Lower Duwamish Waterway Group

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

LOWER DUWAMISH WATERWAY PRE-DESIGN STUDIES DATA EVALUATION REPORT (TASK 6)

FINAL

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
AOC3	Third Amendment to the Administrative Order on Consent
AOC4	Fourth Amendment to the 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

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
HHRA	human health risk assessment
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HpCDD	heptachlorodibenzo-*p*-dioxin
HpCDF	heptachlorodibenzofuran
HQ	hazard quotient
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
RL	reporting limit
RM	river mile
RME	relative margin of error
ROD	Record of Decision
RSD	relative standard deviation
RSS	residual sum of squares
SCL	sediment cleanup level
SCO	sediment cleanup objective
SD	standard deviation
SE	standard error
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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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*. Consistent with Section 13.2.3 of the Record of Decision (ROD) (EPA 2014), the purposes of this study were to establish post-early action area (EAA) cleanup baseline conditions in environmental media, evaluate the effectiveness of EAA cleanups and the degree to which natural recovery has occurred since the remedial investigation/feasibility study (RI/FS), and aid in the evaluation of source control.

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 ROD, which specifies the sediment cleanup remedy for the LDW, was released in 2014.

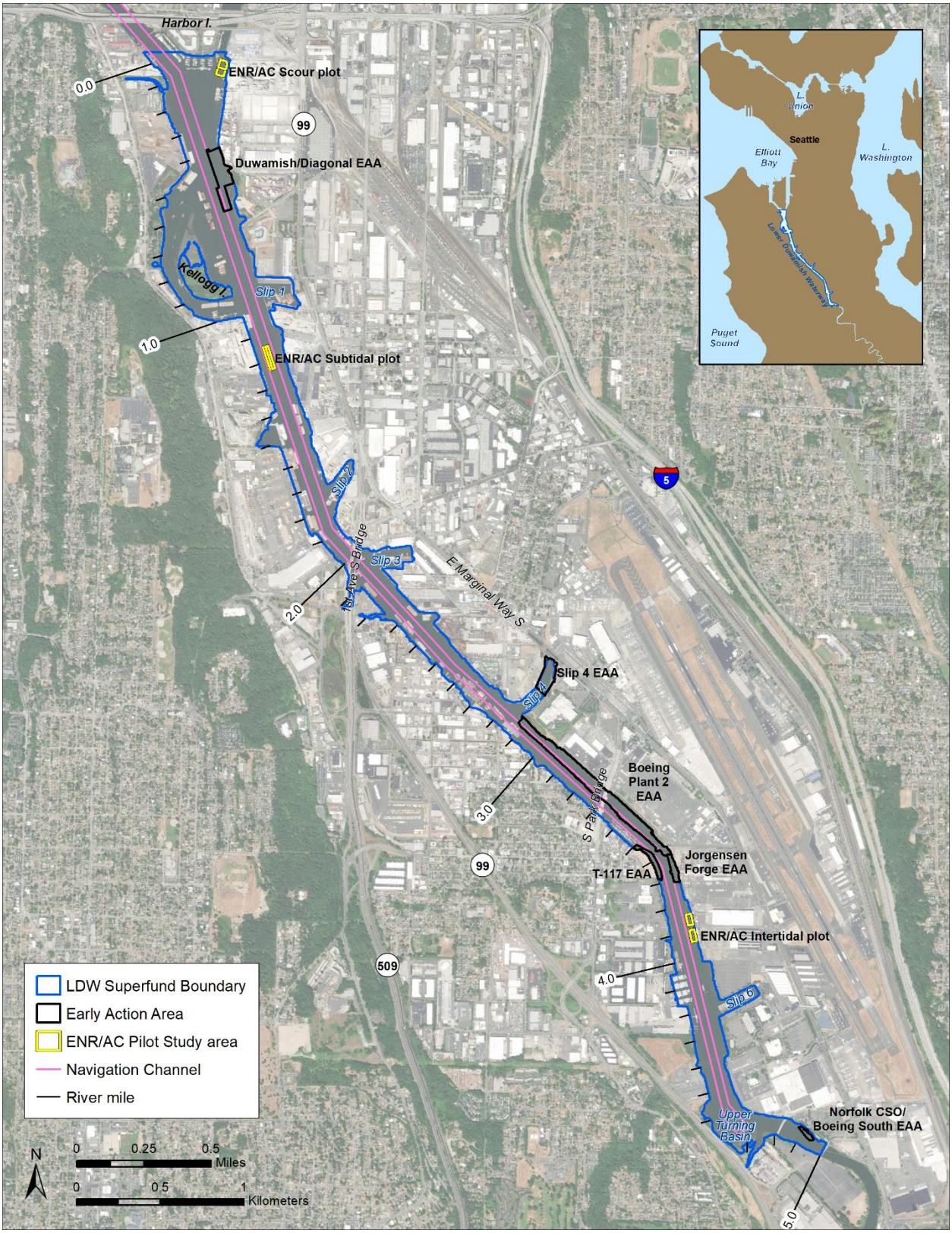


Figure ES-1. Location of the LDW

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 existing data (including post-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 by the data collected. Many of the DQOs involved the comparison of baseline data to ROD cleanup levels in sediment and target tissue levels (TTLs) in tissue. As discussed in the subsections that follow, 95% upper confidence limit (on the mean) (95UCL) concentrations in baseline sediment and tissue samples were calculated for comparison with these cleanup levels and TTLs, respectively. Contaminant of concern (COC) concentrations in individual sediment samples were compared with benthic cleanup levels.[2] The DQOs are listed 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 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 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

[1] Post-FS data were summarized in the Existing Data Compilation.
[2] Individual sample results were also compared to remedial action levels (RALs) per the ROD.

- 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[3]

- Provide near-outfall sediment, bank sediment, and seep data to Ecology to help with source control sufficiency evaluations

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

[3] 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.

DQO Number[a]	DQO	QAPP Wherein DQO Discussed
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
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 COCs 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).[4]

[4] 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 sediment data to RAO 1, 2, and 4 cleanup levels in ROD Table 19

COC	Cleanup Levels				Application Area and Depth		95UCL of Baseline Data[b]
	RAO 1: Human Seafood Consumption	RAO 2: Human Direct Contact	RAO 4: Ecological (River Otter)	Basis for Cleanup Level[a]	Spatial Scale of Application	Compliance Depth	
Total PCBs (µg/kg dw)	2	1,300	128	background (RAO 1) RBTC (RAO 2) RBTC (RAO 4)	LDW-wide	0–10 cm	209
	na	500	na	RBTC	all clamming areas	0–45 cm	1,690
	na	1,700	na	RBTC	individual beaches	0–45 cm	160–1,580
cPAH TEQ (µg/kg dw)	na	380	na	RBTC	LDW-wide	0–10 cm	226
	na	150	na	RBTC	all clamming areas	0–45 cm	913
	na	90	na	RBTC	individual beaches	0–45 cm	63.4–5,310[c]
Dioxin/ furan TEQ (ng/kg dw)	2	37	na	background (RAO 1) RBTC (RAO 2)	LDW-wide	0–10 cm	11.6
	na	13	na	RBTC	all clamming areas	0–45 cm	85.5
	na	28	na	RBTC	individual beaches	0–45 cm	2.38–125
Arsenic (mg/kg dw)	na	7	na	background	LDW-wide	0–10 cm	13.1
	na	7	na	background	all clamming areas	0–45 cm	14.0
	na	7	na	background	individual beaches	0–45 cm	6.31–96.8

Note: Baseline data are greater than the cleanup levels in shaded cells.

[a] RBTC based on 1 in 1,000,000 excess cancer risk or HQ of 1.

[b] Results were compared with RAO 1, 2, and 4 cleanup levels by comparing the 95UCL of LDW data with the RBTC or background-based cleanup level. The alternative method using a distributional comparison of LDW-wide data to the OSV *Bold* data was also explored for arsenic (Appendix B, Section B2.1.3), with similar conclusions.

[c] The maximum cPAH TEQ 95UCL was 8,214 µg/kg with the field replicate included.

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

Total PCB 95UCL concentrations were greater than their cleanup levels for RAO 1 (human seafood consumption), RAO 2 (human direct contact – clamming), and RAO 4 (ecological – river otter protection).

cPAH toxic equivalents (TEQs) 95UCLs were greater than RAO 2 cleanup levels in the ROD for clamming (site-wide composites) and for seven of the eight beaches (Section 2.3.2). The RAO 2 cleanup levels for cPAHs in sediment are risk-based threshold concentrations (RBTCs) for human direct contact calculated using the EPA benzo(a)pyrene cancer toxicity value (e.g., cancer slope factor) used in the human health risk assessment (HHRA) (Windward 2007). As part of its IRIS program, EPA has published an updated assessment of benzo(a)pyrene toxicity that would result in lower cancer risk estimates for exposure to cPAHs and increase the cPAH RBTCs (and resulting cleanup levels). EPA is reviewing the effect of the updated toxicity value on the ROD and expects to update the cPAH cleanup levels to reflect current science (Appendix G).

Dioxin/furan TEQs 95UCLs were greater than cleanup levels for RAO 1 (human seafood consumption) and RAO 2 (human direct contact - clamming areas [site-wide composites] and three of the eight beach play areas).

Arsenic 95UCL 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.

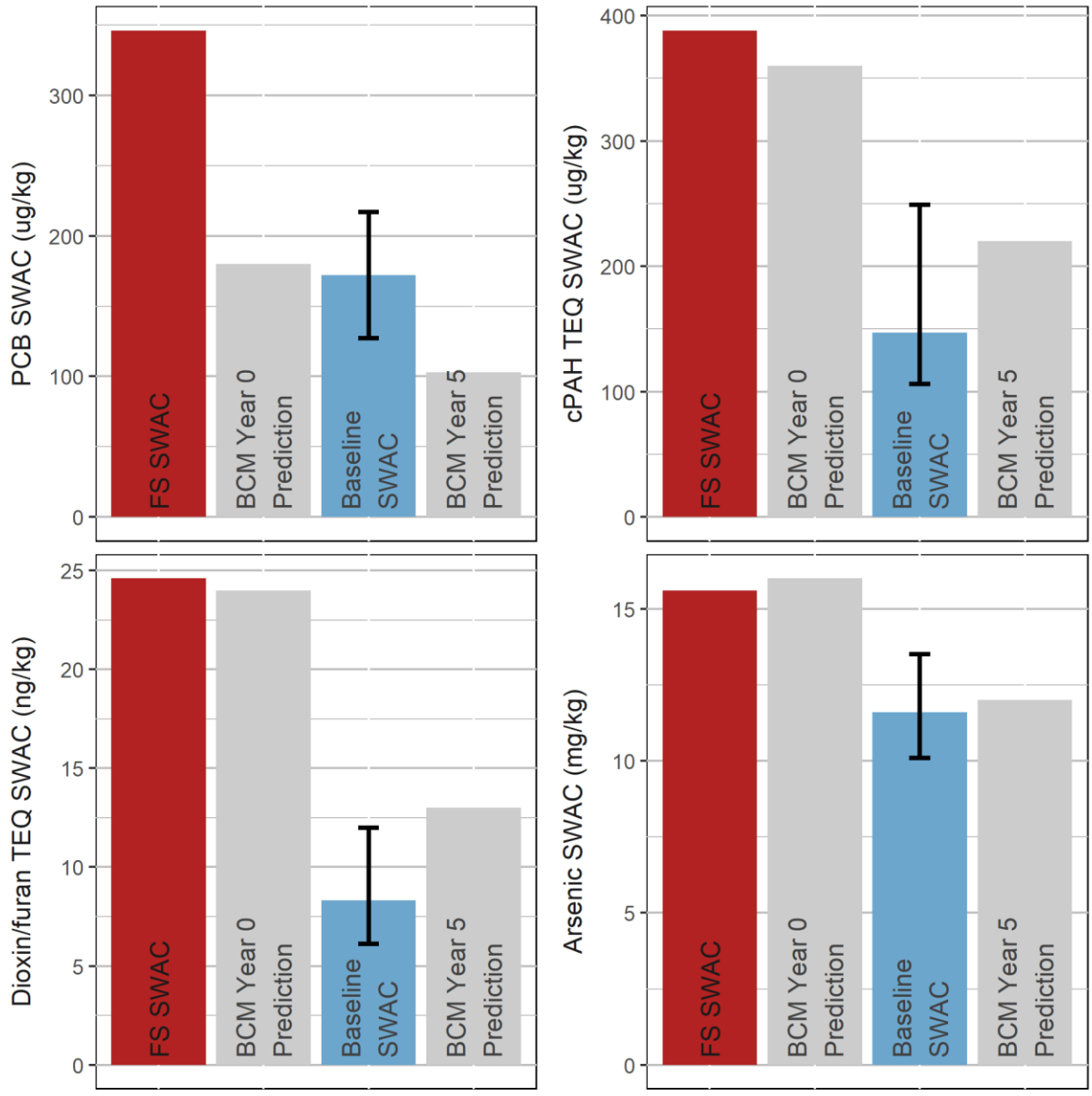
Site-wide SWACs were also calculated for the four human health risk drivers to assess overall changes that have occurred since completion of the EAAs, as well as for use in assessing site-wide trends following completion of the ROD sediment remedy. For all four risk drivers, the baseline site-wide SWACs were lower than those based on the RI/FS dataset (Table 2-3 in the FS (AECOM 2012)) (Table ES-3, Figure ES-2). In other words, the baseline data suggest that the concentrations of the four risk drivers have significantly decreased since RI/FS data collection, consistent with modeling predictions presented in the FS. While there are uncertainties in the data comparison because of differences between the RI/FS and baseline study designs, it appears that source control, early actions, and the ongoing deposition of cleaner, upstream (i.e., Green River) sediments have lowered concentrations in the biologically active zone (upper 10 cm of sediment).

Table ES-3. Comparison of FS, baseline, and model-predicted SWACs

COC	Units	FS SWAC	Model-predicted SWAC Year 0 Post-EAA[a]	LDW Baseline SWAC	Model-predicted SWAC Year 5 Post-EAA[a]
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

[a] BCM model predictions represent base-case predictions for Year 0 following early actions and Year 5 after early actions, as presented in the FS (AECOM 2012). Based on the modeling assumptions used in the FS, Year 0 corresponds with approximately 2015 to 2017, following recent early actions at Boeing Plant 2, T-117, and Jorgensen Forge. Base-case predictions represent sediment quality following continued upstream inputs, as well as a pragmatic assessment of what might be achieved over a decade of source control. The overall uncertainty in BCM predictions is discussed in detail in the FS.

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
SE – standard error
SWAC – spatially weighted average concentration
T-117 – Terminal 117
TEQ – toxic equivalent



Note: The error bars show the 95% confidence interval for the baseline means.

Figure ES-2. Comparison of FS-interpolated, BCM-predicted (Year 0 and Year 5 post-EAAs), and baseline composite LDW-wide SWACs for 0–10-cm sediments

Mean baseline sediment 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). The RI/FS dataset did not include sufficient 0–45-cm data for intertidal areas to support a comparison of site-wide baseline results to past intertidal results.

Table ES-4. Summary of baseline 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	33.6	10.7
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	45.5	30.0	6.24
Beach 5	114	1,150	5.29	8.74
Beach 6	561	1,340	13.2	44.6
Beach 7	65.2	43.1	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[5] 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 for comparison 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 only the benzyl alcohol benthic cleanup level.
- Three had an exceedance of only the total PCB benthic cleanup level.

Individual samples analyzed for both PCB Aroclors and congeners were also assessed. The results for the two methods were similar, with differences that fell 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. A total of 40 samples (32 in the LDW and 8 upstream of the LDW) were collected during dry and wet

[5] 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.

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). It should be noted that six of these chemicals were cPAHs, which have WQC (shown in Table ES-5) that have not been modified to reflect the 2017 benzo(a)pyrene toxicity values. 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 baseline composite-grab surface water samples relative to the lowest WQC ARARs for human health and marine organisms

COC	Units	MDL	RL	LDW Summary Statistics		Upstream Summary Statistics		WQC ARARs		Count of Detects Greater than Lowest WQC ARAR			
										Marine Organisms		Human Health	
				Detection Frequency	Range of Detected Concentrations[a]	Detection Frequency	Range of Detected Concentrations[a]	Lowest WQC for Marine Organisms	Lowest WQC for Human Health	LDW	Upstream	LDW	Upstream
Arsenic (inorganic)	µg/L	0.008	0.025	32/32	0.498–1.67	8/8	0.451–0.993	36	0.14	0	0	32	8
Benzo(a)anthracene	µg/L	0.000750	0.0100	4/32	0.00080 J–0.012	0/8	nd	na	0.00016	na	na	4	0
Benzo(a)pyrene	µg/L	0.00248	0.0100	1/32	0.0070 J	0/8	nd	na	0.000016	na	na	1	0
Benzo(b)fluoranthene	µg/L	0.000460	0.0100	4/32	0.00060 J–0.011	0/8	nd	na	0.00016	na	na	6	0
Benzo(k)fluoranthene	µg/L	0.00321	0.0100	1/32	0.0050 J	0/8	nd	na	0.0016	na	na	1	0
Dibenzo(a,h)anthracene	µg/L	0.00134	0.0100	1/32	0.0020 J	0/8	nd	na	0.000016	na	na	1	0
Indeno(1,2,3-cd)pyrene	µg/L	0.00118	0.0100	2/32	0.0020 J	0/8	nd	na	0.00016	na	na	2	0
BEHP	µg/L	0.345	3.00	2/32	1 J–2.0 J	1/8	0.5 J	na	0.046	na	na	2	1
Total PCB congeners	ng/L	0.000001	0.000004	32/32	0.02172 J–4.942 J	8/8	0.0105 J–0.2289 J	30	0.007	0	0	32	8

Note: Only chemicals with detected values above a WQC ARAR are shown in this table. All concentrations are for unfiltered samples for comparison to the lowest ARAR. Duplicate sample results are not included in these summary statistics.

[a] Non-detected values are presented in the surface water data report (Windward 2019a).

ARAR – applicable or relevant and appropriate requirement
BEHP – bis(2-ethylhexyl) phthalate
COC – contaminant of concern
J – estimated concentration
LDW – Lower Duwamish Waterway
MDL – method detection limit
na – not available
nd – not detected
PCB – polychlorinated biphenyl
RL – reporting limit
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 human health risk drivers to establish baseline conditions. Fish, crab, and clam tissue 95UCLs were compared with TTLs, as presented in ROD Table 21.[6]

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, 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 RI/FS and future data to evaluate trends. The following summarizes the key conclusions with regards to trends:

- Total PCB concentrations in baseline tissue were lower than or similar to those in 2007 tissue samples for English sole and shiner perch (e.g., Figure ES-3) and were generally lower for clams. For graceful crab, concentrations in baseline tissue were higher than concentrations from the 2007 sampling event (see Section 4.2.1.2).
- cPAH TEQs[7] in clam tissue were generally lower than those in the 2004 and 2007 data.
- For inorganic arsenic, no clear temporal trends were observed in clam tissue.
- No RI/FS dioxin/furan tissue data are available for comparison with baseline results, and thus no trend evaluation was possible.

[6] ROD Table 21 is titled *LDW resident fish and shellfish target tissue concentrations.*
[7] cPAHs and inorganic arsenic had TTLs for clam tissue only.

