparison.**

| Analyte               | Mann-Whitney p-level <sup>a</sup> | Direction of Difference | Valid N Pass | Valid N Fail |
|-----------------------|-----------------------------------|-------------------------|--------------|--------------|
| Percent fines         | <b>0.001154</b>                   | Fail>Pass               | 25           | 25           |
| Resin acids           | 0.907787                          | -                       | 7            | 8            |
| Wood content (visual) | 0.147585                          | -                       | 25           | 25           |
| TVS                   | 0.247997                          | -                       | 8            | 8            |
| Ammonia               | <b>0.044608</b>                   | Fail>Pass               | 25           | 25           |
| Sulfide               | <b>0.006408</b>                   | Fail>Pass               | 25           | 25           |
| TOC                   | <b>0.001005</b>                   | Fail>Pass               | 25           | 25           |
| Antimony              | <b>0.026811</b>                   | Fail>Pass               | 25           | 25           |
| Arsenic               | 0.109266                          | -                       | 25           | 25           |
| Cadmium               | 0.122866                          | -                       | 25           | 25           |
| Chromium              | <b>0.023657</b>                   | Fail>Pass               | 25           | 25           |
| Copper                | <b>0.017384</b>                   | Fail>Pass               | 25           | 25           |
| Lead                  | 0.062358                          | -                       | 25           | 25           |
| Mercury               | 0.082371                          | -                       | 25           | 25           |
| Nickel                | <b>0.049676</b>                   | Fail>Pass               | 25           | 25           |
| Silver                | <b>0.005809</b>                   | Fail>Pass               | 25           | 25           |
| Zinc                  | 0.057168                          | -                       | 25           | 25           |
| Total LPAHs           | <b>0.001608</b>                   | Pass>Fail               | 25           | 25           |
| Total HPAHs           | 0.248206                          | -                       | 25           | 25           |
| Dioxins/furans        | <b>0.006409</b>                   | Fail>Pass               | 25           | 25           |

<sup>a</sup> If the Mann-Whitney p-level is less than 0.05, there is a significant difference between chemistry of sediments that passed and failed toxicity tests.

<sup>b</sup> Non-detects were calculated as ½ the detection limit.

**Bold** = significant difference

There was no significant difference between passed and failed sediment samples for the following analytes:

- Resin Acids
- Wood content (visual)
- TVS
- Arsenic
- Cadmium
- Lead
- Mercury
- Zinc
- Total HPAHs

Taken together, the findings of the correlation and hypothesis testing analyses indicate that PAHs are not a source of toxicity in the sediments analyzed. Though the presence of some metals was generally correlated with toxicity, none of the individual metals concentrations exceeded sediment quality standards. Percent fines and TOC were the strongest predictors of toxicity and

also strongly correlated with ammonia, visible wood content, TVS, resin acids, sulfide, all of the metals, and dioxins/furans. However, it is not possible to determine if the toxicity was caused by a combination of all or some of these constituents or simply from toxicity during the tests associated with the fines present. Also, it should be noted that dioxin/furan toxicity is a long-term bioaccumulative effect that cannot be observed in bioassay results.

Three interpretations that could follow from the statistical analyses include:

1. Toxicity is driven not by elevated concentrations of chemical pollutants, but by grain size and organic matter content of the substrate, or another physical characteristic of the sediment such as the presence of fine-grain wood waste
2. Toxicity is driven by a synergistic affect among various low-level contaminants (primarily associated with wood waste – resin acids, sulfides, ammonia, organic matter)
3. Toxicity is driven by the presence of an unmeasured contaminant.

Neither specific industrial waste inputs nor constituents associated with wood waste can be statistically linked to toxicity results, because controlled testing to isolate toxic parameters was not conducted.

The statistical analyses presented above do not prove a specific causal relationship, they simply show mathematical relationships. To determine which of the above conclusions is correct, more testing would be required. This may include toxicity identification and evaluation (TIE) testing to determine the cause of mortality in the test organisms (USEPA 2007). TIE testing results may aid in creating a causal link between toxicity and sediment chemistry, and may be used to determine if organism burial by fines is the primary factor controlling organism mortality in laboratory tests.

## **7.5 Comparison to Reconnaissance Survey Results**

Ecology conducted a survey (reconnaissance study) of Shelton Harbor sediments (Ecology 2000) to evaluate conditions associated with long-term accumulations of wood waste in the harbor, and potential contamination associated with various chemical inputs along the shoreline. Discrete sediment samples were collected at 10 locations along the shoreline to address specific discharge points to the harbor and composite sediment samples were collected from nine broad areas (called strata) extending across the harbor. No bioassay testing was conducted as part of the study.

### **7.5.1 Wood Waste Assessment**

For the reconnaissance study, the harbor was divided into nine strata from which 37 surface samples were collected and composited to evaluate the relative presence of wood waste. Strata

boundaries were defined by bathymetry and similar use characteristics before sampling and three to five sample locations established within each stratum. TVS measurements were used as a surrogate to estimate the amount of wood debris present in sediments. The determination of wood waste content in each sample was based on sieving sample contents into two size fractions (smaller and larger than 1/4-inch [0.6 cm]) and analyzing both fractions separately; an average of 3.5 percent of the wood was larger than 1/4 inch and 96.5 percent was smaller.

