Dioxin in Surface Water Sources to Oakland Bay (Mason County)

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Cover photo: Oakland Bay from the Log Monument on Highway 3.

Dioxin in Surface Water Sources to Oakland Bay (Mason County)

by

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Water Resource Inventory Area (WRIA): 14

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Abstract

An Oakland Bay study in 2008 reported relatively high dioxin and furan concentrations in surface sediments across the study area (Herrera, 2010). In 2011 the Washington State Department of Ecology collected sediment and soil samples to determine if dioxin and furans are being discharged by major surface water sources to Shelton Harbor and Oakland Bay.

Surface sediments were collected from Shelton, Goldsborough, and Johns Creeks. Additionally, two terrestrial soil samples were collected from an ash mound along Shelton Creek. Samples were analyzed for dioxin and furans, total organic carbon, and grain size.

Overall, dioxin concentrations were generally low in sediment compared to guideline or benchmark levels. Only the two downstream sites in Shelton Creek reported dioxin concentrations above background. The 300 to 400 meter reach between the two sites has a large ash mound rising from the creek’s left bank. The highest dioxin concentrations reported for the study were from the two ash mound samples. The ash mound could be a continual dioxin input to Shelton Creek and ultimately Shelton Harbor and Oakland Bay.

As a result of this 2011 study, the following recommendations are made:

- Conduct follow-up sampling to determine areal extent and contaminant boundaries of the ash mound.
- Following removal of the ash mound, monitor Shelton Creek after a period of recovery to verify reduction in dioxin levels.
- Include the unnamed tributary to Shelton Creek in any follow-up sampling to determine where dioxin background levels are exceeded in the downtown area.

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Introduction

Oakland Bay has been identified by the Washington State Department of Ecology (Ecology) as a priority embayment under Ecology's Toxics Cleanup Program's Puget Sound Initiative. Under this plan, seven Puget Sound bays were selected that would benefit most from toxics investigations to protect natural resources and human health.

Oakland Bay, located in Mason County, has a long history of industrial activity, while also being one of the nation's most productive shellfish growing areas (Figure 1). Sediment contamination has been documented in previous investigations.

In 2008 the Toxics Cleanup Program directed a sediment investigation in Oakland Bay to support prioritization of cleanup and restoration. The study reported industrial contaminants of concern below Ecology's Sediment Management Standards (SMS) across the study area. Polychlorinated dibenzo-p-dioxins and dibenzofuran compounds, also called dioxin and furans or dioxin, not addressed in SMS were reported at relatively high concentrations throughout the study area (Herrera, 2010).

The investigation included 44 surface sediment samples from the Shelton Harbor and Oakland Bay study area. Sediment was collected from the top 10 centimeters of the substrate surface. Every site had detectable levels of dioxin ranging from 1 to 175 ng/Kg, Toxic Equivalents (TEQs). The highest concentrations were located along the western edge of Shelton Harbor. The mean total dioxin TEQ was higher in inner Shelton Harbor (42.8 ng/Kg, TEQ) than Oakland Bay (32.1 ng/Kg, TEQ).

Sources of dioxin to Oakland Bay likely include surface water and stormwater inputs, point source discharge (current and historical), and the atmospheric pool through wet and dry deposition. Shelton and Goldsborough Creeks are the largest surface water sources discharging within the urban/industrial area of Shelton Harbor. In addition, Johns Creek discharging to upper Oakland Bay drains an area that includes an industrial park where wood-treating facilities were once located.

Identifying and reducing current inputs of dioxin to Oakland Bay is important because of the relatively high levels of contaminants found in the bay and the need to eliminate sources before sediment cleanup options can be considered. Dioxin has never been measured in streams discharging to Oakland Bay.

This study measured dioxin levels in sediment from Shelton, Goldsborough, and Johns Creeks. Sediments were sampled because dioxin tends to be associated with particulates. Dioxin concentrations in water are normally at such low levels that it is not detectable at current levels of detection.

Figure 1 shows the study area including the location of Shelton, Goldsborough, and Johns Creeks.

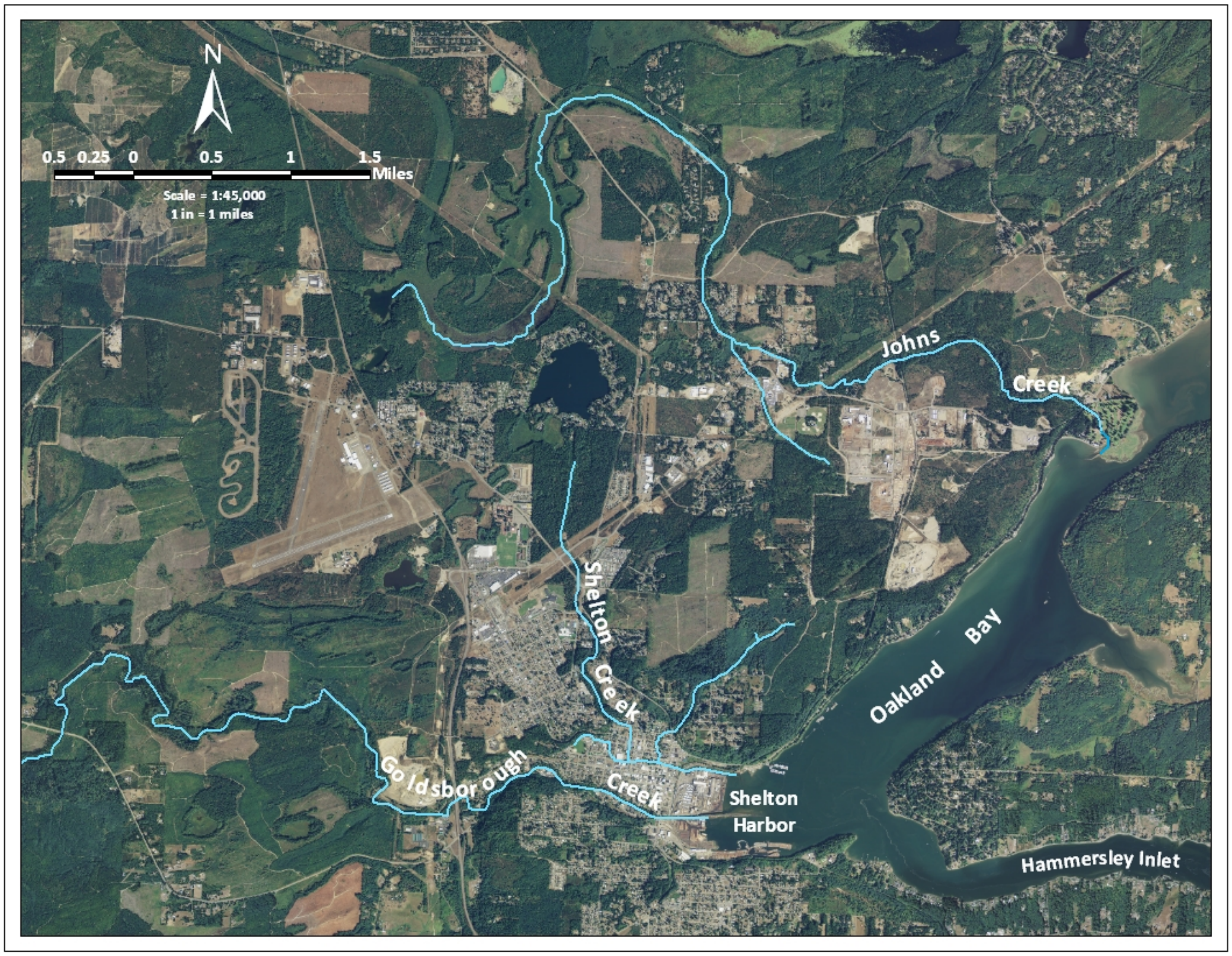

Figure 1. Study area showing Shelton, Goldsborough, and Johns Creeks.

Project Description

Ecology's Environmental Assessment Program collected sediment samples from Shelton, Goldsborough, and Johns Creeks during the fall of 2011. Sampling occurred as close as possible to the point of discharge to marine water and at three upstream sites in Shelton Creek, two sites in Goldsborough Creek, and one upstream site in Johns Creek (Figure 2 and Appendix B). Two surface soil samples were also collected from a mounded fill adjacent to the downstream sampling site on Shelton Creek. The mound appears to be made from a gray ash material.

Sediment samples were analyzed for the seventeen 2,3,7,8-substituted dioxin/furan compounds of concern. Columbia Analytical Services, Houston, Texas, analyzed the sediment for dioxin and furans through a contract with Ecology's Manchester Environmental Laboratory (MEL). Sediment was analyzed by Method 1613B using high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS). Reporting limits were in the fractional parts per trillion (ng/Kg). Ancillary parameters included total organic carbon (TOC) and grain size, using Puget Sound Estuary Program (PSEP) methods.

