Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

LOWER DUWAMISH WATERWAY DATA EVALUATION REPORT (TASK 6)

DRAFT

Prepared for

Lower Duwamish Waterway Group

For submittal to

US Environmental Protection Agency

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Acronyms

95UCL	95% upper confidence limit (on the mean)
AC	activated carbon
ANOVA	analysis of variance
AOC	Administrative Order on Consent
ARAR	applicable or relevant and appropriate requirement
AWQC	ambient water quality criteria
BBP	butyl benzyl phthalate
BCM	bed composition model
BEHP	bis(2-ethylhexyl)phthalate
BHC	benzene hexachloride
Boeing	The Boeing Company
CCC	criterion continuous concentration
CFR	Code of Federal Regulations
cfs	cubic feet per second
CKD	cement kiln dust
CMC	criterion maximum concentration
COC	contaminant of concern
COPC	contaminant of potential concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSM	conceptual site model
CSO	combined sewer overflow
CSL	cleanup screening level
CV	coefficient of variation
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DQO	data quality objective
DF	detection frequency

DL	detection limit
dw	dry weight
EAA	early action area
Ecology	Washington State Department of Ecology
EF	exceedance factor
ENR	enhanced natural recovery
EPA	US Environmental Protection Agency
EVS	EVS Environment Consultants
FWM	food web model
HCB	hexachlorobenzene
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HpCDD	heptachlorodibenzo-*p*-dioxin
HpCDF	heptachlorodibenzofuran
ID	identification
IDW	inverse distance weighting
LAET	lowest apparent effects threshold
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
MDD	minimum detectable difference
MDL	method detection limit
MIT	Massachusetts Institute of Technology
MNR	monitored natural recovery
NTR	National Toxics Rule
NTU	nephelometric turbidity unit
OC	organic carbon
OCDD	octachlorodibenzo-*p*-dioxin
OCDF	octachlorodibenzofuran
OSV	ocean survey vessel

PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
PCUL	preliminary cleanup level
PE	polyethylene
PeCDD	pentachlorodibenzo-*p*-dioxin
PEF	potency equivalency factor
ppt	parts per thousand
PRC	performance reference compound
PSAMP	Puget Sound Ambient Monitoring Program
QAPP	quality assurance project plan
RAL	remedial action level
RAO	remedial action objective
RARE	Regional Applied Research Effort
RBTC	risk-based threshold concentration
RI/FS	remedial investigation / feasibility study
RM	river mile
RME	relative margin of error
ROD	Record of Decision
SCL	sediment cleanup level
SCO	sediment cleanup objective
SD	standard deviation
SMS	Washington State Sediment Management Standards
SPAF	species-predictive accuracy factor
SPU	Seattle Public Utilities
STM	sediment transport model
SPME	solid-phase microextraction
SVOC	semivolatile organic compound
SWAC	spatially weighted average concentration

T-105	Terminal 105
T-107	Terminal 107
T-108	Terminal 108
T-117	Terminal 117
TBT	tributyltin
TCDD	tetrachlorodibenzo-*p*-dioxin
TEF	toxic equivalency factor
TEQ	toxic equivalent
TOC	total organic carbon
TSS	total suspended solids
TTL	target tissue level
USACE	US Army Corps of Engineers
USGS	US Geological Survey
UTL	upper tolerance limit
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WQA	water quality assessment
WQC	water quality criteria
WSOU	Waterway Sediment Operable Unit
ww	wet weight

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- Statistical expertise - Lorraine Read (Terrastat)

Executive Summary

This data evaluation report presents an evaluation of Pre-Design Studies baseline and source-related data collected for the Lower Duwamish Waterway (LDW) Superfund site in 2017 and 2018 to address the third amendment to the Administrative Order on Consent (referred to as AOC3) per the *Pre-Design Studies Work Plan*. The LDW, located in Seattle, Washington (Figure ES-1), was added to US Environmental Protection Agency's (EPA's) National Priorities List (also known as Superfund) in 2001 and to the Washington State Department of Ecology's (Ecology's) Hazardous Sites List in 2002. The Record of Design (ROD), which specifies the sediment cleanup remedy for the LDW, was released in 2014.

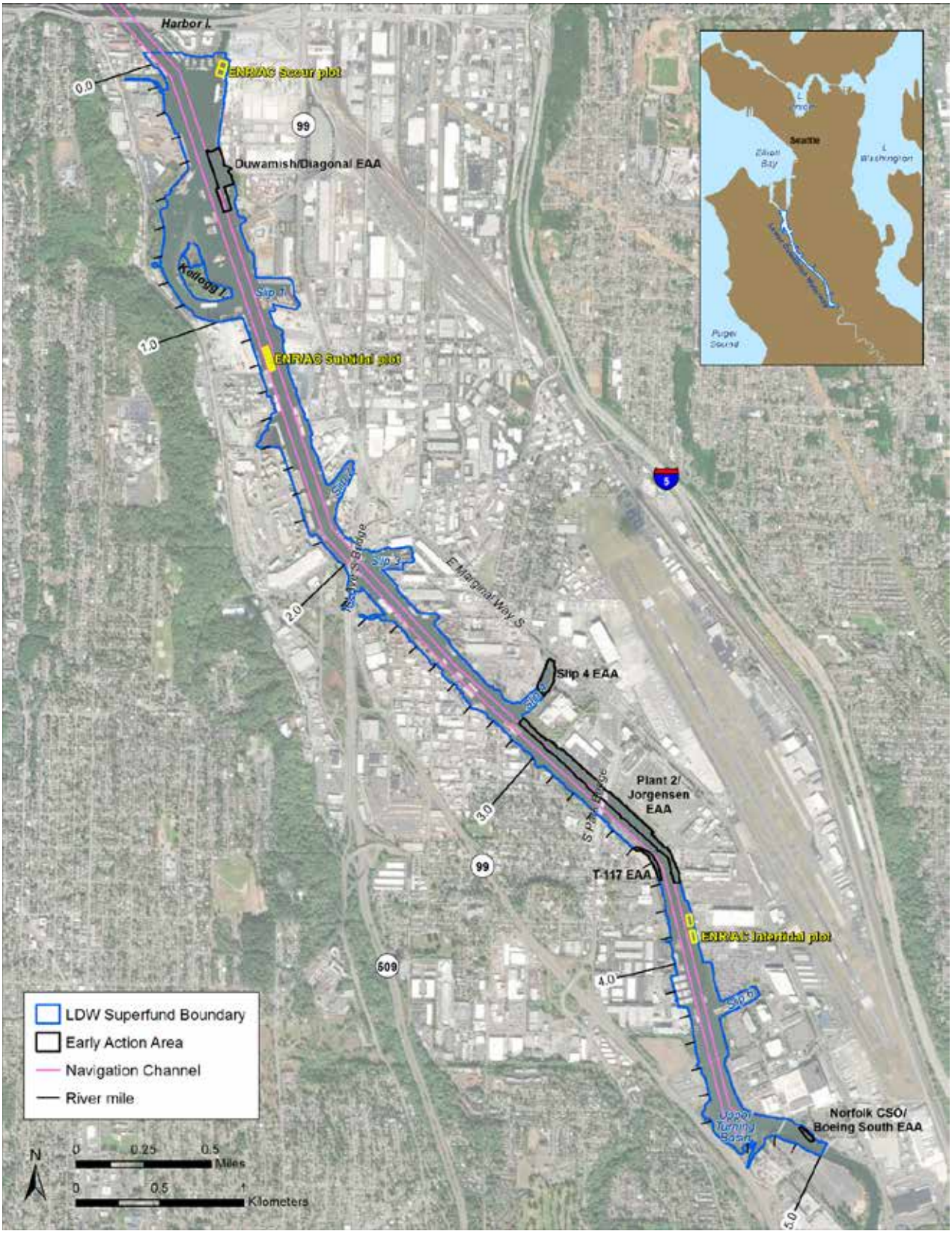


Figure ES-1. Location of the LDW

The main purpose of this data evaluation report is to assess data collected relative to the data quality objectives (DQOs) outlined in the Work Plan and the quality assurance project plans (QAPPs). This evaluation also includes comparisons of baseline sediment and tissue data to historical data (including post-feasibility study [FS] data,[1] where appropriate, to provide context for the baseline results. In addition, this report provides updated input values for the bed composition model (BCM), which was used to predict future sediment contaminant concentrations as part of the FS remedial alternatives analysis.

All DQOs outlined in the QAPPs were met. The DQOs are highlighted below and presented in Table ES-1.

- Establish baseline sediment data to:
  - Compare to cleanup levels in ROD
  - Serve as a foundation for future monitoring and assess the effects of the early action area (EAA) cleanups and continued source control on the spatially weighted average concentrations (SWACs) of the four human health risk drivers (total polychlorinated biphenyls [PCBs], carcinogenic polycyclic aromatic hydrocarbons [cPAH], dioxins/furans, and arsenic)
- Establish baseline surface water data to:
  - Compare to surface water applicable or relevant and appropriate requirements (ARARs)
  - Serve as a foundation for future monitoring of total PCB concentrations
- Establish fish, crab, and clam baseline tissue data to:
  - Compare to the target tissue levels (TTLs) in the ROD
  - Serve as a foundation for future monitoring of human health risk drivers
- Evaluate porewater data relative to other media to:
  - Predict concentrations in porewater for total PCBs and dioxins/furans based on sediment data to establish baseline conditions
  - Assess the relationships among sediment, porewater, and clam tissue for cPAHs to help evaluate whether achieving sediment cleanup levels for cPAHs will reduce concentrations in clam tissue to TTLs[2]
- Provide near-outfall sediment, bank sediment, and seep data to the Ecology to help with source control sufficiency evaluations

[1] Post-FS data were summarized in the Existing Data Compilation.

[2] This question was assessed for arsenic in the Work Plan based on work done for the RARE studies and the remedial investigation (RI)/FS. The results of those analyses are summarized herein.

Table ES-1. Pre-Design Studies DQOs

DQO Number[a]	DQO	QAPP Wherein DQO Discussed
Surface sediment (Section 2.1)		
1	Establish baseline, site-wide 95UCL concentrations of RAOs 1, 2, and 4 risk drivers.	surface sediment
2	Establish baseline, site-wide SWAC to serve as the foundation for assessing trends from before to after sediment remediation for RAOs 1, 2, and 4 risk drivers.	surface sediment
3	Compare (on a point-by-point basis) concentrations in baseline samples collected from within MNR areas to the (benthic) cleanup levels presented in ROD Table 20.[b]	surface sediment
4	Support the evaluation of site-wide trends and comparison of concentrations to predicted natural recovery in MNR areas.	surface sediment
Intertidal sediment (Section 2.2)		
7	Establish baseline 95UCL concentrations of human health risk drivers for RAO 2 across all potential clamming areas identified in the ROD.	surface sediment
8	Establish baseline site-wide potential clamming area mean concentrations to assess trends following sediment remediation for RAO 2 (direct contact – clamming) risk drivers.	surface sediment
9	Establish baseline 95UCL concentrations for risk drivers to achieve RAO 2 in each of the 8 beach play areas.	surface sediment
10	Establish baseline beach play area-specific mean concentrations to assess trends following sediment remediation for RAO 2 (direct contact – beach play) risk drivers.	surface sediment
Surface water (Section 3)		
1	Assess progress toward water quality ARARs as sediment remediation and source control continue.	surface water
2	Establish baseline concentrations to be used to assess trends in total PCB concentrations in surface water as sediment remediation and source control continue.	surface water
Fish and crab tissue (Section 4)		
1	Establish baseline site-wide 95UCL concentrations of risk drivers for comparison to TTLs for RAO 1.	fish and crab tissue
2	Establish baseline site-wide mean concentrations to assess trends following sediment remediation for contaminants with TTLs.	fish and crab tissue
Clam tissue (Section 5)		
1	Establish baseline site-wide 95UCL concentrations of human health risk drivers for comparison to TTLs for RAO 1.	clam tissue
2	Calculate baseline site-wide mean clam tissue concentrations to assess trends following sediment remediation for contaminants with TTLs.	clam tissue
Porewater (Section 6)		
1	Assess the relationships among concentrations of cPAHs in clam tissue, porewater, and sediment to help evaluate whether achieving sediment cleanup levels for cPAHs will reduce concentrations in clam tissue to TTLs.	clam tissue

DQO Number[a]	DQO	QAPP Wherein DQO Discussed
5 (PCB porewater)	Estimate baseline porewater concentrations in MNR/ENR areas for total PCBs. This DQO is primarily intended to help assess the effect of reduced sediment concentrations on biota exposure and tissue concentrations.	surface sediment
Source-related samples (Section 7)		
6	Help Ecology assess the sufficiency of contaminant source control through additional near-outfall sediment sampling and bank sampling[c]	surface sediment

[a] The DQO number is the number listed in each QAPP.

[b] ROD Table 20 is titled *Sediment cleanup levels for ecological (benthic invertebrate) COCs for RAO 3*.

[c] Seep data were also collected and analyzed to aid Ecology in source identification. The seep QAPP identified this as an objective rather than a DQO.

95UCL – 95% upper confidence limit (on the mean)
ARAR – applicable or relevant and appropriate requirement
cPAH – carcinogenic polycyclic aromatic hydrocarbon
COC - contaminant of concern
DQO – data quality objective
Ecology – Washington State Department of Ecology
ENR – enhanced natural recovery
MNR – monitored natural recovery
PCB – polychlorinated biphenyl
QAPP – quality assurance project plan
ROD – Record of Decision
RAO – remedial action objective
SWAC – spatially weighted average concentration
TTL – target tissue level

ES.1 SEDIMENT

Baseline sediment samples were collected as part of the Pre-Design Studies to assess baseline concentrations of contaminants of concern (COC) in sediment, following the cleanups of EAAs and prior to implementing the site-wide remedy defined in the ROD. Composite samples and individual grab samples were analyzed to address key questions.

ES.1.1 Composite sediment samples

Site-wide surface sediments (0–10 cm) and potential clamming area sediments (0–45 cm), as well as individual beach play area sediments (0-45 cm), were analyzed as area-specific composite sediment samples for comparison to remedial action objective (RAO) cleanup levels presented in ROD Table 19 (Table ES-2).[3] Comparisons to cleanup levels are based on 95% upper confidence limits (on the mean) (95UCLs), as shown for the relevant spatial scales in Table ES-2. Total PCB and dioxin / furan concentrations were greater than their cleanup levels for RAO 1 (human seafood consumption) and RAO 2 (direct contact – clamming), and for total PCBs, for RAO 4 (ecological – river otter protection). Total PCB concentrations were less than cleanup level for RAO 2 (human direct contact – beach play), whereas dioxin / furan concentrations were greater than the cleanup level at three of the eight beach play areas.

[3] ROD Table 19 is titled *Cleanup levels for PCBs, arsenic, cPAHs, and dioxins/furans in sediment for human health and ecological COCs (RAOs 1, 2, and 4).*

Table ES-2. Comparison of baseline data to RAO cleanup levels in ROD Table 19

COC	95UCL of Baseline Data	RAO 1: Human Seafood Consumption	RAO 2: Human Direct Contact	RAO 4: Ecological (River Otter)	Spatial Scale of Application and Depth of Compliance
Total PCBs (µg/kg dw)	209	**2**	1,300	**128**	LDW-wide, 0–10 cm
	1,690	na	**500**	na	all clamming areas, 0–45 cm
	160–1,580	na	1,700	na	individual beaches, 0–45 cm
cPAH TEQ[a] (µg/kg dw)	226	na	380 (2,744)	na	LDW-wide, 0–10 cm
	913	na	**150** (1,083)	na	all clamming areas, 0–45 cm
	63.4–5,310	na	**90 (650)**	na	individual Beaches, 0–45 cm
Dioxin/furan TEQ (ng/kg dw)	11.6	**2**	37	na	LDW-wide, 0–10 cm
	88	na	**13**	na	all clamming areas, 0–45 cm
	2.38–125	na	**28**	na	individual beaches, 0–45 cm
Arsenic (mg/kg dw)	13.1	na	**7**	na	LDW-wide, 0–10 cm
	13	na	**7**	na	all clamming areas, 0–45 cm
	6.31–96.8	na	**7**	na	individual beaches, 0–45 cm

Note: Baseline data are greater than the cleanup levels in **bold text**.

[a] ROD cleanup levels (based on risk-based threshold concentrations) are shown with updated RBTCs in parentheses derived using the 2017 benzo(a)pyrene cancer slope factor.

95UCL – 95% upper confidence limit (on the mean)
COC – contaminant of concern
cPAHs – carcinogenic polycyclic aromatic hydrocarbons
dw – dry weight
LDW - Lower Duwamish Waterway
na – not applicable
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
ROD – Record of Decision
RAO – remedial action objective
TEQ - toxic equivalent

The cleanup levels for cPAHs are based on risk-based threshold concentrations (RBTCs) using benzo(a)pyrene cancer toxicity data that have been updated by the US Environmental Protection Agency (EPA) since the ROD was published in 2014.[4] The RBTCs for cPAHs have increased because cPAHs are less toxic than previously thought based on the updated toxicity data. Using the new RBTCs, cPAH concentrations in sediment composite samples are less than all RBTCs, except at three[5] of the eight beaches. In the future, EPA is expected to adjust cPAH cleanup levels based on the updated toxicity information.

[4] The toxicity data for benzo(a)pyrene are used in establishing the carcinogenic potency of the polycyclic aromatic hydrocarbon (PAH) compounds that are represented as cPAHs.

[5] Or four of the eight beaches, depending on the treatment of duplicate results.

Arsenic concentrations were greater than the RAO 2 direct contact cleanup level of 7 mg/kg for all direct contact exposure areas, except for one of the eight beaches.

Site-wide SWACs were also calculated for the four human health risk drivers to assess overall changes that have occurred since completion of the EAAs, as well as for use in assessing site-wide trends following completion of the ROD sediment remedy. The baseline site-wide SWACs were less than those presented in the FS[6] for all four risk drivers (Table ES-3, Figure ES-2). The total PCB SWAC was within the range predicted in the FS by the BCM.[7] SWACs for the other three risk drivers were lower than predicted, although the arsenic SWAC was very similar to the predicted concentration.

Table ES-3. Comparison of FS-interpolated, BCM-predicted, and baseline composite LDW-wide SWACs for 0–10-cm sediments

COC	Units	FS SWAC	BCM-predicted SWAC Year 0 Post-EAA	LDW Baseline SWAC (Pre-Design Studies)	BCM-predicted SWAC Year 5 Post-EAA
Total PCBs	µg/kg	346	180	172	103
cPAH TEQ	µg/kg	388	360	147	220
Dioxin/furan TEQ	ng/kg	24.6	24	8.33	13
Arsenic	mg/kg	15.6	16	11.6	12

BCM – bed composition model
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EAA – early action area
FS – feasibility study
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

[6] The RI/FS dataset included data from 1990 to 2010 and prior to all early actions, except Norfolk.
[7] The range presented herein is for base case predictions for year 0 to year 5 post-early action. The overall uncertainty in BCM predictions is discussed in detail in the FS.

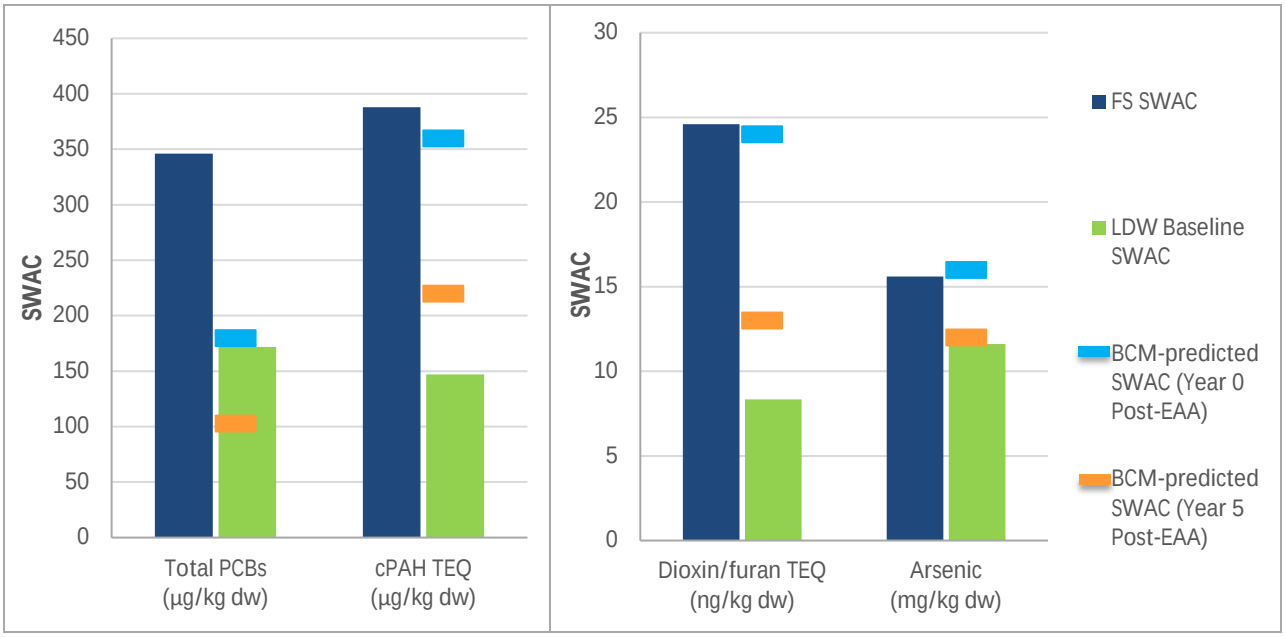


Figure ES-2. Comparison of FS-interpolated, BCM-predicted, and baseline composite LDW-wide SWACs for 0–10-cm sediments

Mean concentrations in intertidal clamming areas and the eight beach play areas were also calculated to serve as the foundation for assessing future trends (Table ES-4). Historical 0–45-cm data for the intertidal areas were too few for a suitable comparison to be assessed.

Table ES-4. Summary of means in potential clamming areas and individual beach play areas for intertidal (0–45-cm) sediments for the four risk drivers

Location	Mean Concentrations			
	Total PCBs (µg/kg dw)	cPAH TEQ (µg/kg dw)	Dioxin/furan TEQ (ng/kg dw)	Arsenic (mg/kg dw)
Clamming areas - site-wide	617	381	35	10
Beach 1	120	169	1.61	14.7
Beach 2	102	276	15.7	44.7
Beach 3	110	100	4.37	4.01
Beach 4	359	45	30	6.24
Beach 5	114	1,150	5.29	8.74
Beach 6	561	1,343	13.2	44.6
Beach 7	65.2	43	2.13	5.44
Beach 8	123	108	4.05	7.72

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

ES.1.2 Individual sediment samples

Twenty individual grab samples were collected within preliminary monitored natural recovery (MNR) areas[8] and compared to RAO 3 cleanup levels for the protection of the benthic community, as presented in ROD Table 20. Concentrations within MNR areas will be monitored to assess compliance with RAO 3 cleanup levels within 10 years following construction of the sediment remedy. Of the 20 samples:

- Eleven had no benthic cleanup level exceedances.
- Six had an exceedance of the benzyl alcohol benthic cleanup level.
- Three had an exceedance of the total PCB benthic cleanup level.

Individual samples analyzed for both PCB Aroclors and congeners were also assessed. The results for the two methods correlate with differences within the analytical variance of the methods.

ES.2 SURFACE WATER

Baseline data for surface water (collected as composite-grab samples) were compared with water quality criteria (WQC) ARARs to evaluate progress toward meeting these ARARs as sediment remediation and source control work progress. Samples were collected during dry and wet baseflow and storm conditions. Nine chemicals were detected at concentrations greater than the lowest ARARs, all of which were based on human health WQC for consumption of organisms (Table ES-5). Concentrations in surface water samples were less than WQC for protection of marine organisms for all COCs.

Table ES-5. Summary statistics for COCs detected in composite-grab surface water samples relative to the lowest ARAR

COC	Units	Summary Statistics		Lowest ARAR	Count of Detects Greater than Lowest ARAR
		DF	Range of Detected Concentrations		
Arsenic (inorganic)	µg/L	48 / 48	0.451–1.72	0.14	48
Benzo(a)anthracene	µg/L	4 / 48	0.00080 J–0.012	0.00016	4
Benzo(a)pyrene	µg/L	1 / 48	0.0070 J	0.000016	1
Benzo(b)fluoranthene	µg/L	6 / 48	0.00060 J–0.011	0.00016	6
Benzo(k)fluoranthene	µg/L	1 / 48	0.0050 J	0.0016	1
Dibenzo(a,h)anthracene	µg/L	1 / 48	0.0020 J	0.000016	1
Indeno(1,2,3-cd)pyrene	µg/L	2 / 48	0.0020 J	0.00016	2
BEHP	µg/L	3 / 48	0.5 J–2.0 J	0.046	3

[8] The remedial boundaries and technology assignments portrayed in ROD Figure 18, titled *Selected remedy*, are likely to change during remedial design. Thus, any reference to MNR, ENR, cap, or dredge areas in this report refers to the preliminary area designations in the ROD.

COC	Units	Summary Statistics		Lowest ARAR	Count of Detects Greater than Lowest ARAR
		DF	Range of Detected Concentrations		
Total PCB congeners	ng/L	48 / 48	0.0105 J–5.573 J	0.007	48

Note: All concentrations are for unfiltered samples for comparison to the lowest ARAR, which was set by human health WQC for consumption of organisms for all COCs listed in this table.

ARAR – applicable or relevant and appropriate requirement
BEHP – bis(2-ethylhexyl) phthalate
COC – contaminant of concern
DF – detection frequency
J – estimated concentration
PCB – polychlorinated biphenyl
WQC – water quality criteria

Baseline freely dissolved concentrations of total PCBs in surface water were determined using passive samplers at two locations in the LDW (river mile [RM] 1.9 and RM 3.3) for future trend analysis. Approximately 30-day deployments were conducted in the summers of 2017 and 2018 during typical dry baseflow conditions. The mean concentrations at these two locations were 1.26 and 1.25 ng/L in 2017 and 0.96 and 1.03 ng/L in 2018.

ES.3 FISH, CRAB, AND CLAM TISSUE

Composite samples of two fish species (English sole and shiner surfperch) and two crab species (Dungeness and Graceful) were collected in 2017, and composite samples of one clam species (Eastern softshell) were collected in 2018 and analyzed for two or more human health risk drivers to establish baseline conditions. Fish, crab, and clam tissue 95UCLs were compared with TTLs, as presented in ROD Table 21.[9]

For the risk driver tissue types with TTLs, baseline data were above the TTL in all cases except for dioxins/furans and crab (both edible meat and whole body) (Table ES-6). While inorganic arsenic 95UCLs were above the TTL, whole-body clam tissue without the siphon skin was found to have much lower inorganic arsenic concentrations, indicating that most of the inorganic arsenic accumulates in the siphon skin. Table ES-6 also presents mean concentrations for comparison with historical and future data to evaluate trends. Total PCB concentrations in baseline tissue were generally lower than or similar to those in 2007 tissue samples (e.g., Figure ES-2), although concentrations in baseline tissue were higher in graceful crab. The LDW food web model (FWM) developed during the remedial investigation accurately predicted total PCB concentrations in tissues. In clams, cPAH TEQs were generally lower; no clear temporal trends were observed in inorganic arsenic concentrations, and no historical dioxin/furan data were available for comparison.

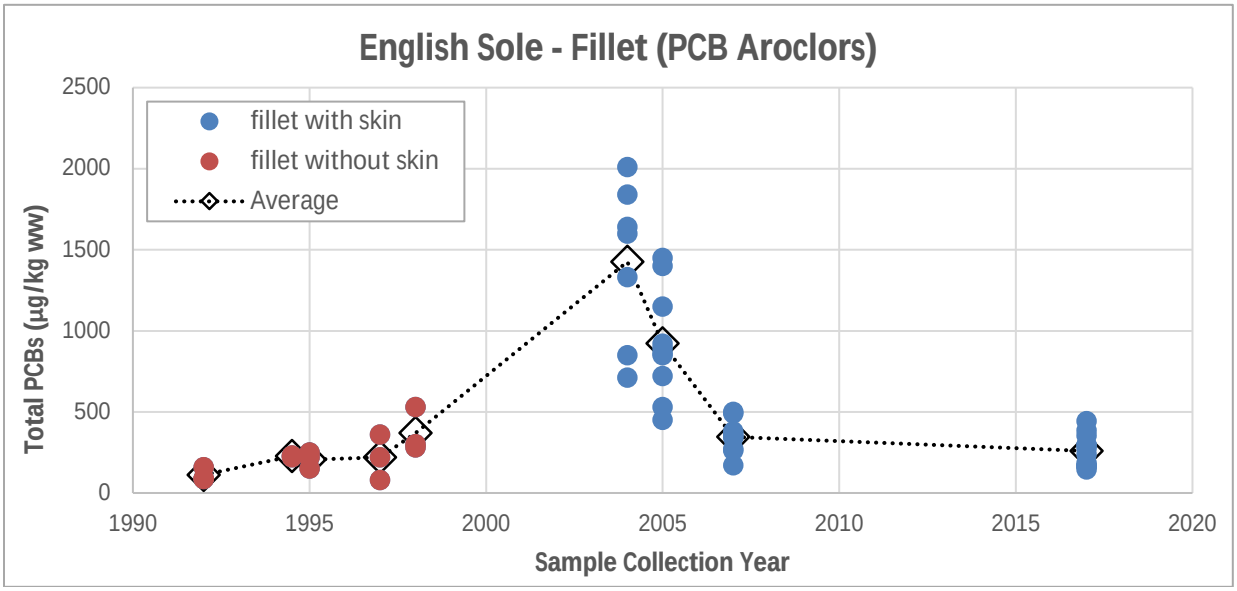
[9] ROD Table 21 is titled *LDW resident fish and shellfish target tissue concentrations.*

Table ES-6. Comparison of baseline tissue data with TTLs in the ROD

COC	Species and Tissue Type	n	Mean Detect	Min. Detect	Max. Detect	95UCL	TTL
Total PCB Aroclors (µg/kg ww)	benthic fish – English sole – fillet	12	259	144.6	442	286	12
	pelagic fish – shiner surfperch – whole body	12	407	308	515	426	1.8
	crab – graceful crab – edible meat	12	115	61.1	165 J	124	1.1
	crab – graceful crab – whole body	12	255	147.3	359 J	275	9.1
	clams – eastern softshell – whole body	9	13.1	8.0	19.6 J	15.1	0.42
cPAH TEQ (µg/kg ww)	clams – eastern softshell – whole body	9	5.18	2.80	11.0	7.85	0.24 (1.8)[a]
Dioxin/furan TEQ (ng/kg ww)	benthic fish – English sole – whole body	12	1.18	0.699 J	1.50 J	1.25	0.35
	crab – graceful crab – edible meat	12	0.41	0.267 J	0.550 J	0.45	0.53
	crab – graceful crab – whole body	12	1.21	0.744 J	1.73 J	1.32	2.0
	clams – eastern softshell – whole body	9	0.87	0.192 J	5.55 J	3.42	0.71
Inorganic arsenic (mg/kg ww)	clams – eastern softshell – whole body	11	5.4	0.7	37.4	19.4	0.09
	clams – eastern softshell – whole body minus siphon skin	11	0.09	0.05	0.19	0.12	

[a] TTL in parentheses based on EPA's 2017 update of the benzo(a)pyrene slope factor.

95UCL – 95% upper confidence limit (on the mean)
cPAH - carcinogenic polycyclic aromatic hydrocarbon
COC – contaminant of concern
EPA – US Environmental Protection Agency
J – estimated concentration
PCB – polychlorinated biphenyl
ROD – Record of Decision
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight



Note: The data collected in the 1990s were from specific areas in the LDW (i.e., are not representative of site-wide conditions).

Figure ES-2. Total PCB concentrations in English sole fillet tissue over time

ES.4 RELATIONSHIPS WITH POREWATER

The relationship between total PCB concentrations in sediment and porewater was investigated using measured porewater data and equilibrium partitioning models. Using site-specific data, LDW-specific congener K_{OC} values were calculated. These values can be used to calculate future porewater total PCB concentrations, if needed.

An equilibrium partitioning model was also used to predict dioxin/furan concentrations in porewater. This model can be used in the future if dioxin/furan concentrations in porewater are needed.

In addition, the ROD stated that additional research would be conducted "to further assess the relationship between arsenic and cPAH concentrations in sediment and in clam tissue, and to assess whether remedial action can reduce clam tissue concentrations to achieve RAO 1." The Regional Applied Research Effort (RARE) study conducted by EPA and the US Army Corps of Engineers (USACE) addressed arsenic. This study determined that following the sediment cleanup and reductions through source control and natural recovery, total arsenic concentrations in sediment are expected to result in reductions in inorganic arsenic concentrations in clam tissue.

The RARE study found porewater data did not further explain the relationship between clam tissue and sediment. It concluded that the intertidal sediment remedial action level (RAL) for arsenic (28 mg/kg) was sufficiently low so that inorganic arsenic concentrations in whole-body clams without siphon skin would meet the TTL for whole clams (0.09 mg/kg wet weight [ww]) following remediation. Additional clam monitoring for inorganic arsenic will be conducted following the remedy.

For cPAHs, the relationships among sediment, clam tissue, and porewater were further addressed in the Pre-Design Studies. The cPAH porewater data are not yet available. Therefore, cPAH results will be discussed in the draft final version of this report or an addendum once the porewater data are available.

ES.5 SOURCE-RELATED DATA

To assist Ecology in source control sufficiency determinations, 19 near-outfall sediment samples, 11 bank samples, and 26 seep samples were collected from locations identified as having data gaps based on discussions with Ecology. These new data were combined with RI/FS and post-FS data and then compared with the lowest surface sediment RALs (near-outfall and bank) and groundwater preliminary cleanup levels (PCULs) calculated by Ecology as protective of the sediment remedy.

Based on these comparisons, of the more than 200 active outfalls in the LDW, 135 had surface sediment samples collected within 50 or 100 ft, depending on the size of the

outfall pipe.[10] Of these 135 outfalls, 83 were located outside of EAAs and had surface sediment samples with RAL exceedances within the applicable radius.[11] Of the total of 80 bank samples with concentrations compared to the lowest surface sediment RAL, 34 had detected concentrations greater than the lowest surface sediment RAL.

Of the total of 66 filtered seep samples compared to groundwater PCULs protective of the sediment remedy, 35 had at least 1 COC concentration that was greater than the groundwater PCUL. In seep water, concentrations were greater than the groundwater PCULs for seven chemicals, primarily chromium.

ES.6 UPDATED BCM INPUT PARAMETERS

Data collected since the FS were compiled to update the three key chemical concentration input parameters to the BCM (lateral, upstream, and bed replacement value) for the four risk drivers. Using methods similar to those used in the FS, the following results were found:

- Total PCBs – Laterals input values were the same as those used in the FS (except for a lower high-sensitivity value), upstream values were generally lower, and bed replacement values were higher.
- cPAH TEQ – All input values were lower than those used in the FS.
- Dioxin/furan TEQ – Input values for laterals and bed replacement were higher than those used in the FS.
- Arsenic – Input values were relatively unchanged.

These differences are likely due to the much larger datasets now available and ongoing source control actions.

ES.7 NEXT STEPS

The next phases of the LDW cleanup process will include additional investigations to support remedial design, construction of the remedy, monitoring of MNR areas, and site-wide long-term monitoring of the site following construction. In addition, source control efforts in support of the cleanup will continue.

The study designs developed for the baseline sampling will be used in long-term monitoring. Section 9 describes recommended refinements to study designs and analytes for sediment, tissue, and surface water sampling based on the information gathered during the Pre-Design Studies.

[10] The other outfalls do not have sediment data within 50 or 100 ft because either the area was not sampleable or they were not recommended for sampling by Ecology. Those not recommended for sampling were because they are inactive or are located within an active cleanup area.

[11] Note that while a sediment sample near an outfall have had an exceedance, the source of contamination may have been historical rather than ongoing or associated with another outfall or upland source.

1 Introduction

This data evaluation report presents an interpretation of Pre-Design Studies baseline and source-related data collected from the Lower Duwamish Waterway (LDW) in 2017 and 2018 to address the third amendment to the Administrative Order on Consent (referred to herein as AOC3) (EPA 2016) per the *Pre-Design Studies Work Plan* (Windward and Integral 2017b), hereafter referred to as the Work Plan.

Per AOC3 (EPA 2016), the purpose of this data evaluation report is to:

- Present baseline characterization results and other analytical data, statistical evaluations, and supporting calculations to determine baseline concentrations in sediment, tissue, and surface water for comparison with future monitoring results as remediation and source control progress.
- Compare baseline data to the cleanup levels in Record of Decision (ROD) Tables 19 and 20, to the target tissue concentrations in ROD Table 21 (EPA 2014), and to surface water applicable or relevant and appropriate requirements (ARARs).[12]
- Assess the effects of the early action area (EAA) cleanups on risk driver surface weighted average concentration (SWAC) reduction by comparing the results of the baseline sediment sampling with the remedial investigation/feasibility study (RI/FS) (Windward 2010a; AECOM 2012) pre-EAA SWACs and bed composition model (BCM) post-EAA model predictions.
- Prepare GIS maps and figures showing data from the Pre-Design Studies as well as RI/FS and post-FS data where appropriate.
- Compare source-related data (from near-outfall sediment, bank, and seep samples) to benchmarks to aid the Washington State Department of Ecology (Ecology) in source control sufficiency determinations (Ecology 2016).
- Compare the BCM input parameters (i.e., bed replacement, upstream, and lateral chemistry values) to new data for these inputs, and make recommendations for revised input parameters for future modeling of refined natural recovery predictions.

[12] ROD tables referred to in this data evaluation report are reproduced in Appendix A for ease of reference. ROD Table 19 is titled *Cleanup levels for PCBs, arsenic, cPAHs, and dioxins/furans in sediment for human health and ecological COCs [RAOs 1, 2, and 4]*; ROD Table 20 is titled *Sediment cleanup levels for ecological (benthic invertebrate) COCs for RAO 3*; and ROD Table 21 is titled *LDW resident fish and shellfish target tissue concentrations.*

- Specify whether the data met the data quality objectives (DQOs), identify data gaps and issues, and present recommendations to resolve them with additional field characterization or other work.

The next phases of the LDW cleanup process will include remedial design, construction of the remedy, and monitoring of the remedy outcome. Pre-Design Studies data were collected to define baseline conditions in sediment, tissue, and surface water. Sediment data will be compared with cleanup levels associated with remedial action objectives (RAOs) 1, 2, and 4 prior to the remedy's implementation.[13] RAO 3 (protection of benthic invertebrates) evaluations will be assessed following remedial construction. Compliance with RAO 3 within monitored natural recovery (MNR) areas will be assessed during a 10-year post-construction monitoring period to determine whether RAO 3 goals are achieved. Baseline data combined with long-term monitoring data will allow trend analysis to assess progress toward compliance with cleanup goals.

All data collected to address AOC3 have been reported in data reports, including data for fish / crab (Windward 2018h), surface sediment (Windward 2018i), seeps (Windward 2018c), clam tissue (Windward 2018g), and surface water (Windward 2018e).[14] These reports include data, sample collection locations, validation results, and any quality assurance project plan (QAPP) deviations. No deviations were identified that would have impacted the use of the data in meeting the DQOs.

This data evaluation report is organized into the following sections:

- Section 2 – Sediment
- Section 3 – Surface Water
- Section 4 – Fish and Crab Tissue
- Section 5 – Clam Tissue
- Section 6 – Porewater Investigations
- Section 7 – Source-Related Data
- Section 8 – Bed Composition Model Input Parameters Updates
- Section 9 – Future Sampling Considerations
- Section 10 – References

The text is supported by the following appendices:

- Appendix A – Relevant ROD Tables and Figures

[13] RAO 1 pertains to risks from seafood ingestion (human health), RAO 2 relates to direct contact risks (human health), RAO 3 relates to risks to the benthic invertebrate community, and RAO 4 deals with risks to higher-trophic-level species (fish, crabs, birds, and mammals - ecological health).

[14] PCB porewater data were reported in the surface sediment QAPP (Windward 2018d). cPAH porewater data will be reported in an addendum to the clam tissue data report.

- Appendix B – Statistical Analyses
- Appendix C – Salinity Profiles
- Appendix D – Porewater Supporting Documentation
- Appendix E – Near-Outfall Sediment Data
- Appendix F – Upstream Data for the Bed Composition Model

2 Sediment

This section provides an interpretation of the sediment data collected in February / March and June 2018 per the sediment QAPP (Windward 2018d). Surface sediment data were collected: 1) to characterize baseline conditions prior to implementation of the sediment remedy and following EAA completions; and 2) to support source control efforts. As described in the sediment QAPP (Windward 2018d), 10 DQOs have been identified for the collection and analysis of baseline surface sediment samples, which included an *ex situ* porewater investigation for polychlorinated biphenyls (PCBs) as well as source-related samples. This section presents the data and interpretation of baseline sediment data related to surface sediment DQOs 1, 2, 3, and 4. The results and interpretation of the *ex situ* porewater investigation are discussed in Section 6, and the results and interpretation of the source-related samples are discussed in Section 7.

2.1 SITE-WIDE SURFACE SEDIMENT (0-10 CM) COMPOSITE SAMPLES

2.1.1 DQOs and data collected

Per the QAPP (Windward 2018d), 24 composite samples (each composed of 7 individual grab samples) were collected throughout the LDW and analyzed for total PCBs (as Aroclors), carcinogenic polycyclic aromatic hydrocarbons (cPAHs), dioxins / furans, and arsenic (RAOs 1, 2, and 4 risk drivers[15]). These composite samples are used to address the following DQOs for the establishment of site-wide baseline conditions in 0–10-cm LDW surface sediment samples:

- **Sediment DQO 1 –** Establish baseline, site-wide 95% upper confidence limit (on the mean) (95UCL) concentrations of total PCBs, cPAHs, dioxins / furans, and arsenic.
- **Sediment DQO 2 –** Establish baseline, site-wide SWACs to serve as the foundation for assessing trends from before to after sediment remediation for PCBs, cPAHs, dioxins / furans, and arsenic.

The baseline surface sediment sampling design was developed to address these two DQOs by collecting 168 individual grab samples from throughout the study area using a spatially balanced random sampling design. Each of the 168 samples was collected at one random location within each sampling grid cell, all of which were of approximately equal area (Map 2-1). Once collected, the surface sediment samples from these 168 locations were combined into 24 composite samples for analysis. Each composite sample contained seven individual grab samples.

[15] Risk drivers for RAOs 1 and 2 are PCBs, dioxins / furans, cPAHs, and arsenic (ROD Table 19 (EPA 2014)). PCBs are the only risk drivers for RAO 4.

Surface sediment sampling was conducted in February / March 2018. The data were validated and no issues were identified with the data that would limit their use in calculating site-wide 95UCLs and SWACs, which are provided in Table 2-1. Details regarding the 95UCL calculations are provided in Appendix B. The SWAC estimates were calculated as the arithmetic mean of the composite datasets as intended per the study design.

Table 2-1. Summary statistics for COCs in surface (0–10-cm) sediment composite samples

COC (units)	Best Fit Distribution	95UCL[a]	SWAC	RME[b,c]	RME Target	Comment
Total PCBs (µg/kg dw)	normal	209	172	22%	25%	RME target was met
cPAH TEQ (µg/kg dw)	lognormal	226	147	51%	25%	One influential value was present (Comp-2, with TEQ of 742 µg/kg). RME was 21% with this value excluded.
Dioxin/furan TEQ (ng/kg, dw)	gamma	11.6	8.33	39%	25%	Two influential values were present; Comp-6 and Comp-11 had the two highest TEQs of 22.5 and 27.7 ng/kg, respectively. RME was 23% with the influential values excluded.
Arsenic (mg/kg dw)	lognormal	13.1	11.6	14%	25%	RME target was met.

[a] 95UCL derived using the best-fit distribution as determined by distributional evaluation. Details provided in Appendix B.

[b] RME calculated as the width of the 95UCL as a percent of the mean.

[c] The target RME specified in the Work Plan and QAPP was 25% (Windward and Integral 2017b; Windward 2018d); the sampling design was based on an estimate of post-remedy variance using data from the preliminary MNR areas to determine the number of samples required to achieve the target RME following remediation.

95UCL – 95% upper confidence limit (on the mean)
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
MNR – monitored natural recovery
PCB – polychlorinated biphenyl
QAPP – quality assurance project plan
RME – relative margin of error
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

Because implementation of the remedy in the ROD will address areas with higher contaminant of concern (COC) concentrations, variance in surface sediment concentrations is expected to decrease following remedial action. Therefore, total PCB data from MNR areas, as shown in ROD Figure 18 (EPA 2014),[16] were used to estimate future (post-remedial action) variance in order to determine the number of composite samples to collect. The goal was to develop a sample design expected to yield a relative

[16] It is acknowledged that the remedial boundaries and technology assignments portrayed in ROD Figure 18, titled *Selected remedy*, are likely to change following design. Thus, any reference to MNR, ENR, cap, or dredge areas in this report refers to preliminary area designations.

margin of error (RME) for the mean of 25% or less,[17] which would be less than analytical variability[18] following construction of the remedy.

The results of this pre-design sampling event generally met these RME goals; however, since the remedy is not yet implemented, higher COC concentrations resulted in the RME goals being exceeded in some cases. The target RME was met for total PCBs and arsenic; the target RME was met for cPAHs when the highest toxic equivalent (TEQ) was excluded and for dioxins/furans when the two highest TEQs were excluded (Table 2-1).

The composite with the highest cPAH TEQ (Comp-2 with 742 µg/kg) was composed of samples collected between river mile (RM) 0.1 and RM 0.25. This area had two surface sediment samples in the RI/FS and post-FS datasets with remedial action level (RAL) exceedances for cPAHs and other polycyclic aromatic hydrocarbons (PAHs).

The composite sample with the highest dioxin/furan TEQ was Comp-11 (27.7 ng/kg), located waterway-wide from RM 1.4 to RM 1.6 (including Glacier Bay). This area had 17 surface sediment samples in the RI/FS and post-FS datasets with RAL exceedances for dioxin/furan TEQs, with a maximum exceedance factor (EF) of 84. The second highest dioxin/furan TEQ was detected in Comp-6 (22.5 ng/kg), located between RM 0.6 and RM 0.9 in the center of the waterway; this area did not have any locations with dioxin/furan TEQ RAL exceedances in the RI/FS or post-FS datasets.

The study design was based on post-remediation expectations for total PCBs in the LDW, since the other COCs were expected to have similar characteristics. The composite samples were expected to be normally distributed, with mean and variance estimates resulting in the target RME. The baseline results indicated that these statistical properties were met or nearly met for all four risk drivers. With the exception of one or two influential composites, each baseline LDW dataset was well-behaved (i.e., normally distributed) and had variability that was similar to or better than the assumed variability used in developing the sampling design. Following remediation, any skewness in the baseline datasets is expected to be reduced.

The baseline surface sediment composite data met DQOs 1 and 2 by providing a dataset suitable to use to calculate site-wide 95UCLs (DQO 1) and SWACs (DQO 2). The post-remediation target RME was met for total PCBs and arsenic and nearly met for cPAHs and dioxins/furans. Thus, the baseline sediment sampling design is expected to meet the target RME in post-remediation monitoring events.

[17] The expectation of a 25% RME or less for the mean was based on a normal distribution and a coefficient of variation of 0.7, or less, for the composite sample dataset.

[18] The analytical precision required by the US Environmental Protection Agency (EPA) functional guidelines for the analytical methods typically used in sediment characterization ranges from 20 to 50%, comparable to a range of 16 to 42% for RME as defined for this project.

2.1.2 Composite sample interpretation

The baseline site-wide 95UCLs calculated from the composite results are provided in Table 2-2; those for total PCBs and dioxin/furan TEQs are one to two orders of magnitude greater than the ROD site-wide cleanup levels for RAO 1 (human seafood consumption) (EPA 2014). RAO 1 cleanup levels were not derived for arsenic or cPAHs, because human health risk was dominated by consumption of clams for these risk drivers, and the data collected during the RI/FS showed little relationship between sediment concentrations of arsenic and cPAH and concentrations in clam tissues. For direct contact (netfishing), the site-wide 95UCLs for total PCBs, cPAHs, and dioxins/furans were all below RAO 2 site-wide cleanup levels in the ROD. Arsenic was the only COC with a 95UCL above the RAO 2 site-wide cleanup level. For RAO 4 (risk to otter), the baseline site-wide 95UCL for total PCBs was above the ROD cleanup level.

Table 2-2. Baseline site-wide 95UCL compared to ROD cleanup levels

COC	Unit	Site-wide 95UCL[a]	ROD Cleanup Levels and Basis		
			RAO 1: Human Seafood Consumption	RAO 2: Human Direct Contact - Netfishing	RAO 4: Ecological (River Otter)
Total PCBs	µg/kg	209	2 (natural background)	1,300 (RBTC)	128 (RBTC)
cPAH TEQ	µg/kg	226	na	380 (RBTC)	na
Dioxin/furan TEQ	ng/kg	11.6	2 (natural background)	37 (RBTC)	na
Arsenic	mg/kg	13.1	na	7 (natural background)[b]	na

[a] 95UCL derived using the best-fit distribution as determined by distributional evaluation. Details provided in Appendix B.

[b] See Appendix B for further discussion of the statistical basis for natural background.

95UCL – 95% upper confidence limit (on the mean)
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
Ecology – Washington State Department of Ecology
na – not applicable
OSV – ocean survey vessel
PCB – polychlorinated biphenyl
RAO – remedial action objective
RBTC – risk-based threshold concentration
ROD – Record of Decision
SCO – sediment cleanup objective
SMS – Washington State Sediment Management Standards
TEQ – toxic equivalent
UTL - upper tolerance limit

DQO 2 required calculation of a SWAC to serve as a baseline for comparison to pre-EAA conditions (FS SWAC), as well as post-EAA predictions based on the BCM immediately following and five years after the completion of EAA remedies. Table 2-3 and Figure 2-1 present the calculated and predicted SWACs in chronological order. The FS dataset included samples collected over an approximately 20-year period for a variety of purposes from locations that were clustered in areas that were targeted for investigation (i.e., not evenly distributed). There is uncertainty around the BCM predictions as discussed in the FS (AECOM 2012). The BCM SWACs presented in Table 2-3 and Figure 2-1 represent the base case condition.

Table 2-3. Comparison of FS-interpolated, BCM-predicted, and baseline composite LDW-wide SWACs for 0–10-cm sediments

COC	Units	FS SWAC	BCM-predicted SWAC Year 0 Post-EAA	LDW Baseline SWAC	BCM-predicted SWAC Year 5 Post-EAA
Total PCBs	µg/kg	346	180	172	103
cPAH TEQ	µg/kg	388	360	147	220
Dioxin/furan TEQ	ng/kg	24.6	24	8.33	13
Arsenic	mg/kg	15.6	16	11.6	12

BCM – bedload composition model
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EAA – early action area
FS – feasibility study
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

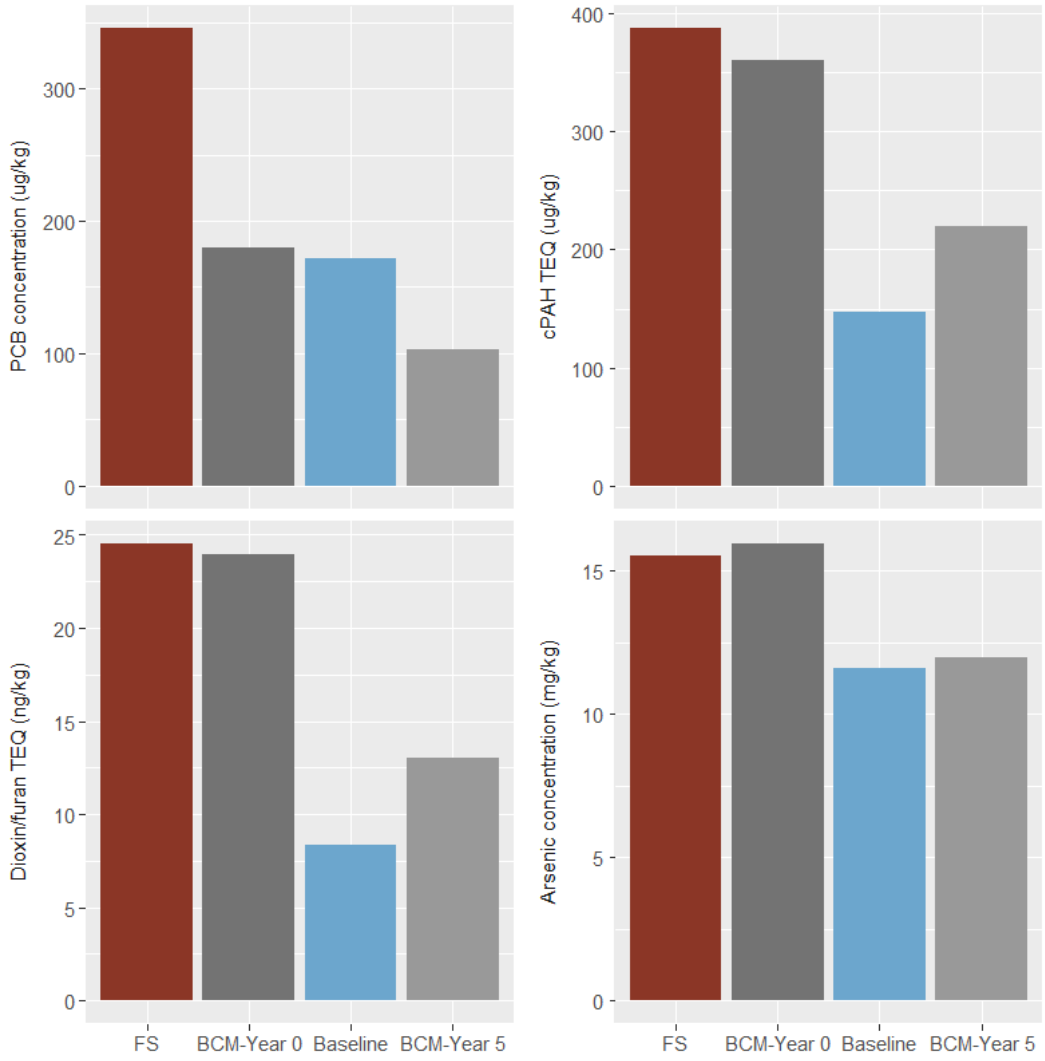


Figure 2-1. Baseline SWACs for total PCBs, cPAH TEQ, dioxin/furan TEQ, and arsenic compared to FS SWAC and BCM-predicted SWACs for Years 0 and 5

Baseline samples for this investigation were collected in 2017, approximately two to five years following the completion of The Boeing Company (Boeing) Plant 2/Jorgensen Forge, Slip 4, and Terminal 117 (T-117) EAAs, so the baseline SWACs were compared to the BCM-predicted SWACs at Years 0 and 5 post-EAA. Note that the RI/FS dataset used to calculate the pre-EAA SWAC in the FS included pre-remediation data for Duwamish/Diagonal (even though the remediation had been completed in 2005); therefore, 13 years had elapsed since that remedy had been completed.

The baseline SWACs for total PCBs were similar to the BCM-predicted SWAC for post-EAA conditions following construction (Year 0). The baseline cPAH and dioxin/furan TEQ SWACs were lower than both Year 0 and 5 post-EAA BCM predictions. The dioxin/furan SWACs calculated for the FS were based on Thiessen polygons, because fewer data were available; thus, the dioxin/furan BCM-predicted SWACs were more uncertain than those calculated for the other risk drivers. The baseline arsenic SWAC was slightly lower than the BCM-predicted SWAC for Year 5 post-EAA remediation. Thus, in general, the SWACs were as expected based on the BCM modeling, with the exception of the SWAC for cPAHs, which was lower than expected. The reason that cPAH SWAC was lower than expected is unknown; it could be due to a combination of factors, including the 20-year age range in the RI/FS dataset and decreases in lateral and upstream inputs of cPAHs to the LDW resulting from source control (see Section 8).

Baseline surface sediment composite results are presented in Maps 2-2 through 2-5 and discussed below for each risk driver.

2.1.2.1 Total PCBs

Total PCB concentrations in the baseline composite samples were less than 240 µg/kg between RM 3 and RM 5 (Map 2-2). The baseline composite samples in the rest of the LDW ranged from 93.4 to 429 µg/kg. Remediation of three EAA areas (Duwamish/Diagonal, Slip 4 and Boeing Plant 2/Jorgensen Forge) has reduced surface sediment total PCB concentrations in the vicinity of the remediated EAA areas.

2.1.2.2 cPAH TEQs

The spatial distribution of sediment cPAH TEQs in the baseline composite samples was similar to the spatial distribution of the total PCB concentrations. The lowest cPAH TEQs were reported for sediment composites between RM 3 and RM 5 (Map 2-3). All of the cPAH TEQs in this area were less than 100 µg/kg. The cPAH TEQs in the rest of the LDW ranged from 64.3 to 742 µg/kg.

2.1.2.3 Dioxin/furan TEQ

The dioxin/furan TEQs were lowest between RM 2.5 and RM 5; all dioxin/furan TEQs in this reach were less than 5 ng/kg (Map 2-4). The dioxin/furan TEQs in the rest of the LDW ranged from 4.98 to 27.7 ng/kg. The highest dioxin/furan TEQ included samples

from within Glacier Bay, which had the highest dioxin/furan TEQs in the RI/FS dataset.

2.1.2.4 Arsenic

The composite sediment arsenic concentrations had a different spatial distribution than did the other COCs, in that the highest arsenic concentration (27.2 mg/kg) was reported for the composite from RM 3.7 to RM 4.0 (Map 2-5). The arsenic concentrations throughout the rest of the site were all less than 20 mg/kg.

2.2 INDIVIDUAL SURFACE SEDIMENT (0–10-CM) SAMPLES

2.2.1 DQOs and Data Collected

Per the sediment QAPP (Windward 2018d), 20 individual grab samples were collected within the MNR areas shown in ROD Figure 18 (EPA 2014). Ten were collected at re-occupied RI/FS locations and 10 were collected at random locations within MNR areas. All 20 samples were analyzed individually for RAO 3 COCs to address DQOs 3 and 4:

- **Sediment DQO 3:** Compare (on a point-by-point basis) concentrations in baseline samples collected from within MNR areas to the (benthic) cleanup levels presented in ROD Table 20.[19]
- **Sediment DQO 4:** Support the evaluation of site-wide trends and comparison of concentrations to predicted natural recovery in MNR areas.

Individual grab samples were collected in February/March 2018. Sample locations from the RI (Windward 2010a) that were re-occupied met the QAPP re-occupation specifications (Windward 2018d). The data validation determined that there were no data quality issues that would limit the use of the data to meet DQOs 3 and 4.

2.2.2 Individual sample interpretation

2.2.2.1 Comparison to SMS and historical data

Of the 20 grab samples collected within the MNR areas[20] (Map 2-6), 11 had no exceedances of ROD RAO 3 cleanup levels (i.e., Washington State Sediment Management Standards [SMS] benthic sediment cleanup objective [SCO]), 3 had exceedances of the benthic SCO for total PCBs, and 6 had exceedances of the benthic SCO for benzyl alcohol (Table 2-4).[21] Benzyl alcohol exceedances of the benthic SCO were more common in sediment samples analyzed after the RI/FS than in the RI/FS

[19] MNR areas are preliminary because remedial boundaries and technology assignments portrayed in ROD Figure 18 (EPA 2014) are likely to change during remedial design.

[20] Concentrations within MNR areas are not necessarily expected to meet natural recovery predictions during baseline sampling because the projections are for 10 years post-remedy.

[21] Benzyl alcohol is a non-persistent chemical with several potential sources, including natural sources associated with plant material such as blackberries (EC 2002).

dataset. It is likely that changes in analytical techniques have resulted in the apparent increase in benzyl alcohol concentrations (Fourie and Fox 2016). In addition, a recent review of the available sediment toxicity data for benzyl alcohol conducted by the US Army Corps of Engineers (USACE) suggests that the benthic toxicity threshold for benzyl alcohol is much higher than the current benthic SCO (Fourie and Fox 2016).

Table 2-4. RAO 3 COC results for individual locations within the MNR areas

Sample Location	RM	RI Location	Year	Estimated Net Sedimentation (cm/year)[a]	Historical Benthic SCO Exceedances	Baseline Benthic SCO Exceedances
Random MNR locations						
8	0.1	na	na	> 1–2	na	ne
23	0.5	na	na	> 1–2	na	ne
40	0.7	na	na	> 0.5–1.0	na	total PCBs > SCO
52[b]	0.9	na	na	> 1–2	na	total PCBs > SCO
69	1.4	na	na	> 1–2	na	benzyl alcohol > SCO
91	2.1	na	na	na	na	total PCBs > SCO
101	2.4	na	na	> 3	na	benzyl alcohol > SCO
130	3.5	na	na	> 3	na	benzyl alcohol > SCO
143	4.1	na	na	> 3	na	ne
161	4.7	na	na	> 3	na	ne
Re-occupied RI/FS stations						
169[c]	0.3	DR005	1998	1–2	BEHP, BBP > SCO	ne
170	0.6	DR010	1998	1–2	BEHP > SCO	ne
174	0.7	WIT288	1997	> 0.5–1.0	total PCBs > SCO	ne
178	1.6	DR092	1998	2–3	phenol > SCO	benzyl alcohol > SCO
179[c]	2.1	DR111	1998, 2004	2–3	2,4-dimethyl phenol, benzyl alcohol > SCO	benzyl alcohol > SCO
183	1.9	DR155	1998	2–3	BEHP > CSL	benzyl alcohol > SCO
184[c]	3.0	WIT270	1997	≤ 0.5	total PCBs > SCO	ne
186	3.9	DR258	1998	> 0.5–1.0	BBP> SCO	ne
187	3.7	R20	1997	≤ 0.5	total PCBs > SCO	ne
188	5.0	DR276	1998	> 3	acenaphthene> SCO	ne

[a] Estimated annual net sedimentation rate from FS (Figure 2-11) (AECOM 2012).

[b] Sample location was revised and the revised location was in an area designated for capping (i.e., not an MNR area).

[c] Baseline sample was collected more than 10 ft from target location. Sample location was within the acceptable distance from the target specified in the QAPP (Windward 2018d).