Total relative wood content was reported by weight for each stratum, ranging from 5.1 to 18.5 percent. These numbers were doubled (per HDG 1999) to estimate wood content by volume, resulting in the following distribution indicated across the harbor:

| Wood Content<br>(by volume) | Portion of Inner<br>Harbor Area |
|-----------------------------|---------------------------------|
| 10-20%                      | 34%                             |
| 20-30%                      | 54%                             |
| 30-40%                      | 12%                             |

Source: Ecology (2000).

Area-weighted averaging of these numbers results in 21.2 percent wood by volume across Shelton Harbor. The highest wood content was found in strata along the south harbor shoreline, near current barge loading and concentrated rafting operations; the lowest wood content was found in strata across the Goldsborough creek alluvial fan and extending east toward Oakland Bay, the remaining half of the harbor fell into the mid-range of wood content.

The Oakland Bay study collected 26 surface samples and 24 core samples across Shelton Harbor (fewer cores as a result of refusal due either to high wood or rock content). Thirteen of the surface samples and 11 of the 1-2 foot core samples, designated as wood waste samples, were analyzed for TVS (Figure 7-1). Sample preparation did not include screening wood into  $\pm 1/4$ -inch (7.6-cm) size fractions, as performed for the reconnaissance study, but did include removing large chunks of wood before analysis by TVS (the large chunks of wood were not analyzed).

A comparison of TVS results by strata from both the reconnaissance study and the current study is provided in Table 7-5; data from both studies correlate well (Kendall's  $\tau = 0.67$ ). TVS values for the current study generally fall within the range of, or are slightly lower than, values presented in the reconnaissance study, which indicate a fair amount of variability across most of the strata. TVS results from the Oakland Bay study generally confirm the reconnaissance study findings, with the lower results partially resulting from removal of large wood pieces before analysis.

Wood content estimates based on the DMMP methodology can be derived by doubling TVS results (USACE et al. 2008). A summary of surface sediment wood content based on reconnaissance study TVS data and Oakland Bay study TVS data and visual estimates are provided in Table 7-6. Substantial variability was seen when comparing visual estimates of wood volume between surface sediment and the 0-1 foot cores, reflecting the fact that samples were

not collected at the exact same location (estimates in Table 7-6 are based on the higher wood content observed in either of the two samples from each location). Visual estimates of wood content are likely biased low, since the small-grain wood material is indistinguishable from the fine grain mineral portion.

**Table 7-5. Comparison of Reconnaissance Study and Oakland Bay study TVS results by strata.**

| Reconnaissance Study Stratum | Reconnaissance Study |                 |             | Oakland Bay Study |                 |
|------------------------------|----------------------|-----------------|-------------|-------------------|-----------------|
|                              | No. of Samples       | Average TVS (%) | Range (%)   | No. of Samples    | Average TVS (%) |
| 1                            | 4                    | 7.2             | 6.0 – 9.5   | 1                 | 5.49            |
| 2                            | 3                    | 10.73           | 3.5 – 15.8  | 1                 | 8.31            |
| 3                            | 5                    | 13.18           | 4.0 – 26.6  | 2                 | 18.16           |
| 4                            | 5                    | 5.12            | 2.0 – 7.4   | 1                 | 2.62            |
| 5                            | 4                    | 10.18           | 3.8 – 16.4  | 1                 | 3.52            |
| 6                            | 4                    | 13.62           | 9.3 – 22.1  | 2                 | 12.47           |
| 7                            | 4                    | 18.48           | 13.4 – 29.9 | 2                 | 15.26           |
| 8                            | 3                    | 17.63           | 16.3 – 18.6 | 1                 | 14.3            |
| 9                            | 5                    | 13.96           | 6.2 – 32.3  | 1                 | 10.26           |
| Harbor-wide                  |                      | 12.23           |             |                   | 10.04           |

**Table 7-6. Comparison (by strata) of Reconnaissance Study and Oakland Bay study wood content estimates.**

| Reconnaissance Study Stratum | Reconnaissance Study Wood Content Estimate |                                    | Oakland Bay Study Wood Content Estimate |                                     |
|------------------------------|--|------------------------------------|---|-------------------------------------|
|                              | TVS – All Wood (%)                         | TVS – >1/4 Inch Chunks Removed (%) | TVS – Large Chunks Removed (%)          | Visual Observation (%) <sup>a</sup> |
| 1                            | 14   | 14                                 | 11                                      | 11                                  |
| 2                            | 22   | 22                                 | 16                                      | 10                                  |
| 3                            | 26   | 26                                 | 36                                      | 38                                  |
| 4                            | 10   | 8                                  | 5                                       | 2                                   |
| 5                            | 20   | 18                                 | 7                                       | 6                                   |
| 6                            | 27   | 23                                 | 25                                      | 25                                  |
| 7                            | 37   | 33                                 | 30                                      | 4                                   |
| 8                            | 35   | 34                                 | 28                                      | 14                                  |
| 9                            | 28   | 25                                 | 20                                      | 6                                   |
| Harbor-wide                  | 24   | 23                                 | 20                                      | 13                                  |

<sup>a</sup> Based on the higher of wood observed in the surface sediment and 0-1 foot core section at each location.

Geophysical results for Shelton Harbor (Figure 4-3) excluded approximately ½ of the harbor area, due either to physical obstructions or gravelly sediment associated with the creek deltas. The reconnaissance study identified high wood content (20 to 40 percent) across the southern



Figure 7-1. Comparison of Reconnaissance Study (Ecology 2000) and Oakland Bay study sample locations in Shelton Harbor.



portion of the harbor. The geophysical survey could not reliably map thickness of the wood-rich layer, due to acoustic signal dampening characteristics of the wood.