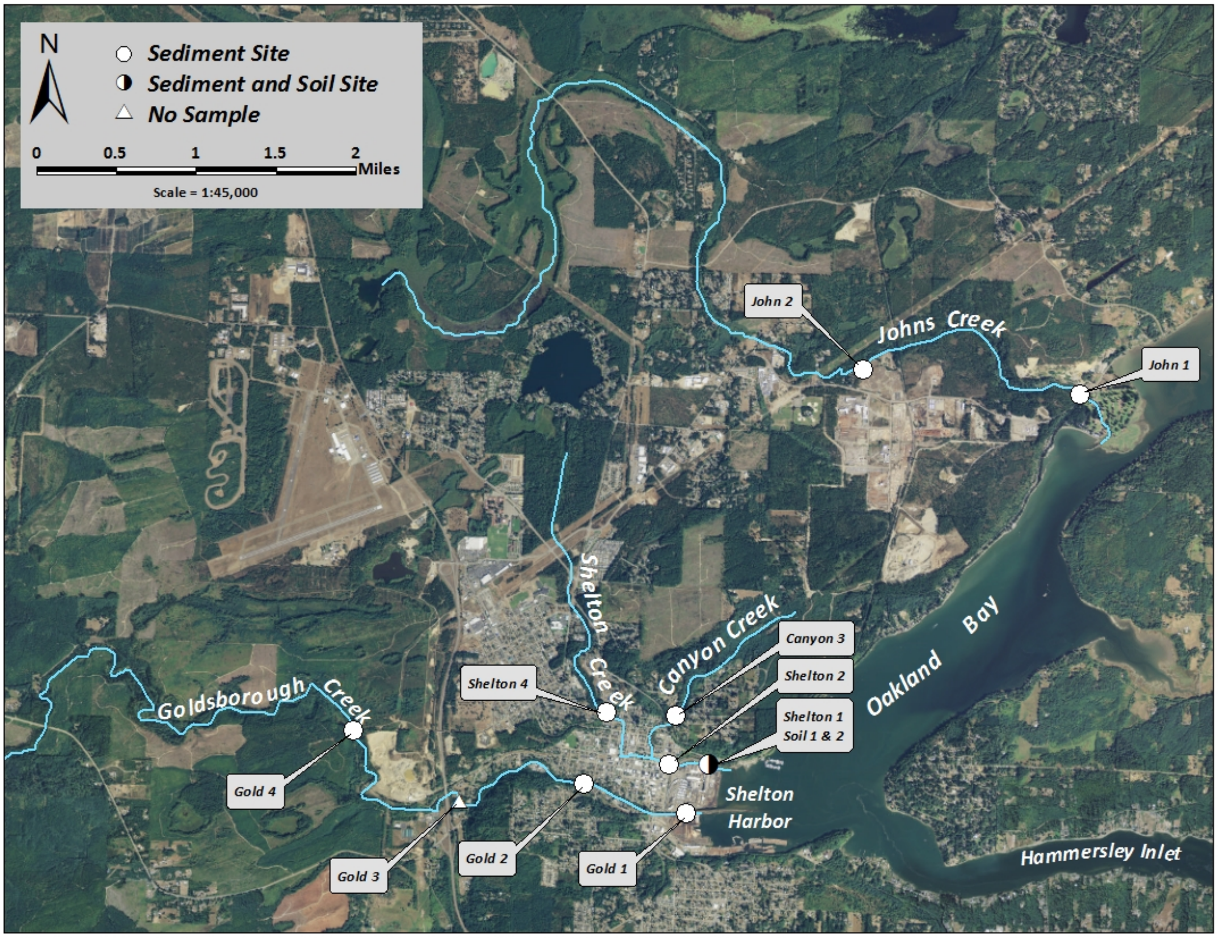

Figure 2. Sampling locations for Shelton, Goldsborough, and Johns Creeks.

Data from the study provide information on (1) the major surface water sources to Oakland Bay associated with urban or industrial activities and (2) whether dioxin is currently being discharged. Study data are compared to background data to determine if current sources are present. Results from upstream sites are compared to downstream sites for assessing the need of future source identification.

On Goldsborough Creek beneath the Highway 101 bridge, a planned sample site was within a high energy reach of the stream. During sample collection, depositional sediments were not available. As an alternative, sediment traps were installed on three occasions in the lowest energy area of the reach. Traps were deployed for two to three weeks. During each of three attempts to collect sediment trap samples, increased discharge during the sample period overloaded the collection cylinders filling them with sand.

Surface soils within this subbasin's reach are largely sands. A long established sand and gravel mine is adjacent to the proposed sample site. After three attempts, it was decided that sediment traps may be a viable collection method for this stream reach, but the traps should be used during low flow of the dry season to avoid rain events.

Goal and Objectives

The goal of the study was to identify whether current or historic sources of dioxin are present in the creeks discharging from urban or industrial areas to the bay. The information will be used by Ecology's Toxics Cleanup Program to determine if upstream controls are needed to eliminate sources of dioxin to Oakland Bay and Shelton Harbor. The objectives were to:

- Determine if dioxin is currently being discharged to Oakland Bay via Shelton, Goldsborough, or Johns Creeks.
- Establish baseline conditions for future sediment evaluations.
- Recommend follow-up characterization as needed.

Methods

Sampling Design

This study generated baseline data for dioxin discharged to Oakland Bay from Shelton, Goldsborough, and Johns Creeks. Data were needed to (1) determine if these major surface water sources are currently discharging dioxin to the bay, (2) establish baseline conditions for comparisons to future sediment evaluations, and (3) recommend needed follow-up activities while assisting with identifying areas of potential upstream sources.

Dioxin concentrations were expected to be below levels of detection in whole water samples. Contaminants in sediment are typically detected at much higher concentrations than the overlying water, and dioxin is known to be associated with particulates. Sediment sampling is a good choice for a screening study because it does not require specialized sampling techniques such as the overlying water does, due to dioxin's hydrophobic nature. Sediment also represents a chronology of contaminant discharge over a longer period than a single point or grab sample from water. Sample sites were selected (1) corresponding to stream access and availability of fine sediment and (2) to isolate areas with differences in land use. When needed, sediment was collected from multiple locations within a reach to meet minimum sediment volumes for the required analyses.

In addition to stream sediment, two terrestrial soil samples were collected from the mounded fill on the left bank adjacent to Shelton Creek's downstream site. The mound appeared to be largely composed of gray-colored consolidated ash with a cemented texture and appearance. The ash mound lies directly alongside Shelton Creek and has less vegetative cover than the surrounding area.

Dioxin TEQs were normalized to TOC and fines to allow site-to-site comparison. Without normalization, comparing sites can be misleading. Samples for TOC and grain size were collected to enable those comparisons.

Sediment and soil samples were collected once at each site during the fall of 2011. Areas with accumulations of fine sediment were targeted for sampling.

Downstream sample locations within study creeks were as close as possible to the point of discharge to marine waters. The downstream stations in Shelton and Goldsborough Creeks were within the tidal zone. Upstream migration of particulates from rising tides was expected to be minimal. Sampling occurred during low tide.

Sample time followed the summer dry period to represent lower flows and allow access to sediment. Sample sites are shown on Figure 2. Table 1 presents latitude, longitude, and a general description for each site. Appendix B contains pictures of the general sample collection area for each site except Gold 1. Pictures of the soil sampling area and unnamed tributary to Shelton Creek are also included.

Table 1. Sample collection sites, coordinates, and locations.

Waterbody (Site)	Latitude	Longitude	Location
Shelton Creek (Shelton 1)	47.21340	-123.09270	100 m from discharge
Shelton Creek (Shelton 2)	47.21370	-123.09790	Below tracks on Front Street
Canyon Creek (Canyon 3)	47.21750	-123.09860	Base of Capitol Hill
Shelton Creek (Shelton 4)	47.21810	-123.10690	Sediment pond at end of Laurel St
Shelton Creek (Soil 1)	47.21396	-123.09509	Adjacent to Shelton 1 site (soil)
Shelton Creek (Soil 2)	47.21393	-123.09503	Adjacent to Shelton 1 site (soil)
Goldsborough Creek (Gold 1)	47.20950	-123.09490	200 m upstream of discharge
Goldsborough Creek (Gold 2)	47.21102	-123.10658	Downstream of 7th Street Bridge
Goldsborough Creek (Gold 4)	47.21191	-123.13808	Above fish weirs at Miles Sand
Johns Creek (John 1)	47.24858	-123.04636	100 m above Highway 3 bridge
Johns Creek (John 2)	47.24995	-123.07548	Just upstream of PUD complex

Datum: NAD 83 HARN

Sampling Procedures

The top two centimeters of surface sediment was collected for samples. Sediment was collected by stainless steel 0.05 m^2 Ponar grab or dedicated stainless steel spoon and bowl, depending on depth of overlying water at the site. Soil samples were collected by dedicated stainless steel trowels, spoons, and bowls. The latitude and longitude of each sediment and soil station was located by a global positioning system (GPS) and recorded in field logs. Other information also recorded in field logs include site name, sampler names, date, time, weather conditions, as well as color, odor, and texture of individual samples and any other pertinent comments about the sample or site.

Sediment samples collected by Ponar were composites made from three separate grabs. Debris on the sediment surface or materials contacting the sides of the Ponar was not retained for analysis. Dedicated stainless steel spoons and bowls were used for sub-sampling and to homogenize sediments from each station to a uniform color and consistency.

Dioxin can be broken down by sunlight (photolysis) and atmospheric free radicals. To avoid the surface material for the two terrestrial samples, the top 10 centimeters of soil was discarded prior to collection. Only soils below the top 10 cm were retained for analysis.

Homogenized sediment and soil from each sample station was placed in 8-oz. glass jars with Teflon-lined lids for analysis of dioxin and furans. Sample containers were cleaned to U.S. Environmental Protection Agency (EPA) quality assurance/quality control (QA/QC) specifications and certified for trace organic analyses (EPA, 1992). Additionally, 2-oz. glass jars were filled with homogenate for TOC analysis, and 8-oz. plastic jars were filled for determination of grain size.

Sample Equipment Cleaning

All equipment used to collect sediment or soil samples was washed thoroughly with tap water and Liquinox detergent, followed by sequential rinses of hot tap water, de-ionized water, and pesticide-grade acetone. Sampling equipment was air dried between each cleaning step under a fume hood. Following the last rinse, the air dried equipment was wrapped in aluminum foil (EAP040; Ecology, 2008), dull side contacting equipment until used. The same cleaning procedure was used on the grab sampler and sediment trap cylinders prior to going to the field.

Immediately following collection, sediment and soil samples were placed in coolers on ice at 4°C and transported to MEL within 48 hours. MEL shipped the samples in coolers to the contract laboratory. Chain-of-custody procedures were maintained throughout the sampling and analysis process.

Analytical Methods

The analytical methods were selected to achieve reporting limits equal to or better than the lowest concentration of interest described in the QA Project Plan (Coots, 2011). Table 2 lists the analytical parameters used for the study, along with descriptions of the methods of analysis and sample preparation.

Table 2. Analytical methods for sediment in Shelton, Goldsborough, and Johns Creeks.

Analysis	Sample Preparation Method	Analytical Method
Dioxin and Furans	Silica-gel	EPA 1613B
Total Organic Carbon	Combustion/NDIR	PSEP-TOC[1]
Grain Size[2]	Sieve and pipette	PSEP, 1996

1: From MEL, 2008.

2: Four fractions – gravel, sand, silt, and clay.

Data Quality

MEL provides written case narratives of data quality for each data package analyzed in-house or from contract laboratories. Case narratives include descriptions of analytical methods and a review of holding times, instrument calibration checks, blank results, labeled standards recoveries, laboratory control samples, and laboratory duplicate analyses.