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
PCB – polychlorinated biphenyl
QAPP – quality assurance project plan

CSL – cleanup screening level
FS – feasibility study
na – not applicable
ne – no detected exceedances
MNR – monitored natural recovery
RAO – remedial action objective
RI – remedial investigation
RM – river mile
SCO – sediment cleanup objective
SMS – Washington State Sediment Management Standards

Historical samples were collected at 10 baseline individual sample locations in 1997 and 1998, with 1 location re-sampled in 2004 (Table 2-4). Thus, baseline sampling to reoccupy these historical locations with benthic SCO exceedances (Map 2-10) occurred approximately 20 years after the original sampling. The FS-estimated net sedimentation rates for these locations ranged from less than 0.5 cm / year to greater than 3 cm / year (AECOM 2012). Therefore, significant amounts of sediment would be expected to have been deposited at these locations in the 20 years since they were last sampled.

Locations of the 10 re-occupied RI / FS locations are shown on Map 2-6 (Windward 2010a; AECOM 2012).[22] The historical and baseline total PCB concentrations for the re-occupied locations in MNR areas are provided in Table 2-5. Baseline total PCB concentrations were generally similar to or less than historical total PCB concentrations. Four locations had substantial (> 50%) decreases in total PCB concentrations (green rows of Table 2-5), and two locations had substantial (> 50%) increases (orange rows of Table 2-5). None of the baseline total PCB concentrations exceeded the benthic SCO at these locations.

Table 2-5. Total PCB results for re-occupied locations

Sample Location	RM	Reoccupied RI Location	Year	Estimated Net Sedimentation (cm/year)[a]	Historical Total PCB Concentration (µg/kg)	Baseline Total PCB Concentration (µg/kg)
169[b]	0.3	DR005	1998	1–2	168	201.8
170	0.6	DR010	1998	1–2	74	56.3 J
171	0.6	DUD040	1995	1–2	620	162.9
174	0.7	WIT288	1997	> 0.5–1.0	340	49.1 J
178	1.6	DR092	1998	2–3	64	242.4
179[b]	2.1	DR111	1998, 2004	2–3	311 (1998), 176 (2004)	122.6
183	1.9	DR155	1998	2–3	18	197.3
184[b]	3.0	WIT270	1997	≤ 0.5	100	102.4 J
186	3.9	DR258	1998	> 0.5–1.0	62	56.5 JN
187	3.7	R20	1997	≤ 0.5	170	65.3
188	5.0	DR276	1998	> 3	32	18.0 U

Green shaded rows indicate a decrease of more than 50% in the baseline sample compared to RI/FS sample.
Orange shaded rows indicate an increase of more than 50% in the baseline sample compared to RI/FS sample.

[22] These 20 locations were re-occupied for the sediment DQO 3 evaluation in MNR areas and the PCB porewater investigation (sediment DQO 5). The PCB porewater investigation reoccupied RI / FS locations throughout the LDW to provide a range of PCB concentrations.

[a] Estimated annual net sedimentation rate from FS (Figure 2-11) (AECOM 2012).

[b] Baseline location was more than 10 ft away from target location. Sample location was within the acceptable distance from the target specified in the QAPP (Windward 2018d).

FS – feasibility study
J – estimated concentration
JN – tentative identification and estimated concentration
N – tentative identification
na – not applicable
PCB – polychlorinated biphenyl
QAPP – quality assurance project plan
RI – remedial investigation
RM – river mile
U – not detected at given concentration

The results for the re-occupied locations are consistent with the results presented in the *Recovery Category Recommendations Report* (Integral et al. 2018). The *Recovery Category Recommendations Report* included a chemical trend evaluation based on the re-occupation of 111 RI/FS locations (Windward 2010a; AECOM 2012). Concentration trends were evaluated for total PCBs, cPAH TEQ, arsenic, and bis(2-ethylhexyl)phthalate (BEHP). Specifically, the concentrations were generally lower than or similar to the RI/FS results.

2.2.2.2 Comparison of PCB Aroclor and congener data

Per the QAPP (Windward 2018d), total PCBs based on detected Aroclor sums were compared with total PCBs based on detected congener sums from the same sample. This comparison was done to evaluate whether the two totals appeared to be reliably correlated, or whether detectable systematic bias existed for one method to over- or under-estimate the total PCB concentration.

The sediment samples selected for the Pre-Design Studies PCB porewater investigation were analyzed for PCB congeners as well as PCB Aroclors (Map 2-7). The paired sediment data are plotted relative to the 1:1 line (indicating perfect agreement) in Figure 2-2. The congener and Aroclor-based total PCB sums were consistent with one another throughout the concentration range of the samples,[23] although the total PCB concentration calculated as the sum of the Aroclors consistently over-predicted the concentration calculated as the sum of the congeners (Figure 2-3).

[23] The ordinary least squares regression line provides a good fit with $R^2 = 0.99$, and 95% confidence interval for the slope [1.1, 1.3].

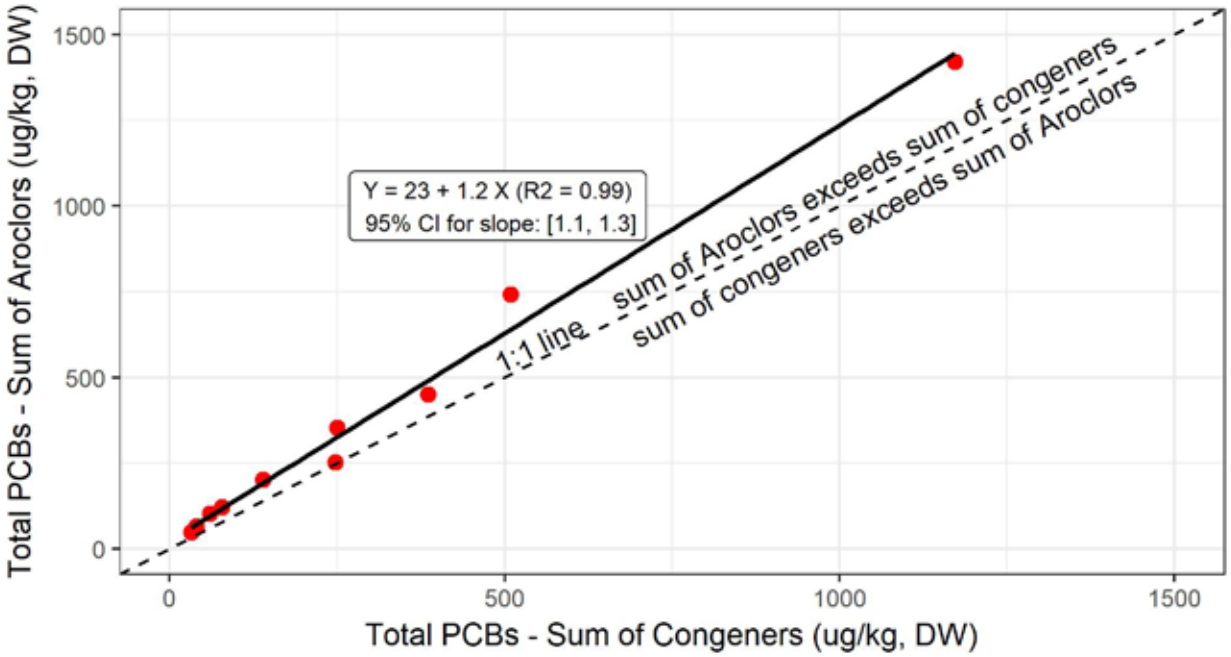


Figure 2-2. Comparison of total PCB concentrations as a sum of Aroclors vs. a sum of congeners for Pre-Design Studies samples (n=10)

The Pre-Design Studies data were also compared to two other available datasets (Windward and Integral 2018b) with PCB congener and Aroclor data for the same samples (Map 2-7). The paired sediment data were plotted relative to the 1:1 line, and the analytical variance around the 1:1 line was estimated based on the accuracy limits for the PCB Aroclor analysis of 50 to 120% (Figure 2-3). The Pre-Design Studies results were consistent with the USACE dataset; the sum of the Aroclors tended to over-estimate the sum of the PCB congeners. In contrast, the sum of the Aroclors both over- and under-predicted the sum of congeners for the South Park Marina dataset, which represents an intensive sampling effort in a small area within the LDW (Map 2-7).

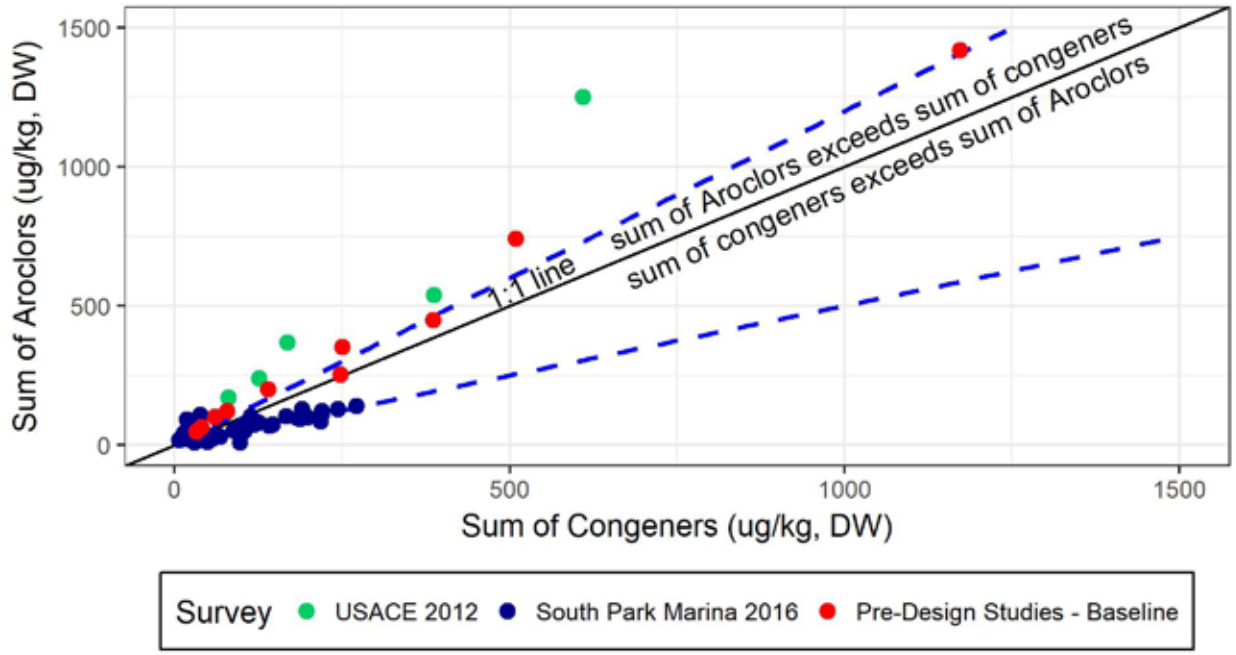


Figure 2-3. Comparison of total PCB concentrations based on Aroclor and congener sums for data from various studies

The apparently different trend exhibited by the South Park Marina dataset may be attributable to different laboratories, different composition of the PCB mixtures, or other factors. Both the USACE and Pre-Design Studies data indicate that the results for the two methods are correlated and the differences are within the analytical variance of the methods. The sum of Aroclors tends to be higher than the sum of PCB congeners and would be more conservative for remedial design decision making and long-term monitoring.

2.3 INTERTIDAL COMPOSITE SURFACE SEDIMENT (0–45-CM) SAMPLES

This section presents the results and interpretation of 0–45-cm sediment samples collected in potential clamming and beach play areas for comparison to RAO 2 direct contact cleanup levels.

2.3.1 Potential clamming areas

2.3.1.1 DQOs and Data Collected

Per the sediment QAPP (Windward 2018d), three 0–45-cm site-wide clamming area composite samples were collected and analyzed for human health direct contact (RAO 2) risk drivers to address the following DQOs:

- **Sediment DQO 7:** Establish baseline 95UCL concentrations of human health risk drivers for RAO 2 across all potential clamming areas identified in the ROD (EPA 2014).

- **Sediment DQO 8:** Establish baseline site-wide potential clamming area mean concentrations to assess trends following sediment remediation for RAO 2 (direct contact – clamming) risk drivers.

Sampling was conducted in June 2018, and the data required to calculate the 95UCLs and site-wide potential clamming area mean concentrations were collected and analyzed as specified in the QAPP (Windward 2018d). The data validation did not identify any data quality issues that would limit the use of the data to meet these DQOs.

Three site-wide composite samples developed from 68 individual grab samples each (for a total of 204 individual grab samples) were created to characterize the site-wide intertidal clamming area sediments (Map 2-8). The locations sampled for the potential clamming area composites were randomly selected within the clamming areas and systematically assigned to one of the three composites (Map 2-8). The results for each composite sample represent independent estimates of the site-wide mean concentration.

The composite samples were analyzed for RAO 2 risk drivers (total PCBs, cPAHs, dioxins/furans, and arsenic) as well as toxaphene, which is identified in ROD Table 14 as a direct contact contaminant of potential concern (COPC) (EPA 2014).[24]

The 95UCLs for the clamming area sediments had high RMEs, with values greater than 25% for all risk drivers (Table 2-6). A 25% target RME was not a stated goal for the clamming area sediments, due to a lack of data from which variance could be estimated in the study design. The variance information obtained in the Pre-Design Studies will be useful in future monitoring efforts to establish a study design with RME targets in mind, although variance in intertidal sediment is predicted to decrease significantly following the remedy.

Table 2-6. Summary statistics in potential clamming areas for intertidal (0–45-cm) sediment composites

COC	Units	Mean[a]	95UCL[b]	RME
Total PCB	µg/kg	617	1,690	174%
cPAH TEQ	µg/kg	381	913	139%
Dioxin/furan TEQ	ng/kg	33.6	85.5	154%
Arsenic	mg/kg	10.7	14.0	31%

[a] The mean of the three site-wide composite samples.

[b] 95UCL calculated using the t-interval (degrees of freedom = 2) for the clamming area composites. Note that these estimates do not use the homogenization duplicates taken for clamming area composite sample 1 (LDW18-IT45-CL-Comp1).

95UCL – 95% upper confidence limit (on the mean)
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RME – relative margin of error
TEQ – toxic equivalent

[24] ROD Table 14 is titled *Summary of COPCs and Rationale for Selection as COCs for Human Health Exposure Scenarios.*

Sampling variability included analytical variance, homogenization variance, and spatial field variance. Field variability was expected in the baseline composites because the clamming areas included areas with elevated COC concentrations that will require active remediation.[25] For example, Trotsky Inlet sediment has some of the highest total PCB concentrations in the LDW. Composite 2 contained a subsample collected near the head of the inlet, where the highest total PCB concentrations in LDW surface sediment (up to 2,900,000 µg/kg) and elevated cPAH TEQ and dioxin/furan TEQs have been reported (AECOM 2012). Composite 2 had a much higher total PCB concentration and cPAH and dioxin/furan TEQs than did the other two composites (Table 2-7).

Table 2-7. Individual intertidal (0–45-cm) sediment composites results for LDW-wide clamming areas.

Sample ID	Total PCB (µg/kg)	cPAH TEQ (µg/kg)	Dioxin/Furan TEQ (ng/kg)	Arsenic (mg/kg)
LDW18-IT45-CL-Comp1	239	388 J	15.3 J	11.8 J
LDW18-IT45-CL-Comp2[a]	1,350 JN	693	69.1 J	11.8 J
LDW18-IT45-CL-Comp3	261 J	61.4	16.3 J	8.35 J

[a] Composite 2 received sediment from interior of Trotsky Inlet.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
ID – identification
J – estimated concentration
JN – tentative identification and estimated concentration
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

The use of composite samples to characterize LDW-wide clamming areas required an assessment of the variance in the homogenized sediment samples. The homogenization variance was assessed by subsampling the compositing trays for Composite 1 (LDW18-IT45-CL-Comp1) three times for a triplicate analysis of cPAHs and PCBs (and total organic carbon [TOC]). Following homogenization of the 68 individual grab samples, approximately equal volumes of sediment were transferred onto two stainless steel baking trays. A 30-square grid was created and equal aliquots of the homogenized sediment were collected from each grid square to fill the analytical sample jars. This process was repeated a total of three times using the same 30-square grids on the two trays to produce the triplicate samples. Using variance components analysis (Appendix B), a relative comparison of the variance among these triplicates to the variance among all clamming area composite samples provided an indication of how effectively the clamming area sediments were homogenized. For total PCBs, the variability among homogenization triplicates was less than 1% of the total variance (CV = 128%), indicating good consistency within the composite tray for this analyte. For cPAHs, variability among homogenization triplicates was 31% of the total variance (CV = 116%). The TOC results were more homogeneous, with a total variance of 23%; and the variability among homogenization triplicates was 49% of the total variance. The greater variability among homogenization triplicates observed for cPAHs likely reflects

[25] Although preliminary, Figure 18 of the ROD indicates active remediation may be required in 12 of the 15 clamming subareas, including Trotsky Inlet.

the many different matrices that PAHs are associated with, including petroleum products, coal particulates, soot particles, and creosote products, all of which may be difficult to completely homogenize within the sample.

The potential clamming area composite data met DQOs 7 and 8. The data allowed the calculation of the site-wide 95UCL (DQO 7) and the site-wide mean (DQO 8). The RME values were high because of variability in the intertidal sediment prior to remediation. The highest variance was seen for cPAHs, which were also variable in the homogenization replicates, potentially reflecting the fact that PAHs are associated with a range of matrices.

2.3.1.2 Intertidal potential clamming area sample interpretation

DQO 7 required a comparison of the 95UCL of the three site-wide potential clamming area composite samples with RAO 2 cleanup levels. DQO 8 required calculation of a mean to represent baseline conditions. The mean and 95UCL values for all four COCs were above the cleanup levels in the ROD (Table 2-8) (EPA 2014). In addition, the samples were analyzed for toxaphene, which was identified as a direct contact contaminant of potential concern in the ROD (Table 14) (EPA 2014).

Table 2-8. Summary of means and 95UCLs in potential clamming areas for intertidal (0–45-cm) sediments

COC	Unit	Clamming Areas Site-wide		ROD Cleanup Level for Human Direct Contact in Intertidal Clamming Areas
		Mean	95UCL[a]	
Total PCBs	µg/kg dw	617	1,687	500 (RBTC)
cPAH TEQ	µg/kg dw	381	913	150[b] (RBTC)
Dioxin/furan TEQ	ng/kg dw	35	88	13 (RBTC)
Arsenic	mg/kg dw	10	13	7 (natural background)
Toxaphene	µg/kg dw	24.7 U	na	na

[a] 95UCL calculated using the t-interval (degrees of freedom = 2) for the three clamming area composites. See Appendix B for details.

[b] EPA has revised the cPAH slope factor. The RBTC using the revised slope factor is 1,080 µg/kg and the risk associated with cPAHs due to direct contact for clamming is less than 1 x 10^{-6}.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
COC – contaminant of concern
dw – dry weight
EPA – US Environmental Protection Agency
na – not applicable
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
ROD – Record of Decision
TEQ – toxic equivalent
U – not detected at given concentration

Total PCBs

The 95UCL for total PCBs in the potential clamming area sediments was 1,690 µg/kg, more than three times the RAO 2 cleanup level. However, two of the three area-wide composite samples had total PCB concentrations below the RAO 2 cleanup level (239

and 261 µg/kg, compared to 500 µg/kg).[26] The third composite had a total PCB concentration of 1,350 µg/kg, which increased variance and the 95UCL. As discussed, this composite (LDW18-IT45-CL-Comp2) included sediment collected from the head of Trotsky Inlet, the area with the highest sediment total PCB concentrations in the LDW.

cPAH TEQs

The 95UCL for the cPAH TEQ in clamming area sediments was 913 µg/kg. This value was above the RAO 2 cleanup level for cPAHs of 150 µg/kg, but less than the updated risk-based threshold concentration (RBTC) of 1,080 µg/kg, based on the updated 2017 benzo(a)pyrene slope factor (EPA 2017).[27]

The three composite samples had cPAH TEQs of 61.4, 388, and 693 µg/kg. The variability of the composite results reflected the high spatial variability of PAHs in the clamming subareas, as well as variance observed in the homogenization of these samples (as discussed above).

Dioxin/Furan TEQ

The 95UCL for the dioxin/furan TEQ in clamming area sediments was 85.5 ng/kg, more than six times the RAO 2 cleanup level of 13 ng/kg. The clamming area composites had dioxin/furan TEQs of 15.3, 16.3, and 69.1 ng/kg. The composite with the highest TEQ included sediment collected from areas with high dioxin/furan TEQs, such as Trotsky Inlet. Subsamples from this area, as well as from other areas with high dioxin/furan TEQs, like the Glacier Bay, are likely responsible for the variability observed in the clamming area composite samples, which increased the 95UCL.

Arsenic

The 95UCL for arsenic in clamming area sediments was 13 mg/kg, which is greater than the RAO 2 background-based cleanup level of 7 mg/kg. The arsenic concentrations of the three LDW site-wide composite samples were 8.35, 11.8, and 11.8 mg/kg, with a grand mean of 10.7 mg/kg.

Toxaphene

Toxaphene was not detected in any of the three clamming area composite samples with a reporting limit (RL) of 25 µg/kg.

[26] Because each clamming area composite result is an estimate of the site-wide mean, it is also appropriate to discuss individual composite results relative to cleanup levels.

[27] Implications of the updated 2017 benzo(a)pyrene slope factor will be further explored in a memorandum in early 2019.

2.3.2 Intertidal beach play areas

2.3.2.1 DQOs and data collected

Per the sediment QAPP (Windward 2018d), eight intertidal beaches were sampled. Beach-specific composite samples were analyzed for RAO 2 risk drivers (total PCBs, cPAHs, dioxins/furans, and arsenic)[28] to address DQOs 9 and 10:

- **Sediment DQO 9:** Establish baseline 95UCL concentrations for risk drivers to achieve RAO 2 in each of the eight beach play areas.
- **Sediment DQO 10:** Establish baseline beach play area-specific mean concentrations to assess trends following sediment remediation for RAO 2 risk drivers.

Sampling was conducted in June 2018, and the data required to calculate the 95UCLs for each of the eight intertidal beach areas were collected and analyzed as specified in the sediment QAPP (Windward 2018d). The data validation determined that there were no data quality issues that would limit the use of the data to meet these DQOs.

Baseline conditions within each of the eight beach play areas were characterized using three composite samples from the 0–45-cm sediment depth for each beach play area (Map 2-9). The number of individual grab samples per composite within each beach play area was roughly proportional to the size of each beach play area, varying from 9 individual grab samples (3 per composite) to 27 individual grab samples (9 per composite). Concentrations in each composite sample represented the mean concentration at each beach; thus, the three composites were independent estimates of the beach-wide mean, capturing small-scale spatial variability as well as sampling and analytical error. The variance among the composite sample concentrations was used to calculate the 95UCL by beach.

Similar to clamming area sediments, there was no sampling variance goal set because sufficient previous data were not available to develop *a priori* variance estimates to use in development of the study design. Summary statistics for the beach composites are provided in Table 2-9.

[28] Toxaphene was also analyzed in the samples.

Table 2-9. Summary statistics for beach play area (0–45-cm) sediment composites

Area	Total PCBs (µg/kg)			cPAH TEQ (µg/kg)			Dioxin/Furan TEQ (ng/kg)			Arsenic (mg/kg)		
	Mean	95UCL[a]	RME	Mean	95UCL[a]	RME	Mean	95UCL[a]	RME	Mean	95UCL[a]	RME
Beach 1	120	445	271%	169	600	255%	1.61	2.38	48%	14.7	37.9	158%
Beach 2	102	179	75%	276	696	152%	15.7	40.7	159%	44.7	73.2	64%
Beach 3	110	396	260%	100	325	225%	4.37	14.3	227%	4.01	6.31	57%
Beach 4	359	815	127%	45	93.4	108%	30	125	317%	6.24	11.8	89%
Beach 5	114	214	88%	1,150	5,310	362%	5.29	7.87	49%	8.74	17.5	100%
Beach 6	561	1,580	182%	1,343	1,650	23%	13.2	31.7	140%	44.6	96.8	117%
Beach 7	65.2	160	145%	43	63.4	47%	2.13	2.69	26%	5.44	7.97	47%
Beach 8	123	302	146%	108	232	115%	4.05	6.86	69%	7.72	13	68%

[a] 95UCL calculated using Chebyshev's inequality for the three beach composites. See Appendix B for details.

95UCL – 95% upper confidence limit (on the mean) PCB – polychlorinated biphenyl TEQ – toxic equivalent
cPAH – carcinogenic polycyclic aromatic hydrocarbon RME – relative margin of error

At two of the beach areas (Beach 1 and Beach 6), field duplicate samples were collected for each composite. Two samples were collected at each individual grab sampling location so that each composite sample had an associated field duplicate composite created using samples from the same hole as the parent sample. The relative variability (expressed as coefficient of variation [CV]) observed between the parent samples and the field duplicates is an important part of the sampling variance. The CV values between parent samples and field duplicates are provided in Table 2-10.

Table 2-10. Relative variability of field duplicates for beach area composites

Sample	Total PCBs CV	cPAH TEQ CV	Dioxin/Furan TEQ CV	Arsenic CV
Beach 1				
LDW18-IT45-B1-Comp1	20%	83%	61%	76%
LDW18-IT45-B1-Comp2	18%	19%	19%	24%
LDW18-IT45-B1-Comp3	25%	16%	7%	64%
Beach 6				
LDW18-IT45-B6-Comp1	14%	107%	30%	19%
LDW18-IT45-B6-Comp2	7%	54%	25%	19%
LDW18-IT45-B6-Comp3	1%	47%	76%	49%

cPAH – carcinogenic polycyclic aromatic hydrocarbon
CV – coefficient of variation (standard deviation/mean)
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

The variability between field duplicates for total PCBs was relatively low for both beaches (< 25%). There was more variability for the other analytes—the greatest CVs were observed for cPAH TEQ. The observed variability in the field duplicates included spatial variance within the sampling locations, homogenization variance, and analytical variance. The spatial variance would be expected to be reduced following construction of the remedy.

The beach play area composite data met DQOs 9 and 10. The data were sufficient to calculate the 95UCL for each beach (DQO 9) and the mean concentrations for each beach (DQO 10). The RME values were high because of variability in the intertidal sediment prior to remediation. The highest variance was for cPAHs, which were also variable in the field duplicates, potentially reflecting the fact that PAHs are associated with a range of matrices.

2.3.2.2 Beach play area sample interpretation

The ROD RAO 2 cleanup levels are compared to the eight individual beach 95UCL values for the four risk drivers in Table 2-11. Mean concentrations of the risk drivers are also presented for each beach and risk driver. These mean concentrations will be relevant when assessing trends with future monitoring data. Based on Figure 18 in the ROD, seven of the eight beach areas may be actively remediated in part or all of the beach.

Table 2-11. Summary of means and 95UCLs in beach play areas for intertidal (0–45-cm) sediments

Area	Cleanup Levels								Risk Drivers Above Cleanup Level
	Total PCBs (µg/kg) 1,700 (RBTC)		cPAH TEQ (µg/kg) 90 and 650 (RBTC)[a]		Dioxin/Furan TEQ (ng/kg) 28 (RBTC)		Arsenic (mg/kg) 7 (natural background)		
	Mean	95UCL[b]	Mean	95UCL[b]	Mean	95UCL[b]	Mean	95UCL[b]	
Beach 1	120	445	169	600	1.61	2.38	14.7	37.9	cPAH TEQ[c,d], arsenic
Beach 2	102	179	276	696	15.7	40.7	44.7	73.2	cPAH TEQ, dioxin/furan TEQ, arsenic
Beach 3	110	396	100	325	4.37	14.3	4.01	6.31	cPAH TEQ[c]
Beach 4	359	815	45	93.4	30.0	125	6.24	11.8	cPAH TEQ[c], dioxin/furan TEQ, arsenic
Beach 5	114	214	1,150	5,310	5.29	7.87	8.74	17.5	cPAH TEQ, arsenic
Beach 6	561	1,580	1,343	1,650	13.2	31.7	44.6	96.8	cPAH TEQ, dioxin/furan TEQ, arsenic
Beach 7	65.2	160	43	63.4	2.13	2.69	5.44	7.97	arsenic
Beach 8	123	302	108	232	4.05	6.86	7.72	13.0	cPAH TEQ[c], arsenic

[a] The ROD RBTC-based cleanup level for cPAH TEQ is 90 µg/kg; the RBTC based on the updated benzo(a)pyrene slope factor (EPA 2017) is 650 µg/kg.

[b] 95UCL calculated using Chebyshev's Inequality (n = 3 all areas).

[c] These beaches exceed the ROD RBTC-based cleanup level (90 µg/kg) but do not exceed the updated cPAH TEQ RBTC (650 µg/kg).

[d] The Beach 1 95UCL calculated with field duplicates (1,504 µg/kg) is greater than the updated cPAH RBTC.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DQO – data quality objective
PCB – polychlorinated biphenyl
RAO – remedial action objective
RBTC – risk-based threshold concentration
ROD – Record of Decision
TEQ – toxic equivalent

The 95UCL values for total PCBs at all eight beaches were below the cleanup level of 1,700 µg/kg. Only one beach had a cPAH TEQ 95UCL (90 µg/kg) less than the ROD cleanup level; however, five of eight beaches had cPAH TEQ 95UCLs less than the cPAH RBTC value (650 µg/kg) based on the updated 2017 benzo(a)pyrene slope factor (EPA 2017). The 95UCL for Beach 1 was 600 µg/kg. However, when the 95UCL was calculated including the field duplicate results, the 95UCL was 1,504 µg/kg, a value greater than the revised cPAH RBTC. The effects of field duplicates on the 95UCLs are discussed in Appendix B. Five of the dioxin/furan TEQ 95UCLs were less than the cleanup level of 28 ng/kg, whereas only one beach had an arsenic 95UCL less than the cleanup level of 7 mg/kg.[29] The beach locations and a list of risk drivers with 95UCLs above cleanup levels are provided on Map 2-9.

Although beach-specific data were presented in the FS (AECOM 2012), baseline data should not be compared to those data for most of the beaches, because the FS 95UCLs were derived using surface sediment samples (0–10 cm), which are not comparable to the 0–45-cm beach composite samples. Two beaches—Beach 1 and Beach 6—were characterized based on 0–45-cm beach composites in the FS, as discussed below. 95UCLs were not derived in the FS because there were not sufficient samples. Therefore, the FS beach composite results and the baseline beach composite results were compared based on the means.

Beach 1

Beach 1 is located between RM 0.1W and RM 0.25W. The mean arsenic concentration for the two FS composite samples (16 mg/kg) was comparable to the mean arsenic concentration for the three baseline beach composite samples (14.7 mg/kg). The mean cPAH TEQ for the two FS composite samples (380 µg/kg) was greater than the mean cPAH TEQ for the three baseline beach composite samples (169 µg/kg). The mean total PCB concentration for the two FS composite samples (56 µg/kg) was less than the mean of the three baseline composite samples (120 µg/kg). The mean dioxin/furan TEQ for the FS samples (2.42 ng/kg) was comparable to the mean of the baseline samples (1.61 ng/kg).

Beach 6

Beach 6 is located north of Slip 4 at RM 2.75W. One FS composite sample was collected for this beach. In this composite, the cPAH TEQ (7,100 µg/kg) and arsenic concentration (94 mg/kg) were greater than the mean cPAH TEQ (1,343 µg/kg) and arsenic concentration (44.6 mg/kg) for the three baseline beach composite samples. The FS composite sample dioxin/furan TEQ (8.99 ng/kg) was less than the mean dioxin/furan TEQ for the three baseline beach composite samples (13.2 ng/kg). The FS composite sample total PCB concentration (860 µg/kg) was greater than the mean total PCB concentration for the baseline beach composite samples (561 µg/kg).

[29] As discussed in Section 8.2, upstream data indicate incoming sediment has arsenic concentrations greater than 7 mg/kg.

2.4 SUMMARY AND KEY POINTS

The baseline sediment dataset met the goals of DQOs 1, 2, 3, and 4 for 0–10-cm surface sediment collected throughout the LDW, and of DQOs 7, 8, 9, and 10 for 0–45-cm intertidal sediment collected from LDW-wide potential clamming areas and beach play areas. This was accomplished by establishing 95UCLs for risk drivers for comparison to cleanup levels and to serve as a baseline for future monitoring.

A summary of the key points for sediment dataset is presented in Table 2-12.

Table 2-12. Summary of key points for baseline sediment investigations

Sample Type	Spatial area evaluated	Chemical	Summary of Key Conclusions
Surface sediment composites (0–10 cm)	LDW-wide SWAC and 95% UCL	Total PCBs	· 95UCL below cleanup level for RAO 2 (netfishing) and above cleanup levels for RAOs 1 and 4 · The SWAC was half of the RI/FS SWAC · SWAC consistent with SWAC predicted using the BCM to characterize post-EAA concentrations
		cPAH TEQ	· 95UCL below cleanup level for RAO 2 (netfishing) · SWAC lower than SWAC predicted using the BCM to characterize post-EAA concentrations
		dioxin/ furan TEQ	· 95UCL below the cleanup level for RAO 2 (netfishing) and above the cleanup level for RAO 1 · SWAC lower than the RI/FS SWAC and the SWAC predicted using the BCM to characterize post-EAA concentrations
		arsenic	· 95UCL above the cleanup level for RAO 2 (netfishing) · SWAC consistent with SWAC predicted using the BCM to characterize post-EAA concentrations
Individual samples (0–10 cm)	Point-based comparisons	SMS	· Out of 20 locations in MNR areas, 9 had RAO 3 benthic SCO cleanup exceedances: 6 for benzyl alcohol and 3 for total PCBs · None of the re-occupied locations had benthic SCO exceedances for the same chemicals that exceeded in the RI/FS samples
		PCB Aroclors and congeners	· Total PCBs calculated as the sum of Aroclors and as the sum of congeners in 20 samples were generally consistent with one another
Potential clamming areas (0–45 cm)	LDW-wide clamming area	total PCBs	· 95UCL above the cleanup level for RAO 2 (clamming) · High variance among composite samples; low homogenization variance
		cPAH TEQ	· 95UCL above the ROD cleanup level for RAO 2 (clamming) but below the RBTC based on the updated benzo(a)pyrene slope factor (EPA 2017) · High variance among composite samples; high homogenization variance
		dioxin/furan TEQ	· 95UCL above the cleanup level for RAO 2 (clamming) · Significant variance among the composite samples; unknown homogenization variance
		arsenic	· 95UCL above the cleanup level for RAO 2 (clamming) · Variance among the composite samples low
Beach play areas (0–45 cm)	Individual beaches (8 beaches)	total PCBs	· None of the 8 beach play areas had 95UCLs greater than the cleanup levels for RAO 2 (beach play)
		cPAH TEQ	· 7 of the 8 beaches had 95UCLs above the ROD cleanup levels for RAO 2 (beach play) · 4 of the 8 beaches had 95UCLs above the RBTC for RAO 2 based on the updated benzo(a)pyrene slope factor (EPA 2017)
		dioxin/furan TEQ	· 3 of the 8 beaches had 95UCLs above the cleanup level for RAO 2 (beach play)
		arsenic	· 3 of the 8 beaches had 95UCLs above the cleanup level for RAO 2 (beach play)

95UCL – 95% upper confidence limit (on the mean)
BCM – bedload composition model
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EAA – early action area
Ecology – Washington State Department of Ecology
LDW – Lower Duwamish Waterway
MNR – monitored natural recovery
PCB – polychlorinated biphenyl
RAO – Remedial Action Objective
RI/FS – remedial investigation/feasibility study
ROD – Record of Decision
SCO – sediment cleanup objective
SMS – Washington State Sediment Management Standards
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

3 Surface Water

This section provides an interpretation of the surface water data collected from August 2017 to September 2018 per the surface water QAPP (Windward 2017b, 2018a).

3.1 DQOs and Data Collected

Per the surface water QAPP (Windward 2017b, 2018a), surface water samples were collected to address the two surface water DQOs:

- **Surface water DQO 1 –** Assess progress toward water quality ARARs as sediment remediation and source control continue.
- **Surface water DQO 2 –** Establish baseline concentrations to be used to assess trends in total PCB concentrations in surface water as sediment remediation and source control continue.

To address each DQO, a different type of surface water sampling was conducted as discussed below.

3.1.1 Composite-grab samples

To address DQO 1, composite-grab samples[30] were collected from two depths at two LDW locations (SW1 at RM 0.75 and SW2 at RM 3.3) and from one depth at one upstream reference location in the Green River (SW3 at RM 10). Samples were collected during eight sampling events that represented a range of conditions in the LDW (i.e., dry season baseflow, wet season baseflow, and storm events of various types; Table 3-1 and Map 3-1). These surface water samples were analyzed for chemicals with water quality criteria listed as ARARs for the LDW.

Table 3-1. Summary of surface water composite-grab sampling events

Event Type	Precipitation	Howard Hanson Dam Release Rates	Event Dates
Dry baseflow (2 events)	3-day antecedent period without measurable rainfall	dry season average conditions (e.g., 200–600 cfs)	August 28, 2017; July 30, 2018
Wet baseflow (2 events)	3-day antecedent period without measurable rainfall	wet season average conditions (e.g., 800–1,200 cfs)	February 22, 2018; April 3, 2018
Storms (4 events)	Storms with ≥ 0.25 or 0.5 in. of rainfall within a 24-hour period. Storms 1, 2, and 3 required a 48-hour antecedent period without heavy rainfall.	Storms 1, 2, and 3 were sampled at flows below the threshold for a significant dam release (< 2,000 cfs). Storm 4 was sampled during a significant dam release (> 2,000 cfs).	September 19, 2017; October 19, 2017; March 8, 2018; April 7, 2018

cfs – cubic feet per second

[30] Each composite-grab sample comprised equal aliquots of four grabs, each collected at least one hour apart.

Surface water composite-grab samples were collected during the targeted eight sampling events from August 2017 to July 2018. For the first three sampling events, composite-grab samples were analyzed for all chemicals for which an ARAR was available. After these first three events, in consultation with EPA, the resulting data were evaluated, and chemicals that were either not detected or had concentrations below ARARs were removed from the analyte list. Based on this review, the analyte list for the remaining five composite-grab sampling events included select metals, PAHs, BEHP, PCB congeners, and conventionals (Windward 2018e). The surface water composite-grab data were validated, and no issues were identified with the data that would limit their use for comparison with ARARs.

Thus, the baseline surface water composite-grab data met DQO 1 by providing a dataset that included samples collected during the targeted range of sampling conditions for comparison with the surface water ARARs.

3.1.2 Passive samplers

To address DQO 2, passive samplers were deployed at two locations (PS2 at RM 1.9 [Linear Logistics] and PS1 at RM 3.3 [South Park Bridge]) in the LDW (Map 3-1) at a depth of 1 m above the bottom for a 30-day period. These passive samplers were used to measure freely dissolved concentrations (C_{free})[31] of total PCBs during the targeted dry season baseflow conditions.

The two passive sampler deployments were conducted in August / September 2017 and July / August 2018. The passive sampler data were validated, and no issues were identified with the data that would limit their use for evaluating trends in total PCBs in surface water. However, one of the nine replicates at PS1 (RM 3.3) in 2018 was rejected because of an issue with the performance reference compounds (PRCs) for this sample (Windward 2018e). The loss of this replicate did not alter the utility of these data to assess trends from baseline because of the conservative study design, as discussed below.

When developing the study design in the Work Plan and surface water QAPP (Windward and Integral 2017b; Windward 2017b, 2018a), data from Apell and Gschwend (2017) were used to make assumptions about the mean, variance, and distribution of total PCB C_{free} concentrations. Although the Apell and Gschwend (2017) dataset was somewhat different than the Pre-Design Studies baseline datasets (e.g., near-surface exposure [rather than near-bottom] and only 27 congeners [rather than all 209 congeners] analyzed) (see Table 3-2), total PCB C_{free} summary statistics from the Apell and Gschwend (2017) study were used to determine the number of replicates to include in the study.

[31] C_{free} is based on PCBs analyzed in the passive samplers. The total PCB concentrations of the passive samplers are used along with partition coefficients to calculate the estimated freely dissolved concentration in LDW surface water.

Table 3-2. Evaluation of passive sampler data

Summary Statistic	Apell and Gschwend (2017) Dataset[a]	Pre-Design Studies Baseline Dataset	
		Aug/Sept 2017	July/Aug 2018
Sample Design Notes			
Station locations	RM 0.9, RM 2.0, and RM 4.7	RM 1.9 (PS2) RM 3.3 (PS1)	RM 1.9 (PS2) RM 3.3 (PS1)
Exposure depth	near-surface	near-bottom	near-bottom
Number of PCB congeners included in total	27	209	209
Count of samples	3 (1 rep per location)	18 (9 reps per location)	17 (8 at PS1[b] and 9 at PS2)
Total PCB C_{free} Summary Statistics			
Mean total PCB C_{free} ($\bar{x}$) (ng/L)	0.327 (sum of 27 congeners)	1.26 (1.25 at PS1 and 1.26 at PS2)	0.99 (1.03 at PS1 and 0.96 at PS2)
SD for total PCB C_{free} (ng/L)	0.081	0.115[c] (0.101 at PS1 and 0.128 at PS2)	0.101[c] (0.115 at PS1 and 0.086 at PS2)
CV = SD / $\bar{x}$	25%	9.2%[d]	10.1%[d]

[a] Apell and Gschwend (2017) reported total PCB C_{free} as the sum of 27 congeners, with values ranging from 0.28 to 0.42 ng/L with a geometric mean of 0.32 ng/L.

[b] The results for one replicate sample at location PS1 (RM 3.3) in 2018 were rejected due to issues with the PRC for this sample (Windward 2018e).

[c] The combined SD values reported for the Pre-Design Studies baseline samples are the residual standard errors across both stations within each sampling year.

[d] The CVs reported for Pre-Design Studies baseline data use the values combined across the two stations.

CV – coefficient of variation
PCB – polychlorinated biphenyl
PRC – performance reference compound
RM – river mile
SD – standard deviation

When designing the passive sampler program, the number of replicate passive samplers to be analyzed was determined based on the assumption of a relative variance estimate of 25% (the relative variance estimate, or CV, is the standard deviation [SD] expressed as a percent of the mean). This value was derived from the Apell and Gschwend (2017) passive sampler data for the LDW, which included single observations from each of three locations (Table 3-2). Based on this limited dataset and the potential for a skewed distribution, the *a priori* power analysis estimated that nine passive sampler replicates would be needed for a minimum detectable difference (MDD) of approximately 25% of the baseline mean.[32] The results for the Pre-Design Studies baseline data were assessed relative to this assumption. Using the baseline passive sampler dataset (n = 35), the data

[32] Assumes a parametric *t*-interval testing for the difference of means between baseline (two years) and future (two years) at a single station, using a normal distribution and type I and II errors both set at 10%.

were determined to be normally distributed, and to have a relative variance estimate (i.e., CV) that was much lower than expected (equal to 9 to 10%, rather than 25%). Considering the lower CV, the MDD expected for the current design (i.e., nine replicates in each of the two years) during baseline and future is 10% from the baseline mean of 1.1 ng/L, or a statistically detectable change of 0.11 ng/L. Therefore, the loss of the one replicate in the 2018 sampling does not affect the ability of the baseline passive sampler dataset to meet DQO 2; the variability in this dataset is sufficiently low to meet DQO 2 and establish the baseline total PCB concentrations to be used in evaluating surface water trends based on future monitoring data.

3.2 SURFACE WATER DATA INTERPRETATION

This section presents a comparison of the baseline data with ARARs for DQO 1, as well as additional details for the chemicals with concentrations that were greater than ARARs. This section also presents a discussion of the passive sampler data to establish a baseline for evaluating trends in total PCB concentrations to support DQO 2.

3.2.1 DQO 1 – progress toward ARARs

Data for composite-grab samples were compared with ARARs to evaluate progress toward meeting ARARs as sediment remediation and source control work progress. Table 3-3 presents summary statistics for each chemical and indicates whether chemicals were analyzed as dissolved or total fractions for comparison with the ARAR. The nine chemicals that were detected at concentrations greater than the lowest ARAR are highlighted in green in Table 3-3. The following summarizes the ARAR comparison by chemical group:

- **Total PCBs** – PCBs were detected in all 48 surface water samples, with total PCBs at concentrations above the ARAR for the human health criteria for consumption of organisms. PCBs were detected at concentrations below the ARAR for aquatic life marine acute and chronic water quality criteria (WQC) in all 48 samples.
- **PAHs** – All 12 of the PAHs with WQC were detected in 1 or more samples, and 6 of the 7 cPAHs (i.e., all cPAHs except chrysene) were detected at concentrations above the ARARs for the human health criteria for consumption of organisms.
- **Dioxins/furans** – The only dioxin/furan congener with an ARAR is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), which was not detected in any of the surface water samples. Of the remaining 18 congeners, 4 were detected in surface water samples.
- **Metals** – Only inorganic arsenic was detected at concentrations above the ARAR; all 48 samples had inorganic arsenic concentrations greater than the ARAR for the human health criteria for consumption of organisms. All other metals had detected concentrations below the ARARs for human health (consumption of organisms), and all metals had detected concentrations below the ARAR for

aquatic life (both marine acute and chronic WQC). Silver, thallium, and tributyltin (TBT) were never detected.

- **Phthalates** – BEHP was detected in 3 of 48 samples; all detected concentrations were above the ARARs for human health (criteria based on the consumption of organisms). The other four phthalate compounds were not detected in any of the samples.
- **Other semivolatile organic compounds (SVOCs)** – No other SVOCs were detected.
- **Organochlorine pesticides** – No pesticides were detected.
- **Organophosphate pesticides and carbaryl** – As specified in the surface water QAPP, three organophosphate pesticides and the herbicide carbaryl were analyzed in samples collected during the first storm event (Windward 2017b, 2018a). None of these compounds were detected in the water samples.

Table 3-3. Summary of the surface water results relative to ARARs

Chemical	Fraction	Summary Statistics						National Criteria			Washington State Criteria			Lowest ARAR
		DF		Detected Concentrations			RL or Range of RLs	AWQC - Marine		Human Health	Marine[b]		Human Health[b]	
		Ratio	%	Min.	Max.	Mean		CMC (Acute)	CCC (Chronic)	Consumption of Organism Only	Acute	Chronic	Consumption of Organism Only	
Metals (µg/L)[a]														
Antimony	T	12/30	40	0.032	0.273 J	0.18	0.306–1.02	–	–	640	–	–	90	90
Arsenic	D	30/30	100	0.453	2.10	1.23	na	69[c]	36[c]		69[c]	36[c]		36[c]
Arsenic (inorganic)	T	48/48	100	0.451	1.72	1.07	na	–	–	0.14	–	–	0.14	0.14
Cadmium	D	4/30	13	0.023 J	0.123 J	0.068	0.003–1.02	33[c]	7.9[c]	–	42[c]	9.3[c]	–	7.9[c]
Chromium	D	6/30	20	0.120	1.22 J	0.503	0.138–1.91	1,100[c]	50[c]	–	1,100[c]	50[c]	–	50[c]
Copper	D	44/48	92	0.279	2.32	0.878	1.68	4.8[c]	3.1[c]	–	4.8[c]	3.1[c]	–	3.1[c]
Lead	D	5/30	17	0.0450	0.121	0.0786	0.383	210[c]	8.1[c]	–	210.0[c]	8.1[c]	–	8.1[c]
Nickel	D	23/30	77	0.165	3.24	0.839	1.76	74[c]	8.2[c]	4,600	74.0[c]	8.2[c]	100	8.2[c]
Selenium	D	5/30	17	0.023 J	0.554 J	0.14	0.028–1.43	290[c]	71[c]	4,200	290[c]	71.0[c]	200	71[c]
Silver	D	0/30	0	nd	nd	nd	0.021–0.536	1.9[c]	–	–	1.9[c]	–	–	1.9[c]
Thallium	T	0/30	0	nd	nd	nd	0.004–1.02	–	–	0.47	–	–	0.27	0.27
Zinc	D	23/30	77	1.66	14.5	4.38	3.36–10.2	90[b]	81[b]	26,000	90[c]	81[c]	1000	81[c]
Mercury (ng/L)														
Mercury	T	21/30	70	0.76	4.17	1.9	0.85–1.37	1800	940		1800	25	–	25
Organometals (µg/L)														
TBT	T	0/18	0	nd	nd	nd	0.0052	0.42	0.0074	–	–	–	–	0.0074
PAHs (µg/L)														
Acenaphthene	T	29/48	60	0.0030 J	0.0090 J	0.0050	0.010	–	–	90	–	–	30	30
Anthracene	T	10/48	21	0.0010 J	0.0050 J	0.0021	0.0010–0.010	–	–	400	–	–	100	100
Benzo(a)anthracene	T	4/48	8	0.00080 J	0.012	0.0037	0.010	–	–	0.0013	–	–	0.00016	0.00016
Benzo(a)pyrene	T	1/48	2	0.0070 J	0.0070 J	na	0.010	–	–	0.00013	–	–	0.000016	0.000016
Benzo(b)fluoranthene	T	6/48	13	0.00060 J	0.011	0.0026	0.010	–	–	0.0013	–	–	0.00016	0.00016
Benzo(k)fluoranthene	T	1/48	2	0.0050 J	0.0050 J	na	0.010	–	–	0.013	–	–	0.0016	0.0016
Chrysene	T	10/48	21	0.0010 J	0.0070 J	0.0017	0.010	–	–	0.13	–	–	0.016	0.016
Dibenzo(a,h)anthracene	T	1/48	2	0.0020 J	0.0020 J	na	0.010	–	–	0.00013	–	–	0.000016	0.000016

Table 3-3. Summary of the surface water results relative to ARARs

Chemical	Fraction	Summary Statistics						National Criteria			Washington State Criteria			Lowest ARAR
		DF		Detected Concentrations				AWQC - Marine		Human Health	Marine[b]		Human Health[b]	
		Ratio	%	Min.	Max.	Mean	RL or Range of RLs	CMC (Acute)	CCC (Chronic)	Consumption of Organism Only	Acute	Chronic	Consumption of Organism Only	
Fluoranthene	T	33/48	69	0.0020 J	0.010 J	0.0043	0.0030–0.010	–	–	20	–	–	6	6
Fluorene	T	25/48	52	0.0020 J	0.0060 J	0.0030	0.0020–0.010	–	–	70	–	–	10	10
Indeno(1,2,3-cd)pyrene	T	2/48	4	0.0020 J	0.0020 J	0.0020	0.010	–	–	0.0013	–	–	0.00016	0.00016
Pyrene	T	22/48	46	0.0010 J	0.010 J	0.0037	0.0010–0.010	–	–	30	–	–	8	8
Phthalates (µg/L)														
BEHP	T	3/48	6	0.5 J	2.0 J	1.2	3.0	–	–	0.37	–	–	0.046	0.046
BBP	T	0/18	0	nd	nd	nd	1.0	–	–	0.1	–	–	0.013	0.013
Diethyl phthalate	T	0/18	0	nd	nd	nd	1.0	–	–	600	–	–	200	200
Dimethyl phthalate	T	0/18	0	nd	nd	nd	1.0	–	–	2,000	–	–	600	600
Di-n-butyl phthalate	T	0/18	0	nd	nd	nd	1.0	–	–	30	–	–	8	8
Other SVOCs (µg/L)[d]														
1,2,4,5-Tetrachloro-benzene	T	0/18	0	nd	nd	nd	1.0	–	–	0.03	–	–	–	0.03
2,2'-oxybis(1-chloro)propane	T	0/18	0	nd	nd	nd	1.0	–	–	0.2	–	–	0.02	0.02
2,4,5-Trichlorophenol	T	0/18	0	nd	nd	nd	5.0	–	–	600	–	–	–	600
2,4,6-Trichlorophenol	T	0/18	0	nd	nd	nd	3.0	–	–	2.8	–	–	0.28	0.28
2,4-Dichlorophenol	T	0/18	0	nd	nd	nd	3.0	–	–	60	–	–	10	10
2,4-Dimethylphenol	T	0/18	0	nd	nd	nd	3.0	–	–	3,000	–	–	97	97
2,4-Dinitrophenol	T	0/18	0	nd	nd	nd	20.0	–	–	300	–	–	100	100
2,4-Dinitrotoluene	T	0/18	0	nd	nd	nd	3.0	–	–	1.7	–	–	0.18	0.18
2,5-Dinitrophenol	T	0/18	0	nd	nd	nd	25.0	–	–	1000	–	–	100	100
2-Chloronaphthalene	T	0/18	0	nd	nd	nd	1.0	–	–	800	–	–	17	17
2-Chlorophenol	T	0/18	0	nd	nd	nd	1.0	–	–	0.15	–	–	0.0033	0.0033
3,3'-Dichlorobenzidine	T	0/18	0	nd	nd	nd	5.0	–	–	30	–	–	7	7
4,6-Dinitro-o-cresol	T	0/18	0	nd	nd	nd	10.0	–	–	2,000	–	–	36	36
4-Chloro-3-methylphenol	T	0/18	0	nd	nd	nd	3.0	–	–	0.011	–	–	0.000023	0.000023
Azobenzene	T	0/18	0	nd	nd	nd	1.0	–	–	2.2	–	–	0.06	0.06

Table 3-3. Summary of the surface water results relative to ARARs

Chemical	Fraction	Summary Statistics						National Criteria			Washington State Criteria			Lowest ARAR
		DF		Detected Concentrations			RL or Range of RLs	AWQC - Marine		Human Health	Marine[b]		Human Health[b]	
		Ratio	%	Min.	Max.	Mean		CMC (Acute)	CCC (Chronic)	Consumption of Organism Only	Acute	Chronic	Consumption of Organism Only	
Benzidine[a]	T	0/18	0	nd	nd	nd	10.0	–	–	0.000079	–	–	0.000005	0.000005
bis(2-chloroethyl)ether	T	0/18	0	nd	nd	nd	1.0	–	–	4	–	–	1	1
Hexachlorobenzene	T	0/18	0	nd	nd	nd	1.0	–	–	0.1	–	–	0.02	0.02
Hexachlorocyclopentadiene	T	0/18	0	nd	nd	nd	5.0	–	–	1,800	–	–	110	110
Hexachloroethane	T	0/18	0	nd	nd	nd	2.0	–	–	1.24	–	–	–	1.24
Isophorone	T	0/18	0	nd	nd	nd	1.0	–	–	3	–	–	0.34	0.34
N-Nitrosodiethylamine	T	0/18	0	nd	nd	nd	2.0	–	–	0.22	–	–	–	0.22
n-Nitrosodimethylamine	T	0/18	0	nd	nd	nd	3.0	–	–	0.51	–	–	0.058	0.058
N-Nitroso-di-n-butylamine	T	0/18	0	nd	nd	nd	1.0	–	–	6	–	–	0.69	0.69
n-Nitroso-di-n-propylamine	T	0/18	0	nd	nd	nd	1.0	–	–	34	–	–	–	34
n-Nitrosodiphenylamine	T	0/18	0	nd	nd	nd	1.0	–	–	600	–	–	100	100
N-Nitrosopyrrolidine	T	0/18	0	nd	nd	nd	1.0	7	1.7	–	–	–	–	1.7
Nitrobenzene	T	0/18	0	nd	nd	nd	1.0	–	–	0.1	–	–	–	0.1
Nonylphenol (mixed isomers)	T	0/18	0	nd	nd	nd	1.0	13	7.9	0.04	13	7.9	0.002	0.002
Pentachlorobenzene	T	0/18	0	nd	nd	nd	1.0	–	–	300,000	–	–	70,000	70,000
Phenol	T	0/18	0	nd	nd	nd	10.0	–	–	0.03	–	–	–	0.03
Total PCBs (ng/L)														
Total PCB congeners	T	48/48	100	0.0105 J	5.573 J	0.937	na	–	30	0.064	10,000	30	0.007	0.007
Pesticides (µg/L)[e]														
4,4'-DDD	T	0/18	0	nd	nd	nd	0.050	–	–	0.00012	–	–	0.0000079	0.0000079
4,4'-DDE	T	0/18	0	nd	nd	nd	0.050	–	–	0.000018	–	–	0.00000088	0.00000088
4,4'-DDT	T	0/18	0	nd	nd	nd	0.050	0.13	0.001	0.00003	0.13	0.001	0.0000012	0.0000012
Aldrin	T	0/18	0	nd	nd	nd	0.025	1.3		0.00000077	0.71[f]	0.0019[f]	0.000000041	0.000000041
Dieldrin	T	0/18	0	nd	nd	nd	0.050	0.71	0.0019	0.0000012	0.71[f]	0.0019[f]	0.00000007	0.00000007
alpha-BHC	T	0/18	0	nd	nd	nd	0.025	–	–	0.00039	–	–	0.000048	0.000048
beta-BHC	T	0/18	0	nd	nd	nd	0.025	–	–	0.014	–	–	0.0014	0.0014

Table 3-3. Summary of the surface water results relative to ARARs

Chemical	Fraction	Summary Statistics						National Criteria			Washington State Criteria			Lowest ARAR
		DF		Detected Concentrations				AWQC - Marine		Human Health	Marine[b]		Human Health[b]	
		Ratio	%	Min.	Max.	Mean	RL or Range of RLs	CMC (Acute)	CCC (Chronic)	Consumption of Organism Only	Acute	Chronic	Consumption of Organism Only	
gamma-BHC	T	0/18	0	nd	nd	nd	0.025	0.16	–	4.4	0.16		0.43	0.16
alpha-Chlordane	T	0/18	0	nd	nd	nd	0.025	0.16	–	4.4	0.16		0.43	0.16
beta-Chlordane	T	0/18	0	nd	nd	nd	0.025	0.09[g]	0.004[g]	0.00032[g]	0.09[g]	0.004[g]	0.000022[g]	0.000022[g]
alpha-Endosulfan	T	0/18	0	nd	nd	nd	0.025	0.034[h]	0.0087[h]	30	0.034[h]	0.0087[h]	7	0.0087[h]
beta-Endosulfan	T	0/18	0	nd	nd	nd	0.050	0.034[h]	0.0087[h]	40	0.034[h]	0.0087[h]	10	0.0087[h]
Endosulfan sulfate	T	0/18	0	nd	nd	nd	0.050	–	–	40	–	–	10	10
Endrin	T	0/18	0	nd	nd	nd	0.050	0.037	0.0023	0.03	0.037	0.0023	0.002	0.002
Endrin aldehyde	T	0/18	0	nd	nd	nd	0.050	–	–	1	–	–	0.035	0.035
Heptachlor	T	0/18	0	nd	nd	nd	0.025	0.053	0.0036	0.0000059	0.053	0.0036	0.00000034	0.00000034
Heptachlor epoxide	T	0/18	0	nd	nd	nd	0.050	0.053	0.0036	0.000032	–	–	0.0000024	0.0000024
Methoxychlor	T	0/18	0	nd	nd	nd	0.250	–	0.03	0.02	–	–	–	0.02
Mirex	T	0/18	0	nd	nd	nd	0.050	–	0.001	–	–	–	–	0.001
cis-Nonachlor	T	0/18	0	nd	nd	nd	0.050	0.09[g]	0.004[g]	0.00032[g]	0.09[g]	0.004[g]	0.000022[g]	0.000022[g]
trans-Nonachlor	T	0/18	0	nd	nd	nd	0.050	0.09[g]	0.004[g]	0.00032[g]	0.09[g]	0.004[g]	0.000022[g]	0.000022[g]
Oxychlordane	T	0/18	0	nd	nd	nd	0.050	0.09[g]	0.004[g]	0.00032[g]	0.09[g]	0.004[g]	0.000022[g]	0.000022[g]
Toxaphene	T	0/18	0	nd	nd	nd	1.25	0.21	0.0002	0.00071	0.21	0.0002	0.000032	0.000032
Organophosphate pesticides and carbaryl (µg/L)														
Carbaryl	T	0/6	0	nd	nd	nd	0.020	1.6	–	–	–	–	–	1.6
Chlorpyrifos	T	0/6	0	nd	nd	nd	0.20 - 0.21	0.011	0.0056	–	0.011	0.0056	–	0.0056
Diazinon	T	0/6	0	nd	nd	nd	0.20 - 0.21	0.82	0.82	–	–	–	–	0.82
Malathion	T	0/6	0	nd	nd	nd	0.20 - 0.21	–	0.1	–	–	–	–	0.1
Dioxins/Furans (pg/L)														
2,3,7,8-TCDD	T	0/18	0	nd	nd	nd	0.248 - 0.696	–	–	0.0051	–	–	0.014	0.0051

Green highlighting indicates that analyte was detected at concentrations greater than the ARAR.

[a] All chemicals were analyzed in unfiltered water samples, except for select metals, which were only analyzed in filtered samples because the aquatic life criteria for these metals are for comparison to dissolved (i.e., filtered) metals concentrations (and these ARARs were the lowest ARARs for these metals). The analyte list was described in the QAPP (Windward 2017b, 2018a).

[b] Washington State Criteria include standards promulgated in WAC 173-201A and human health criteria consistent with NTR 40 CFR 131.45 as applied to Washington 40 CFR 131(d)(14), including the 40 CFR 131 criteria updated on November 28, 2016. These criteria were updated after publication of the ROD (EPA 2014).

[c] Criteria applied to dissolved fraction.

[d] Target analytes provided. Two non-target analytes, 2,5-dinitrophenol and azobenzene, were reported by the laboratory as not detected in all samples. There are no WQC for these chemicals.

[e] Target analytes provided. The laboratory also reported delta-BHC, which was not targeted. This compound was detected in two samples with JN qualification, indicating that the compound was tentatively identified and the concentration was estimated. There are no WQC for this compound.

[f] Criteria for sum of aldrin and dieldrin.

[g] Criteria for total chlordane (sum of alpha chlordane, beta chlordane, oxychlordane, cis-nonachlor, and trans-nonachlor).

[h] Criteria for sum of alpha-Endosulfan and beta-Endosulfan.