The best estimate of wood distribution with depth should be based on core log information displayed in Figure 5-2. Of the 12 cores advanced across the south harbor, wood was measured up to 12 feet (3.7 meters) thick at two locations, with neither core reaching the full extent of wood present. In some cases, no wood was found at the surface, but was found at depth. The vertical distribution of wood does not appear to be consistent across broad portions of the harbor. Three areas of significant wood accumulation were estimated in the harbor based on visual observations of cores, including former sawmill #4, the railway log dump, and the former pond saw.

### **7.5.2 Chemical Assessment**

Reconnaissance study surface sediment samples collected at the 10 shoreline discharge locations were analyzed for conventional analytes (total solids, TOC, grain size, TVS), metals, SVOCs, TBTs, and PCBs; the nine composite samples were analyzed for conventional analytes and SVOCs.

SQS criteria were exceeded at 7 sampling locations by a total of 11 constituents of concern, including some metals and semi-volatiles (Figure 7-2). CSL criteria were exceeded at 6 sampling locations by 4 of the 11 SQS constituents of concern. TBTs, which do not have SMS criteria, also were found at two locations exceeding screening values. Of the nine composite samples collected, both SQS and CSL criteria were exceeded across four strata by three constituents of concern.

In this study, no surface samples exceeded either SQS or CSL criteria; only one sample in Shelton Harbor exceeded the LAET for fluoranthene. Figure 7-2 provides Oakland Bay study laboratory results for those analytes that exceeded SMS criteria in the reconnaissance study at nearby locations. In all cases, concentrations were significantly lower in the Oakland Bay study. It is likely that variability in study results can be attributable to relatively small impact areas defined by few samples collected, mixing of sediment that results from significant human activities, and significant addition of sediment from Goldsborough and Shelton Creeks.

General results of the two studies compare, as follows:

- Mercury was found adjacent to the southwest harbor shoreline in the reconnaissance study at 0.45 and 0.50 mg/kg, slightly exceeding the SQS criterion of 0.41 mg/kg; mercury was not evident in the Oakland Bay study.
- Copper was found adjacent to the marina and marine railway/vessel haul out in the reconnaissance study at 447 and 493 mg/kg, respectively, exceeding the SQS criterion of 390 mg/kg; copper was not evident in the Oakland Bay study.

- TBTs were found near the base of the marine railway launching rails in the reconnaissance study at 1,300 µg/kg butyltin ion, 4,100 µg/kg dibutyltin ion, and 1,500 µg/kg tributyltin ion. Three samples were collected in the Oakland Bay study near the marina and former marine railway, with TBTs found only near the marine railway (8.0 µg/kg butyltin ion, 30 µg/kg dibutyltin ion, and 13 µg/kg tributyltin ion), south of the vessel haul out at the end of the Pine Street right of way. Sampling conducted by Ecology in 2005 indicated TBT concentrations of 979 and 2,136 µg/kg along the marine railway rails. Sampling indicates TBT presence to be localized near the rails.
- PAHs were the most common SVOCs found in both studies. The reconnaissance study found the highest concentrations near the marina and near historical sawmill #3; the Oakland Bay study found the highest concentrations near the former marine railway and near historical sawmill #3. Both studies identified total HPAH concentrations as higher than total LPAH concentrations across the harbor.
- The reconnaissance study found three wood waste-related SVOCs (phenol, 4-methylphenol, 2,4-dimethylphenol, and benzoic acid) at elevated concentrations along the south and southwest harbor shoreline and benzoic acid near the marina. The current investigation did not find any of these compounds at elevated levels in surface samples; however, two samples collected from the south-central part of the harbor had retene concentrations of 16,000 and 21,000 µg/kg in 1-2 foot core sections (other resin acids not analyzed for the reconnaissance study also were found at high concentrations in surface and 1-2 foot core samples).
- PCB concentrations were identified at low concentrations in all samples analyzed in the reconnaissance study, but detected at only two locations (SH-01 and HI-06) in the Oakland Bay study.
- The reconnaissance study identified PCP at all chemical screening sites, except one; the SQS criterion (360 µg/kg) was exceeded at the railway log dump (400 µg/kg - estimated value) and near the marina (380 µg/kg). No PCP was detected in any samples collected for the current investigation.
- The reconnaissance study identified di-n-butylphthalate at concentrations ranging between 11 and 40 mg/kg OC at three sampling stations – two along the southern shoreline and one near the marina; the Oakland Bay study did not find this compound at any location, but did identify BEHP (ranging between 1.5 and 3.5 mg/kg OC) across the entire harbor and butylbenzylphthalate (1.0 mg/kg OC) at the Shelton Creek discharge point.





## **8.0 Conclusions**

The Oakland Bay study was conducted to characterize marine sediment in the Oakland Bay system (Oakland Bay, Shelton Harbor, and the western portion of Hammersley Inlet) to define the bay-wide nature and extent of potential sediment contamination, including wood waste. The bay-wide approach (rather than a cleanup site-specific approach) was developed to evaluate the overall health of the bay as part of the Puget Sound Initiative process, and to identify whether there are specific source areas or areas of concern within the system.