MEL conducted the QA review to verify that laboratory performance met QC specifications outlined in the analytical methods and the Contract Laboratory Program (CLP) National Functional Guidelines for the Organic Data Review. In cases where data required qualification based on more than one issue, the more restrictive qualifier was applied.

Overall, a review of the data QC and QA from laboratory case narratives indicates the data are useable as qualified by MEL. Most data met measurement quality objectives established in the QA Project Plan (Coots, 2011).

A summary by parameter of MEL's QA review is presented in the *Results* section. The complete narratives and data reports are available by request from the study author.

Results

Summary results are presented below by parameter, and a data quality assessment summary is included. The complete data set for the study is available at Ecology's Environmental Information Management (EIM) database (www.ecy.wa.gov/eim). Search study ID, rcoo0012.

Dioxin and Furans

Appendix A, Table A1, presents study results for dioxin and furan concentrations along with the calculated TEQ for sample totals. The TEQ calculations included "J" and "NJ" qualified results at full value. Congeners with concentrations below estimated detection limits (EDLs) were not included in TEQ totals. The toxic equivalency factor (TEF) adjusted concentrations of individual congeners are shown in Table A2. Dioxin and furan analyses were completed by HRGC/HRMS using EPA 1613B methods.

Quality Assessment

Results were reviewed for qualitative and quantitative accuracy following the National Functional Guidelines for Organic Data Review adapted for high resolution dioxin analysis using the EPA Region 10 SOP for the Validation of PCDD/PCDF.

The analytical lab received the samples frozen in good condition. When samples were removed from the freezer for analysis, sample container 1112023-08 (Gold 2) broke. Other study samples were kept frozen on hold at the lab until a replacement could be sent. The archive sample from the site composed of the original homogenate was sent to the lab. All study samples were then analyzed for dioxin and furans in two sample batches meeting the one-year recommended holding time.

Internal standard recoveries (labeled standards) were within QC limits with a few exceptions. Those exceptions were qualified with a "J" (estimate) for detected compounds and a "UJ" (approximate quantitative limit) for non-detected compounds. Most results met the isotopic abundance ratio and retention time criteria. Those that did not were "NJ" qualified (approximate – tentatively identified).

Method blanks labeled EQ1200081-01 and EQ1200097-01 had OCDD and OCDF detected at low concentrations. For dioxin and furan method blanks, these two compounds are common laboratory contaminants. No data were qualified because of the blank contamination. These detected contaminants were not considered significant, as no field samples had concentrations reported less than 5 times the concentration reported in method blanks.

Recoveries for target analytes from on-going precision and recovery (OPR), also known as laboratory control samples (LCS), were all within the method specified control limits (relative percent difference, RPD <50%).

Total Organic Carbon and Grain Size

Table 3 presents study results for TOC and grain size. Methods for the analysis included PSEP-TOC (Puget Sound Estuary Program) for TOC @ 70° C and grain size by Major Components of Apparent Grain Size Distribution by PSEP Methodology.

Table 3. Total organic carbon and grain size for Shelton, Goldsborough, and Johns Creeks.

Sample ID	Sample No.	TOC (70 °C)	Gravel (>2,000 um)	Sand (2,000 to 62.5 um)	Silt (62.5 um to 4 um)	Clay (<4 um)	Total Fines (silt + clay)
Shelton 1	1112023-01	5.75	36.9	31.1	28.3	3.6	31.9
Shelton 2	1112023-02	7.84	1.2	61.6	35.2	2.0	37.2
Canyon 3	1112023-03[1]	7.05	3.8	54.3	38.3	3.7	42.0
Shelton 4	1112023-04	7.06	39.7	37.4	20.7	2.2	22.9
Soil 1	1112023-05	5.61	18.7	70.8	10.4	0.1	10.5
Soil 2	1112023-06	5.42	38.2	53.2	8.1	0.5	8.6
Gold 1	1112023-07	0.47	1.5	86.9	11.7	0.0	11.7
Gold 2	1112023-08	1.92	0.1	84.1	15.7	0.0	15.7
Gold 4	1112023-10	2.02	4.5	76.4	19.1	0.0	19.1
John 1	1112023-11	7.12	8.8	71.5	18.5	1.2	19.7
John 2	1112023-12	20.2	1.3	68.4	28.2 J	2.1 J	30.3 J

TOC: Total organic carbon.

1: Grain size sample analyzed in triplicate; result is a mean.

J: Sample result is an estimate.

Quality Assessment

Results of the TOC and grain size analyses met measurement quality objectives for the study. No significant problems were encountered during the analysis, and few data required qualification.

All samples for TOC and grain size met recommended holding times for the methods. No organic carbon was detected in method blanks associated with study samples. Laboratory TOC duplicates met control requirements of <20% RPD, while SRMs (standard reference materials) were reported within the 75-125% recovery requirement.

The grain size sample 1112023-12 (John 2) was “J” qualified as an estimate for not meeting the QA ratio for moisture content. The laboratory described the sample as highly organic and contained fibrous organic debris. The result was used as qualified.

Discussion

Dioxin and Furans

Currently Ecology's Toxics Cleanup Program has no numeric Sediment Quality Standards (SQS) or Cleanup Screening Level (CSL) criteria for dioxin. To help identify elevated dioxin levels, the following were used as a best comparison to study results: Washington State background concentrations generated from forested and open spaces (Bradley, 2010), a benchmark value proposed for Puget Sound-wide background levels (USACE, 2009), and results from Shelton Harbor and Oakland Bay sediment investigations (Herrera, 2010).

Calculating Toxic Equivalency Factors

TEF methodology was applied to study data to normalize the dioxin mixture to its most toxic constituent and allow comparison to criteria. This methodology is typically used for evaluating the health risk from exposure to 2,3,7,8-substituted dioxin compounds.

TEFs are laboratory-derived estimates of the relative toxicity of the 16 other 2,3,7,8-substituted dioxin and furan congeners to the reference and most toxic congener - 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD or TCDD). The value of 1.0 is given to TCDD with the other 16 reported as the relative fractional toxicity to TCDD as a decimal. TEF values are listed in Appendix A, Table A1.

Dioxin and furan congener concentrations were adjusted by their respective TEF by multiplying the congener concentration by the TEF. For this study, the total TEQ per sample is defined as the sum of all TEF products from detected congeners per sample. An overall assessment of toxicity is made possible by comparing a sample total TEQ to human health criteria for 2,3,7,8-TCDD. The World Health Organization TEFs for mammals (Van den Berg et al., 2005) were used for calculating TEQs. Estimated qualified results ("J" or "NJ") were included at full value.

A summary of dioxin TEQs reported for the study are presented below in Table 4. Different totaling methods for regulatory application have been used for calculating dioxin TEQs. Table 4 presents three methods. When dioxin TEQs are calculated without including non-detects, a minimum TEQ is generated. The TEQ used throughout this report includes only detected values. Methods calculating TEQ totals using one-half the estimated detection limit (EDL) and the full EDL for non-detected congeners are presented for informational purposes.

Also included for comparison are mean dioxin TEQ data recently generated for Shelton Harbor and Oakland Bay (Herrera, 2010), a Puget Sound-wide background study (USACE, 2009), and a statewide soils background study (Bradley, 2010).

The three methods for calculating TEQs made little difference in study results. Differences for TEQs calculated, using only detected values and TEQs that included the full EDL, ranged from 0 to 2%, except for Gold 2 and 4 which were over 20%. These two samples had the lowest dioxin levels for the study. The differences are at least partially a function of low concentrations.

Table 4. Dioxin TEQs for Shelton Harbor, Oakland Bay, and background results (ng/Kg, TEQ).

Site	Total Dioxin/Furan TEQ[1]	Total TEQ 1/2 EDL[2]	Total TEQ Full EDL[3]	Shelton Harbor Mean TEQ[4]	Oakland Bay Mean TEQ[4]	Puget Sound Background Sediment TEQ[5]	Statewide Background Soils TEQ[6]
Shelton 1	8.66 J	8.67 J	8.68 J	42.8	32.1	4.0	5.21
Shelton 2	5.77 J	5.78 J	5.79 J				
Canyon 3	1.34 J	1.35 J	1.36 J				
Shelton 4	2.46 J	2.46 J	2.46 J				
Soil 1	21.3 J	21.3 J	21.3 J				
Soil 2	41.1 J	41.1 J	41.1 J				
Gold 1	0.628 J	0.631 J	0.634 J				
Gold 2	0.110 J	0.127 J	0.143 J				
Gold 4	0.140 J	0.167 J	0.195 J				
John 1	0.673 J	0.681 J	0.689 J				
John 2	2.17 J	2.20 J	2.22 J				

TEQ: Toxic equivalency to 2,3,7,8-TCDD.
J: Presence of the analyte has been positively identified; the numerical value is an estimate.
1: Total dioxin/furan TEQs calculated using only detected values.
2: Total dioxin/furan TEQs calculated using ½ EDL for non-detects.
3: Total dioxin/furan TEQs calculated using the EDL for non-detects.
4: Herrera, 2010.
5: USACE, 2009.
6: Bradley, 2010. (The 90th percentile value of forested and open areas. The basis for the MTCA natural background value.)

Shelton Creek[1]

Shelton Creek sediments had the highest dioxin TEQs of the studied streams (Table 4). Concentrations at the three mainstem sites increased from upstream (Shelton 4) to downstream (Shelton 1). A tributary to Shelton Creek, locally known as Canyon Creek (Canyon 3), was also sampled, isolating Capitol Hill (Figure 3), an older residential area of Shelton.

Dioxin TEQs increased from Shelton 4 to Shelton 2 by slightly more than 50%, from 2.46 to 5.77 ng/Kg, TEQ. The Laurel Street sediment pond (Shelton 4) drains portions of the Mountainview and Northcliff neighborhoods (Figure 3). Land use for the Mountainview area is mainly residential but includes some commercial, while the Northcliff area is largely newer residential.

Dioxin TEQs for the Mountainview/Northcliff (Shelton 4) and Capitol Hill (Canyon 3) areas suggest that aggregate dioxin inputs to Shelton Creek are elevated slightly beyond background levels within the downtown area of the drainage. Land use between Shelton 4 and Shelton 2 is downtown residential, commercial, and some minor industry, another older area of Shelton.