ARAR – applicable or relevant and appropriate requirement
AWQC – ambient water quality criteria
BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
BHC – benzene hexachloride
CCC – criterion continuous concentration
CFR – Code of Federal Regulations
CMC – criterion maximum concentration
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
DF – detection frequency
J – estimated concentration
JN – tentatively identified and estimated concentration
na – not applicable
nd – not detected
NTR – National Toxics Rule
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RL – reporting limit
ROD – Record of Decision
SVOC – semivolatile organic compound
TBT – tributyltin
TCDD – tetrachlorodibenzo-*p*-dioxin
WAC – Washington Administrative Code
WQC – water quality criteria

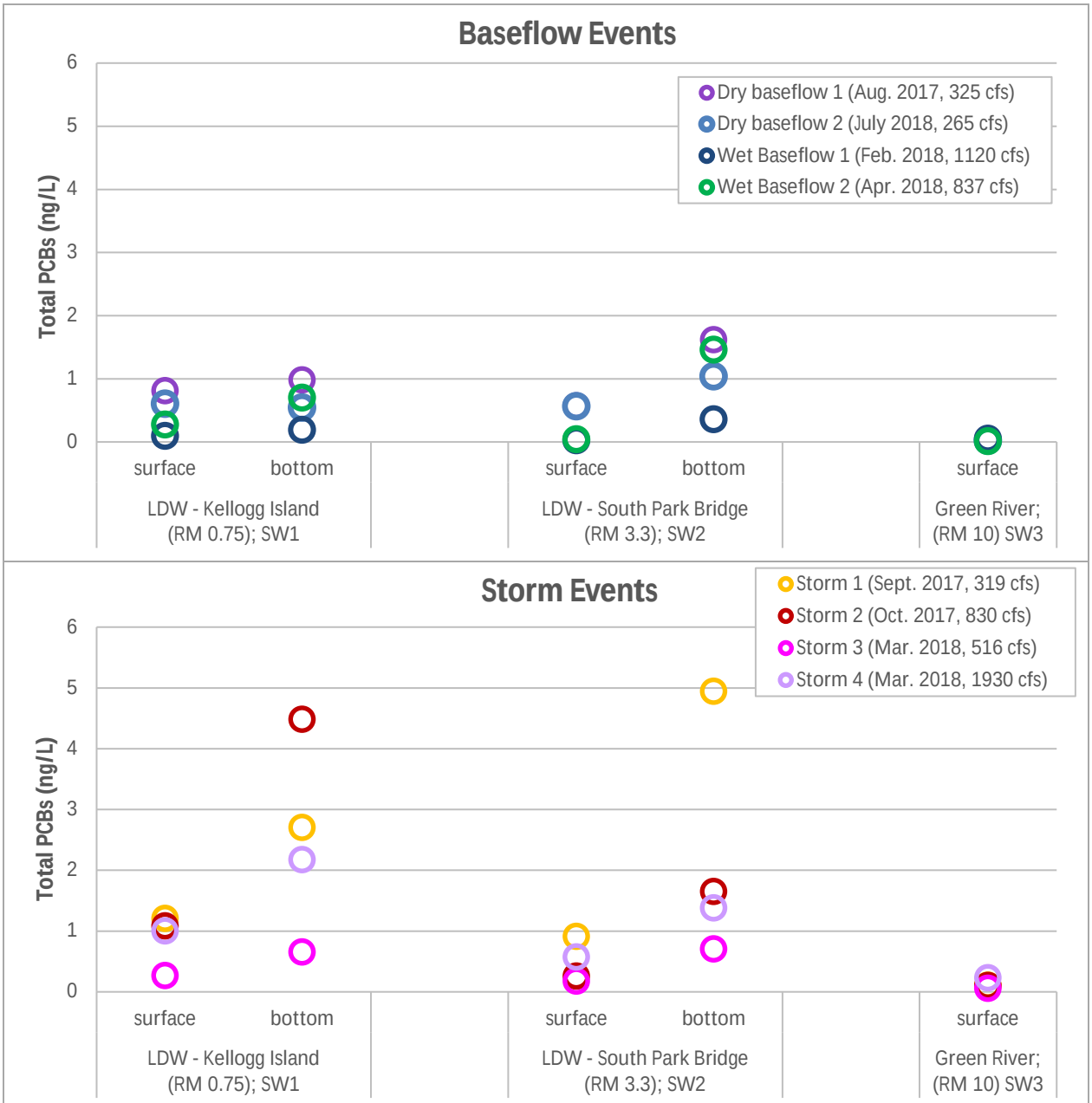
A total of 10 chemicals were detected at concentrations greater than the lowest ARARs. It is noteworthy that 9 of these 10 chemicals were risk drivers (total PCBs, 7 cPAHs, and inorganic arsenic). The only risk driver without any ARAR exceedances was dioxins/furans. Each of the 10 chemicals is discussed in the sections below.

3.2.1.1 Total PCBs

PCBs were detected in all 48 surface water composite-grab samples. Total PCBs concentrations ranged from 0.0217 to 5.5730 ng/L in the LDW and from 0.11 to 0.229 ng/L in the upstream Green River location during the eight surface water sampling events (Figure 3-1). Key observations regarding the patterns of total PCBs in surface water composite-grab samples are as follows.

- **Storm vs. baseflow samples** – On average, total PCB concentrations in the dry baseflow samples (particularly dry baseflow 1) were higher than those in the wet baseflow samples. The variability in concentrations was much lower in the baseflow samples than in the storm event samples. Of the storm events, Storms 1 and 2 had the highest concentrations, and Storm 3 had the lowest. All three of these storms required an antecedent dry period of at least 48 hours prior to the storm and had dam release rates below the significant release threshold defined in the QAPP of 2,000 cubic feet per second (cfs).[33] Storms 1 and 3 were > 0.25-in. storms, and Storm 2 was a > 0.5-in. storm. The primary difference in these three storms was the timing of the sampling: Storms 1 and 2 were sampled within 12 hours after the peak of the forecasted rain, whereas Storm 3 was sampled immediately after/during the period of peak rainfall intensity.
- **Near-surface vs. near-bottom** – For all sampling events, total PCB concentrations for a given event were higher in near-bottom samples than in near-surface samples. This was particularly true for the storm event samples.
- **Spatial pattern in near-surface samples** – For all sampling events, total PCB concentrations were lower in the mid-depth samples collected from the upstream location (i.e., SW3 on the Green River) than in near-surface samples collected from the LDW locations. In general, near-surface water concentrations were highest in samples from the furthest downstream location (i.e., SW1 at RM 0.75).
- Sp**atial pattern in near-bottom samples** – Total PCB concentrations in the near-bottom samples were generally higher in SW2 samples (RM 3.3) than in SW1 samples (RM 0.75). Two exceptions to this pattern were for Storms 2 and 4, for which the SW1 concentration was higher.

[33] The threshold for a significant dam release of 2,000 cfs was defined in the surface water QAPP (Windward 2017b, 2018a) for this sampling program, and was not associated with USACE dam operations.



ARARs for total PCBs are as follows:

	AWQC – Marine (Acute)	AWQC – Marine (Chronic)	Human Health – Consumption of Organism Only
National Criteria	-	30 ng/L	0.064 ng/L
Washington State Criteria	10,000 ng/L	30 ng/L	0.007 ng/L

Note: The sampling month and year, as well as the Howard Hanson dam release rate at the time of sampling, are presented in parentheticals after the sampling event name in the figure legends.

Figure 3-1. Total PCBs in Pre-Design Studies baseline surface water composite-grab samples

Comparison with Historical Data

Historical surface water grab sample data collected by King County from August to December 2005 were compared with baseline data collected as part of the Pre-Design Studies. To ensure that this comparison used samples collected under similar conditions, Table 3-4 summarizes key rainfall and dam release conditions for the two studies. Of the four King County events, two can be characterized as dry baseflow events and one can be characterized as a storm event. The fourth event did not fit into any of the Pre-Design Studies sampling condition categories, and therefore was not used in this comparison.

Table 3-4. Comparison of Pre-Design Studies Baseline and King County sampling conditions

Event	Event Type	Date	Summary of Sampling Conditions						
				Rainfall (in.)					
			Dam Release Rate (cfs)	Antecedent Period[a]	24-Hour Rainfall[b]	12 Hours Prior to Sampling	During Sampling	Tide	Lunar Phase
LDW Pre-Design Studies Baseline Samples									
DB1	dry baseflow	8/28/2017	325	0 (72 hours)	0	0	0	high/outgoing	neap
DB2	dry baseflow	7/30/2018	265	0 (72 hours)	0	0	0	high/outgoing	spring
WB1	wet baseflow	2/28/2018	1,120	0 (72 hours)	0	0[c]	0.05[c]	high	neap
WB2	wet baseflow	4/3/2018	837	0 (72 hours hours	0	0	0	high/outgoing	spring
ST1	storm (> 0.25)	9/19/2017	319	0.35 (48 hours)	0.35	0.1	0.03	low/incoming	spring
ST2	storm (> 0.5)	10/19/2017	830	0.06 (48 hours)	1.43	0.94	0.12	outgoing/low	spring
ST3	storm (> 0.25)	3/8/2018	515	0 (48 hours)	0.5	0.17	0.07	outgoing	neap
ST4	storm (> 0.5)	4/7/2018	1,930	0.23 (48 hours)	0.95	0.63	0.13	outgoing	neap
King County									
-	dry baseflow	8/22/2005	290	0 (72 hours)	0	0	0	low/outgoing	spring
-	dry baseflow	9/26/2005[d]	440	0 (72 hours)	0	0	0	incoming	neap
-	na	11/28/2005	697	0.71 (48hours)	0	0	0	incoming	spring
-	storm	12/19/2005	287	0 (48 hours)	0.14	0.14	0.01	low	na

Note: King County samples included water from single grabs, whereas the Pre-Design Studies baseline samples were composites of equal volumes from four grabs.

[a] The antecedent period is the period prior to the start of the storm (for storm events) or the period prior to sampling (for baseflow events).

[b] The 24-hour rainfall is the total rainfall that fell in the 24 hours ending at the completion of sampling.

[c] A total of 0.05 in. of precipitation was recorded at the Hamm Creek gage during sampling, as a result of the approximately 0.5 in. of snow that fell in the LDW area the night prior to sampling. The precipitation was not recorded on the Hamm Creek gage until the snow melted in the morning.

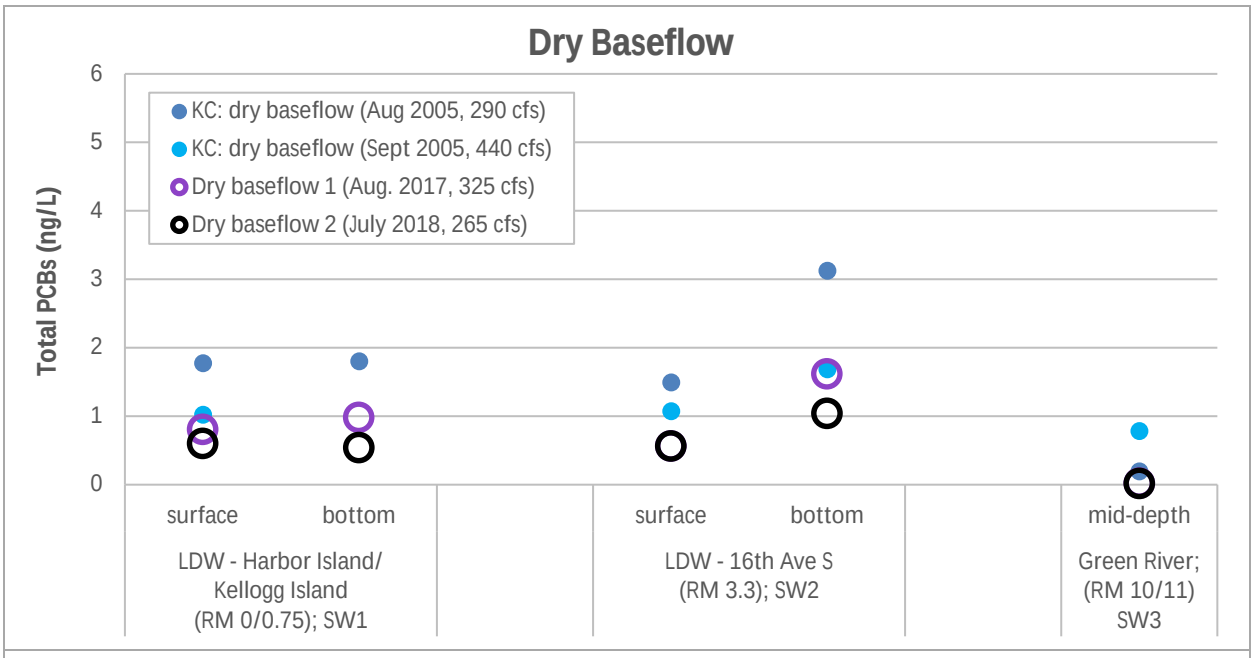
[d] No near-bottom sample was collected at SW1 during this King County sampling event.

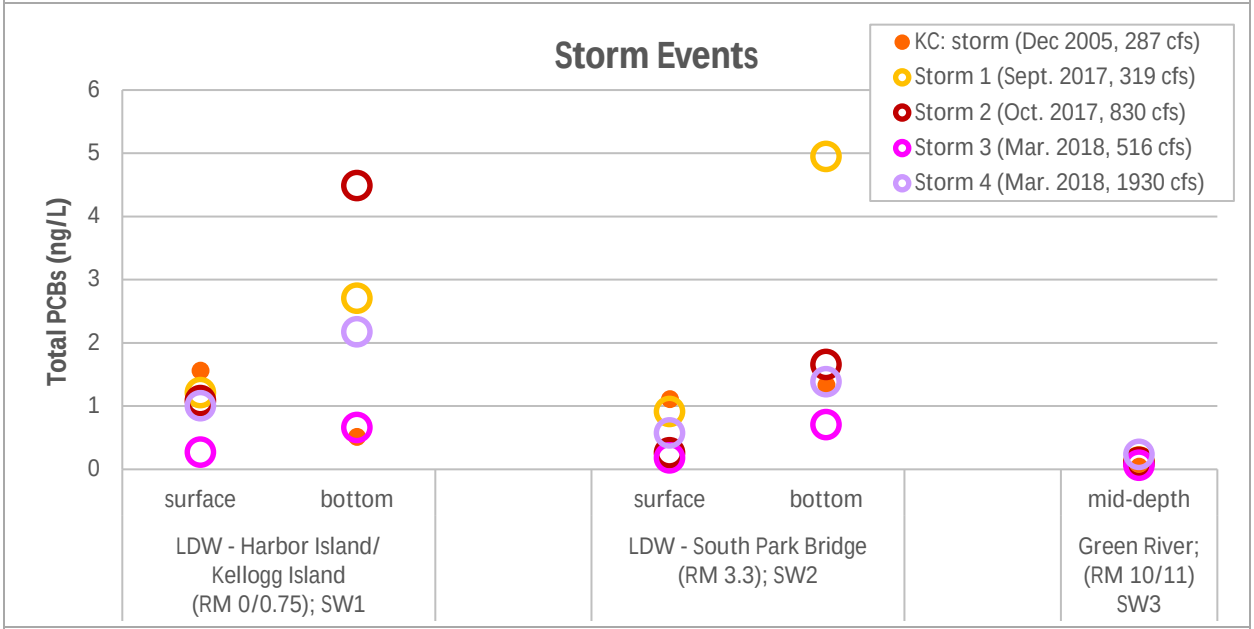
cfs – cubic feet per second

LDW – Lower Duwamish Waterway

na – not applicable

Both the King County (2005) and Pre-Design Studies baseline (2017/2018) datasets included dry baseflow events; therefore, it was possible to compare total PCBs concentrations in these dry baseflow samples to evaluate potential changes in concentrations (Figure 3-2). Total PCB concentrations in the 2005 King County dry baseflow samples (particularly the August 2005 samples) were generally higher than those in the 2017/2018 Pre-Design Studies baseline samples (Figure 3-2). On average, concentrations were about twice as high at a given event/depth during the 2005 sampling event. Comparisons for storm event data are less conclusive. The total PCB concentrations for samples collected during a King County storm event were generally within the range of the concentrations for the 2017/2018 Pre-Design Studies baseline storm events. Compared with Pre-Design Studies baseline Storm 1, which appears to have been the most similar to the 2005 King County storm event, total PCB concentrations were similar in the near-surface samples but lower in 2005 in the near-bottom samples. However, the rainfall for Storm 1 was approximately double that of the rainfall during the 2005 storm, and the 2005 sample was a single grab sample as opposed to the composite-grab samples collected in 2017.





ARARs for total PCBs are as follows:

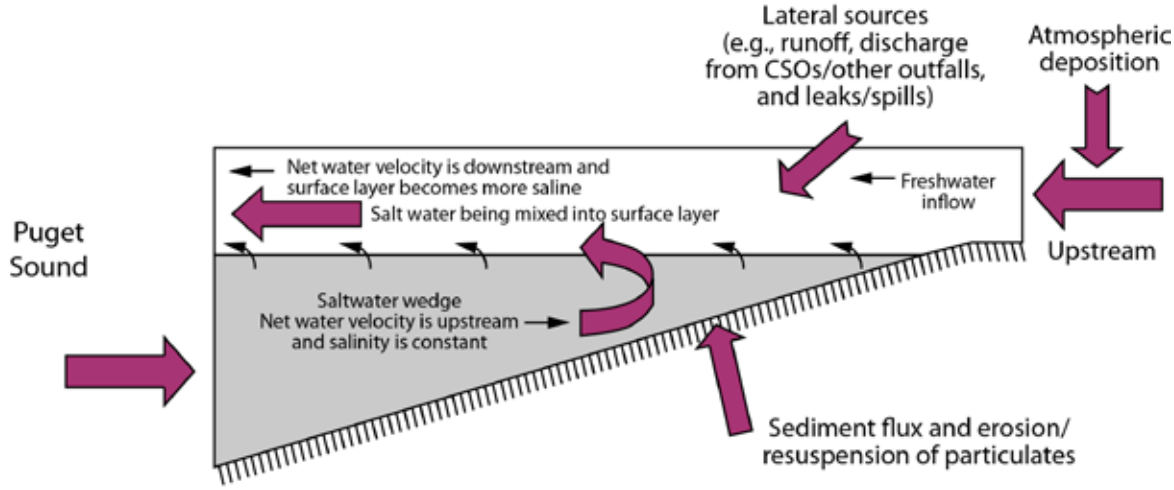
	AWQC – Marine (Acute)	AWQC – Marine (Chronic)	Human Health – Consumption of Organism Only
National Criteria	-	30 ng/L	0.064 ng/L
Washington State Criteria	10,000 ng/L	30 ng/L	0.007 ng/L

Note: The Green River King County sample was collected from further upstream (RM 11) than the Pre-Design Studies baseline upstream samples (which were collected at approximately RM 10).

Figure 3-2. Comparison of total PCB concentrations in surface water in 2017/2018 Pre-Design Studies baseline composite-grab samples with historical (2005) LDW and Green River grab samples

Consistency with Conceptual Site Model

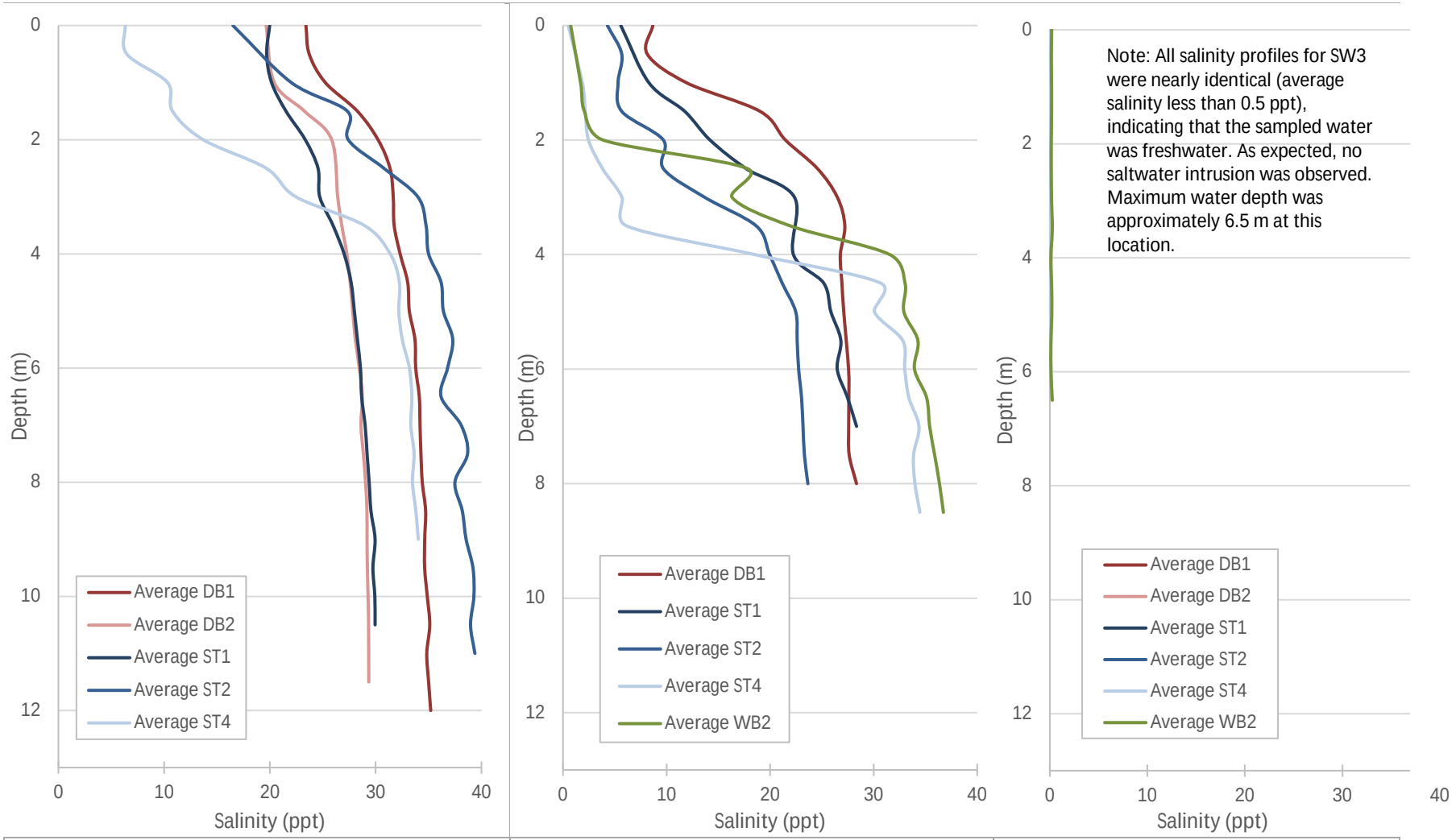
The surface water data collected to date support the conceptual site model (CSM) (Figure 3-3) described in the Work Plan (Windward and Integral 2017b). In this model, total PCB concentrations detected in LDW surface waters are affected by freshwater flow as well as estuarine circulation. Higher total PCB concentrations are expected in the bottom layer of the LDW with movement upstream (i.e., higher at location SW2 [RM 3.3] than at location SW1 [RM 0.75]), due to the increased residence time (time within the LDW) of bottom water and flux from LDW sediment into the bottom water. The total PCB concentrations in the surface layer, on the other hand, are expected to increase from upstream to downstream, reflecting greater cumulative mixing with the bottom water (Stern 2015). In addition, lateral sources within the LDW may influence surface layer concentration patterns.



Data source: Mickelson and Williston (2006).

Figure 3-3. Simplified conceptual model of PCB transport in LDW surface water

In addition to the total PCB concentrations, it is useful to consider the salinity profiles recorded during the eight surface water grab sampling events when verifying this CSM. Salinity profiles for each sampling location and sampling event (representing the average of the individual salinity profiles for each grab included in the composite) are presented in Figure 3-4. When interpreting these salinity profiles, it is important to recognize that some variability in the salinity measurements is expected; thus, only general conclusions should be drawn from these plots.



A) Salinity profiles for SW1 (RM 0.75)	B) Salinity profiles for SW2 (RM 3.3)	C) Salinity profiles for SW3 (Green River)

Note: As a result of issues with the water quality probe, no salinity profiles are available for all three locations during ST3 sampling, for all three locations during WB1 sampling, for location SW1 during WB2 sampling, or for location SW2 during DB2 sampling.

Figure 3-4.Salinity profiles for surface water composite-grab samples

Overall, the salinity profiles matched what was expected based on the LDW CSM. Salinity averaged less than 0.5 parts per thousand (ppt) at SW3 (the Green River location) for all events, matching the expectation that these samples would represent freshwater and not be impacted by the salt wedge (Figure 3-4). As expected, surface layer salinity was higher at SW1 (RM 0.75) than at SW2 (RM 3.3). The profiles indicated that the salt wedge was present at SW2 (to varying extents) during all eight sampling events, and that the influence of the incoming freshwater from the Green River was more prominent at SW2 than at SW1, with variability at these locations depending on tidal conditions and flow. Relative to the CSM, the Figure 3-4 also shows:

- The salt wedge was observed to extend further upstream during DB2, during which time the tides were more extreme than during DB1.
- The salinity profiles across the events show the impact of differing flow rates on the salt wedge. Storm 4 had the highest dam release rate (1,930 cfs); dam release rates for the other sampling events ranged from 260 to 940 cfs. For Storm 4, the salinity of the surface layer was generally lower than that for the other events, both at SW1 and SW2, emphasizing the influence of the incoming freshwater.
- Storm 4 and wet baseflow 2 events were conducted within several days of one another, and both occurred during an outgoing tide. While the upper and lower portions of the salinity profiles at SW2 for these curves are similar, the middle portion of the curve differs as a result of the difference in flow. The freshwater layer extended deeper during Storm 4 (dam release of 1,930 cfs) than during wet baseflow 2 (dam release of 837 cfs).
- For plots showing the individual profiles for a single event (Appendix C), the movement of the salt wedge over the course of the sampling event relative to the tidal changes can be observed. For example, for Storm 4, the first grabs were collected just before high tide, and subsequent grabs were collected during an outgoing tide. The downstream movement of the salt wedge over the course of the grabs during this sampling event is apparent.

3.2.1.2 cPAHs

At least 1 individual cPAH was detected[34] in 10 of the 48 surface water grab samples. Because cPAHs were detected relatively infrequently, patterns of cPAH concentrations are more uncertain. The following summarizes the events and locations where cPAHs were detected at concentrations above ARARs (Table 3-5). No cPAHs were detected at concentrations above ARARs in near-surface samples collected at SW2 (RM 3.3) or in samples collected at SW3 (Green River).

- **Storm vs. baseflow samples** – In general, cPAH concentrations in dry baseflow samples were lower than those in wet baseflow samples (i.e., there were more

[34] Most of the detected cPAH concentrations (19 of 21 detects) were between the RL and method detection limit (MDL), and thus were J-flagged as estimated values.

ARAR exceedances in wet baseflow samples). In the storm events, cPAHs were only detected in samples from Storm 4. This event had the greatest number of individual cPAHs detected (five out of seven) and concentrations were generally highest. Storm 4 was the only storm sampling event during which samples were collected with significant dam release (i.e., a release rate greater than 2,000 cfs).

- **Near-surface vs. near-bottom** – Insufficient detected values were available to determine whether cPAHs were generally higher in near-surface or near-bottom water samples.
- **Spatial pattern in near-surface samples** – In the near-surface samples, cPAHs were only detected at concentrations greater than ARARs in samples collected during the two wet baseflow events, and only at SW1 at RM 0.75 (i.e., no detects in the near-surface sample at SW2 at RM 3.3). This indicates that concentrations were higher in the samples collected from the downstream LDW location (i.e., SW1 at RM 0.75).
- **Spatial pattern in near-bottom samples** – With one exception (the SW1 near-bottom water sample collected during wet baseflow 1), cPAHs were only detected in near-bottom water samples collected from the upstream LDW location (i.e., SW2 at RM 3.3). At SW2, one cPAH was detected in the near-bottom sample collected during dry baseflow 1, and five cPAHs were detected at comparatively high concentrations during Storm 4.

Table 3-5. Summary of cPAHs with detected values in surface water composite-grab samples greater than ARARs

cPAH	DF	Detects > ARAR?	Events During Which Detected cPAH Concentrations were greater than ARAR by Location and Depth				
			SW1 (RM 0.75)		SW2 (RM 3.3)		SW3 (Green River; RM 10)
			surface	bottom	surface	bottom	mid-depth
Benzo(a)anthracene	4/48	yes (all 4 detects)	WB1 WB2	WB1	-	ST4	-
Benzo(a)pyrene	1/48	yes	-	-	-	ST4	-
Benzo(b)fluoranthene	6/48	yes (all 6 detects)	WB1 WB2	-	-	DB1 ST4	-
Benzo(k)fluoranthene	1/48	yes	-	-	-	ST4	-
Dibenzo(a,h)anthracene	1/48	yes	WB2	-	-	-	-
Indeno(1,2,3-cd)pyrene	2/48	yes (both detects)	WB2	-	-	ST4	-

ARAR – applicable or relevant and appropriate requirement
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DF – detection frequency

Insufficient detected cPAH data are available to fully evaluate relative to the CSM described for total PCBs. However, where detected results were available, these data appear to further support the CSM. The higher numbers of ARAR exceedances in the

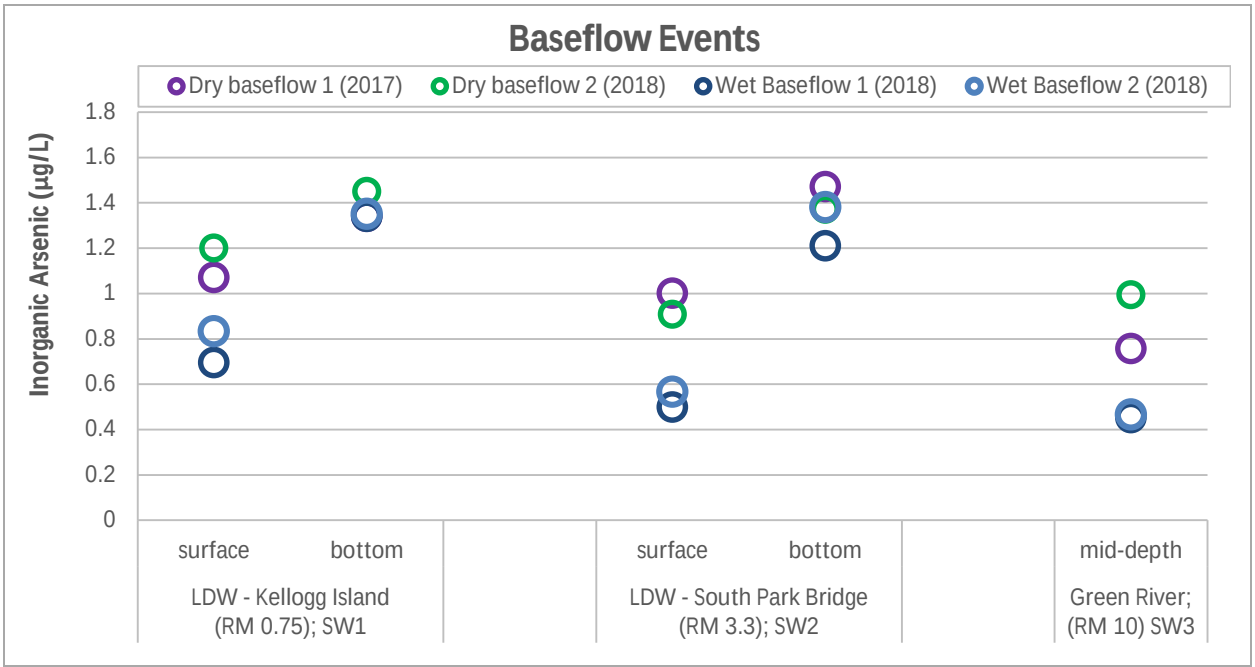
near-surface sample at SW1 and the near-bottom samples at SW2 indicate that concentrations are higher at these two locations, where concentrations of total PCBs are also highest.

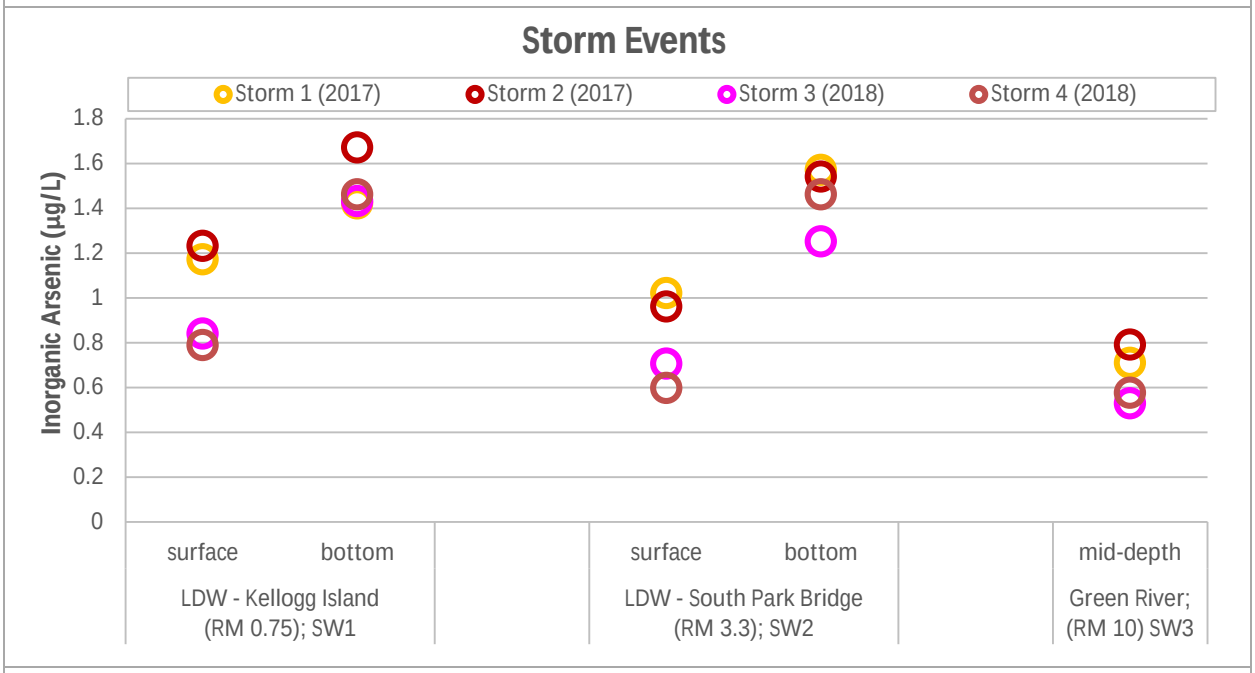
Available historical cPAH data were not suitable for comparison with Pre-Design Studies baseline data. No cPAHs were detected in any of the 1996/1997 King County water quality assessment (WQA) surface water samples, and RLs were higher for these samples. No other LDW cPAH surface water data were available for comparison.

3.2.1.3 Inorganic arsenic

Inorganic arsenic was detected in all 48 samples. Inorganic arsenic concentrations ranged from 0.466 to 1.72 µg/L in the LDW samples and from 0.451 to 0.993 µg/L in the Green River samples (Figure 3-5). Concentrations of inorganic arsenic were relatively consistent across events at each location and sampling depth. The following describes key observations regarding the inorganic arsenic concentrations in the surface water grab samples.

- **Baseflow vs. storm events** – Unlike total PCB concentrations, inorganic arsenic concentrations were relatively similar for the storm and baseflow events, although concentrations in near-surface water samples were 1.5 to 2 times higher during dry baseflow events than during wet baseflow events. For the storm events, the near-bottom water samples collected at SW1 and SW2 were similar across events. However, near-surface water samples collected during Storms 1 and 2 had inorganic arsenic concentrations that were about 1.5 times higher than those in samples from Storms 3 and 4. Storms 1 and 2 required a dry antecedent period before the storm and low dam release rates and were sampled within approximately 12 hours of the period of maximum rainfall intensity. Storm 3 was similar, but it was sampled during the period of peak rainfall. Storm 4 did not require a dry antecedent period and was sampled during a period of high dam release.
- **Near-surface vs. near-bottom** – For all sampling events, concentrations of inorganic arsenic in near-bottom water samples were higher than those in near-surface grab samples.
- **CSM** – Concentrations of inorganic arsenic further confirm the CSM for the LDW (Figure 3-3). Inorganic arsenic concentrations were highest in near-bottom water samples, but concentrations at both locations (i.e., SW1 and SW2) were relatively similar. In near-surface water samples, concentrations were lowest in upstream samples (SW3) and increased slightly with movement downstream (i.e., concentrations in near-surface samples were highest at SW1, while concentrations at SW2 were between those at SW1 and SW3).





The ARAR for inorganic arsenic is 0.14 µg/L, which is the national and Washington State criteria for the protection of human health (consumption of organism only). No inorganic arsenic marine AWQC are available.

Figure 3-5. Inorganic arsenic in Pre-Design Studies baseline surface water composite-grab samples

No historical inorganic arsenic surface water data are available for comparison with the 2017/2018 Pre-Design Studies baseline data, although arsenic (dissolved fraction) data are available for comparison. Arsenic data are available from three locations in 1996/1997 and from one location in 2011/2012 for comparison with the Pre-Design

Studies baseline dataset (2017/2918) (Figure 3-6). Details of these two older datasets are as follows:

- **1996/1997 King County WQA data** – Water quality samples were collected from October 31, 1996, through June 4, 1997, at three locations in the LDW, approximately RM 1.1, RM 2, and RM 4.9 (King County 1999). Discrete grab samples were collected using a Niskin sampler at two depths (1 m below the surface and 1 m above the bottom). Samples were collected weekly, as well as for three days following storm events.
- **2011/2012 King County receiving water characterization study** – Water quality data were collected monthly from June 2011 to December 2012 from one location in the LDW (at approximately RM 4.8) (Mickelson 2013). Discrete grab samples were collected from the center of the channel at a depth of 1 m below the water surface using a van Dorn-style device.

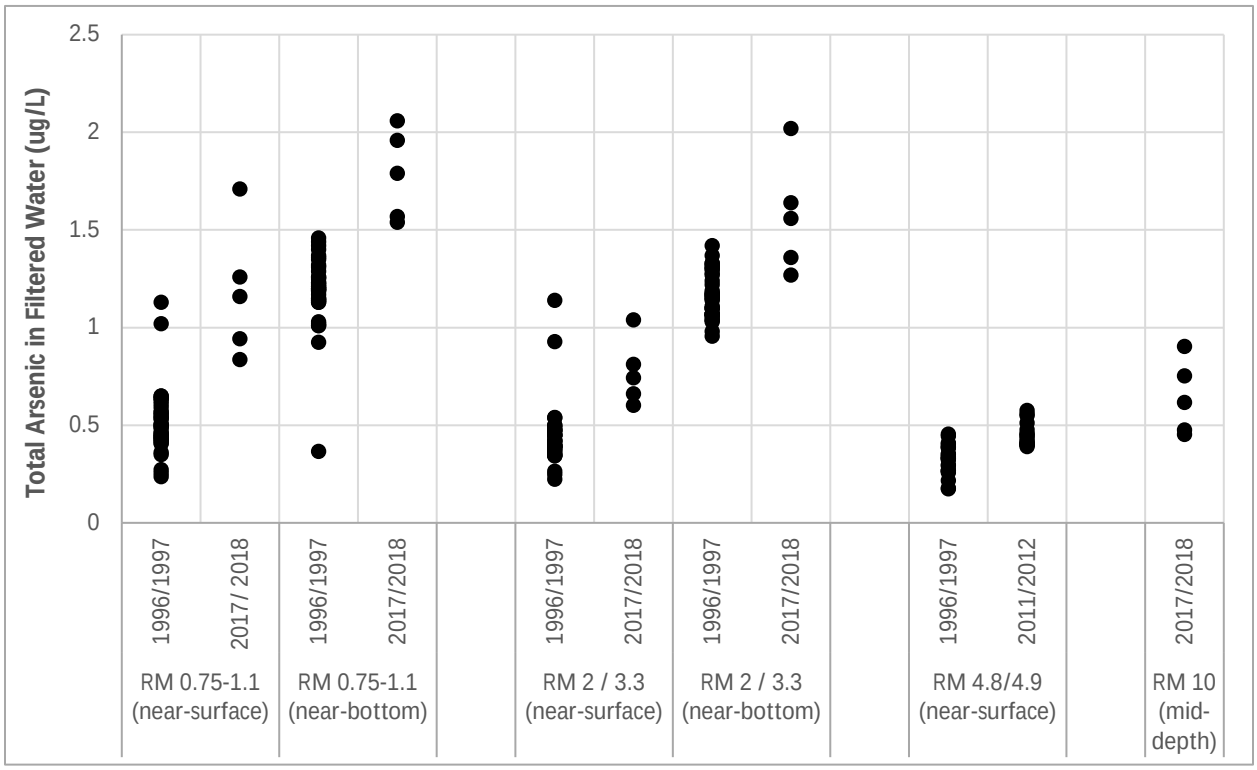
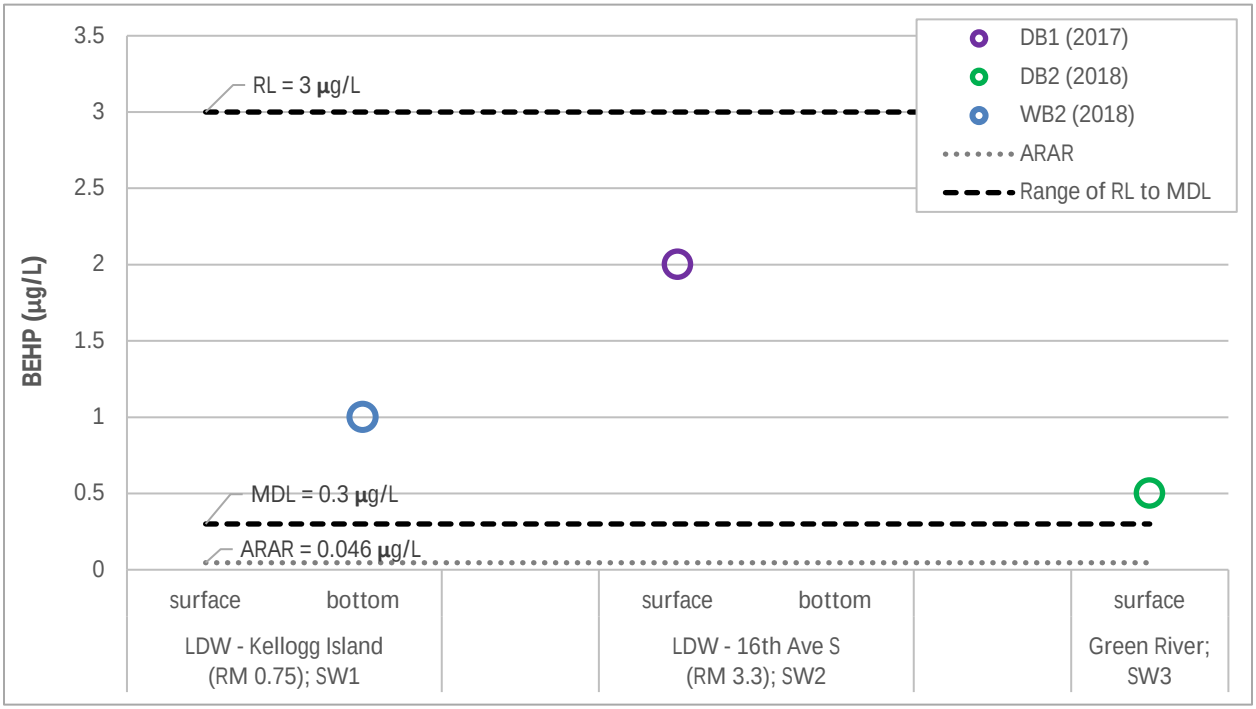


Figure 3-6. Comparison of total arsenic (in filtered samples) in historical LDW and Green River surface water grab samples

Thus, while the concentration of total arsenic (dissolved fraction) in the 2017/2018 samples appears higher than in the historical samples, this comparison is uncertain because of differences in sampling locations, depths, and methodology.

3.2.1.4 BEHP

BEHP, the only non-risk driver chemical with ARAR exceedances, was detected in 3 of the 48 surface water grab samples.[35] The three detected values were each from different baseflow sampling events and different locations (Figure 3-7). Other than the fact that BEHP was not detected in any of the storm event samples, too few data are available to decipher a pattern.



Note: Samples in which BEHP was not detected are not shown on this figure.

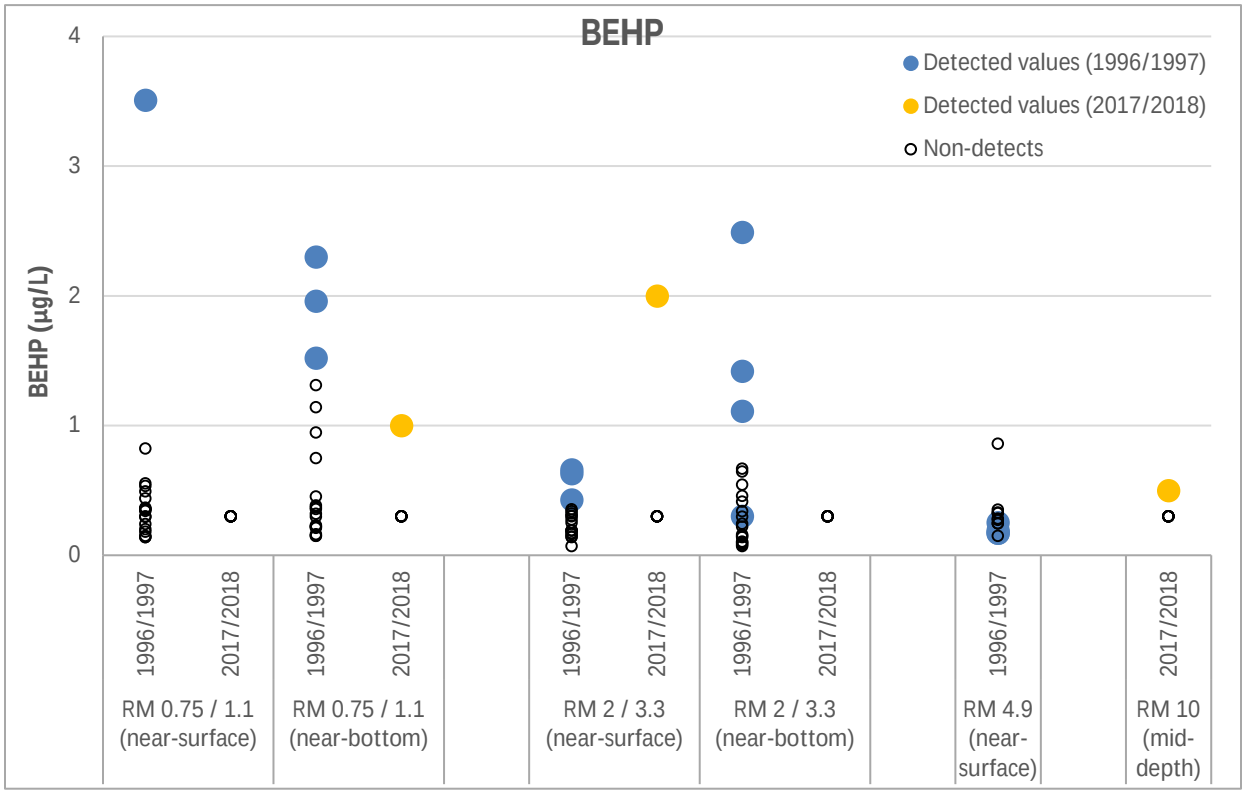
Figure 3-7. BEHP in Pre-Design Studies baseline surface water composite-grab samples

Historical 1996/1997 King County WQA data are available for BEHP (Figure 3-8). BEHP was detected in 19 of 94 surface water grab samples from the 1996/1997 event (detection frequency [DF] of 20%), with detected concentrations ranging from 0.14 to 23.8 µg/L.[36] These data were compared with the 2017/2018 data, in which the three detected concentrations ranged from 0.5 to 2 µg/L (Figure 3-8). Details regarding these three sampling events are discussed in Section 3.2.1.3. Thus, while the historical BEHP

[35] These detected concentrations were above the MDL (0.3 µg/L) but below the RL (3 µg/L) and thus were J-flagged to indicate estimated values. BEHP was not detected above the MDL of 0.3 µg/L in any other samples.

[36] As a result of laboratory contamination issues, BEHP was frequently detected in method blank samples. Results with values less than 10 times higher than the method blank were treated as non-detects per data validation guidelines. Results with values more than 10 times higher than the method blank are presented as detects, although these values may be biased high as a result of the laboratory contamination issue.

concentrations appear higher than those in the 2017/2018 samples, this comparison is uncertain because of differences in sampling locations, depths, and methodology.



Note: Non-detected values are shown as ½ RL for the 1996/1997 data, but as the MDL of 0.3 µg/L for the 2017/2018 data. The highest value (23.8 µg/L) for the 1996/1997 samples at RM 2 is not shown.

Figure 3-8. Comparison with historical BEHP concentrations in surface water

3.2.2 DQO 2 – baseline total PCB concentrations for trends

Passive samplers were used to estimate total PCB C_{free} in LDW surface water to establish a baseline for future trend analysis for DQO 2. Total PCB C_{free} in surface water under dry baseflow conditions were estimated using passive samplers deployed in the LDW for approximately 30 days. As described in the surface water data report (Windward 2018e), average dam release rates for the 2017 and 2018 deployments were similar (299 and 264 cfs, respectively). The total rainfall recorded during the 2017 deployment was 0.92 in. (the majority of which [0.68 in.] fell during a 27-hour period), which was more than the total rainfall recorded during the 2018 deployment (0.14 in.).

A total of 35 passive samplers were analyzed: 9 replicates[37] at each of two locations (PS1 at RM 3.3 and PS2 at RM 1.9) in both 2017 and 2018. The total PCB C_{free} in surface water

[37] The results for one replicate sample at PS1 (South Park Bridge) in 2018 were rejected due to issues with the PRCs for this sample (Windward 2018e).

estimated from the passive samplers are presented in Figure 3-9. For a given sampling year, concentrations at PS1 and PS2 were not significantly different ($p = 0.45$), but concentrations for 2017 and 2018 were significantly different from one another ($p < 0.001$).[38] Although the difference between the two sampling years was small (i.e., C_{free} of 1.26 ng/L for 2017 and 0.99 ng/L for 2018), it was statistically significant because of the low variability among replicate samples. It is unknown whether the differences in the sampling conditions (primarily the total rainfall) affected these results.

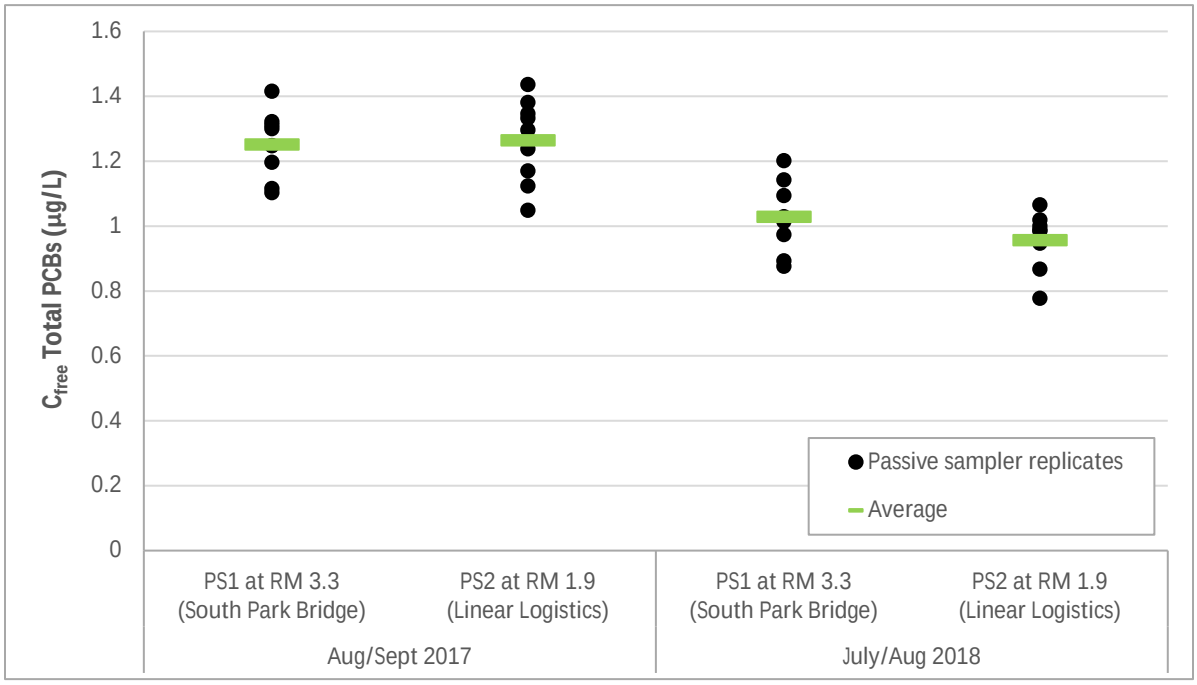


Figure 3-9. Total PCB C_{free} calculated from passive samplers

The two passive sampler deployment locations (PS1 at South Park Bridge [RM 3.3] and PS2 at Linear Logistics [RM 1.9]) had nearly identical means and variances (Table 3-6). A variance components analysis (Appendix B) indicated that of the total variance in the passive sampler dataset, 25% could be attributed to residual variability among replicate samplers, 75% could be attributed to year-to-year variability, and essentially 0% could be attributed to location-to-location variability. The results of this variance components analysis and a visual review of the data (Figure 3-9) indicate that the two locations provide redundant information about average total PCB concentrations.

[38] Statistical comparisons were done using a two-factor analysis of variance (ANOVA) design, with sampling location crossed with sampling year (Appendix B).

Table 3-6. Summary statistics for total PCB C_{free} data based on LDW passive samplers

Summary Statistic	Dry Baseflow 1 (2017)		Dry Baseflow 2 (2018)	
	PS1 (RM 3.3)	PS2 (RM 1.9)	PS1 (RM 3.3)	PS2 (RM 1.9)
Detection frequency	9 / 9	9 / 9	8 / 8[a]	9 / 9
Total PCB C_{free} – mean value (ng/L)	1.25	1.26	1.03	0.96
Total PCBs C_{free}– SD[b] (ng/L)	0.115		0.101	
CV = SD / mean	9.2%		9.5%	

[a] The results for one replicate sample at location PS1 (South Park Bridge) in 2018 were rejected due to issues with the PRC for this sample (Windward 2018e).

[b] The SD is equal to the residual standard error.

CV – coefficient of variation
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
PRC – performance reference compound
RM – river mile
SD – standard deviation

3.3 SUMMARY AND KEY POINTS

The baseline surface water data met the DQOs by providing a dataset for comparison to the surface water ARARs (DQO 1) and establishing a baseline total PCB concentration in surface water to evaluate trends (DQO 2). Key points for each risk driver chemical and the non-risk driver chemicals are presented in Table 3-7.

Table 3-7. Summary of key points for surface water

Chemical	Summary of Key Conclusions
DQO 1 – Comparison with ARARs	
Total PCBs	· PCBs were detected at concentrations above the ARAR for the human health criteria for consumption of organisms in all 48 surface water grab samples; no samples exceeded aquatic life WQC · Concentrations in near-bottom water samples were higher than those in near-surface water samples · Concentrations in the storm samples (particularly the near-bottom samples) were generally higher than those in the baseflow samples · Concentrations in dry baseflow samples were generally higher than those in wet baseflow samples · Data were consistent with the CSM. In the CSM, higher total PCB concentrations were expected in the bottom layer of the LDW with movement upstream, due to the increased residence time of bottom water and flux from sediment. Whereas, the total PCB concentrations in the surface layer were expected to increase from upstream to downstream, reflecting greater cumulative mixing with the bottom water.
Dioxins/ furans TEQ	· An ARAR was only available for 2,3,7,8-TCDD, which was not detected in any of the surface water grab samples · Of the remaining 18 congeners, 4 were detected in surface water grab samples

Chemical	Summary of Key Conclusions
cPAHs	· 6 of the 7 cPAHs were detected at concentrations above the lowest ARARs (all cPAHs except chrysene) · cPAHs were infrequently detected, so patterns of cPAH concentrations are uncertain. However, the available data appear to support the CSM · cPAH concentrations were higher in wet baseflow samples than in dry baseflow samples. The highest concentrations were detected in the near-bottom sample at SW2 (RM 3.3) during Storm 4, which was the storm sampled during high dam release conditions. cPAHs were not detected in any of the other storm samples.
Inorganic arsenic	· Inorganic arsenic was detected at concentrations above the ARAR for the human health criteria for consumption of organisms in all 48 surface water grab samples · As with PCBs, concentrations in near-bottom water samples were higher than those in near-surface water samples, and concentrations in dry baseflow samples were generally higher than those in wet baseflow samples. However, unlike total PCB concentrations, inorganic arsenic concentrations were relatively similar across the storm and baseflow event samples.
Non-risk driver chemicals	· BEHP, which was detected in 3 of 48 samples, was the only non-risk driver chemical detected at concentrations above the lowest ARAR
DQO 2 – Total PCB Trends Using Passive Sampler Data	
Total PCBs	· Average total PCB C_{free} estimated using the passive samplers were 1.26 ng/L in 2017 and 0.99 ng/L in 2018 · An analysis of the variance in these samples found that 75% of the total variance could be attributed to the year-to-year variability and 25% of the variance could be attributed to variability among replicate samples. Essentially 0% of the variance could be attributed to location-to-location variability.

ARAR – applicable or relevant and appropriate requirement
BEHP – bis(2-ethylhexyl) phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSM – conceptual site model
DQO – data quality objective
EF – exceedance factor
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
TCDD – tetrachlorodibenzo-p-dioxin
TEQ – toxic equivalent

4 Fish and Crab Tissue

This section provides an interpretation of the baseline fish and crab tissue data collected in accordance with the fish and crab QAPP (Windward 2017a).

4.1 DQOs and Data Collected

As described in the fish and crab tissue QAPP (Windward 2017a), composite tissue samples were collected to address the following two DQOs related to fish and crab tissue:

- **Fish and crab DQO 1 –** Establish baseline site-wide 95UCL tissue concentrations of risk drivers for comparison to target tissue levels (TTLs)[39] for RAO 1 (human health).
- **Fish and crab DQO 2** – Establish baseline site-wide mean tissue concentrations to assess trends following sediment remediation for contaminants with TTLs.

To address these DQOs, English sole (*Parophrys vetulus*), shiner surfperch (*Cymatogaster aggregata*), graceful crab (*Metacarcinus gracilis*), and Dungeness crab (*Metacarcinus magister*) were collected as described in Table 4-1. All tissue samples were analyzed for RAOs 1 and 4 risk drivers.[40] In addition, a subset of samples was analyzed for the non-risk driver chemicals, as specified in the ROD.[41]

[39] TTLs are specified in ROD Table 21 (EPA 2014).

[40] Risk drivers are PCBs, dioxins/furans, cPAHs, and arsenic (ROD Table 19) (EPA 2014). PCBs are the only risk drivers for RAO 4.

[41] Non-risk driver chemicals, as specified in the ROD (EPA 2014), include vanadium, TBT, select SVOCs (BEHP, carbazole, hexachlorobenzene [HCB], and pentachlorophenol [PCP]), and organochlorine pesticides.

Table 4-1. Summary of fish/crab tissue dataset

Species	Tissue Types Evaluated	No. Individuals Per Sample	Number of Baseline Samples	
			Total	By Sampling Area (Map 4-1)
English sole	fillet	10	12	6 samples of each tissue type from each of the 2 reaches
	whole body[a]	10	12	
Shiner surfperch	whole body	15	12	3 samples from each of the 4 subreaches
Graceful crab	edible meat	7	12	6 samples of each tissue type from each of the 2 reaches
	whole body[b]	7	12	
Dungeness crab	edible meat	3	3	for both tissue types, 2 samples from Reach 2 (3 crab each); 1 sample with 3 crabs that represented both reaches (1 crab from Reach 1 and 2 from Reach 2)
	whole body[b]	3	3	

[a] The whole-body concentration for English sole was calculated mathematically by combining the fillet and remainder tissue concentrations based on the fraction of the English sole whole body represented by each tissue type, as described in the fish and crab data report (Windward 2018h).

[b] The whole-body concentration for crab was calculated mathematically by combining the edible meat and hepatopancreas concentrations based on the fraction of the crab whole body represented by each tissue type, as described in the fish and crab data report (Windward 2018h).

RM – river mile

Fish and crab tissue data were collected in August/September 2017 for the target (or alternate) species as described in the QAPP (Windward 2018h). Insufficient numbers of Dungeness crab were collected during the 2017 sampling effort so, as specified in the fish and crab QAPP, graceful crab were collected as the alternate species (as discussed further below).

4.1.1 Evaluation of study design

The sampling design (i.e., number of individual specimens per composite and total number of composites per area) was established to achieve a target RME of 25% (Windward 2017a; Windward and Integral 2017b). This target RME was based on conservative assumptions about variability and was considered reasonable and achievable in light of analytical variability. Variability and RMEs were evaluated for each COC and tissue type for which TTLs were developed in the ROD (i.e., four tissue types for total PCBs and three for dioxins/furans) (EPA 2014). To develop the baseline sampling design for fish and crab tissues, the calculated sample size was based on a conservatively high estimate of variance; to further reduce variance, the number of individuals per composite was increased relative to the number per composite in the RI.[42] Both of these sample design features reduced the RME in the baseline tissue dataset.

[42] The number of organisms per composite in the RI was 5 for English sole, 10 for shiner surfperch, and 5 for graceful crab (or 5 to 18 for hepatopancreas crab samples). For the Pre-Design Studies samples, the number of organisms per composite is presented in Table 4-1.

As presented in Table 4-2, the DQOs were met for the baseline tissue samples (i.e., variability was lower than anticipated[43]), so the data are suitable for establishing baseline 95UCLs for comparison with TTLs and mean concentrations for use in future monitoring. With regard to using the baseline dataset for future comparisons, the MDD for baseline and future sampling ranged from 10 to 25% for total PCBs and from 14 to 24% for dioxin/furan TEQ for the species/tissue types for which a TTL was available (see Appendix B).

Table 4-2. Data quality evaluation for fish and crab tissue

COC	Species and Tissue Type	Distribution	RME (%)	RME Target	Data Quality Goals Met?
Total PCB Aroclors (µg/kg ww)	English sole – fillet	normal	10%	25%	yes
	shiner surfperch – whole body	normal	5%	25%	yes
	crab – edible meat	normal	8%	25%	yes
	crab – whole body	normal	8%	25%	yes
Dioxin/furan TEQ (ng/kg ww)	English sole – whole body	normal	6%	25%	yes
	crab – edible meat	normal	10%	25%	yes
	crab – whole body	normal	9%	25%	yes

CV – coefficient of variation
COC – contaminant of concern
PCB – polychlorinated biphenyl
RME – relative margin of error
TEQ – toxic equivalent
ww – wet weight

The fish and crab tissue data were validated, and no issues were identified with the data that would limit their use for comparison with TTLs or for the calculation of means to evaluate trends. Thus, the baseline fish and crab tissue data met DQOs 1 and 2 by providing a dataset within targeted RMEs that represents site-wide conditions and that can be used to calculate 95UCLs for comparison with TTLs and means in order to evaluate trends.