This study emphasized locations associated with specific upland inputs to the bay and wood deposition from rafting and wood chip processing operations. The study included a geomorphic assessment to evaluate physical processes that drive the accumulation and movement of sediment across the bay, and sediment sample collection for chemical and biological testing to determine the distribution of chemicals and the potential for toxicity. Field investigations included a geophysical study and collection of both surface and subsurface sediment samples for physical, chemical and biological (toxicity) analyses.

### **8.1 Sediment Accumulation and Transport**

An evaluation of sediment transport determined that while there is some transport of fine-grained sediment (silt and clay) from Shelton Harbor to central Oakland Bay, most sediment discharged to the bay remains close to where it first enters marine waters, mostly from creeks. Coarser sediment falls close to the creek outlets, while finer grained sediment and small particles may be carried out further into the harbor and bay. The majority of sediment input to the Oakland Bay system is from Goldsborough Creek. Based on radiologic dating of three sediment cores, sedimentation in Oakland Bay ranges from 0.10 to 0.26 inches/year (0.25 to 0.66 cm/year) and in alluvial fans up to 0.39 inches/year (1 cm/year). The pattern of circulation and sediment transport in the bay is primarily determined by tidal motion – sediment transport is flood-dominated along the seabed, with the ebb tide dominated by flow at the surface containing relatively small amounts of fine-grained sediment. As a result, very little sediment moves out of the system.

### **8.2 Wood Debris**

Wood waste enters and is distributed across the Oakland Bay system in two primary ways: low concentrations spread across deeper portions of Oakland Bay by tidal flows near the sediment bed, and significant accumulations (greater than 20 percent by volume) near both historical and current log rafting and wood processing (milling) locations. Milling primarily generates wood chips and sawdust, and log rafting primarily generates bark. Wood fibers are found in low concentrations, probably the result of historical discharge of sulfite liquor waste and fiberboard processes. Most wood mass exists in sediment as a widespread, low-concentration deposit mixed

within the recently deposited marine bed surface associated with the onset of wood industry operations in the late 1800s. Geophysical survey results indicate this layer averages 3 feet (1 meter) thick (measured from 0 to 8 feet [0 to 2.5 meters]). The persistence of both significant local wood accumulation and low wood concentrations across both Shelton Harbor and Oakland Bay supports indications that wood waste, like sediment, is relatively immobile.

Four areas of significant wood accumulation were identified based on visual evaluation of sediment cores: the former saw pond, the railway log dump, and Sawmill #4 in Shelton Harbor, and at the head of the bay north of Bayshore Point. Specific boundaries of significant wood waste accumulations at these locations cannot be established with existing data. Due to poor signal resolution, geophysical techniques employed during the study could not be used to define lateral or vertical boundaries. Visual and chemical analyses would be required at many more locations to effectively evaluate accumulations on a local scale.

### **8.3 Chemical Analysis**

Chemical analyses of surface and subsurface sediment collected from across the Oakland Bay system identified only one SMS criteria exceedance in Shelton Harbor, implicating no significant industrial inputs to the bay (fluoranthene found at 2,000  $\mu\text{g}/\text{kg}$  dry weight compared to the LAET criterion of 1,700  $\mu\text{g}/\text{kg}$ ). Dioxins/furans, however, were found in all 63 samples collected, including both surface and subsurface sediment. Sixty-five percent of the samples exceeded 10 ng/kg TEQ, the draft maximum concentration allowable for open-water disposal under the DMMP. The highest concentrations were generally found in Shelton Harbor, but samples with low concentrations were found adjacent to samples with high concentrations, indicating significant mixing or covering of sediments in this highly trafficked area. Medium-range study area concentrations found in surface samples at the head of the bay (21.9 to 54.4 mg/kg TEQ) indicate spatially consistent input and stable sediment extending across all of Oakland Bay (reference samples collected 20 miles to the east and OSV Bold survey results had significantly lower concentrations).

No discernable source-specific spatial pattern was identified based on concentration gradients; however, dioxin/furan concentrations were much higher in Shelton Harbor, and were also higher in subsurface samples, on average (subsurface samples were collected at 25 percent of surface sample locations). This indicates that inputs to the system, at least in part, originated in Shelton Harbor and that inputs to the system appear to be diminishing, with recent, cleaner sediments likely covering older, more contaminated deposits. Considering sediment accumulation rates, it is not known why dioxin continues to be elevated in surface sediments. It is possible that there is a continuing source of dioxin, sediments from higher concentration areas are being redistributed to lower concentration areas through tidal currents, or that mixing of deeper with shallower sediments has occurred as a result of human or natural processes.

## **8.4 Dioxin Profiles**

The following were used to generate visual profiles (bar graphs) that show the proportion of each dioxin and furan congener to total mass of congeners:

- Dioxin and furan congener source-specific information generated by USEPA
- Nearby Goose Lake sampling results available from Ecology's EIM database
- Puget Sound area-wide data from the 2008 OSV Bold survey

These visual profiles were compared to profiles from Oakland Bay study samples to identify possible dioxin and furan sources. Five of the 15 USEPA-provided congener profiles evaluated were similar to those found in Oakland Bay sediments, including:

- Technical grade PCP
- Black liquor recovery boiler stack emissions
- Forest fires
- Combustion of Bleach-Kraft mill sludge in wood residue boilers
- Unleaded fuel emissions from automobiles with catalytic converters

The liquid PCP and black liquor recovery boiler emissions appear to match the closest. Profiles were not available for sulfite waste liquor incineration; sulfite waste liquor; or boiler ash from burning salt-laden wood. Goose Lake surface and subsurface sediment congener profile patterns indicate surface sediments to be similar to those of Oakland Bay sediments (the lake received sulfite liquor waste discharges); subsurface sediment profiles were less similar. The congener profiles found across the Oakland Bay study area also are very similar to the Puget Sound sub-basins characterized by the OSV Bold survey; however, total concentrations of dioxins/furans in Oakland Bay were much higher than generally found throughout Puget Sound.