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[1] Dioxin TEQs reported throughout this report include only detected values, unless otherwise noted.

After the sediment sample for the study was collected from the Shelton 2 site, the stream reach from between Simpson Timber Company's property fence to Front Street was dredged by the City of Shelton. Between one and two feet of sediment was removed to alleviate downtown flooding. The dredging operation started at the Shelton 2 sample location and moved upstream to Front Street.

From Shelton 2 downstream to Shelton 1 near discharge to Shelton Harbor, dioxin TEQs increased by about one-third from 5.77 to 8.66 ng/Kg, TEQ. This reach is bounded within Simpson Timber Company property. The dioxin increase from Shelton 2 to Shelton 1 is over a 300 to 400 meter distance (Figure 3).

At the Laurel Street sediment pond (Shelton 4), dioxin TEQs were about one-half the Washington State background levels for dioxin TEQs in forested and open land-use soils (Bradley, 2010) and just over half the Puget Sound background levels for sediment (USACE, 2009). The Shelton 2 site, just below Front Street, had dioxin TEQs about 30% higher than Puget Sound background levels, while the downstream site at Shelton 1 was more than twice as high. The Canyon 3 site had about one-third of the dioxin TEQ proposed for Puget Sound background (USACE, 2009) and about one-quarter of the dioxin TEQ reported for the background level reported for Washington State soils from forested and open spaces (Bradley, 2010).

Dioxin TEQs from Canyon Creek were roughly one-half the level reported for the site upstream at the Laurel Street sediment pond (Shelton 4), and about one-quarter the level reported for the next downstream site (Shelton 2). The lower inputs measured in Canyon Creek did not off-set dioxin enrichment between Shelton 4 and Shelton 2 (Figure 3).

In addition to Canyon Creek, an unnamed tributary joins Shelton Creek near the intersection of 5th and Franklin Streets downtown. This tributary was not sampled and could be a potential source of dioxin. The unnamed tributary begins around the Junior High Apartments (old Junior High School) and the current Shelton City Public Works maintenance shops, daylighting at the east end of Shelton's Animal Control Building property. Any input to Shelton Creek from this tributary would not be included in Shelton 4 results but would be reflected in Shelton 2 results (Figure 3).

The Canyon 3 site, above the Northcliff Road crossing, isolates Capitol Hill from the downtown (Figure 3). Results for Canyon 3 do not reflect the entire tributary but instead reflects the watershed upstream of the sample point. Inputs downstream through the older residential area for the five or six block distance to the confluence with Shelton Creek would not be represented. Canyon Creek joins Shelton Creek near the old City Hall/new Shelton Fire Station.

Figure 3 shows study sites and relative comparisons of Shelton Creek dioxin TEQs and Puget Sound sediment and Washington State soils background levels.

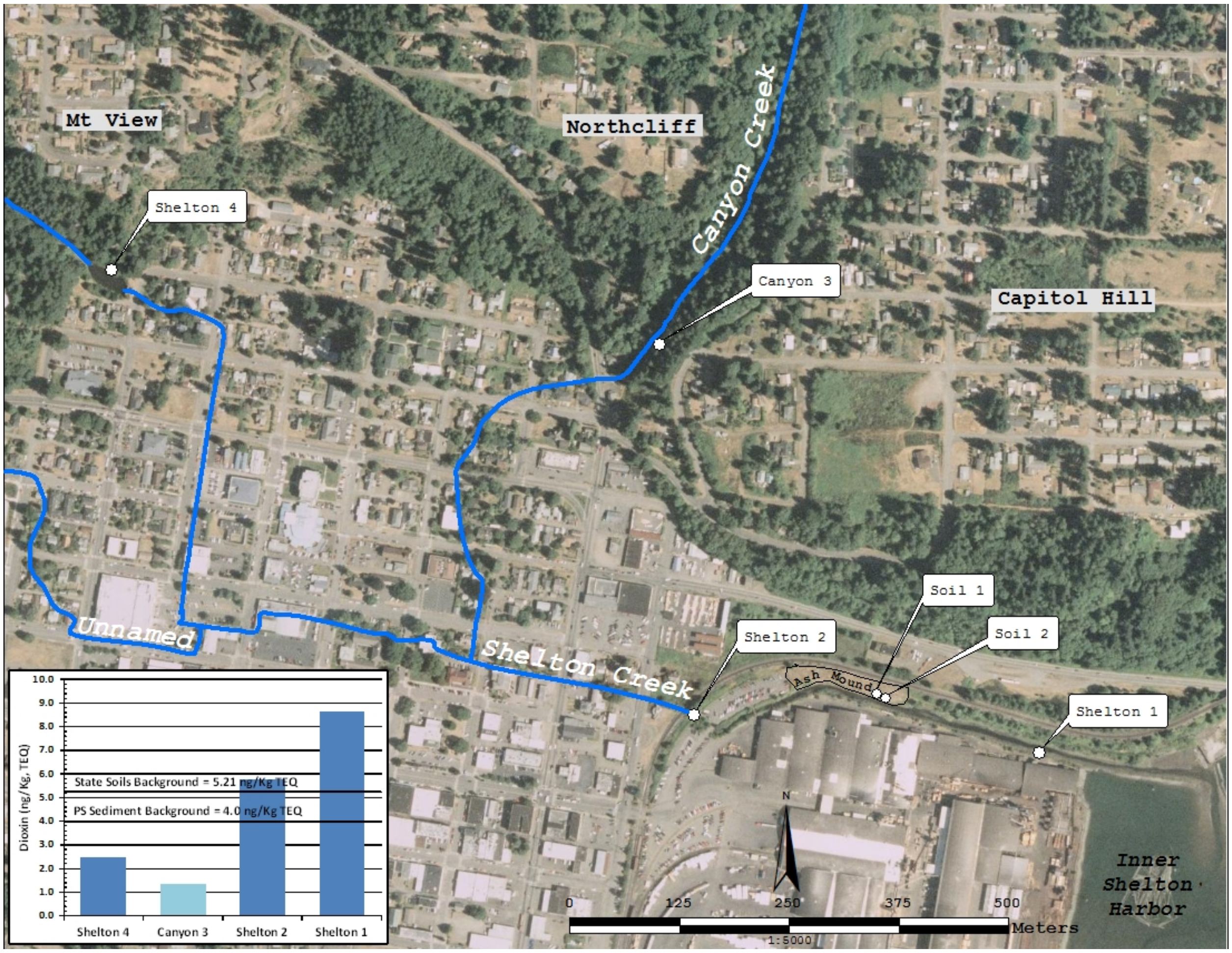

Figure 3. Shelton Creek sites and dioxin TEQs (ng/Kg, TEQ).

Ash Mound

A large ash mound rises from Shelton Creek’s left bank between the two downstream sites (Figure 3). The mound begins near the end of the parking lot within the fenced property on the north side of Shelton Creek. Based on visual observations of sparser vegetative cover and gray ash-colored surface materials, the mound appears to be about 25 meters wide by 125 meters long. Further sampling would be needed to define the ash mound area and levels of dioxin.

Two terrestrial soil samples were collected from the ash mound adjacent to the Shelton 1 site. The two soil samples had the highest dioxin concentrations reported for the study (21.3 and 41.1 ng/Kg, TEQ). Dioxin results from the ash mound show TEQs appear more aligned with mean TEQs from Shelton Harbor and Oakland Bay surface sediments than TEQs from Shelton, Goldsborough, or Johns Creeks. Results exceeded Washington State background levels for dioxin TEQs in forested and open land-use soils (5.21 ng/Kg, TEQ) by about 4 and 8 times, respectively. These results also exceed a benchmark value proposed for Puget Sound-wide background levels of 4.0 ng/Kg, TEQ (USACE, 2009).

Dioxin surface concentrations from a large volume of ash at the site suggest a potentially long-term wash-off threat to Shelton Harbor and Oakland Bay. The ash mound washes directly into Shelton Creek. During storm events, dioxin loading is likely exacerbated. Any future sampling of the mound should determine the areal and vertical extent of the contaminant boundaries for dioxin and the depth where cleanup levels are met.

Collection of the two soil samples was difficult. Wood ash is known to have cementitious properties. Hardening of the ash surface appeared uniform over the mound. The ash material was difficult to break up by hand using stainless steel trowels and spoons. The hardened surface may act as an impervious cover. This limiting of precipitation to percolate through the soil profile would increase run-off. Fragments of what appeared to be firebrick was mixed with ash materials (see pictures in Appendix B).

Figure 4 compares dioxin TEQs from the ash mound samples collected adjacent to Shelton Creek to recent surface sediment results from Shelton Harbor and Oakland Bay (Herrera, 2010) and Washington State background levels for forested and open areas (Bradley, 2010).

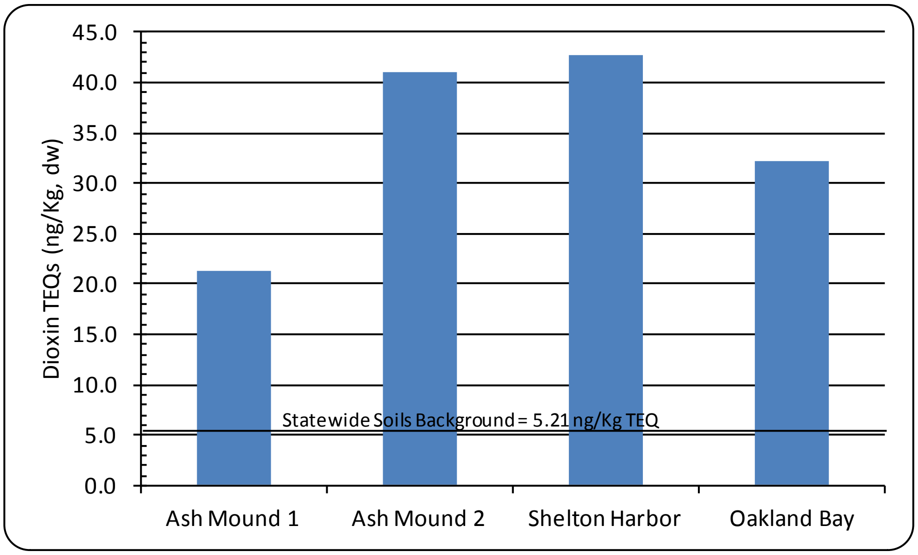

Figure 4. Ash Mound, Shelton Harbor, and Oakland Bay dioxin TEQs (ng/Kg, TEQ).