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

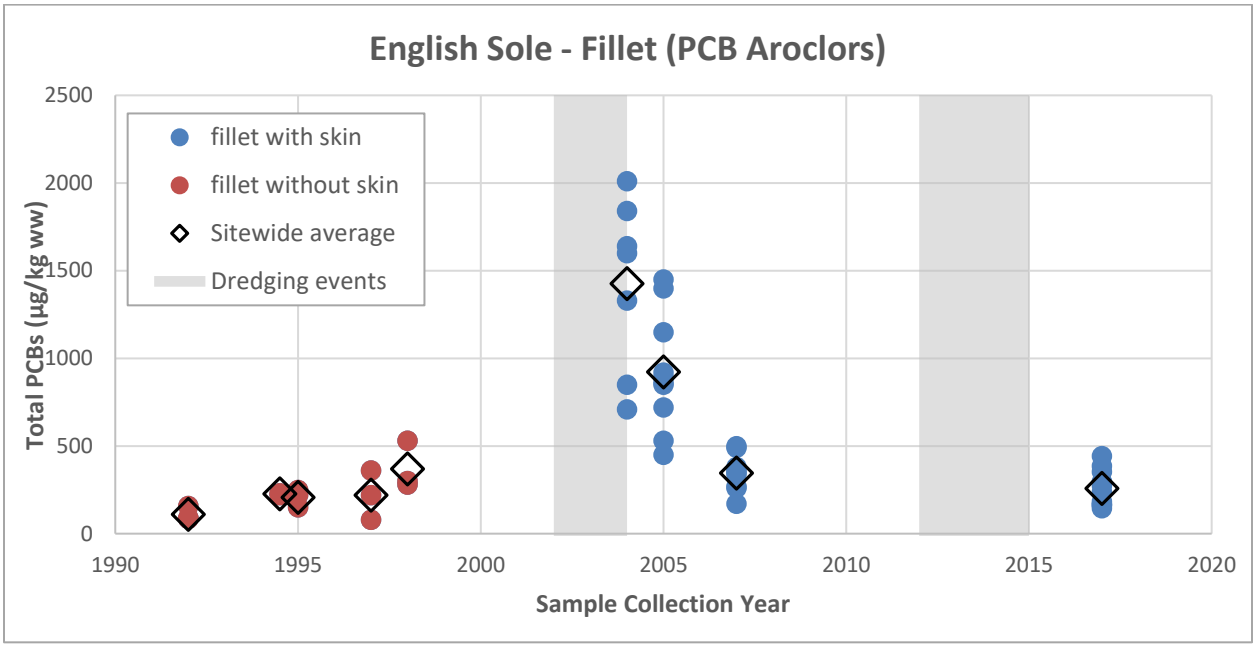
COC	Species and Tissue Type	n	Mean	Min.	Max.	95UCL	TTL
Total PCB Aroclors (µg/kg ww)	benthic fish – English sole – fillet	12	259	144.6	442	286	12
	pelagic fish – shiner surfperch – whole body	12	407	308	515	426	1.8
	crab – graceful crab – edible meat	12	115	61.1	165 J	124	1.1
	crab – graceful crab – 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[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[b]	0.53
	crab – graceful crab – whole body	12	1.21	0.744 J	1.73 J	1.32[b]	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	

Note: Grey shading indicates 95UCLs that are greater than the TTL.

[a] Based on EPA's 2017 update of the benzo(a)pyrene slope factor, the 1×10^{-6} RBTC (which is the basis for the TTL) is 1.8 µg/kg ww.

[b] The statistical power of the comparison test between the 95UCL and the TTL was > 99%.

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-3. Total PCB concentrations in English sole fillet tissue over time and major remediation dredging events

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 porewater total PCB concentrations, if needed in the future.

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

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 RAL for arsenic (28 mg/kg) was sufficiently low. Following remediation, inorganic arsenic

concentrations in clam tissue without siphon skins are predicted to reach 0.09 mg/kg wet weight [ww], the TTL for whole clams (i.e., including siphon skin).

For cPAHs, the relationships among sediment, clam tissue, and porewater were further addressed in the Pre-Design Studies. cPAH concentrations in clam tissue were only moderately correlated with cPAH concentrations in sediment and porewater. In addition, at locations with low sediment cPAH TEQs, the tissue concentrations were all very similar to each other and within the range of analytical variability, making it difficult to identify a relationship.

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; then, all near-outfall sediment data were compared with the surface sediment RALs for the appropriate recovery category, all bank data were compared with the lowest surface sediment RALs, and all seep data were compared with 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.[8] Of these 135 outfalls, 76 were located outside of EAAs and had surface sediment samples with RAL exceedances. Note that where exceedances occurred near outfalls, the source of contamination may have been historical rather than ongoing, or it may have been associated with another outfall or upland source.

Of the 66 bank samples, 22 had detected concentrations greater than the lowest surface sediment RAL.

Of the 66 filtered seep samples compared to groundwater PCULs protective of the sediment remedy, 11 had at least 1 COC concentration that was greater than the groundwater PCUL. Six chemicals were detected at concentrations greater than the groundwater PCULs in one or more seep samples.

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:

[8] The applicable radius was dependent on the size of the outfall pipe. The remaining outfalls do not have sediment data within 50 or 100 ft, either because the area was not sampleable, or because they were not recommended for sampling by Ecology due to being inactive or located within an active cleanup area.

- 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 long-term monitoring of the site. In addition, source control efforts in support of the cleanup will continue.

The study designs developed for the baseline sampling provide a foundation for site-wide long-term monitoring plans. The site-wide monitoring designs may require adjustments over time; 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.

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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 2017c), 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).[9]
- 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.

[9] 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.[10] RAO 3 (protection of benthic invertebrates) evaluations will be assessed following remedial construction. Comparison of sediment concentrations with RAO 3 cleanup levels 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 cleanup goals.

All data collected to address AOC3 have been reported in data reports, including data for fish/crab (Windward 2018g), surface sediment (Windward 2019c), seeps (Windward 2018c), clam tissue (Windward 2019b), and surface water (Windward 2019a).[11] These reports include data, sample collection locations, validation results, and any quality assurance project plan (QAPP) deviations. All of the data presented in the data reports and this data evaluation report were managed following the data management rules presented in the Work Plan (Windward and Integral 2017b). 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

[10] 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).

[11] 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.

The text is supported by the following appendices:

- Appendix A – Relevant ROD Tables and Figures
- 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
- Appendix G – Technical Memorandum Regarding the Implications of the Updated Toxicity Values for Benzo(a)Pyrene
- Appendix H – Memorandum Regarding cPAHs in LDW Clam Siphon Skin
- Appendix I – Stable Isotope Evaluation for Crab

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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, 4, 7, 8, 9, and 10. The results and interpretation of the *ex situ* porewater investigation (DQO 5) are discussed in Section 6, and the results and interpretation of the source-related samples (DQO 6) 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[12]). 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.

[12] 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. Details regarding the 95UCL calculations are provided in Appendix B, Section B2.1.2. The SWAC estimates were calculated as the arithmetic mean of the composite datasets as intended per the study design.

In the development of the baseline study design, the RI/FS data from MNR areas were used to generate spatially balanced bootstrap estimates of the coefficients of variation (CVs) for PCBs, cPAH TEQs, and arsenic (Section 2.1, Appendix A of the Work Plan (Windward and Integral 2017c)). Insufficient data were available to estimate variability for dioxins/furans. The data for PCBs were used to develop the sampling plan, because PCBs had one of the highest estimated CVs and the most comprehensive dataset (n = 545). Using the highest, PCB-based CV was expected to result in similar or smaller relative margin of error (RME) values for the other COCs with similar or lower CVs. Based on simulations using the PCB dataset (Section 2.3, Appendix A of the Work Plan), the composite sampling design was expected to generate normally distributed data, with mean and variance estimates that resulted in the target or smaller RME following remediation (i.e., when concentrations greater than the RAL have been remediated).

The baseline results indicated that the PCB data were normally distributed and the 25% RME was met for PCBs and arsenic; the RME targets were not met for cPAHs and dioxins/furans (Table 2-1). However, if the few influential values were removed, the data for cPAHs and dioxins/furans would have been normally distributed and the target RMEs would have been met (Table 2-1). This suggests that, following remediation, the skewness should be reduced and the RMEs for all four risk drivers should meet the targets.

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

COC (unit)	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. One influential value was present (COMP-20 with concentration of 27.2 mg/kg). RME was 23% with this value excluded.

[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 2017c; 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

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 some individual polycyclic aromatic hydrocarbons (PAHs); exceedance factors (EFs) ranged from 1.2 to 1.9.

The composite sample with the highest dioxin/furan TEQ was Comp-11 (27.7 ng/kg), which was collected from locations from RM 1.4 to RM 1.6, including the Glacier Triangle. 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 EF of 84. The second highest dioxin/furan TEQ was detected in Comp-6 (22.5 ng/kg), which was collected from locations between RM 0.6 and RM 0.9 in the center of the waterway north of Kellogg Island; this area did not have any locations with dioxin/furan TEQ RAL exceedances in the RI/FS or post-FS datasets.

In conclusion, 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 for trend analysis (DQO 2). The target RME was met for total PCBs and arsenic. For cPAHs and dioxins/furans, there were one (cPAHs) or two (dioxins/furans) influential composite samples that were responsible for elevating the variance to a level that resulted in RMEs greater than the targeted 25%. Based on RI/FS and post-FS data, these three composites included sediment from areas that are expected to have RAL exceedances and thus be remediated. Following remediation, the variance is expected to be reduced in the site-wide dataset, meeting the target RME for the risk driver COCs (see Table 2-1).

2.1.2 Composite sample interpretation

DQO 1 required the derivation of a baseline site-wide surface sediment dataset for comparison to site-wide cleanup levels. 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. Similarly, investigations conducted after the RI/FS did not suggest that relationships between arsenic and cPAH concentrations in sediment

and clam tissue were strong enough to derive sediment cleanup levels for arsenic and cPAHs for RAO 1 (see Windward and Integral 2017a, Appendix G).

Table 2-2. Baseline site-wide 95UCLs 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)	na

Shading indicates which ROD cleanup levels are exceeded based on baseline data.

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

95UCL – 95% upper confidence limit (on the mean)
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
na – not applicable
PCB – polychlorinated biphenyl
RAO – remedial action objective
RBTC – risk-based threshold concentration
ROD – Record of Decision
TEQ – toxic equivalent

For RAO 2 (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.[13] For RAO 4 (risk to otter), the baseline site-wide 95UCL for total PCBs was above the ROD cleanup level.

DQO 2 required calculation of a SWAC to serve as a baseline for comparison to pre-EAA conditions (FS SWAC), post-EAA predictions based on the BCM immediately following and five years after the construction of EAA remedies, and future long-term monitoring results.[14] Comparisons among the FS, baseline, and predicted base case SWAC[15] values are presented in Table 2-3 and Figure 2-1 in chronological order.

[13] Statistical power was calculated using a normal (for PCBs) or lognormal (for cPAH and dioxin/furan TEQs) one-sample, one-tailed t-test to compare the baseline mean to the RAO cleanup level. The site-wide mean concentrations in the 0–10-cm sediments were significantly lower ($\alpha = 0.05$) than the RAO 2 cleanup levels for PCBs, cPAH TEQ, and dioxin/furan TEQ. The statistical power of these comparisons was > 99%. Power was not calculated for arsenic, which exceeded the cleanup level.

[14] The statistical power calculations for comparisons between baseline and a future monitoring dataset are presented in Appendix B, Section B2.1.4.

[15] The base case condition represents sediment with continuing upstream inputs, as well as a pragmatic assessment of what might be achieved in the next decade with anticipated levels of source control. At the time of the FS, the next decade was 2012 to 2022. There are uncertainties in this comparison, both in FS data and in BCM predictions.

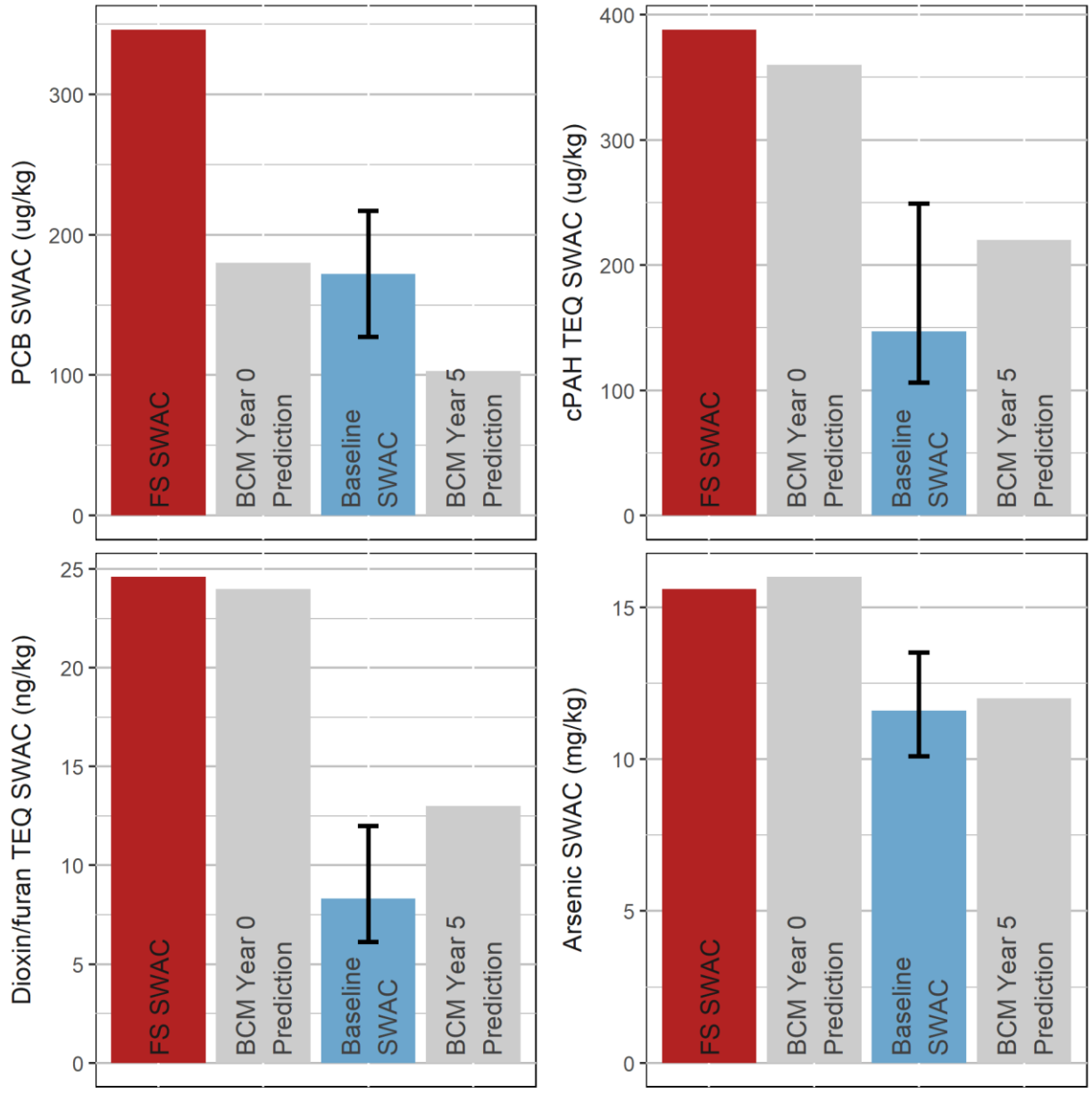
Table 2-3. Comparison of FS, baseline, and model-predicted SWACs

COC	Unit	FS SWAC[a]	Model-predicted SWAC Year 0 Post-EAA[b]	LDW Baseline SWAC [95% CI]	Model-predicted SWAC Year 5 Post-EAA[b]
Total PCBs	µg/kg	346	180	172 [127, 217]	103
cPAH TEQ	µg/kg	388	360	147 [106, 249]	220
Dioxin/furan TEQ	ng/kg	24.6	24	8.33 [6.12, 12.0]	13
Arsenic	mg/kg	15.6	16	11.6 [10.1, 13.5]	12

[a] 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., the data were not evenly distributed).

[b] BCM model predictions represent base-case predictions for Year 0 following early actions and Year 5 after early actions, as presented in the FS (AECOM 2012). Based on the modeling assumptions used in the FS, Year 0 corresponds with approximately 2015 to 2017, following recent early actions at Boeing Plant 2, T-117, and Jorgensen Forge. Base-case predictions represent sediment quality following continued upstream inputs, as well as a pragmatic assessment of what might be achieved over a decade of source control. The overall uncertainty in BCM predictions is discussed in detail in the FS (AECOM 2012).

BCM – bed composition model
CI – confidence interval
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EAA – early action area
FS – feasibility study
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
SE – standard error
SWAC – spatially weighted average concentration
T-117 – Terminal 117
TEQ – toxic equivalent



Note: The error bars show the 95% confidence interval for the baseline means.

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 sediment data were collected in 2018, which was between Years 0 and 5 of the BCM predictions (approximately 2015-2017 and 2020 -2022). Note that not all early actions were conducted at the same time; for this comparison, Year 0 was assumed to represent a time when all of the early actions had been constructed, although some were constructed much earlier than others (e.g., Duwamish/Diagonal and Norfolk) and one is not yet complete (Jorgensen Forge). The baseline SWAC for total PCBs was

similar to the BCM-predicted SWAC for post-EAA conditions following construction (Year 0) and greater than the Year 5 prediction. 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 lower than the BCM-predicted SWAC for Year 0 post-EAA remediation and similar to the BCM-predicted value for Year 5.

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 qualitative discussions of the spatial distributions for each risk driver are provided below.

2.1.2.1 Total PCBs

Total PCB concentrations in the baseline composite samples were generally lower between RM 2.9 and RM 3.7 and upstream of Slip 6 (Map 2-2). Remediation of four EAA areas (Slip 4, Boeing Plant 2, T-117, and Jorgensen Forge) has reduced total PCB concentrations between RM 2.9 and RM 3.7 since collection of the RI/FS dataset.[16] The baseline composite samples downstream of RM 2.9 had PCB concentrations ranging from 113.1 J µg/kg in Comp 16 to 429 J µg/kg in Comp 1.

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, with the samples with the lowest cPAH TEQs (ranging from 16.2 J to 83.1 µg/kg) located upstream of RM 2.9 (Map 2-3). The cPAH TEQs downstream from RM 2.9 ranged from 86.0 to 742 µg/kg.

2.1.2.3 Dioxin/furan TEQ

The dioxin/furan TEQs were lowest upstream of RM 2.9, ranging from 0.462 J to 3.09 J ng/kg (Map 2-4). The dioxin/furan TEQs downstream of RM 2.9 ranged from 3.88 J to 27.7 J ng/kg. The highest dioxin/furan TEQ included samples from within Glacier Triangle, which had the highest dioxin/furan TEQs in the RI/FS dataset.

[16] The Norfolk EAA, which was remediated in 1999, is located at RM 4.9. The RI/FS dataset included post-remediation data at Norfolk.

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). Sediment samples collected during the RI/FS at RM 3.8 had some of the highest arsenic concentrations in LDW, prompting selection of this area for the RARE study (Kerns et al. 2017). The composite sediment arsenic concentrations throughout the rest of the site ranged from 5.90 to 15.9 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).[17] 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.
- **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. Seven of the 10 sample locations from the RI (Windward 2010a) that were re-occupied were within 3 m (10 ft) of the target locations. All 10 were within 10 m (32 ft) of the original location, as specified in the QAPP (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 with benthic cleanup levels and RI/FS data in MNR areas

Twenty grab samples were collected for analysis of RAO3 COCs within the MNR areas.[18] In addition, one sample (SS-171) was collected in an MNR area for the analysis of PCBs for the PCB porewater study (Map 2-6). Twelve baseline samples had no exceedances of RAO 3 cleanup levels (i.e., Washington State Sediment Management Standards [SMS] benthic sediment cleanup objective [SCO]), 3 had exceedances of the benthic cleanup level for total PCBs, and 6 had exceedances of the benthic cleanup level

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

[18] 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.

for benzyl alcohol (Table 2-4).[19] Benzyl alcohol exceedances of the benthic cleanup level were more common in sediment samples analyzed after the RI/FS than in the RI/FS dataset. The most likely cause of the increase in benzyl alcohol detections and concentrations since 2010 is changes in the analytical methods used for the analysis of semi-volatile organic compounds (SVOCs) (Fourie and Fox 2016). The changes in analytical methods include improvements in sample extraction methods, extract cleanup methods, and analytical technology, including chromatographic equipment and instrument conditions, such as injection port temperatures. This topic is discussed in greater detail in Attachment A of the draft final Pre-Design Investigation work plan (Windward and Anchor 2019).