Based on available data, no specific dioxin/furan source can be definitively linked to the Oakland Bay study results without additional sampling. Nothing stands out as distinguishable from area-wide profiles, and no concentration gradient can be seen pointing to a single location/point source in the study area (although concentrations are generally much higher in Shelton Harbor than in Oakland Bay). Potential sources include pulp mill process wastewaters, discharge of discharge of sulfite liquor waste, spillage of PCP, air deposition from burning of various materials including salt-laden hog fuel and sulfite liquor (there are five historical emissions stacks along the Shelton waterfront area), and discharge of baghouse residues to the wastewater treatment plant. Similarities between Oakland Bay and Goose Lake profiles indicate a possible similar source, which could be either liquid-based, aerial emissions, or both. If aerial deposition is assumed to be the primary mechanism for distribution of dioxins/furans across Puget Sound, the high dioxin/furan concentrations found in Oakland Bay indicate the Shelton waterfront as a possible source. Additional upland testing would be required to define concentration gradients from specific emission stacks or the operational area in general.

## **8.5 Biological Testing**

Although only one SMS chemical criterion was exceeded, 25 of the 50 bioassay samples did not meet SQS and/or CSL criteria: nine samples exceeded SQS criteria and 16 samples exceeded CSL criteria. The acute larval test had the most failures (14 CSL and seven SQS), the chronic polychaete test had seven SQS failures, and the acute amphipod and chronic Microtox test each had one SQS failure. Toxicity test pass/fail results for samples collected in areas with high accumulation of wood waste were inconsistent – samples collected from the Shelton and Goldsborough Creek discharge area generally failed the larval acute test; however, two samples collected from the Sawmill #4 wood waste accumulation area passed all tests. To evaluate a possible link between physical or chemical conditions to toxicity, both correlation analysis and hypothesis testing were performed.

When considering all data, percent fines and parameters linked to wood waste (TOC, resin acids, and TVS) were those most highly correlated to larval toxicity. When considering only Shelton Harbor data, resin acids, TVS, and ammonia showed the strongest correlations with larval toxicity. The analysis also determined that TOC and percent fines were highly correlated with ammonia, sulfide, and all of the metals. So, it is possible that these other constituents, associated with fine organic material, also may contribute to larval toxicity. Further hypothesis testing indicated that samples that failed the toxicity tests exhibited significantly higher levels of percent fines, TOC, metals (antimony, chromium, copper, lead, silver, zinc), and dioxins/furans.

Taken together, the findings of the correlation and hypothesis testing analyses indicate that percent fines and TOC are the strongest predictors of toxicity and are also strongly correlated with ammonia, wood content, TVS, resin acids, sulfide, TOC, all of the metals, and dioxins/furans. However, it is not possible to determine if toxicity was caused by a combination of all or some of these pollutants or simply from poor growth habitat associated with the fines present.

Three possible interpretations for toxicity in Oakland Bay based on the statistical evaluation are:

1. Toxicity is driven not by elevated concentrations of chemical pollutants, but by grain size and organic matter content of the substrate, or another physical characteristic of the sediment such as the presence of fine-grain wood waste.
2. Toxicity is driven by a synergistic effect among various low-level contaminants (primarily associated with wood waste – resin acids, sulfides, ammonia, organic materials).
3. Toxicity is driven by the presence of an unmeasured contaminant.

The statistical analyses presented show mathematical relationships, but cannot prove a specific causal relationship. To determine which of the conclusions above is correct, more testing would be required.

## **8.6 Comparisons with 1999 Reconnaissance Study**

Wood content determined by TVS analysis correlated well between the 37 surface sediment samples collected for the 1999 reconnaissance survey and the 26 surface sediment samples collected from the same area for the Oakland Bay study, with the Oakland Bay study results lower in eight of the nine strata; the harbor-wide average was approximately 20 percent lower. Visual estimates of wood content made during the Oakland Bay study were approximately 30 percent lower than estimates based on TVS results for the same samples. The highest wood content area was identified across the southern harbor in both studies, and the lowest wood content area was identified across the Goldsborough and Shelton Creek alluvial fans. Core samples collected for the Oakland Bay study identified the following:

- High wood content greater than 12 feet (3.7 meters) deep at two locations in the south harbor area (neither core reached the bottom of the wood layer)
- High wood content below surface samples with little or no wood content
- Highly variable wood content at adjacent locations (possibly due to dredging or mixing from activities above)

Three areas of high wood content were identified in the harbor based on visual observations of cores: the former pond saw, the railroad log dump, and Sawmill #4. The reconnaissance study called out the area associated with Sawmill #4 and a portion of the railroad log dump based on strata averages; however, by including individual samples in neighboring strata, areas of high wood content appear similar to those identified in the Oakland Bay study (the former pond saw area was not sampled as part of the reconnaissance study).