Goldsborough Creek

Dioxin TEQs in Goldsborough Creek sediments were low. The highest concentration measured within the drainage was nearly an order of magnitude below statewide soils background concentrations (Bradley, 2010). Gold 1, located just before discharge to Oakland Bay (Figure 2), had lower dioxin TEQs than all Shelton Creek sites and about the same as Johns Creek's downstream station (John 1 - Table 4). Both TOC and percent fines were much lower in Goldsborough Creek than Shelton or Johns Creeks, which could partially account for the lower dioxin TEQs at these Goldsborough Creek sites.

At Gold 4, dioxin TEQs were higher by about 20% than those reported for the next downstream site (Gold 2). Land use upstream of Gold 4 is generally rural and forested, while downstream land use to Gold 2 (just below the 7th Street Bridge) begins in a rural forested area and transitions to older downtown development and residential. Dioxin TEQs at both stations were low and well within Washington State background levels for forested and open land-use soils and proposed Puget Sound background levels. The higher dioxin level upstream is likely an artifact of the overall low concentrations and the natural variability of sediments.

A sample was targeted for collection at the Goldsborough Creek/Highway 101 crossing (see Figure 2, Gold 3). This site was located just downstream of a historical garbage dump that used open pit burning, predating the Mason County Landfill. Sediment could not be collected due to high stream energy through the reach. The decreasing dioxin TEQ from Gold 4 to Gold 2 suggests major impacts would not be expected from this area.

Dioxin TEQs increased by about five times, or just over 0.5 ng/Kg TEQ, between Gold 2 and Gold 1. This increase was over a distance of about 1000 meters through old residential, along railway lines, and through Simpson Timber Company mill property to just before discharge to Oakland Bay. The Gold 1 station had the highest TEQ in the drainage. Dioxin was low, measuring only about 12% of background levels for soils from forested and open spaces in Washington State (Bradley, 2010) or 16% of Puget Sound sediments (USACE, 2009).

Johns Creek

Dioxin TEQs were low at the two Johns Creek sites (Figure 2). The upstream site (John 2) had a higher TEQ than the downstream (John 1). The TEQ at John 1 was about one-third of the TEQ reported for John 2, which measured only about 40% of statewide background levels reported for forested and open spaces (Bradley, 2010).

TOC at the John 2 site was high, at an estimated 20%. This is almost three times the level reported for John 1 and likely accounts for some of the TEQ difference. Comparisons should not be made with dioxin TEQs when a sample is high in TOC. Below is a discussion about the effects of TOC and grain size on dioxin TEQs.

Total Organic Carbon and Grain Size

TOC and grain size can affect toxicity and habitat quality. Concentrations of nonpolar organic contaminants like dioxin and their toxicity have been found to correlate well with the organic carbon content of the sample (DiToro et al., 1991).

Nonpolar compounds preferentially partition into organic carbon and to certain grain size fractions (silts + clays) in a sample. Sediment organic carbon provides additional adsorptive surface to fines for binding contaminants, particularly those with high K_{ow}s (octanol-water partitioning coefficient) like dioxin. Typical TOCs in freshwater sediments range from less than 1% to approximately 15% (Sloan and Blakley, 2009).

Comparing dioxin TEQs from site to site without regard to TOC content or grain size distribution can be misleading. Table 5 shows dioxin TEQs normalized to TOC and percent fines on a per-sample basis. Results for individual congeners per sample normalized to TOC and percent fines are presented in Appendix A, Tables A3 and A4.

Table 5. Dioxin TEQs normalized to total organic carbon and percent fines.

Sample ID	TOC (70 °C)	% Fines (Silts+Clays)	Total Dioxin TEQ[1]	Total Dioxin TEQ_{TOC}[2]	Total Dioxin $\text{TEQ}_{\text{Fines}}$[3]
Shelton 1	5.75	31.9	8.66 J	151 J	27.1 J
Shelton 2	7.84	37.2	5.77 J	73.6 J	15.5 J
Canyon 3	7.05	42.0	1.34 J	19.0 J	3.19 J
Shelton 4	7.06	22.9	2.46 J	34.8 J	10.7 J
Soil 1	5.61	10.5	21.3 J	380 J	203 J
Soil 2	5.42	8.6	41.1 J	758 J	478 J
Gold 1	0.47	11.7	0.628 J	134 J	5.37 J
Gold 2	1.92	15.7	0.110 J	5.73 J	0.701 J
Gold 4	2.02	19.1	0.140 J	6.93 J	0.733 J
John 1	7.12	19.7	0.673 J	9.45 J	3.42 J
John 2	20.2	30.3 J	2.17 J	10.7 J	7.16 J

1: Dioxin TEQ value equivalent to 2,3,7,8-TCDD toxicity.

2: Dioxin TEQ value normalized to TOC (total organic carbon).

3: Dioxin TEQ value normalized to percent fines (silts + clays).

Dioxin TEQs normalized by TOC and percent fines did not change the order of any concentration gradient. Normalization to TOC and percent fines did change relative levels of contamination between sites. Dioxin TEQ, $\text{TEQ}_{\text{TOC},}$ and $\text{TEQ}_{\text{Fines}}$ were all lowest at the upstream site in Shelton Creek, with increasing concentration downstream.

TOC less than 0.5% is considered low, common to sandy or gravelly areas. Natural TOCs may also be high in marshy or wetland environments. Artificially high sediment TOC contents can be from enrichment of organics, sewage, petroleum, or wood chips. TOC is often elevated in areas with wood wastes.

TOC and fines were low in Goldsborough Creek sediments. The highest values from Goldsborough were lower than any reported from Shelton or Johns Creeks. The high TEQ_{TOC} at Gold 1 (134 ng/Kg, TEQ_{TOC}) is a function of the low TOC content.

At John 2 (upstream), TOC was reported at 20%. The high TOC at John 2 appears to account for much of the difference in the Johns Creek TEQs. The TEQ at John 1 was lower than the TEQ at John 2 by roughly 69%, while the TEQ_{TOC} was lower by only about 12%.

To see if study parameters had predictive relationships based on partitioning, the distribution of TOC and fines in sediment samples was compared to dioxin TEQs by linear regression. The percent TOC showed a weak positive relationship with dioxin TEQ content (r^2=0.19), while the percent fines was moderately correlated (r^2=0.55).

Conclusions

Dioxin measured in the three study streams shows concentrations in sediment were much lower than those most recently reported for surface sediments from Shelton Harbor and Oakland Bay. Based on this study's results, the three major surface water inputs do not appear responsible for dioxin levels reported in surface sediments from Shelton Harbor and Oakland Bay. Dioxin TEQs were low in Goldsborough and Johns Creeks, while Shelton Creek was only moderately enriched above background levels at the two downstream stations.

The upper Shelton Creek drainage is largely residential. Location of the upstream site isolated Shelton's downtown from the residential area. Aggregate dioxin inputs increased in Shelton's downtown area to Front Street, only slightly above background levels.

Between Shelton Creek at Front Street and its discharge to Shelton Harbor, dioxin TEQs increased by about one-third over a distance of 300 to 400 meters. The cause of this increase may be related to the large ash mound on the creek's left bank, just before the downstream site and discharge to Shelton Harbor.

Results from two ash-mound soil samples suggest a potential continual source of dioxin to Shelton Harbor and Oakland Bay. Dioxin levels from these two soil sites were the highest for the study and more similar to mean values reported from inner Shelton Harbor and Oakland Bay (Herrera, 2010) than study streams. More study would be required to determine the areal extent of the ash mound.

This 2011 study was a first look at streams as dioxin sources discharging to Oakland Bay. Collection of sediment followed lower seasonal flow in study streams. During run-off periods and higher flow, dioxin inputs to the bay could be much higher, due to erosion and transport of sediment.

Recommendations

Results of this 2011 study support the following recommendations:

- Conduct follow-up sampling of the ash mound along Shelton Creek's left bank just before discharge to Shelton Harbor to establish contaminant boundaries and the extent dioxin is impacting the soil profile. Sampling should determine where the levels of concern are met.
- If the ash mound along Shelton Creek is removed, sampling should be conducted following recovery of the area to verify dioxin reductions have occurred.
- If follow-up dioxin monitoring is conducted in downtown Shelton, include the unnamed tributary to further establish source areas for dioxin increases beyond background in the lower reaches of Shelton Creek.

References

Bradley, Dave, 2010. Natural Background for Dioxin/Furans in WA Soils, Technical Memorandum #8. Washington State Department of Ecology, Olympia, WA. August 2010 Publication No. 10-09-053.
https://fortress.wa.gov/ecy/publications/SummaryPages/1009053.html

Coots, Randy, 2011. Quality Assurance Project Plan: Dioxin in Surface Water Sources to Oakland Bay. Washington State Department of Ecology, Olympia, WA. December 2011. Publication No. 11-03-118. 27 pages.
https://fortress.wa.gov/ecy/publications/publications/1103118.pdf

DiToro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, N.A. Thomas, and P.R. Paquin, 1991. Technical Basis for Establishing Sediment Quality Criteria for Nonionic Organic Chemicals Using Equilibrium Partitioning. Environment Toxicology and Chemistry 10:1541-1583.

Ecology, 2008. Standard Operating Procedure for Obtaining Freshwater Sediment Samples, Versions 1.1. SOP #EAP040. Washington State Department of Ecology, Olympia, WA.
http://www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_FreshWaterSedimentSampling_v1_1EAP040.pdf

EPA, 1992. Specifications and Guidance for Contaminant Free Sample Containers. U.S. Environmental Protection Agency. Publication Nos. 9240.0-05A; A540/R-93/051. December 1992.

Herrera Environmental Consultants, 2010. Sediment Investigation Report, Oakland Bay Sediment Characterization Study, Mason County, Washington. Prepared for Washington State Department of Ecology, Toxics Cleanup Program, Southwest Regional Office. November 17, 2010.