Table 2-4. Exceedances of benthic cleanup levels at individual locations within the MNR areas

Baseline Sample Location	RM	RI Location	Year	Estimated Net Sedimentation (cm/year)[a]	RI/FS Benthic Cleanup Level Exceedances	Baseline Benthic Cleanup Level Exceedances
Re-occupied RI/FS stations						
SS-169[b]	0.3	DR005	1998	1–2	BEHP, BBP	none
SS-170	0.6	DR010	1998	1–2	BEHP	none
SS-171[c]	0.6	DUD040	1995	1–2	total PCBs	none
SS-174	0.7	WIT288	1997	> 0.5–1.0	total PCBs	none[d]
SS-178	1.6	DR092	1998	2–3	phenol	benzyl alcohol
SS-179[b]	2.1	DR111	1998, 2004	2–3	2,4-dimethyl phenol, benzyl alcohol	benzyl alcohol
SS-183	1.9	DR155	1998	2–3	BEHP	benzyl alcohol
SS-184[b]	3.0	WIT270	1997	≤ 0.5	total PCBs	none[d]
SS-186	3.9	DR258	1998	> 0.5–1.0	BBP	none
SS-187	3.7	R20	1997	≤ 0.5	total PCBs	none[d]
SS-188	5.0	DR276	1998	> 3	acenaphthene	none
Randomly selected locations in MNR areas[e]						
SS-8	0.1	na	na	> 1–2	na	none[b]
SS-23	0.5	na	na	> 1–2	na	none
SS-40	0.7	na	na	> 0.5–1.0	na	total PCBs[d]
SS-52[f]	0.9	na	na	> 1–2	na	total PCBs
SS-69	1.4	na	na	> 1–2	na	benzyl alcohol
SS-91	2.1	na	na	na	na	total PCBs
SS-101	2.4	na	na	> 3	na	benzyl alcohol
SS-130	3.5	na	na	> 3	na	benzyl alcohol
SS-143	4.1	na	na	> 3	na	none[d]
SS-161	4.7	na	na	> 3	na	none

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

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

[b] 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).

[c] Sample collected for PCB porewater investigation and was analyzed for PCBs only.

[d] The RL associated with the non-detected result for hexachlorobenzene was greater than the SCO.

[e] The randomly selected locations did not re-occupy RI/FS locations.

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

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
FS – feasibility study
na – not applicable
MNR – monitored natural recovery
PCB – polychlorinated biphenyl
QAPP – quality assurance project plan
RAO – remedial action objective
RI – remedial investigation
RL – reporting limit
RM – river mile
SCO – sediment cleanup objective

Baseline individual samples were collected at 11 RI/FS locations (Table 2-4). Baseline sampling to re-occupy these RI/FS locations with benthic SCO exceedances 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 11 re-occupied RI/FS locations in MNR areas are shown on Map 2-6.[20] The RI/FS and baseline total PCB concentrations for the re-occupied locations in MNR areas are provided in Table 2-5. Four locations had substantial (> 50%) decreases in total PCB concentrations (green rows of Table 2-5), and two locations had substantial (> 50%) increases (grey rows of Table 2-5). None of the baseline results for re-occupied RI/FS locations within MNR areas exceeded the benthic cleanup level for total PCBs (12 mg/kg OC), including the those for four locations that had previously had results exceeding the PCB cleanup level (Table 2-4). However, 3 of the 10 randomly located sampling locations in MNR areas did have results that exceeded the benthic cleanup level for PCBs.

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

Sample Location	RM	Re-occupied RI Location	Year	Estimated Net Sedimentation (cm/year)[a]	RI/FS Total PCB Concentration (µg/kg)	Baseline Total PCB Concentration (µg/kg)
SS-169[b]	0.3	DR005	1998	1–2	168	201.8
SS-170	0.6	DR010	1998	1–2	74	56.3 J
SS-171	0.6	DUD040	1995	1–2	620	162.9
SS-174	0.7	WIT288	1997	> 0.5–1.0	340	49.1 J
SS-178	1.6	DR092	1998	2–3	64	242.4
SS-179[b]	2.1	DR111	1998, 2004	2–3	311 (1998), 176 (2004)	122.6

[20] These 11 locations were re-occupied for the sediment DQO 3 evaluation in MNR areas and the PCB porewater investigation (sediment DQO 5).

Sample Location	RM	Re-occupied RI Location	Year	Estimated Net Sedimentation (cm/year)[a]	RI/FS Total PCB Concentration (µg/kg)	Baseline Total PCB Concentration (µg/kg)
SS-183	1.9	DR155	1998	2–3	18	197.3
SS-184[b]	3.0	WIT270	1997	≤ 0.5	100	102.4 J
SS-186	3.9	DR258	1998	> 0.5–1.0	62	56.5 JN
SS-187	3.7	R20	1997	≤ 0.5	170	65.3
SS-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.
Grey shaded rows indicate an increase of more than 50% in the baseline sample compared to RI/FS sample.

[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
MNR – monitored natural recovery
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. 2019). The *Recovery Category Recommendations Report* included a chemical trend evaluation based on the re-occupation of 111 RI/FS locations[21] (Windward 2010a; AECOM 2012). Concentration trends were evaluated for total PCBs, cPAH TEQ, arsenic, and bis(2-ethylhexyl)phthalate (BEHP). Since the FS, 38 locations with PCB concentrations above the RAL in the RI/FS samples have been re-occupied. The concentrations decreased at 32 of these 38 locations. In the Integral analysis, there were no RI/FS locations with BEHP RAL exceedances and fewer locations with RAL cPAH TEQ exceedances (four locations) and arsenic exceedances (two locations); the concentration of the COCs decreased at all of these locations (Integral et al. 2019). This result was expected following years of source control, cleanup, and natural recovery.

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 between the two methods for quantifying the total PCB concentrations.

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

[21] The data include 97 post-FS samples and 12 baseline samples.

Figure 2-2. The congener and Aroclor-based total PCB sums were consistent with one another throughout the concentration range of the samples,[22] although the total PCB concentration calculated as the sum of the Aroclors consistently over-estimated the concentration calculated as the sum of the congeners (Figure 2-3). 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 be higher than the sum of the PCB congeners. In the South Park Marina dataset, the sum of the Aroclors tended to be lower than the sum of the congeners.

[22] 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].

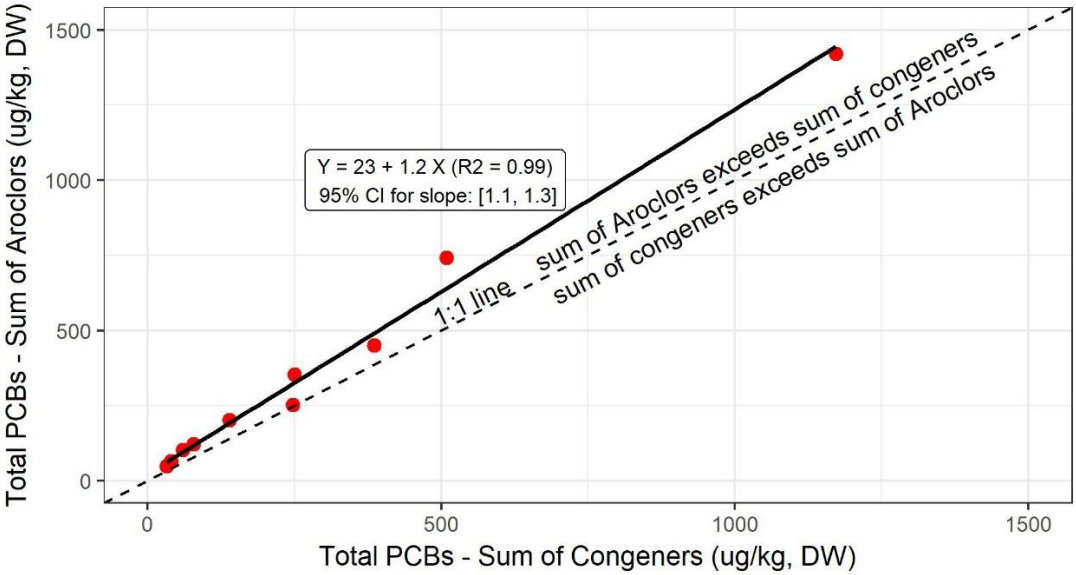


Figure 2-2. Comparison of total PCB concentrations as a sum of Aroclors vs. a sum of congeners for Pre-Design Studies samples (n=10)

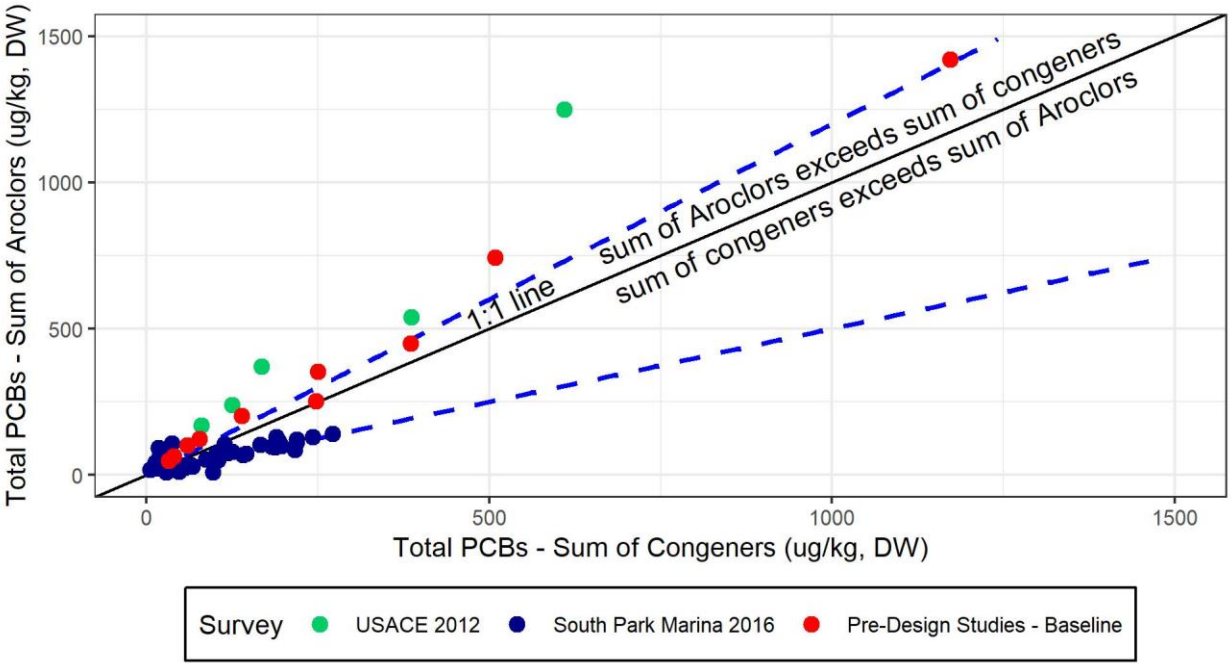


Figure 2-3. Comparison of total PCB concentrations based on Aroclor and congener sums for data from various studies

The South Park Marina dataset represents an intensive sampling effort in a small area within the LDW (Map 2-7). The apparently different trend exhibited by the South Park Marina dataset may be attributable to different laboratories and the fact that the South

Park Marina study reported only detected concentrations of Aroclors 1248 and 1260,[23] whereas the USACE and Pre-Design Studies reported detected concentrations of Aroclors 1248, 1254, and 1260. The USACE and Pre-Design Studies data suggest that the results for the two methods are correlated.

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. Different composite sampling approaches were used to evaluate baseline conditions in the LDW-wide potential clamming areas and in each of the eight beach play areas. The characterization of baseline conditions in the clamming and beach play areas used composite sampling in order to obtain robust estimates of the area-specific concentrations.

The three LDW-wide potential clamming area composite samples included samples collected from throughout the intertidal clamming areas to compare to the LDW-wide cleanup level. Three composites from each of the eight beach play areas were created to compare concentrations in each area to beach play area cleanup levels. The sampling approaches for potential clamming areas and beach play areas are described further in Sections 2.3.1.1 and 2.3.2.1, respectively.

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

[23] Detected concentrations of PCB congeners 105, 110, and 118 in the South Park Marina samples, which are typically associated with Aroclor 1254, suggest that Aroclor 1254 should have been reported as detected for these samples. It is likely that including Aroclor 1254 would have resulted in Aroclor sums that were more similar to the congener sums. In addition, there is uncertainty associated with Aroclor results in lower concentration ranges because of the lower sensitivity of the Aroclor method compared to the PCB congener method.

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 0–45-cm grab samples each (for a total of 204 individual grab samples) were created to characterize the site-wide intertidal clamming area sediments. Grab sampling locations were distributed throughout the 16 RI potential clamming areas (Map 2-8), some of which are in areas addressed by EAA cleanups. Transects were established in each sampling area and divided into evenly spaced intervals; sampling locations were placed randomly on alternating sides of the transect, using a random number generator to determine the distance from the transect to the sampling location (Windward 2018d). The samples were systematically assigned to 1 of the 3 composites, so that each composite had an equal number of grab samples from each of the 16 potential clamming areas. The results for each composite sample represent independent estimates of the site-wide mean concentration. There was no sampling variance goal set for the clamming area composite samples, because sufficient previous data were not available to develop *a priori* variance estimates to use in development of the study design.

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).

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 (Table 2-6) were above the cleanup levels in the ROD (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). RME and CV information is also presented in Table 2-6. The variance information obtained in the Pre-Design Studies will be useful in designing future monitoring efforts (see Sections 2.3.1.3 and 9.1).

Table 2-6. LDW-wide 0–45-cm clamming area sediment composite sample results

Sample ID, Summary Statistics, Cleanup Level	Total PCBs (µg/kg)	cPAH TEQ (µg/kg)	Dioxin/Furan TEQ (ng/kg)	Arsenic (mg/kg)	Toxaphene (µg/kg)	TOC (%)
Composite sample concentrations:						
LDW18-IT45-CL-Comp1	239	388 J	15.3 J	11.8 J	25.0 U	1.60
LDW18-IT45-CL-Comp2	1,350 JN	693	69.1 J	11.8 J	24.4 U	1.93
LDW18-IT45-CL-Comp3	261 J	61.4	16.3 J	8.35 J	24.9 U	1.41
Summary statistics:						
Mean	617	381	33.6	10.7	24.7 U	1.65
CV	103%	83%	92%	19%	nc	16%

Sample ID, Summary Statistics, Cleanup Level	Total PCBs (µg/kg)	cPAH TEQ (µg/kg)	Dioxin/Furan TEQ (ng/kg)	Arsenic (mg/kg)	Toxaphene (µg/kg)	TOC (%)
Acceptable analytical precision[a]	±35%	±35%	±20%	±20%	±35%	±20%
95UCL[b]	1,690	913	85.5	14.0	nc[c]	na
RME	174%	139%	154%	31%	nc[c]	na
ROD cleanup level for human direct contact in intertidal clamming areas (and basis)	500 (RBTC)	150[d] (RBTC)	13 (RBTC)	7 (natural background)	na	na

Shading indicates which ROD cleanup levels are exceeded by the baseline 95UCLs.

[a] Acceptable analytical precision is as established in Table 4-18 of the sediment QAPP (Windward 2018d).

[b] 95UCL was calculated using the t-interval (degrees of freedom = 2) for the three primary clamming area composites (homogenization replicates were not included). See Appendix B, Section B2.2.1.1, for details. Including homogenization replicates in the 95UCL calculation does not change the values significantly (95UCL of 1,690 µg/kg for total PCBs and 878 ng/kg for cPAH TEQ). See Appendix B for details.

[c] Toxaphene was not detected in any of the clamming area composite samples. Therefore, the 95UCL was not calculated.

[d] EPA revised the benzo(a)pyrene slope factor in January 2017. Using the updated slope factor, the risk associated with cPAHs due to direct contact for clamming is less than the risk threshold of 1×10^{-6}, meaning that an RBTC and a cleanup level would not be needed for cPAHs and clamming.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CV – coefficient of variation
EPA – US Environmental Protection Agency
ID – identification
J – estimated concentration
JN - tentative identification and estimated concentration
LDW – Lower Duwamish Waterway
na – not available
nc – not calculated
PCB – polychlorinated biphenyl
QAPP – quality assurance project plan
RME – relative margin of error
ROD – record of decision
RBTC – risk-based threshold concentration
TEQ – toxic equivalent
TOC – total organic carbon
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 (500 µg/kg). Two of the three area-wide composite samples had total PCB concentrations below the RAO 2 cleanup level (239 and 261 µg/kg).[24] The third composite had a total PCB concentration of 1,350 µg/kg. The variance among these concentrations resulted in a 95UCL 2.7 times higher than the mean of 617 µg/kg. The higher variance likely reflected the influence of samples from areas with elevated PCB concentrations that contributed to the second composite.

cPAH TEQs

The 95UCL for the cPAH TEQ in clamming area sediments was 913 µg/kg. This value is above the ROD RAO 2 cleanup level for cPAHs of 150 µg/kg, which is the risk-based threshold concentration (RBTC) developed in the RI/FS and presented in the ROD. However, using the HHRA exposure assumptions and the updated 2017

[24] 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.

benzo(a)pyrene slope factor (EPA 2017), excess cancer risks for cPAHs for tribal clamming would be less than 1×10^{-6}, and cPAHs would no longer be a COC for this pathway (Appendix G). EPA is considering how this change may affect the ROD.

The three composite samples had cPAH TEQs of 61.4, 388, and 693 µg/kg. The variance among cPAH TEQs resulted in a 95UCL 2.4 times higher than the mean of 381 µg/kg.

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 variability among these dioxin/furan TEQs resulted in a 95UCL 2.5 times higher than the mean of 33.6 ng/kg.

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 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.[25]

2.3.1.3 Evaluation of variance in clamming area sediment composites

Variability in the clamming area sediment composites is a result of both small-scale variance resulting from heterogeneity within samples, and large-scale variance resulting from heterogeneity throughout the site-wide potential clamming areas. The small-scale variance was calculated based on homogenization triplicate results. The large-scale variance was calculated using the three site-wide composites (Table 2-6). The site-wide composites included samples from areas where past RAL exceedances suggest that remediation will be required.[26] After remediation, the large-scale variability is expected to be lower.

For total PCBs, cPAHs, and dioxin/furans, large-scale variability was high relative to the mean, with CVs close to 100% (103, 83, and 92%, respectively; Table 2-6), indicating high spatial heterogeneity in the current distribution of concentrations of these contaminants throughout the LDW. For arsenic and TOC, the large-scale CVs were low

[25] This RL is less than the human health values of 1,600 µg/kg (industrial risk-based concentration) and 6,300 µg/kg (screening value) referenced in the human health risk assessment (HHRA) (Windward 2007). Toxaphene was detected in 1% of RI/FS samples.

[26] Figure 18 of the ROD, which is based on RI/FS data, indicates that active remediation may be required in most of the 16 clamming subareas, including Trotsky Inlet. The final active remedial action areas will be determined as part of design, following the delineation of RAL exceedances (Anchor and Windward 2019; Windward and Anchor 2019).

(19 and 16%, respectively; Table 2-6), indicating relatively homogeneous concentrations throughout the sampled area.