4.1.2 Stable isotope evaluation for crab

An important factor in interpreting the crab tissue data for the LDW is the inclusion of several species of crab in the LDW dataset. The majority of the tissue samples were either graceful crab (also called slender crab) or Dungeness crab. In addition, several red rock crab samples were collected in 1998. For the 2017 baseline sampling, Dungeness crab were the primary crab target species, because they are the species of the most interest from a human health perspective. However, the abundance of Dungeness

[43] Based on these results, it was not necessary to analyze any of the archived fish/crab tissue samples to help reduce the variability.

crab can vary considerably from year to year; in 2017, graceful crab was needed as a surrogate despite considerable effort expended to collect Dungeness crab.[44]

The relatively low numbers of Dungeness crab encountered in the LDW during sampling is consistent with the Washington Department of Fish and Wildlife's (WDWF's) characterization of 2017 as a "downturn year" for Dungeness crab (Rothaus 2017). WDFW further noted that the catch rates for Dungeness in Puget Sound were unusually low in 2017. This information, coupled with the fact that the siltier substrate of estuarine systems such as the LDW is not preferred habitat for Dungeness crab, resulted in the decision to collect graceful crab (which are more tolerant of short-term salinity fluctuations and siltier substrates) as the alternate species.

To evaluate the use of graceful crab as a surrogate, carbon and nitrogen stable isotope analyses were conducted to assess the similarity of trophic position and general habitat use of the two crab species. This section discusses the results of the stable isotope analyses conducted.

Carbon and nitrogen stable isotopes are commonly employed in toxicity and food web studies to investigate trophic dynamics. Specifically, $\delta^{15}N$ provides information about the trophic position and diet of consumers (Peterson and Fry 1987; Fry 1988; Peterson et al. 1985). $\delta^{13}C$ is useful for distinguishing among different food web types (e.g., different types of primary producers; terrestrial vs. marine sources) or the locations in which consumers feed along a salinity gradient (e.g., Stewart et al. 2004; France 1995). Stable isotope results for Dungeness and graceful crab in the LDW are shown in Table 4-3 and Figure 4-1.

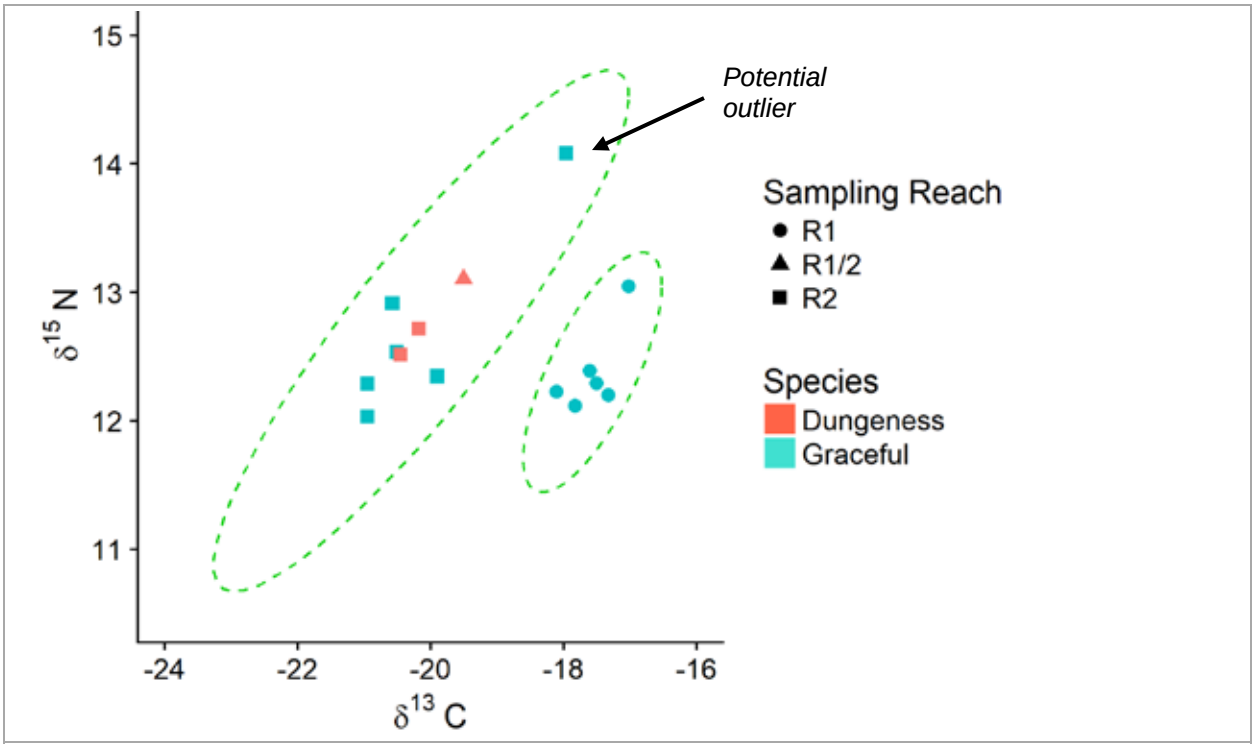
Table 4-3. Summary of stable isotope results for crab tissue samples

Species/Area	Count of Edible Meat Composite Samples	Range of Stable Carbon Isotope Values (i.e., $\delta^{13}C$ Values) (per mil)[a]	Range of Stable Nitrogen Isotope Values (i.e., $\delta^{15}N$ values) (per mil)[a]
Dungeness Crab			
Reaches 1 and 2[b]	1	-19.5	13.1
Reach 2	2	-20.5 to -20.2	12.5 to 12.7
Graceful Crab			
Reach 1	6	-18.1 to -17.0	12.1 to 13.0
Reach 2	6	-21.0 to -18.0	12.0 to 14.1

[a] Stable isotope values are reported as "delta" values in parts per thousand, which are also commonly referred to as "per mil." These values indicate the enrichment or depletion of the stable isotope relative to the standard (Stable Isotope Ecology Laboratory 1997).

[b] Because relatively few Dungeness crab were collected during the 2017 sampling, this Dungeness crab composite was made up of three crabs (one crab from Reach 1 and two crabs from Reach 2).

[44] Crab traps were deployed in the LDW over the course of five days, with soak times ranging from two to four hours, or up to overnight. This was an increased level of effort from what was specified in the fish and crab QAPP in an effort to catch more Dungeness crab (Windward 2017a). Despite this, a total of only 9 Dungeness crab (7 of which were larger than the legal size limit of 6.25 in.) were collected during the 2017 sampling (as compared with the target of 60).



Note: The ellipses shown in this figure represent the 90% probability ellipses, which are the 90th quantiles from a bivariate normal distribution with the mean, variance, and correlation exhibited by the graceful crab samples in each reach. There were insufficient data to calculate ellipses for Dungeness crab.

Figure 4-1. Scatterplot of stable isotope results for crab

The stable isotope results indicate the following:

- **Dungeness crab and graceful crab have similar trophic positions** – Excluding one potential outlier,[45] $\delta^{15}N$ values for both crab species are similar and range from 12 to 13.1. In general, a difference in trophic level corresponds to a 3 to 5 per mil[46] difference in $\delta^{15}N$ (Peterson and Fry 1987). In Figure 4-1, the probability bounds are drawn around the graceful crab data only, because insufficient data were available to estimate probability bounds for Dungeness crab. The Dungeness crab samples fall within the 90% probability ellipses for graceful crab from the same reach, an indication that the results are similar. The similarity of $\delta^{15}N$ in Dungeness and graceful crab in the LDW indicates that the two species occupy similar trophic positions and are ecologically comparable.

[45] One sample was identified as a potential outlier using Tukey's outlier test (i.e., values greater than 1.5 times the interquartile range from an outer quartile).

[46] Stable isotope values are reported as "delta" values in parts per thousand, which are also commonly referred to as "per mil." These values indicate the enrichment or depletion of the stable isotope relative to the standard (Stable Isotope Ecology Laboratory 1997).

- **No difference in trophic level by reach** – The overlap in stable nitrogen isotope values between Reaches 1 and 2 indicates that the trophic positions of Dungeness and graceful crabs and their prey are similar by reach.
- **Stable carbon isotopes results correlate with salinity** – $\delta^{13}C$ values are similar for the two crab species and differ only by reach, with higher $\delta^{13}C$ for crabs in Reach 1 (as compared with those from Reach 2). Increased salinity (and more marine food sources) generally correlates with higher carbon stable isotope values (e.g., Claudino et al. 2013; Garcia et al. 2007). Thus, the higher $\delta^{13}C$ values for the Reach 1 samples match the expected result.

Based on the results of this evaluation, the use of graceful crab as a surrogate for Dungeness crab to evaluate progress towards the TTL is reasonable, given the species' similar trophic position and general habitat use. Future sampling events will target both types of crab. Graceful crab, which are commonly present in the LDW (and less subject to "downturn years") can reliably be collected to evaluate trends. Dungeness crab will be targeted and collected when present because they are the species of greatest interest from a human health perspective.

4.2 FISH AND CRAB TISSUE DATA INTERPRETATION

This section presents the interpretation of fish and crab tissue data, including the comparison of site-wide baseline tissue 95UCLs with TTLs, and the calculation of mean concentrations to assess trends for the risk driver concentrations. Additional data (e.g., spatial distribution, comparisons with historical and background data, and food web model [FWM] results) are also presented as available.

4.2.1 Evaluation of tissue data for risk drivers with TTLs

4.2.1.1 Comparison with TTLs

The ROD (EPA 2014) presented TTLs for total PCBs and dioxins/furans for crab and fish tissue (Table 4-4).[47] Non-urban background tissue datasets were developed for the four risk driver chemicals as part of the LDW FS (AECOM 2012). These datasets were used in the ROD (EPA 2014) to develop TTLs for tissue: either the non-urban background concentration or the species-specific RBTC, whichever was higher.[48] While the total PCBs TTL for pelagic fish was set equal to the species-specific RBTC, all other TTLs for fish and crab were based on the 95UCLs of non-urban background tissue datasets.

[47] TTLs for cPAHs and inorganic arsenic were developed only for clams, because clams represent the majority of the human health risk associated with these chemicals in the HHRA.

[48] Species-specific RBTCs were presented in the LDW FS (AECOM 2012), and were developed based on an acceptable excess cancer risk level of 1×10^{-6} for the seafood consumption reasonable maximum exposure scenarios. These species-specific RBTCs were developed with the assumption that the relationship between concentrations in the different seafood types in the market basket would remain the same over time and following the remedy (i.e., would decrease at the same rate).

Table 4-4. TTLs for fish and crab and their bases

Risk Driver	TTL	TTL Basis	Non-urban Background Data			
			DF	Range of Detected Values	Mean	95UCL
Total PCBs (µg/kg ww)						
Benthic fish (fillet)	12	non-urban background	158/242	1.3–75.4	11	12
Pelagic fish (whole body)	1.8	species-specific RBTC	-	-	-	-
Crab (edible meat)	1.1	non-urban background	17/17	0.43–1.9	0.86	1.1
Crab (whole body)	9.1	non-urban background	15/15	3.0– 6	7.1	9.1
Dioxin/furan TEQ (ng/kg ww)						
Benthic fish (whole body)	0.35	non-urban background	7/7	0.15–0.42	0.28	0.35
Crab (edible meat)	0.53	non-urban background	27/27	0.027–1.4	0.57	0.53
Crab (whole body)	2.0	non-urban background	25/25	0.089–5.1	0.81	2.0

Note: Values in this table are reproduced from the LDW ROD and ROD errata (Tables 4[49] and 21) (EPA 2014, 2015a). Fish/crab TTLs were not developed for the other two risk drivers (inorganic arsenic and cPAHs), because the majority of the risk associated with these chemicals is attributable to the consumption of clams.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DF – detection frequency
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
ROD – record of decision
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

Site-wide 95UCL concentrations in baseline fish and crab tissue were calculated for comparison with the TTLs to address DQO 1(Table 4-5). Details regarding the calculation of the 95UCLs are presented in Appendix B. For total PCBs, the 95UCLs were well above the TTL for all four tissue types for which TTLs were available (Table 4-5). For dioxin/furan TEQ, the site-wide 95UCL for whole-body English sole was greater than the TTL, whereas the site-wide 95UCLs for crab (both edible meat and whole-body tissue) were below the TTL (Table 4-5). In addition to the 95UCLs, Table 4-5 presents the mean values for DQO 2; these means will be used in trend analysis with future monitoring data.

[49] Table 4 of the ROD is titled *Summary of PCB, arsenic, cPAH, and dioxin/furan data for natural background concentrations in fish and shellfish tissue.*

Table 4-5. Comparison of baseline fish and crab tissue data with TTLs

COC	Species and Tissue Type	n	Mean Detect	Min. Detect	Max. Detect	Normal 95UCL[a]	TTL	95UCL < TTL?
Total PCB Aroclors (µg/kg ww)	English sole – fillet	12	259	144.6	442	286	12	no
	shiner surfperch – whole body	12	407	308	515	426	1.8	no
	graceful crab – edible meat[b]	12	115	61.1	165 J	124	1.1	no
	graceful crab – whole body[b]	12	255	147.3	359 J	275	9.1	no
Dioxin/furan TEQ (ng/kg ww)	English sole – whole body	12	1.18	0.699 J	1.50 J	1.25	0.35	no
	graceful crab – edible meat[b]	12	0.41	0.267 J	0.550 J	0.45	0.53	**yes**
	graceful crab – whole body[b]	12	1.21	0.744 J	1.73 J	1.32	2.0	**yes**

[a] 95UCLs are for the stratified site-wide mean concentration. They were calculated using a t-interval (the assumption of normality was not rejected) and n = 12 for each tissue type; degrees of freedom were 8 for shiners and 10 for other tissues.

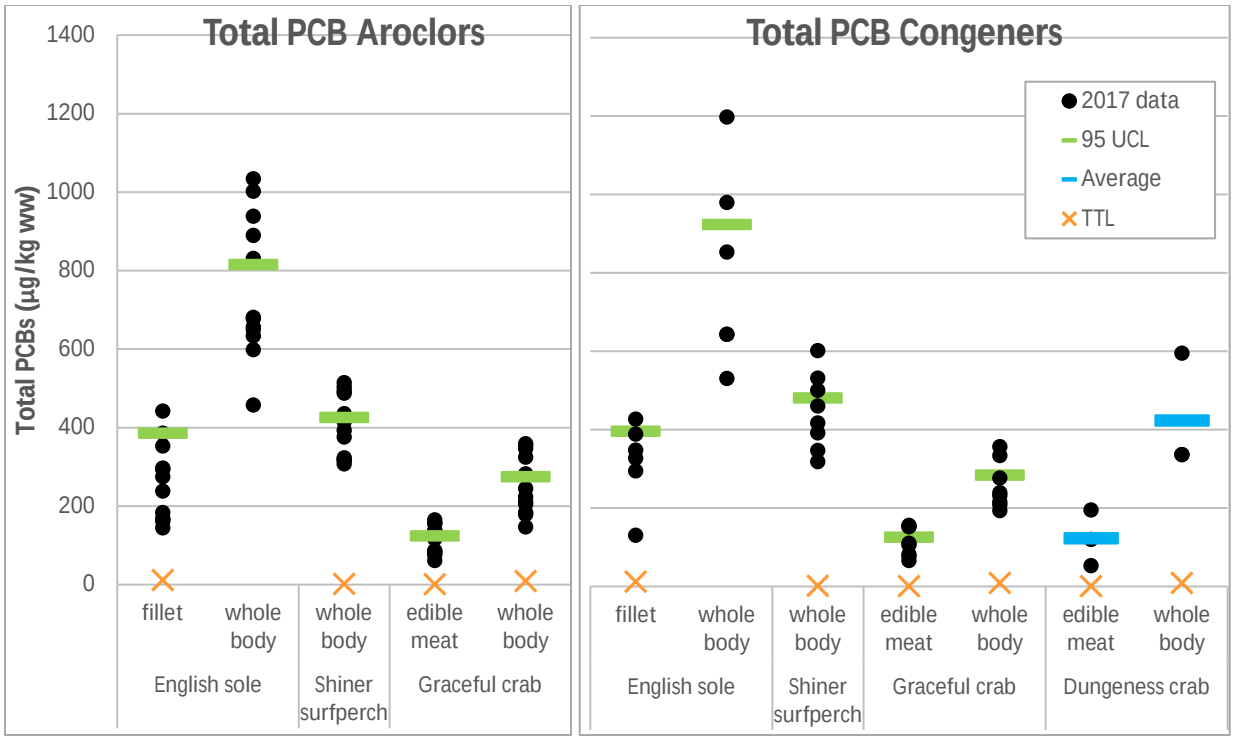
[b] TTL in ROD Table 21 was based on Dungeness crab; the LDW data are for graceful crab because a sufficient number of Dungeness crab were not available.

95UCL – 95% upper confidence limit (on the mean)
COC – contaminant of concern
J – estimated concentration
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
ROD – record of decision
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

Additional details regarding spatial distributions and comparisons of baseline tissue data with available historical data are presented for total PCBs and dioxins/furans in the subsections below.

4.2.1.2 Total PCBs

As described in the QAPP (Windward 2017a), all baseline fish and crab tissue samples were analyzed for PCB Aroclors, and a subset were also analyzed for all 209 PCB congeners. Thus, both total PCB Aroclors and total PCB congeners results are presented in Figure 4-2, which presents the data in detail. In general, total PCBs calculated as the sum of Aroclors and congeners were similar, although total PCBs based on Aroclors were generally slightly lower than those based on congeners (see Appendix B for details).



Notes: Total PCB TTLs are available for all fish and crab species/tissue types, with the exception of English sole whole-body tissue. The crab TTLs in the ROD are for Dungeness crab, but both graceful and Dungeness crab data are compared to the TTL in this figure. Average values are presented where 95UCLs could not be calculated.

Figure 4-2. Total PCB concentrations in Pre-Design Studies baseline fish/crab tissues compared with TTLs

The remainder of this section presents a discussion of temporal and spatial trends for total PCBs by species (i.e., English sole, shiner surfperch, and crab), as well as a discussion of the LDW FWM performance relative to the Pre-Design Studies baseline dataset.

Total PCBs and English Sole – Trends and Spatial Patterns

English sole fillet and whole-body data in the LDW RI dataset were collected as far back as 1992 (fillet tissue) and 2004 (whole-body tissue); the events for which data are available are summarized in Table 4-6. This table also highlights differences in the sampling methods and events (e.g., number of fish per composite and sampling area) and presents the average percent lipid values for each sampling event. Although lipid fractions can provide useful information for the interpretation of concentration data, the uncertainties associated with these fractions (particularly for historical data) must be considered.[50] When comparing total PCB data over such a large time span, it is

[50] Lipid content in fish may be affected by fish condition, size, age, sex, reproductive status, genetic background, diet, water temperature, and seasonality (Mraz 2012; Iverson et al. 2002). Although consideration of lipid fractions can be useful when interpreting concentration data, it is important to

important to note that changes in PCB analytical methods, extraction methods, and quantification techniques also present uncertainties for comparing datasets.

Table 4-6. Summary of available English sole tissue data

Sampling Month/Year	Fillet		Whole Body		No. of Fish per Composite	Sampling Area	Sampling Program
	n	Average Lipid (%)	n	Average Lipid (%)			
May 1992	3 (skinless)	0.48	-	-	10	near Kellogg Island only	PSAMP
May 1995	3 (skinless)	0.35	-	-	20	near Kellogg Island only	PSAMP
Dec 1995	3 (skinless)	11	-	-	6	near RM 1 only	EVS 1995
May 1997	3 (skinless)	0.30	-	-	20	near Kellogg Island only	King County WQA
October 1998	3 (skinless)	nr	-	-	5	RM 2.1 and RM 3.6	WSOU
August 2004	7 (skin-on)	2.9	21	5.8	5	site-wide	LDW RI
Aug/Sept 2005	10 (skin-on)	3.5	21	5.2	5	site-wide	LDW RI
Sept 2006	-	-	6	3.7	5	near Kellogg Island only	King County
Sept 2007	19 (skin-on)	3.0	9	6.2	5	site-wide	LDW RI
Aug/Sept 2017	12 (skin-on)	2.3	12	5.4	10	site-wide	LDW Pre-Design Studies

AOC – Administrative Order on Consent
EVS – EVS Environment Consultants
LDW – Lower Duwamish Waterway
nr – not reported
PSAMP – Puget Sound Ambient Monitoring Program
RI – remedial investigation
RM – river mile
WQA – water quality assessment
WSOU – Waterway Sediment Operable Unit

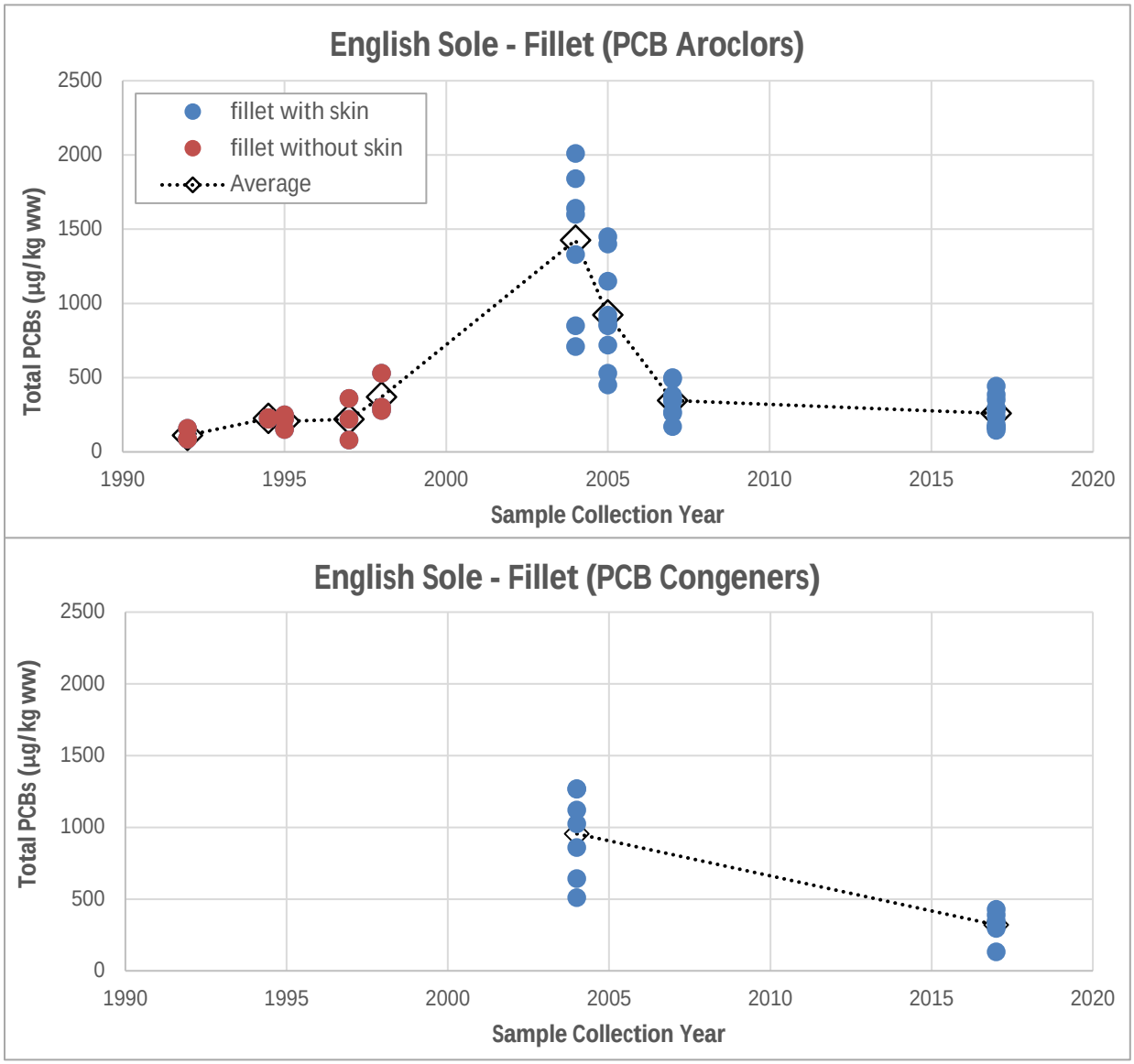
Temporal Evaluation

English sole were collected site-wide by the Lower Duwamish Waterway Group (LDWG) in 2004, 2005, and 2007 as part of the RI, and were collected by LDWG in 2017 as part of the Pre-Design Studies baseline sampling. These samples were collected and analyzed using similar methods throughout this time period (Windward 2004, 2005, 2017a), and the samples had similar lipid fractions (Table 4-6), allowing for clear temporal comparisons.

During this time period, total PCB concentrations were highest in 2004 following dredging remediation work in the LDW and the West and East Waterways that had occurred in 2003/2004; concentrations decreased from 2005 to 2007 (Figures 4-3 and 4-4). A statistical comparison of the total PCB Aroclor data from 2007 to 2017 indicated that total PCB concentrations in fillet tissues from 2017 were significantly lower than those in 2007 (259 µg/kg wet weight [ww] vs. 361 µg/kg ww; $p = 0.02$);

recognize that there is uncertainty regarding the analytical methods used to measure lipid concentrations in the historical data. Lipid fractions for the older data were likely determined using a variety of methods and extraction solvents, which can result in large differences in lipid fractions for the same tissue samples. Differences in extraction methods can also affect comparability.

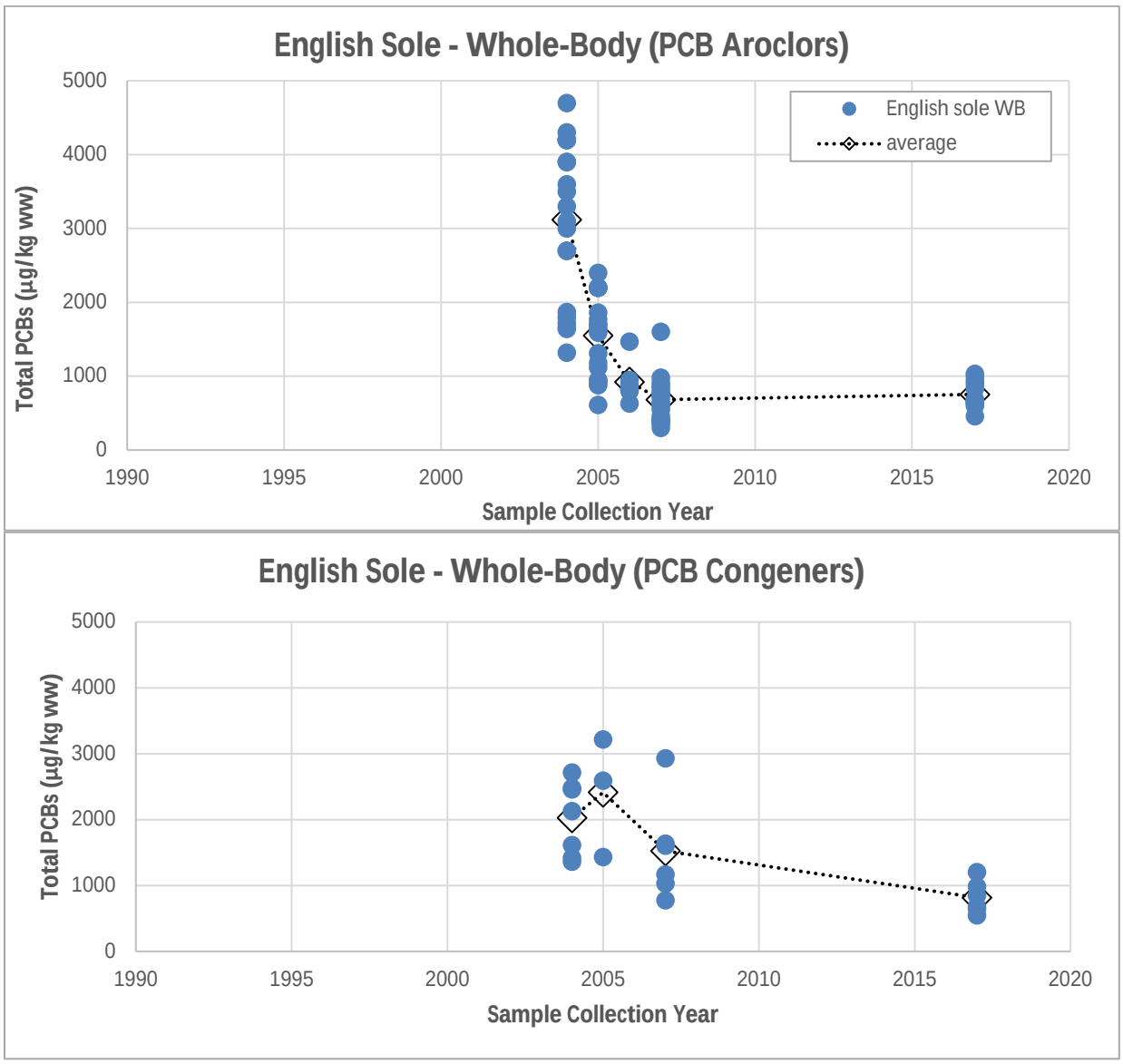
whole-body tissue concentrations were not significantly different (704 µg/kg ww in 2017 vs. 709 µg/kg ww in 2007; $p > 0.05$) (Figure 4-4).[51] A comparison between the 2007 and 2017 total PCB congener concentrations in whole-body tissues was also not significantly different (808 µg/kg ww in 2017 vs. 1,640 µg/kg ww in 2007; $p > 0.05$) because of the relatively small sample size and higher level of variance in the 2007 data (Figure 4-4). Insufficient PCB congener data were available to complete a congener comparison for English sole fillet tissue.



Note: Details regarding the samples included in these figures are presented in Table 4-6. The data collected in the 1990s were from specific areas in the LDW (i.e., are not representative of site-wide conditions).

Figure 4-3. Total PCB concentrations in English sole fillet tissue over time

[51] Statistical comparisons were done using a nested ANOVA design, with sampling reach nested within sampling year (Appendix B).

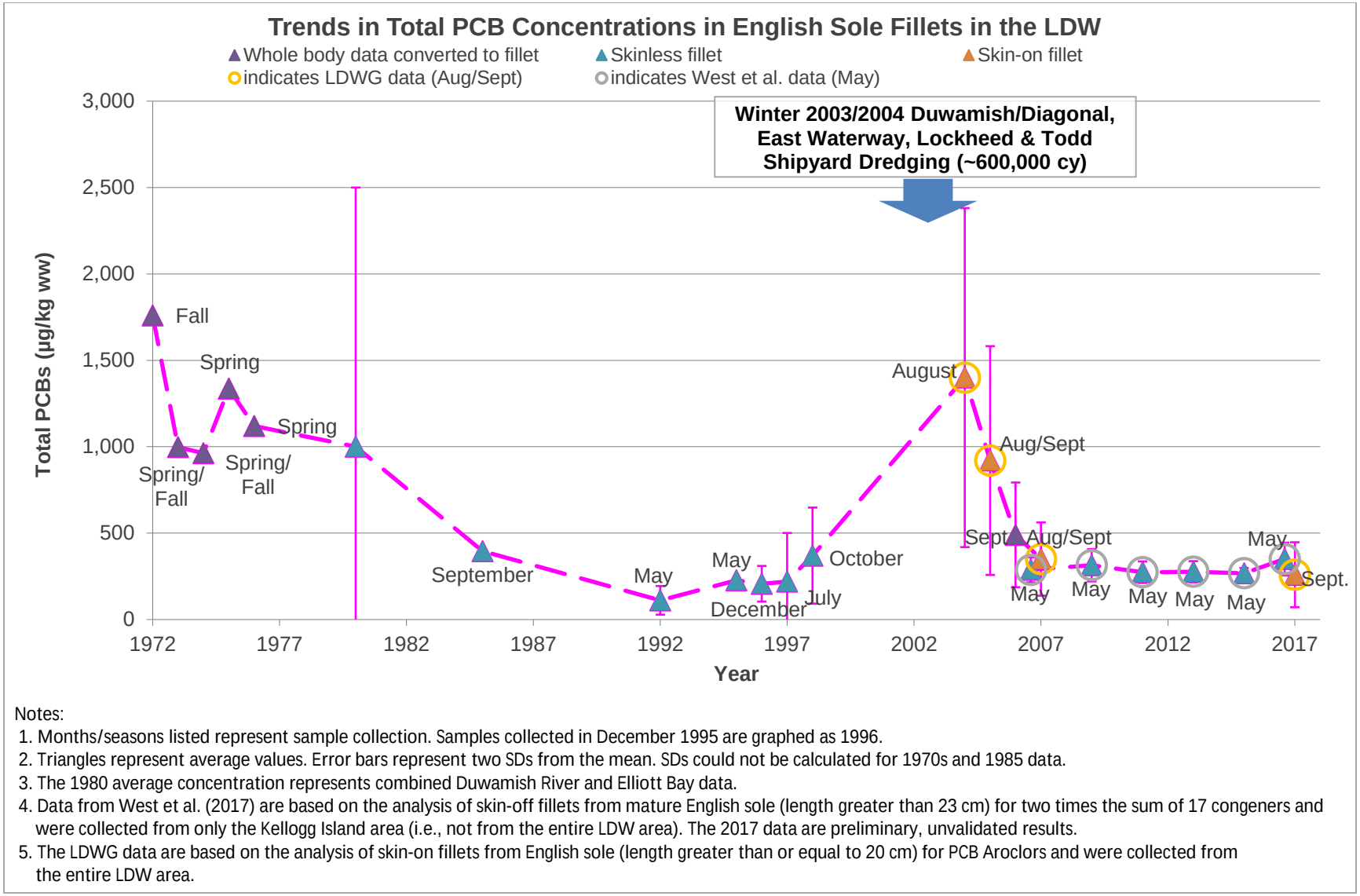


Note: Details regarding the sampling events included in these figures are presented in Table 4-6. The 2006 data were collected from a specific area (i.e., are not representative of site-wide conditions).

Figure 4-4.Total PCB concentrations in English sole whole-body tissue over time

In addition to the tissue dataset collected by LDWG and some older data included in the RI dataset, English sole fillet data from the LDW collected by other parties were compiled; these data are presented in Figure 4-5. Differences exist in the sampling, sample preparation, and analytical methods used for these historical datasets relative to both each other and to the LDWG sampling events. For example, many of the historical datasets presented data for skin-off English sole fillets (pre-2004 data in Figure 4-3), so the RI investigated whether total PCB concentrations would be significantly different in skin-off vs. skin-on English sole fillets. As discussed in the LDW RI, the total PCB concentrations in English sole fillet samples with and without skin were determined not

to be significantly different, meaning that the presence or absence of skin is not anticipated to impact historical data comparisons (Windward 2010b).



Notes:

1. Months/seasons listed represent sample collection. Samples collected in December 1995 are graphed as 1996.
2. Triangles represent average values. Error bars represent two SDs from the mean. SDs could not be calculated for 1970s and 1985 data.
3. The 1980 average concentration represents combined Duwamish River and Elliott Bay data.
4. Data from West et al. (2017) are based on the analysis of skin-off fillets from mature English sole (length greater than 23 cm) for two times the sum of 17 congeners and were collected from only the Kellogg Island area (i.e., not from the entire LDW area). The 2017 data are preliminary, unvalidated results.
5. The LDWG data are based on the analysis of skin-on fillets from English sole (length greater than or equal to 20 cm) for PCB Aroclors and were collected from the entire LDW area.

Figure 4-5. Total PCB concentrations in English sole fillets over time (1972 to 2017)

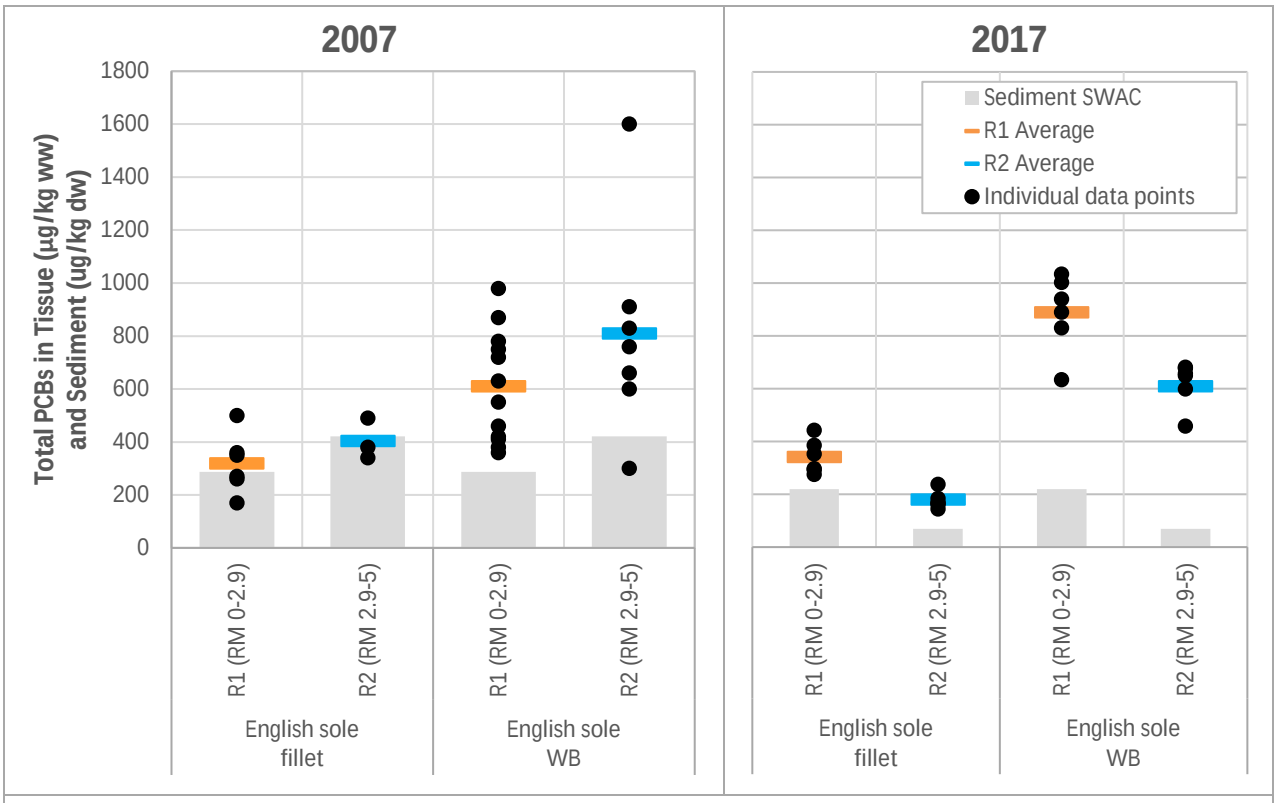
Other differences in historical datasets include collection location, season, lipid fraction, compositing details, and analytical methods (see notes on Figure 4-5). These differences are important to consider when interpreting these data, since they may impact some of the year-to-year variation observed in the dataset. For example, the lipid fraction of tissue collected in May is generally lower than that for tissue collected in August/September.

Despite these uncertainties, a general discussion of the observed trends is useful. In general, the data suggest that concentrations of total PCBs in English sole fillet were much higher in the 1970s (average concentrations ranging from 960 to 1760 µg/kg ww), and that they decreased in the 1980s, consistent with the 1979 ban of PCBs in the United States. Concentrations continued to decrease during the 1990s, with average concentrations in samples ranging from about 100 to 400 µg/kg ww (about five times lower, on average, than during the 1970s). As noted, a spike in concentrations was observed in samples collected in 2004 (i.e., samples collected after the 2003/2004 dredging); similar responses to dredging operations have been observed at other sites throughout the United States (Louis Berger 2010; Patmont et al. 2018). The data indicate that concentrations continued to recover in 2005 and 2006 and had returned to concentrations similar to those observed in pre-dredge conditions (i.e., 1990s concentrations) by 2007. The West et al. (2017) data collected every other year between 2007 and 2017 were found to be similar among all years.

Spatial Evaluation

Figure 4-6 presents English sole tissue and surface sediment total PCB data by reach for 2007 and 2017. In general, concentrations by reach in sediment and English sole tissue followed a similar pattern:

- In 2007 (i.e., prior to early actions at Boeing Plant 2/Jorgensen Forge, Slip 4, and T-117, but more than two years after Duwamish/Diagonal dredging in 2003/2004), total PCB concentrations in sediment were about 1.5 times higher in Reach 2 than in Reach 1. Similarly, average concentrations in English sole tissue were generally higher in Reach 2 than in Reach 1 (Figure 4-6).
- In 2017, total PCB concentrations in sediment were lower in both reaches than they had been in 2007 (by factors of 1.3 and 6.1 for Reaches 1 and 2, respectively), and the concentration pattern in sediment was reversed—concentrations were higher in Reach 1 sediment (by about a factor of 3) than in Reach 2. This general pattern was also observed in English sole tissue.



Media	Concentration of Total PCBs							
	2007				2017			
	Fillet		Whole Body		Fillet		Whole Body	
	Reach 1	Reach 2	Reach 1	Reach 2	Reach 1	Reach 2	Reach 1	Reach 2
Sediment SWAC (µg/kg dw)	287	421	287	421	219	69	219	69
Average concentration in tissue (µg/kg ww)	318	403	609	809	341	180	888	609
Average lipid (%)	3.1	2.7	6.3	6.1	2.4	2.1	5.4	5.4

Figure 4-6. Comparison of total PCB Aroclor concentrations in English sole and surface sediment in 2007 and 2017 by reach

Although there is uncertainty associated with the typical foraging area and movement of English sole in the LDW (Appendix D of Windward 2010b), the data suggest that a relationship may exist at the reach level within the LDW (i.e., tissue concentrations appear to reflect trends in sediment concentrations on a reach basis). This conclusion matches information in available literature, which notes that larger-scale movement primarily occurs as part of seasonal spawning migration (e.g., Lassuy 1989).

Total PCBs and Shiner Surfperch – Trends and Spatial Patterns

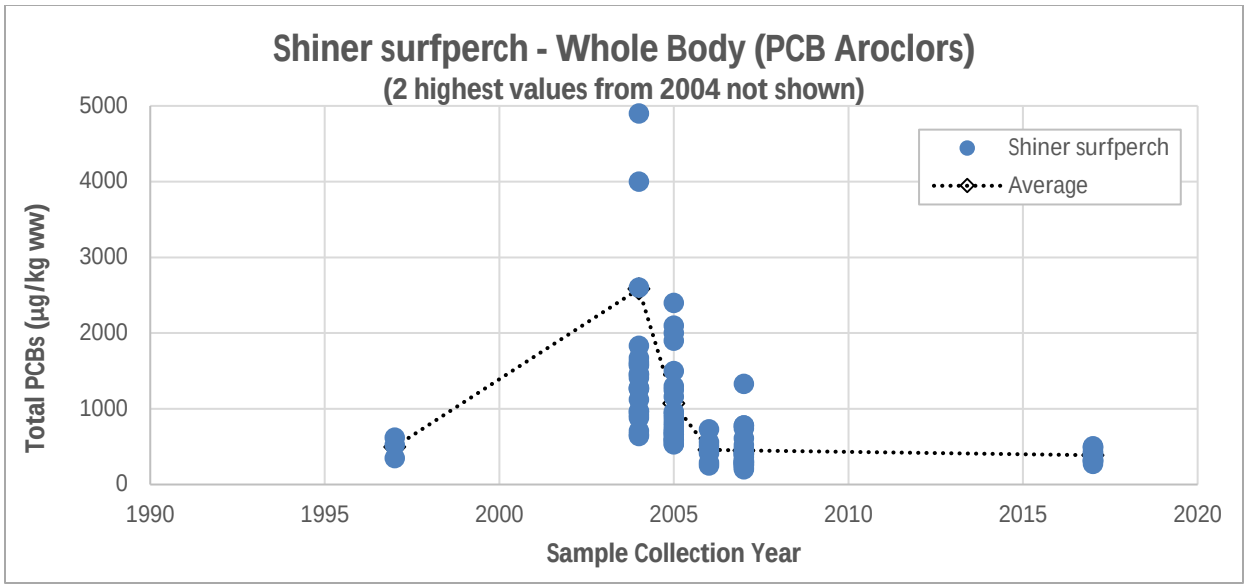
Total PCB concentrations in shiner surfperch have also been monitored over time. Data included in the RI dataset were reported for 1997, 2004, 2005, 2006, and 2007 prior to the

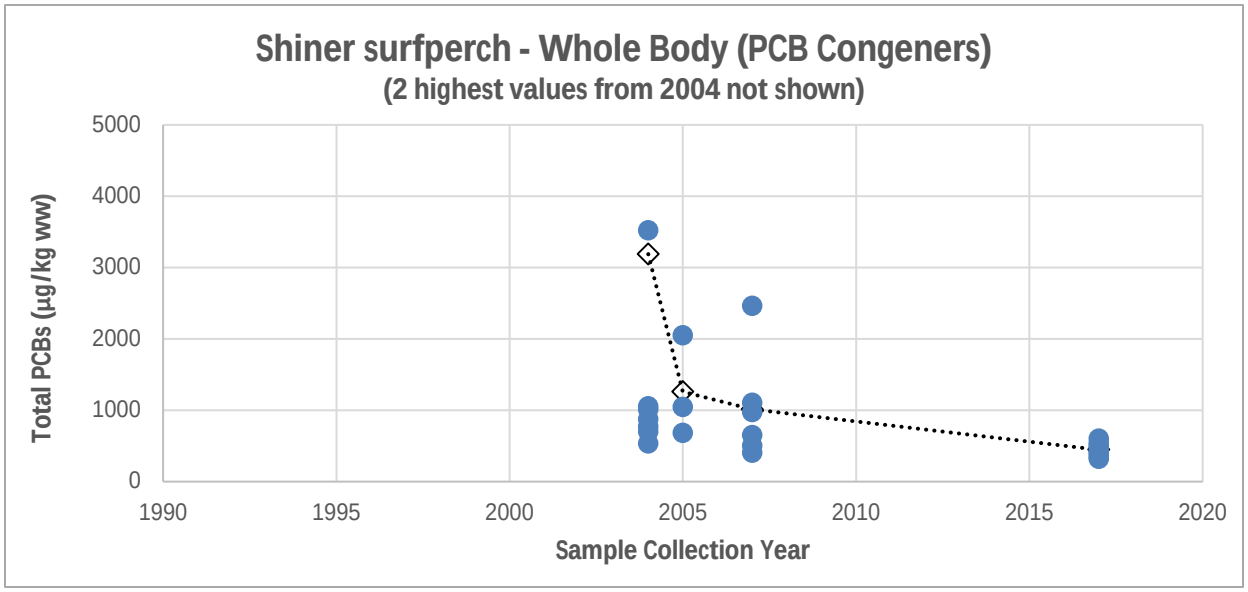
baseline sampling in 2017 (Figure 4-7); the events for which data are available are summarized in Table 4-7.

Table 4-7. Summary of available shiner surfperch tissue data

Sampling Year/Month	No. of Samples (Whole Body)	Average Lipids (%)	No. of Fish per Composite	Sampling Area	Sampling Program
April 1997	3	2.8	10	near Kellogg Island only	King County WQA
August 2004	24	3.9	9–10	site-wide	LDW RI
Aug/Sept 2005	22	5.7	10	site-wide	LDW RI
September 2006	7	5.2	10–11	near Kellogg Island only	King County
September 2007	22	3.9	10	site-wide	LDW RI
Aug/Sept 2017	12	5.1	15	site-wide	LDW Pre-Design Studies

AOC – Administrative Order on Consent
LDW – Lower Duwamish Waterway
RI – remedial investigation
WQA – water quality assessment





Note: The two highest total PCB values for the 2004 dataset are not shown on this figure (but were included in the average) to allow for better visual presentation of the other data. The total PCB Aroclor values were 8,800 µg/kg ww (8,010 µg/kg ww for total PCB congeners) and 18,400 µg/kg ww (12,228 µg/kg ww for total PCB congeners). Details regarding the samples included in these figures are presented in Table 4-7. The 1997 and 2006 data were collected from specific areas (i.e., are not representative of LDW-wide conditions).

Figure 4-7. Total PCB concentrations in shiner surfperch whole-body tissue over time

Temporal Evaluation

Shiner surfperch were collected site wide by LDWG in 2004, 2005, and 2007 as part of the RI, and in 2017 as part of the Pre-Design Studies baseline sampling. These samples were collected and analyzed using similar methods throughout this time period (Windward 2004, 2005, 2017a), and have similar lipid fractions (Table 4-7), allowing for clear temporal comparisons.

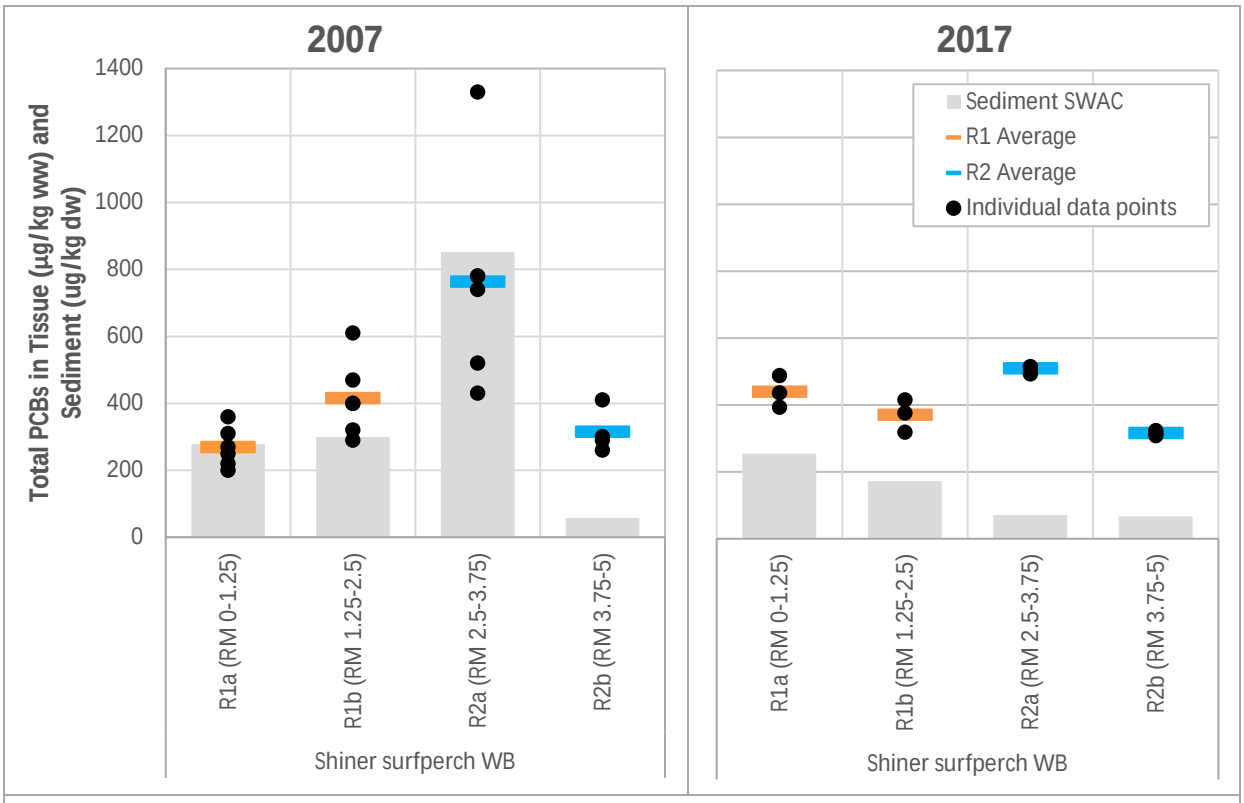
Like the English sole data, total PCB concentrations in shiner surfperch samples showed a significant spike in 2004 after the 2003/2004 dredge operations. Concentrations decreased in 2005, and by 2007, average concentrations had returned to levels similar to those in the 1990s. Concentrations in the 2017 baseline samples were slightly lower than those in 2007, but the change was not significant.[52]

Spatial Evaluation

Figure 4-8 presents shiner surfperch tissue and surface sediment total PCB Aroclor data by reach for 2007 and 2017. For shiner surfperch, fish were collected in smaller subreach areas during the LDW RI and 2017 baseline sampling efforts, because of differences by subreach in the RI shiner surfperch tissue dataset and the fact that shiner surfperch tissue concentrations had more spatial variability in samples collected as part of the RI than did concentrations in other species (Windward 2017a). In general, total PCB concentrations by reach in sediment and shiner surfperch tissue followed a similar pattern:

- In 2007 (i.e., prior to early actions at Boeing Plant 2/Jorgensen Forge, Slip 4, and T-117, but more than two years after Duwamish/Diagonal dredging in 2003/2004), total PCB concentrations in sediment were highest in subreach 2a (852 µg/kg dry weight [dw]), lower in subreaches 1a and 1b (278 to 299 µg/kg e), and lowest in subreach 2b (58 µg/kg dw) (Figure 4-8). The 2007 shiner surfperch samples followed this same pattern—concentrations were highest in subreach 2a (average of 763 µg/kg ww) but were relatively similar across the other three subreaches (averages ranging from 268 to 415 µg/kg ww).
- In 2017, total PCB concentrations in sediment were highest in subreach 1a (254 µg/kg dw) and lowest in subreaches 2a and 2b (67 to 71 µg/kg dw). With the exception of subreach 2a (highest tissue concentration, but low sediment concentration), concentrations in shiner surfperch tissue followed a similar pattern (Figure 4-8). Variance in the total PCB concentrations among shiner surfperch composite samples was low in 2017 compared with 2007, which may be attributable to the increased number of individual fish per composite.

[52] The decrease observed in site-wide PCB Aroclor concentrations from 2007 (440 µg/kg ww) to 2017 (407 µg/kg ww) was not statistically significant (p = 0.42, nested ANOVA). The decrease in PCB congener concentrations within Reach 1 from 2007 (632 µg/kg ww) to 2017 (450 µg/kg ww) was also non-significant (p = 0.25, nested ANOVA for Reach 1 samples only; Reach 2 data not amenable to statistical analysis). See Appendix B for details.



Media	Concentration of Total PCBs							
	2007				2017			
	R1a	R1b	R2a	R2b	R1a	R1b	R2a	R2b
Sediment SWAC (µg/kg dw)	278	299	852	58	254	172	71	67
Average concentration in tissue (µg/kg ww)	268	415	763	315	439	370	509	316
Average lipid (%)	3.1	4.0	4.1	4.3	5.6	5.3	5.0	4.4

Figure 4-8. Comparison of total PCB Aroclor concentrations in shiner surfperch tissue and surface sediment in 2007 and 2017 by subreach

The relationship between tissue and sediment concentrations for shiner surfperch indicates uncertainty associated with the typical foraging area of this species in the LDW. The available literature is not conclusive, but it suggests that shiner surfperch may exhibit seasonal movements (shallower water in the spring and deeper waters in the winter) as well as daily movements (shallower waters during the day and deeper waters at night) (Gordon 1965; Shaw et al. 1974, as cited in Baltz 1984). This is supported by information presented in Appendix D of the LDW RI (Windward 2010b), which indicates that shiner surfperch are rare in the LDW from February to April and abundant from May to October, with abundance peaking during September when juveniles are present. Thus, the extent to which shiner surfperch tissue concentrations should reflect the area of the LDW from which they are collected is uncertain.

Total PCBs and Crab – Trends and Spatial Patterns

Total PCB concentrations in crab tissue (both edible meat and whole-body) have also been monitored over time. Data included in the LDW RI dataset were collected as far back as 1997. These data consist of a mix of Dungeness crab, graceful crab, and red rock crab, all of which can be found in the LDW. The events for which data are available are summarized in Table 4-8.

Table 4-8. Summary of available crab tissue data

Sampling Month/Year	Edible Meat		Whole Body[a]		No. of Crab per Composite	Crab Species	Sampling Area	Sampling Program
	n	Average Lipid (%)	n	Average Lipid (%)				
April 1997	2	2.0	2	5.4	3	Dungeness crab	near Kellogg Island only	King County WQA
October 1998	4	nr	-	-	5	Dungeness and red rock crab	near Kellogg Island only	WSOU
Aug/Sept 2004	19	0.43	19	1.5	5	Dungeness and graceful crab	site-wide	LDW RI
Aug/Sept 2005	4	0.22	4	1.7	5	Dungeness and graceful crab	site-wide	LDW RI
Sept 2007	10	0.48	10	1.5	2–5	Dungeness and graceful crab	site-wide	LDW RI
May 2012	1	0.20	-	-	5	Dungeness crab	near Kellogg Island only	WDFW
Aug/Sept 2017	15	0.75	15	1.4	3 - 14	Dungeness and graceful crab	site-wide	LDW Pre-Design Studies

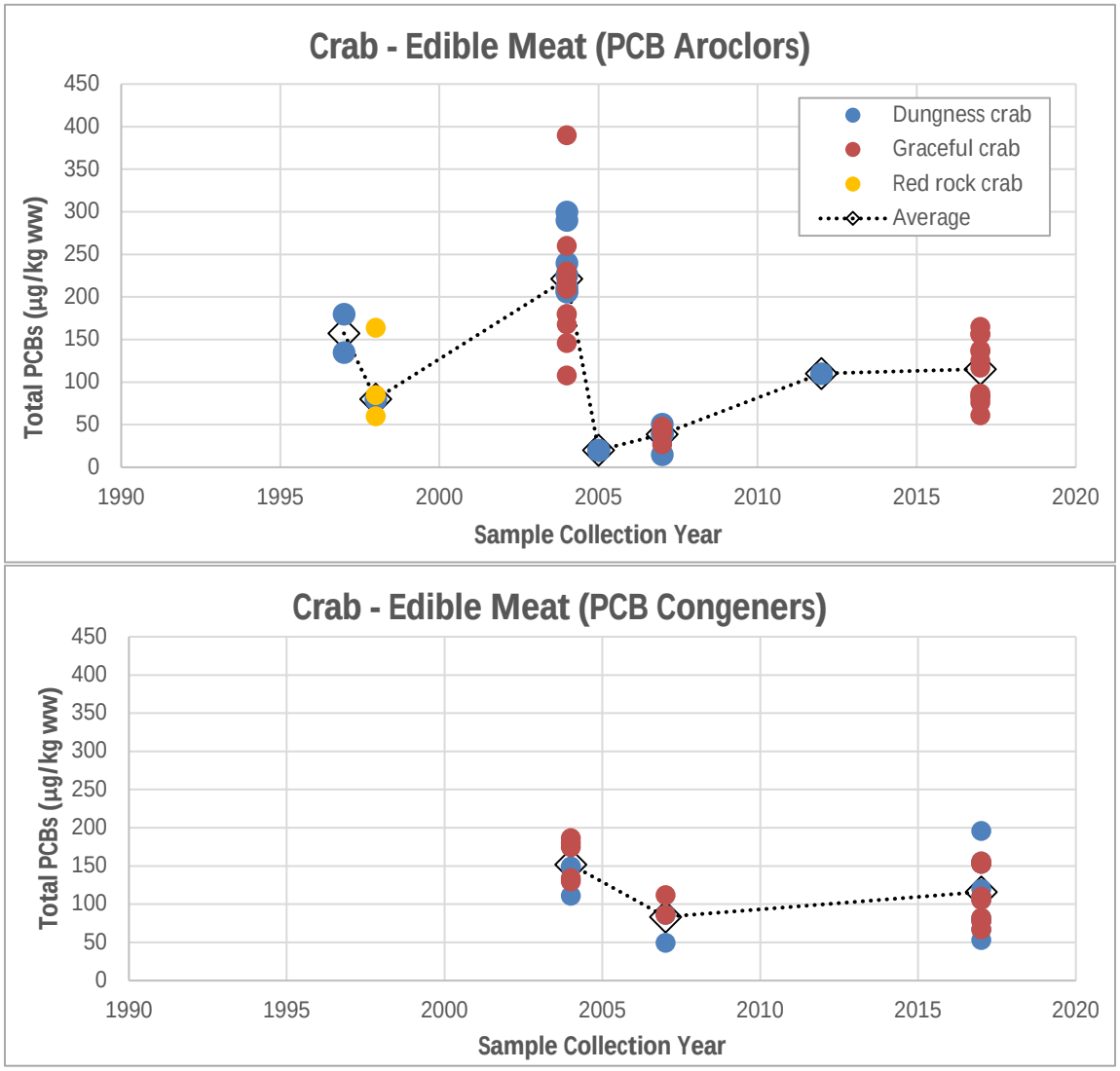
[a] Concentrations in all whole-body samples were calculated from edible meat and hepatopancreas samples.

LDW – Lower Duwamish Waterway
nr – not reported
RI – remedial investigation
WDFW – Washington Department of Fish and Wildlife
WQA – water quality assessment
WSOU – Waterway Sediment Operable Unit

Temporal Evaluation

Crab were collected site wide by LDWG in 2004, 2005, and 2007 as part of the RI and in 2017 as part of the Pre-Design Studies baseline sampling. These samples were collected and analyzed using similar methods throughout this time (Windward 2004, 2005, 2017a), and have similar lipid fractions (Table 4-8), allowing for clear temporal comparisons. Like concentrations in English sole and shiner surfperch data, total PCB concentrations in crab tissue (both edible meat and whole body) showed a large spike in 2004 after the 2003/2004 dredge operations (Figures 4-9 and 4-10). Concentrations in both tissue types were lower in the 2005 and 2007 samples. Temporal trends are less clear because relatively few samples are available prior to 2003/2004, and crab included in samples prior to this time were only collected from the area near Kellogg Island (i.e., they are not representative of site-wide conditions). The 2012 Dungeness crab data

from the WDFW study[53] fall within the range of concentrations observed in 2017 baseline sampling. To account for differences between 2007 and 2017 in the collection areas and species, a statistical evaluation was conducted using only graceful crab in Reach 1.[54] Total PCB Aroclor concentrations were significantly higher in 2017 than in 2007. Insufficient data are available to conduct additional statistical comparisons.