MEL, 2008. Manchester Environmental Laboratory Lab Users Manual, Ninth Edition. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

PSEP, 1996. Puget Sound Estuary Program (PSEP): Recommended Protocols for Measuring Selected Variables in Puget Sound. U.S. Environmental Protection Agency, Region 10, Office of Puget Sound, Seattle.

Sloan, J .and N. Blakley, 2009. Baseline Characterization of Nine Proposed Freshwater Sediment Reference Sites, 2008. Washington State Department of Ecology, Olympia, WA. Publication No. 09-03-032.
https://fortress.wa.gov/ecy/publications/SummaryPages/0903032.html

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

Van den Berg et al., 2005. The World Health Organization Re-Evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxin and Dioxin-Like Compounds.
ToxSci Advance Access, July 2006.

Appendices

Appendix A. Study Results

Table A1. Dioxin and Furans Concentration and TEQs in Shelton, Goldsborough, and Johns Creeks Sediment, Fall 2011 (ng/Kg, dw).

Congener	TEF	Shelton Creek						Goldsborough Creek			Johns Creek	
	1112023-	1	2	Canyon 3	4	Soil 1	Soil 2	1	2	4	1	2
2,3,7,8-TCDD	1	**0.313 NJ**	**0.333 NJ**	**0.225 J**	**0.0887 NJ**	**4.17**	**7.19**	**0.0275 NJ**	0.0167 U	0.0209 U	**0.232 NJ**	**1.30**
1,2,3,7,8-PeCDD	1	**1.72 J**	**1.42 J**	**0.458 NJ**	**0.532 J**	**7.94**	**16.8**	**0.122 J**	**0.0309 NJ**	0.0207 U	**0.0945 NJ**	**0.271 J**
1,2,3,4,7,8-HxCDD	0.1	**2.70 J**	**1.76 J**	**0.281 NJ**	**0.718 NJ**	**4.16**	**13.9**	**0.150 J**	**0.0434 J**	**0.0322 NJ**	**0.136 J**	**0.303 J**
1,2,3,6,7,8-HxCDD	0.1	**11.8**	**7.25**	**0.894 J**	**3.09**	**13.6**	**26.2**	**0.733 J**	**0.165 J**	**0.182 J**	**0.536 NJ**	**1.08 J**
1,2,3,7,8,9-HxCDD	0.1	**6.72**	**4.90**	**0.902 J**	**2.06 J**	**11.6**	**25.7**	**0.362 J**	**0.0992 NJ**	**0.101 NJ**	**0.356 J**	**0.926 NJ**
1,2,3,4,6,7,8-HpCDD	0.01	**215**	**123**	**9.07**	**60.1**	**58.6**	**89.7**	**13.9**	**2.36**	**4.18**	**11.8**	**14.5**
OCDD	0.0003	**1820**	**1080**	**89.7**	**544**	**218**	**175**	**250**	**20.4**	**89.9**	**118**	**118**
Dioxin TEQ:		**6.85 J**	**4.70 J**	**1.01 J**	**1.97 J**	**15.7**	**31.5**	**0.488 J**	**0.0914 J**	**0.100 J**	**0.583 J**	**1.98 J**
2,3,7,8-TCDF	0.1	**0.607 J**	**0.678 J**	**0.539**	**0.295 J**	**10.6**	**19.0**	0.0577 U	0.0985 U	0.0985 U	0.109 U	0.209 U
1,2,3,7,8-PeCDF	0.03	**1.05 NJ**	**0.598 NJ**	**0.260 NJ**	**0.227 NJ**	**6.50 NJ**	**11.3 NJ**	**0.0796 NJ**	0.0135 U	0.0179 U	**0.0722 J**	0.0935 U
2,3,4,7,8-PeCDF	0.3	**1.14 J**	**0.723 J**	**0.435 J**	**0.337 J**	**7.83 NJ**	**14.3 NJ**	**0.0805 J**	0.014 U	**0.0437 NJ**	**0.110 NJ**	**0.335 J**
1,2,3,4,7,8-HxCDF	0.1	**3.77 NJ**	**1.77 NJ**	**0.472 NJ**	**1.02 J**	**8.05 NJ**	**13.1 NJ**	**0.347 NJ**	**0.0494 NJ**	**0.0765 NJ**	**0.180 J**	**0.478 NJ**
1,2,3,6,7,8-HxCDF	0.1	**1.90 J**	**1.09 J**	**0.231 NJ**	**0.470 J**	**4.28**	**7.13**	**0.111 J**	**0.0336 J**	**0.0341 J**	**0.0854 J**	0.114 U
1,2,3,7,8,9-HxCDF	0.1	0.184 U	0.164 U	0.132 U	0.0492 U	**0.349 NJ**	**0.501 NJ**	**0.0401 NJ**	0.0201 U	0.0236 U	0.0474 U	0.176 U
2,3,4,6,7,8-HxCDF	0.1	**2.84**	**1.62 NJ**	**0.434 J**	**0.771 NJ**	**4.79**	**7.90 NJ**	**0.158 NJ**	**0.0505 J**	**0.0556 J**	**0.0863 NJ**	**0.355 NJ**
1,2,3,4,6,7,8-HpCDF	0.01	**45.1 J**	**27.1**	**2.39 J**	**10.5**	**19.2**	**21.2**	**4.18**	**0.478 J**	**0.844 J**	**1.62 J**	**0.244 J**
1,2,3,4,7,8,9-HpCDF	0.01	**2.09 J**	**1.14 J**	0.146 U	**0.486 J**	**1.33 J**	**1.41 J**	**0.195 J**	0.0244 U	0.0396 U	**0.141 J**	0.149 U
OCDF	0.0003	**185**	**136**	**10.1**	**35.9**	**15.1 NJ**	**11.9 NJ**	**14.1**	**1.32 J**	**4.42**	**9.29**	**5.16 J**
Furan TEQ:		**1.81 J**	**1.07 J**	**0.333 J**	**0.484 J**	**5.56 J**	**9.62 J**	**0.140 J**	**0.0185 J**	**0.0395 J**	**0.0907 J**	**0.188 J**
TCDD TEQ:		**8.66 J**	**5.77 J**	**1.34 J**	**2.46 J**	**21.3 J**	**41.1 J**	**0.628 J**	**0.110 J**	**0.140 J**	**0.673 J**	**2.17 J**

Bold: Visual aid to detected compounds

NJ: Presence of the analyte has been “tentatively identified”; the numerical value is an approximate concentration.

J: Presence of the analyte has been positively identified; the numerical value is an estimate.

U: Analyte was not detected at or above the reporting limit shown.

TEF: Toxic equivalence factors, from Van den Berg et al., 2005.

TEQ: Toxic equivalency to 2,3,7,8-TCDD, from summing sample TEFs.

Table A2. Dioxin and Furan TEF-adjusted Concentrations and TEQs, Shelton, Goldsborough, and Johns Creeks, Fall 2011 (ng/Kg, TEQ).

Congener	TEF	Shelton Creek						Goldsborough Creek			Johns Creek	
1112023-		1	2	Canyon 3	4	Soil 1	Soil 2	1	2	4	1	2
2,3,7,8-TCDD	1	**0.313 NJ**	**0.333 NJ**	**0.225 J**	**0.0887 NJ**	**4.17**	**7.19**	**0.0275 NJ**	0.0167 U	0.0209 U	**0.232 NJ**	**1.30**
1,2,3,7,8-PeCDD	1	**1.72 J**	**1.42 J**	**0.458 NJ**	**0.532 J**	**7.94**	**16.8**	**0.122 J**	**0.0309 NJ**	0.0207 U	**0.0945 NJ**	**0.271 J**
1,2,3,4,7,8-HxCDD	0.1	**0.270 J**	**0.176 J**	**0.0281 NJ**	**0.0718 NJ**	**0.416**	**1.39**	**0.015 J**	**0.00434 J**	**0.00322 NJ**	**0.0136 J**	**0.0303 J**
1,2,3,6,7,8-HxCDD	0.1	**1.18**	**0.725**	**0.0894 J**	**0.309**	**1.36**	**2.62**	**0.0733 J**	**0.0165 J**	**0.0182 J**	**0.0536 NJ**	**0.108 J**
1,2,3,7,8,9-HxCDD	0.1	**0.672**	**0.490**	**0.0902 J**	**0.206 J**	**1.16**	**2.57**	**0.0362 J**	**0.00992 NJ**	**0.0101 NJ**	**0.0356 J**	**0.0926 NJ**
1,2,3,4,6,7,8-HpCDD	0.01	**2.15**	**1.23**	**0.0907**	**0.601**	**0.586**	**0.897**	**0.139**	**0.0236**	**0.0418**	**0.118**	**0.145**
OCDD	0.0003	**0.546**	**0.324**	**0.0269**	**0.163**	**0.0654**	**0.0525**	**0.0750**	**0.00612**	**0.0270**	**0.0354**	**0.0354**
Dioxin TEQ:		**6.85 J**	**4.70 J**	**1.01 J**	**1.97 J**	**15.7**	**31.5**	**0.488 J**	**0.0914 J**	**0.100 J**	**0.583 NJ**	**1.98 J**
2,3,7,8-TCDF	0.1	**0.0607 J**	**0.0678 J**	**0.0539**	**0.0295 J**	**1.06**	**1.90**	0.0577 U	0.0985 U	0.0985 U	0.109 U	0.209 U
1,2,3,7,8-PeCDF	0.03	**0.0315 NJ**	**0.0179 NJ**	**0.0078 NJ**	**0.00681 NJ**	**0.195 NJ**	**0.339 NJ**	**0.00239 NJ**	0.0135 U	0.0179 U	**0.00217 J**	0.0935 U
2,3,4,7,8-PeCDF	0.3	**0.342 J**	**0.217 J**	**0.131 J**	**0.101 J**	**2.35 NJ**	**4.29 NJ**	**0.0242 J**	0.014 U	**0.0131 NJ**	**0.0330 NJ**	**0.101 J**
1,2,3,4,7,8-HxCDF	0.1	**0.377 NJ**	**0.177 NJ**	**0.0472 NJ**	**0.102 J**	**0.805 NJ**	**1.31 NJ**	**0.0347 NJ**	**0.00494 NJ**	**0.00765 NJ**	**0.0180 J**	**0.0478 NJ**
1,2,3,6,7,8-HxCDF	0.1	**0.190 J**	**0.109 J**	**0.0231 NJ**	**0.0470 J**	**0.428**	**0.713**	**0.0111 J**	**0.00336 J**	**0.00341 J**	**0.00854 J**	0.114 U
1,2,3,7,8,9-HxCDF	0.1	0.184 U	0.164 U	0.132 U	0.0492 U	**0.0349 NJ**	**0.0501 NJ**	**0.00401 NJ**	0.0201 U	0.0236 U	0.0474 U	0.176 U
2,3,4,6,7,8-HxCDF	0.1	**0.284**	**0.162 NJ**	**0.0434 J**	**0.0771 NJ**	**0.479**	**0.790 NJ**	**0.0158 NJ**	**0.00505 J**	**0.00556 J**	**0.00863 NJ**	**0.0355 NJ**
1,2,3,4,6,7,8-HpCDF	0.01	**0.451 J**	**0.271**	**0.0239 J**	**0.105**	**0.192**	**0.212**	**0.0418**	**0.00478 J**	**0.00844 J**	**0.0162 J**	**0.00244 J**
1,2,3,4,7,8,9-HpCDF	0.01	**0.0209 J**	**0.0114 J**	0.146 U	**0.00486 J**	**0.0133 J**	**0.0141 J**	**0.00195 J**	0.0244 U	0.0396 U	**0.00141 J**	0.149 U
OCDF	0.0003	**0.0555**	**0.0408**	**0.00303**	**0.0108**	**0.00453 NJ**	**0.00357 NJ**	**0.00423**	**0.000396 J**	**0.00133**	**0.00279**	**0.00155 J**
Furan TEQ:		**1.81 J**	**1.07 J**	**0.333 J**	**0.484 J**	**5.56 NJ**	**9.62 NJ**	**0.140 J**	**0.0185 J**	**0.0395 J**	**0.0907 J**	**0.188 J**
TCDD TEQ:		**8.66 J**	**5.77 J**	**1.34 J**	**2.46 J**	**21.3 J**	**41.1 J**	**0.628 J**	**0.110 J**	**0.140 J**	**0.673 J**	**2.17 J**