Table 2-7. Results for homogenization replicates for clamming area composite 1

Sample	Total PCBs (µg/kg)	cPAH TEQ (µg/kg)	TOC (%)
LDW18-IT45-CL-Comp1	239	388 J	1.60
LDW18-IT45-CL-Comp4	195	102	1.17 J
LDW18-IT45-CL-Comp5	276	83.9	1.21 J
Summary statistics:			
Mean	237	191	1.33
SD	636	171	0.238
CV	17%	89%	18%
Acceptable analytical precision[a]	35%	35%	20%

[a] Acceptable analytical precision is as established in Table 4-18 of the sediment QAPP (Windward 2018d).

cPAH – carcinogenic polycyclic aromatic hydrocarbon
CV – coefficient of variation (SD/mean)
PCB – polychlorinated biphenyl
QAPP – quality assurance project plan
SD – standard deviation
TEQ – toxic equivalent
TOC – total organic carbon

The small-scale variance reflects the heterogeneity within a homogenized sample. A low CV for the small-scale variance suggests that the homogenization techniques were effective, whereas a high CV indicates more heterogeneity within the homogenized sample.

In accordance with the QAPP (Windward 2018d), in order to assess the variability of the homogenized composite samples, three samples were created by subsampling the trays three times to allow for a triplicate analysis of cPAHs for composite 1.[27] For cPAHs, the small-scale variability was higher than analytical precision (CV of 89%) (Table 2-7). The greater variability among homogenization triplicates observed for cPAHs likely reflects 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 variance associated with total PCBs and TOC for the composite 1 triplicates was low (i.e., within the acceptable analytical precision for these methods) (Table 2-7).

Despite the variability, the potential clamming area sediment composite data met DQOs 7 and 8. The data enabled the calculation of the site-wide 95UCL (DQO 7) and the site-wide mean (DQO 8). The small- and large-scale variability observed in these samples provides information that will be useful for designing future sampling of these intertidal sediments in the long-term monitoring plan.

[27] The second and third samples collected from the composite 1 homogenate are referred to as Comp4 and Comp5 in Table 2-7.

2.3.2 Intertidal beach play areas

2.3.2.1 DQOs and data collected

Per the sediment QAPP (Windward 2018d), eight intertidal beach play areas were sampled using a compositing approach to generate three composite samples for analysis per beach. 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). Actual sampling locations were determined using a transect approach, with a random number generator to place locations at randomly selected distances on either side of the transect (Windward 2018d). 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). Sample density ranged from 2.4 to 9.0 samples per acre in the beach areas. Concentrations in each composite sample represented the mean concentration at each beach; thus, the three composites were independent estimates of each beach play area-specific mean, capturing large-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. 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[29] as a direct contact COPC (EPA 2014).

[28] Toxaphene was also analyzed in the samples.

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

2.3.2.2 Beach play area sample interpretation

Summary statistics for the four human health risk drivers,[30] including a comparison of 95UCLs with RAO 2 beach play cleanup levels, are presented for the eight individual beaches in Table 2-8. The beach-specific mean concentrations will be relevant in trends assessment with future monitoring data if cleanup levels are not met after active remediation of RAL exceedances.

Table 2-8. Summary of beach play area 0–45-cm sediment data

Beach	Samples per Composite	Composite Concentrations			Summary Statistics			
		Comp1	Comp2	Comp3	Mean[a]	CV	95UCL[b]	RME
Total PCBs (µg/kg)								
Beach 1	3	265	78.7 J	17.0	120	108%	445	271%
Beach 2	3	120.3 J	118.1	66.2	102	30%	179	75%
Beach 3	5	69.7 J	238.6	23.0 JN	110	103%	396	260%
Beach 4	5	322 J	556 JN	199.5	359	50%	815	127%
Beach 5	9	92.4 JN	160.2 J	90.4 JN	114	35%	214	88%
Beach 6	3	184	990 J	510	561	72%	1,580	182%
Beach 7	6	36.9	50.5	108.2	65.2	58%	160	145%
Beach 8	9	92.1 J	204.2	71.9	123	58%	302	146%
Beach play area cleanup level based on RBTC							**1,700**	
cPAH TEQ (µg/kg) [c]								
Beach 1	3	362	111	35.3	169	101%	600	255%
Beach 2	3	272	445	111	276	61%	696	152%
Beach 3	5	197 J	83.7	20.7	100	89%	325	225%
Beach 4	5	57.1	55.8	23.5	45	42%	93.4	108%
Beach 5	9	357	41.9	3,050	1,150	144%	5,310	362%
Beach 6	3	1,240	1,480	1,310	1,343	9%	1,650	23%
Beach 7	6	38.3	38.5	52.4	43	19%	63.4	47%
Beach 8	9	58.9	106	158	108	46%	232	115%
Beach play area cleanup level based on RBTC							**90[c]**	
Dioxin/Furan TEQ (ng/kg)								
Beach 1	3	1.39 J	1.96 J	1.47 J	1.61	19%	2.38	48%
Beach 2	3	27.0 J	11.7 J	8.34 J	15.7	63%	40.7	159%
Beach 3	5	4.62 J	8.19 J	0.306 J	4.37	90%	14.3	227%
Beach 4	5	12.0 J	73.4 J	4.68 J	30	126%	125	317%
Beach 5	9	4.40 J	6.41 J	5.07 J	5.29	19%	7.87	49%
Beach 6	3	8.86 J	21.7 J	9.16 J	13.2	56%	31.7	140%

[30] Toxaphene was also analyzed in the beach play area composites. Toxaphene was not detected in any of the beach play area samples with RLs ranging from 24.1 to 25.0 µg/kg (Windward 2019c) and is not included in Table 2-8.

Beach	Samples per Composite	Composite Concentrations			Summary Statistics			
		Comp1	Comp2	Comp3	Mean[a]	CV	95UCL[b]	RME
Beach 7	6	1.87 J	2.24 J	2.27 J	2.13	10%	2.69	26%
Beach 8	9	2.92 J	4.08 J	5.15 J	4.05	28%	6.86	69%
Beach play area cleanup level based on RBTC							**28**	
Arsenic (mg/kg)								
Beach 1	3	4.93 J	16.0 J	23.2 J	14.7	63%	37.9	158%
Beach 2	3	55.3 J	32.8 J	46.1 J	44.7	25%	73.2	64%
Beach 3	5	4.60	2.96	4.48	4.01	23%	6.31	57%
Beach 4	5	8.51 J	6.14 J	4.08 J	6.24	36%	11.8	89%
Beach 5	9	5.52 J	12.4 J	8.31 J	8.74	40%	17.5	100%
Beach 6	3	68.1	28.8	37.0	44.6	46%	96.8	117%
Beach 7	6	4.95	4.78	6.60	5.44	18%	7.97	47%
Beach 8	9	6.93	10.1	6.12	7.72	27%	13.0	68%
Beach play area cleanup level based on natural background							**7**	

Note: Grey shading indicates that baseline 95UCLs are greater than the beach play area cleanup levels in ROD Table 19.

[a] The mean is the arithmetic average of the three composite samples for each beach.

[b] 95UCLs were calculated using Chebyshev's Inequality (n = 3 all areas). Field replicates from Beaches 1 and 6 were not included in this calculation (see Section 2.3.2.3 for evaluation of field replicate sampling results).

[c] The RBTC based on the updated benzo(a)pyrene slope factor (EPA 2017) is 650 µg/kg (Appendix G).

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CV – coefficient of variation
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
ROD – Record of Decision
RME – relative margin of error
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 less than the cleanup level (90 µg/kg); however, five[31] 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 (Appendix G). Five of the beaches had dioxin/furan TEQ 95UCLs that 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.[32] 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 could 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

[31] The 95UCL for Beach 1 was 600 µg/kg. When the 95UCL was calculated including the field replicate results, the 95UCL was 1,504 µg/kg, a value greater than the updated cPAH RBTC. The variability of field replicate results is presented in Table 2-10, and the effects of field replicates on the 95UCLs are presented in Appendix Table B2-6.

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

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 sample size was insufficient($n \leq 2$). Therefore, the FS beach composite results and the baseline beach composite results were compared based on the means.

Beach 1 is located between RM 0.1W and RM 0.25W. The mean for the two FS composite samples was compared with the mean for the three baseline beach composite samples (Table 2-9). As shown in Table 2-9, the FS and baseline mean values were similar for arsenic and dioxin/furan TEQ, whereas the FS mean value was higher for cPAH TEQ and the baseline mean value was higher for total PCBs.

Table 2-9. Comparison of FS and baseline composite samples for Beaches 1 and 6

Area	Dataset	Description of Composite Samples	Average of Composite Samples			
			Total PCBs (µg/kg dw)	cPAH TEQ (µg/kg dw)	Dioxin/Furan TEQ (ng/kg dw)	Arsenic (mg/kg dw)
Beach 1 (RM 0.1W to RM 0.25W)	FS	2 composite samples (each composed of 8 discrete grabs)	56	380	2.42	16
	baseline[a]	3 composite samples (each composed of 3 discrete grabs)	120	169	1.61	14.7
Beach 6 (RM 2.75W)	FS	1 composite sample (composed of 8 discrete grabs)	860	7,100	8.99	94
	baseline[a]	3 composite samples (each composed of 3 discrete grabs)	561	1,343	13.2	44.6

[a] Mean of the three primary composites (excluding the field replicates).

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
FS – feasibility study
PCB – polychlorinated biphenyl
RM – river mile
TEQ – toxic equivalent

Beach 6 is located north of Slip 4 at RM 2.75W. The one FS composite sample that was collected for this beach was compared with the three baseline composite samples. For Beach 6, concentrations in the FS composite were greater than the averages of the baseline composite samples for arsenic, cPAH TEQ, and total PCBs (Table 2-9). The FS composite sample dioxin/furan TEQ was less than the mean dioxin/furan TEQ for the three baseline beach composite samples.

2.3.2.3 Evaluation of variance in beach play composites

At two of the beach areas (Beach 1 and Beach 6), field replicate 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 replicate composite created using samples from the same hole as the primary sample. The CV observed between the primary samples and the field replicates contributes to overall sampling variance. The CV values between primary samples and field replicates are provided in Table 2-10.

Table 2-10. CV of field replicates for beach play area composites

Sample	n	CV			
		Total PCBs	cPAH TEQ	Dioxin/Furan TEQ	Arsenic
Beach 1					
LDW18-IT45-B1-Comp1	2	20%	83%	61%	76%
LDW18-IT45-B1-Comp2	2	18%	19%	19%	24%
LDW18-IT45-B1-Comp3	2	25%	16%	7%	64%
Beach 6					
LDW18-IT45-B6-Comp1	2	14%	107%	30%	19%
LDW18-IT45-B6-Comp2	2	7%	54%	25%	19%
LDW18-IT45-B6-Comp3	2	1%	47%	76%	49%
Acceptable analytical precision[a]		±35%	±35%	±20%	±20%

[a] Acceptable analytical precision as established in Table 4-18 of the sediment QAPP (Windward 2018d). The CVs reported in this table include spatial and homogenization variance in addition to analytical variance.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
CV – coefficient of variation (standard deviation/mean)
n – number of field replicates summarized
PCB – polychlorinated biphenyl
QAPP – quality assurance project plan
TEQ – toxic equivalent

The observed variability among field replicates included spatial variance within the sampling locations, homogenization variance, and analytical variance.[33] The variability among field replicates for total PCBs was within the analytical precision required for this analysis. The variability for cPAH TEQ, dioxin/furan TEQ and arsenic was greater with CV values greater than the acceptable analytical precision (Table 2-10).

The highest CVs were observed for cPAH TEQ. The spatial variance among locations is expected to be reduced following construction of the remedy at beaches where cPAH TEQs are currently above the RAL. The homogenization variance is likely associated with small-scale variance in cPAH matrices, which is unlikely to be reduced outside areas of active remediation. An evaluation of the extent to which beach-wide variance may be expected to be reduced for the four COCs when concentrations above RALs have been remediated is presented in Section B2.2.2.2 of Appendix B.

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).

[33] An exploratory variance components analysis (VCA) conducted on the data summarized in Table 2-10 further elaborated the contribution of small-scale spatial variance relative to the total variance within a beach for each of the four COCs (see Appendix B, Section B2.2.2.2). Results suggested that small-scale spatial variability accounted for 6% or less at the two beaches for total PCBs; and accounted for more than 50% of the total variance for cPAHs and dioxins/furans at both Beach 1 and 6, and for arsenic at Beach 1 (see Table B2-8). These results should be considered exploratory because of limited data (i.e., two field replicates in each of three field composites).

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 2-11.

Table 2-11. 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 was below cleanup level for RAO 2 for netfishing and above cleanup levels for RAOs 1 and 4. • The SWAC was half of the RI/FS SWAC. • SWAC was consistent with SWAC predicted using the BCM to characterize post-EAA concentrations.
		cPAH TEQ	• 95UCL was below ROD cleanup level for RAO 2 for netfishing.[a] • SWAC was lower than SWAC predicted using the BCM to characterize post-EAA concentrations.
		dioxin/furan TEQ	• 95UCL was below the cleanup level for RAO 2 for netfishing and above the cleanup level for RAO 1. • SWAC was lower than the RI/FS SWAC and the SWAC predicted using the BCM to characterize post-EAA concentrations.
		arsenic	• 95UCL was above the cleanup level for RAO 2 for netfishing. • SWAC was 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 had exceedances in the RI/FS samples.
		PCB Aroclors and congeners	• Total PCBs calculated as the sum of Aroclors were consistent with or higher than total PCB concentrations calculated based on PCB congener analyses of 10 samples that were analyzed using both methods.
Potential clamming areas (0–45 cm)	LDW-wide clamming area	total PCBs	• 95UCL was above the cleanup level for RAO 2 for clamming. • High variance occurred among composite samples; homogenization variance was low.
		cPAH TEQ	• 95UCL was above the ROD cleanup level for RAO 2 for clamming but below the RBTC based on the updated benzo(a)pyrene slope factor (EPA 2017). • High variance occurred among composite samples; homogenization variance was high.
		dioxin/ furan TEQ	• 95UCL was above the cleanup level for RAO 2 for clamming. • High variance occurred among the composite samples; homogenization variance could not be estimated because homogenization triplicates were not analyzed for dioxins/furans.

Sample Type	Spatial Area Evaluated	Chemical	Summary of Key Conclusions
		arsenic	• 95UCL was above the cleanup level for RAO 2 for clamming. • Variance among the composite samples was low; homogenization variance could not be estimated because homogenization triplicates were not analyzed for arsenic.
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)

[a] cPAHs are not a COC for netfishing based on the updated benzo(a)pyrene slope factor (EPA 2017).

95UCL – 95% upper confidence limit (on the mean)
BCM – bedload composition model
COC – contaminant of concern
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
RBTC – risk-based threshold concentration
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

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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[34] 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 (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). A total of 40 surface water samples (32 LDW and 8 upstream samples) were collected. 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

[34] 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 (which included one dry baseflow event and two storm 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 2019a). 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. Baseline surface water composite-grab samples from the LDW are compared with ARARs on a sample-by-sample basis to estimate the frequency of exceedances. Data from the upstream location are presented for reference as a boundary condition.

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})[35] of total PCBs during the targeted dry season baseflow conditions. The two passive sampler deployments were conducted, one in August/September 2017 and one in July/August 2018.

The freely dissolved fraction of total PCBs (i.e., the portion of the total concentration that is associated with neither particulates nor dissolved organic carbon in the water column) is different than the results obtained using the composite-grabs (i.e., the total water concentration including both the dissolved and particulate-associated fractions). Furthermore, the passive sampler concentrations represent time-averaged concentrations that span the duration of the deployment time (approximately one month); the composite-grab samples represent a four-hour composite from one sampling day. Thus, the freely dissolved total PCB concentrations based on the passive samplers should not be compared directly with surface water quality ARARs or the composite-grab concentrations.

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

[35] 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.

the performance reference compounds (PRCs) for this sample (Windward 2019a). 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. This was an isolated analytical issue and has no implications for future passive sampling.

Data from Apell and Gschwend (2017) were used in developing the baseline study design 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 baseline datasets (i.e., 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 baseline study design. Further comparison between the datasets is highly uncertain because of differences in the study designs and analytical approaches.[36]

Table 3-2. Evaluation of passive sampler data

Summary Statistic	Apell and Gschwend (2017) Dataset[a]	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 analyzed	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), sum of all 209 congeners	na	1.26 (1.25 at PS1 and 1.26 at PS2)	0.993 (1.03 at PS1 and 0.957 at PS2)
Mean of the sum of 27 PCB congeners C_{free} ($\bar{x}$) (ng/L)[c]	0.32	0.688 (0.682 at PS1 and 0.695 at PS2)	0.527 (0.551 at PS1 and 0.507 at PS2)
SD for total PCB C_{free} (ng/L)	na	0.115[d] (0.101 at PS1 and 0.128 at PS2)	0.101[d] (0.115 at PS1 and 0.0864 at PS2)
Total PCB CV = SD / $\bar{x}$	na	9.16%[e]	10.1%[e]

[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.

[36] The total PCB sums are not comparable because they include different numbers of congeners. Comparison of individual PCB congeners is uncertain because Apell and Gschwend did not report congener co-elutions.

[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 2019a).

[c] The 27 PCB congeners included in this sum are PCBs 8, 11, 18, 28, 44, 52, 66, 70, 77, 95, 101, 105, 110, 118, 126, 128, 138, 149, 153, 170, 179, 180, 187, 195, 199, 202, and 206. For the Pre-Design Studies dataset, the 27 congeners co-eluted with an additional 7 congeners (PCBs 30, 47, 65, 115, 166, 168, and 193). For the Apell and Gschwend (2017) dataset, co-elutions were not identified.

[d] The combined SD values reported for the Pre-Design Studies baseline samples for each year are the estimated SDs of the residuals around the station means within each sampling year.

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

CV – coefficient of variation
na – not applicable
PCB – polychlorinated biphenyl
PRC – performance reference compound
RM – river mile
SD – standard deviation

The number of replicate passive samplers to be analyzed was based on the assumption of a CV of 25%, derived from Apell and Gschwend (2017), using single replicates 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.[37] The results for the Pre-Design Studies baseline data were assessed relative to this assumption. The baseline passive sampler dataset (n = 35) was 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. 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 on a sample-by-sample basis with ARARs to evaluate progress toward meeting ARARs as sediment remediation and source control work progress. As described in the ROD (EPA 2014), surface water quality ARARs are the most stringent among the applicable promulgated state water

[37] 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%.

quality standards, the National Toxics Rule, and federal recommended ambient water quality criteria (AWQC). 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.[38] 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 32 LDW surface water samples and all 8 upstream samples, with total PCBs at concentrations being above the lowest ARAR (i.e., the human health criterion for the consumption of organisms of 0.007 ng/L). PCBs were detected at concentrations below the ARAR for aquatic life marine acute and chronic water quality criteria (WQC) (10,000 ng/L and 30 ng/L, respectively) in all 40 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 criterion for consumption of organisms. Based on the updated toxicity values published by EPA in 2017 (Appendix G), the WQC for these cPAHs may be updated.
- **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 lowest ARAR (i.e., the human health criterion of 0.14 µg/L for the consumption of organisms); all 32 LDW samples and all 8 upstream samples had inorganic arsenic concentrations greater than the ARAR for the human health criterion 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 not detected.
- **SVOCs –** BEHP was detected in 2 of 32 LDW samples and 1 of 8 upstream samples;[39] all detected concentrations were above the lowest ARARs (i.e., the human health criterion of 0.046 µg/L for the consumption of organisms). The other four phthalate compounds were not detected in any of the samples. No other SVOCs were detected.
- **Organochlorine pesticides –** No pesticides were detected.

[38] Concentrations of most chemicals (with the exception of some metals, as indicated in Table 3-3) are for whole water samples (i.e., unfiltered), meaning that some portion of the concentration presented is associated with particulates in the water column.

[39] The BEHP MDL is ~ 10X the Washington State ARAR.