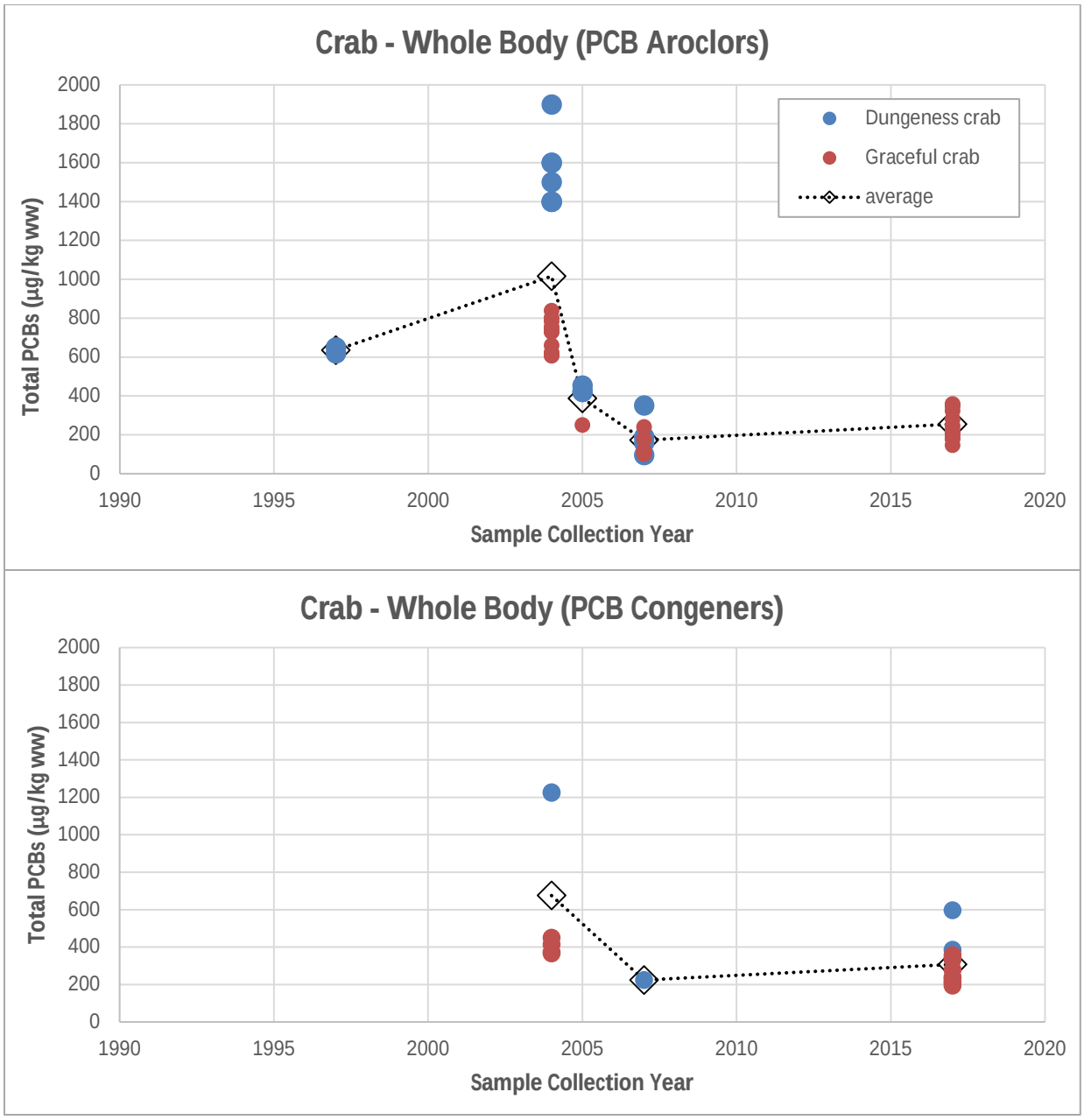


Note: Details regarding the sampling events included in these figures are presented in Table 4-8. The 1997, 1998, and 2012 data were collected from specific areas (i.e., are not representative of LDW-wide conditions).

Figure 4-9. Total PCB concentrations in edible meat crab tissue in the LDW over time

[53] Dungeness crab data from the 2012 WDFW study represent total PCBs using a different analytical method; they were calculated as the sum of 18 PCB congeners multiplied by 2.

[54] Comparisons were made between years using only data from within Reach 1 because no graceful crab data were available from Reach 2 from 2007. Both edible meat and whole body tissues were significantly higher in 2017 compared to 2007 ($p < 0.001$, ANOVA) (Appendix B).



Note: Details regarding the sampling events included in these figures are presented in Table 4-8. The 1997 samples represent crab collected from only the area near Kellogg Island.

Figure 4-10. Total PCB concentrations in whole-body crab tissue in the LDW over time

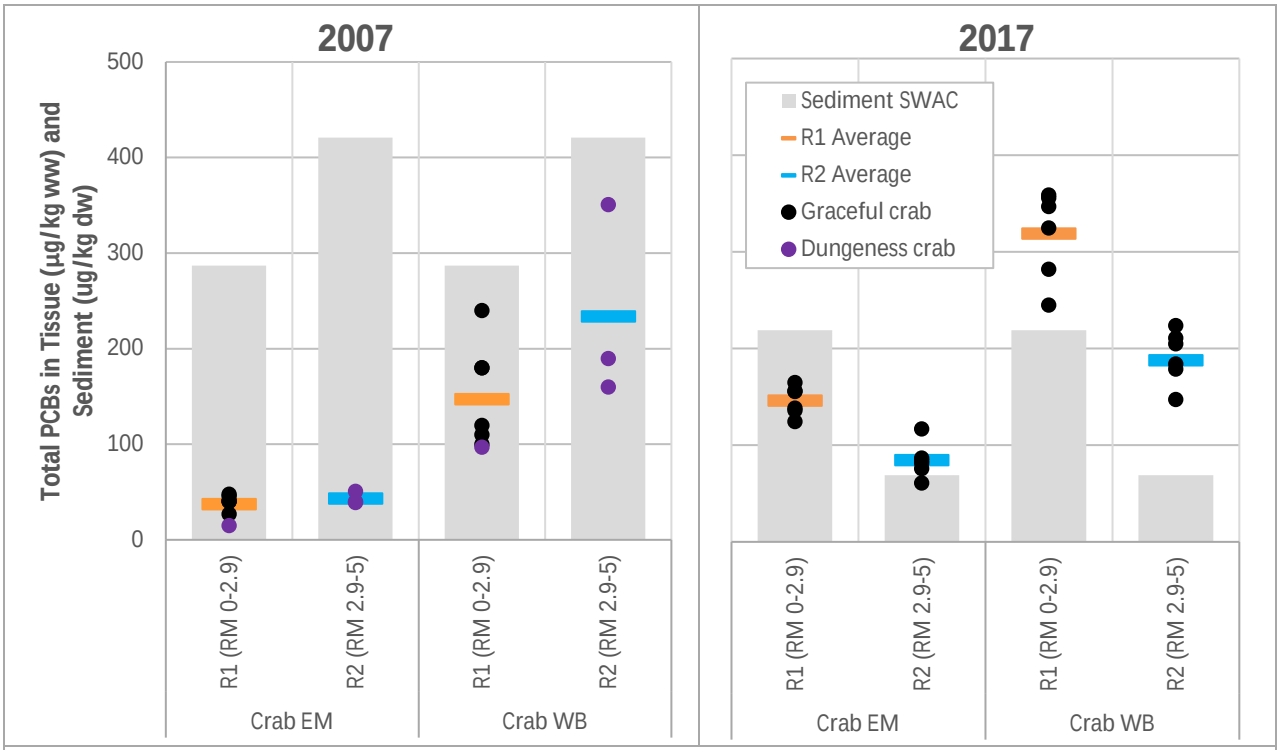
Spatial Evaluation

Figure 4-11 presents crab tissue and surface sediment total PCB Aroclor data by reach for 2007 and 2017. General conclusions are:

- In 2007, concentrations in sediment and whole-body crab tissue were generally higher in Reach 2 than in Reach 1. In edible meat samples, concentrations were

similar across the two reaches, although relatively few Reach 2 samples were available.

- In 2017, this pattern was reversed. Concentrations in both sediment and tissue (edible meat and whole body) were higher in Reach 1 than in Reach 2.



Media	Concentration of Total PCBs							
	2007				2017			
	Edible Meat		Whole Body		Edible Meat		Whole Body	
	Reach 1	Reach 2	Reach 1	Reach 2	Reach 1	Reach 2	Reach 1	Reach 2
Sediment SWAC (µg/kg dw)	287	421	287	421	219	69	219	69
Average concentration in tissue (µg/kg ww)	37	43	147	234	146	85	319	188
Average lipid (%)	0.48	0.56	1.3	2.2	0.65	0.67	1.1	1.1

Figure 4-11. Comparison of total PCB Aroclor concentrations in graceful crab tissue and sediment in 2007 and 2017 by reach

As was noted for English sole and shiner surfperch, there is uncertainty associated with the movement and typical foraging area of the various crab species in the LDW (Appendix D of Windward 2010b). Crab may move between reaches and in and out of the LDW over the course of the year, which complicates this comparison.

Evaluation of FWM Predictions for Total PCBs

This section discusses the Pre-Design Studies baseline data relative to the LDW FWM developed as part of the RI (Windward 2010b). The objective of this comparison was to determine whether tissue concentrations are responding to changes in LDW sediment and water total PCB concentrations consistent with FWM predictions.

FWM Overview

The LDW FWM is an Arnot and Gobas-style FWM, which was developed and calibrated[55] for the LDW using site-specific data. Two independent calibrations were developed:

- **Calibration 1**, wherein the FWM was calibrated using LDW fish and crab tissue data from the late 1990s, 2004, and 2005.
- **Calibration 2**, wherein the FWM was calibrated using LDW fish and crab tissue data included in the Calibration 1 dataset, except for data from 2004, which were excluded.

These two separate FWM calibrations were conducted because the 2004 tissue data appeared to have been influenced by the 2003/2004 remedial dredging events. The higher concentrations in 2004 tissue were likely a result of a spike in total PCB water concentrations (dissolved and/or particulate in the water column) created by the dredging. Therefore, the 2004 tissue concentrations were not representative of steady-state conditions in the LDW, and a recalibration of the FWM was conducted excluding the 2004 LDW tissue data.

Site-wide FWM Results – Comparison of Calibration 1 and 2

Both calibrations of the LDW FWM were run on a site-wide basis and compared with the 2017 Pre-Design Studies baseline tissue dataset. For these site-wide model runs, total PCB concentrations in sediment were set equal to the Pre-Design Studies baseline site-wide SWAC of 172 µg/kg ww (Section 2). The concentration in water was set equal to 0.9 ng/L, which was the average concentration in the near-bottom surface water composite grab samples collected during the four baseflow sampling events (Section 3).[56] Two methods were used to evaluate model performance:

- **Species-predictive accuracy factor (SPAF)** – The SPAF was calculated as the higher of either the FWM-predicted concentration or the LDW average observed concentration divided by the lower of these two values. If the predicted concentrations were higher than the LDW average, a plus sign (+) was added

[55] The FWM was calibrated using literature-derived and site-specific environmental data. The purpose of the calibration process was to identify sets of parameter values that best predicted LDW data.

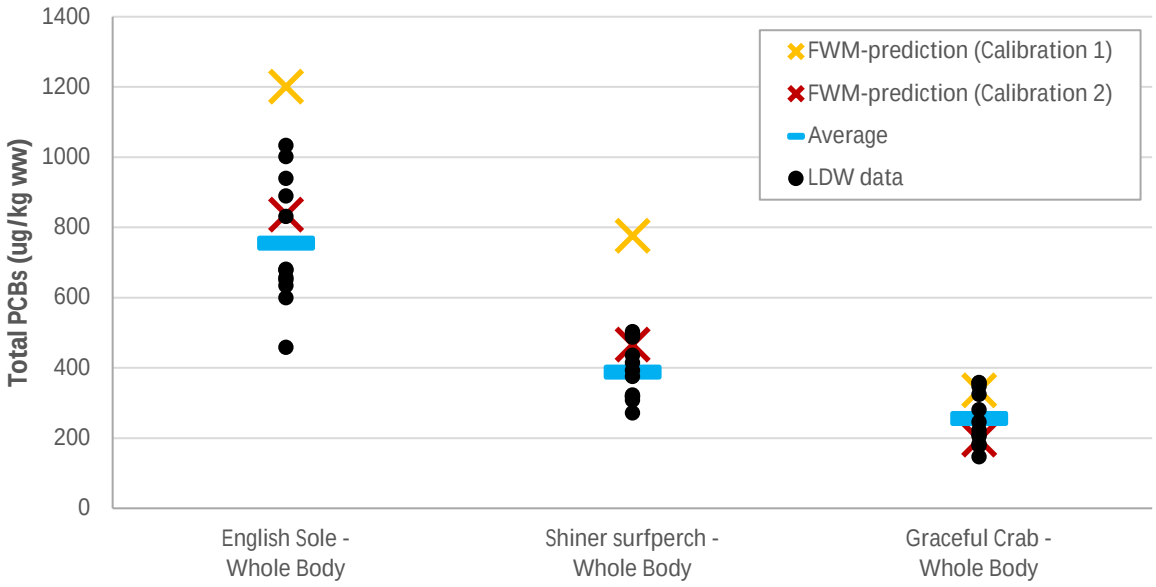
[56] Although the first dry baseflow composite-grab sampling event occurred contemporaneously with the fish and crab tissue sampling event, all of the 2017/2018 baseflow event data were used to represent exposure from surface water to better estimate the overall, year-round concentrations to which fish/crab are exposed.

before the SPAF to indicate that the model was over-predicting concentrations. Conversely, if the predicted concentration was lower than the LDW average, a minus sign (-) was added before the SPAF to indicate that the model was under-predicting concentrations. As discussed in the LDW RI (Windward 2010b), desired SPAFs for FWMs are generally less than two and include a mix of under- and over-predictions.

- **Visual review of LDW dataset** – The distribution of the LDW dataset was compared with the model-predicted concentrations to evaluate the model's predictive ability.

Model results are compared with site-wide 2017/2018 baseline LDW data in Figure 4-12. Calibration 1 model predictions were generally higher than the LDW data (i.e., the model was over-predicting), whereas Calibration 2 performed well, with all SPAFs less than or equal to 1.3.[57] Based on this evaluation, Calibration 2 was determined to be more appropriate for use (i.e., predictions were more similar to the Pre-Design Studies baseline concentrations). The Calibration 1 model over-predicted relative to the Pre-Design Studies baseline dataset as a result of the inclusion of the 2004 LDW data (which were biased high as a result of the 2003/2004 dredging) in the calibration dataset.

[57] The same sediment and water concentrations, based on Pre-Design Studies data, were used as input to both Calibration 1 and 2 model runs.



Model run	SPAF		
	English sole - whole body	Shiner surfperch – whole body	Graceful crab – whole body
Calibration 1	+ 1.6	+ 2.0	+ 1.3
Calibration 2	+1.1	+ 1.2	- 1.3

Note: For both sets of FWM predictions, sediment was set to site-wide SWAC of 172 µg/kg dw and water was set to 0.9 ng/L.

Figure 4-12. Site-wide FWM evaluation – comparison of total PCB concentrations in Pre-Design Studies baseline tissue to concentrations predicted using Calibrations 1 and 2 of the LDW FWM

FWM Results by Reach – Calibration 2

Based on the site-wide evaluation, which showed that Calibration 2 better predicted total PCB concentrations in the Pre-Design Studies baseline tissue dataset, FWM predictions were also evaluated for the sampling reaches (i.e., rather than on a site-wide basis as shown in Figure 4-12). Table 4-9 presents a summary of the FWM performance (as represented by SPAFs) by reach for English sole and graceful crab and by subreach for shiner surfperch. The model performed well for all three species (all SPAFs were less than 1.8). Model predictions relative to LDW baseline tissue data by reach or subreach are shown in Figure 4-13. The model slightly over-predicted in the downstream reaches and subreaches and slightly under-predicted in the upstream reaches for English sole and shiner surfperch (Figure 4-13); model performance was especially good for graceful crab (within a factor of 1.2 of LDW data).

Table 4-9. Total PCB FWM inputs for model runs by LDW reach using 2017 data

FWM Inputs	2017 FWM Runs					
	Reach 1	Reach 2	Reach 1a	Reach 1b	Reach 2a	Reach 2b
FWM Inputs						
Sediment SWAC[a] (µg/kg dw)	219	69	254	172	71	67
Water (ng/L)	0.9	0.9	0.9	0.9	0.9	0.9
SPAFs						
English sole	+1.1	-1.3	-	-	-	-
Shiner surfperch[a]	-	-	+1.4	+1.3	-1.7	-1.1
Graceful crab	-1.1	-1.2	-	-	-	-

[a] Equal to the average concentration in baseflow near-bottom water samples.

dw – dry weight
FWM – food web model
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
SPAF – species-predictive accuracy factor
SWAC – spatially-weighted average concentration

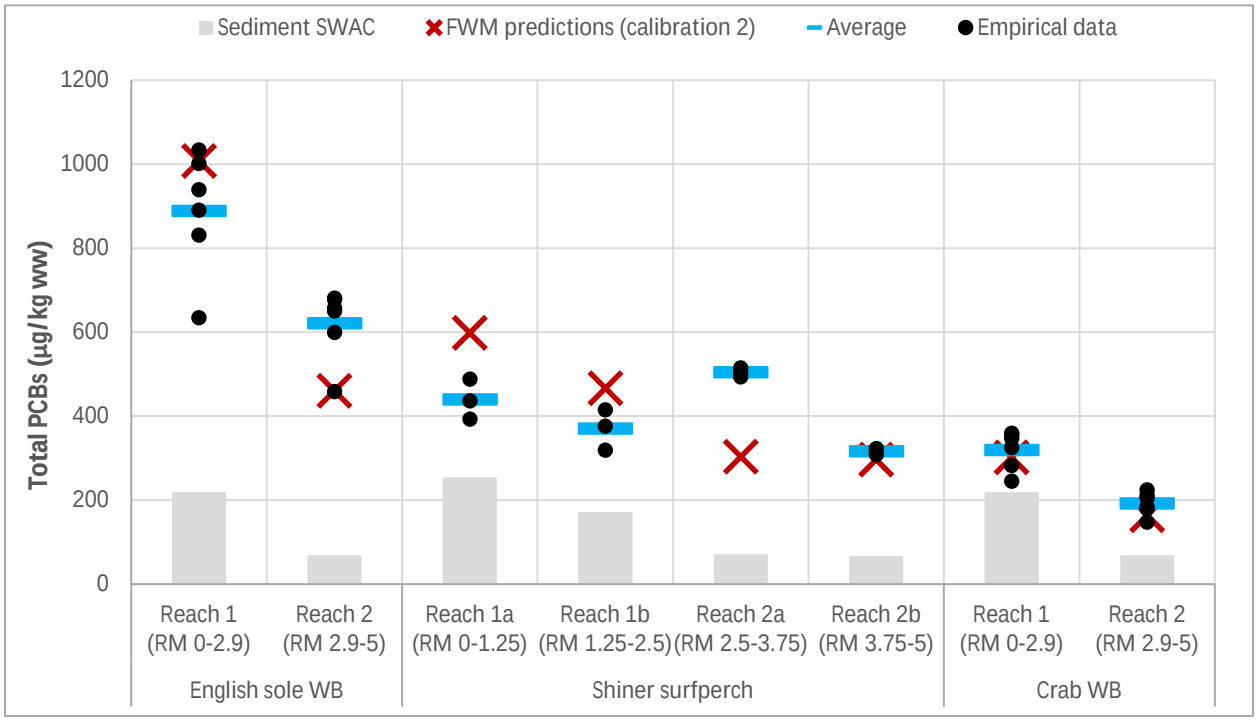
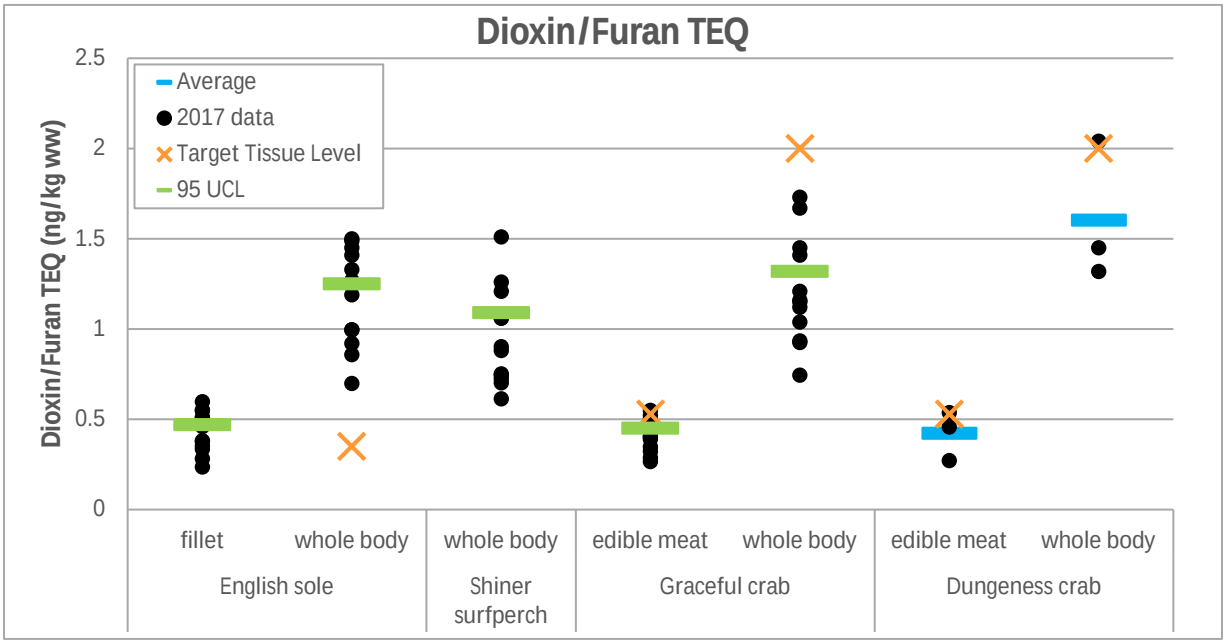


Figure 4-13. FWM results by reach for Pre-Design Studies baseline data

As discussed for all three species, there are uncertainties associated with the movement and typical foraging areas of these fish and crab in the LDW that are also important to consider when running the FWM on smaller spatial scales (Appendix D of Windward 2010b). Individuals may utilize an area larger than the area from which they were collected, meaning that their exposure is not necessarily reflective of the area-specific sediment SWAC. Despite this, the similarity between the FWM predictions and the Pre-Design Studies dataset indicates that tissue concentrations are generally responding as expected to ongoing remediation.

4.2.1.3 Dioxins/furans

This section provides additional discussion of the dioxin / furan baseline tissue data. Figure 4-14 presents an overview of the individual data points, 95UCLs, and TTLs for dioxin / furan TEQs in tissue. As discussed in Section 4.2.1.1, the 95UCL was below the TTL for crab (both edible meat and whole body) but above the TTL for English sole whole body (no TTL was developed in the ROD for English sole fillet). The remainder of this section presents available information regarding the spatial distribution of dioxins / furans; no historical tissue data are available, thus no temporal evaluation is presented.

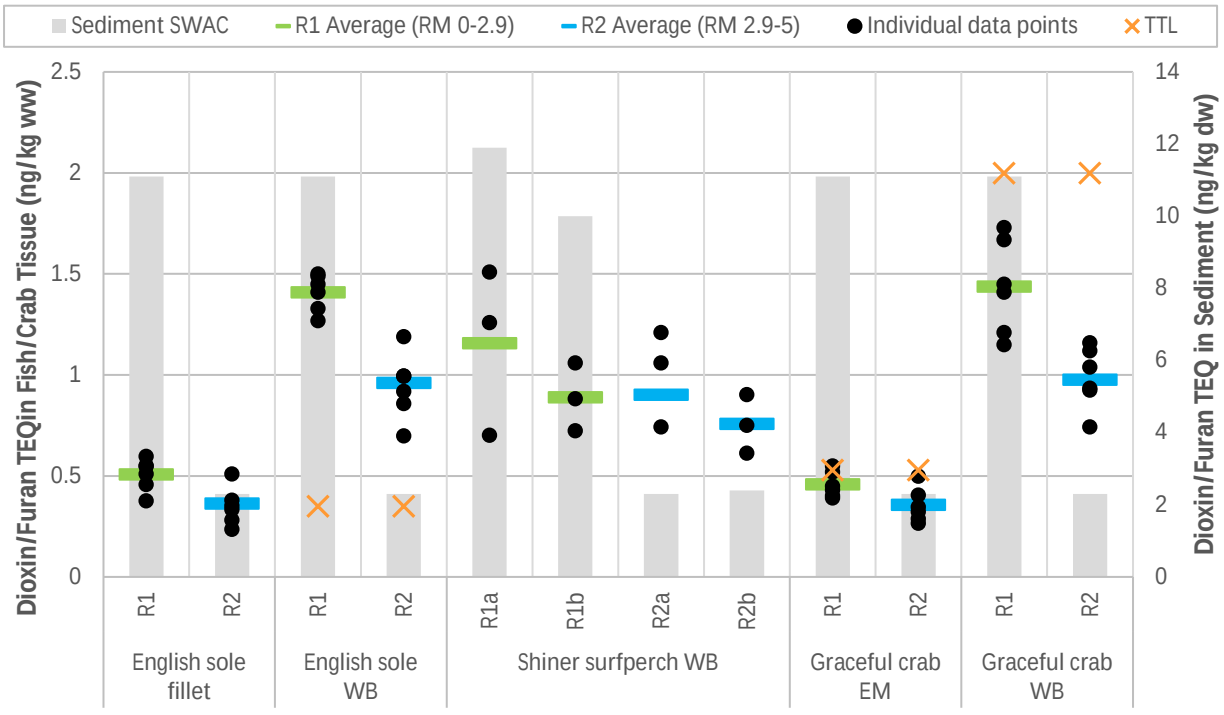


Notes: TTLs are available for all species/tissue types, with the exception of English sole fillet and shiner surfperch (for which no non-urban background data were available to develop a TTL). The TTL in the ROD is for Dungeness crab but is compared with both graceful and Dungeness crab data in this figure. Average values are presented where 95UCLs could not be calculated.

Figure 4-14. Dioxin/furan TEQs in Pre-Design Studies baseline fish/crab tissue compared with TTLs

Figure 4-15 presents Pre-Design Studies baseline tissue dioxin / furan data by sampling reach, along with the reach-specific surface sediment SWACs and average lipid fractions. Dioxin / furan TEQs in sediment and tissue generally followed the same pattern by reach exhibited by total PCBs. Dioxin / furan sediment SWACs were higher in Reach 1 (11.1 ng / kg dw) than in Reach 2 (2.3 ng / kg dw) and higher in Subreaches 1a and 1b than in Subreaches 2a and 2b. Dioxin / furan TEQs in English sole and crab tissues were also higher in Reach 1 than in Reach 2 (similar to the pattern observed for total PCBs). For shiner surfperch, dioxin / furan TEQs in tissue were highest in samples from Subreach 1a and lowest in samples from Subreach 2b, but similar in samples from the two middle areas (i.e., Subreaches 1b and 2a). As discussed for total PCBs, this pattern may indicate that shiner surfperch may utilize an area larger than the

subreaches from which they were sampled (i.e., they may be exposed to sediment from outside of the sampling reach from which they were collected).



Data	Dioxins/furan TEQ					
	English Sole/Crab Reaches		Shiner Surfperch Subreaches			
	Reach 1	Reach 2	R1a	R1b	R2a	R2b
Sediment SWAC (ng/kg dw)	11.1	2.3	11.9	10.0	2.3	2.4
Average tissue concentration (ng/kg dw)						
English sole – fillet | whole body	0.51 | 1.41	0.36 | 0.96	-	-	-	-
Shiner surfperch	-	-	1.16	0.89	0.90	0.76
Graceful crab – edible meat | whole body	0.46 | 1.46	0.36 | 0.98	-	-	-	-
Average lipid (%)						
English sole – fillet | whole body	2.4 | 5.4	2.1 | 5.4	-	-	-	-
Shiner surfperch	-	-	5.6	5.3	5.0	4.4
Graceful crab – edible meat | whole body	0.65 | 1.1	0.67 | 1.1	-	-	-	-

Figure 4-15. Dioxin/furan TEQ fish and crab data by sampling reach

4.2.2 Evaluation of baseline tissue data for risk drivers without TTLs

TTLs were not developed for inorganic arsenic or cPAHs for fish or crab, because the majority of risk to human health from seafood consumption is due to the consumption of clams (EPA 2014). However, as specified in the AOC3 (EPA 2016), all tissue samples were analyzed for these risk driver chemicals and thus mean concentrations can be calculated for comparison to future data.

Table 4-10 presents a summary of the 2017 data for these risk driver chemicals compared with the tissue dataset used in the HHRA (Windward 2007). Concentrations of inorganic arsenic in the 2017 baseline samples were relatively similar to or slightly higher than those used to evaluate risks to human health in the HHRA. cPAHs were not detected in any of the 2017 baseline crab samples.

Table 4-10. Other risk driver chemicals

Analyte and Tissue Type	Summary of 2017 Data			Summary of HHRA Data		
	DF	Range of Values	Average[a]	DF	Range of Values	Average[a]
Inorganic arsenic (mg/kg ww)						
English sole – fillet	1/12	0.005 J–0.010 U	0.005	6 / 8	0.003–0.006 J	0.004
English sole – whole body	12/12	0.056–0.369	0.122	8 / 8	0.020–0.090	0.056
Shiner surfperch – whole body	12/12	0.028–0.076	0.046	8 / 10	0.010 U–0.160	0.057
Graceful crab – edible meat	12/12	0.031–0.251	0.097	6 / 6	0.010–0.030	0.023
Graceful crab – whole body	12/12	0.070–0.253	0.114	6 / 6	0.022 J–0.123	0.075
cPAH TEQ (µg/kg ww)[b]						
Graceful crab – edible meat	0/12	0.91 U[c]	nc	8 / 21	0.33 J–29 U	1.8
Graceful crab – whole body	0/12	0.91 U[c]	nc	19 / 21	0.45–17 U	1.5

[a] The average is calculated using the ½ RL for non-detects. Averages were not calculated when there were no detected values.

[b] Fish samples were not analyzed for cPAHs because of the ability of fish to metabolize PAHs (Windward 2017a).

[c] Values calculated as the ½ MDL.

DF – detection frequency
cPAH – carcinogenic polycyclic aromatic hydrocarbon
HHRA – human health risk assessment
J – estimated concentration
MDL – method detection limit
na – not applicable
nc – not calculated
PAH – polycyclic aromatic hydrocarbon
QAPP – quality assurance project plan
RL – reporting limit
U – not detected at given concentration
ww – wet weight

4.2.3 Baseline tissue data for non-risk driver chemicals

As specified in AOC3 (EPA 2016), non-risk driver chemicals were analyzed in a subset (two samples per species / tissue type) of fish and crab tissue samples collected in 2017, per the fish and crab QAPP (Windward 2017a). Tables 4-11 through 4-13 present summaries of the 2017 data compared with the dataset used to evaluate risks in the LDW HHRA (Windward 2007). The following summarizes differences in these comparisons by chemical or chemical group.

- **Vanadium** – Concentrations in the 2017 baseline tissue samples were similar to those in the HHRA dataset.
- **TBT** – Concentrations in the 2017 samples were lower than those in the HHRA dataset.

- **SVOCs** – In general, concentrations in the HHRA dataset of BEHP, carbazole, HCB, and PCP were mostly non-detects, frequently with high RLs. Concentrations in the 2017 dataset were mostly detects, with concentrations generally lower than those in 2007.
- **Pesticides** – Concentrations of all pesticides were lower in the 2017 baseline tissue samples than in the HHRA dataset. In addition, the majority of the detected concentrations were J-flagged because concentrations were below the RL.

Table 4-11. Non-risk driver chemistry results (metals) for baseline tissue samples compared with the HHRA dataset

Analyte and Tissue Type	Summary of 2017 Baseline Data			Summary of HHRA Data		
	DF	Range of Values	Average[a]	DF	Range of Values	Average[a]
Vanadium (mg/kg ww)						
English sole – fillet	2/2	0.0461–0.0480	0.0471	0 / 8	0.25 U	nc
English sole – whole body	2/2	0.336–0.357	0.347	24 / 24	0.2 J–0.5	0.4
Shiner surfperch – whole body	2/2	0.761–0.821	0.791	22 / 26	0.21 J–1.23	0.4
Graceful crab – edible meat	2/2	0.199–0.241	0.220	0 / 19	0.21 U	nc
Graceful crab – whole body	2/2	0.202–0.235	0.219	12 / 19	0.11 U–0.2 J	0.1
TBT (mg/kg ww)						
English sole – fillet	0/2	3.84 U–3.85 U	nc	10 / 17	0.74 U–5.7	2.0
English sole – whole body	0/2	3.82 U–3.84 U	nc	18 / 23	1.5 U–15	5.7
Shiner surfperch – whole body	2/2	8.44–12.1	10.3	31 / 31	4.8–180	51
Graceful crab – edible meat	0/2	3.84 U–3.85 U	nc	9 / 25	1.5 U–82	6.2
Graceful crab – whole body	0/2	3.84 U–3.85 U	nc	15 / 21	0.75 U–75	9.9

[a] Average is the average of the value or ½ RL (for non-detects). Averages were not calculated when there were no detected values.

DF – detection frequency
HHRA – human health risk assessment
J – estimated concentration
nc – not calculated
TBT – tributyltin
U – not detected at given concentration
ww – wet weight

Table 4-12. Non-risk driver chemistry results (select SVOCs) for baseline tissue samples compared with the HHRA dataset

Analyte and Tissue Type	Summary of 2017 Baseline Data			Summary of HHRA Data		
	DF	Range of Values	Average[a]	DF	Range of Values	Average[a]
BEHP (µg/kg ww)						
English sole – fillet	0/2	49.6 U	nc	2/14	3.6 U–1300 J	190
English sole – whole body	2/2	340–341	341	0/24	66 U–3600 U	nc
Shiner surfperch – whole body	2/2	495–496	496	5/29	24 U–3600 J	740
Graceful crab – edible meat	2/2	49.7–49.9	49.8	0/21	16 U–260 U	nc
Graceful crab – whole body	2/2	77.6–78.0	77.8	3/21	9.2 U–100 U	30
Carbazole (µg/kg ww)						
English sole – fillet	0/2	19.8 U	nc	0/14	3.6 U–2900 U	nc
English sole – whole body	2/2	16.6	16.6	0/24	1500 U–2900 U	nc
Shiner surfperch – whole body	2/2	19.8	19.8	2/29	40 U–14000	1,200
Graceful crab – edible meat	2/2	19.9–20.0	20.0	0/21	27 U–2900 U	nc
Graceful crab – whole body	2/2	19.9–20.0	20.0	0/21	16 U–1500 U	nc
HCB (µg/kg ww)						
English sole – fillet	0/2	19.8 U	nc	1/14	1.1 JN–18 U	5.5
English sole – whole body	2/2	16.6	16.6	4/24	4.4 JN–10 U	4.5
Shiner surfperch – whole body	2/2	19.8	19.8	1/29	1.5 U–24 U	2.5
Graceful crab – edible meat	2/2	19.9–20.0	20.0	1/21	0.93 JN–16 U	2.3
Graceful crab – whole body	2/2	19.9–20.0	20.0	4/21	0.75 U–9.2 U	2.0
PCP (µg/kg ww)						
English sole – fillet	0/2	99.2 U	nc	0/14	3.3 U–5800 U	nc
English sole – whole body	2/2	82.9	82.9	6/24	1.1 J–2900 U	610
Shiner surfperch – whole body	2/2	99.0–99.2	99.1	2/29	2.8 U–2900 U	63
Graceful crab – edible meat	2/2	99.4–99.8	99.6	0/21	3.3 U–580 U	nc
Graceful crab – whole body	2/2	99.4–99.7	99.6	0/21	1.7 J–2,000 U	nc

[a] Average refers to the average of the value or ½ RL (for non-detects). Averages were not calculated when there were no detected values.

BEHP – bis(2-ethylhexyl) phthalate
DF – detection frequency
HCB – hexachlorobenzene
HHRA – human health risk assessment
J – estimated concentration
JN – tentative identification of estimated concentration
nc – not calculated
PCP – pentachlorophenol
SVOC – semivolatile organic compound
U – not detected at given concentration
ww – wet weight

Table 4-13. Non-risk driver chemistry results (organochlorine pesticides) for baseline tissue samples compared with HHRA dataset

Analyte and Tissue Type	Summary of 2017 Baseline Data			Summary of HHRA Data		
	DF	Range of Values	Average[a]	DF	Range of Values	Average[a]
Aldrin (µg/kg ww)						
English sole – fillet	0/2	0.77 U–0.89 U	nc	0/17	0.5 U–7.2 U	nc
English sole – whole body	0/2	0.79 U–0.91 U	nc	1/24	6.2 JN–10 U	4.2
Shiner surfperch – whole body	0/2	0.88 U–0.92 U	nc	1/26	1.4 JN–7.2 U	1.0
Graceful crab – edible meat	1/2	0.34 J–0.96 U	0.41	0/19	1.5 U–7.2 U	nc
Graceful crab – whole body	1/2	0.37 J–0.94 U	0.42	0/19	0.75 U–3.6 U	nc
alpha-BHC (µg/kg ww)						
English sole – fillet	2/2	0.42 J–0.83 J	0.63	1/17	0.38 JN–7.2 U	1.6
English sole – whole body	2/2	0.49 J–0.68 J	0.59	0/24	1.0 U–10 U	nc
Shiner surfperch – whole body	2/2	0.55 J–1.1 J	0.83	2/26	0.45 JN–7.2 U	1.2
Graceful crab – edible meat	2/2	0.60 J–0.61 J	0.61	0/19	1.5 U–7.2 U	nc
Graceful crab – whole body	2/2	0.56 J–0.57 J	0.57	3/19	0.75 U–3.6 U	1.0
beta-BHC (µg/kg ww)						
English sole – fillet	0/2	0.77 U–0.89 U	nc	2/17	0.5 U–7.2 U	1.6
English sole – whole body	0/2	0.79 U–0.91 U	nc	9/24	4.0 JN–10 U	4.6
Shiner surfperch – whole body	0/2	0.88 U–0.92 U	nc	16/26	1.5 U–15 JN	5.7
Graceful crab – edible meat	0/2	0.92 U–0.96 U	nc	0/19	1.5 U–8.2 U	nc
Graceful crab – whole body	0/2	0.91 U–0.94 U	nc	0/19	0.75 U–3.6 U	nc
gamma-BHC (µg/kg ww)						
English sole – fillet	1/2	0.25 J–0.89 U	0.35	0/17	0.5 U–7.2 U	nc
English sole – whole body	1/2	0.35 J–0.91 U	0.41	2/24	2.3 JN–10 U	4.1
Shiner surfperch – whole body	2/2	0.22 J–0.47 J	0.35	7/26	0.59 JN–7.2 U	1.4
Graceful crab – edible meat	2/2	0.31 J–0.38 J	0.35	1/19	1.5 U–7.2 U	1.8
Graceful crab – whole body	2/2	0.35 J–0.40 J	0.38	1/19	0.75 U–3.6 U	1.4
Total chlordane (µg/kg ww)						
English sole – fillet	2/2	1.04 J–1.31 J	1.18	11/17	1.6 J–28 JN	8.6
English sole – whole body	2/2	3.4 J–4.5 J	4.0	24/24	6.3 JN–59 JN	33
Shiner surfperch – whole body	2/2	1.27 J–2.26 J	1.77	26/26	3.9 JN–330	31
Graceful crab – edible meat	1/2	0.11 J–2.3 U	0.66	19/19	2.0 JN - 63 JN	4
Graceful crab – whole body	2/2	0.20 J–0.46 J	0.33	19/19	9.0 JN–26 JN	16

Analyte and Tissue Type	Summary of 2017 Baseline Data			Summary of HHRA Data		
	DF	Range of Values	Average[a]	DF	Range of Values	Average[a]
Total DDTs (µg/kg ww)						
English sole – fillet	2/2	3.0 J–6.3 J	4.7	15/17	1.1–103 JN	37
English sole – whole body	2/2	11.3 J–15.4 J	13.4	24/24	51 JN–280 JN	170
Shiner surfperch – whole body	2/2	3.9 J -7.9 J	5.9	26/26	10 JN–1,020 JN	170
Graceful crab – edible meat	2/2	0.94 J -1.7 J	1.3	19/19	11 JN–32 JN	21
Graceful crab – whole body	2/2	3.9 J	3.9	19/19	48 JN–150 JN	90
Dieldrin (µg/kg ww)						
English sole – fillet	1/2	0.30 J–0.89 U	0.38	0/17	1.0 U -7.2 U	nc
English sole – whole body	2/2	0.66 J–0.79	0.73	0/24	2.0 U–10 U	nc
Shiner surfperch – whole body	0/2	0.88 U–0.92 U	nc	0/26	1.5 U–7.2 U	nc
Graceful crab – edible meat	0/2	0.92 U–0.96 U	nc	1/19	1.3 JN–7.2 U	1.9
Graceful crab – whole body	0/2	0.91 U–0.94 U	nc	1/19	1.6 U–7.8 U	1.7
Heptachlor (µg/kg ww)						
English sole – fillet	2/2	0.14 J–0.20 J	0.17	0/17	0.5 U–7.2 U	nc
English sole – whole body	2/2	0.11 J–0.20 J	0.16	2/24	1.0 U–10 U	4.2
Shiner surfperch – whole body	2/2	0.25 J -0.27 J	0.26	1/26	1.5 U–9.7 JN	1.7
Graceful crab – edible meat	2/2	0.24 J–0.25 J	0.25	0/19	1.5 U–7.2 U	nc
Graceful crab – whole body	2/2	0.22 J–0.23 J	0.23	0/19	1.5 U–9.7 U	nc
Heptachlor epoxide (µg/kg ww)						
English sole – fillet	0/2	0.77 U–0.89 U	nc	0/17	0.5 U–7.2 U	nc
English sole – whole body	1/2	0.29 J–0.91 U	0.38	13/24	7.2 U–45 JN	16
Shiner surfperch – whole body	0/2	0.88 U–0.92 U	nc	5/26	1.5 U–10 JN	2.6
Graceful crab – edible meat	1/2	0.19 J - 0.92 U	0.33	15/19	0.93 JN–7.2 U	1.9
Graceful crab – whole body	1/2	0.26 J–0.91 U	0.36	15/19	1.0 U–5.5 JN	3.2

[a] Average refers to the average of the value or ½ RL (for non-detects). Averages were not calculated when there were no detected values.

BHC – benzene hexachloride
DDT – dichlorodiphenyltrichloroethane
DF – detection frequency
HHRA – human health risk assessment
J – estimated concentration
JN – tentative identification and estimated concentration
nc – not calculated
U – not detected at given concentration
ww – wet weight

4.3 SUMMARY AND KEY POINTS

The baseline fish and crab tissue dataset met the goals of DQOs 1 and 2 by establishing robust 95UCL and mean concentrations of risk drivers for comparison to TTLs and to serve as a baseline for future monitoring. A summary of the key points for each chemical is presented in Table 4-14.

Table 4-14. Summary of key points for baseline fish and crab tissue

Chemical	Summary of Key Conclusions
Total PCBs	· TTLs were available for four fish/crab seafood categories (English sole whole body, shiner surfperch, crab edible meat, and crab whole body). Site-wide 95UCLs for all species were above the TTLs. · A statistical comparison of the 2007 and 2017 total PCB Aroclor data concluded that concentrations in English sole fillet were significantly lower in 2017, were not statistically different between English sole whole body and shiner surfperch and were significantly higher in 2017 for crab (edible meat and whole body; based on only Reach 1 data because insufficient Reach 2 data were available). · Concentrations of total PCBs in Pre-Design Studies baseline fish and crab tissue generally reflected the pattern of concentrations in sediment (i.e., higher concentrations in Reach 1 than in Reach 2). · The LDW FWM predictions (using Calibration 2) and the Pre-Design Studies dataset are similar, indicating that the tissue concentrations are responding as expected to the ongoing remediation in the LDW.
Dioxin/ furan TEQ	· The site-wide 95UCL for English sole (whole body) was above the TTL; site-wide 95UCLs for crab (both edible meat and whole body) were below the TTL. · Dioxin/furan TEQs were generally higher in tissue in Reach 1 than in tissue in Reach 2, corresponding with sediment TEQs.
cPAH TEQ	· cPAHs were not detected in baseline crab tissue samples.
Inorganic arsenic	· Concentrations of inorganic arsenic detected in baseline fish and crab tissue were similar to or slightly higher than those in the HHRA dataset.
Non-risk driver chemicals	· Concentrations of non-risk driver chemicals (vanadium, TBT, select SVOCs, and organochlorine pesticides) were generally similar to or lower than those reported in the HHRA dataset.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DL – detection limit
FWM – food web model
HCB – hexachlorobenzene
HHRA – human health risk assessment
LDW – Lower Duwamish Waterway
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
SVOC – semivolatile organic compound
SWAC – spatially weighted average concentration
TBT – tributyltin
TEQ – toxic equivalent
TTL – target tissue level

5 Clam Tissue

This section provides an interpretation of the clam tissue data collected in May 2018 in accordance with the clam tissue QAPP (Windward 2018f).

5.1 DQOs and Data Collected

As described in the clam tissue QAPP (Windward 2018f), clam tissue was collected to address the following two DQOs related to clam tissue:

- **Clam tissue DQO 1** – Establish baseline site-wide 95UCL concentrations of human health risk drivers for comparison to TTLs for RAO 1 (human health).
- **Clam tissue DQO 2** – Calculate baseline site-wide mean clam tissue concentrations to assess trends following sediment remediation for contaminants with TTLs.

The target species of clams for the LDW was the Eastern softshell clam (*Mya arenaria*), both because it is the most abundant species throughout the LDW and because it would be the primary target of clamming activities on the LDW. To address clam tissue DQOs 1 and 2, three types of clam tissue composites were collected, as described in Table 5-1. In addition, the clam tissue QAPP (Windward 2018f) covered the collection of co-located sediment and clam tissue for the cPAH porewater investigation, which is discussed in Section 6.

Table 5-1. Summary of clam tissue sampling design and number of samples

Composite Type	Summary of Sampling Design	Total No. of Samples
Inorganic arsenic composites	Composites of 3 clams each were collected from each of the 11 intertidal clam tissue collection areas (Map 5-1). For each composite, inorganic arsenic was analyzed in siphon skin and the clam tissue without siphon skin (concentrations in whole body including siphon skin calculated later). The siphon skin was analyzed separately because inorganic arsenic has been shown to accumulate preferentially in *M. arenaria* siphon skin.	11 siphon skin and 11 whole-body without siphon skin samples
Composites for other risk drivers[a]	Composites of 10 clams each were collected from 9 of the 11 intertidal clam tissue collection areas and analyzed for PCBs, cPAHs and dioxins/furans; insufficient numbers of clams were collected from areas C07 and C09 to create a composite sample.	9 whole-body samples
Segment-wide composites for non-risk driver chemicals	Composites for non-risk driver chemicals[b] were created using an equal mass of tissue from each intertidal clam tissue collection area in a given segment (i.e., one composite was created for each of the three intertidal segments shown on Map 5-1). Segment 1 (RM 0 to 1.3) includes clams from areas C01, C02, and C03; segment 2 (RM 1.3 to 2.6) includes clams from areas C04, C05, and C06; and segment 3 (above RM 2.6) includes clams from areas C08, C10, and C11. For consistency with the RI, clam collection was targeted in only the clam tissue collection areas; clams were not collected from other areas within these segments.	3 whole-body samples

[a] Unlike for inorganic arsenic, siphon skin was not analyzed separately for the other risk driver chemicals. Siphon skins were not analyzed separately for cPAHs because the evaluation of siphon skin cPAH concentrations conducted in June 2017 found that cPAHs were not elevated in clam siphon skin relative to the main-body portion of the clam tissue. Thus, whole-body clam composites were analyzed for cPAHs. In addition, the other

risk driver chemicals (i.e., total PCBs and dioxins/furans) have not been found to preferentially accumulate in siphon skin.

[b] Non-risk driver chemicals, as specified in the ROD (EPA 2014), include vanadium, TBT, select SVOCs (BEHP, carbazole, HCB, and PCP), and organochlorine pesticides.

BEHP – bis(2-ethylhexyl) phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
HCB – hexachlorobenzene
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
PCP – pentachlorophenol
RI – remedial investigation
ROD – record of decision
SVOC – semivolatile organic compound
TBT – tributyltin
TEQ – toxic equivalent

Clam tissue was collected as described in the QAPP (Windward 2018f) in May 2018. The clam tissue data were validated and no issues were identified with the data that would limit their use for calculating 95UCLs for comparison with TTLs or for evaluating trends in clam tissue concentrations.

The sampling design for clam tissue DQOs 1 and 2 was not based on a target RME as was the sampling design for fish / crab (Section 4.1). Instead, the clam tissue sampling design used an approach similar to that of the clam tissue collection done as part of the LDW RI (Windward 2010b): one clam tissue composite sample collected in each of the RI clam tissue collection areas. In addition, clams were collected for three different segment-wide composite samples for non-risk driver chemicals, per AOC3 (EPA 2016). Although few clams were found in clam tissue collection areas C07 and C09 (as described in Table 5-1), the absence of composites from these areas did not impact the usability of the baseline dataset to define site-wide conditions. The prevalence of clams in each clam tissue collection area will change over time, and therefore, all targeted clam tissue collection areas may not have a sufficient number of clams each time clams are collected to meet the total number of clams of size specified in the sampling design.

Variance within the clam tissue dataset represents differences in COC concentrations among the clam tissue collection areas located throughout the LDW. The sediment concentrations vary for risk drivers throughout the LDW, including in clam tissue collection areas. This is likely why the mean and variance in the baseline dataset can be high for some risk drivers (Table 5-2). However, because portions of many of these clam tissue collection areas are expected to be remediated, the mean and variance are expected to be lower in future datasets. For example, when the highest values were excluded from the whole-body inorganic arsenic dataset (area C11 at RM 3.8E) and the dioxin / furan TEQ dataset (area C04, commonly known as Glacier Bay), the RME was reduced from over 200% to approximately 25 to 30% (Table 5-2). Based on RI / FS sediment concentrations exceeding ROD-specified RALs in these areas (for dioxins / furans in area C04 and for arsenic in area C11), sediment remediation will occur in these areas. Therefore, reductions in site-wide variance of risk drivers in clam tissue are expected following remediation.

Table 5-2. Clam Tissue 95UCLs and evaluation of variance

Risk Driver	Sample Count	Estimation Method for 95UCL	95UCL	Mean	RME
Total PCBs (µg/kg ww)					
Total PCB Aroclors	9	normal	15.1	13.1	15%
Total PCB Congeners	6	normal	26.7	22.3	15%
cPAH TEQ (µg/kg ww)					
Non-detects = MDL	9	gamma	7.85	5.18	52%
Non-detects = MDL (excluding highest value – sample from area C05 [Slip 2])	8	gamma	6.45	4.45	45%
Non-detects = ½ MDL	9	gamma	7.80	4.59	70%
Non-detects = 0	9	gamma	8.05	4.01	101%
Dioxin/furan TEQ (ng/kg ww)					
All data	9	Chebyshev (non-parametric)	3.42	0.87	293%
Excluding highest value (sample from area C04 [Glacier Bay])	8	normal	0.35	0.28	25%
Inorganic arsenic (mg/kg ww)					
Whole body (all data)	11	Chebyshev (non-parametric)	19.4	5.40	259%
Whole body (excluding highest value – sample from area C11 at RM 3.8E)[a]	10	normal	2.89	2.20	31%
Whole body without siphon skin	11	lognormal	0.12	0.088	36%
Whole body without siphon skin (excluding highest values – samples from areas C04 and C11)[a]	9	lognormal	0.081	0.068	19%

[a] The distribution of the data is different for inorganic arsenic for whole-body clams and whole-body clam tissue without siphon skin. In the whole-body tissue dataset, the concentration in the sample from area C11 was more than nine times higher than that in the next highest sample. For the whole-body without siphon skin dataset, inorganic arsenic concentrations in samples from areas C04 and C11 were similar and were about twice as high as the next highest sample.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
MDL – method detection limit
PCB – polychlorinated biphenyl
RM – river mile
RME – relative margin of error
TEQ – toxic equivalent
ww – wet weight

The baseline clam tissue dataset met DQOs 1 and 2 by providing a dataset that represents site-wide conditions, and can be used to calculate 95UCLs for comparison with the TTLs and to calculate means for evaluating trends.

5.2 CLAM TISSUE DATA INTERPRETATION

This section presents the interpretation for clam tissue data, including the comparison of site-wide 95UCLs with TTLs and temporal and spatial context for the risk driver concentrations (e.g., spatial distribution, comparisons with historical and background data, and siphon skin results).

5.2.1 Evaluation of clam tissue data for risk driver chemicals

For DQO 1, site-wide 95UCL concentrations in clam tissue were compared with TTLs for each of the four risk drivers for which TTLs were presented in the ROD (EPA 2014) (Table 5-3). The TTLs for tissue were set as either the non-urban background concentration or the species-specific RBTC. For total PCBs, dioxin/furan TEQ, and inorganic arsenic, TTLs were based on non-urban background datasets developed as part of the LDW FS (AECOM 2012). As shown in Table 5-3, the selected non-urban background value was the 95UCL of those datasets. For cPAH TEQ, the TTL was based on a species-specific RBTC because insufficient data were available to develop a non-urban background value (EPA 2015a). The RBTC was developed in the RI based on a target excess cancer risk of 1×10^{-6} and assuming that the proportional relationship between concentrations in the different types of seafood included in the risk scenarios would remain the same (Windward 2010b).

Table 5-3. Clam tissue TTLs and non-urban background values from the LDW ROD

Risk Driver	TTL	TTL Basis	Non-urban Background Data			
			DF	Range of Detected Values	Mean	95UCL
Total PCBs (µg/kg ww)	0.42	non-urban background	24/70	0.09–1.4	0.3	0.42
cPAH TEQ (µg/kg ww)	1.8[a]	species-specific RBTC (using 2017 SF)	na[b]	na	na	na
Dioxin/furan TEQ (ng/kg ww)	0.71	non-urban background	43/43	0.011–1.6	0.34	0.71
Inorganic arsenic (mg/kg ww)	0.09	non-urban background	6/6	0.047–0.112	0.064	0.09

Note: Values in this table are reproduced from the LDW ROD and ROD errata (Tables 4[58] and 21) (EPA 2014, 2015a).

[a] TTL is based on EPA's 2017 update of the benzo(a)pyrene slope factor. The TTL presented in the ROD was 0.24 µg/kg ww (EPA 2014).

[b] Insufficient data were available do develop a non-urban background value for cPAHs in clams (EPA 2015a).

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DF – detection frequency
EPA – US Environmental Protection Agency
LDW – Lower Duwamish Waterway
na – not applicable
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
ROD – record of decision
SF – slope factor
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

Site-wide 95UCL concentrations in baseline clam tissue were calculated for comparison with the TTLs to address DQO 1. Details regarding the calculation of 95UCLs are presented in Appendix B. The 95UCLs for all four risk drivers were above their respective TTLs (Table 5-4). Results for each composite sample are shown along with

[58] Table 4 of the ROD is titled *Summary of PCB, arsenic, cPAH, and dioxin/furan data for natural background concentrations in fish and shellfish tissue.*

the TTL and 95UCL for each of the risk drivers in Figure 5-1. In addition to the 95UCLs, Table 5-4 presents the mean values for DQO 2 for comparison with future monitoring data.

Table 5-4. Comparison of clam tissue data with TTLs

Risk Driver	n	Mean Detect	Min. Detect	Max. Detect	95UCL[a]	TTL	95UCL < TTL?
Total PCBs (µg/kg ww)							
Total PCB Aroclors	9	13.1	8.0	19.6 J	15.1	0.42	no
Total PCB congeners	6	22.3	16.126 J	27.810 J	25.7		no
cPAH TEQ (µg/kg ww)							
Non-detects = MDL	9	5.18	2.80	11.0	7.85	1.8[b]	no
Dioxin/furan TEQ (ng/kg ww)							
All data	9	0.87	0.192 J	5.55 J	3.42	0.71	no
Inorganic arsenic (mg/kg ww)[c]							
Whole body	11	5.4	0.7	37.4	19.4	0.09	no
Whole body without siphon skin	11	0.09	0.05	0.19	0.12		no

Note: Tissue type is whole body unless otherwise specified.

[a] The 95UCL was calculated using the equation for normal, lognormal, or gamma distribution, or Chebyshev's inequality for a non-parametric estimate, as determined by the data. See Appendix B for details.

[b] TTL was based on EPA's 2017 update of the benzo(a)pyrene slope factor (EPA 2017). The TTL presented in the ROD was 0.24 µg/kg ww.