Bold: Visual aid to detected compounds

NJ: Presence of the analyte has been “tentatively identified”; the numerical value is an approximate concentration.

J: Presence of the analyte has been positively identified; the numerical value is an estimate.

U: Analyte was not detected at or above the reporting limit shown.

TEF: Toxic equivalence factors for individual congeners, from Van den Berg et al., 2005.

TEQ: Toxic equivalency to 2,3,7,8-TCDD, from summed sample TEFs.

Table A3. Dioxin and Furan TEQ Results TOC Normalized from Shelton, Goldsborough, and Johns Creeks, Fall 2011 (ng/Kg, TEQ$_{TOC}$).

Congener	TEF	Shelton Creek						Goldsborough Creek			Johns Creek	
1112023-		1	2	Canyon 3	4	Soil 1	Soil 2	1	2	4	1	2
Total Organic Carbon:		**5.75**	**7.84**	**7.05**	**7.06**	**5.61**	**5.42**	**0.470**	**1.92**	**2.02**	**7.12**	**20.2**
2,3,7,8-TCDD	1	**5.44 NJ**	**4.25 NJ**	**3.19 J**	**1.26 NJ**	**74.3**	**133**	**5.85 NJ**	0.0167 U	0.0209 U	**3.26 NJ**	**6.44**
1,2,3,7,8-PeCDD	1	**29.9 J**	**18.1 J**	**6.50 NJ**	**7.54 J**	**142**	**310**	**26.0 J**	**1.61 NJ**	0.0207 U	**1.33 NJ**	**1.34 J**
1,2,3,4,7,8-HxCDD	0.1	**4.70 J**	**2.24 J**	**0.399 NJ**	**1.02 NJ**	**7.42**	**25.6**	**3.19 J**	**0.226 J**	**0.159 NJ**	**0.191 J**	**0.150 J**
1,2,3,6,7,8-HxCDD	0.1	**20.5**	**9.25**	**1.27 J**	**4.38**	**24.2**	**48.3**	**15.6 J**	**0.859 J**	**0.901 J**	**0.753 NJ**	**0.535 J**
1,2,3,7,8,9-HxCDD	0.1	**11.7**	**6.25**	**1.28 J**	**2.92 J**	**20.7**	**47.4**	**7.70 J**	**0.517 NJ**	**0.500 NJ**	**0.500 J**	**0.458 NJ**
1,2,3,4,6,7,8-HpCDD	0.01	**37.4**	**15.7**	**1.29**	**8.51**	**10.4**	**16.5**	**29.6**	**1.23**	**2.07**	**1.66**	**0.718**
OCDD	0.0003	**9.50**	**4.13**	**0.382**	**2.31**	**1.17**	**0.969**	**16.0**	**0.319**	**1.34**	**0.497**	**0.175**
Dioxin TEQ$_{TOC}$:		**119**	**59.9**	**14.3**	**27.9**	**280**	**582**	**104**	**4.76**	**4.97**	**8.18**	**9.81**
2,3,7,8-TCDF	0.1	**1.06 J**	**0.865 J**	**0.765**	**0.418 J**	**18.9**	**35.1**	0.0577 U	0.0985 U	0.0985 U	0.109 U	0.209 U
1,2,3,7,8-PeCDF	0.03	**0.548 NJ**	**0.228 NJ**	**0.111 NJ**	**0.0965 NJ**	**3.48 NJ**	**6.25 NJ**	**0.509 NJ**	0.0135 U	0.0179 U	**0.0305 J**	0.0935 U
2,3,4,7,8-PeCDF	0.3	**5.95 J**	**2.77 J**	**1.86 J**	**1.43 J**	**41.9 NJ**	**79.2 NJ**	**5.15 J**	0.0140 U	**0.649 NJ**	**0.463 NJ**	**0.500 J**
1,2,3,4,7,8-HxCDF	0.1	**6.56 NJ**	**2.26 NJ**	**0.670 NJ**	**1.44 J**	**14.3 NJ**	**24.2 NJ**	**7.38 NJ**	**0.257 NJ**	**0.379 NJ**	**0.253 J**	**0.237 NJ**
1,2,3,6,7,8-HxCDF	0.1	**3.30 J**	**1.39 J**	**0.328 NJ**	**0.666 J**	**7.63**	**13.2**	**2.36 J**	**0.175 J**	**0.169 J**	**0.120 J**	0.114 U
1,2,3,7,8,9-HxCDF	0.1	0.184 U	0.164 U	0.132 U	0.0492 U	**0.622 NJ**	**0.924 NJ**	**0.853 NJ**	0.0201 U	0.0236 U	0.0474 U	0.176 U
2,3,4,6,7,8-HxCDF	0.1	**4.94**	**2.07 NJ**	**0.616 J**	**1.09 NJ**	**8.54**	**14.6 NJ**	**3.36 NJ**	**0.263 J**	**0.275 J**	**0.121 NJ**	**0.176 NJ**
1,2,3,4,6,7,8-HpCDF	0.01	**7.84 J**	**3.46**	**0.339 J**	**1.49**	**3.42**	**3.91**	**8.89**	**0.249 J**	**0.418 J**	**0.228 J**	**0.0121 J**
1,2,3,4,7,8,9-HpCDF	0.01	**0.363 J**	**0.145 J**	0.146 U	**0.0688 J**	**0.237J**	**0.260 J**	**0.415 J**	0.0244 U	0.0396 U	**0.0198 J**	0.149 U
OCDF	0.0003	**0.965**	**0.520**	**0.0430**	**0.153**	**0.0807 N**	**0.0659 NJ**	**0.900**	**0.0206 J**	**0.0658**	**0.0392**	**0.00767 J**
Furan TEQ$_{TOC}$:		**31.5**	**13.7**	**4.73**	**6.86**	**99.1**	**178**	**29.8**	**0.944**	**1.95**	**1.27**	**0.93**
TCDD TEQ$_{TOC}$:		**151**	**73.6**	**19**	**34.8**	**379**	**759**	**134**	**5.70**	**6.92**	**9.46**	**10.7**

Bold: Visual aid to detected compounds

NJ: Presence of the analyte has been “tentatively identified”; the numerical value is an approximate concentration.

J: Presence of the analyte has been positively identified, the numerical value is an estimate.

U: Analyte was not detected at or above the laboratory derived reporting limit shown, nor was it normalized to TOC.

TEF: Toxic equivalence factors for individual congeners, from Van den Berg et al., 2005.

TEQ: The sum of sample TEFs, representing the toxic equivalency to 2,3,7,8-TCDD.

TOC: Total organic carbon.

Table A4. Dioxin and Furan TEQ Results Normalized to Fines from Shelton, Goldsborough, and Johns Creeks, Fall 2011 (ng/Kg, TEQ_{Fines}).