- **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	LDW Summary Statistics					Upstream Summary Statistics					National Recommended Criteria			Washington State Criteria			Lowest ARAR
		Detection Frequency		Mean Value	Range of Detected Concentrations	RL or Range of RLs	Detection Frequency		Mean Value	Range of Detected Concentrations	RL or Range of RLs	AWQC - Marine		Human Health	Marine[b]		Human Health[b]	
		Ratio	%				Ratio	%				CMC (Acute)	CCC (Chronic)	Consumption of Organism Only	Acute	Chronic	Consumption of Organism Only	
Metals (µg/L)[a]																		
Antimony	T	6/20	30	0.335	0.175–0.273 J	0.306–1.02	5/5	100	0.11	0.032–0.189	na	–	–	640	–	–	90	90
Arsenic	D	20/20	100	1.32	0.602 J–2.06	na	5/5	100	0.641	0.453–0.904	na	69[c]	36[c]		69[c]	36[c]		36[c]
Arsenic (inorganic)	T	32/32	100	1.15	0.498–1.67	na	8/8	100	0.659	0.451–0.993	na	–	–	0.14	–	–	0.14	0.14
Cadmium	D	3/20	15	0.23	0.023 J–0.123 J	0.102–1.02	0/5	0	0.010	nd	0.003–0.041	33[c]	7.9[c]	–	42[c]	9.3[c]	–	7.9[c]
Chromium	D	2/20	10	0.925	0.651 J–0.668 J	1.91	3/5	60	0.126	0.120–0.190	0.138–0.160	1,100[c]	50[c]	–	1,100[c]	50[c]	–	50[c]
Copper	D	29/32	91	0.955	0.573 J–2.32	1.68	8/8	100	0.555	0.279–1.20	na	4.8[c]	3.1[c]	–	4.8[c]	3.1[c]	–	3.1[c]
Lead	D	0/20	0	0.192	nd	0.383	5/5	100	0.0786	0.0450–0.121	na	210[c]	8.1[c]	–	210.0[c]	8.1[c]	–	8.1[c]
Nickel	D	14/20	70	0.876	0.404 J–1.42 J	1.76	5/5	100	0.248	0.165–0.329	na	74[c]	8.2[c]	4,600	74.0[c]	8.2[c]	100	8.2[c]
Selenium	D	0/20	0	0.715	nd	1.43	4/5	80	0.034	0.023 J–0.047 J	0.028	290[c]	71[c]	4,200	290[c]	71.0[c]	200	71[c]
Silver	D	0/20	0	0.268	nd	0.536	0/5	0	0.011	nd	0.021	1.9[c]	–	–	1.9[c]	–	–	1.9[c]
Thallium	T	0/20	0	0.418	nd	0.102–1.02	0/5	0	0.017	nd	0.004–0.041	–	–	0.47	–	–	6.3	0.47
Zinc	D	15/20	75	4.04	1.71 J–6.73 J	3.36–10.2	4/5	80	3.31	1.66–6.50	4.12	90[b]	81[b]	26,000	90[c]	81[c]	1,000	81[c]
Mercury (ng/L)																		
Mercury	T	15/20	75	1.4	0.76–4.17	0.85–1.26	3/5	60	1.4	0.81–2.62	1.22–1.35	1800	940		1800	25	–	25
Organometals (µg/L)																		
TBT	T	0/12	0	0.0026	nd	0.0052	0/3	0	0.0026	nd	0.0052	0.42	0.0074	–	–	–	–	0.0074
PAHs (µg/L)																		
Acenaphthene	T	22/32	69	0.0051	0.0030 J–0.0090 J	0.010	2/8	25	0.0046	0.0030 J–0.0040 J	0.010	–	–	90	–	–	30	30
Anthracene	T	8/32	25	0.0040	0.0010 J–0.0050 J	0.0010–0.010	0/8	0	0.0050	nd	0.010	–	–	400	–	–	100	100
Benzo(a)anthracene	T	4/32	13	0.0048	0.00080 J–0.012	0.010	0/8	0	0.0050	nd	0.010	–	–	0.0013	–	–	0.00016	0.00016
Benzo(a)pyrene	T	1/32	3	0.0051	0.0070 J	0.010	0/8	0	0.0050	nd	0.010	–	–	0.00013	–	–	0.000016	0.000016
Benzo(b)fluoranthene	T	4/32	13	0.0048	0.00060 J–0.011	0.010	0/8	0	0.0050	nd	0.010	–	–	0.0013	–	–	0.00016	0.00016
Benzo(k)fluoranthene	T	1/32	3	0.0050	0.0050 J	0.010	0/8	0	0.0050	nd	0.010	–	–	0.013	–	–	0.0016	0.0016
Chrysene	T	8/32	25	0.0042	0.0010 J–0.0070 J	0.010	0/8	0	0.0050	nd	0.010	–	–	0.13	–	–	0.016	0.016
Dibenzo(a,h)anthracene	T	1/32	3	0.0049	0.0020 J	0.010	0/8	0	0.0050	nd	0.010	–	–	0.00013	–	–	0.000016	0.000016
Fluoranthene	T	24/32	75	0.0045	0.0020 J–0.010 J	0.0030–0.010	3/8	38	0.0039	0.0020 J	0.010	–	–	20	–	–	6	6
Fluorene	T	18/32	56	0.0034	0.0020 J–0.0060 J	0.0020–0.010	2/8	25	0.0044	0.0020 J–0.0030 J	0.010	–	–	70	–	–	10	10
Indeno(1,2,3-cd)pyrene	T	2/32	6	0.0048	0.0020 J	0.010	0/8	0	0.0050	nd	0.010	–	–	0.0013	–	–	0.00016	0.00016
Pyrene	T	15/32	47	0.0029	0.0010 J–0.010 J	0.0010–0.010	3/8	38	0.0033	0.0010 J–0.0020 J	0.0020–0.010	–	–	30	–	–	8	8
Phthalates (µg/L)																		
BEHP	T	2/32	6	1.5	1.0 J–2.0 J	3.0	1/8	13	1.4	0.5 J	3.0	–	–	0.37	–	–	0.046	0.046
BBP	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	0.1	–	–	0.013	0.013
Diethyl phthalate	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	600	–	–	200	200
Dimethyl phthalate	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	2,000	–	–	600	600
Di-n-butyl phthalate	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	30	–	–	8	8
Other SVOCs (µg/L)[d]																		
1,2,4,5-Tetrachloro-benzene	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	0.03	–	–	–	0.03
2,2'-oxybis(1-chloro)propane	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	4,000	–	–	900	900

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

Chemical	Fraction	LDW Summary Statistics					Upstream Summary Statistics					National Recommended Criteria			Washington State Criteria			Lowest ARAR
		Detection Frequency		Mean Value	Range of Detected Concentrations	RL or Range of RLs	Detection Frequency		Mean Value	Range of Detected Concentrations	RL or Range of RLs	AWQC - Marine		Human Health	Marine[b]		Human Health[b]	
		Ratio	%				Ratio	%				CMC (Acute)	CCC (Chronic)	Consumption of Organism Only	Acute	Chronic	Consumption of Organism Only	
2,4,5-Trichlorophenol	T	0/12	0	2.5	nd	5.0	0/3	0	2.5	nd	5.0	–	–	600	–	–	–	600
2,4,6-Trichlorophenol	T	0/12	0	1.5	nd	3.0	0/3	0	1.5	nd	3.0	–	–	2.8	–	–	0.28	0.28
2,4-Dichlorophenol	T	0/12	0	1.5	nd	3.0	0/3	0	1.5	nd	3.0	–	–	60	–	–	10	10
2,4-Dimethylphenol	T	0/12	0	1.5	nd	3.0	0/3	0	1.5	nd	3.0	–	–	3,000	–	–	97	97
2,4-Dinitrophenol	T	0/12	0	10.0	nd	20.0	0/3	0	10.0	nd	20.0	–	–	300	–	–	100	100
2,4-Dinitrotoluene	T	0/12	0	1.5	nd	3.0	0/3	0	1.5	nd	3.0	–	–	1.7	–	–	0.18	0.18
2-Chloronaphthalene	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	1,000	–	–	100	100
2-Chlorophenol	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	800	–	–	17	17
3,3'-Dichlorobenzidine	T	0/12	0	2.5	nd	5.0	0/3	0	2.5	nd	5.0	–	–	0.15	–	–	0.0033	0.0033
4,6-Dinitro-o-cresol	T	0/12	0	5.00	nd	10.0	0/3	0	5.00	nd	10.0	–	–	30	–	–	7	7
4-Chloro-3-methylphenol	T	0/12	0	1.5	nd	3.0	0/3	0	1.5	nd	3.0	–	–	2,000	–	–	36	36
Benzidine[a]	T	0/12	0	5.00	nd	10.0	0/3	0	5.00	nd	10.0	–	–	0.011	–	–	0.000023	0.000023
bis(2-chloroethyl)ether	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	2.2	–	–	0.06	0.06
Hexachlorobenzene	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	0.000079	–	–	0.000005	0.000005
Hexachlorocyclopentadiene	T	0/12	0	2.5	nd	5.0	0/3	0	2.5	nd	5.0	–	–	4	–	–	1	1
Hexachloroethane	T	0/12	0	1.0	nd	2.0	0/3	0	1.0	nd	2.0	–	–	0.1	–	–	0.02	0.02
Isophorone	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	1,800	–	–	110	110
N-Nitrosodiethylamine	T	0/12	0	1.0	nd	2.0	0/3	0	1.0	nd	2.0	–	–	1.24	–	–	–	1.24
n-Nitrosodimethylamine	T	0/12	0	1.5	nd	3.0	0/3	0	1.5	nd	3.0	–	–	3	–	–	0.34	0.34
N-Nitroso-di-n-butylamine	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	0.22	–	–	–	0.22
n-Nitroso-di-n-propylamine	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	0.51	–	–	0.058	0.058
n-Nitrosophenylamine	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	6	–	–	0.69	0.69
N-Nitrosopyrrolidine	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	34	–	–	–	34
Nitrobenzene	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	600	–	–	100	100
Nonylphenol (mixed isomers)	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	7	1.7	–	–	–	–	1.7
Pentachlorobenzene	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	0.1	–	–	–	0.1
Pentachlorophenol	T	0/12	0	5.00	nd	10.0	0/3	0	5.00	nd	10.0	13	7.9	0.04	13	7.9	0.002	0.002
Phenol	T	0/12	0	0.50	nd	1.0	0/3	0	0.50	nd	1.0	–	–	300,000	–	–	70,000	70,000
Total PCBs (ng/L)																		
Total PCB congeners	T	32/32	100	1.060	0.02172 J–4.942 J	na	8/8	100	0.0739	0.01052 J–0.2289 J	na	–	30	0.064	10,000	30	0.007	0.007
Pesticides (µg/L)[e]																		
4,4'-DDD	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	–	–	0.00012	–	–	0.0000079	0.0000079
4,4'-DDE	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	–	–	0.000018	–	–	0.00000088	0.00000088
4,4'-DDT	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	0.13	0.001	0.00003	0.13	0.001	0.0000012	0.0000012
Aldrin	T	0/12	0	0.013	nd	0.025	0/3	0	0.013	nd	0.025	1.3		0.00000077	0.71[f]	0.0019[f]	0.000000041	0.000000041
Dieldrin	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	0.71	0.0019	0.0000012	0.71[f]	0.0019[f]	0.00000007	0.00000007
alpha-BHC	T	0/12	0	0.013	nd	0.025	0/3	0	0.013	nd	0.025	–	–	0.00039	–	–	0.000048	0.000048
beta-BHC	T	0/12	0	0.013	nd	0.025	0/3	0	0.013	nd	0.025	–	–	0.014	–	–	0.0014	0.0014
gamma-BHC	T	0/12	0	0.013	nd	0.025	0/3	0	0.013	nd	0.025	0.16	–	4.4	0.16		0.43	0.16

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

Chemical	Fraction	LDW Summary Statistics					Upstream Summary Statistics					National Recommended Criteria			Washington State Criteria			Lowest ARAR
		Detection Frequency		Mean Value	Range of Detected Concentrations	RL or Range of RLs	Detection Frequency		Mean Value	Range of Detected Concentrations	RL or Range of RLs	AWQC - Marine		Human Health	Marine[b]		Human Health[b]	
		Ratio	%				Ratio	%				CMC (Acute)	CCC (Chronic)	Consumption of Organism Only	Acute	Chronic	Consumption of Organism Only	
alpha-Chlordane	T	0/12	0	0.013	nd	0.025	0/3	0	0.013	nd	0.025	0.09[g]	0.004[g]	0.00032[g]	0.09[g]	0.004[g]	0.000022[g]	0.000022[g]
beta-Chlordane	T	0/12	0	0.013	nd	0.025	0/3	0	0.013	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	0/12	0	0.013	nd	0.025	0/3	0	0.013	nd	0.025	0.034[h]	0.0087[h]	30	0.034[h]	0.0087[h]	7	0.0087[h]
beta-Endosulfan	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	0.034[h]	0.0087[h]	40	0.034[h]	0.0087[h]	10	0.0087[h]
Endosulfan sulfate	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	–	–	40	–	–	10	10
Endrin	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	0.037	0.0023	0.03	0.037	0.0023	0.002	0.002
Endrin aldehyde	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	–	–	1	–	–	0.035	0.035
Heptachlor	T	0/12	0	0.013	nd	0.025	0/3	0	0.013	nd	0.025	0.053	0.0036	0.0000059	0.053	0.0036	0.00000034	0.00000034
Heptachlor epoxide	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	0.053	0.0036	0.000032	–	–	0.0000024	0.0000024
Methoxychlor	T	0/12	0	0.125	nd	0.250	0/3	0	0.125	nd	0.250	–	0.03	0.02	–	–	–	0.02
Mirex	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	nd	0.050	–	0.001	–	–	–	–	0.001
cis-Nonachlor	T	0/12	0	0.025	nd	0.050	0/3	0	0.025	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	0/12	0	0.025	nd	0.050	0/3	0	0.025	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	0/12	0	0.025	nd	0.050	0/3	0	0.025	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	0/12	0	0.625	nd	1.25	0/3	0	0.625	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	0/4	0	0.010	nd	0.020	0/1	0	na	nd	0.020	1.6	–	–	–	–	–	1.6
Chlorpyrifos	T	0/4	0	0.11	nd	0.20–0.21	0/1	0	na	nd	0.20	0.011	0.0056	–	0.011	0.0056	–	0.0056
Diazinon	T	0/4	0	0.11	nd	0.20–0.21	0/1	0	na	nd	0.20	0.82	0.82	–	–	–	–	0.82
Malathion	T	0/4	0	0.11	nd	0.20–0.21	0/1	0	na	nd	0.20	–	0.1	–	–	–	–	0.1
Dioxins/Furans (pg/L)																		
2,3,7,8-TCDD	T	0/12	0	0.218	nd	0.248–0.696	0/3	0	0.212	nd	0.251–0.511	–	–	0.0051	–	–	0.014	0.0051

Grey highlighting indicates that analyte was detected at concentrations greater than the ARAR in one or more samples.

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).

[a] Non-detected values are presented in the surface water data report (Windward 2019a).

[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
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

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A total of 10 chemicals were detected at concentrations greater than the lowest ARARs. It is noteworthy that 9 of these 10 chemicals were human health risk drivers with sediment cleanup levels (total PCBs, 7 cPAHs, and inorganic arsenic). Each of the 10 chemicals is discussed in the sections below. The only risk driver without any ARAR exceedances was dioxins/furans, so no subsection for dioxins/furans was needed.

3.2.1.1 Total PCBs

Concentration Patterns

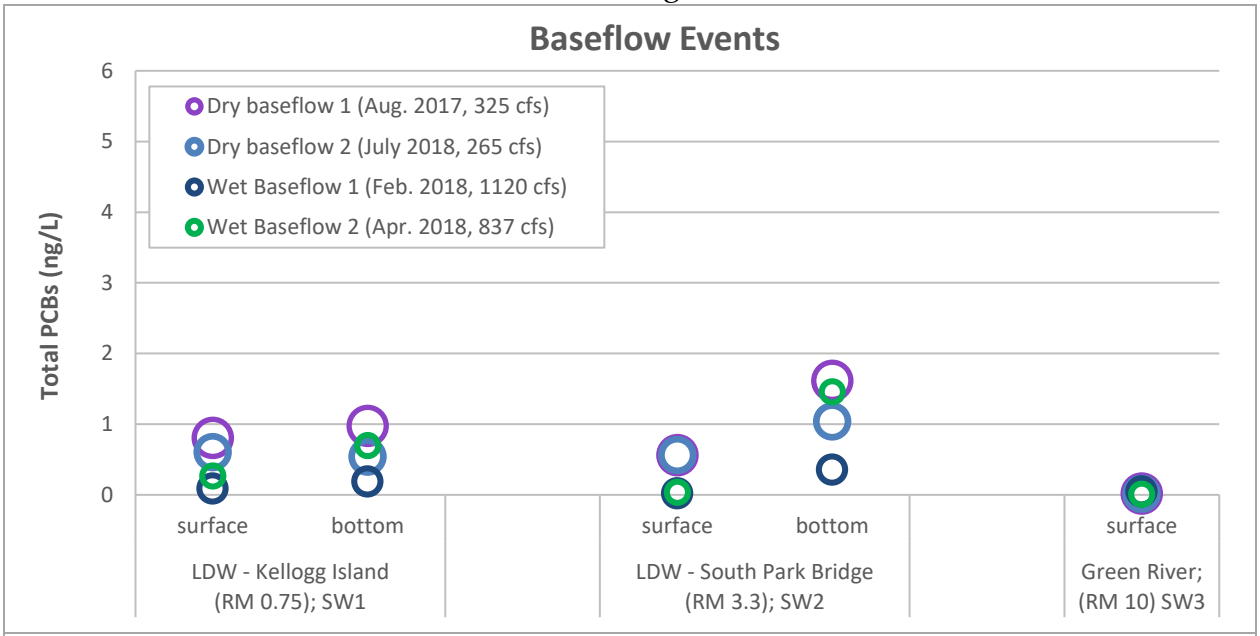
PCBs were detected in all 40 surface water composite-grab samples. Total PCBs concentrations ranged from 0.0217 to 4.942 ng/L in the LDW and from 0.11 to 0.229 ng/L in the 8 upstream locations during the eight surface water sampling events (Figure 3-1).

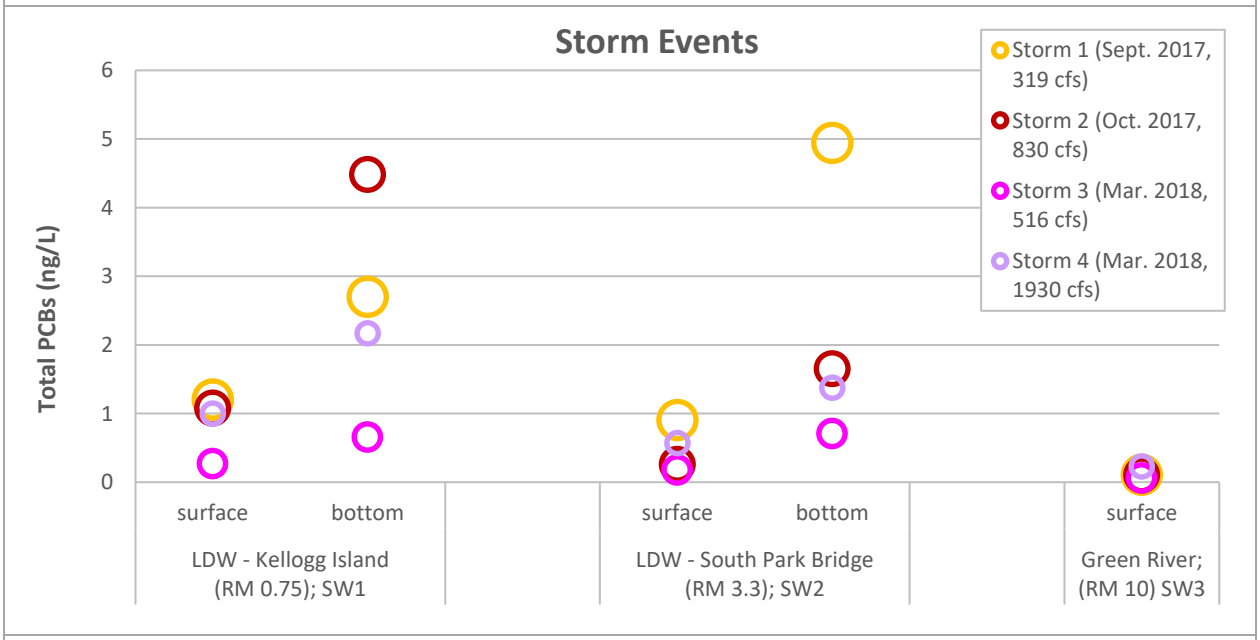
Key observations regarding the patterns of total PCBs in surface water composite-grab samples are as follows.