95UCL – 95% upper confidence limit (on the mean)
EPA – US Environmental Protection Agency
cPAH – carcinogenic polycyclic aromatic hydrocarbon
MDL – method detection limit
PCB – polychlorinated biphenyl
ROD – Record of Decision
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

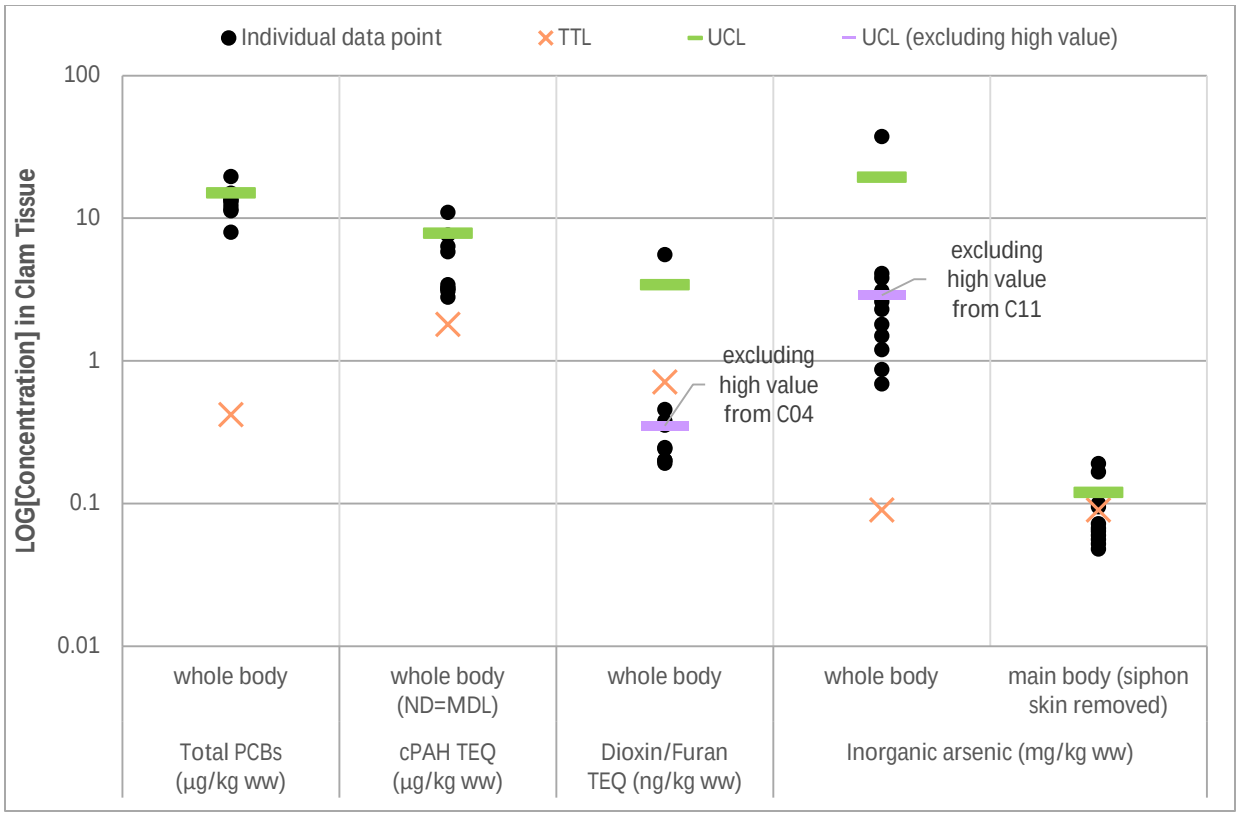
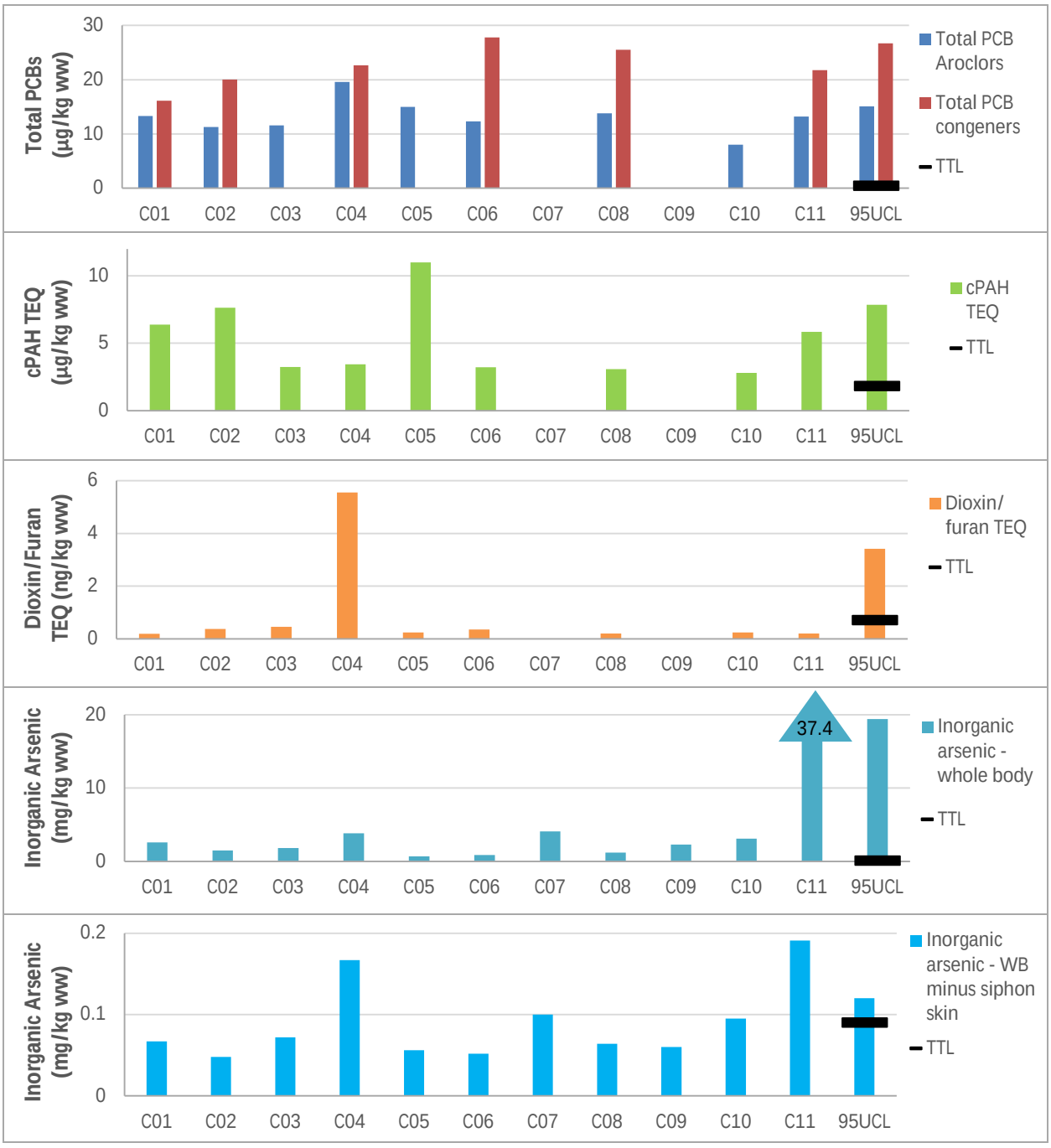


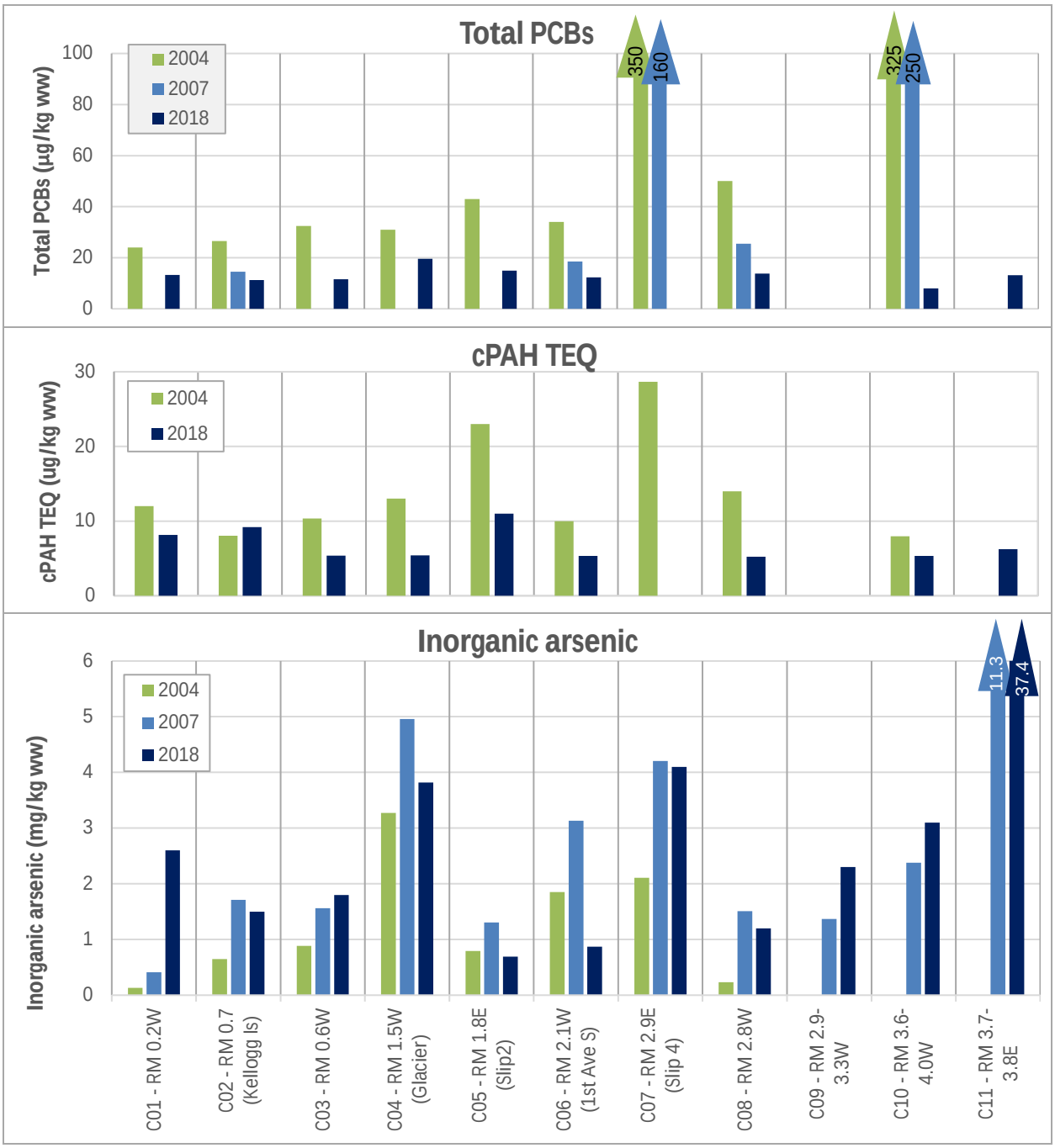
Figure 5-1. Comparison of clam tissue concentrations and TTLs for risk drivers

In addition to the site-wide comparison with TTLs, it is useful to look at concentrations as a function of the clam tissue collection areas (Map 5-1) where samples were collected and changes in these areas over time on an area-by-area basis. Figures 5-2 and 5-3 provide spatial and temporal comparisons, respectively, of clam tissue concentrations for the risk driver chemicals. For the temporal evaluation, details regarding each event that are relevant when assessing trends are summarized in Table 5-5. The subsections that follow provide a narrative of the baseline data for the risk driver chemicals, along with other available contextual information (e.g., non-urban background values and historical data).



Note: No data are available in areas C07 and C09 for cPAHs, dioxins/furans, and PCBs because insufficient clams were available in these areas. In area C07 (Slip 4), the low density of clams can be attributed to the recent remediation of that area; in area C09, it can be attributed to a lack of suitable clam habitat throughout most of this area in 2018.

Figure 5-2. Risk driver concentrations in clam composite samples across areas as well as a comparison of the site-wide 95UCL with the TTL



Note: For areas for which multiple samples were available (i.e., areas C2, C3, C7, and C10 for the 2004 and 2007 datasets), average values are presented in this figure. Where no bar is shown, no clam tissue data were collected for that year-chemical combination (see Table 5-5 for details).

Figure 5-3. Comparison of historical clam tissue data (2004/2007) with 2018 baseline data

Table 5-5. Overview of available LDW clam tissue data by year

Location Description	Sampling Year		
	2004	2007	2018
Mean values by Sampling Year:			
Total PCBs (µg/kg ww)	140	105[a] (6 locations only)	13.1
cPAH TEQ (µg/kg ww)	15.1	na (no data)	5.18
Dioxin/furan TEQ (ng/kg ww)	na (no data)	na (no data)	0.87 (0.28 excluding high value from area C04)
Inorganic arsenic (mg/kg ww)	1.2 (no sample collected from area C11[b])	2.7[a]	5.4 (2.2 excluding high value from area C11)
Overview of Sampling Details:			
Number of sampling locations	14	16 (depurated and non-depurated samples at some locations)	11
Clams per composite sample	19 to 52 (most samples had 20 to 30 clams)	20 to 23	3 for inorganic arsenic, 10 for other chemicals
Clam species	*M. arenaria, several Macoma nasuta*[c]	*M. arenaria*	*M. arenaria*
Sampling month	August	August	May
Analyzed for all risk drivers?	no – all except dioxins/furans	no – only analyzed for total and inorganic arsenic (all samples), PCBs (select samples)	yes
Location IDs by Sampling Year:			
RM 0.1–RM 0.3 West (T-105 Park)	C1	C1	C1
RM 0.6–RM 0.9 (Kellogg Island)	C2-1, C2-2 (n=2)	C2-1, C2-2 (n=2)	C2
RM 0.6–RM 0.7 West (T-107 Park)	C3-1, C3-2 (n=2)	C3-1, C3-2 (n=2)	C3
RM 1.4–RM 1.5 West (Glacier Bay)	C4	C4	C4
RM 1.8 East (Slip 2)	C5	C5	C5
RM 2.1 West (1st Ave S Bridge)	C6	C6	C6
RM 2.8 East (Slip 4)	C7-1, C7-2, C8 (n=3)	C7-1, C7-2, C8 (n=3)	C7 (arsenic only)
RM 2.8 West	C9	C9	C8
RM 2.9–RM 3.3 West (area including Duwamish Waterway Park)	none	C11	C9 (arsenic only)
RM 3.6–RM 4.0 West (area including and to the south of T-117)	C10-1, C10-2 (n=2)	C10-1, C10-2 (n=2)	C10
RM 3.7–RM 3.8 East	none	C12	C11

Note: All clam tissue data are for *M. arenaria* clams (Eastern softshell), unless otherwise specified.

[a] Calculated using depurated and non-depurated samples (no consistent difference in concentrations was observed in these data).

[b] The 2004 dataset does not include a sample collected in area C11 near RM 3.8E; this was the sample with the highest inorganic arsenic concentration in both the 2004 and 2007 datasets.

[c] The majority of the clams included in the composite samples were *M. arenaria*; in composite samples from C7-1, C10-1, and C10-2, several small *M. nasuta* were also included in the composite (2 to 3 clams for each sample).

cPAH – carcinogenic polycyclic aromatic hydrocarbon
ID – identification
LDW – Lower Duwamish Waterway
na – not applicable
PCB – polychlorinated biphenyl
RM – river mile
T-105 – Terminal 105
T-107 – Terminal 107
T-117 – Terminal 117
TEQ – toxic equivalent
ww – wet weight

5.2.1.1 Total PCBs

Total PCB concentrations in clam tissue were greater than the TTL for all samples (Figure 5-2). The variance in these samples was low (RME equal to 15%, Table 5-2), meaning that concentrations were relatively similar in samples from all locations (ranging from 8.0 to 19.6 µg/kg ww in clam tissue).

With respect to temporal trends, concentrations of total PCBs in LDW clams have decreased since 2004 at all locations throughout the LDW (Figure 5-3). For the eight areas for which historical data were available, concentrations in the 2018 samples were the lowest.

Two of the areas from which clams were collected in 2004 and 2007 have since been remediated: area C07, which is in the Slip 4 EAA (remediation completed in 2012), and area C10, which includes the T-117 EAA (sediment remediation completed in 2015) (Map 5-1). There are no baseline PCB clam tissue data from area C07 in 2018 because insufficient clams were available. In area C10, the 2004 samples (total PCB concentrations of 320 and 330 µg/kg ww) and 2007 samples (total PCB concentrations of 270 and 230 µg/kg ww) were collected in the northernmost portion the area (i.e., adjacent to T-117 at approximately RM 3.6). No clams were found in this part of area C10 during the 2018 sampling effort, so most 2018 clams were collected near RM 3.8. Therefore, the comparison of clam tissue concentrations from the three sampling years for area C10 does not reflect the same area.

Overall, the average total PCB concentration in clams has decreased from 140 µg/kg ww in 2004 to 13.1 µg/kg ww in 2018 (Table 5-5). Thus, although the 95UCL remains above the TTL, concentrations of total PCBs in clam tissue are decreasing, likely as a result of EAA remediation, source control, and natural recovery.

5.2.1.2 cPAH TEQ

The detection of the individual cPAHs used to calculate the cPAH TEQ ranged from one of seven (14%) to seven of seven (100%) for the clam tissue samples. When an individual cPAH is not detected, the assumption regarding the value of the non-detected cPAH has an important impact on the resulting TEQ, particularly when few cPAHs are detected. Thus, to evaluate the impact of the non-detected cPAHs, three different non-detect assumptions (i.e., equal to the MDL, equal to ½ MDL, or equal to zero) are presented in Table 5-6. As shown, although the mean value decreases as assumed values for the non-detected components decrease, the site-wide 95UCL actually increases slightly as a result of increasing variance.

Table 5-6. Comparison of Pre-Design Studies baseline clam tissue data with TTL for cPAH TEQ

Clam Tissue Collection Area	DF of cPAHs Included in cPAH TEQ	cPAH TEQ Calculated Using Different Non-Detect Assumptions (µg/kg ww)		
		Non-Detects = MDL	Non-Detects = ½ MDL	Non-Detects = 0
Individual sample results				
C01	5 / 7	6.37 J	5.89 J	5.41 J
C02	6 / 7	7.63 J	7.17 J	6.72 J
C03	4 / 7	3.23 J	2.43 J	1.63 J
C04	5 / 7	3.43 J	2.67 J	1.91 J
C05	7 / 7	11 J	11 J	11 J
C06	4 / 7	3.21 J	2.42 J	1.62 J
C08	4 / 7	3.08 J	2.29 J	1.49 J
C10	1 / 7	2.8	1.92	1.04
C11	6 / 7	5.84 J	5.54 J	5.23 J
Summary statistics and comparison with TTL				
Mean value		5.18	4.59	4.01
95UCL[a]		7.85	7.80	8.05
95UCL < TTL (1.8 µg/kg ww[b])?		no	no	no

[a] The 95UCL was calculated using the equation for normal, lognormal, or gamma distribution, or Chebyshev's inequality for a non-parametric estimate, as determined by the data. See Appendix B for details.

[b] TTL was based on EPA's 2017 update of the benzo(a)pyrene slope factor (EPA 2017). The TTL presented in the ROD was 0.24 µg/kg ww.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DF – detection frequency
EPA – US Environmental Protection Agency
MDL – method detection limit
ROD – Record of Decision
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

Clam tissue composite samples from all nine areas had cPAH TEQs that were above the TTL of 1.8 µg/kg ww (Figure 5-2). Because detection of individual cPAHs was an issue, comparisons with the TTL were also examined using the three assumptions presented in Table 5-6 for non-detected cPAHs (Figure 5-4). As shown in Figure 5-4, the clam tissue concentration in the sample from area C05 (located in Slip 2)—which had the highest cPAH TEQ (11 µg/kg ww)—remained the same because all cPAHs were detected. However, for samples in which the DF of the individual cPAHs was low (e.g., only one of the seven individual cPAHs was detected in the sample from area C10, located along the western shoreline from RM 3.6 to RM 4.0), the assumption regarding the value used for non-detected concentrations influenced the calculation of the TEQ. For the clam tissue collection area C10 sample, the cPAH TEQ was equal to 2.8 µg/kg ww, assuming non-detects were equal to the MDL; to 1.9 µg/kg ww, assuming non-detects were equal to ½ MDL; and to 1.04, assuming non-detects were equal to zero (Figure 5-4).

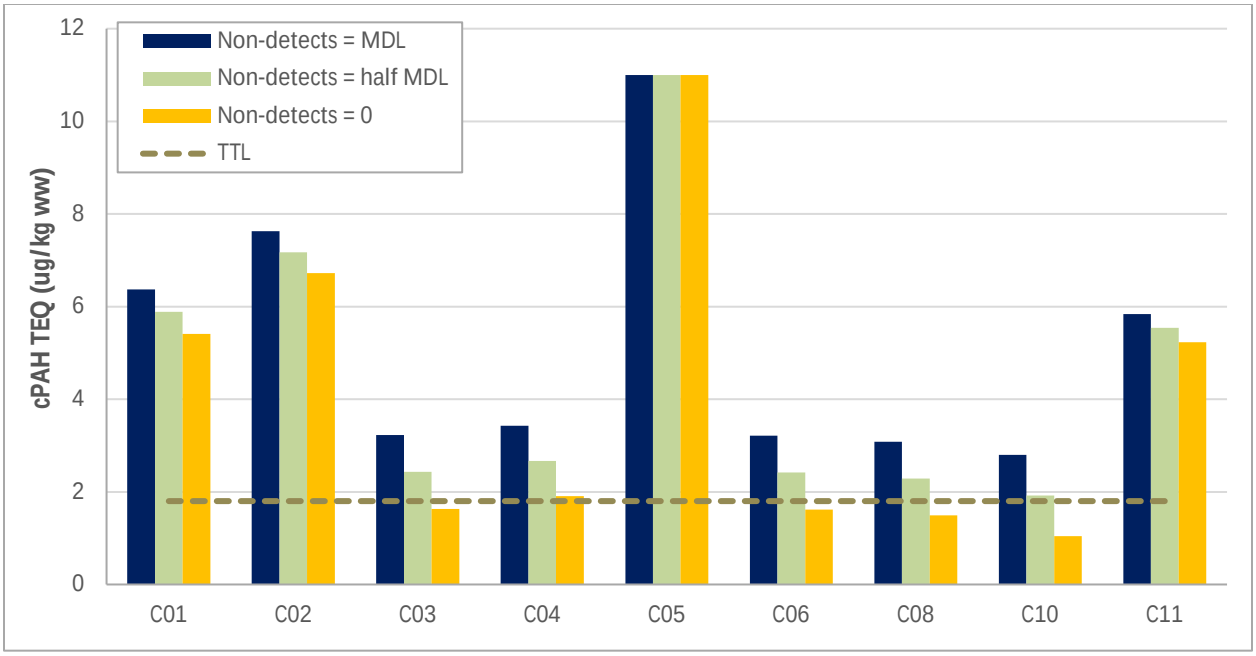


Figure 5-4.cPAH TEQs in clam tissue using different assumptions for non-detects

For context, the 2018 data were compared with the non-urban background dataset, which included 11 clam samples. The detected non-urban background cPAH TEQs for clams ranged from 0.069 to 0.17 µg/kg ww for the three samples with detected PAH concentrations (all geoducks); cPAHs were not detected in the other eight samples (geoducks, butter clams, and littleneck clams). These detected concentrations (for which a high-resolution analytical method was used) were lower than those detected in LDW clams.

For the sampling areas for which both 2004 and 2018 data were available, cPAH TEQs decreased in seven of the eight areas and slightly increased in one area (i.e., area C02, Kellogg Island) (Figure 5-3). In area C02, two composite clam tissue samples were collected from smaller areas within this area in 2004 (cPAH TEQs of 6.8 and 9.3 µg/kg ww), whereas in 2018, the composite sample (cPAH TEQ of 9.2 µg/kg ww) represented clams collected from throughout area C02.

Overall, the available data suggest a generally decreasing trend in cPAH TEQs in clam tissue.

5.2.1.3 Dioxin/furan TEQ

With the exception of the sample from area C04 (for which the dioxin/furan TEQ was 5.55 ng/kg ww), all clam tissue composite samples had TEQs less than the TTL of 0.72 ng/kg ww (Figure 5-2). Area C04 (Glacier Bay) has known dioxin/furan contamination and will be remediated as part of EPA's cleanup plan. As shown in Table 5-7, the site-wide 95UCL would be less than the TTL if the composite sample from area C04 (Glacier Bay) was excluded.

Table 5-7. Comparison of clam tissue data with TTLs for dioxins/furans

Dataset Description	n	Dioxin/Furan TEQ in Clam Tissue (ng/kg ww)					95UCL < TTL?
		Mean Detect	Min. Detect	Max. Detect	95UCL[a]	TTL	
All data	9	0.87	0.192 J	5.55 J	3.42	0.71	no
Excluding highest value (sample from area C04 [Glacier Bay])	8	0.28	0.192 J	0.456 J	0.35		yes

[a] The 95UCL was calculated using the equation for normal, lognormal, or gamma distribution, or Chebyshev's inequality for a non-parametric estimate, as determined by the data. See Appendix B for details.

95UCL – 95% upper confidence limit (on the mean)
J – estimated concentration
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

Most of the clam tissue composite samples collected in the LDW had dioxin / furan TEQs within the range of TEQs for clams in the non-urban background dataset (0.011 to 1.6 ng / kg ww for the 43 clam tissue samples[59]). Dioxins / furans were not analyzed in 2004 and 2007, so comparison to historical data was not possible.

5.2.1.4 Inorganic arsenic

For inorganic arsenic, concentrations in siphon skin are an important consideration based on the results of the Regional Applied Research Effort (RARE) study (Kerns et al. 2017) and research done by the Oregon Department of Environmental Quality (Oregon DEQ 2015). These efforts found that concentrations of inorganic arsenic in *M. arenaria* tissue are orders of magnitude higher in siphon skin than in rest of the tissue. Therefore, inorganic arsenic concentrations in both whole-body and whole-body without siphon skin samples were compared with the TTL. As discussed in the RARE study (Kerns et al. 2017), although whole-body concentrations may remain above the TTL (as is the case for the Pre-Design Studies baseline tissue 95UCL), whole-body without siphon skin tissue may reach (or drop below) the TTL after completion of the remedy. This conclusion is consistent with the baseline data, which show that the whole-body without siphon skin 95UCL is less than the TTL when the two highest values are excluded (Table 5-8).

[59] Background clams included butter, littleneck, horse and geoduck.

Table 5-8. Comparison of clam tissue data with TTLs for inorganic arsenic

Dataset Description	n	Inorganic Arsenic in Clam Tissue (mg/kg ww)					95UCL < TTL?
		Mean Detect	Min. Detect	Max. Detect	95UCL[a]	TTL	
Whole body (all data)	11	5.4	0.7	37.4	19.4	0.09	no
Whole body (excluding highest value – sample from area C11 at RM 3.8E)[b]	10	2.2	0.7	4.1	2.89		no
Whole body without siphon skin	11	0.09	0.05	0.19	0.12		no
Whole body without siphon skin (excluding highest values from areas C04 and C11)[b]	9	0.07	0.05	0.1	0.08		yes

[a] The 95UCL was calculated using the equation for normal, lognormal, or gamma distribution, or Chebyshev's inequality for a non-parametric estimate, as determined by the data. See Appendix B for details.

[b] The distribution of the data is different for inorganic arsenic for whole-body clams and whole-body clam tissue without siphon skin. In the whole-body tissue dataset, the inorganic arsenic concentration in the sample from area C11 was more than nine times higher than that in the next highest sample (Figure 5-2). For the whole-body without siphon skin dataset, inorganic arsenic concentrations in areas C04 and C11 were similar and were about twice as high as the next highest sample (Figure 5-2).

95UCL – 95% upper confidence limit (on the mean)
RM – river mile
TTL – target tissue level
ww – wet weight

The siphon skin of clams made up an average of 9% of the clams mass (similar to the 5.7% of the mass reported in the RARE study (Kerns et al. 2017)). Despite the low mass, the inorganic arsenic in the siphon skin accounted for nearly all (average of 97%) of the inorganic arsenic concentration in whole-body clam tissue (Figure 5-5). In other words, concentrations in siphon skin tissue were approximately 160 to 1,600 times higher than those in whole-body tissue without siphon skin. These results were similar to those of the RARE study, in which concentrations in siphon skin tissue were approximately 530 to 850 times higher than those in whole-body tissue without siphon skin.

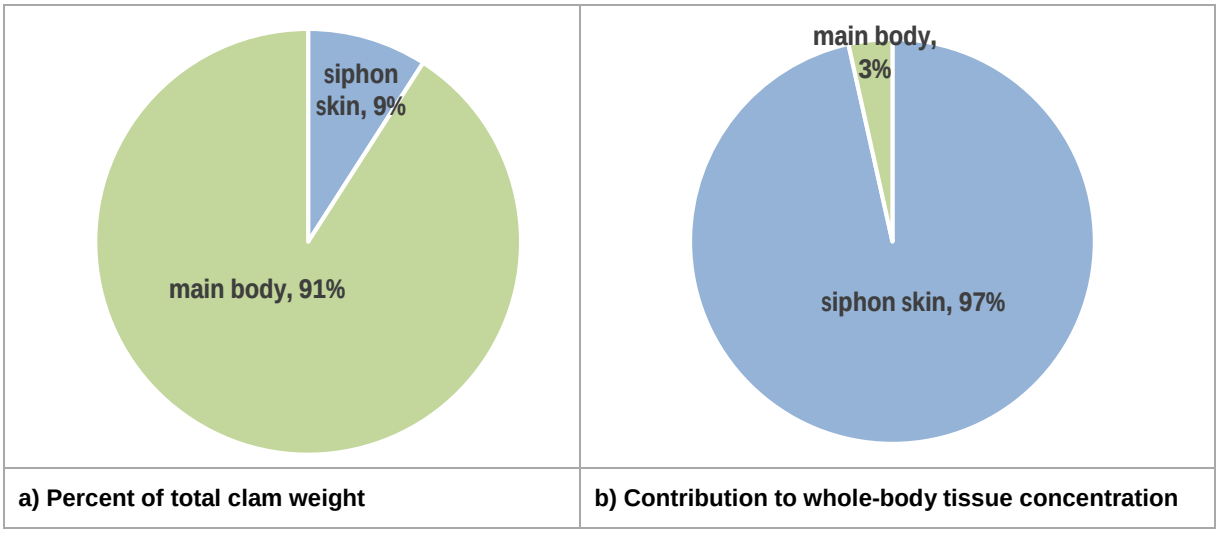


Figure 5-5.*M. arenaria* clam siphon skin results for inorganic arsenic

The TTL for inorganic arsenic (0.09 mg/kg ww) was based on the 95UCL of inorganic arsenic concentrations in six whole-body *M. arenaria* clam samples from one non-urban background location (Dungeness Spit, located near Sequim, Washington). Concentrations in these samples ranged from 0.047 to 0.112 mg/kg ww. Inorganic arsenic concentrations in the whole-body Pre-Design Studies baseline samples ranged from 0.69 to 37.4 mg/kg ww, or from 0.69 to 4.1 mg/kg ww excluding the highest tissue sample (collected from area C11 at RM 3.8E), which has a concentration that was more than nine times higher than that in the next highest sample (Figure 5-2). Whole-body inorganic arsenic concentrations in all 11 baseline samples were greater than the TTL and were above the range of non-urban background concentrations used to develop the TTL.

Without the siphon skin, however, inorganic arsenic concentrations were similar to or less than the TTL of 0.09 mg/kg ww at all locations except areas C04 (Glacier Bay) and C11 (RM 3.8E). These two locations are expected to be remediated as part of EPA's cleanup plan because of sediment RAL exceedances. Following remediation of these areas, clam tissue 95UCLs should have inorganic arsenic concentrations in whole-body tissue without siphon skin less than the TTL. These results further support the conclusions of the RARE study (Kerns et al. 2017), which noted that although whole-body concentrations may remain well above the TTL, concentrations in whole-body tissue without siphon skin may reach (or drop below) the TTL over time.

No clear temporal pattern exists with regard to inorganic arsenic concentrations in clam tissue (Figure 5-3). In some areas, concentrations were highest in the 2018 composite tissue sample; in other areas, the highest concentrations were in the 2004/2007 composite tissue samples. As noted in Table 5-5, the 2018 composites analyzed for inorganic arsenic represented 3 individual clams, whereas the 2004/2007 samples represented between 19 and 52 clams, adding to the uncertainty associated with this comparison.

5.2.2 Evaluation of clam tissue data for non-risk driver chemicals

The clamming areas were divided into three segments (Map 5-1) for composite samples to be collected and analyzed for the non-risk driver chemicals. Each composite sample was composed of equal portions of the whole-body tissue from each clam tissue collection area within the given intertidal segment. DFs and average concentrations (for detected chemicals) were compared with data from 2004 to evaluate changes in concentrations of these chemicals (Table 5-9). Although this comparison is useful for evaluating changes in clam tissue concentrations, differences in the sampling designs are important to recognize. The 2004 dataset included 14 composite samples (19 to 52 clams per composite) from a total of 9 areas. The 2018 dataset for the non-risk driver chemicals, as described above, was made up of 3 segment-wide composite samples that each represented 3 clamming areas (30 clams per segment-wide composite).

Table 5-9. Non-risk driver chemistry results compared with 2004 data

Analyte	Unit (ww)	Summary of 2018 Data			Summary of HHRA Data		
		DF	Range of Values	Average[a]	DF	Range of Values	Average[a]
Metals and organometals							
Vanadium	mg/kg	3/3	1.23–1.38	1.32	14/14	0.68–2.65	1.3
TBT	µg/kg	3/3	5.34–7.44	6.32	14/14	150–660	320
SVOCs							
BEHP	µg/kg	1/3	50.0 U–70.7	40.2	10/14	56 J–220 J	140
Carbazole	µg/kg	0/3	19.9 U–20.0 U	nc	0/14	200 U	nc
HCB	µg/kg	0/3	19.9 U–20.0 U	nc	9/14	0.38 JN–1.0 JN	0.66
PCP	µg/kg	0/3	99.6 UJ–100 UJ	nc	0/14	390 U–400 U	nc
Organochlorine pesticides							
Total DDTs	µg/kg	0/3	0.70 U	nc	14/14	3.8 JN–33 JN	12
Aldrin	µg/kg	0/3	0.22 U–0.23 U	nc	3/14	0.77 JN–1.0 JN	0.59
Dieldrin	µg/kg	0/3	0.22 U–0.23 U	nc	4/14	3.8 JN–5.0 JN	2.4
alpha-BHC	µg/kg	0/3	0.26 U	nc	1/14	0.35 JN–1.0 U	0.49
gamma-BHC	µg/kg	0/3	0.22 U–0.23 U	nc	3/14	0.51 JN–1.0 U	0.68
Total chlordane	µg/kg	0/3	0.77 U	nc	14/14	0.86 JN–9.3 JN	2.1
Heptachlor	µg/kg	0/3	0.22 U–0.23 U	nc	0/14	1.0 U	nc
Heptachlor epoxide	µg/kg	0/3	0.22 U–0.23 U	nc	5/14	1.0 U–1.5 JN	0.81

[a] Average is the average of the value or ½ RL (for non-detects). Averages were not calculated when there were no detected values.

BEHP – bis(2-ethylhexyl) phthalate
BHC – benzene hexachloride
DDT – dichlorodiphenyltrichloroethane
DF – detection frequency
HCB – hexachlorobenzene
HHRA – human health risk assessment
J – estimated concentration
JN – tentative identification and estimated concentration
nc – not calculated
PCP – pentachlorophenol
RL – reporting limit
SVOC – semivolatile organic compound
TBT – tributyltin
U – not detected at given concentration
UJ – not detected at estimated concentration
ww – wet weight

As shown in Table 5-9, only three of the non-risk driver chemicals (vanadium, TBT, and BEHP) were detected in the 2018 clam tissue samples. Only one sample had a detected concentration of BEHP (no other phthalates were detected), and no pesticides were detected in any of the samples. Changes in the clam tissue concentrations for the three chemicals detected in 2018 are discussed further below:

- **Vanadium** – Concentrations in the 2018 Pre-Design Studies baseline samples were similar to those in the HHRA dataset.
- **TBT** – Concentrations in the 2018 Pre-Design Studies baseline samples were (on average) about 50 times lower than those in the HHRA dataset.
- **BEHP** – Concentrations in the 2018 Pre-Design Studies baseline samples were lower than those in the HHRA.

5.3 SUMMARY AND KEY POINTS

The baseline dataset met the goals of DQOs 1 and 2 by establishing a baseline dataset to calculate 95UCLs and mean concentrations for risk drivers for comparison with TTLs and for use in future monitoring of the four risk driver chemicals. A summary of the key points for each risk driver chemical and the non-risk driver chemicals is presented in Table 5-10.

Table 5-10. Summary of key points for baseline clam tissue

Chemical	Summary of Key Conclusions
Total PCBs	· Total PCB concentrations in clam tissue have decreased since the HHRA was performed. Nonetheless, the site-wide 95UCL remains above the TTL for clams. · Total PCB concentrations in LDW clams have decreased since 2004 at all locations throughout the LDW for which historical and baseline data are available.
cPAH TEQ	· cPAH TEQs in clam tissue have decreased since the HHRA was performed. However, the site-wide 95UCL for clams remains above the updated 2017 RBTC-based TTL for clams
Dioxin/ furan TEQ	· The site-wide 95UCL was above the non-urban background-based TTL for clams; however, excluding the highest value (sample from area C04 [Glacier Bay]), the site-wide 95UCL was below the TTL. · No historical clam tissue data were available for dioxins/furans; thus no temporal comparison could be conducted.
Inorganic arsenic	· Inorganic arsenic concentrations in whole-body clam tissue are similar to those used in the HHRA. The site-wide 95UCL for whole-body clam tissue was above the TTL for clams, both including all data and excluding the highest value (sample from area C11 at RM 3.8). · The Pre-Design Studies baseline results support the conclusions of the RARE study (Kerns et al. 2017), which discussed that although whole-body concentrations may remain above the TTL (as was the case for the 2018 site-wide 95UCL), concentrations in whole-body tissue without siphon skin may reach (or drop below) the TTL after completion of the remedy. The 95UCL for whole-body tissue without siphon skin (0.12 mg/kg ww) was just above the TTL (0.09 mg/kg ww).
Non-risk driver chemicals	· The only non-risk driver chemicals detected in clam tissue samples were vanadium, TBT, and BEHP. The other SVOCs and pesticides were not detected. For the detected chemicals, concentrations decreased for TBT and BEHP relative to the HHRA dataset and remained similar for vanadium.

95UCL – 95% upper confidence limit (on the mean)
BEHP – bis(2-ethylhexyl) phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
HHRA – human health risk assessment
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RARE – Regional Applied Research Effort
SVOC – semivolatile organic compound
T-117 – Terminal 117
TBT – tributyltin
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

6 Porewater Investigations

This section provides an interpretation of the porewater data collected in 2018 per the porewater addendum to the Work Plan (Windward and Integral 2017a).

6.1 DQOs and Data Collected

The porewater addendum compiled the available LDW porewater data for cPAHs, arsenic, total PCBs, and dioxins/furans to determine whether the existing data were sufficient to establish baseline porewater concentrations. Per the porewater addendum to the Work Plan (Windward and Integral 2017a) porewater data were collected to address the two porewater DQOs:

- **Porewater DQO 1** – Assess the relationship among concentrations of cPAHs in clam tissue, porewater, and sediment to help evaluate whether achieving sediment cleanup levels for cPAHs will reduce concentrations in clam tissue to TTLs.
- **Porewater DQO 2**[60] – Estimate baseline porewater concentrations in MNR and enhanced natural recovery (ENR) areas for total PCBs and dioxins/furans. This DQO is primarily intended to help assess the effect of reduced sediment concentrations on biota exposure and tissue concentrations.

Arsenic and cPAHs are COCs for human health primarily due to risks associated with clam consumption (Windward 2010b). Based on a review of the available LDW porewater data for arsenic in the porewater addendum, it was determined that existing arsenic data were sufficient to address data needs for arsenic related to clams and their consumption by humans (Windward and Integral 2017a). Therefore, only cPAH porewater data were collected as part of the Pre-Design Studies for porewater DQO 1. Porewater DQO 1 addresses the relationships among clam tissue, porewater, and sediment to assess whether sediment cleanup will reduce cPAH concentrations in clams and whether porewater information for cPAHs is helpful in this assessment.

Porewater DQO 2 addresses baseline porewater concentrations for total PCBs and dioxins/furans. The existing PCB porewater data were evaluated in the porewater addendum, wherein it was determined that the collection of additional PCB porewater data was necessary to establish the relationship between sediment and porewater PCB concentrations.

No porewater data exist for dioxins/furans for the LDW. However, rather than collecting additional data, it was concluded that the methods for collecting porewater data for dioxins/furans have not been sufficiently developed. Specifically, the partition coefficients needed to reliably measure LDW porewater dioxin/furan concentrations

[60] Porewater DQO 2 from the porewater addendum to the Work Plan (Windward and Integral 2017a) was included in the sediment QAPP as DQO 5 (Windward 2018d).

using passive samplers are still under development. Therefore, a decision was made to use literature partition coefficients to model porewater concentrations of dioxins/furans to address DQO 2.

The study design to address DQO 1 for cPAHs in porewater was detailed in the clam QAPP (Windward 2018f). cPAH concentrations in co-located intertidal sediment (0–10-cm), clam tissue, and porewater were investigated to assess the utility of porewater data in better understanding the clam tissue-sediment relationship. To this end, a total of 16 locations were sampled for co-located clam tissue and sediment from May 15 through 18, 2018 (Map 6-1). In consultation with EPA, 10 cPAH porewater investigation samples (i.e., those from areas A01, A02, A04, A06, A07, A08, A10, A11, A17, and A18) were selected for porewater investigation based on a review of the sediment results for cPAH TEQ, individual cPAHs, and TOC, as well as co-located clam tissue results for cPAH TEQ and the individual cPAHs (Windward 2018g). Passive samplers were exposed to sediment *ex situ* for 28 days (from May 25, 2018, to June 22, 2018) in order to assess the freely dissolved concentrations of individual cPAHs in porewater.

After these passive samplers were analyzed, it became apparent that at least two passive samplers had been swapped at some point in the analytical process (Windward 2018g). Because there was no way to definitively identify all the passive samplers that had been affected, it was agreed that the *ex situ* exposures will be redone using sediment from the 10 locations that has been archived, frozen, at Analytical Resources, Inc. The resulting cPAH sediment, clam tissue and porewater data will be presented and interpreted in an addendum to the data evaluation report in early 2019, when available.

The plan to address porewater DQO 2 for total PCBs was detailed in the sediment QAPP (Windward 2018d). For this investigation, 20 0–10-cm sediment samples were collected in February/March 2018. Based on the results for PCB Aroclors, TOC, and black carbon, 10 of the 20 samples were selected for *ex situ* exposure to passive samplers for analysis of PCB congeners (Map 6-2). Five of these 10 sediment samples were collected from locations within MNR/ENR areas identified in the ROD (EPA 2014).[61] The other five samples were collected from locations in areas identified for dredging in the ROD. The locations were selected to provide a range of total PCB concentrations, from 3.54 to 46.0 mg/kg organic carbon (OC).

For the PCB porewater test, polyethylene (PE) strips were placed in jars with sediment slurries and shaken for 28 days (Windward 2018i). From the analyses of these PE strips, measured porewater concentration (referred to as freely dissolved total PCB porewater concentrations) were calculated from the PCB congener concentrations detected

[61] Preliminary ENR and MNR areas were established in Figure 18 of the ROD (EPA 2014) based on RI/FS data. The boundaries of these areas, as well as others, are likely to change based on design-level sampling and evaluations. This report refers to these areas simply as ENR and MNR areas, but it is acknowledged that these areas are preliminary.

following equilibration with sediment. The PCB porewater data were validated and no issues were identified that would limit the use of this data.

6.2 POREWATER DATA INTERPRETATION

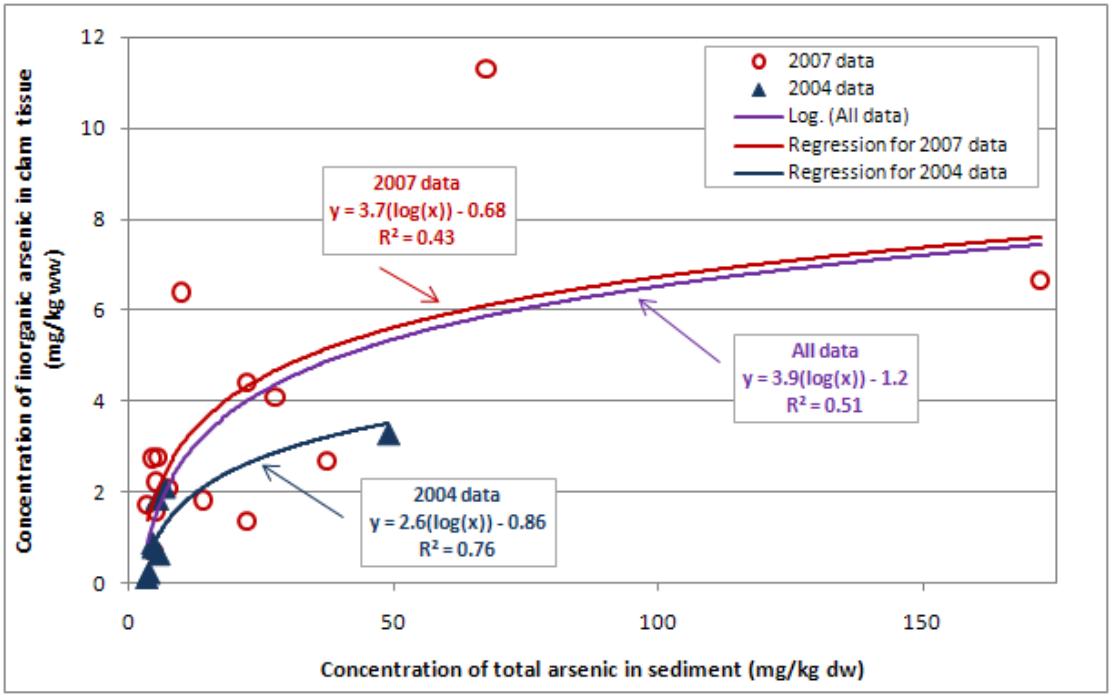
6.2.1 cPAH porewater investigation

As noted above, exposure of the PE strips to calculate freely dissolved concentrations of cPAH had to be re-run. Therefore, the results of the cPAH porewater investigation with respect to DQO 1 will be provided in an addendum to this report in 2019.

6.2.2 Review of existing arsenic data

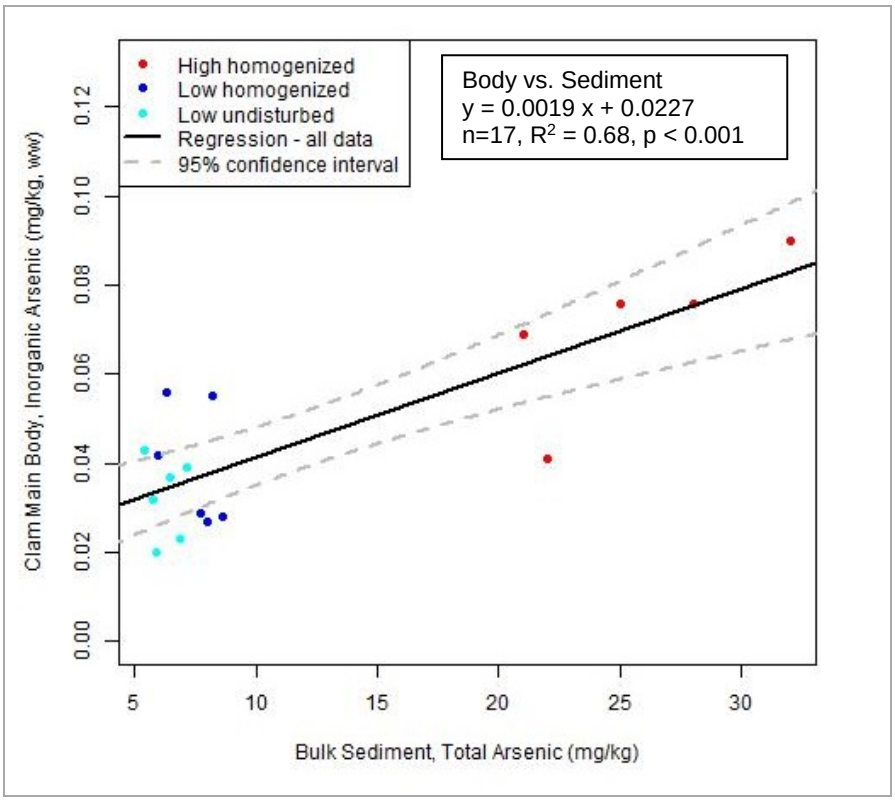
Arsenic was not included in DQO 1 because the existing data evaluated in the porewater addendum to the Work Plan were determined to be sufficient (Windward and Integral 2017a). The addendum presented the co-located sediment and clam tissue data collected for the RI (Windward 2010a) and the co-located sediment, clam tissue, and porewater data collected in the RARE study (Kerns et al. 2017). Based on these data, the addendum concluded that:

- **The available porewater data did not help to explain the bioaccumulation of inorganic arsenic by** *M. arenaria*. The RARE study demonstrated that concentrations of total arsenic in porewater were closely related to those in sediment, and that the relationship between clam tissue and sediment was stronger than that between clam tissue and porewater (Kerns et al. 2017). Thus, the available porewater data did not help to explain the variance around the clam tissue-sediment relationship.
- **Both the RI and the RARE studies found a moderate clam tissue-sediment relationship**. Moderate-strength clam tissue-sediment relationships were developed using data from the LDW RI (Windward 2010a), as presented in Figure 6-1, and from the RARE study (Kerns et al. 2017), as presented in Figure 6-2. The considerable uncertainty around the regressions suggests that additional non-sediment factors are important.
- **The TTL for whole clams can be achieved in whole-body clam tissue without the siphon skin with the current remedy**. As discussed in the RARE study (Kerns et al. 2017), inorganic arsenic concentrations in whole-body tissue minus siphon skin are predicted to reach the TTL of 0.09 mg/kg at a sediment concentration of 36 mg/kg total arsenic, which is greater than the intertidal RAL for total arsenic of 28 mg/kg dw and the site-wide sediment cleanup goal of 7 mg/kg dw.



Source: Windward (2010a)

Figure 6-1. Logarithmic regression of inorganic arsenic concentrations in LDW clam tissue relative to total arsenic concentrations in co-located sediment using 2004 and 2007 data



Note: The gray dashed lines indicate the 95% confidence limits.

Figure 6-2. Regression of inorganic arsenic concentrations in whole-body clam tissue minus siphon skim relative to total arsenic concentrations in co-located sediment samples from the *in situ* portion of the RARE study

Based on the regression analysis presented in the RARE study (Kerns et al. 2017), total arsenic sediment concentrations reduced through sediment cleanup, source control, and natural recovery in the LDW are expected to result in reductions in inorganic arsenic concentrations in clam tissue. As stated in the RARE study, the intertidal sediment RAL for arsenic (28 mg / kg) appears to be sufficiently low that inorganic arsenic concentrations in whole-body clams (without siphon skin) will meet the TTL for whole clams (0.09 mg / kg ww) following remediation. However, concentrations of inorganic arsenic in the siphon skin may not be reduced sufficiently to allow the whole-body clam tissue to achieve the TTL, which is relevant since consumption of whole clams is a potential exposure route for tribal and subsistence harvesters. The RARE study further notes that sediment is not the only exposure pathway for clams. Arsenic in surface water and solids (including suspended materials and phytoplankton) at the sediment-water interface may also affect clam tissue concentrations.

Thus, the data from both the RI (Windward 2010a) and the RARE (Kerns et al. 2017) studies support the following conclusions:

- Reducing arsenic concentrations in sediment is expected to reduce arsenic concentrations in clam tissue.
- Clams have multiple exposure pathways; the porewater data did not explain the variance between arsenic concentrations in clam tissue and sediment.
- Additional arsenic porewater data will not provide additional insights.
- The sediment cleanup level in intertidal sediment is likely to be protective of human clam consumption, provided siphon skins are removed.

6.2.3 PCB porewater investigation

A porewater PCB investigation was conducted to address DQO 2, and to measure PCB porewater concentrations associated with the range of sediment total PCB concentrations in MNR and ENR areas. In addition, the data were used to evaluate the relationship between sediment and porewater concentrations to determine whether equilibrium partitioning models could be used to calculate total PCB concentrations in porewater.

Surface sediment samples were exposed *ex situ* to PE strips in order to determine total PCB C_{free}[62] in porewater associated with total PCB concentrations and organic matter in sediment (Table 6-1). The strong relationship between the porewater and sediment concentrations for one PCB congener (PCB-66) is shown in Figure 6-3. Total PCB concentrations in porewater increased with increased OC-normalized total PCB sediment concentrations (Figure 6-4). The range of OC-normalized total PCB concentrations in sediment included the upper limits for ENR, thus enabling the estimation of baseline porewater concentrations in MNR and ENR areas per DQO 2.

Table 6-1. Total PCB (sum of congeners) concentrations in porewater and sediment

Sample ID	Total PCBs (Congener Sum) in Porewater (ng/L)[a]	Total PCBs (Congener Sum) in Sediment		TOC (%)	Black Carbon (%)
		µg/kg	mg/kg OC		
LDW18-PW-SS169	3.082 J	138.93 J	6.68	2.08 J	0.035 J
LDW18-PW-SS172	7.339 J	508.6 J	10.2	4.97	0.133 J
LDW18-PW-SS174	1.6019 J	32.68 J	3.67	0.890	0.047 J
LDW18-PW-SS175	11.586 J	250.6 J	15.9	1.58	0.051 J
LDW18-PW-SS177	4.134 J	385.5 J	12.1	3.19 J	0.051 J

[62] Calculations were required to estimate concentrations in porewater based on concentrations in passive samplers exposed to sediment. Details of these calculations are presented in the sediment data report (Windward 2018i). The resulting total PCB concentrations represent the freely dissolved concentration (C_{free}) of PCBs in porewater.

Sample ID	Total PCBs (Congener Sum) in Porewater (ng/L)[a]	Total PCBs (Congener Sum) in Sediment		TOC (%)	Black Carbon (%)
		µg/kg	mg/kg OC		
LDW18-PW-SS179	2.470 J	78.06 J	3.00	2.60 J	0.070 J
LDW18-PW-SS180	19.59 J	1,172.6 J	46.0	2.55 J	0.087 J
LDW18-PW-SS184	2.468 J	59.63 J	6.08	0.980 J	0.010 UJ
LDW18-PW-SS185	5.780 J	247.5 J	21.3	1.16 J	0.010 UJ
LDW18-PW-SS187	2.215 J	40.34 J	3.54	1.14 J	0.031 J

[a] Freely dissolved concentration (C_{free}) in porewater.

ID – identification
J – estimated concentration
OC – organic carbon
PCB – polychlorinated biphenyl
TOC – total organic carbon
UJ – not detected at estimated concentration

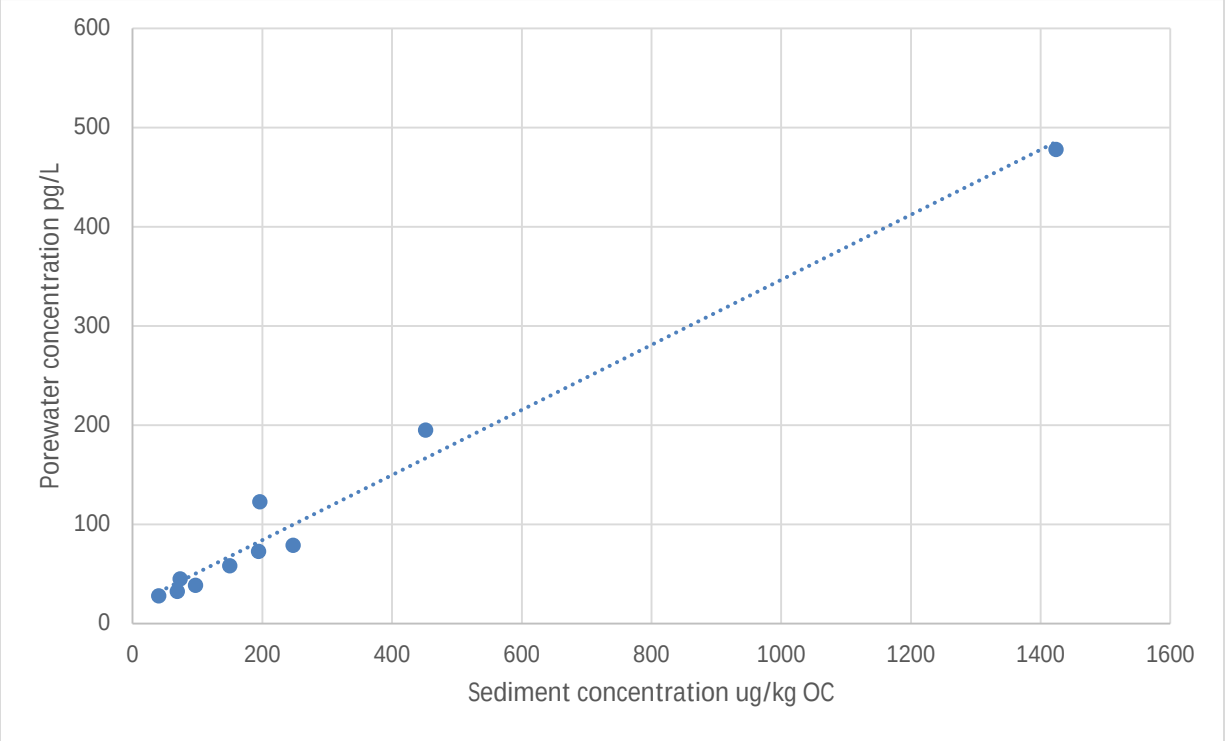


Figure 6-3. PCB congener PCB-66 C_{free} in porewater as a function of OC-normalized total PCB concentrations in LDW sediment

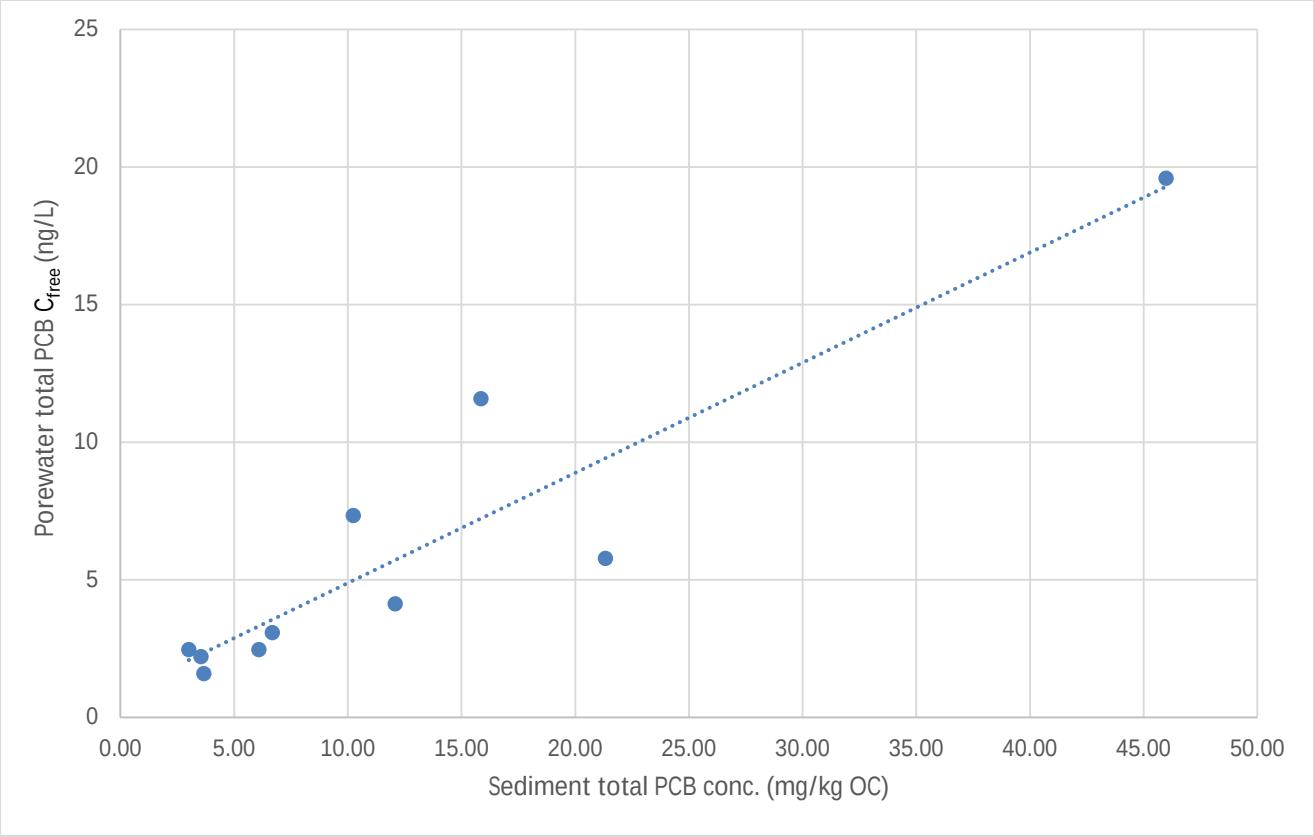


Figure 6-4. Total PCB C_{free} in porewater as a function of OC-normalized total PCB concentrations in LDW sediment

Total PCB concentrations in porewater can also be predicted using one- and two-carbon equilibrium partitioning models. These models have been developed to predict porewater concentrations from total PCB concentrations in sediment and the fractions of TOC and black carbon in sediment (Koelmans et al. 2006). If the measured porewater concentrations are consistent with the model results, then equilibrium models can be used to supplement the dataset.

A one-carbon model requires total PCB concentrations in sediment and the fraction of OC in the sediment (Equation 1). Modeling is done on a PCB congener-specific basis. The congener concentration and fraction of OC in sediment combined with the partition coefficient are used to calculate the corresponding freely dissolved PCB congener concentration in porewater.

$$C_S = f_{OC} \times K_{OC} \times C_W \quad \textbf{Equation 1}$$

Where:

C_S = bulk sediment concentration

f_{OC} = fraction of organic carbon in the sediment

K_{OC} = organic carbon-to-water partition coefficient

C_W = freely dissolved concentration in porewater calculated from PE samplers

This one-carbon model does not account for the more strongly sorbing black carbon phases in sediments, and therefore does not account for the variations in the sorptive properties of sediments encountered in urban waterways. Black carbon is generally composed of charcoal, soot, pitch, or other coal-based industrial byproducts, while OC is typically composed of natural detritus and organic matter from the environment (Koelmans et al. 2006). EPA (2012) provides guidelines on how to account for these differences by adding an additional black carbon phase to the model, as proposed by Accardi-Dey and Gschwend (2002) (Equation 2).

$$C_S = (f_{OC} \times K_{OC} \times C_W) + (f_{BC} \times K_{BC} \times C_W^n) \quad \textbf{Equation 2}$$

Where the additional terms are defined as:

f_{BC} = fraction of black carbon in the sediment

K_{BC} = black carbon-to-water partition coefficient

n = Freundlich exponent describing sorption non-linearity to black carbon

In the case of the two-carbon model, partition coefficients are required for both TOC and black carbon. The PCB congener partition coefficients used to predict porewater concentrations are provided in Appendix D. The literature partition coefficients (K_{oc} and K_{BC} values) used for the Massachusetts Institute of Technology (MIT) LDW investigation (Apell and Gschwend 2016) were those provided by Hansen et al. (1999) and Koelmans et al. (2006), respectively. The same partition coefficients were used in the modeling presented herein.

To predict total PCB concentrations in LDW porewater, each detected sediment PCB congener concentration and the sediment TOC and black carbon contents within the same sample were used to calculate each porewater PCB congener concentration, and the results were summed to determine total PCB C_{free}. The total PCB C_{free} in porewater predicted by the one- and two-carbon models are compared with measured porewater concentrations in Figure 6-4.

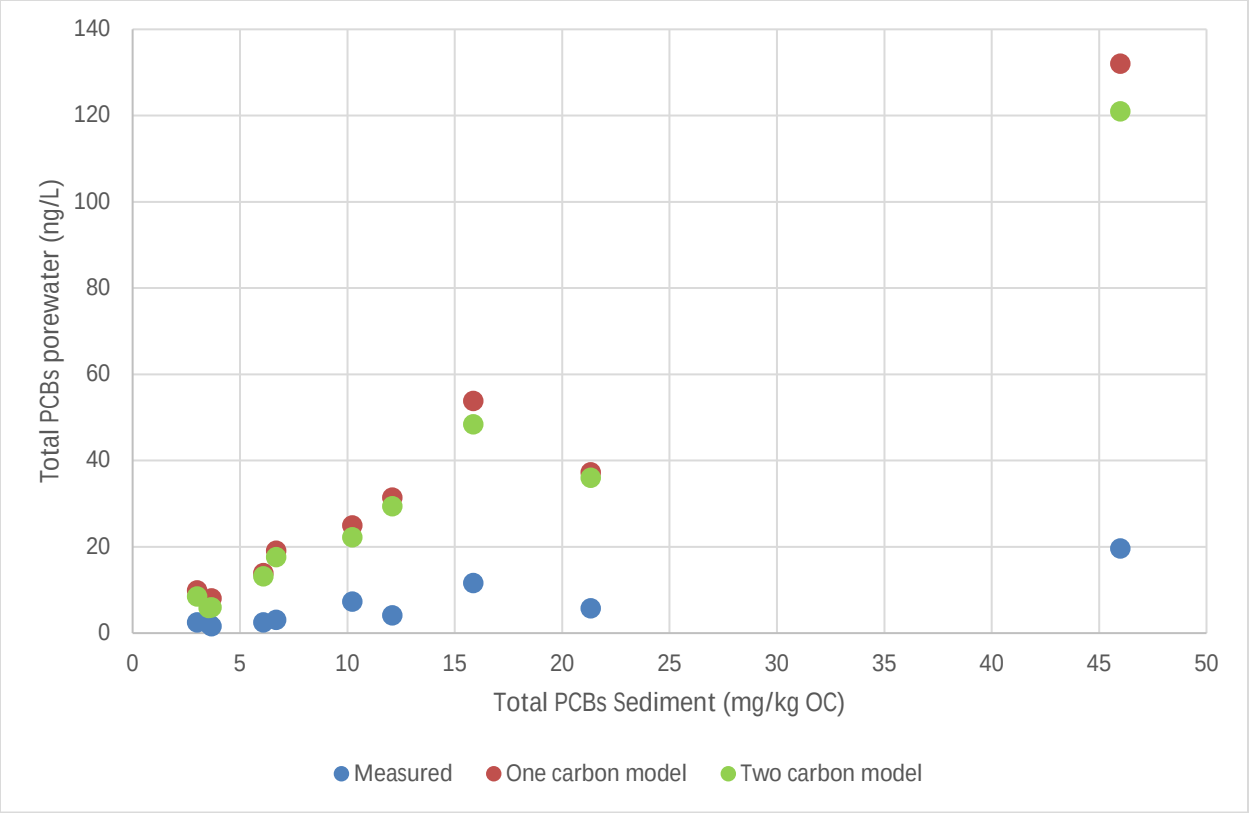


Figure 6-4. Comparison of LDW measured and predicted total PCB concentrations in porewater using one- and two-carbon models.