Congener	TEF	Shelton Creek						Goldsborough Creek			Johns Creek	
1112023-		1	2	Canyon 3	4	Soil 1	Soil 2	1	2	4	1	2
Percent Fines:		**31.9**	**37.2**	**42.0**	**22.9**	**10.5**	**8.6**	**11.7**	**15.7**	**19.1**	**19.7**	**30.3 J**
2,3,7,8-TCDD	1	**0.981 NJ**	**0.895 NJ**	**0.536 J**	**0.387 NJ**	**39.7**	**83.6**	**0.235 NJ**	0.0167 U	0.0209 U	**1.18 NJ**	**4.29**
1,2,3,7,8-PeCDD	1	**5.39 J**	**3.82 J**	**1.09 NJ**	**2.32 J**	**75.6**	**195**	**1.04 J**	**0.197 NJ**	0.0207 U	**0.480 NJ**	**0.894 J**
1,2,3,4,7,8-HxCDD	0.1	**0.846 J**	**0.473 J**	**0.067 NJ**	**0.314 NJ**	**3.96**	**16.2**	**0.128 J**	**0.0276 J**	**0.0169 NJ**	**0.0690 J**	**0.100 J**
1,2,3,6,7,8-HxCDD	0.1	**3.70**	**1.95**	**0.213 J**	**1.35**	**13.0**	**30.5**	**0.626 J**	**0.105 J**	**0.0953 J**	**0.272 NJ**	**0.356 J**
1,2,3,7,8,9-HxCDD	0.1	**2.11**	**1.32**	**0.215 J**	**0.900 J**	**11.0**	**29.9**	**0.309 J**	**0.0632 NJ**	**0.0529 NJ**	**0.181 J**	**0.306 NJ**
1,2,3,4,6,7,8-HpCDD	0.01	**6.74**	**3.31**	**0.216**	**2.62**	**5.58**	**10.4**	**1.19**	**0.150**	**0.219**	**0.599**	**0.479**
OCDD	0.0003	**1.71**	**0.871**	**0.0640**	**0.712**	**0.623**	**0.610**	**0.641**	**0.0390**	**0.141**	**0.180**	**0.117**
Dioxin TEQ_{Fines}:		**21.5**	**12.6**	**2.40**	**8.60**	**149**	**366**	**1.83**	**0.582**	**0.525**	**2.96**	**6.54**
2,3,7,8-TCDF	0.1	**0.190 J**	**0.182 J**	**0.128**	**0.129 J**	**10.1**	**22.1**	0.0577 U	0.0985 U	0.0985 U	0.109 U	0.209 U
1,2,3,7,8-PeCDF	0.03	**0.0987 NJ**	**0.0481 NJ**	**0.0186 NJ**	**0.0297 NJ**	**1.86 NJ**	**3.94 NJ**	**0.0204 NJ**	0.0135 U	0.0179 U	**0.0110 J**	0.0935 U
2,3,4,7,8-PeCDF	0.3	**1.07 J**	**0.583 J**	**0.312 J**	**0.441 J**	**22.4 NJ**	**49.9 NJ**	**0.207 J**	0.0140 U	**0.0686 NJ**	**0.168 NJ**	**0.333 J**
1,2,3,4,7,8-HxCDF	0.1	**1.18 NJ**	**0.476 NJ**	**0.112 NJ**	**0.445 J**	**7.67 NJ**	**15.2 NJ**	**0.297 NJ**	**0.0315 NJ**	**0.0401 NJ**	**0.0914 J**	**0.158 NJ**
1,2,3,6,7,8-HxCDF	0.1	**0.596 J**	**0.293 J**	**0.0550 NJ**	**0.205 J**	**4.08**	**8.29**	**0.0949 J**	**0.0214 J**	**0.0179 J**	**0.0434 J**	0.114 U
1,2,3,7,8,9-HxCDF	0.1	0.184 U	0.164 U	0.132 U	0.0492 U	**0.332 NJ**	**0.583 NJ**	**0.0343 NJ**	0.0201 U	0.0236 U	0.0474 U	0.176 U
2,3,4,6,7,8-HxCDF	0.1	**0.890**	**0.435 NJ**	**0.103 J**	**0.337 NJ**	**4.56**	**9.19 NJ**	**0.135 NJ**	**0.0322 J**	**0.0291 J**	**0.0438 NJ**	**0.117 NJ**
1,2,3,4,6,7,8-HpCDF	0.01	**1.41 J**	**0.728**	**0.0569 J**	**0.459**	**1.83**	**2.47**	**0.357**	**0.0304 J**	**0.0442 J**	**0.0822 J**	**0.00805 J**
1,2,3,4,7,8,9-HpCDF	0.01	**0.0655 J**	**0.0306 J**	0.146 U	**0.0212 J**	**0.127 J**	**0.164 J**	**0.0167 J**	0.0244 U	0.0396 U	**0.00716 J**	0.149 U
OCDF	0.0003	**0.174**	**0.110**	**0.00721**	**0.0472**	**0.0431 NJ**	**0.0415 NJ**	**0.0362**	**0.00252 J**	**0.00696**	**0.0142**	**0.00512 J**
Furan TEQ_{Fines}:		**5.67**	**2.89**	**0.793**	**2.11**	**20.6**	**112**	**1.20**	**0.118**	**0.207**	**0.461**	**0.621**
TCDD TEQ_{Fines}:		**27.2**	**15.5**	**3.19**	**10.7**	**170**	**478**	**3.03**	**0.700**	**0.732**	**3.42**	**7.16**

Bold: Visual aid to detected compounds

NJ: Presence of the analyte has been "tentatively identified"; the numerical value is an approximate concentration.

J: Presence of the analyte has been positively identified; the numerical value is an estimate.

U: Analyte was not detected at or above the laboratory derived reporting limit shown, nor was it normalized to fines.

TEF: Toxic equivalence factors for individual congeners, from Van den Berg et al., 2005.

TEQ: The sum of sample TEFs, representing the toxic equivalency to 2,3,7,8-TCDD.

Fines: Total percent of the clay + silt fraction in a sample.

Appendix B. Site Photos

Figure B1. Shelton 1, Sediment Collection Area, Near the End of the Ash Mound.

Figure B2. Ash Mound Surface at Shelton 1.

Figure B3. Ash Mound Surface at Shelton 1.

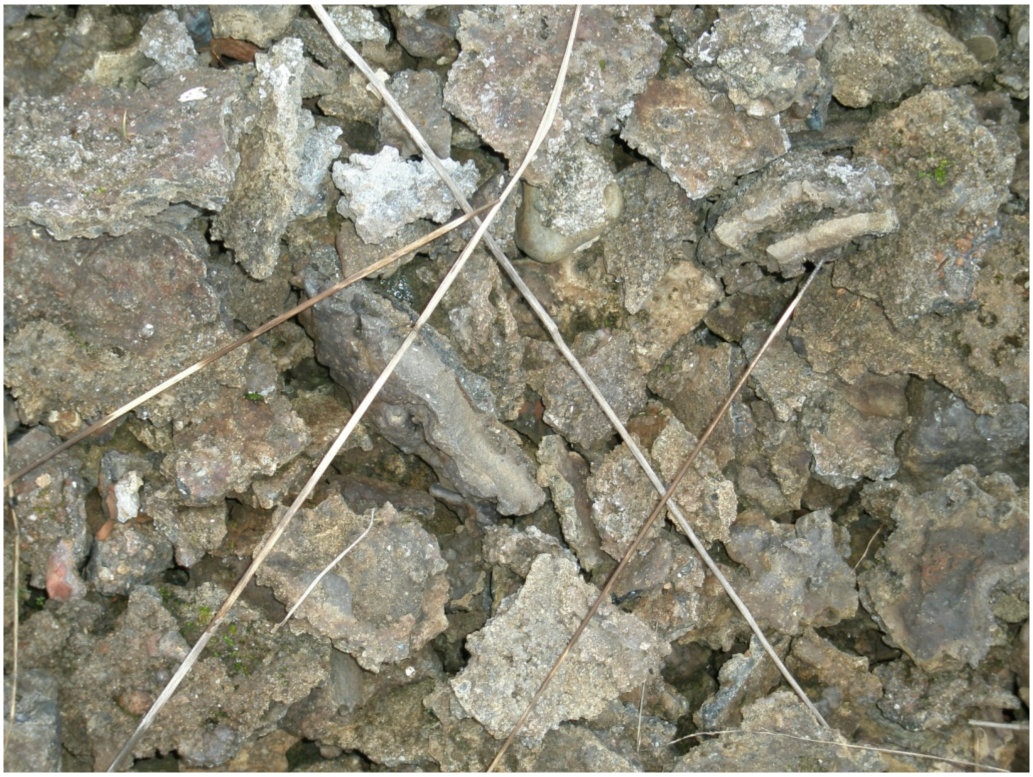

Figure B4. Ash Mound Surface at Shelton 1.

Figure B5. Shelton 2, below Front Street.

Figure B6. Canyon 3, Upstream of the Northcliff Road.

Figure B7. Unnamed Tributary to Shelton Creek, Daylights at the City Animal Shelter.

Figure B8. Shelton 4, Laurel Street Sediment Pond.

Figure B9. Gold 2, Sediment Collection Reach.

Figure B10. Gold 4, Upstream of Fish Weirs.

Figure B11. Gold 4, Upstream of Fish Weirs.

Figure B12. John 1, Sediment Collection Area.

Figure B13. John 2, Sediment Collection Area.

Appendix C. Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Areal flow: Surface water discharge per unit of watershed area, in units of length per time (for example, inches per day).

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Congener: In chemistry, congeners are related chemicals. For example, polychlorinated biphenyls (PCBs) are a group of 209 related chemicals that are called congeners.

Dioxins and furans: Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans.

Grab sample: A discrete sample from a single point in the water column or sediment surface.

K_{ow}: Octanol-water partitioning coefficient is a measure of solubility. K_{ow} is the ratio of a compounds concentration in a known volume of octanol compared to its concentration in a known volume of water after reaching equilibrium.

Marine water: Salt water.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Point source: Source of pollution that discharges at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Reach: A specific portion or segment of a stream.

Sediment: Solid fragmented material (soil and organic matter) that is transported and deposited by water and covered with water (example, river or lake bottom).

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Toxic equivalency factor (TEF): The toxic equivalent factor of individual congeners compared to 2,3,7,8-TCDD as a decimal.

Toxic equivalency quotient (TEQ): Toxic equivalency to 2,3,7,8-TCDD. The total of all TEF normalized dioxin congeners in a sample. Allows comparison to the dioxin criterion for 2,3,7,8-TCDD.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
EDL	Estimated detection limit
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
K_{ow}	Octanol-water partition coefficient
MEL	Manchester Environmental Laboratory
OCDD	Octachlorodibenzo-p-dioxin
OCDF	Octachlorodibenzofuran
PBT	Persistent, bioaccumulative, and toxic substance
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
QA	Quality assurance
QC	Quality control
RPD	Relative percent difference
SMS	Sediment Management Standards
SOP	Standard operating procedures
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCDF	2,3,7,8- tetrachlorodibenzofuran
TEF	Toxic equivalency factor
TEQ	Toxic equivalency to 2,3,7,8-TCDD
TEQ_{Fines}	TEQ normalized to percent fines
TEQ_{TOC}	TEQ normalized to TOC
TOC	Total organic carbon
WAC	Washington Administrative Code

Units of Measurement

°C	degrees centigrade
dw	dry weight
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
m	meter
mg/Kg	milligrams per kilogram (parts per million)
ng/Kg	nanograms per kilogram (parts per trillion)
ug/Kg	micrograms per kilogram (parts per billion)