- **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).[40] 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) 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

[40] 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.

SW1 samples (RM 0.75). Two exceptions to this pattern were for Storms 2 and 4, for which the SW1 concentration was higher.





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 RI/FS 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							Range of Total PCBs in LDW Samples (ng/L)
			Dam Release Rate (cfs)	Rainfall (in.)				Tide	Lunar Phase	
				Antecedent Period[a]	24-Hour Rainfall[b]	12 Hours Prior to Sampling	During Sampling			
LDW Pre-Design Studies Baseline Samples (LDW samples collected at RM 0.75 and RM 3.3)										
DB1	dry baseflow	8/28/2017	325	0 (72 hours)	0	0	0	high/outgoing	neap	0.5655 J–1.6149 J
DB2	dry baseflow	7/30/2018	265	0 (72 hours)	0	0	0	high/outgoing	spring	0.5391 J–1.0379 J
WB1	wet baseflow	2/28/2018	1,120	0 (72 hours)	0	0[c]	0.05[c]	High	neap	0.02172 J–0.3535 J
WB2	wet baseflow	4/3/2018	837	0 (72 hours)	0	0	0	high/outgoing	spring	0.03806 J–1.4589 J
ST1	storm (> 0.25)	9/19/2017	319	0.35 (48 hours)	0.35	0.1	0.03	low/incoming	spring	0.9077 J–4.942 J
ST2	storm (> 0.5)	10/19/2017	830	0.06 (48 hours)	1.43	0.94	0.12	outgoing/low	spring	0.2574 J–4.484 J
ST3	storm (> 0.25)	3/8/2018	515	0 (48 hours)	0.5	0.17	0.07	outgoing	neap	0.1757 J–0.7030 J
ST4	storm (> 0.5)	4/7/2018	1,930	0.23 (48 hours)	0.95	0.63	0.13	outgoing	neap	0.5695 J–2.171 J
King County (LDW samples collected at RM 0 and RM 3.3)										
-	dry baseflow	8/22/2005	290	0 (72 hours)	0	0	0	low/outgoing	spring	1.4275 J–3.211
-	dry baseflow	9/26/2005[d]	440	0 (72 hours)	0	0	0	incoming	neap	1.0236–1.883 J
-	na	11/28/2005	697	0.71 (48hours)	0	0	0	incoming	spring	0.1318–0.5908
-	storm	12/19/2005	287	0 (48 hours)	0.14	0.14	0.01	Low	na	0.6205–1.9473 J

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
J – estimated concentration
LDW – Lower Duwamish Waterway
na – not applicable
PCB – polychlorinated biphenyl
RM – river mile

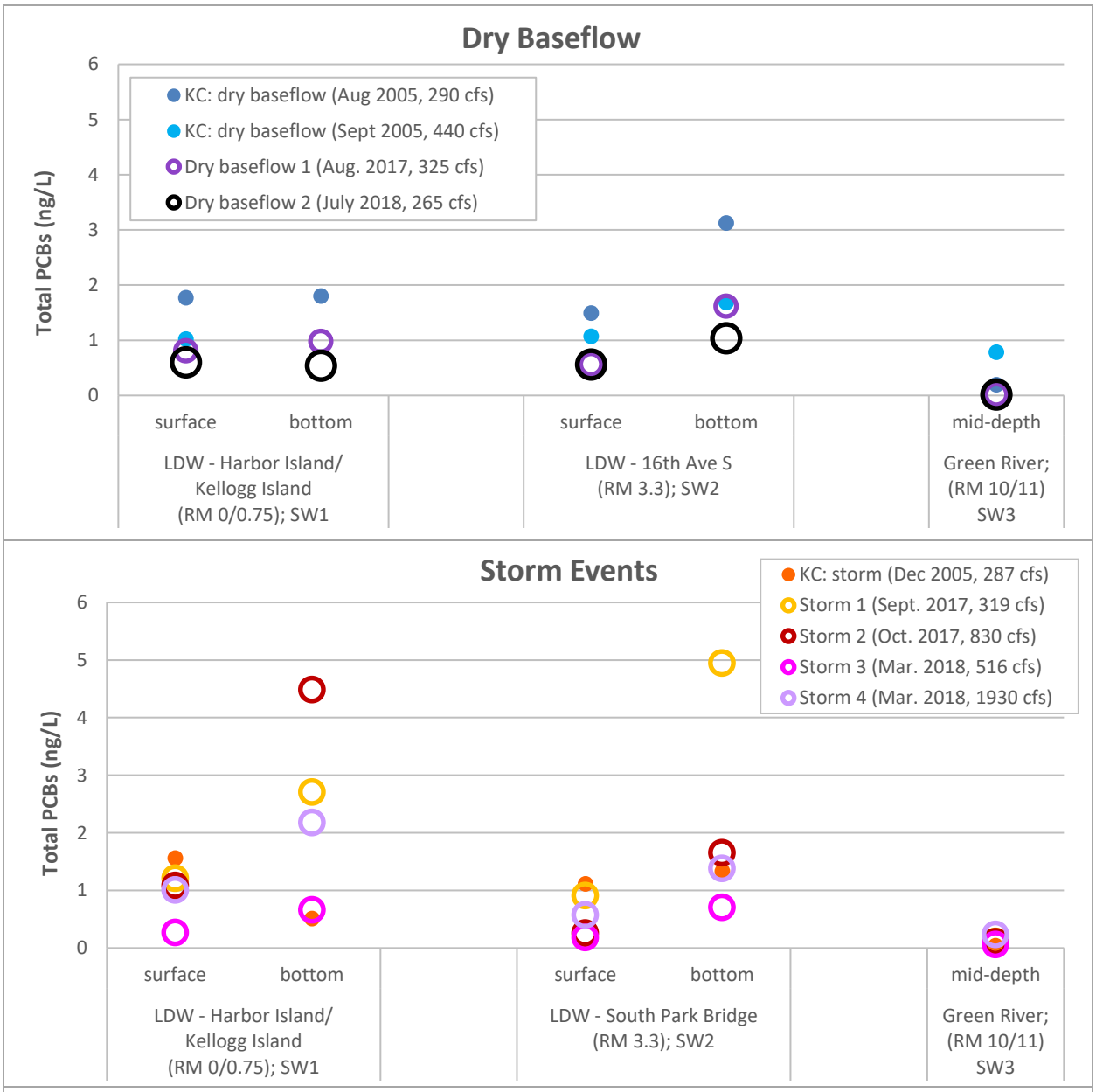
Both the King County (2005) and Pre-Design Studies baseline (2017/2018) datasets included dry baseflow events; therefore, it was possible to compare total PCBs concentrations in these dry baseflow samples to evaluate potential changes in concentrations (Figure 3-2) although there are uncertainties associated with these comparisons.[41]

- **Dry baseflow samples** – 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.
- **Storm samples –** 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.

Thus, while PCB concentrations in dry baseflow samples collected in 2017/2018 are lower than those in samples collected in 2005, there are insufficient data to conclude whether PCB concentrations in LDW water have changed since 2005.

The range of PCB concentrations in the baseline dataset can also be compared to the range of concentrations reported for surface water in East Waterway and Elliott Bay. The baseline PCB concentrations (0.02172–4.942 ng/L, n=32) are similar to the range of concentrations reported for East Waterway (0.068–5.8 ng/L, n=57). The PCB concentrations in Elliott Bay are generally lower (0.056–0.098 ng/L, n=4).

[41] Uncertainties include differences in sampling conditions and methods (single grabs for the King County samples vs. composite grabs for the Pre-Design Studies baseline samples), as well as the relatively small numbers of samples.



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 upstream 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).

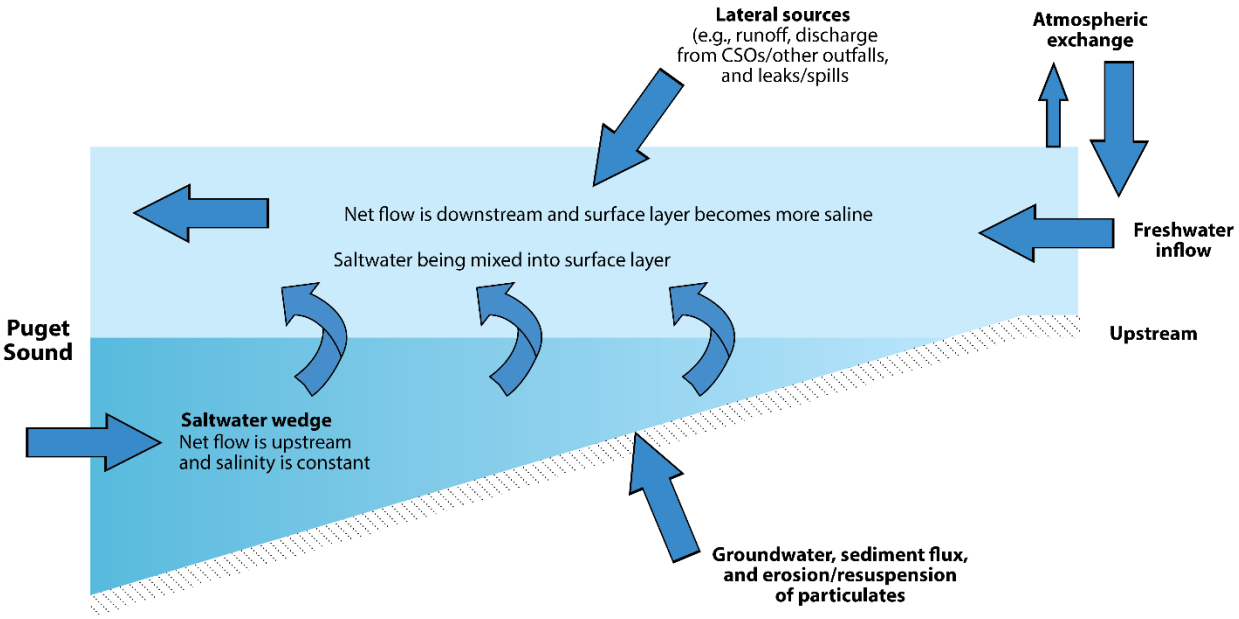
Figure 3-2. Comparison of total PCB concentrations in surface water in 2017/2018 Pre-Design Studies baseline composite-grab samples with RI/FS (2005) LDW and upstream grab samples

Consistency with Conceptual Site Model

The surface water data collected to date generally support the conceptual site model (CSM) (Figure 3-3) described in the Work Plan (Windward and Integral 2017c). In this model, total PCB concentrations detected in LDW surface waters are affected by freshwater flow as well as estuarine circulation. The following bullets summarize the key aspects of the CSM and describe how the baseline dataset is consistent with the CSM:

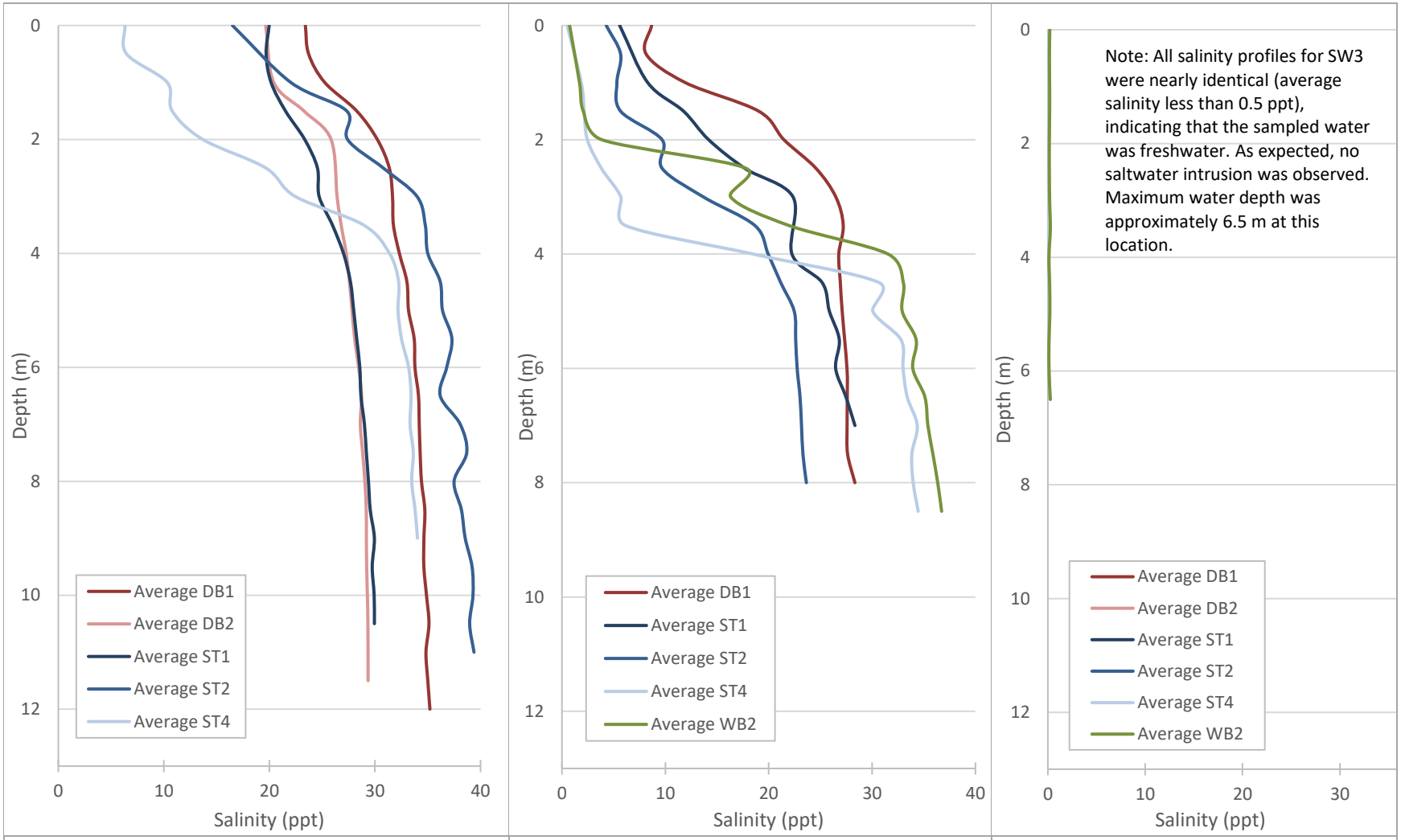
- **Bottom layer water patterns –** Total PCB concentrations are expected to be higher (per the CSM) in the bottom layer of the LDW at the toe of the salt wedge than PCB concentrations further downstream (i.e., higher at location SW2 [RM 3.3] than at location SW1 [RM 0.75]), due to the increased residence time (time within the LDW) of bottom water and flux from LDW sediment into the bottom water. As expected, total PCB concentrations for near-bottom water in the Pre-Design Studies dataset were generally higher for a given event in the samples collected from the furthest upstream sampling location (SW2 at RM 3.3), while they were lower at the downstream location (SW1 at RM 0.75) (Figure 3-1).
- **Surface layer water patterns –** Unlike the bottom layer, the surface layer is expected to have total PCB concentrations (per the CSM) that 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. As expected, total PCB concentrations for near-surface water in the Pre-Design Studies dataset were generally highest for a given event in the samples collected from the furthest downstream sampling location (SW1 at RM 0.75), while they were lowest in the samples collected from upstream (Figure 3-1). This is consistent with upward mixing of bottom-layer water as water from the upstream Green River with lower concentrations flows downstream.
- **Bottom layer vs. surface layer water concentrations** – As expected based on the CSM, total PCB concentrations for a given sampling event and location were, with one exception wherein concentrations were similar, higher in near-bottom samples (where more interaction with the sediment occurs) than in near-surface water samples (Figure 3-1).

Thus, the concentration patterns based on the baseline composite-grab samples provide qualitative (non-statistical) support for the CSM (Figure 3-3). In addition, 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 the salinity and concentration profiles, it is important to recognize that some variability in the measurements is expected; thus, only general conclusions should be drawn from these plots.



Source: Modified from Stern (2015).

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



A) Salinity profiles for SW1 (RM 0.75) | **B) Salinity profiles for SW2 (RM 3.3)** | **C) Salinity profiles for SW3 (upstream)**

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 upstream 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 upstream 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, when the tides were more extreme than during DB1. This is shown by the higher salinity at depth at SW1, and by the comparison of the laboratory-measured salinities for these two events (i.e., salinities for DB2 were higher than those for SW1 at each depth and location).[42]
- 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 increase in flows from the larger dam releases.
- 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 (Figure 3-5). 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.

[42] As presented in Table 4-5 of the surface water data report (Windward 2019a), salinities for DB1 were 1.5 to 6 psu lower than those for DB2 at each depth and location.

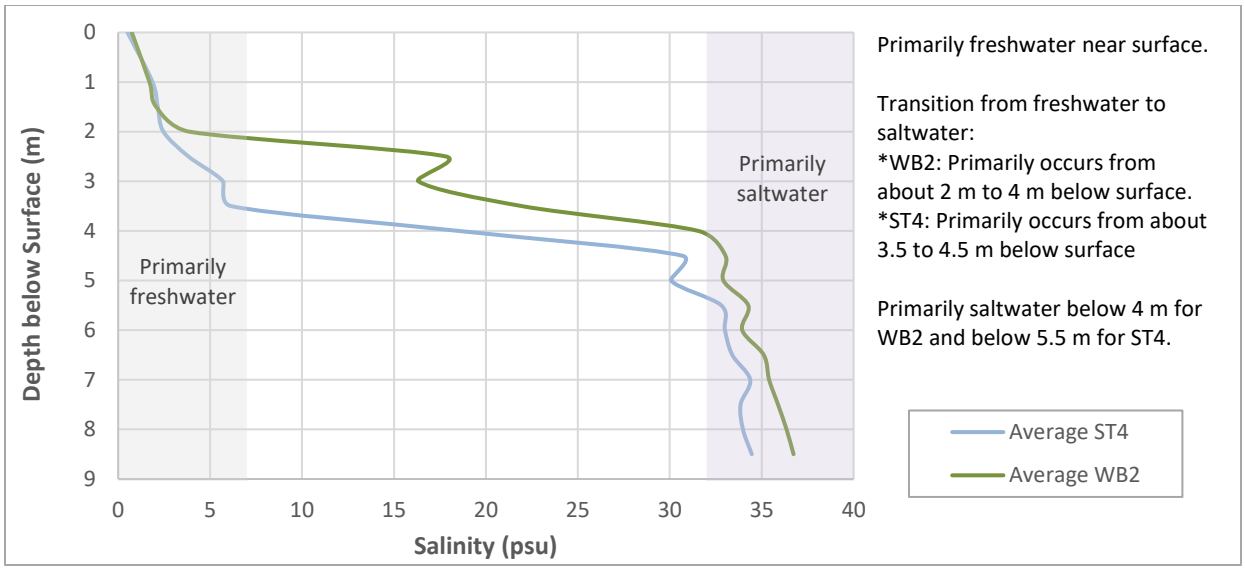


Figure 3-5. Comparison of storm 4 (ST4) and wet baseflow 2 (WB2) salinity profiles at location SW2

3.2.1.2 cPAHs

Concentration Patterns

At least 1 individual cPAH was detected[43] in 9 of the 32 surface water grab samples in the LDW. No cPAHs were detected in the eight upstream 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 (upstream).