The reconnaissance study identified 12 chemical constituents of concern in Shelton Harbor based on SMS or PSDDA criteria. Contaminants exceeded SMS criteria by factors ranging from 1.1 to 3.9 times; the PSDDA screening value for TBT was exceeded by 1.3 and 18 times at two of the locations sampled in the vicinity of the marine railway. The Oakland Bay study identified only one SMS exceedance by 1.2 times at one location; TBTs were found at one of three locations sampled, below the PSDDA screening level used by the reconnaissance study (based on a dry weight basis instead of the current pore water criterion – an approach selected to provide comparable data between the two studies). All Oakland Bay study samples collected near reconnaissance study samples indicated significantly lower concentrations of those constituents initially found to exceed SMS criteria. It is possible that:

- Over the 8 years separating the two studies, organic contaminants have degraded by physical, chemical, and biological processes
- Over the 8 years separating the two studies, chemical inputs to the harbor have decreased and the previous surface has been covered by added wood and sediment

- The distribution of chemicals is variable across the sample space, requiring additional samples to better define site conditions

## **8.7 Summary**

This investigation has determined that sediment enters the Oakland Bay system primarily through creeks, with large-grain sediments depositing in creek deltas and fine-grain sediments redistributing across the bay; little sediment leaves the system into Hammersley Inlet. Similarly, wood waste generated primarily from wood processing along the southern portion of Shelton Harbor and log rafting across the harbor and along the Oakland Bay shoreline settles vertically, and does not move significantly through the bay system. Significant industrial chemical input was not observed across the study area and no chemical source areas were identified. The 1999 reconnaissance study did find chemical concentrations exceeding SMS criteria at eight locations along the Shelton Harbor shoreline; further sampling at historical discharge locations may be necessary to address all known potential sources.

Area-wide dioxin/furan contamination was identified as extending across the entire study area, with the highest concentrations found in Shelton Harbor. Particularly high concentrations, increasing with depth, were identified along the western shore of Shelton Harbor and into southern Oakland Bay. No concentration gradient pattern could be developed pointing to a specific source; fingerprint analysis identified PCP and black liquor recovery boiler emissions sources as the closest matches to available USEPA library profiles – PCP was reportedly used somewhere in the wood processing area west of the Shelton Harbor shoreline and sulfite liquor waste (similar to black liquor waste) was burned at various locations near the southern harbor shore.

Significant wood waste deposits were noted at four locations across the study area, and low level wood waste was found in the sediment layer that has accumulated throughout the bay since the 1800s.

Sediments in several areas failed SMS criteria for toxicity, and these areas should be considered for further investigation and cleanup. Any removal of wood waste or sediment must consider elevated dioxin/furan concentrations found across the study area.

## 9.0 References

- Albertson, S.L. 2004. Oakland Bay Study: A Dye and Modeling Study in an Enclosed Estuary with a High Degree of Refluxing. Washington State Department of Ecology, Olympia, Washington.
- ATSDR. 1995a. Toxicological Profile for Fuel Oils. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp75.pdf>.
- ATSDR. 1995b. Toxicological Profile for Gasoline. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp72.pdf>.
- ATSDR. 1995c. Toxicological Profile for Polycyclic Aromatic Hydrocarbons. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp69.pdf>.
- ATSDR. 1997. Toxicological Profile for Used Mineral-Based Crankcase Motor Oil. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp102.pdf>.
- ATSDR. 1999a. Toxicological Profile for Cadmium. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/tfacts5.html>.
- ATSDR. 1999b. Toxicological Profile for Mercury. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp46.pdf>.
- ATSDR. 2000. Toxicological Profile for Chromium Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp7.pdf>.
- ATSDR. 2001a. Toxicological Profile for Di-n-butyl phthalate. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp135.pdf>.
- ATSDR. 2001b. Toxicological Profile for Pentachlorophenol. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. [www.atsdr.cdc.gov/toxprofiles/tp51.html](http://www.atsdr.cdc.gov/toxprofiles/tp51.html).
- ATSDR. 2001c. Toxicological Profile for Polychlorinated Biphenyls. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/tfacts17.html>.

ATSDR. 2002. Toxicological Profile for DDD, DDE, and DDT. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/tfacts35.html>.

ATSDR. 2004a. Toxicological Profile for Ammonia. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp126.pdf>.

ATSDR. 2004b. Toxicological Profile for Copper. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/tfacts132.html>.

ATSDR. 2005. Toxicological Profile for Zinc. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/tfacts60.html>.

ATSDR. 2006a. Toxicological Profile for Hydrogen Sulfide. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/toxprofiles/tp114.pdf>.

ATSDR. 2006b. Toxicological Profile for Phenol. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/tfacts115.html>.

ATSDR. 2007a. Toxicological Profile for Arsenic. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/tfacts2.html>.

ATSDR. 2007b. Toxicological Profile for Lead. Atlanta, GA. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. <http://www.atsdr.cdc.gov/tfacts13.html>.

ATSDR. 2010. ToxFAQs. <http://www.atsdr.cdc.gov/tfacts22.html>.

Berbells, Scott. 2003. 2003 Shoreline Survey of the Oakland Bay Shellfish Growing Area. Public Health Advisor for the Washington State Department of Health, Division of Environmental Health, Shellfish and Water Protection Office.

CALTRANS. 2001. Data Analysis Tool Excel Add-In Documentation. California Department of Transportation (CALTRANS). January 30, 2001.