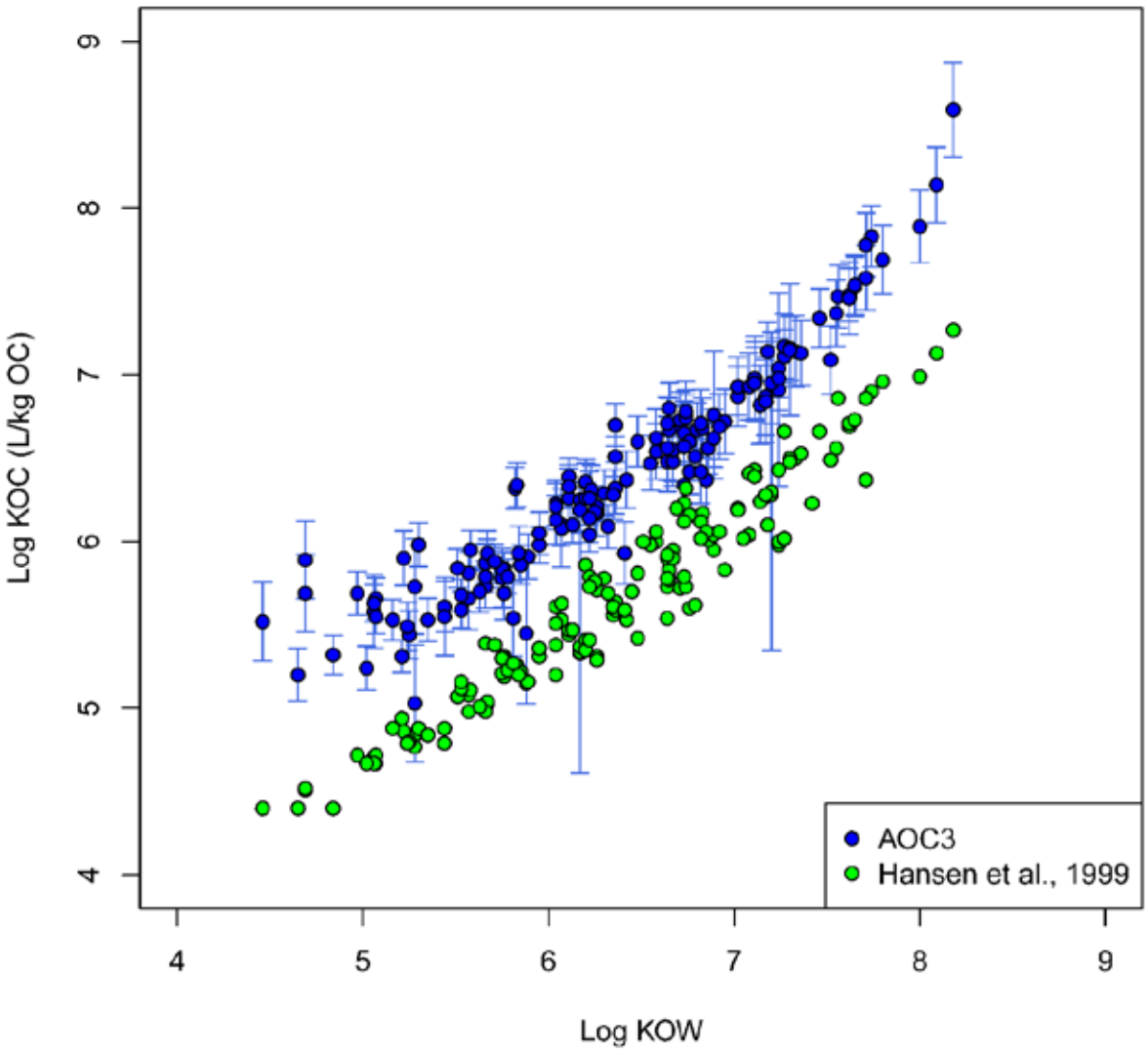
In the LDW, the porewater concentrations predicted using the one- and two-carbon models are similar because only a small fraction of the sediment OC was black carbon. Black carbon ranged from 1.6 to 5.3% of the total carbon when it was detected. The measured total PCB concentrations in porewater were less than those predicted using the equilibrium partitioning models across the entire range of sampled sediment (Figure 6-4). The predicted total PCB concentrations were 3.1 to 7.6 times higher than the measured porewater concentrations for both the one carbon and the two carbon models. This result is consistent with the porewater results from Apell and Gschwend (2016), who reported measured LDW PCB congener concentrations that were lower than predicted porewater concentrations by a factor of 3.8 to 5.3.[63]

The relationship between sediment and porewater concentrations is represented by the OC to water partition coefficient (Koc). K_{OC} values can vary widely (orders of magnitude) based on the nature and characteristics of carbon (Ghosh et al. 2003). When PCB congeners are more strongly associated with sediment OC, a higher Koc value will be calculated. Apell and Gschwend (2016) reported that their site-specific Koc values

[63] Apell and Gschwend (2016) measured PCB porewater concentrations using PE passive samplers and *ex situ* porewater exposure. The only significant difference from the Pre-Design Studies methodology was that the authors analyzed only 35 PCB congeners in the sediment and porewater samples.

were 6.5 times higher than the generic Koc values reported by Hansen et al. (1999) (Apell and Gschwend 2016).

The Pre-Design Studies PCB congener concentrations measured in sediment and porewater, as well as measured OC contents, were used to calculate LDW-specific K_{OC} values for the LDW using a one-carbon equilibrium partitioning model. There was no need to incorporate the complexity of a two-carbon model because of the low levels of black carbon in the sediment. The LDW-specific K_{OC} values were consistently higher than the Hansen et al. (1999) values by a factor of approximately 6.5 (Figure 6-5) and were strongly correlated with the congener-specific K_{OW} values, with an r^2 of 0.89. These results support the use of an equilibrium partitioning model to calculate porewater total PCB concentrations. The model derived with the LDW-specific K_{OC}-to-K_{OW} relationship is Log K_{OC} = 0.77 × Log K_{OW} + 1.5.



Note: Error bars represent SD

Figure 6-5. Mean observed LDW-specific K_{OC} values and literature K_{OC} values vs. log K_{OW} values for each PCB congener

In addition to the Pre-Design Study porewater investigation, two other investigations have been conducted in the LDW to assess total PCB concentrations in porewater (Table 6-2, Map 6-2). In 2012, a group at MIT, using both *in situ* and *ex situ* passive samplers, measured total PCB concentrations (based on 35 of 209 congeners) in porewater at five sites throughout the LDW (Apell and Gschwend 2016). Total PCB concentrations (based on 209 congeners) in porewater were also measured *in situ* and *ex situ* as part of the ENR / activated carbon (AC) pilot study (AMEC et al. 2016); passive samplers were used at three 1-acre plots (total of 18 samples) representing intertidal and subtidal conditions in the LDW (Map 6-2). The concentrations from these investigations

reflected baseline conditions prior to the application of an ENR sand layer or an ENR layer augmented with AC.

Table 6-2. Summary of LDW-specific sediment and porewater data for total PCBs

Study	Total PCB Concentrations[a]								
	Sediment (µg/kg dw)				Porewater (ng/L)				
	n	Mean	Min.	Max.	Locations	n	Mean	Min.	Max.
Apell and Gschwend (2016)	8	109	72[b]	144[b]	5	10[b] (*in situ*)	1.1	0.5	1.4
						5 (*ex situ*) [c]	1.7	1.4	2.2
ENR/AC pilot study baseline dataset (2016)	18	178	17	468	2[d]	12 (*in situ*)[e]	20.0	1.2	75
					1[d]	6 (*ex situ*)[e]	71.7	26	150
Pre-Design Studies (2018)	10	291	32.7	1,173	10	10 (*ex situ*)	6.0	1.6	19.6
LDW RI/FS[f]	672	120	2.2	790	na	0	na	na	na

[a] Total PCB concentrations for sediment represent both detected PCB Aroclor and PCB congener summations, as available; the total PCB concentrations in porewater represent detected PCB congener summations only. The total PCB concentrations in the MIT investigations are the sum of 35 congeners or co-eluting groups of congeners. The total PCB concentrations in the ENR/AC pilot study preliminary dataset are the sum of 209 PCB congeners. The total PCB concentrations in the RI/FS ENR/MNR areas are the sum of PCB Aroclors.

[b] Two replicate measurements were taken at each of five locations.

[c] The porewater PCB concentrations were measured using PE strips suspended in sediment slurries for 28 days. The sediment slurries were tumbled end over end at room temperature.

[d] In the ENR/AC pilot study, 18 passive sampler measurements were made per subplot (6 subplots for a total of 108 passive samplers used). For each subplot, 3 composite samples were created from 6 passive samplers to create a total of 18 composite porewater sampler results from all 3 1-acre plots.

[e] Porewater PCB concentrations were measured using SPME fibers placed *in situ* in the scour and intertidal plots (deployed for approximately 5.5 weeks) and exposed *ex situ* in a laboratory for the subtidal plot (for approximately 7 weeks).

[f] The RI/FS did not collect porewater data for PCBs; this row presents the total PCB data for sediment in MNR and ENR areas, per the ROD.

AC – activated carbon
dw – dry weight
ENR – enhanced natural recovery
LDW – Lower Duwamish Waterway
MIT – Massachusetts Institute of Technology
MNR – monitored natural recovery
n – sample count
na – not applicable
PCB – polychlorinated biphenyl
PE – polyethylene
RI/FS – remedial investigation/feasibility study
ROD – Record of Decision
SPME – solid-phase microextraction

The porewater concentrations measured in the ENR / AC pilot study were higher than those measured in the Pre-Design Studies porewater investigation at the same sediment concentrations. The ENR / AC pilot study sediment samples had larger contributions of lower-molecular-weight PCB congeners in both the sediment and porewater samples than did the Pre-Design Studies samples. The differences in the porewater concentrations of the lower-molecular-weight PCB congeners were likely a contributing factor of the differences in the measured total PCB porewater concentrations for these two studies.

There are significant methodological differences between the three LDW PCB porewater studies that make it difficult to compare the porewater data among the

studies. The Pre-Design Studies porewater dataset is comprehensive for the MNR and ENR areas of the LDW for all 209 PCB congeners. Apell and Gschwend (2016) analyzed only a limited number of congeners in sediment and porewater. The ENR/AC pilot study analyzed all 209 congeners in its intensive investigation of three study areas but used a different passive sampler medium. In addition, the Pre-Design Studies investigation used an agitated *ex situ* passive sampling approach instead of the *in situ* passive sampling methods used by Apell and Gschwend (2016) and the ENR/AC pilot study.[64] Agitation of the passive sampler *ex situ* allowed it to achieve a greater degree of equilibration with the porewater, which led to a more precise estimate of the concentration of total PCBs in porewater (Jalalizadeh and Ghosh 2017).

Thus, the LDW-specific K_{OC} values calculated for the Pre-Design Study represent the best values with which to predict concentrations of PCBs in porewater using TOC and concentrations of PCBs in sediment. The Pre-Design Study K_{OC} values represent a wide variety of carbon types in samples collected throughout the LDW. These values are also consistent with the K_{OC} values calculated by Apell and Gschwend (2016) for the congeners measured in both studies. The K_{OC} values were strongly correlated with congener K_{OW} values ($r^2 = 0.89$). The LDW-specific K_{OC} values for all 209 PCB congeners (based on the Pre-Design Studies) are provided in Appendix D.

PCB concentrations in porewater can be modeled using these LDW-specific partition coefficients, TOC, black carbon and PCB congener concentrations in sediment. The one-carbon model is appropriate when black carbon is a small proportion of the TOC (less than 10%), and the Pre-Design Studies K_{OC} values are recommended for use in the one-carbon model. The two-carbon model can be used when black carbon represents more than 10% of the TOC, using the Pre-Design Study K_{OC} values for non-black carbon and literature-derived K_{BC} values for black carbon.

The results of the PCB porewater investigation provide baseline porewater concentrations in MNR and ENR areas as required by DQO 2. The sediment PCB concentrations are correlated to the porewater concentrations as predicted by equilibrium partitioning models, which indicates that reduced sediment concentrations following remediation will result in reduced porewater concentrations. The LDW-specific K_{OC} values can be used to model additional PCB porewater data as needed, if the remedial action has not introduced forms of carbon that are not similar to the OC in the baseline sediments. In areas where the different forms of carbon have been introduced (i.e., black carbon amendment or cap material), porewater measurements may be required in order to establish the partition coefficients for the remediated sediment.

[64] The ENR/AC pilot study used an *ex situ* passive sampling approach for the subtidal plot measurements, but the samplers were not agitated per requirements of the study QAPP addendum 1 (Amec Foster Wheeler 2017).

6.2.4 Dioxins/furans

Dioxin/furan, TOC, and black carbon concentrations in LDW sediment were used to model porewater dioxin/furan concentrations based on the sediment dioxin/furan data from the Pre-Design Studies in order to address DQO 2. The dioxin/furan TEQs in the 24 composite surface sediment baseline samples ranged from 0.462 to 27.7 ng/kg. Dioxin/furans were also analyzed in eight near-outfall sediment samples,[65] with dioxin/furan TEQs ranging from 6.65 to 247 ng/kg (for more information, see Section 7.2). All of the composite sediment samples and seven of the eight near-outfall samples had dioxin/furan TEQs below the ENR upper limit for dioxin/furan in sediment (75 ng/kg TEQ).[66]

The porewater concentrations were calculated using the one-carbon equilibrium partitioning model (Equation 1), because black carbon was a small fraction (less than 10%) of the total carbon and was not found to be significant in modeling the PCB congener concentrations in porewater (Section 6.1). The partition coefficients for dioxin/furan congeners were developed for the CARP model (Lambert et al. 2011); these coefficients are summarized in Appendix D. The results of the PCB porewater investigation suggest that the use of generic literature partition coefficients may result in conservative estimates of actual porewater dioxin/furan concentrations.

The one-carbon model predicts a linear relationship between sediment and porewater concentrations for each congener. The sediment and modelled porewater concentrations of 1,2,3,7,8-pentachlorodibenzo-*p*-dioxin (PeCDD), for example, are shown in Figure 6-6. The ranges of sediment concentrations and modelled porewater concentrations for the dioxin/furan congeners are provided in Table 6-3.

[65] The draft final data evaluation report will be updated with validated dioxin/furan concentrations from five additional near-outfall sediment samples when the data are available in early 2019.

[66] This upper limit was established for Recovery Categories 2 and 3; see Table 28 in the ROD, *Remedial action levels, ENR upper limits, and areas and depths of application* (EPA 2014).

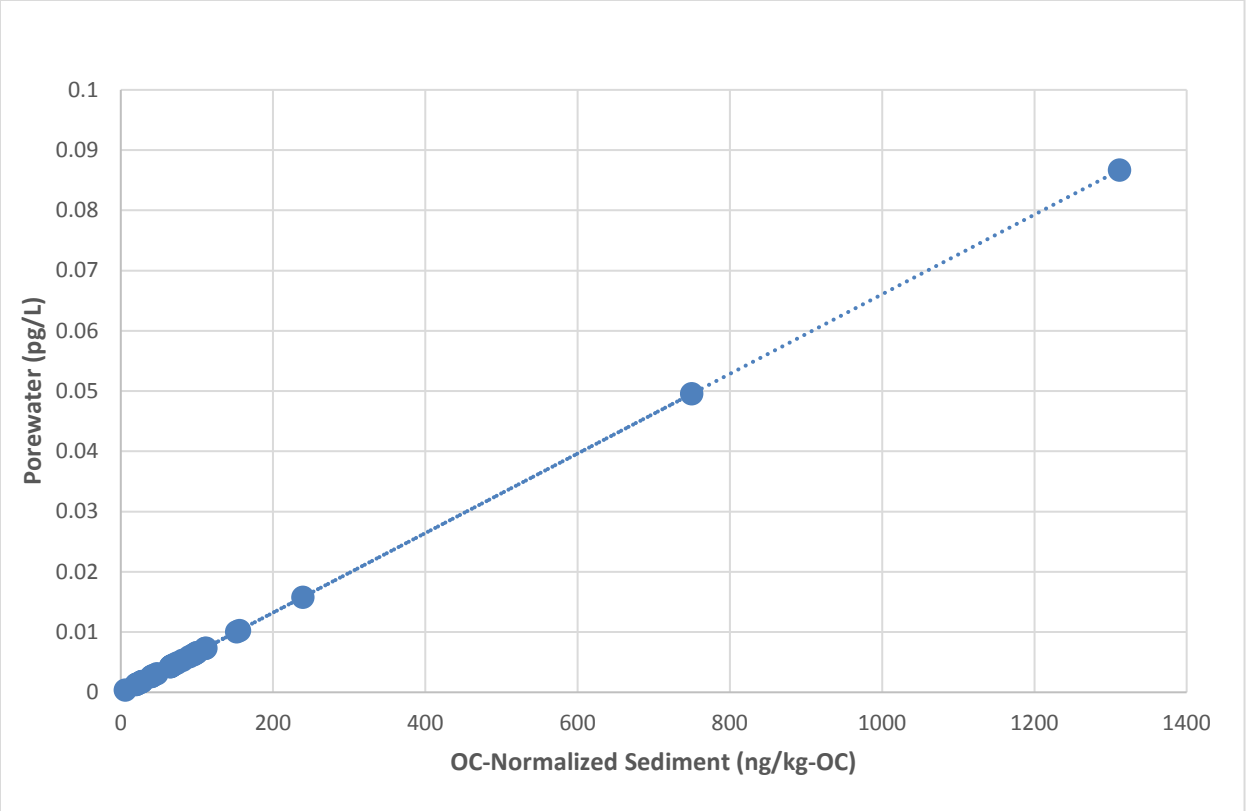


Figure 6-6. LDW sediment and modelled freely dissolved 1,2,3,7,8-PeCDD concentration in porewater

Table 6-3. LDW sediment and modelled freely dissolved concentrations of dioxin/furan congeners in porewater

Dioxin/Furan Congener	Range of Sediment Concentrations (ng/kg)	Range of Predicted Porewater Concentrations (pg/L)
2,3,7,8-TCDD	0.100 U EMPC–2.58	0.0006–0.016
1,2,3,7,8-PeCDD	0.153 U EMPC–20.2	0.0004–0.087
1,2,3,4,7,8-HxCDD	0.171 U EPMC–8.46	0.00004–0.0035
1,2,3,6,7,8-HxCDD	0.491 J–25.5	0.00011–0.0040
1,2,3,7,8,9-HxCDD	0.394 J–33.8	0.000076–0.0056
1,2,3,4,6,7,8-HpCDD	11.4–1,170	0.00011–0.0079
OCDD	87.9–6,500	0.000083–0.0043
2,3,7,8-TCDF	0.11 U EMPC–7.04	0.00055–0.061
1,2,3,7,8-PeCDF	0.117 J–3.22	0.00046–0.011
2,3,4,7,8-PeCDF	0.101 U EMPC–523	0.00016–1.42
1,2,3,4,7,8-HxCDF	0.219 J - 133	0.000175–0.093
1,2,3,6,7,8-HxCDF	0.124 J–45.7	0.000064–0.021
1,2,3,7,8,9-HxCDF	0.0439 UJ–0.675 J	0.00018–0.0038
2,3,4,6,7,8-HxCDF	0.103 J–20.6	0.000070–0.012

Dioxin/Furan Congener	Range of Sediment Concentrations (ng/kg)	Range of Predicted Porewater Concentrations (pg/L)
1,2,3,4,6,7,8-HpCDF	2.32–208	0.000074–0.0047
1,2,3,4,7,8,9-HpCDF	0.185 J–26.0	0.000025–0.0025
OCDF	4.84 - 907	0.000018–0.0024

EMPC – estimated maximum possible concentration
HpCDD – heptachlorodibenzo-*p*-dioxin
HpCDF – heptachlorodibenzofuran
HxCDD – hexachlorodibenzo-*p*-dioxin
HxCDF – hexachlorodibenzofuran
J – estimated octachlorodibenzo-p-dioxin concentration
OCDD – octachlorodibenzo-*p*-dioxin
OCDF – octachlorodibenzofuran
PeCDD – pentachlorodibenzo-*p*-dioxin
PeCDF – pentachlorodibenzofuran
TCDD – tetrachlorodibenzo-*p*-dioxin
TCDF – tetrachlorodibenzofuran
U – not detected at given concentration

As required by DQO 2, the results of the dioxin / furan porewater modelling provide baseline porewater concentrations in MNR and ENR areas, as defined in the ROD; these areas have dioxin / furan TEQs in sediment below the ENR upper limit for dioxins / furans (75 ng / kg).

6.3 SUMMARY AND KEY POINTS

The cPAH porewater data will be assessed in a later version of this data evaluation report or as an addendum to this report in 2019 when the porewater data are available. These data will be used to address DQO 1.

The baseline PCB porewater investigation met DQO 2 by establishing baseline porewater datasets for PCBs. Equilibrium modeling established a baseline dataset for dioxins / furans, as required by the Work Plan (Windward and Integral 2017b).

The key conclusions for the porewater evaluation are provided in Table 6-4.

Table 6-4. Summary of porewater evaluation for each risk driver

DQO	Chemical	Summary of Key Conclusions
DQO 1	cPAH TEQ	· The results of the cPAH porewater investigation will be provided when the full dataset is available in 2019.
	Arsenic	· The RARE study evaluated the inorganic arsenic relationships among porewater, sediment, and clam tissue and determined that the strongest relationship was between sediment and clam tissue concentrations. Porewater data did not improve the relationship.
DQO 2	Total PCBs	· Measured baseline porewater PCB concentrations correlated with sediment PCB concentrations. · Measured porewater PCB concentrations were lower than predicted using equilibrium partitioning models based on literature K_{OC} values. · LDW-specific congener K_{OC} values were calculated and can be used to calculate additional porewater PCB concentrations, if needed.
	Dioxin/ furan TEQ	· Modelled porewater dioxin/furan congener concentrations in porewater were calculated for sediment dioxin/furan concentrations below the ENR upper limit. · Equilibrium partitioning models can be used in the future if porewater concentrations are needed.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
DQO – data quality objective
ENR - enhanced natural recovery
LDW – Lower Duwamish Waterway
OC – organic carbon
PCB – polychlorinated biphenyl
RARE – Regional Applied Research Effort
TEQ – toxic equivalent

7 Source-Related Data

This section presents the source-related data collected to assist Ecology in source control efforts. Specifically, the near-outfall sediment, bank, and seep data collected as part of the Pre-Design Studies are discussed in this section relative to various source control screening benchmarks to help Ecology identify areas of interest. Near-outfall sediment and bank data were collected from February through June 2018 per the sediment QAPP (Windward 2018d). Seep data were collected in May and June 2018 per the seep QAPP (Windward 2018b).

7.1 DQOs and Data Collected

As part of the Pre-Design Studies, 19 near-outfall surface sediment and 11 bank samples were collected to address sediment DQO 6, as outlined in the sediment QAPP (Windward 2018d). These samples were collected from a depth of 0–10 cm and were analyzed as individual samples per the QAPP.

- **Sediment DQO 6:** Collect bank and near-outfall sediment data to assist Ecology with source control efforts.

Near-outfall sediment and bank samples were collected to fill data gaps identified in coordination with Ecology following near-outfall sediment and bank sampling conducted by SAIC / Leidos on behalf of Ecology (SAIC 2011; Leidos 2014a; Hart Crowser 2012b).

Seep data were collected to fulfill a study objective rather than a DQO, per the seep QAPP (Windward 2018d). The study objective was to aid Ecology in source identification by collecting seep samples in areas where existing groundwater data are insufficient to determine if groundwater may be a significant ongoing source of sediment contamination. To meet this objective, 26 seep samples were collected in June 2018 based on a review of existing data and a May 2018 seep reconnaissance.

The near-outfall sediment, bank, and seep data were validated and no issues were identified with the data that would limit their use in meeting the DQO and study objective.

7.2 Near-outfall Sediment Samples

Near-outfall sediment samples were defined as surface sediment samples collected within 50 ft of an outfall with a ≤ 24-in.-diameter pipe and within 100 ft of an outfall with a > 24-in.-diameter pipe, per the sediment QAPP (Windward 2018d). The 19 near-outfall sediment samples collected were identified in coordination with Ecology based on data gaps identified by Ecology (Leidos 2014a), the sufficiency of existing nearby sediment data, and sampleability. These samples were analyzed for the parameters listed in Table 20 of the ROD (EPA 2014). In addition, seven of the samples were initially analyzed for dioxins / furans, and an additional seven of the archived

samples were analyzed for dioxins/furans in November 2018 based on a review of existing data combined with those collected as part of the Pre-Design Studies and EPA/Ecology consultation (documented in an appendix to the surface sediment data report (Windward 2018i)). The results of these analyses will be presented in the surface sediment data report and discussed in the draft final version of this data evaluation report.

The results of the analyses of the near-outfall sediment samples were compared to the lowest surface sediment RALs—which include the Recovery Category 1 RALs from Table 27 of the ROD and the lowest RAL for the top 10 cm of sediment for total PCBs, arsenic, cPAHs, and dioxin/furans, as listed in Table 28 of the ROD (EPA 2014)—to assist Ecology in identifying drainage basins of potential interest for additional source control investigations. To provide a comprehensive analysis, this comparison was extended to include all RI/FS (1990 to 2010), post-FS (2010 to 2018), and Pre-Design Studies (2018) surface sediment data that fell within 50 or 100 ft of an active outfall located on the LDW and not in an EAA (Appendix E). Table 7-1 provides the results of this comparison. Maps 7-1a through 7-1d show the outfall and sediment sample locations.

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
2149	L1505	0.0 W	50	1	ns	ns	zinc, BBP, benzyl alcohol, BEHP, total PCBs (4/20/2011)
2233	L1508	0.1 W	50	1	ns	cPAH TEQ (3/14/2005)	ns
2157	L1514	0.4 W	50	1	ns	ns	benzyl alcohol (3/24/2011)
Siphon-West CSO (Duwamish West CSO)	L1515	0.4 W	100	3	ns	total PCBs (3/8/2005)	fluoranthene, phenanthrene, BEHP, benzyl alcohol, hexachlorobenzene (3) (4/8/2011)
2225	L0205	0.6 E	50	1	ns	BBP (8/20/1994)	ns
2245	L0309	0.9 E	100	4	ns	ne	benzyl alcohol (3) (4/8/2011), total PCBs (6/4/2015)
2246	L0306	0.9 E	50	1	ns	ne	benzyl alcohol (3/21/2011)
2247	L0307	0.9 E	50	2	ns	ne	benzyl alcohol (2) (3/21/2011)
5000	L0308	0.9 E	100	3	ns	ns	benzyl alcohol (3) (4/8/2011)
5001	L0310	0.9 E	100	4	ns	ne	benzyl alcohol (3) (4/8/2011), total PCBs (6/4/2015)
2244	L0401	1.1 E	50	2	ns	ns	acenaphthene, dibenzofuran, fluorene, phenanthrene, benzyl alcohol (2) (3/21/2011)
2223 (Brandon CSO)	L0402	1.1 E	50	1	ns	ns	BBP, total PCBs (8/29/2011)
2008	L0501	1.2 E	50	1	ns	ns	benzyl alcohol (3/8/2011)
5003	L1607	1.2 W	100	4	ns	ne	arsenic (2), benzyl alcohol (4), hexachlorobenzene, total PCBs (2) (3/24/2011)

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
5004	L1608	1.2 W	100	3	ns	ne	arsenic (2), benzyl alcohol (3), total PCBs (2) (3/24/2011)
5005	L1701	1.2 W	100	1	ns	ns	benzyl alcohol (3/24/2011)
2009	L0502	1.3 E	50	2	ns	ns	benzyl alcohol (2) (3/8/2011)
AML-DP2	L1704	1.3 W	50	1	ns	arsenic, copper, zinc (3/10/2005)	ns
2010	L0503	1.4 E	50	1	ns	ns	benzyl alcohol (3/21/2011)
2130	L1712	1.4 W	50	1	ns	ns	arsenic, copper, lead, zinc, dioxin/furan TEQ (5/23/2012)
2127 (SW Kenny St SD/T115 CSO)	L1802	1.5 W	100	3	ns	cPAH TEQ (9/15/1998), dioxin/furan TEQ (3/14/2005)	benzyl alcohol (5/22/2012)
2015	L0508	1.6 E	50	1	ns	ns	benzyl alcohol (3/8/2011)
6146	L1803	1.6 W	50	3	ns	ns	benzyl alcohol (3) (3/8/2011 and 3/21/2011)
2019	L0603	1.7 E	50	2	ns	total PCBs (11/4/1997)	benzyl alcohol (4/15/2011)
2220	L1804	1.8 W	50	1	ns	BBP (4/28/2009)	ns
2022	L0607	1.9 E	50	3	ns	total PCBs (3/16/2005)	benzyl alcohol (2), total PCBs (3/24/2011)
2501	L0610	1.9 E	100	1	ns	total PCBs (3/15/2005)	ne
2502	L0609	1.9 E	100	1	ns	total PCBs (3/15/2005)	ne
2125	L1806	1.9 W	100	2	ns	BEHP, BBP, dimethyl phthalate, total PCBs (10/15/1997); BEHP (1/21/2005)	ns
2122	L1808	1.9 W	50	2	ns	ns	benzyl alcohol (2), BBP (3/8/2011)

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
S River St SD	L0701	2.0 E	50	1	ns	ne	benzyl alcohol (3/4/2011)
2506	L1810	2.0 W	100	2	ns	ne	BEHP (2), BBP, 1,4-dichlorobenzene, benzyl alcohol, hexachlorobenzene (3/7/2011)
2025	L0705	2.1 E	50	1	ns	ns	arsenic, zinc, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, total HPAHs, cPAH TEQ, 2,4-dimethylphenol (4/15/2011)
S Brighton St SD	L0706	2.1 E	100	3	ns	ns	cPAH TEQ, benzyl alcohol (3), hexachlorobenzene (3/14/2011)
2508	L2001	2.1 W	50	1	total PCBs (3/2/2018)	ns	ns
2512	L1902	2.1 W	50	1	ns	ns	BBP (3/7/2011)

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
2118	L2005	2.2 W	50	3	ns	ns	chromium, lead (2), mercury, zinc, 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, cPAH TEQ, dibenzo(a,h)anthracene, dibenzofuran, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, pyrene, total benzofluoranthenes, total HPAHs, total LPAHs, BEHP, BBP, di-n-butyl phthalate, 1,2-dichlorobenzene, 2,4-dimethylphenol, benzyl alcohol, n-nitrosodiphenylamine, PCP, phenol, total PCBs (3) (7/3/2012)
DawnFoods	L0801	2.3 E	50	1	benzo(a)anthracene, chrysene, dibenzo(a,h)anthra-cene, fluoranthene, total HPAHs, cPAH TEQ, total PCBs (2/28/2018)	ne	ns
2117	L2006	2.3 W	50	1	ns	ns	total PCBs (7/2/2012)
2116	L2007	2.3 W	50	1	ns	total PCBs (12/16/2009)	ns
2028	L0806	2.4 E	50	1	ns	dioxin/furan TEQ (1/24/2005)	ns
2026	L0808	2.4 E	100	2	ns	dioxin/furan TEQ (1/24/2005)	mercury, zinc, BEHP, BBP, benzoic acid, benzyl alcohol, total PCBs (3/24/2011)
2035	L0810	2.5 E	100	4	ns	ns	acenaphthene, dibenzofuran TEQ, benzyl alcohol (3) (3/7/2011); total PCBs (3/16/2015)

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
5thAveS	L2012	2.5 W	50	1	dioxin/furan TEQ (2/23/2018)	ne	ns
Clean-ScapesB	L0816	2.7 E	50	1	benzyl alcohol, cPAH TEQ, total PCBs (2/28/2018)	ns	ns
2112	L2102	2.7 W	100	3	ns	cPAH TEQ, BEHP, BBP, fluoranthene (10/4/2006); 2-methylnaphthalene, acenaphthene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, cPAH TEQ, dibenzo(a,h)anthracene, dibenzofuran, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, phenanthrene, total benzofluoranthenes, total HPAHs, total LPAHs, total PCBs, dioxin/furan TEQ (12/15/2009)	mercury, BBP, BEHP, benzyl alcohol, hexachlorobenzene, total PCBs (4/8/2011)
2042	L0901	2.8 E	50	1	ns	ns	BEHP, total PCBs (7/23/2013)
5006	L0902	2.8 E	50	1	ns	ne	total PCBs (3/12/2015)
5008	L0904	2.8 E	50	1	ns	ns	total PCBs, dioxin/furan TEQ (7/23/2013)

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
5009	L0905	2.8 E	50	7	ns	ns	benzyl alcohol (2), total PCBs (2) (8/24/2011); benzyl alcohol, total PCBs (2/1/2012); 2-methylnaphthalene, acenaphthene, dibenzofuran, fluoranthene, fluorene, phenanthrene, total LPAHs, benzyl alcohol, total PCBs (2/2/2012); total PCBs (3/5/2013); total PCBs (7/24/2013); benzyl alcohol (12/10/2014)
2107 (8th Avenue CSO)	L2103	2.8 W	100	6	ns	total PCBs (10/24/1997)	1,4-dichlorobenzene, benzyl alcohol (2), total PCBs (3/4/2011); benzyl alcohol (3), total PCBs (3/7/2011)
2106	L2104	2.8 W	50	3	ns	ns	benzyl alcohol, total PCBs (3/4/2011); benzyl alcohol (2), total PCBs (3/7/2011)
2108	L2105	2.8 W	50	4	ns	ns	benzyl alcohol and total PCBs (3/4/2011), benzyl alcohol (3), total PCBs (3/7/2011)
2052	L0920	2.9 E	100	1	ns	total PCBs (10/7/1997)	ne
2053	L0919	2.9 E	100	1	ns	total PCBs (10/7/1997)	ne
South Park Marina	L2202	3.4 W	50	1	ns	ns	total PCBs (2/24/2016)
2214	L2203	3.5 W	50	5	ns	total PCBs (9/14/2004), total PCBs (8/29/2008)	4-methylphenol, benzyl alcohol (3), phenol, total PCBs (2) (3/7/2011)

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
T-117	L2204	3.5 W	50	4	ns	benzyl alcohol, total PCBs (12/8/2003); total PCBs (9/14/2004); total PCBs (8/29/2008)	4-methylphenol, benzyl alcohol, phenol, total PCBs (3/7/2011)
2062	L1102	3.8 E	100	5	ns	arsenic, benzo(a)anthracene, benzo(a)pyrene, chrysene, cPAH TEQ, dibenzo(a,h)anthracene, phenanthrene, total benzofluoranthenes, total HPAHs (10/8/1997); acenaphthene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzofuran, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, phenanthrene, cPAH TEQ, total benzofluoranthenes, total HPAHs, total LPAHs, BBP, BEHP, total PCBs (10/11/1997); total PCBs (11/12/1997); chrysene, cPAH TEQ, dibenzo(a,h)anthracene, fluoranthene, phenanthrene, total HPAHs (1/25/2005); cPAH TEQ, benzoic acid, BBP (3/16/2005)	ne

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
2061	L1103	3.8 E	50	3	ns	acenaphthene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzofuran, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, phenanthrene, total benzofluoranthenes, total HPAHs, total LPAHs, cPAH TEQ BBP, BEHP, total PCBs (10/11/1997); chrysene, dibenzo(a,h)anthracene, fluoranthene, phenanthrene, cPAH TEQ, total HPAHs (1/25/2005); cPAH TEQ, benzoic acid, BBP (3/16/2005)	ns
SP3	L2212	3.8 W	50	1	ns	ns	zinc, benzyl alcohol (3/24/2011)
2077	L1104	3.9 E	50	1	ns	mercury, BBP, 1,2,4-trichlorobenzene, total PCBs (10/25/2006)	ns
2075	L1202	3.9 E	100	10	ns	total PCBs (9/25/1997), BBP, total PCBs (1/19/2005); mercury, BBP (4), total PCBs (4) (10/25/2006); lead, zinc, BBP, benzoic acid, total PCBs (2/11/2008)	total PCBs (2) (10/29/2014)
2073	L1204	4.0 E	50	3	ns	fluoranthene, phenanthrene, BBP (12/4/2006); total PCBs (12/5/2006)	ns

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
2080	L1208	4.2 E	100	2	ns	cPAH TEQ, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, BEHP, phenol (8/24/2004)	benzyl alcohol, dimethyl phthalate (3/21/2011)
2081	L1209	4.2 E	100	1	ns	benzo(g,h,i)perylene, cPAH TEQ, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, BEHP (8/25/2004)	ns
2082	L1210	4.2 E	50	2	ns	benzyl alcohol (2) (3/17/2011)	ne
DeltaMarine	L2301	4.2 W	50	1	benzyl alcohol (3/8/2018)	ns	ns
2089	L1301	4.3 E	50	3	ns	benzo(g,h,i)perylene, cPAH TEQ, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene (10/13/1997)	benzyl alcohol (2) (3/17/2011)
2099	L2402	4.4 W	50	1	ns	ns	benzyl alcohol (3/3/2011)
2085	L1306	4.5 E	100	1	ns	ne	benzyl alcohol (3/17/2011)
2090	L1307	4.5 E	100	3	ns	total PCBs (10/15/1997)	benzyl alcohol (2) (3/17/2011)
2200	L2405	4.5 W	100	2	ns	ne	benzyl alcohol (2) (3/18/2011)
BDC-3	L1309	4.7 E	50	1	ns	ns	benzyl alcohol (3/17/2011)
BDC-4	L1310	4.8 E	50	1	ns	acenaphthene (10/15/1997)	ne
2091	L1311	4.8 E	100	1	ns	lead (8/26/1998)	ne
2092	L1401	4.8 E	50	2	ns	total PCBs (12/6/1995)	benzyl alcohol (3/18/2011)
BDC-5	L1403	4.9 E	50	3	ns	total PCBs (2) (12/5/1995), total PCBs (12/6/1995)	ns
2097	L1402	4.9 E	50	6	ns	benzoic acid, total PCBs (3) (12/6/1995); total PCBs (1/26/2005)	benzyl alcohol (2) (3/18/2011)

Table 7-1. Near-outfall sediment data with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Concentrations > Lowest Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Lowest Sediment RALs[a] (Sample Dates in Parentheses)		
					Pre-Design Studies	RI/FS	Post-FS
2096	L1404	4.9 E	50	1	ns	total PCBs (3/15/2005)	ns
2093	L1405	4.9 E	50	11	ns	cPAH TEQ, BBP, BEHP, total PCBs (2/10/2000); total PCBs (4) (7/9/2002)	total PCBs (10/5/2010, 11/4/2011, 9/9/2014 [2], 9/10/2015)
2095	L1407	4.9 E	100	7	ns	BEHP (8/18/1994), BEHP, BBP, fluoranthene, total PCBs (8/22/1994); 1,4-dichlorobenzene (10/18/1997); BBP (4/24/2001); total PCBs (4/30/2002); total PCBs (7/9/2002); BBP (5/1/2008)	ns
E&E-1	L1408	5.0 E	50	1	ns	cPAH TEQ, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, phenanthrene (8/18/1994)	ns

Note: Only detected results are included in this table. Field duplicates are excluded.

[a] cPAH TEQs were calculated using PEFs for mammals presented in Ecology (2013). Dioxin/furan TEQs were calculated using TEFs for mammals presented in Ecology (2013). TEQs were calculated for each sample by summing the TEQs for each of the component compounds or congeners. If an individual compound or congener was not detected, the PEF or TEF for that chemical was multiplied by ½ RL for that congener. Sediment data were compared to the lowest surface sediment RALs, which include the Recovery Category 1 RALs from Table 27 of the ROD and the lowest RAL for the top 10 cm of sediment for total PCBs, arsenic, cPAHs, and dioxins/furans, as listed in Table 28 of the ROD (EPA 2014). Note that the 0–10-cm cPAH TEQ RAL in the ROD is under EPA review and will be modified based on the updated benzo(a)pyrene slope factor developed by EPA.

BBP – butyl benzyl phthalate
BEHP – bis(2ethylhexyl)phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
Ecology – Washington State Department of Ecology
EPA – US Environmental Protection Agency
FS – feasibility study
HPAH – high-molecular-weight carcinogenic polycyclic aromatic hydrocarbon
ID – identification
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
ne – no exceedances
ns – no sample collected
PCB – polychlorinated biphenyl
PCP – pentachlorophenol
PEF – potency equivalency factor
RAL – remedial action level
RI/FS – remedial investigation/feasibility study
RL – reporting limit
RM – river mile
ROD – Record of Decision
SD – T-117 – Terminal 117
TEF – toxic equivalency factor
TEQ – toxic equivalent

As discussed in the FS, there are approximately 208 direct discharge points along the LDW shoreline; 203 of these are public or private outfalls and 5 are ditches, creeks, or streams (AECOM 2012).[67] There are also 7 major seeps and 22 abandoned outfalls, identified during shoreline surveys. Of the direct discharge points, 135 had surface sediment samples collected within 50 or 100 ft, depending on the diameter of the outfall.[68] Of these 135 outfalls, 83 were located outside of EAAs and had surface sediment samples with COC concentrations greater than the lowest surface sediment RALs for that diameter. It is acknowledged that while a sample collected near an outfall may have an exceedance, the source of contamination may be historical rather than ongoing or associated with another outfall or upland source. Ecology will evaluate if and what additional source control investigations are needed.

Table 7-2 presents a summary by COC of the number of outfalls with nearby near-outfall sediment samples that had concentrations greater than the lowest surface sediment RAL.

Table 7-2. Summary of COCs in near-outfall samples with concentrations greater than the lowest surface sediment RALs

COC	No. of Outfalls with Nearby Sediment Concentrations > Lowest Surface Sediment RAL	Range of Concentrations in Nearby Sediment > Lowest Surface Sediment RAL
Total PCBs	45	5.45–10,600 mg/kg OC
cPAH TEQ[a]	15	1,060–110,000 µg/kg
Dioxin/furan TEQ	7	25.3 J–247 ng/kg
Arsenic	6	67–269 mg/kg
Other	68	see Appendix E

[a] EPA has revised the cPAH slope factor. If the RAL (currently 1,000 µg/kg) were to increase by a factor of seven (the equivalent change in slope factor), then only one near-outfall sediment sample would be greater than this adjusted RAL.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
EPA – US Environmental Protection Agency
J – estimated concentration
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level
TEQ – toxic equivalent

In general, benzyl alcohol concentrations greater than the lowest sediment RAL (i.e., benthic SCO) were more common in sediment samples analyzed after the RI/FS than in the RI/FS dataset. It is likely that changes in analytical techniques have resulted in the apparent increase in benzyl alcohol concentrations (Fourie and Fox 2016). In

[67] The total number of outfalls on the LDW based on the Leidos (2014b) outfall survey—excluding points categorized as "not an outfall" and updated to account for outfalls reported as added or removed by various parties since the FS—is 254.

[68] The other 87 outfalls do not have sediment data within 50 or 100 ft because either the area was not sampleable or they were not recommended for sampling in Leidos (2014a). Those not recommended for sampling are inactive or located within an active cleanup area.

addition, a recent review of the available sediment toxicity data for benzyl alcohol conducted by USACE suggests that the benthic toxicity threshold for benzyl alcohol is much higher than the current benthic SCO (Fourie and Fox 2016).

Based on the collection of near-outfall sediment data requested by EPA and Ecology, the DQO has been met for near-outfall sediment.

7.3 BANK SAMPLES

Eleven bank samples were collected as part of the Pre-Design Studies based on the analysis presented in the surface sediment QAPP (Windward 2018d). In coordination with Ecology, this analysis considered which banks had already been characterized, whether or not banks were located adjacent to upland properties under or expected to be under an Agreed Order for site investigation, existing sediment data for the vicinity of the bank, and whether or not the bank was sampleable. Bank samples collected during the Pre-Design Studies were grab samples representing exposed soils, generally at elevations of +4 to +12 ft MLLW. The bank samples were analyzed for the analytes listed in Table 20 of the ROD (EPA 2014). In addition, the sample from Bank 2 (RM 0.9 to RM 1.0 W; Map 7-2a) was analyzed for dioxins/furans; samples from the other banks were archived for potential dioxin/furan analysis. Five additional bank samples were analyzed for dioxins/furans in November 2018 based on a review of existing data combined with samples collected as part of the Pre-Design Studies and EPA/Ecology consultation (documented in an appendix to the surface sediment data report (Windward 2018i)). The results of these additional analyses will be presented in the surface sediment data report and discussed in a draft final version of this data evaluation report.

As a conservative screen, results of bank sample analyses were compared to the lowest surface sediment RALs [69] for source control informational purposes. This screen is considered conservative since eroded bank material would combine with upstream inputs and other sediment in the adjacent surface sediment. The comparison included all available bank data, not just the bank data collected as part of the Pre-Design Studies. Specifically, the screen included Ecology's 2011 bank samples reported by Hart Crowser (2012a) (45 samples collected throughout the LDW, as shown on Maps 7-2a through 7-2c), the Terminal 108 (T-108) bank samples collected in 2012 and 2015 (9 samples) (Windward and Integral 2018b), the Duwamish/Diagonal bank samples collected in 2005 (2 samples) (Windward 2010a), and the 8 RI/FS (Windward 2010a) and

[69] The bank sample results were compared to the lowest sediment RALs. These included the Recovery Category 1 RALs from Table 27 of the ROD (titled *Selected remedy RAO 3 RALs*) and the lowest RAL for the top 10 cm of sediment for cPAHs, arsenic, total PCBs, and dioxin/furans, as listed in Table 28 of the ROD (EPA 2014). For samples with TOC concentrations outside the range of 0.5 to 3.5% (per Ecology SCUM II guidance for assessing sediments compared to SMS (Ecology 2017)), results were compared to the lowest apparent effects threshold (LAET).

5 post-FS samples (Windward 2010a; Windward and Integral 2018b).[70] Bank samples with COC concentrations greater than the lowest surface sediment RALs from the LDW ROD are shown on Maps 7-2a through 7-2c and summarized in Table 7-3.

Table 7-3. Banks with COC concentrations that are greater than the lowest surface sediment RALs from the LDW ROD

RM Range[a]	Samples within RM Range	No. of Samples with Concentrations > Lowest RAL	Chemicals with Concentrations > Lowest RAL[b]
0.0–0.1 W	3 post-FS samples collected in 2011	3	arsenic (3), zinc, benzyl alcohol
0.1–0.2 W	5 samples collected at Riverside Marina bank for Ecology in 2011	2	arsenic, mercury, cPAH TEQ, dioxin/furan TEQ
0.0–0.7 E	9 samples collected from T-108 in 2012 and 2015 and 2 bank samples collected from the Duwamish/Diagonal bank area collected in 2005	3	mercury, acenaphthene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, dibenzofuran, fluorene, indeno(1,2,3-cd)pyrene, phenanthrene, BBP, benzoic acid, phenol, total PCBs (2)
0.5–0.9 W	6 samples collected at T-107 CKD for Ecology in 2011 and 1 Pre-Design Studies sample (LDW18-BNK1-1)	5	arsenic (5), lead (5), zinc (5)
0.7–2.9 E[c]	3 samples collected at SeaTac Marine bank for Ecology in 2011, 15 samples collected at Seattle Iron and Metals and Puget Sound Truck Lines for Ecology in 2011	10	arsenic (7), cadmium, chromium (4), copper (3), lead (2), zinc (3), anthracene, benzo(a)anthracene, benzo(a)pyrene (2), benzo(g,h,i)perylene (2), chrysene (2), dibenzo(a,h)anthracene (2), dibenzofuran, fluoranthene (2), indeno(1,2,3-cd)pyrene (2), phenanthrene (2), pyrene, total benzofluoranthenes, total HPAHs (2), total LPAHs (2), cPAH TEQ (2), BBP (2), 2,4-dimethylphenol, 4-methylphenol, phenol, total PCBs (2), dioxin/furan TEQ (2)
2.1–2.5 W	4 samples collected at Boyer Trotsky street end for Ecology in 2011	2	total PCBs, dioxin/furan TEQ (2)
3.0–4.3 W	4 samples collected at South Park street end for Ecology in 2011, 6 samples collected at Sea King Industrial for Ecology in 2011	2	benzoic acid, BBP
4.7–5.0 W	2 Pre-Design Studies samples from Bank 6 (LDW18-BNK6-1 and LDW18-BNK6-2)	1	total PCBs
4.8–5.0 E	8 RI/FS samples and 2 post-FS samples	5	1,4-dichlorobenzene, total PCBs (4)

[70] The RI/FS and post-FS sample locations shown on Maps 7-2a through 7-2c are sample locations located within 12 ft of the FS shoreline line. These locations were used to determine whether banks were characterized in the surface sediment QAPP (Windward 2018d). Elevation data were not available for these locations, and as such, it is not known if they are bank or upland samples. The most recent data from each of these locations were considered.

Note: Results from Ecology 2011 samples were presented in Hart Crowser (2012a).

[a] RM ranges with bank samples with no concentrations greater than the lowest surface sediment RALs are not included in this table.

[b] Numbers in parentheses indicate how many of the samples had concentrations greater than the lowest RAL for that COC, if more than one sample.

[c] There are bank samples with concentrations greater than the lowest RALs throughout this bank area; the highest density of exceedances is at the SeaTac Marine bank area at the head of Slip 3 (Maps 7-2a and 7-2b).

BBP – butyl benzyl phthalate
CKD – cement kiln dust
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
Ecology – Washington State Department of Ecology
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RAL – remedial action level
RI/FS – remedial investigation/feasibility study
RM – river mile
ROD – Record of Decision
T-107 – Terminal 107
T-108 – Terminal 108
TEQ – toxic equivalent

A total of 80 bank samples were evaluated, 34 of which had detected COC concentrations greater than the lowest surface sediment RALs. The following is a summary of these bank areas:

- Total PCBs: Five bank areas had concentrations greater than the RAL for total PCBs (12 mg/kg OC); these bank areas are located throughout the LDW.
- cPAH TEQ: Two bank areas had concentrations greater than the cPAH TEQ RAL (1,000 µg/kg); these areas are located in the lower two-thirds of the LDW.
- Dioxin/furan TEQ: Three bank areas had concentrations greater than the dioxin/furan TEQ RAL (25 ng/kg); these areas are located in the lower two-thirds of the LDW.
- Arsenic: Four bank areas had concentrations greater than the arsenic RAL (28 mg/kg); these areas are located in the lower two-thirds of the LDW.
- Other: Seven bank areas had concentrations greater than the lowest sediment RALs for chemicals other than the risk-drivers listed above. These areas are located throughout the LDW.

Based on the collection of bank data requested by EPA and Ecology, the DQO has been met for banks.

7.4 SEEPS

In the RI, 16 seeps were sampled; between 2010 and 2017, an additional 46 seeps were sampled. To supplement these data, 26 additional seeps were sampled as part of the Pre-Design Studies (Windward 2018b). The Pre-Design Studies seep samples were all analyzed for the analytes listed in ROD Tables 19 and 20 (EPA 2014). Dioxins/furans were initially analyzed in 12 seep samples; an additional seep sample was analyzed for

dioxins/furans.[71] Seeps samples in the RI/FS and after the FS were analyzed for metals and total PCBs; some of these samples were also analyzed for some PAHs, dioxins/furans, PCP, and some phthalates. Together, the Pre-Design Studies data and data from the RI/FS and post-FS samples provide results for 88 seeps throughout the LDW (Map 7-3).

RI/FS and post-FS data were used in the seep QAPP (Windward 2018b) as part of the screen to determine which seeps should be included in the May 2018 seep reconnaissance conducted for the Pre-Design Studies. Seeps were not included in the reconnaissance if one of the following conditions were met: 1) already been sampled, 2) located adjacent to a cleanup site under or expected to be under an Agreed Order for site investigation, or 3) nearby groundwater data indicated that the groundwater was not of concern.

During the reconnaissance, seeps that were not accessible, that did not have sufficient flow rates, or that had conductivity greater than 30,000 µmhos/cm were screened out per the QAPP. Field measurements were collected at the remaining seeps and were used, in coordination with EPA and Ecology, to select seeps to be sampled during the Pre-Design Studies.[72] Seep samples collected during the Pre-Design Studies were collected pursuant to the QAPP. Disturbances to the seep were minimized as much as possible and collected seep water with turbidity greater than 25 nephelometric turbidity units (NTU) was allowed to settle for 5 minutes prior to transfer to the sample bottles, in an effort to minimize particulates in the seep water. Prior to analysis, samples for SVOCs, PCB Aroclors, PAHs, and organochlorine pesticides were filtered through a 1-µm glass fiber filter to remove any non-colloidal particles that may have been introduced into the seep water during sampling. Samples for metals (including mercury) analyses were filtered using a 0.45-µm polyvinylidene difluoride filter.

The results from 66 of the 88 seep samples (sampled as part of the RI/FS, post-FS investigations, and Pre-Design Studies) had filtered water data that were compared to screening levels calculated for groundwater to be protective of the sediment remedy (Ecology 2018b, a). These levels, referred to as groundwater preliminary cleanup levels (PCULs) by Ecology, are inherently conservative. Only filtered seep water data were compared to groundwater PCULs so as to minimize the potential for suspended intertidal sediment to influence the seep results. Unfiltered seep water likely contains sediment and is not representative of groundwater.

Seep sample locations are shown on Map 7-3. This map and Table 7-4 identify seep locations with detected concentrations that were greater than groundwater PCULs. Four chemicals (acenaphthene, BEHP, chromium, and cPAH TEQ) in the Pre-Design

[71] Based on an assessment presented in an appendix to the surface sediment data report (Windward 2018i), one additional seep sample (LDW18-SP-83) was analyzed for dioxins/furans. The validated dioxin/furan TEQ results will be presented in an addendum to the seep data report and discussed in the draft final data evaluation report.

[72] During the Pre-Design Studies, 31 seeps were targeted for sampling; 26 of these were sampled.

Studies seep dataset and four chemicals (arsenic, chromium, copper, and total PCBs) in the RI/FS and post-FS datasets had detected concentrations in filtered seep water that were greater than groundwater PCULs.

Table 7-4. Seeps with chemical concentrations greater than Ecology's groundwater PCULs

Seep Location	Data Group	Approximate RM	Chemicals with Concentrations Greater than the PCUL[a]
SP-88	Pre-Design Studies	0.2 E	chromium
SP-73	Pre-Design Studies	0.6 E	chromium
SP-74	Pre-Design Studies	0.7 E	chromium
SP-76	RI/FS	1.0 E	arsenic
SP-77	Pre-Design Studies	1.1 E	acenaphthene, chromium, cPAH TEQ
SP-78	Pre-Design Studies	1.4 E	chromium
SP-79	Pre-Design Studies	1.5 E	BEHP, chromium
SP-80	RI/FS	1.6 E	copper
SP-84	Pre-Design Studies	1.7 E	chromium
SEEP82	post-FS	1.8 E	chromium, copper
SP-83	Pre-Design Studies	2.1 E	chromium
SP-01	Pre-Design Studies	2.2 E	chromium, cPAH TEQ
SP-05	Pre-Design Studies	2.6 E	chromium, cPAH TEQ
SP-06	Pre-Design Studies	2.6 E	chromium
IT-SEEP-1	post-FS	3.8 E	chromium
SP-24	Pre-Design Studies	4.2 E	chromium, cPAH TEQ
SP-35	Pre-Design Studies	4.6 E	chromium
SP-33	Pre-Design Studies	4.8 E	BEHP, chromium, cPAH TEQ
SP-70	Pre-Design Studies	0.2 W	chromium
SP-86	Pre-Design Studies	0.8 W	chromium
SP-66	Pre-Design Studies	0.9 W	chromium, cPAH TEQ
SP-57	Pre-Design Studies	2.0 W	chromium
SP-87	Pre-Design Studies	2.1 W	chromium
SP-1	post-FS	2.2 W	chromium
SEEP-1	post-FS	2.2 W	chromium
SP-54	RI/FS	2.2 W	total PCB Aroclors
SP-47	Pre-Design Studies	3.1 W	chromium
SP-45	Pre-Design Studies	3.3 W	chromium
SEEP_3	post-FS	3.5 W	chromium
SEEP_2	post-FS	3.6 W	chromium
SP-43	Pre-Design Studies	3.8 W	chromium

Table 7-4. Seeps with chemical concentrations greater than Ecology's groundwater PCULs

Seep Location	Data Group	Approximate RM	Chemicals with Concentrations Greater than the PCUL[a]
SP-42	Pre-Design Studies	3.9 W	chromium
SP-38	Pre-Design Studies	4.4 W	chromium
SP-32	Pre-Design Studies	4.8 W	chromium
SP-30	Pre-Design Studies	4.9 W	chromium

Note: Only seeps with filtered data are included.

[a] Data were compared to the groundwater PCULs protective of sediment.

BEHP – bis(2-ethylhexyl)phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
Ecology – Washington State Department of Ecology
FS – feasibility study
PCUL – preliminary cleanup level
PCB – polychlorinated biphenyl
RI/FS – remedial investigation/feasibility study
RM – river mile
TEQ – toxic equivalent

Of the 66 seep samples evaluated, 35 had at least 1 detected concentration greater than a groundwater PCUL (Table 7-4). Table 7-5 presents a summary of the chemicals with concentrations greater than groundwater PCULs.

Table 7-5. Summary of chemicals with concentrations in seeps samples greater than groundwater PCULs

Chemical	Groundwater PCUL Protective of Sediment (µg/L)	No. of Seeps Analyzed for this Chemical	No. of Seeps with a Concentration > Groundwater PCUL[a]	Range of Results (µg/L)	Seeps (and Approximate RM Location) with Concentrations > Groundwater PCUL
Total PCBs	0.022	42	1	0.26	SP-54 (RM 2.2 W)
cPAH TEQ	0.0049	26	6	0.0082 J– 0.0091 J	SP-01 (RM 2.2 E), SP-05 (RM 2.6 E), SP-24 (RM 4.2 E), SP-33 (RM 4.8 E), SP-66 (RM 0.9 W), SP-77 (RM 1.1 E)
Arsenic	220	61	1	253	SP-76 (RM 1.0 E)
BEHP	0.62	40	2	0.7 J– 1.4 J	SP-33 (RM 4.8 E), SP-79 (RM 1.5 E)

Table 7-5. Summary of chemicals with concentrations in seeps samples greater than groundwater PCULs

Chemical	Groundwater PCUL Protective of Sediment (µg/L)	No. of Seeps Analyzed for this Chemical	No. of Seeps with a Concentration > Groundwater PCUL[a]	Range of Results (µg/L)	Seeps (and Approximate RM Location) with Concentrations > Groundwater PCUL
Chromium	0.06	61	32	0.6–11.7 J	SP-01 (RM 2.2 E), SP-05 (RM 2.6 E), SP-06 (RM 2.6 E), SP-24 (RM 4.2 E), SP-30 (RM 4.9 W), SP-32 (RM 4.8 W), SP-33 (RM 4.8 E), SP-35 (RM 4.6 E), SP-38 (RM 4.4 W), SP-42 (RM 3.9 W), SP-43 (RM 3.8 W), SP-45 (RM 3.3 W), SP-47 (RM 3.1 W), SP-57 (RM 2.0 W), SP-66 (RM 0.9 W), SP-70 (RM 0.2 W), SP-73 (RM 0.6 E), SP-74 (RM 0.7 E), SP-77 (RM 1.1 E), SP-78 (RM 1.4 E), SP-79 (RM 1.5 E), SP-83 (RM 2.1 E), SP-84 (RM 1.7 E), SP-86 (RM 0.8 W), SP-87 (RM 2.1 W), SP-88 (RM 0.2 E), IT-SEEP-1 (RM 3.8 E), SEEP82 (RM 1.8 E), SEEP-1 and SP-1 (RM 2.2 W), SEEP_2 (RM 3.6 W), SEEP_3 (RM 3.5 W)
Copper	14	61	2	20.3 J–22.8	SP-80 (RM 1.6 E), SEEP82 (RM 1.8 E)
Acenaphthene	5.3	41	1	6.7	SP-77 (RM 1.1 E)

[a] Only detected concentrations in filtered seep water were compared to groundwater PCULs.

BEHP – bis(2-ethylhexyl)phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
PCUL – preliminary cleanup level
PCB – polychlorinated biphenyl
RM – river mile
TEQ – toxic equivalent

Chemicals with concentrations greater than groundwater PCULs in at least four seeps are discussed individually below.

7.4.1 cPAHs

Assuming ½ RLs for non-detected compounds, cPAH TEQs were detected at concentrations greater than the groundwater PCUL (0.0049 µg/L) in six seeps sampled as part of the Pre-Design Studies. In the other seep samples, no individual cPAH compound was detected—meaning cPAH TEQ was based on ½ RL values—at an RL of 0.0091 µg/L. This RL is greater than the cPAH groundwater PCUL (Figure 7-1). Thus, cPAH TEQs were also calculated using ½ MDL and zero values for non-detects. With these other non-detect assumptions, none of the seep samples had cPAH TEQs greater than the groundwater PCUL. Because of this, none of the cPAH results in seeps indicate a potential sediment contamination issue for cPAHs.