- **Storm vs. baseflow samples** – Unlike PCB concentrations, cPAH concentrations in dry baseflow samples were generally lower than those in wet baseflow samples (i.e., there were more 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 (for which PCB concentrations were low) was the only storm sampling event during which samples were collected with significant dam release (i.e., a release rate of 1,930 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.

[43] 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.

- **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	Detection Frequency	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 (upstream; RM 10)
			Surface	Bottom	Surface	Bottom	Mid-depth
Benzo(a)anthracene	4/40	yes (all 4 detects)	WB1 WB2	WB1	-	ST4	-
Benzo(a)pyrene	1/40	yes	-	-	-	ST4	-
Benzo(b)fluoranthene	4/40	yes (all 4 detects)	WB1 WB2	-	-	DB1 ST4	-
Benzo(k)fluoranthene	1/40	yes	-	-	-	ST4	-
Dibenzo(a,h)anthracene	1/40	yes	WB2	-	-	-	-
Indeno(1,2,3-cd)pyrene	2/40	yes (both detects)	WB2	-	-	ST4	-

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

Comparison with RI/FS Data

cPAH data presented in the RI/FS are 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 (RLs were higher), and no other LDW cPAH surface water data are available for comparison.

Individual cPAHs had low detection frequencies in the East Waterway and Elliott Bay at concentrations similar to those reported for the baseline samples.

Consistency with Conceptual Site Model

Concentrations of PAHs are generally low in LDW surface water, and thus few detected concentrations are available to assess whether the CSM described for total PCBs is applicable for cPAHs. The available data suggest that there may be some similarities in the patterns of PCB and PAH concentrations (e.g., 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 total measured PCB concentrations in water were also highest). However, no definitive conclusions can be made. While patterns of PCB and PAH concentrations in water may be similar, lateral sources and contaminated sediments contribute different amounts of each to the water column at different locations and times as water moves through the system.

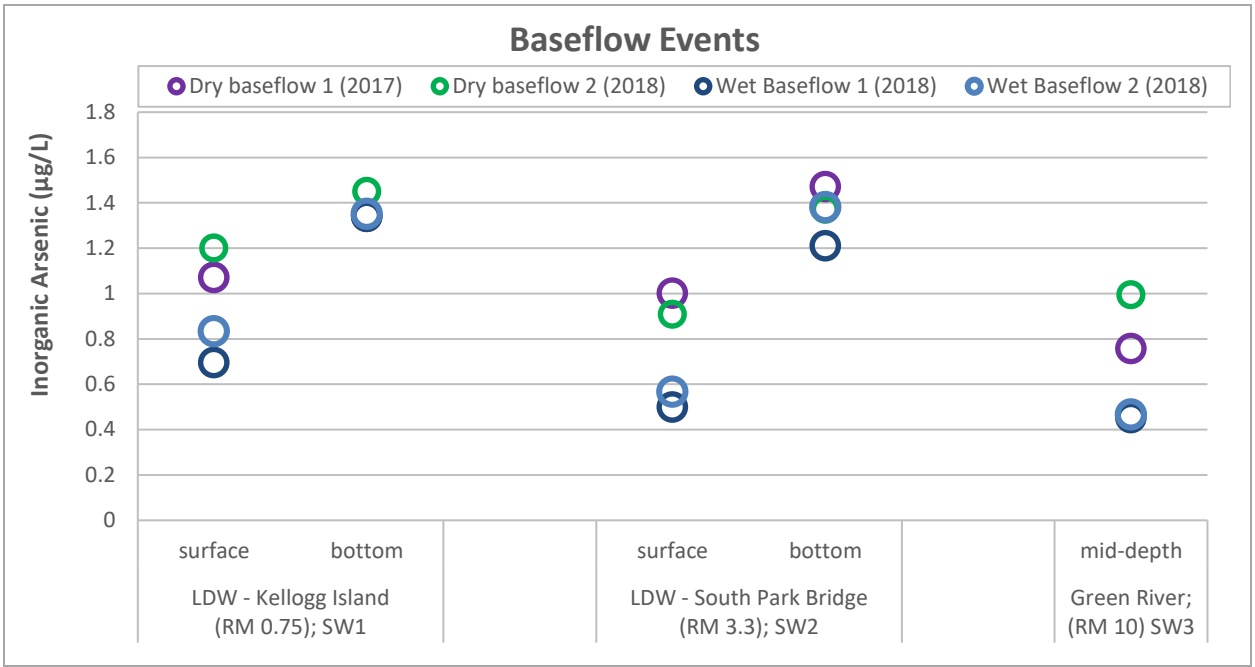
3.2.1.3 Inorganic arsenic

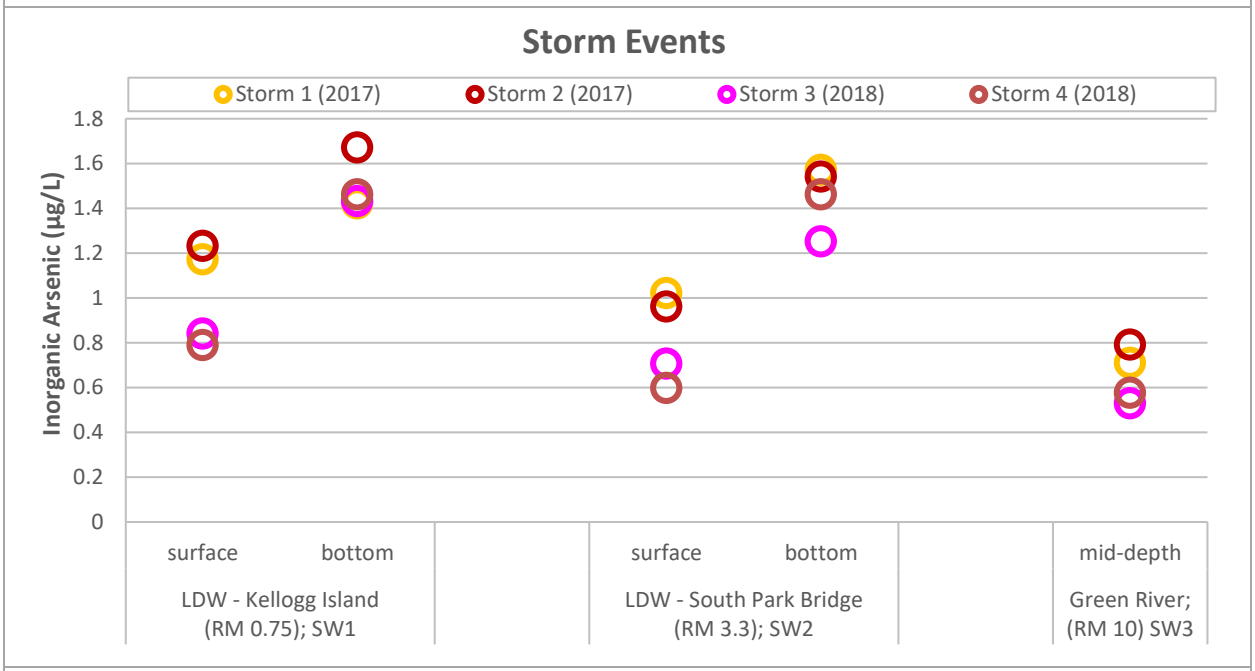
Concentration Patterns

Inorganic arsenic was detected in all 40 surface water grab samples. Inorganic arsenic concentrations ranged from 0.466 to 1.72 µg/L in the 32 LDW samples and from 0.451 to 0.993 µg/L in the 8 upstream samples (Figure 3-6).

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 — the highest of which were in samples collected during storm events — 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. This pattern is similar to that observed for total PCBs. However, unlike for total PCB concentrations, concentrations of arsenic in the near-bottom water samples were similar at SW1 and SW2.





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 3-6. Inorganic arsenic in Pre-Design Studies baseline surface water composite-grab samples

Comparison with RI/FS Data

While there are no RI/FS surface water data for inorganic arsenic, total arsenic (inorganic plus organic) surface water data are available from filtered water samples (dissolved fraction) collected from three locations in 1996/1997 and from one location in

2011/2012 for comparison with the baseline dataset (2017/2018) (Figure 3-7). Details of these two older datasets are as follows:

- **1996/1997 King County WQA data** – Filtered 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** – Filtered 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.

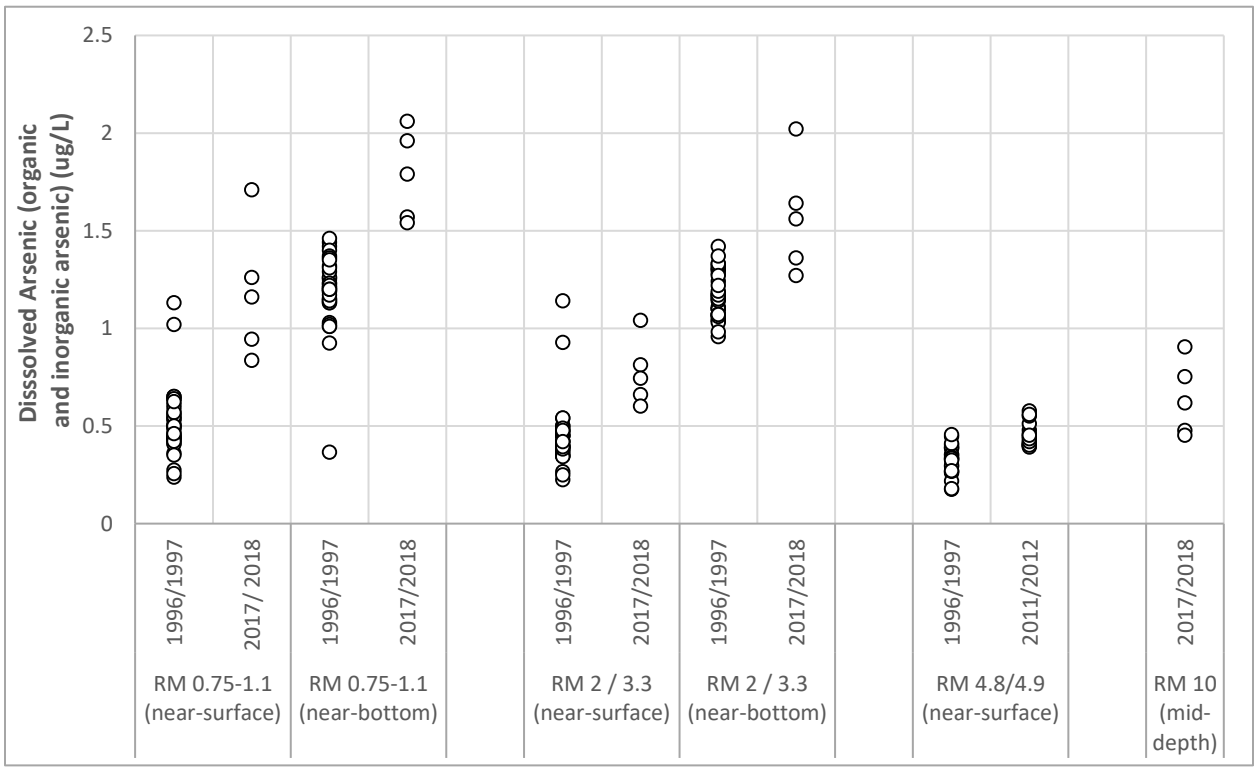


Figure 3-7. Comparison of 1996/1997 dissolved arsenic concentrations (organic and inorganic arsenic) with 2017/2018 baseline data in the LDW and upstream

Thus, while the concentration of dissolved arsenic in the 2017/2018 samples appears higher than in the 1996/1997 samples, this comparison is uncertain because of differences in sampling locations, depths, and methodology.

Baseline dissolved arsenic concentrations (0.602-2.06 µg/L, n=32) are similar to dissolved arsenic concentrations reported for East Waterway (0.43 – 1.43 µg/L, n=130) and Elliott Bay (0.96 – 1.5 µg/L, n=22).

Consistency with Conceptual Site Model

Concentrations of inorganic arsenic in surface water grab samples were compared with the CSM for the LDW (Figure 3-3). In general, the inorganic arsenic concentrations appear to be consistent with the CSM, similar to the pattern for total PCB concentrations:

- Inorganic arsenic concentrations for each event were highest in near-bottom water samples, although, in contrast to PCBs, concentrations at both locations (i.e., SW1 and SW2) were relatively similar.
- In near-surface water samples, concentrations were highest at SW1 (RM 0.75), while concentrations at SW2 (RM 3.3) were between those at SW1 and SW3, likely representing upward mixing of bottom water.

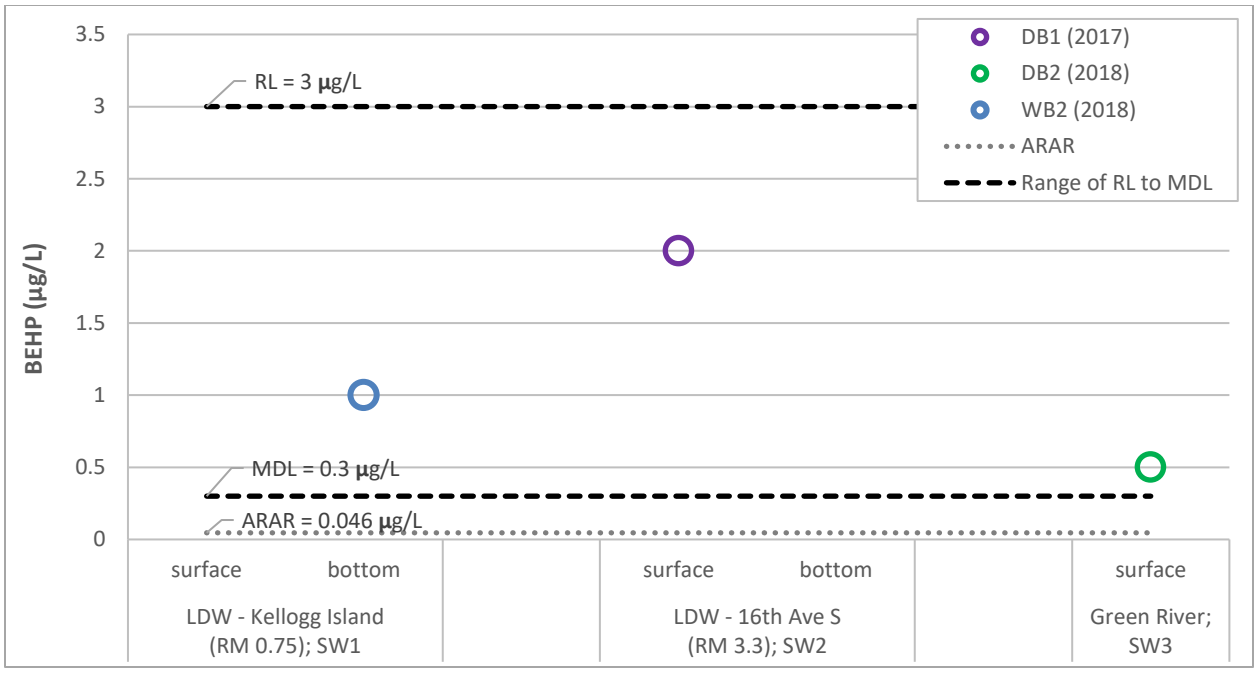
3.2.1.4 BEHP

Concentration Patterns

BEHP, the only non-risk driver chemical with ARAR exceedances, was detected in 2 of the 32 LDW surface water grab samples and 1 of the 8 upstream surface water grab samples.[44] All three detected values were above the human-health based ARAR, and all non-detected values (at the MDL) were also above the ARAR.

The three detected values were each from different baseflow sampling events and different locations (Figure 3-8). 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.

[44] 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.



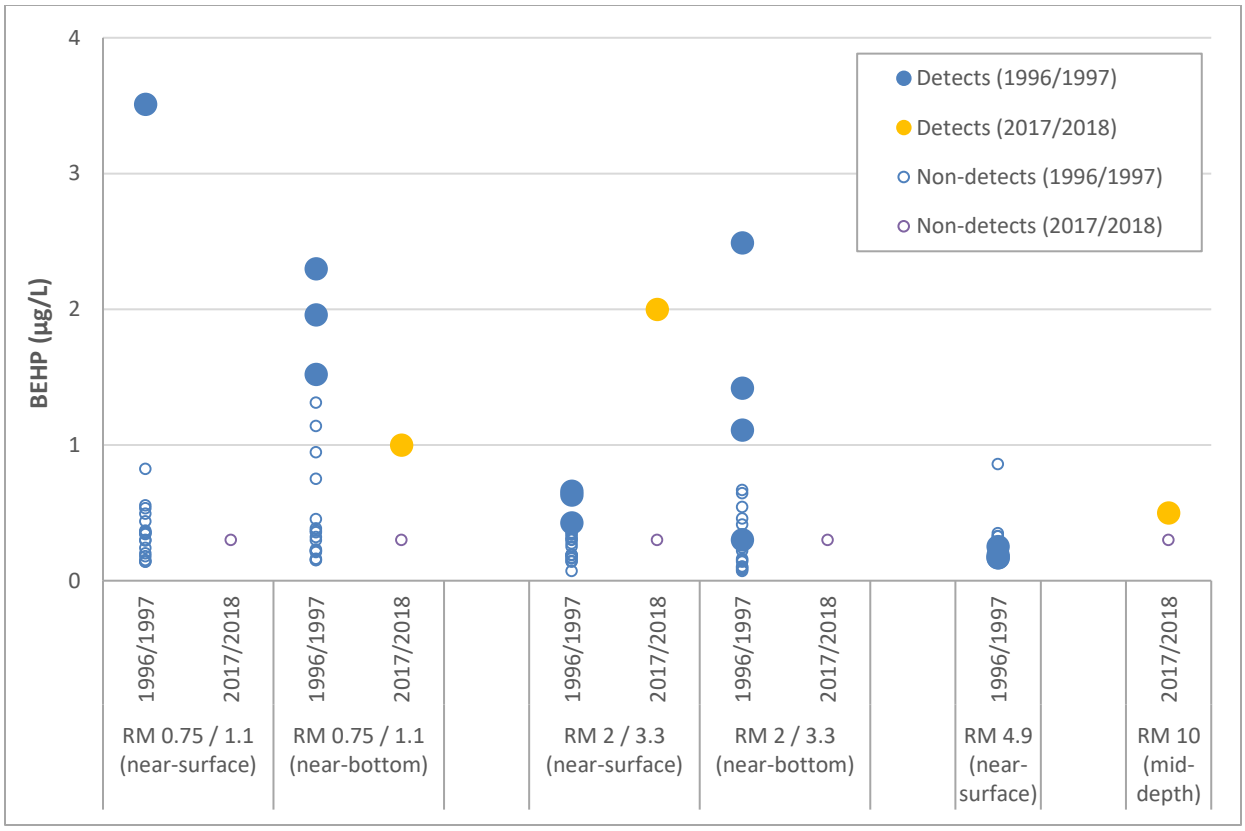
Note: Samples in which BEHP was not detected are not shown on this figure.