CH2M Hill. 1987. Final Dioxin Study Report – Simpson Timber Company. Report was prepared for Simpson Timber Company. March 1987. The report is available at the Washington Southwest Regional State Archives (Box 519 [location: 02-A-207]; folder – Simpson Dioxin Study 1986, 1987).

DMMP. 2002. DMMP Clarification Paper: Ammonia and amphipod toxicity testing. Prepared by Justine Barton (USEPA Region 10) for the Dredged Material Management Program agencies. June 15, 2002.

DMMP. 2004. DMMP Clarification Paper: Ammonia and sulfide guidance relative to *Neanthes* growth bioassay. Prepared by David Kendall (US Army Corps of Engineers) and Justine Barton (USEPA Region 10) for the Dredged Material Management Program agencies. June 15, 2004.

DMMP. 2010. Dredged Material Management program Proposed Changes to Interim Guidelines for Dioxins. April 19, 2010. [http://www.nws.usace.army.mil/PublicMenu/documents/DMMO/DMMP\\_Proposed\\_Changes\\_to\\_Interim\\_Guidelines\\_for\\_Dioxins\\_4-19-2010.pdf](http://www.nws.usace.army.mil/PublicMenu/documents/DMMO/DMMP_Proposed_Changes_to_Interim_Guidelines_for_Dioxins_4-19-2010.pdf).

Ecology. 1990. Shelton Storm Drain Sediment Study (1989) Results. Ecology Memorandum 90-e15. Prepared by Betsy Dickes, Washington Department of Ecology, Investigations and Laboratory Services Program, to Darrel Anderson, Ecology Southwest Regional Office. August 6, 1990.

Ecology. 1998. Washington State Dioxin Source Assessment. Washington State Department of Ecology, Environmental Investigations and Laboratory Services, and Hazardous Waste and Toxics Reduction Program. Publication No. 98-320. July 1998.

Ecology. 2000. Reconnaissance Survey of Inner Shelton Harbor Sediments – Chemical screening of nearshore sites and evaluation of wood waste distribution. Report was prepared by Dale Norton, Randy Cootz, and Katina Kapantais of the Washington State Department of Ecology, Environmental Assessment Program, Olympia, Washington. Publication No. 00-03-014. May 2000.

Ecology. 2004a. Oakland Bay Study – a dye and modeling study in an enclosed estuary with a high degree of refluxing. Report prepared by S.L. Albertson, Washington Department of Ecology, Environmental Assessment Program, Olympia, Washington. Publication No. 04-03-020. May 2004.

Ecology. 2004b. Quality Assurance Project Plan – Fecal Coliform Bacteria TMDL for Oakland Bay-Hammersley Inlet and Tributaries. The QAPP was prepared by Anise Ahmed and Lawrence Sullivan, Washington State Department of Ecology, Environmental Assessment Program, Olympia, Washington. Publication No. 04-03-111. September 2004.  
<http://www.ecy.wa.gov/pubs/0403111.pdf>.

Ecology. 2005. Initial Investigation Field Report – Simpson Marine Railway. Washington State Department of Ecology, Environmental Report Tracking System (ERTS) no. 542245. Report was provided to Herrera Environmental Consultants, Inc. by Cynthia Erickson of Ecology via email on April 11, 2008.

Ecology. 2008. Sediment Sampling and Analysis Plan Appendix. Guidance on the Development of Sediment Sampling and Analysis Plans Meeting Requirements of the Sediment Management Standards (WAC Chapter 173-204). Publication No. 03-09-043. Washington Department of Ecology, Olympia, Washington. Revised February 2008.

Farallon Consulting, LLC. 2005. Final Remedial Investigation Report – Evergreen Fuel Facility, 661 East Pine Street, Shelton, Washington. Report was prepared by Farallon and Anchor Environmental, LLC for CC Cole and Sons, Inc., D.B.A. Evergreen Fuel Company and Chevron Corporation. November 30, 2005. The two volumes report is available in central records of the Washington State Department of Ecology, Southwest Regional Office in Lacey, Washington.

Fredson, Michael. 1976. Oakland to Shelton: The Sawdust Trail. Mason County Historical Society, includes a 1889 Mason County Map by Maxine Morse.  
[http://www.historylink.org/index.cfm?DisplayPage=output.cfm&file\\_id=7730](http://www.historylink.org/index.cfm?DisplayPage=output.cfm&file_id=7730).

HDG (Hylebos Debris Group). 1999. Head of Hylebos Waterway Wood Debris Program – Draft Cleanup Study Work Plan. Agency draft prepared for the Hylebos Wood Debris Group by Floyd and Snyder, Pentec Environmental, Evans-Hamilton and Ogden Beeman and Assoc, Inc., Seattle, Washington.

Helsel, D. 1990. Less than obvious: Statistical treatment of data below the detection limit. *Environmental Science and Technology* 24(12):1766-1774.

Helsel, D.R. and R.M. Hirsch. 2002. *Statistical Methods in Water Resources*. Elsevier, Amsterdam.

Herrera. 2008a. Final Summary of Existing Information and Identification of Data Gaps Technical Memorandum. Prepared for Washington Department of Ecology, Toxics Cleanup Program, Southwest Regional Office, Olympia, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. April 22, 2008.

Herrera. 2008b. Sampling and Analysis Plan, Oakland Bay Sediment Characterization Study, Mason County, Washington. Prepared for Washington Department of Ecology, Toxics Cleanup Program, Southwest Regional Office, by Herrera Environmental Consultants, Inc., Seattle, Washington. September 18, 2008.