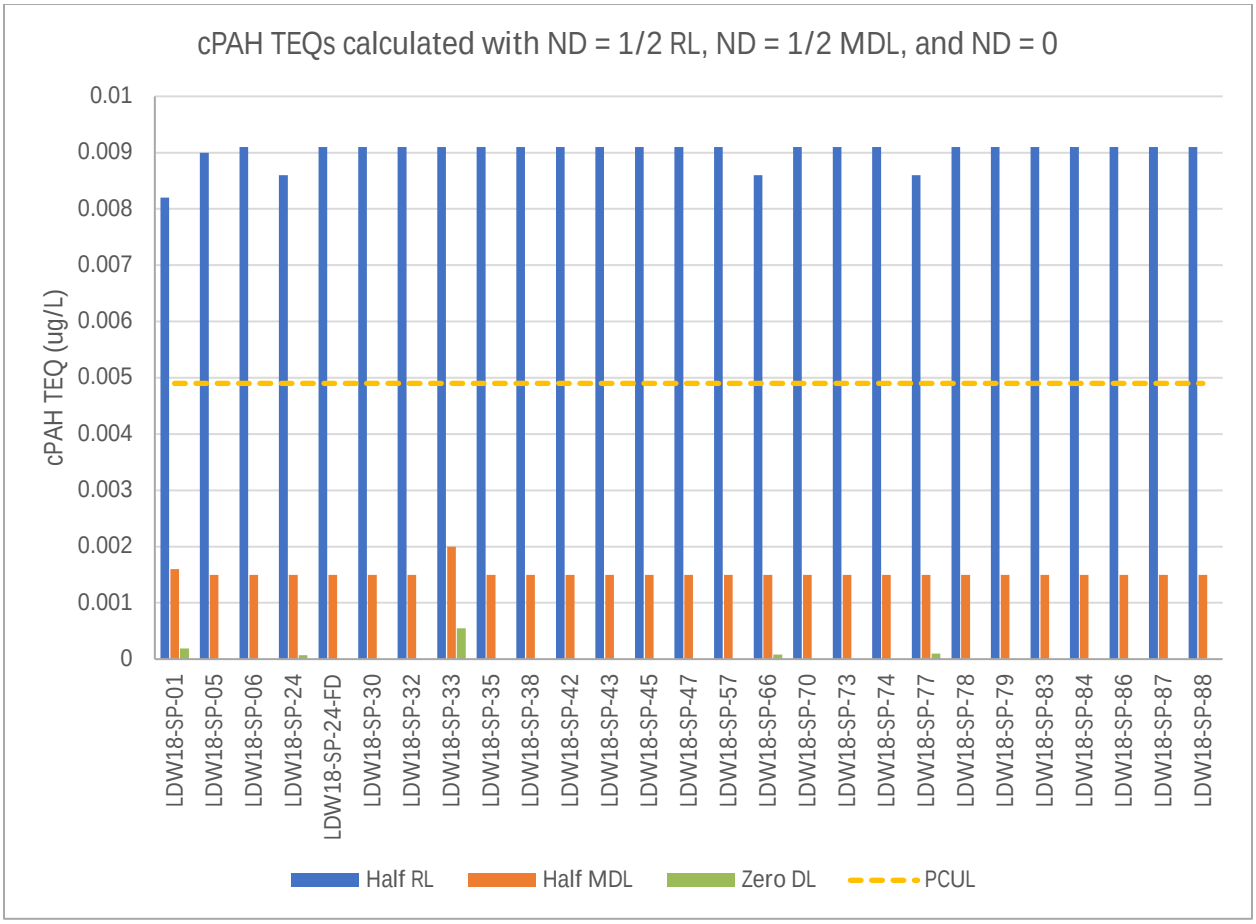


Figure 7-1. Contribution of detected and non-detected values to cPAH TEQs in seep samples collected during the Pre-Design Studies

7.4.2 BEHP

BEHP was detected at concentrations greater than the groundwater PCUL of 0.62 µg/L in two seep samples collected as part of the Pre-Design Studies (Map 7-3). BEHP was detected at concentrations less than the groundwater PCUL in two seep samples collected as part of the Pre-Design Studies. In the other 22 seep samples, BEHP was not detected at an RL of 3 µg/L, which is greater than the groundwater PCUL. BEHP was not detected in filtered seep water in any of the RI/FS or post-FS seep samples; the RLs for these samples were greater than the groundwater PCUL and ranged from 1 to 3.8 µg/L.

There were BEHP RAL exceedances in surface sediment sampled near four seeps during the Pre-Design Studies (Map 7-3) (SP-73, SP-77, SP-57, and SP-24); these seeps did not have detected BEHP concentrations greater than the groundwater PCUL.

7.4.3 Chromium

Chromium was detected in all 26 of the Pre-Design Studies seep samples and in 6 of the RI/FS and post-FS seep samples. The chromium groundwater PCUL is 0.06 µg/L. All seep results for chromium were greater than the groundwater PCUL.

Of the 32 seeps with chromium concentrations greater than the groundwater PCUL, 2 had concentrations of chromium greater than the sediment RAL in nearby sediment. There were surface sediment RAL exceedances for chromium in Trotsky Inlet, in sediment samples collected near seeps SP-1 and SEEP-1 that had chromium concentrations greater than the groundwater PCULs (Map 7-3). The chromium concentration in seep water from SP-1 was 0.6 µg/L, and the chromium concentration in seep water from SEEP-1 was 1.5 µg/L.

7.4.4 Summary

The data evaluation presented herein is an assessment of the available seep data using Ecology's screening groundwater PCUL values to assist Ecology with source control investigations. Based on the seep data collected as part of the Pre-Design Studies, the study objective for seeps has been met.

8 Bed Composition Model Input Parameters Update

As part of the RI/FS (Windward 2010a; AECOM 2012), a sediment transport model (STM) was developed to simulate sediment dynamics and bed evolution processes (e.g., net sedimentation rates) in the LDW (QEA 2008). In the FS, a BCM was developed and used to predict future COC concentrations in surface sediments, and therefore recovery potential following sediment remediation (AECOM 2012). The BCM takes output directly from the physical STM and adds contaminant concentrations to modeled sediment particles.

In this section, per the Work Plan (Windward and Integral 2017b), three key input parameters to the BCM (chemical concentrations for lateral, upstream, and bed replacement value) are revisited for the four risk drivers to determine if data collected since the FS (AECOM 2012) warrant revisions to BCM input parameters. The BCM may be used in future modeling to refine natural recovery predictions.

8.1 LATERALS

In the FS, lateral input values were estimated for total PCBs, arsenic, cPAH, and dioxin/furan concentrations associated with particles discharged to the LDW from storm drains, combined sewer overflows (CSOs), and streams (AECOM 2012). The following is a summary of the FS analysis used to estimate lateral input values (AECOM 2012, Appendix C).

During the FS, the available source-tracing dataset of storm drain solids data collected by various parties through 2009—including Seattle Public Utilities (SPU), Boeing, and King County—was used. This dataset included samples from on-site and right-of-way catch basins and in-line solids grabs and in-line sediment traps. Over 900 samples were analyzed for PCBs and over 500 samples were analyzed for metals and SVOCs. Fewer samples were analyzed for dioxins/furans, so the dataset was supplemented with sediment data collected in the vicinity of storm drains from the Greater Seattle metropolitan area as part of the RI (Windward 2010a).

The storm drain solids data were used to simulate potential lateral inputs after implementation of various degrees of source control (e.g., higher concentrations were screened out because these concentrations would be controlled over time). Summary statistics were generated to identify the BCM base case (or mid) input value and low- and high-sensitivity values for each risk driver based on best professional judgement from the source control work group. These values represent the following (AECOM 2012):

- BCM high-sensitivity value – Conservative representation of current conditions assuming modest level of source control (e.g., management of high priority sources)

- BCM base case (or mid) input value – Pragmatic assessment of what might be achieved in the next decade[73] with anticipated levels of source control
- BCM low-sensitivity value – Best scenario that might be attainable in 30 to 40 years with increased coverage and continued aggressive source control

Since the FS was completed, additional storm drain solids data and CSO solids data have been collected through various source-tracing efforts. These data were summarized in the Pre-Design Studies existing data compilation memorandum (Windward and Integral 2018a). These data were combined with the 2009 dataset,[74] and the following data rules were applied for estimating the updated BCM lateral input values:

- Prioritize data to be most representative of what is entering the LDW by including only in-line samples collected as close to the end-of-pipe as possible. If end-of-pipe in-line samples are not available, include other in-line samples collected further up the pipe, plus catch basin samples collected downstream of the in-line samples. If no other in-line samples are available, use catch basin samples collected throughout the system.
- If time series data are available at a single location and no significant source control actions have been conducted, include all of the available data for that location.
- If an area has had line cleaning or significant remedial or source control actions, only use data following the action(s).

The data rules have been applied so that the source-tracing dataset best represents solids potentially entering the LDW. The updated dataset contains 379 samples for PCBs, 341 samples for cPAHs, 351 samples for arsenic, and 57 samples for dioxins/furans. Following application of the above data rules, Maps 8-1 through 8-4 show the locations and data concentration ranges of the data used for each of the four risk drivers.

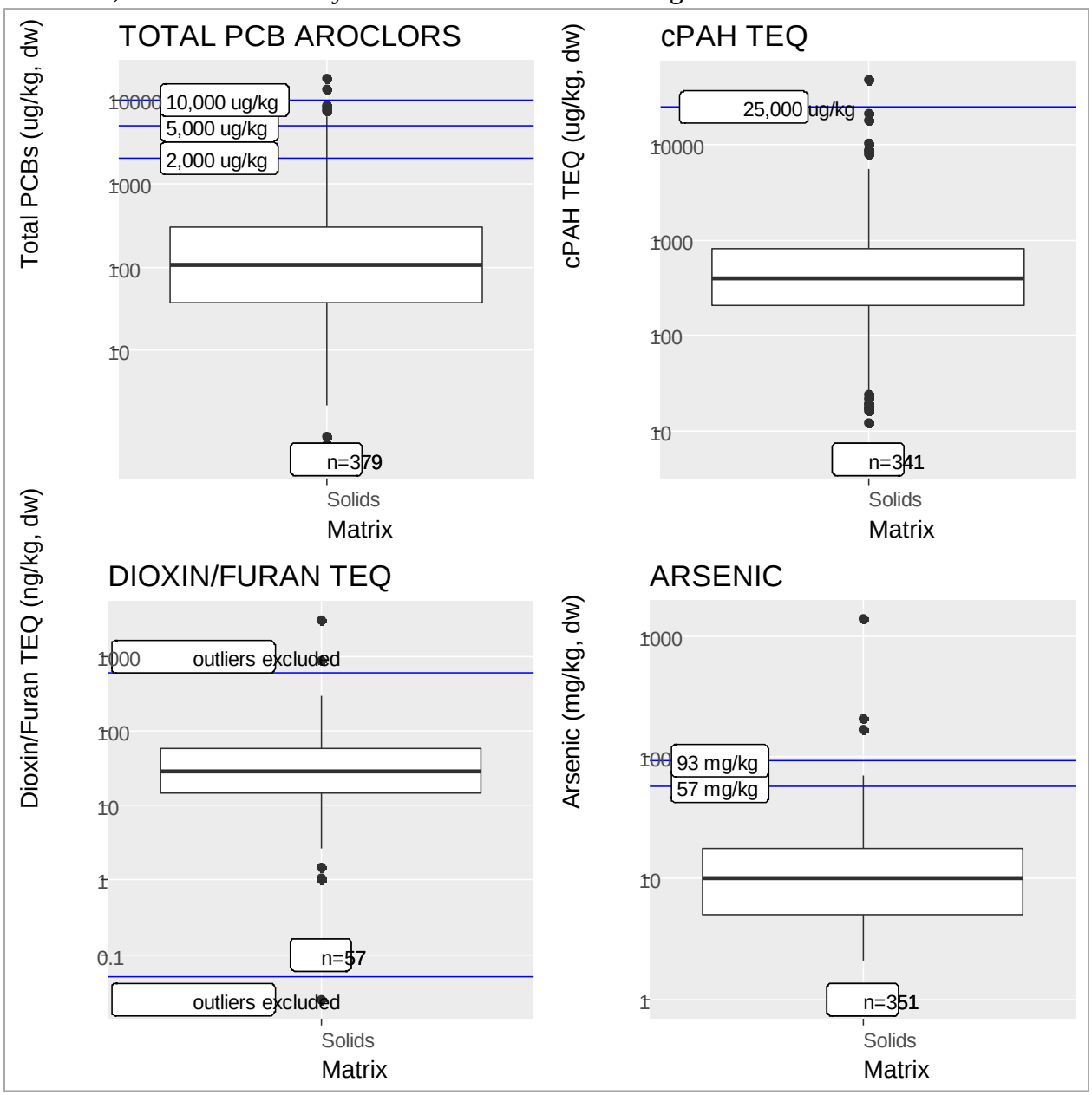
Box plots summarizing the updated datasets are displayed in Figure 8-1 (all data combined, using ½ detection limit [DL] for the data below detection). Summary statistics from the lateral input datasets are provided in Table 8-1. To determine updated lateral input values, the same summary statistics used in the FS (AECOM 2012) were generated, the only differences being:

- PCB data were not flow weighted because the new dataset no longer has a disproportionate amount of data from a few locations.
- Surface sediment data from the Greater Seattle metropolitan area are no longer needed for dioxins/furans, because more source-tracing solids data are available.

[73] At the time of the FS, the next decade was 2012 to 2022.

[74] The date range for the updated dataset runs from May 2010 through April 2016 for dioxins/furans, and from August 2003 through July 2017 for total PCBs, cPAHs, and arsenic.

The same approach for screening out (or excluding) high values used for the FS (AECOM 2012) was also used for the updated BCM lateral input parameters. The recommended lateral input values are summarized and compared to the FS values in Table 8-2, then discussed by risk driver in the following subsections.



Note: Boxplot parameters (quartiles, median, etc.) were calculated from each full dataset ("all samples" rows in Table 8-1). The screening values used to exclude samples for the various summary statistics (data rules identified in Table 8-1) are indicated with the horizontal lines on these boxplots. Data below detection were included at ½ DL.

Figure 8-1. Boxplots of the updated laterals dataset showing the distribution of values used to generate BCM inputs summarized in Table 8-1

Table 8-1. Summary statistics for the updated BCM laterals dataset

COC	Data Rules Applied[b]	n Total	No. Non-detects	DF (%)	Min. Detect	Min. Non-detect	Max. Detect	Max. Non-detect	Summary Statistics[a]						
									Percentile						
									25th	75th	10th	90th	Median	Mean	95UCL
Total PCB Aroclors (ug/kg dw)	all samples	379	88	77	2.2	1.5	18,300	10,000	37	302	9.98	736	105	503	nc
Total PCB Aroclors (ug/kg dw)	exclude samples > 10,000	377	88	77	2.2	1.5	8,500	10,000	37	301	9.96	710	104	422	nc
Total PCB Aroclors (ug/kg dw)	exclude samples > 5,000	369	87	76	2.2	1.5	4,570	4,000	36	274	9.83	544	100	285	nc
Total PCB Aroclors (ug/kg dw)	exclude samples > 2,000	358	86	76	2.2	1.5	1,930	960	32.8	248	9.54	507	96.6	196	nc
cPAHs - mammal – ½ DL (ug/kg dw)	all samples	341	7	98	12	35	49,324	181	205	830	78.4	1,600	400	975	nc
cPAHs - mammal – ½ DL (ug/kg dw)	exclude samples > 25,000	340	7	98	12	35	21,440	181	204	815	78.2	1,546	398	833	nc
Dioxin/furan TEQ – mammal (½ DL) (ng/kg dw)	all samples	57	0	100	0.0248	na	3,160	na	14.9	57.6	4.54	158	29	117	366
Dioxin/furan TEQ – mammal (½ DL) (ng/kg dw)	exclude 2 extreme values (886 and 3,160 ng/kg)	55	0	100	0.0248	na	305	na	13.8	53.3	4.05	93.2	22	48	63
Dioxin/furan TEQ – mammal (½ DL) (ng/kg dw)	exclude 3 extreme values (0.025, 886 and 3,160 ng/kg)	54	0	100	1.01	na	305	na	14.9	53.4	6.67	93.5	26	49	64
Arsenic (mg/kg dw)	all samples	351	112	68	2.64	4.22	1,390	80	5	17.8	3.5	26	10	17.5	nc
Arsenic (mg/kg dw)	exclude samples > 93	348	112	68	2.64	4.22	70	80	5	17.1	3.5	25	10	12.6	nc
Arsenic (mg/kg dw)	exclude samples > 57	343	112	67	2.64	4.22	55	80	5	16.2	3.5	22.9	10	11.8	nc

[a] The percentiles and the mean were calculated using substitution at ½ DL for non-detects.

[b] The same data rules applied to the laterals datasets in the FS were applied herein, as follows:

- For total PCBs, screening values were chosen based on best professional judgement, as described in the FS (AECOM 2012, Appendix C).
- For cPAHs, a single screening value (25,000 ug TEQ/kg dw) was used based on best professional judgment (AECOM 2012, Appendix C).

- For dioxins/furans, the dataset had extreme values based on an outlier analysis; these were removed prior to calculating summary statistics in order to reflect the attributes of the primary data distribution.
- For arsenic, screening values applied were the sediment quality standard (57 mg/kg dw) and the CSL (93 mg/kg dw).

95UCL – 95% upper confidence limit (on the mean)
BCM – bed composition model
COC – chemical of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSL – cleanup screening level
DF – detection frequency
DL – detection limit
dw – dry weight
FS – feasibility study
PCB – polychlorinated biphenyl
na – not applicable
nc – not calculated
TEQ – toxic equivalent

Table 8-2. Lateral input values for the BCM in the FS and recommended values based on the updated dataset

COC	Approach and Values					
	Input (Base or Mid)		Low		High	
	FS	Updated	FS	Updated	FS	Updated
Total PCBs (µg/kg)[a]	300 (mean)	300 (mean)	100 (median)	100 (median)	1,000 (90th percentile)	700 (90th percentile)
cPAH TEQ (µg/kg)[b]	1,400 (mean)	830 (mean)	500 (median)	400 (median)	3,400 (90th percentile)	1,500 (90th percentile)
Dioxin/furan TEQ (ng/kg)[c]	20 (mean)	50 (mean)	10 (median)	30 (median)	40 (95UCL)	60 (95UCL)
Arsenic (mg/kg)[d]	13 (mean)	13 (mean)	9 (median)	10 (median)	30 (90th percentile)	25 (90th percentile)

[a] Data from Rainier Commons, North Boeing Field/Georgetown Steam Plant, and Boeing Plant 2/Jorgensen Forge were flow weighted in the FS analysis (but not in the updated analysis) because a disproportionate amount of data was available from a few locations. Extreme values greater than 5,000, 2,000, and 10,000 µg/kg dw were excluded prior to calculation of summary statistics for the mid, low, and high input values, respectively. The same extreme value levels were used in both the FS and updated analyses.

[b] Extreme values greater than 25,000 µg/kg dw were excluded prior to calculation of summary statistics for the mid, low, and high input values. The same extreme value was used in both the FS and updated analyses.

[c] Extreme values were removed prior to calculation of summary statistics (i.e., values < 0.1 or > 880 ng/kg in the Pre-Design Studies dataset); two high values were excluded from the FS dataset following an extreme value analysis, and results were rounded to one significant figure.

[d] Values greater than 93 mg/kg dw were excluded prior to calculation of summary statistics to determine the mid, low, and high input values. The same extreme value was used in both the FS and updated analyses.

95UCL – 95% upper confidence limit (on the mean)
BCM – bed composition model
cPAH – carcinogenic polycyclic aromatic hydrocarbon
COC – contaminant of concern
dw – dry weight
FS – feasibility study
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

8.1.1 Total PCBs

The base case (or mid) input value remained the same as that used during the FS (300 µg/kg) (AECOM 2012). The high-sensitivity input value decreased from 1,000 to 700 µg/kg, and the low-sensitivity input value remained the same (100 µg/kg). The base case (or mid) input value result was consistent with the assumptions made in the FS regarding the expected total PCB lateral input value representing what might be achieved in the next decade (2012 to 2022). However, the estimated current conditions (high-sensitivity) value was lower likely as a result of continued source control actions in the LDW drainage basin.

8.1.2 cPAH TEQ

The base case (or mid) input value decreased from 1,400 to 830 µg/kg. The high-sensitivity input value came down substantially from 3,400 to 1,500 µg/kg. The

low-sensitivity value remained the same as that used in the FS, 400 µg/kg (AECOM 2012). These results were consistent with the observed decrease in cPAH TEQs detected in LDW surface sediment (Table 2-4), although the apparent change in laterals concentrations is not likely the sole reason that cPAH TEQs in sediment decreased (i.e., natural recovery processes have also had an effect).

8.1.3 Dioxins/furans TEQs

The dioxin/furan dataset used for the FS input values was limited (n = 21), even with the addition of Greater Seattle metropolitan area sediment data (AECOM 2012);[75] the updated dataset had more source tracing solids data available collected over a large area (n = 57). With the updated dataset, the base case (or mid) input value increased from 20 to 50 ng/kg TEQ. The low- and high-sensitivity values also increased from 10 to 30 and from 40 to 60 ng/kg, respectively.

The 95UCL was selected as the high value for dioxins/furans for a similar reason to that selected in the FS (AECOM 2012). Even with the new source solids data, the dioxin/furan dataset was smaller than the datasets for the other risk drivers (57 vs. 341 or more). After extreme values were excluded, the upper range of the distribution was defined by four dioxin/furan TEQs greater than 200 ng/kg. The value represented by the 95UCL better serves as an upper-bound representative for conditions following a modest level of source control.

8.1.4 Arsenic

The base case (or mid) input value remained the same as that used in the FS, 13 mg/kg (AECOM 2012). The high-sensitivity input value decreased from 30 to 25 mg/kg, while the low-sensitivity value increased slightly from 9 to 10 mg/kg.

8.2 UPSTREAM

In the FS, upstream input values were estimated for total PCB, arsenic, cPAH, and dioxin/furan concentrations associated with particles entering the LDW from upstream (AECOM 2012). The following is a summary of the FS analysis used to estimate upstream input values (AECOM 2012, Appendix C).

Four sources of data were used to characterize upstream concentrations:

- Upstream water quality monitoring data from King County (2001 to 2008), which were used to estimate concentrations associated with suspended solids
- Centrifuged solids samples collected upstream of the LDW by Ecology (2008 to 2009)
- Upstream surface sediment data from RM 5.0 to RM 7.0 collected by several parties (1994 to 2008)

[75] Of the 21 lateral input samples for dioxins/furans, 12 were from sediments near outfalls in the Greater Seattle metropolitan area.

- Sediment core data collected from the Turning Basin (RM 4.3 to RM 4.75) by USACE (1990 to 2009)

From these datasets, concentrations representing the potential range of upstream concentrations of each constituent were determined. Multiple datasets were evaluated because each dataset was influenced by various sediment transport phenomena, sampling methodology, spatially varying physical properties, and localized geographical, meteorological, and chemical loading factors. No single dataset adequately represented the concentrations in upstream sediment particles deposited in the LDW (AECOM 2012, Appendix C). Each dataset was discussed in the FS.

Since the FS was completed, additional data from upstream and the LDW Turning Basin have been collected through various studies.[76] The following more recent datasets have been identified:

- Filtered solids collected at Foster Links by King County (2013 to 2015)
- Solids collected in sediment traps at Foster Links by King County (2013 to 2015)
- Centrifuged solids collected at Foster Links by US Geological Survey (USGS) (2013, 2015, and 2017)
- Fine-grained (< 62.5 µm) bedded sediments collected at Foster Links by USGS (2013, 2014, to 2015)
- Sediment core data collected at the Turning Basin (RM 4.3 to RM 4.75) by USACE (2011 and 2017)

These datasets represent lines of evidence to estimate COC concentrations in solids that are likely to be deposited within the LDW; details of these datasets, including maps of sample locations, are presented in Appendix F. The pros and cons of the various types of data to estimate upstream inputs were discussed in detail in the FS (AECOM 2012, Appendix C). Summary statistics for the results compiled from these studies were calculated in ProUCL 5.1 (EPA 2015b) and are summarized in Tables 8-3 and 8-4 and Figure 8-2.

[76] The Turning Basin sediment and upstream suspended solids data were summarized in the Pre-Design Studies existing data compilation memorandum (Windward and Integral 2018a).

Table 8-3. BCM upstream summary table – study specific

COC	Study-specific Data									
	Ecology Centrifuged Solids	King County Filtered Solids	King County Sediment Traps[a]	USGS Centrifuged Solids	Ecology Upstream Bedded Sediment	USGS Bedded Sediment	USACE Turning Basin Cores			
	2008–2009	2013–2015	2013–2015	2013–2017	2008	2013–2015	2008	2009	2011	2017
	All Conditions	Baseflow, Storm, Dam[b]	Baffle, Jar	Baseflow, Storm, Dam[b]	RM 5–RM 7 and >30% fines	RM 10 and < 62.5 µm	RM 4.3 - RM 4.75			
PCBs (µg/kg)	n = 7 8 (median) 15 (mean) 67 (95UCL[c])	n = 3, 5, 4 7, 59, 5 (median) 8, 49, 6 (mean) 66 (95UCL[c])	n = 5, 4 1, 9 (median) 5, 13 (mean) 15 (95UCL[c])	n = 10, 17, 10 8, 18, 2 (median) 8, 25,3 (mean) 24 (95UCL[c])	n = 30 2 (median) 5 (mean) 10 (95UCL[c])	n = 7 6 (median) 6 (mean) 9 (95UCL[c])	n = 2 39 (median) 39 (mean)	n = 2 14 (median) 14 (mean)	n = 8 10 (median) 11 (mean)	n = 5 50 (median) 50 (mean)
							41 (95UCL[c] 2008 - 2017); 43 (95UCL[c] 2011, 2017)			
cPAH TEQ (µg/kg)	n = 7 53 (median) 138 (mean) 640 (95UCL[c])	n = 2, 3, 4 36, 350, 39 (median) 36, 315, 44 (mean) 415 (95UCL[c])	n = 4, 4 35, 45 (median) 45, 54 (mean) 80 (95UCL[c])	n = 5, 17, 10 33, 141, 14 (median) 53, 156, 28 (mean) 157 (95UCL[c])	n = 31 16 (median) 37 (mean) 72 (95UCL[c])	n = 7 18 (median) 23 (mean) 31 (95UCL[c])	n = 2 75 (median) 75 (mean)	n = 2 17 (median) 17 (mean)	n = 9 20 (median) 25 (mean)	n = 5 28 (median) 27 (mean)
							40 (95UCL[c] 2008 - 2017); 30 (95UCL[c] 2011, 2017)			
Dioxin/furan TEQ (ng/kg)	n = 6 3 (median) 6 (mean) 10 (95UCL[c])	n = 3, 3, 4 3, 8, 3 (median) 3, 12, 4 (mean) 11 (95UCL[c])	n = 3, 2 1, 3 (median) 2, 3 (mean) 5 (95UCL[c])	n = 11, 17, 10 3, 9, 1 (median) 4, 10, 2 (mean) 9 (95UCL[c])	n = 31 2 (median) 2 (mean) 2 (95UCL[c])	n = 7 3 (median) 3 (mean) 4 (95UCL[c])	n = 2 3 (median) 3 (mean)	no data	n = 5 1 (median) 1 (mean)	n = 5 3 (median) 3 (mean)
							3 (95UCL[c] 2008 - 2017); 3 (95UCL[c] 2011, 2017)			
Arsenic (mg/kg)	n = 7 14 (median) 17 (mean) 22 (95UCL[c])	n = 3, 3, 4 37, 17, 11 (median) 40, 19 11 (mean) 30 (95UCL[c])	n = 5, 2 5, 13 (median) 9, 13 (mean) 20 (95UCL[c])	n = 8, 17, 10 21, 15, 10 (median) 20, 18, 10 (mean) 20 (95UCL[c])	n = 31 9 (median) 9 (mean) 10 (95UCL[c])	n = 7 10 (median) 10 (mean) 11 (95UCL[c])	n = 2 12 (median) 12 (mean)	n = 2 5 (median) 5 (mean)	n = 9 10 (median) 9 (mean)	n = 5 13 (median) 11 (mean)
							11 (95UCL[c] 2008 - 2017); 11 (95UCL[c] 2011, 2017)			

Note: PCBs were calculated as the sum of detected congeners, when available; otherwise, calculated as the sum of detected Aroclors. If all constituents were non-detects, then the maximum DL was reported, and ½ DL was substituted when calculating the summary statistics presented in this table. Dioxin/furan and cPAH TEQs were calculated using substitution at ½ RL or MDL, depending on the study (see Appendix F for details).

[a] The traps were deployed for three-month intervals, within summer, fall, and winter seasons.

[b] King County and USGS suspended solids data (i.e., centrifuged or filtered solids) include baseflow and storm events with and without significant dam releases (qualified as > 2,000 cfs at USGS gage below Howard Hanson Dam), indicated as “Storm” and “Dam,” respectively.

[c] The sample sizes were too small to estimate a 95UCL for many of the subsets within each study (e.g., baseflow, storm, baffle, or jar), so a single 95UCL is reported for the combined values from each study.

95UCL – 95% upper confidence limit (on the mean)
BCM – bed composition model
cfs – cubic feet per second
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DL – detection limit
Ecology – Washington State Department of Ecology
MDL – method detection limit
PCB – polychlorinated biphenyl
RL – reporting limit
RM – river mile
TEQ – toxic equivalent
USGS – US Geological Survey

Table 8-4. BCM upstream summary table – binned

COC	Bedded Sediment Data	Suspended Sediments Data			Turning Basin Cores
	Ecology 2008; USGS 2014/2015[a]	King County Filtered Solids: 2013–2015; USGS Centrifuged Solids: 2013–2017		Ecology Centrifuged Solids: 2008/2009; King County Filtered Solids: 2013–2015; King County Sediment Traps: 2013–2015; USGS Centrifuged Solids: 2013–2017	USACE: 2008, 2009, 2011, 2017
	All Conditions	Baseflow	Storms[b]	Combined Baseflow and All Storm Events[c]	RM 4.3–RM 4.75
PCBs (µg/kg)	n = 37 3 (median) 6 (mean) 8 (95UCL) 12 (90th pctile)	n = 13 7 (median) 8 (mean) 11 (95UCL) 14 (90th pctile)	n = 36 12 (median) **20** (mean) 29 (95UCL) 55 (90th pctile)	n = 65 8 (median) 16 (mean) 20 (95UCL) 42 (90th pctile)	n = 17 16 (median) 26 (mean) 41 (95UCL) 55 (90th pctile)
cPAH TEQ (µg/kg)	n = 38 17 (median) 34 (mean) 63 (95UCL) 72 (90th pctile)	n = 7 33 (median) 48 (mean) 75 (95UCL) 89 (90th pctile)	n = 34 60 (median) 119 (mean) 172 (95UCL) 331 (90th pctile)	n = 56 **55** (median) 103 (mean) 134 (95UCL) 238 (90th pctile)	n = 18 27 (median) 30 (mean) 40 (95UCL) 41 (90th pctile)
Arsenic (mg/kg)	n = 38 9 (median) 9 (mean) 10 (95UCL) 12 (90th pctile)	n = 11 26 (median) 25 (mean) 32 (95UCL) 37 (90th pctile)	n = 34 13 (median) 15 (mean) 17 (95UCL) 24 (90th pctile)	n = 59 14 (median) 16 (mean) 18 (95UCL) 26 (90th pctile)	n = 18 **10** (median) 10 (mean) 11 (95UCL) 13 (90th pctile)
Dioxin/ furan TEQ (ng/kg)	n = 38 2 (median) 2 (mean) 2 (95UCL) 3 (90th pctile)	n = 14 3 (median) 4 (mean) 5 (95UCL) 6 (90th pctile)	n = 34 6 (median) 7 (mean) 10 (95UCL) 18 (90th pctile)	n = 59 **4** (median) 6 (mean) 7 (95UCL) 13 (90th pctile)	n = 12 2 (median) 2 (mean) 3 (95UCL) 3 (90th pctile)

Note: Summary statistics calculated using results as reported from original sources. PCBs were sum of detected Aroclors or congeners only, and the ½ RL was used in these summaries if all constituents were non-detects. TEQs were calculated using substitution at ½ RL.

[a] Combined upstream bedded sediment data includes 2008 Ecology data from RM 5–RM 7 (> 30% fines), and 2014/2015 USGS data from RM 10 (only the silt/clay sediments [with grain size < 62.5 µm]).

[b] All storm events include observations with and without significant dam releases (qualified as > 2,000 cfs at USGS gage below Howard Hanson Dam).

[c] All baseflow and storm events (with and without significant dam releases) were included in combined calculations.

95UCL – 95% upper confidence limit (on the mean)
BCM – bed composition model
cfs – cubic feet per second
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
Ecology – Washington State Department of Ecology
PCB – polychlorinated biphenyl
RL – reporting limit
RM – river mile
TEQ – toxic equivalent
USGS – US Geological Survey

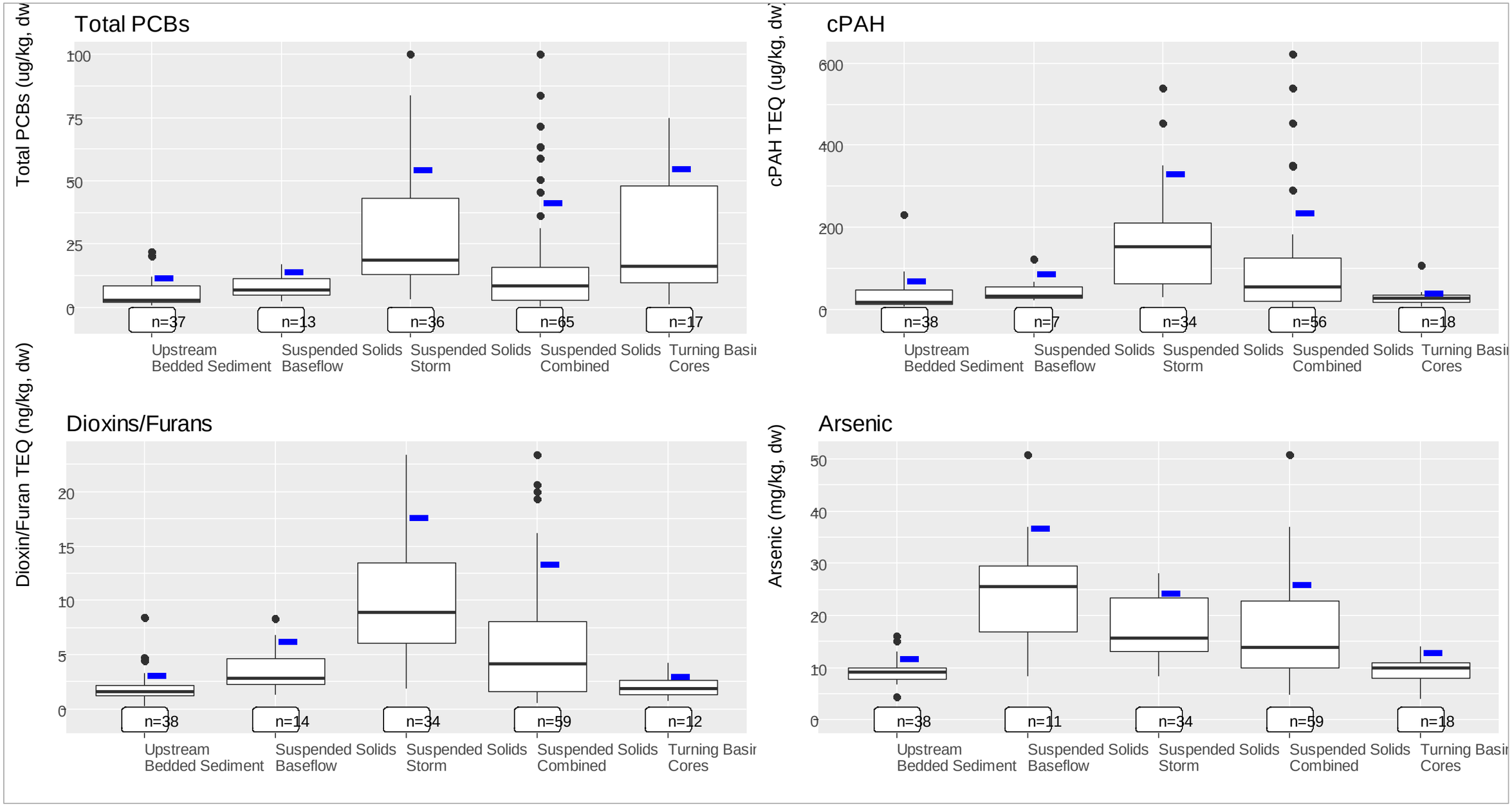


Figure 8-2. Distributions of upstream sediment data by dataset

Since the FS was completed, a great deal of work has been conducted to collect additional data to better characterize sediments that are expected to be deposited in the LDW from the Green River. All of these datasets have been considered as lines of evidence to update upstream input values for the BCM. The lines of evidence include upstream bedded sediments (finer fractions), suspended particulates upstream of the LDW, and Turning Basin data (since the Turning Basin acts as a sediment trap).

A similar approach as that used in the FS was followed for the updated values (AECOM 2012). Specifically, datasets with upstream solids data were compiled and assessed with respect to their relevance in estimating concentrations of the four risk drivers associated with upstream particles likely to be deposited within the LDW (Appendix F). Each of these lines of evidence has value as well as inherent bias in estimating the upstream input parameter values. For example, the suspended solids data from upstream provide a measurement of contaminant concentration in those particles, but not all of the particles will settle in the LDW. If particles that do not settle in the LDW have higher concentrations, then using suspended solids (e.g., arsenic suspended solids data) could overestimate the concentrations settling in the LDW.

The upstream input values for the BCM were developed as a range using best professional judgment. As was done in the FS, the data were viewed holistically to select low, middle, and high values from these various datasets, the intent being to select the central values of these datasets for the BCM base case (or mid) input value, as well as low- and high-sensitivity values to bound the estimates. The updated upstream input values are summarized and compared to the FS values (AECOM 2012) in Table 8-5, then discussed by risk driver in the following subsections.

Table 8-5. Upstream input values for the BCM in the FS and recommended values based on the updated dataset

COC	Estimation Approach and Values					
	Input (Base or Mid)		Low		High	
	FS	Updated	FS	Updated	FS	Updated
Total PCBs (µg/kg)	35 (mean of Turning Basin core data)	20 (mean of storm suspended sediments data)	5 (mean of Ecology upstream with > 30% fines)	6 (mean of fine-grained upstream bedded sediment data)	80 (95UCL of TSS-normalized King County water)	55 (90th percentile of Turning Basin core data)
cPAH TEQ (µg/kg)	70 (mean of Turning Basin core data)	55 (median of combined suspended solids)	40 (mean of Ecology upstream with > 30% fines)	34 (mean of fine-grained upstream bedded sediment data)	270 (95UCL of TSS-normalized King County water)	134 (95UCL of combined suspended solids)
Dioxin/furan TEQ (ng/kg)	4 (midpoint of means of the two available datasets)	4 (median of combined suspended solids)	2 (mean of Ecology upstream with > 30% fines)	2 (mean of fine-grained upstream bedded sediment data)	8 (midpoint between mean and 95UCL of upstream centrifuged solids)	7 (95UCL of combined suspended solids)
Arsenic (mg/kg)	9 (mean of Ecology upstream with > 30% fines)	10 (mean of Turning Basin core data)	7 (mean of Turning Basin core data)	9 (mean of fine-grained upstream bedded sediment data)	10 (95UCL of Ecology with > 30% fines)	12 (90th percentile of fine grained upstream bedded sediment data)

Note: Pre-Design Studies combined upstream datasets are summarized in Table 8-4.

95UCL – 95% upper confidence limit (on the mean)
BCM – bed composition model
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
Ecology – Washington State Department of Ecology
FS – feasibility study
PCB – polychlorinated biphenyl
TEQ – toxic equivalent
TSS – total suspended solids

8.2.1 Total PCBs

Over the past 10 years, Ecology, King County, and USGS have collected suspended solids samples from Green River at Foster Links (RM 10) to assess total PCB concentrations associated with these solids entering the LDW (Table 8-3). In combination, the data from these studies provided a large dataset from which to select a base case (or mid) BCM input parameter (Table 8-4). The mean storm value was selected for this purpose (20 µg/kg). The low-sensitivity value (6 µg/kg) was based on the mean of upstream fine-bedded sediment, and the high-sensitivity value (55 µg/kg) was the 90th percentile of the updated Turning Basin sediment from RM 4.3 to RM 4.75. These values, summarized in Table 8-5, consider the range of data available from the various lines of evidence.

8.2.2 cPAH TEQ

The suspended sediment dataset was used to supply the base case (or mid) input value for cPAH TEQ (55 µg/kg), which was the median of the combined dataset. The low-sensitivity value (34 µg/kg) was selected as the mean of the upstream fine-bedded sediment. The high-sensitivity value (134 µg/kg) was selected from the combined suspended sediment dataset. This value represented a higher value than a mean (95UCL) in the combined dataset but was sufficiently low to be consistent with the Pre-Design Studies SWAC of 147 µg/kg, which was lower than previous BCM model predictions (Table 2-4). Comparison to the SWAC was important because the high-sensitivity value should not be higher than the SWAC. All three selected upstream input values for cPAH TEQ were lower than those used in the FS (Table 8-5) (AECOM 2012).

8.2.3 Dioxin/furan TEQ

The selected dioxin/furan TEQ upstream input parameters are the same, or very similar to, the concentrations used in the FS (AECOM 2012). A value of 4 ng/kg was selected as the base case (or mid) input value, again using the median of the combined suspended sediment dataset. A value of 2 ng/kg was selected as the low-sensitivity value based on multiple lines of evidence: the median, mean, and 95UCL of the upstream fine-bedded sediment, as well as the median and mean of the Turning Basin data. The high-sensitivity value (7 ng/kg) was based on the 95UCL of the combined suspended sediment dataset.

8.2.4 Arsenic

Input values similar to those used in the FS were also selected for arsenic (AECOM 2012). The base case (or mid) input value of 10 mg/kg was selected based on the median and mean of Turning Basin data, rather than the combined suspended sediment dataset. Because higher arsenic concentrations are believed to associate with a finer fraction of the suspended solids that does not settle in the LDW, the suspended solids

data for arsenic were not used. This is supported by the fact the baseline LDW SWAC for arsenic is lower than the mean of suspended solids data. The low-sensitivity value (9 mg/kg) was selected based on the mean (and median) of the upstream bedded sediment, which was used for the other risk drivers as well. The high-sensitivity value (12 mg/kg), the 90th percentile of the upstream fine bedded sediment, was selected based on the assumption that the high-sensitivity value should not be greater than the Pre-Design Studies SWAC (11.6 mg/kg).

8.3 BED REPLACEMENT VALUE

A bed replacement value replaces the concentration in bedded sediment (C_{bed}) in the BCM in areas that have been actively remediated (i.e., dredging, capping, or ENR). This replacement is important in calculating post-remedy SWACs because the remediated sediment surface will be influenced by surrounding sediment through sediment transport processes. Thus, as described in the FS, the bed replacement value is intended to represent near-term (zero- to two-year) conditions following the cleanup (AECOM 2012). Non-zero COC concentrations in the zero- to two-year timeframe following remediation have been observed at the completed EAAs in the LDW (King County and Anchor 2008; Amec Foster Wheeler 2016).

The same overall approach used in the FS was applied to update the estimated bed replacement value for use in the BCM. In the FS, bed replacement values were estimated by varying the degrees of mixing between clean fill material combined with average sediment conditions outside of the active remedy footprint (AECOM 2012). COC concentrations in clean fill materials (for capped or ENR or dredged areas in intertidal areas[77]) were estimated based on 95UCL values from the 2008 EPA ocean survey vessel (OSV) *Bold* survey. As an update, 95UCL values for the OSV *Bold* Plus dataset were used (Table 10-1, Ecology 2015), which were either the same or very similar to the OSV *Bold* 95UCLs (Table 8-6).

Table 8-6. BCM bed replacement values in the FS and updated analysis

COC	Components Used to Calculate Bed Replacement Values				Bed Replacement Values					
	Clean Fill Material		Average Sediment Concentrations Outside Remedial Footprint		Input (Base or Mid) (50:50)[a]		Low (75:25)[a]		High (25:75)[a]	
	FS	Updated	FS	Updated	FS	Updated	FS	Updated	FS	Updated
Total PCBs (µg/kg)	2	2	120	142	60	72	30	37	90	107
cPAH TEQ (µg/kg)	9	8	270	214	140	111	70	60	200	163
Dioxin/furan TEQ (ng/kg)	2	2	7	13	4	8	2	5	6	10

[77] When dredging is performed in intertidal areas, the sediment bed is returned to existing elevations through backfill of clean material.

COC	Components Used to Calculate Bed Replacement Values				Bed Replacement Values					
	Clean Fill Material		Average Sediment Concentrations Outside Remedial Footprint		Input (Base or Mid) (50:50)[a]		Low (75:25)[a]		High (25:75)[a]	
	FS	Updated	FS	Updated	FS	Updated	FS	Updated	FS	Updated
Arsenic (mg/kg)	7	7	12	12	10	10	9	8	11	11

[a] Ratio of clean fill material to the SWAC of surrounding sediment outside of the remedial footprint.

BCM – bed composition model
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
FS – feasibility study
PCB – polychlorinated biphenyl
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

For the average sediment conditions outside of the active remedy footprint, the FS used the RI/FS SWAC for the area outside of area of potential concern 1 (AECOM 2012). As an update, SWACs were calculated for areas outside of the active remediation areas as approximated by ROD Figure 18 (EPA 2014). Surface sediment data (individual grab samples) from 2005 to 2018 were used to calculate the SWACs, which were derived by developing IDW interpolations for total PCBs, cPAHs, and arsenic and then clipping out the active remedy areas. Thiessen polygons were used for dioxins/furans because the dioxin/furan data density was less than that of the other risk drivers.

As stated in the FS, the expected concentrations of COCs shortly following remediation is dependent on several factors, including the type of remedial activity, specific design elements, construction methods, best management practices, engineering controls, and contingency measures (AECOM 2012). Therefore, bed sediment replacement values for the BCM were developed as a range using best professional judgment. The base case (or mid) input value was applied to areas slated for dredging, capping, ENR, or thin-layer placement of sand inside the dredge footprint for residuals management, and the low and high values were used to assess sensitivity to this parameter.

The updated ranges of bed replacement values were similar to those used in the FS, although they were somewhat higher for total PCBs and dioxins/furans and lower for cPAHs (Table 8-6).

8.4 SUMMARY OF UPDATED BCM INPUT PARAMETERS

Data collected since the FS (AECOM 2012) have been reviewed for the three key input parameters to the BCM (lateral, upstream, and bed replacement value) to update BCM input parameters for the four risk drivers per AOC3 (EPA 2016). A summary of the recommended values is presented in Table 8-7. The updated input parameters were generally consistent with those used in the FS; the following results were found:

- Total PCBs – Laterals values were the same as those in the FS (except for a lower high-sensitivity value), upstream values were generally lower, and bed replacement values were higher.

- cPAH TEQ – All input values were lower.
- Dioxin/furan TEQ – Input values for laterals and bed replacement were higher.
- Arsenic – Input values were relatively unchanged.

These differences are likely due to the much larger datasets now available and ongoing source control actions.

Table 8-7. Summary of recommended BCM input parameters based on updated data

COC	Recommended BCM Input Parameters								
	Input (Base or Mid)			Low			High		
	Lateral	Upstream	Bed Replacement Value	Lateral	Upstream	Bed Replacement Value	Lateral	Upstream	Bed Replacement Value
Total PCBs (µg/kg)	300	20	72	100	6	37	700	55	107
cPAH TEQ (µg/kg)	830	55	111	400	34	60	1,500	134	163
Dioxin/furan TEQ (ng/kg)	50	4	8	30	2	5	60	7	10
Arsenic (mg/kg)	13	10	10	10	9	8	25	12	11

BCM – bed composition model
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

9 Future Sampling Considerations

The Pre-Design Studies datasets provide valuable baseline information and CSM support that will serve as a foundation to assess remedy effectiveness and variability within the LDW. Per AOC3, this data evaluation report is required to "identify data gaps and issues and present recommendations to resolve any gaps or issues requiring additional field characterization or other work" (EPA 2016). As discussed in each section of this report, all DQOs outlined in the QAPPs were met, thus, no data gaps were identified.

This section provides a summary of information gathered during the Pre-Design Studies investigations that will be helpful in future monitoring events. Specific study design considerations were identified for sediment, surface water, fish and crab tissue, and clam tissue; these considerations are discussed below. After the full cPAH porewater, clam tissue, and sediment investigation results are available, any data gaps or future sampling considerations will be evaluated in a later version of this report or in an addendum. With respect to source-related sampling, LDWG will continue to work with Ecology as it continues its source-sufficiency evaluations.

9.1 SEDIMENT

The study designs for the collection of site-wide 0–10-cm composite samples, site-wide 0–45-cm potential clamming area composite samples, and 0–45-cm beach play area composite samples are intended for use in future monitoring events. These efforts will collect comparable data to assess compliance with cleanup levels as well as trends following the remedy. Additional 0–10-cm individual surface sediment data will also be collected for remedial design and following construction activities of the remedy as part of MNR and long-term monitoring. This section discusses the study design performance and, where applicable, minor refinements to be considered for future monitoring events.

9.1.1 Site-wide surface sediment (0–10-cm) samples

The site-wide composite sample datasets for the four COCs were generally statistically well-behaved. With the exception of one or two individual samples, the data distributions were normally distributed with CVs of approximately 0.6 or less, leading to an RME for the mean of 21% or less. The individual composite samples that skewed the distributions for cPAH TEQ and dioxin/furan TEQ were from areas that will be remediated, so mean and variance from the post-remedy sampling event is expected to be less than baseline mean and variance. Thus, no changes to the study design are recommended.

9.1.2 Potential clamming area sediments

The sampling design for the potential clamming area sediments called for three site-wide composites, each with 68 grab samples. Analysis of these data relied on the central limit theorem to calculate a 95UCL based on the normal distribution. Baseline estimates of sampling variability for the three samples were low for arsenic (CV of 19%) but relatively high for total PCBs, cPAH TEQs, and dioxin/furan TEQs (CVs of 103, 83, and 92%, respectively). For total PCBs and dioxins/furans, these high sampling variances were likely the result of contributions from areas with especially high concentrations, such as Trotsky Inlet,[78] to Composite 2. Composites 1 and 3 had total PCB and dioxin/furan concentrations of similar magnitude. While Composite 2 also had the highest cPAH TEQ, the cPAH TEQ in Composite 1 was also significantly higher than that in Composite 3.

Site-wide heterogeneity after remediation is expected to decrease markedly, which will result in less variance among the site-wide composites. Thus, no changes to the study design are recommended.

9.1.3 Beach play area sediments

The sampling design for the beach play area sediments called for three beach-wide composites per beach, with three to nine samples per composite (proportional to the size of each beach). To estimate the 95UCL, Chebyshev's inequality was used. The conservativeness of Chebyshev's inequality coupled with some high sampling variance for all risk drivers meant that RMEs were as high as 362% for cPAHs.

Despite the conservative estimate of the 95UCL, the 95UCL for total PCBs was below the RBTC at all beaches, suggesting that total PCBs do not pose an unacceptable risk for direct contact exposures in beach play areas.

The 95UCLs for arsenic were above the RBTC at seven of the eight beaches. The 95UCL for dioxin/furan TEQs was above the RBTC at three of the eight beaches, and the 95UCL for cPAHs was above the updated RBTC[79] at three or four of the beaches, depending on treatment of duplicate results. Thus, design sampling will be required at these beaches. Based on Figure 18 in the ROD, seven of the eight beach areas may be actively remediated, either in part or in entirety, which is expected to reduce risk driver concentrations and variance in these beaches.

Note, however, that the variance components analysis on the field duplicates collected at Beaches 1 and 6 indicated that small-scale field variability was relatively high for

[78] Trotsky Inlet had, by far, the highest concentrations of PCBs in surface sediment among all locations within the LDW (AECOM 2012); it also had high concentrations of many other COCs. The contamination was highest further into the inlet, where the grab samples for Composite 2 were collected.

[79] RBTC updated based on EPA's 2017 update of the benzo(a)pyrene slope factor (EPA 2017).

dioxins/furans and cPAHs. Therefore, in future beach sampling efforts, it is recommended that field duplicates be collected for composite samples at larger beaches[80] to better understand the small-scale variability.

9.2 SURFACE WATER

The study design for the collection of passive sampler data for PCBs is intended for use in future monitoring events to collect comparable data to assess trends. In addition, composite-grab surface water samples will be collected to assess progress toward meeting ARARs following construction. This section discusses refinements that are recommended for future sampling events.

9.2.1 Composite-grab samples

Recommended refinements for the composite-grab surface water sampling design include changes to the number of sampling events and changes to the analyte list.

9.2.1.1 Number of sampling events

Based on the results of the composite-grab sampling events, it is recommended that any future sampling should focus on a subset of the eight events that were sampled as part of the Pre-Design Studies baseline effort. Table 9-1 summarizes the events for which concentrations were highest for the chemicals with ARAR exceedances.

Table 9-1. Summary of highest concentrations in surface water composite-grab samples for chemicals with concentrations greater than an ARAR

Chemical	DF	Event with Highest Concentrations
Total PCBs	48/48	Storm 2
cPAHs[a]	1/48–6/48	wet baseflow
Inorganic arsenic	48/48	Storm 2
BEHP	3/48	dry baseflow

[a] Six of the seven individual PAHs had detected concentrations greater than an ARAR.

ARAR – applicable or relevant and appropriate requirement
BEHP – bis(2-ethylhexyl) phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DF – detection frequency
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl

Based on the information presented in Table 9-1, the highest chemical concentrations are expected in three types of baseline sampling events, which are recommended for future monitoring efforts.

- **Storm 2** – Both Storm 1 and Storm 2 required a storm (0.25 in. for Storm 1 and 0.5 in. for Storm 2 during a 24-hour period) following a 48-hour antecedent

[80] Beaches 1 and 6 are the smallest beach play areas, and thus fewer grab samples were collected. At larger beaches, more grab samples will be collected because the number of samples is proportional to the size of the beach. Duplicates of more grab sample locations will provide better information to understand small-scale variability.

period without significant dam release (i.e., < 2,000 cfs). Concentrations of total PCBs and inorganic arsenic were highest in these events, and thus the higher rainfall event (i.e., Storm 2) is recommended for future sampling.

- **Dry baseflow** – One dry baseflow event (minimum of a three-day antecedent dry period and average dry season dam release [e.g., 200 to 600 cfs]) is recommended because the highest concentration of BEHP was detected during a dry baseflow event.
- **Wet baseflow** – One wet baseflow event (minimum of a three-day antecedent dry period and wet season average dam release [e.g., 800 to 1,200 cfs]) is recommended for sampling because the highest cPAH concentrations were detected during a wet baseflow event.

9.2.1.2 Analyte list

In the approved surface water analyte memorandum and in the surface water QAPP addendum (Windward 2018a, j), it was recommended that the analyte list be refined in future monitoring to include only inorganic arsenic, PAHs, BEHP, PCBs, and conventional parameters. All other parameters were either not detected or had detected concentrations that were consistently below ARARs.

9.2.2 Passive samplers

Recommended refinements for the passive sampler portion of the surface water sampling design include changes to the number of locations and the number of passive sampler replicates.

9.2.2.1 Number of locations

The evaluation of passive sampler PCB data (Section 3.2.2) indicates that the total variability observed is primarily due to variability across sampling years (75% of the total) and across replicates (25% of the total). Because the variability across locations accounts for essentially 0% of the variance, it is recommended that future passive sampler deployments be limited to a single location. Location PS1 (South Park Bridge) is recommended for future sampling over PS2 to avoid any potential access issues or changes to the pier structure at PS2.

9.2.2.2 Number of passive sampler replicates

In addition, because the CV observed in the baseline dataset was much lower than the variance used to develop the sampling design in the Work Plan phase (which was based on the MIT study (Apell et al. 2018)), it is recommended that fewer replicates be analyzed during future sampling events. Using the CV achieved in the baseline sampling, the MDD for a comparison between baseline and a future sampling event is

expected to be approximately 10%.[81] With a baseline mean of 1.1 ng/L, this MDD results in a statistically detectable change of 0.11 ng/L.

Nine passive sampler replicates were analyzed in the baseline sampling effort. If future variance remains the same as the variance observed in 2017 and 2018, reducing the number of replicates analyzed to three during future sampling events would still result in an MDD of < 15% of the baseline mean (Appendix B). Reducing the number to five passive sampler results in future years would allow for sufficient replicates to confirm the normality of the data while still achieving a low MDD (approximately 12%) for comparisons to baseline; therefore, the analysis of five of the nine replicates is recommended for the next round of passive sampler deployments. Nine replicates are still recommended for deployment during future efforts. Four of these nine samplers would be archived and only analyzed if needed in the event of higher-than-anticipated variability or if some of the samplers are lost in the field or needed by the laboratory.

9.3 FISH AND CRAB TISSUE

The study design for the collection of fish and crab tissue samples is intended for use in future monitoring events in order to collect comparable data to assess trends and to evaluate concentrations relative to TTLs. This section evaluates possible refinements to the non-risk driver analyte list, as well as the species of crab that is recommended for collection in planning future events. All other study design elements are appropriate for future monitoring.

9.3.1 Analyte list

Continued monitoring of the concentrations of all human health risk drivers analyzed during the baseline investigation (total PCBs, dioxins/furans, and inorganic arsenic) is recommended. As was done for the baseline sampling, cPAHs could continue to be analyzed in crab tissue but not fish tissue, because fish are known to metabolize PAHs. Note, however, that cPAHs were not detected in crab tissues. Therefore, the need to continue monitoring concentrations of cPAHs in crab tissue, which does not have a TTL, should be discussed. If cPAHs are still not detected in the next round of monitoring, additional monitoring is not recommended.

For the non-risk driver chemicals, based on the information presented in Section 4.2.3, concentrations of TBT and pesticides were generally lower than those in the HHRA dataset or were not detected.

- **TBT** – Concentrations in the 2017 samples were lower than those in the HHRA dataset. Based on this decrease in concentrations, the resulting HHRA risk estimates would be well below the non-cancer threshold (i.e., hazard quotient less than 1) for all three reasonable maximum seafood consumption exposure scenarios.

[81] This MDD was calculated assuming a single location and depth.

- **Pesticides** – Concentrations of all pesticides were lower in the 2017 baseline tissue samples than in the HHRA dataset. In addition, the majority of the detected concentrations in the 2017 baseline tissue samples were J-flagged because concentrations were below the RL. Based on these lower (and many non-detected) concentrations, risks from seafood consumption were also lower.

The need to continue monitoring these chemicals should to be evaluated as part of the development of future sampling efforts.

9.3.2 Target crab species

Based on the results of the stable isotope evaluation (Section 4.1), graceful crab and Dungeness crab occupy similar trophic positions. Thus, for the purpose of trend evaluations, it is recommended that graceful crab be used because it is commonly available in the LDW. However, because Dungeness crab is the preferred species for human consumption, future sampling efforts would also continue collect Dungeness crab to the extent that it is available.

9.4 CLAM TISSUE

The study design for the collection of clam tissue samples is intended for use in future monitoring events in order to collect comparable data to assess trends and to evaluate concentrations relative to TTLs. This section discusses recommended refinements to the study design and analyte list for future monitoring events.

9.4.1 Study design

The DQOs for clam tissue sampling required site-wide estimates of the human health risk driver (i.e., total PCBs, cPAH TEQ, dioxins/furans, and inorganic arsenic) concentrations. The study design for clam tissue was not based on a target RME (as were the fish/crab tissue sampling designs), but instead followed the approach used in the RI, wherein one clam tissue composite sample was collected in each of the clam tissue collection areas. As a result, variance within the clam tissue dataset includes differences in COC concentrations among the clam tissue collection areas located throughout the LDW. This variance was skewed by samples from one or more areas for all analytes, except total PCBs (Appendix B).

Sediments with COC concentrations above RALs will be remediated according to the ROD; therefore, when clams are collected from these areas in the future, clam tissue concentrations are expected to be lower and the variance within the clam tissue dataset would be reduced. Because the CVs estimated from the baseline dataset are not representative of future variance, the RMEs for future datasets and the MDDs between baseline and future monitoring cannot be adequately predicted at this time.

For total PCBs, cPAHs, and dioxins/furans, the clam tissue composites from each area were each composed of 10 clams, whereas for inorganic arsenic, the composites for each area were each composed of three clams. To better evaluate the progress of inorganic

arsenic concentrations towards the TTL (particularly for whole-body tissue without siphon skin), it is recommended that future sampling efforts include the collection of additional composites from each area where clams are found for inorganic arsenic analysis. The analysis of a greater number of clam composites for inorganic arsenic[82] will help to capture more of the population variability within each clamming area, which should reduce sampling variability and provide a better estimate of the site-wide clam tissue concentration. This approach would use the same number of individuals per composite used in the Pre-Design Studies baseline dataset and would allow for the evaluation of more clams where they are available.

9.4.2 Analyte list

Continued monitoring of the concentrations of the four risk drivers (i.e., total PCBs, cPAHs, dioxins/furans, and inorganic arsenic) is recommended. For cPAHs, if concentrations in clam tissue continue to decrease, improved analytical sensitivity will be necessary to detect cPAH concentrations at lower levels in order to attain a site-wide 95UCL that achieves the TTL.

Thus, future monitoring could consider using a more sensitive analytical method for cPAHs. An ultra-trace modified method (EPA method 8270/1625) is available that can achieve an MDL of 0.1 to 0.2 ng/g for tissue (compared with the MDL of 0.5 to 1.5 ng/g in the Pre-Design Studies dataset). This method would enable a determination of whether cPAH TEQs in clam tissue are below the updated TTL of 1.8 µg/kg dw,[83] even if all cPAHs were undetected. Specifically, using EPA method 8270D (the method used for the Pre-Design Studies samples), if all cPAHs in a given sample were not detected, the cPAH TEQ would be equal to 1.8 µg/kg dw (i.e., equal to the updated TTL for clams) using the MDL as the value for non-detects or to 0.9 µg/kg dw using ½ MDL as the value for non-detects. Alternatively, using the ultra-trace modified EPA method 8270/1625, if all cPAHs in a given sample were not detected, the cPAH TEQs would be 0.23 or 0.12 µg/kg dw using the MDL or ½ MDL, respectively.

Of the non-risk driver chemicals, only vanadium, TBT, and BEHP were detected; none of the three other SVOCs or pesticides were detected, and RLs for these chemicals were generally lower than those for the HHRA database samples (Table 5-9). For the detected non-risk driver chemicals, concentrations of TBT and BEHP were lower than those in the 2004 HHRA dataset, while concentrations of vanadium were similar. TBT concentrations in 2018 samples were (on average) about 50 times lower than those in the HHRA (Windward 2007). Using the maximum 2018 TBT value of 7.44 µg/kg ww, the resulting HHRA risk estimates would be well below the non-cancer threshold (hazard quotient less than 1) for all three reasonable maximum seafood consumption exposure

[82] As shown in Table 5-2, the variance in total PCBs and dioxins/furans was acceptable (excluding the composite from the Glacier Bay area). Future cPAH variance will depend on the ability to detect cPAHs in clam tissue.

[83] TTL based on EPA's 2017 update of the benzo(a)pyrene slope factor (EPA 2017).

scenarios. Therefore, the following recommendations are made for the clam tissue analysis:

- Continue monitoring for all four risk drivers (total PCBs, cPAH TEQ, dioxins/furans, and inorganic arsenic).
- Use the ultra-trace modified EPA method 8270/1625 for the analysis of cPAHs in clam tissue.
- Remove TBT from the clam tissue analyte list.
- Discuss whether monitoring of the non-risk driver chemicals that were not detected in clam tissue should continue. If they are still not detected in the next round of monitoring, additional monitoring is not recommended.

9.5 NEXT STEPS

Upcoming efforts in the LDW related to the ROD include additional investigations to support remedial design, construction of the remedy, monitoring of MNR areas, and site-wide long-term monitoring of the site following construction. The study designs used in the baseline sampling are well suited for long-term monitoring, although some refinements are recommended for future monitoring efforts. The Pre-Design Studies datasets provide valuable baseline information and CSM support that will serve as a foundation to assess remedy effectiveness and variability within the LDW.

10 References

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