Kenny, Stephanie. 2007. Oakland Bay Action Plan. Ms. Kenny is an Environmental Health Specialist with the Mason County Public Health. August 16, 2007.

Lewis, Richard J., Sr. 1997. *Hawley's Condensed Chemical Dictionary*. Thirteenth Edition. Van Nostrand Reinhold, division of International Thomson Publishing, Inc., New York, New York.

Michelsen, Teresa and Travis C. Shaw. 1996. Technical Information Memorandum. Statistical Evaluation of Bioassay Results. Prepared for the Puget Sound Dredged Disposal Analysis / Sediment Management Standards Agencies. July 1996.

Michelsen, Teresa. 1992. Technical Information Memorandum. Organic Carbon Normalization of Sediment Data. Washington Department of Ecology, Sediment Management Unit. December 1992.

MRC. 2008. Whatcom County Marine Resources Committee Projects – Marine Creosote Log Remediation Project. [http://whatcom-mrc.wsu.edu/MRC/projects/restoration\\_creosote.htm](http://whatcom-mrc.wsu.edu/MRC/projects/restoration_creosote.htm).

NOAA. 2007. Mussel Watch Status and Trends: Sampling for Coastal Trends, Contaminants Monitored List. <http://celebrating200years.noaa.gov/datasets/mussel/welcome.html#con>. January 30, 2007.

PSEP. 1995. Recommended Guidelines for Conducting Laboratory Bioassays on Puget Sound Sediments – Final Report. Puget Sound Estuary Program. Prepared for U.S. Environmental Protection Agency, Region 10, Office of Puget Sound, Seattle, WA, and Washington Department of Ecology, Olympia, Washington.

PTI. 1988. The Apparent Effects Threshold Approach, Briefing Report to the EPA Science Advisory Board, Office of Puget Sound Puget Sound Estuary Program, USEPA Region 10. Prepared by PTI Environmental Services, Bellevue, Washington. September 1988.

Schumacher, Brian A. 2002. Methods for the Determination of Total Organic Carbon (TOC) in Soils and Sediments, United States Environmental Protection Agency Environmental Sciences Division National Exposure Research Laboratory, Las Vegas, NCEA-C- 1282, EMASC-001.

Shaffer, J. Anne. 2003. Water Quality as a Contemporary Limiting Factor to Olympia Oyster (*Ostreola conchaphila*) Restoration in Washington State. Document from the 2003 Georgia Basin/Puget Sound Research Conference. [http://www.psat.wa.gov/Publications/2003research/rc03\\_abstracts/oral\\_sessions/session\\_8f.htm](http://www.psat.wa.gov/Publications/2003research/rc03_abstracts/oral_sessions/session_8f.htm).

Shumway, R.H. and R.S. Azari. 2000. Statistical Approaches to Estimating Mean Water Quality Concentrations with Detection Limits. Unpublished report to Caltrans. October 20, 2000.

Syvitski, J.P.M., A.J. Kettner, S.D. Peckham, and S.J. Kao. 2005. Predicting the Flux of Sediment to the Coastal Zone: Application to the Lanyang Watershed, Northern Taiwan. *Journal of Coastal Research* 21(3):580-587.

Taylor. 1987. Quality Assurance of Chemical Measurements, Lewis Publishers, Chelsea, pp 203-205.

USACE (U.S. Army Corps of Engineers), USEPA, Ecology, WDNR. 2008. Dredged Material Evaluation and Disposal Procedures (User's Manual). Prepared by the Dredged Material Management Office, U.S. Army Corps of Engineers, Seattle District. July 2008.

USACE. 2009. Data Summaries of Dioxin/Furan Congeners, PCB Aroclors, PCB Congeners, Total Organic Carbon, Grain Size, and Pesticides Puget Sound Dioxin/PCB Survey, OSV Bold, 2008. January 21.

USEPA. 2006. An inventory of sources and environmental releases of dioxin-like compounds in the United States for the years 1987, 1995, and 2000. U.S. Environmental Protection Agency, National Center for Environmental Assessment, Washington, D.C. Publication No. EPA/600/P-03/002F. <http://cfpub.epa.gov/ncea/cfm/recorddisplay.cfm?deid=159286>.

USEPA. 2007. Sediment Toxicity Identification Evaluation (TIE) Phases I, II, and III Guidance Document, Office of Research and Development, EPA/600-R07-080, September.

USEPA. 2010a. Basic Information about antimony in Drinking Water.  
<http://www.epa.gov/safewater/contaminants/basicinformation/antimony.html>.

USEPA. 2010b. Basic Information about barium in Drinking Water.  
<http://www.epa.gov/safewater/contaminants/basicinformation/barium.html>.

USEPA. 2010c. Technology Transfer Network Air Toxics Website.  
<http://www.epa.gov/ttn/atw/hlthef/nickel.html>.

Van den Berg, M., L.S. Birnbaum, M. Denison, M. De Vito, W. Farland, M. Feeley, H. Fiedler, H. Hakansson, A. Hanberg, L. Haws, M. Rose, S. Safe, D. Schrenk, C. Tohyama, A. Tritscher, J. Tuomisto, M. Tysklind, N. Walker, and R.E. Peterson. 2006. The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological Sciences* 93(2):223-241.