Figure 3-8. BEHP in Pre-Design Studies baseline surface water composite-grab samples

Comparison with RI/FS Data

Data from the 1996/1997 King County WQA are available for BEHP (Figure 3-9). However, BEHP was frequently detected in method blank samples in this dataset.[45] As a result, its comparability with the baseline dataset is uncertain. In the 2017/2018 dataset, BEHP was detected in 2 of the 32 LDW samples (concentrations of 1 and 2 µg/L) and in 1 of the 8 upstream samples (concentration of 0.5 µg/L) (Figure 3-9). Details regarding these two sampling events are discussed in Section 3.2.1.3. Thus, while the BEHP concentrations in 1996/1997 appear to be higher than those in the 2017/2018 samples, this comparison is uncertain because of differences in sampling locations, depths, methodology, and blank contamination.

[45] 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. BEHP was detected in 19 of 94 surface water grab samples from the 1996/1997 event (detection frequency of 20%), with detected concentrations ranging from 0.14 to 23.8 µg/L.



Note: Non-detected values are shown as ½ RL for the 1996/1997 data, consistent with data treatment for the King County dataset. For the baseline dataset, the laboratory reported detected values to the MDL; thus, non-detected values are shown 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 3-9.Comparison with historical BEHP concentrations in surface water

Consistency with Conceptual Site Model

Insufficient detected BEHP data are available to evaluate the consistency of these results with the CSM described above for total PCBs.

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. PCB C_{free} derived using passive samplers was selected for trends analysis because it reflects a 30-day average concentration during a dry season, which should have less variance than a concentration reflecting a wet season or individual whole-water samples. PCB C_{free} is not comparable to the PCB concentrations in whole-water samples, which include both freely dissolved PCBs and PCBs associated with particles and dissolved organics (< 0.45 µm).

As described in the surface water data report (Windward 2019a), average dam release rates for the 2017 and 2018 dry season 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[46] 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 estimated from the passive samplers are presented in Figure 3-10. 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 ($p < 0.001$).[47] 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 higher total rainfall in 2017) affected these results.

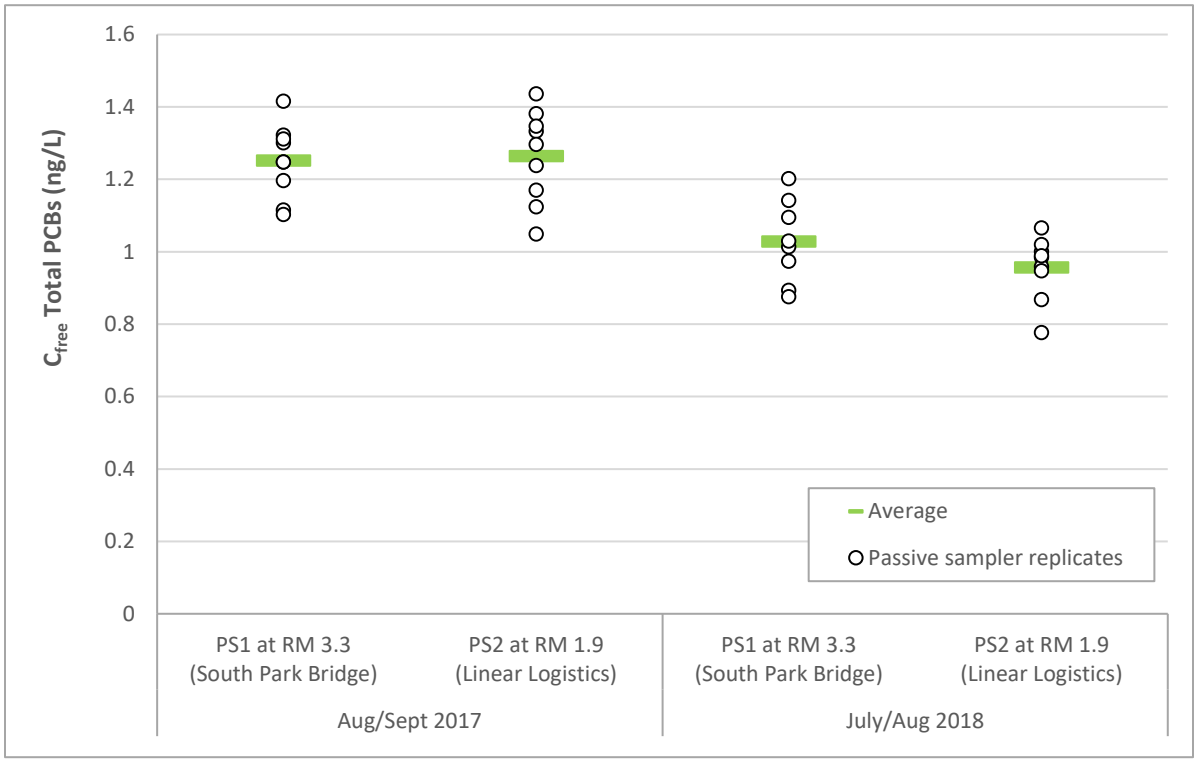


Figure 3-10. Total PCB C_{free} calculated from passive samplers

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, Section B3.2) indicated that of the total variance in the passive sampler dataset, 25% could be attributed to residual variability among replicate samplers, 74% could be attributed to year-to-year variability, and

[46] 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 2019a).

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

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 3-10) indicate that the two locations provide redundant information about average total PCB concentrations.

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 2019a).

[b] The SD is equal to the residual SE.

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

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 human health 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 40 surface water grab samples (i.e., all 32 LDW samples and all 8 upstream 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.

Chemical	Summary of Key Conclusions
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
cPAHs	• 6 of the 7 cPAHs were detected in LDW samples at concentrations above the lowest ARARs (all cPAHs except chrysene); no cPAHs were detected in the upstream samples • 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 40 surface water grab samples (i.e., all 32 LDW samples and all 8 upstream 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 40 samples (i.e., 2 of 32 LDW samples and 1 of 8 upstream 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 ± SD total PCB C_{free} estimated using the passive samplers were 1.26 ± 0.12 ng/L in 2017 and 0.99 ± 0.10 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
SD – standard deviation

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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 human health risk drivers for comparison to target tissue levels (TTLs)[48] for RAO 1.
- **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.[49] In addition, a subset of samples was analyzed for the non-risk driver chemicals, as specified in the ROD.[50]

The baseline sampling design used for the collection of fish and crab tissue will be repeated in the future to generate comparable monitoring results as remediation and source control progress. The same fish and crab species will be collected, and consistent sampling areas; sample collection, preparation, and compositing methods; and analytical approaches (except where noted in Section 9) will be used so that future datasets are comparable to the baseline dataset.

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	

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

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

[50] 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.

Species	Tissue Types Evaluated	No. Individuals Per Sample	Number of Baseline Samples	
			Total	By Sampling Area (Map 4-1)
	whole body[b]	7	12	6 samples of each tissue type from each of the 2 reaches
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 2018g).

[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 2018g).

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 2018g). 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).

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 2017c). 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.[51] Both of these sample design features reduced the RME in the baseline tissue dataset.

As presented in Table 4-2, the DQOs were met for the baseline tissue samples and variability was lower than anticipated,[52] 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, Section B4.5).

[51] 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.

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

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.

Note that an important factor in interpreting the crab tissue data for the LDW is the inclusion of two species of crab to assess site conditions: graceful crab (also called slender crab) and Dungeness crab. Dungeness crab were present in small numbers compared to graceful crab during baseline sampling in 2017. This was not unexpected, based on information from the Washington Department of Fish and Wildlife on Dungeness crab populations in Puget Sound in 2017. The use of graceful crab as a suitable surrogate was confirmed using carbon and nitrogen stable isotope analyses (see Appendix I for details).

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, homolog patterns, and food web model [FWM] results) are also presented as available. Not all of the historical data were conducive to statistical comparison with the baseline data. Comparisons of arithmetic means and ranges are presented herein to indicate general trends; when statistical comparisons are appropriate, confidence intervals or 95UCLs are presented.

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 (ROD Table 21).[53] 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.[54] 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.

Site-wide 95UCL concentrations in baseline fish and crab tissue were calculated for comparison with the TTLs to address DQO 1 (Table 4-3). 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 4-3). 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 4-3). In addition to the 95UCLs, Table 4-3 presents the mean values for DQO 2; these means will be used in trend analysis with future monitoring data.

[53] 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 human health risk assessment (HHRA).

[54] 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 4-3. Comparison of baseline fish and crab tissue data with ROD TTLs

ROD Species Group and Tissue Type	Baseline Species	Summary Statistics for Baseline Dataset				ROD TTL[b]	ROD TTL Basis
		Detection Frequency	Mean Value	Range of Values	95UCL[a]		
Total PCB Aroclors (µg/kg ww)							
Benthic fish – fillet	English sole[c]	12/12	259	144.6–442	286	12	non-urban background
Pelagic fish – whole body	shiner surfperch	12/12	407	308–515	426	1.8	species-specific RBTC
Crab – edible meat	graceful crab[d]	12/12	115	61.1–165 J	124	1.1	non-urban background
Crab – whole body	graceful crab[d]	12/12	255	147.3–359 J	275	9.1	non-urban background
Dioxin/furan TEQ (ng/kg ww)							
Benthic fish – whole body	English sole[c]	12/12	1.18	0.699 J–1.50 J	1.25	0.35	non-urban background
Crab – edible meat	graceful crab[d]	12/12	0.41	0.267 J–0.550 J	0.45[e]	0.53	non-urban background
Crab – whole body	graceful crab[d]	12/12	1.21	0.744 J–1.73 J	1.32[e]	2.0	non-urban background

Note: Grey shading indicates 95UCL above the TTL.

[a] 95UCLs are for the stratified site-wide mean baseline 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] TTLs are as presented in Table 21 of the ROD.

[c] The TTL in ROD Table 21 for benthic fish was based on non-urban background concentrations in a combination of species available in the Puget Sound tissue dataset, including English sole, rock sole, and starry flounder.

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

[e] For the 95UCLs that were less than the TTL, the statistical power of the comparison was 64% for crab edible meat, and > 90% for crab whole body.

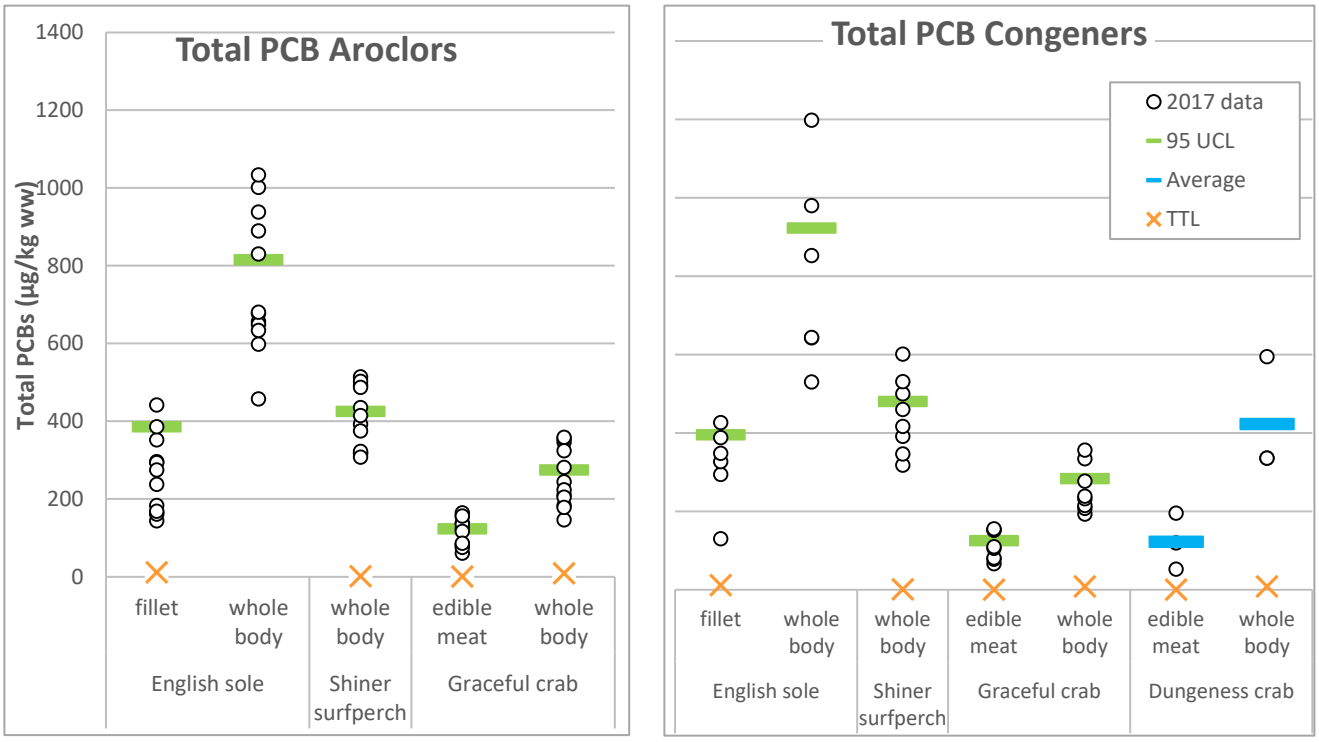
95UCL – 95% upper confidence limit (on the mean)
J – estimated concentration
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
ROD – record of decision
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

Additional details regarding spatial distributions and comparisons of baseline tissue data with available RI/FS 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 4-1, 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. This relationship differs from that observed for baseline sediment samples, wherein total PCB concentrations

based on Aroclors were consistently higher than those based on the congener sum (Section 2.2.2). The relationship between Aroclors and congeners was further evaluated in Appendix B (see Section B.4.4 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 4-1. 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

Temporal Evaluation

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 4-4. 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 RI/FS data) must be

considered.[55] When comparing total PCB data over such a large time span, it is important to note that changes in PCB analytical methods, extraction methods, and quantification techniques also present uncertainties for comparing datasets.

Table 4-4. 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

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

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 2004b, 2005, 2017a), and the samples had similar lipid fractions (Table 4-4), allowing for clear temporal comparisons.

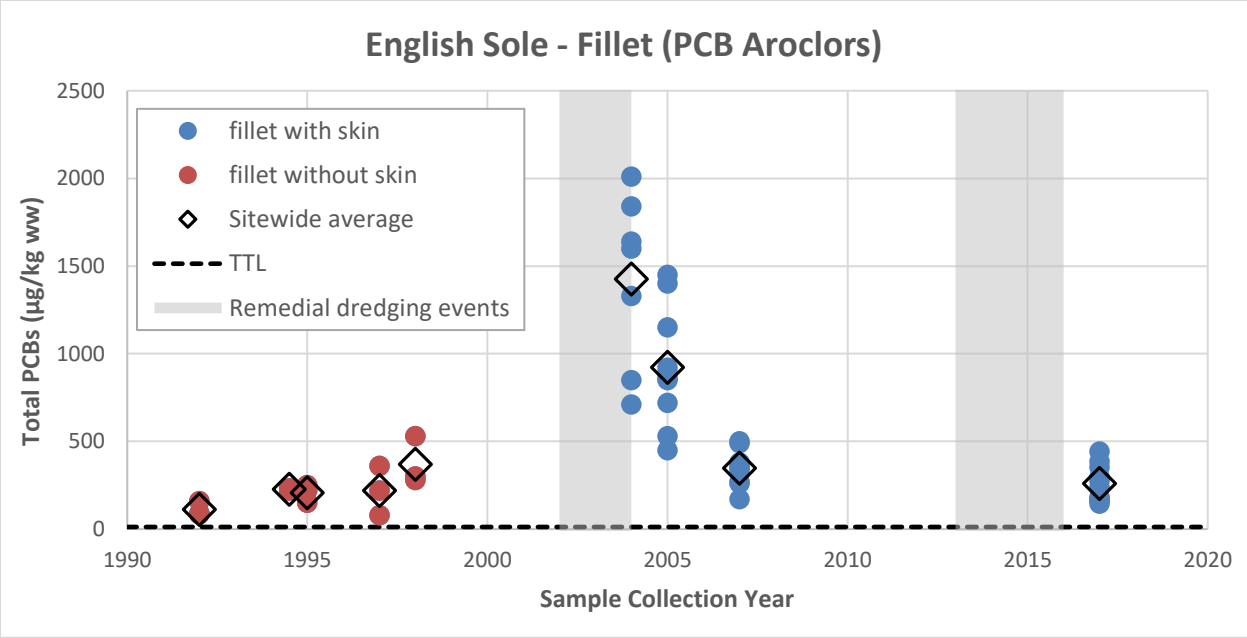
During this time period, total PCB Aroclor concentrations were highest in 2004 following dredging remediation work in the LDW and the West and East Waterways that had occurred in 2003/2004; total PCB Aroclor concentrations decreased from 2005 to 2007 (Figures 4-2 and 4-3).

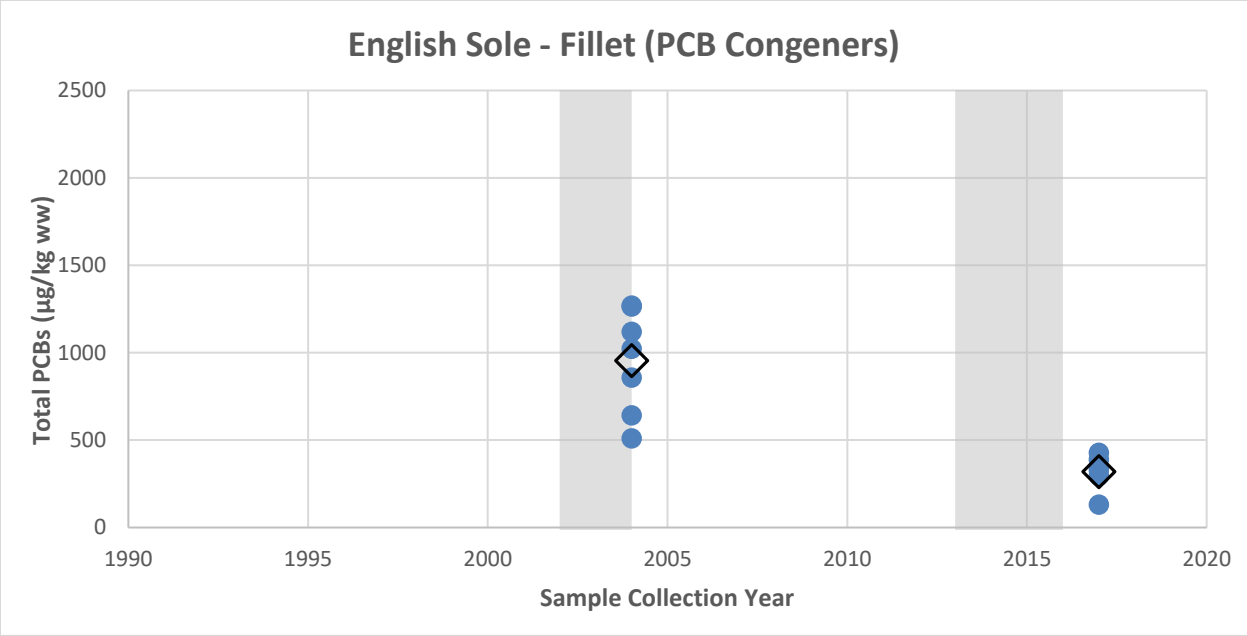
[55] Lipid content in fish may be affected by fish condition, size, age, sex, reproductive status, genetic background, diet, water temperature, and seasonality (Mraz 2012; Iverson et al. 2002). Although consideration of lipid fractions can be useful when interpreting concentration data, it is important to recognize that there is uncertainty regarding the analytical methods used to measure lipid concentrations in the RI/FS 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.

To evaluate changes in English sole tissue concentrations between 2007 and 2017, a statistical evaluation ($\alpha = 0.05$) was conducted. Because of a variety of methodological differences between the samples collected in 2007 and those collected in 2017, the statistical results do not provide definitive evidence regarding trends. Rather, these results simply provide information about the magnitude and statistical significance of observed changes in tissue concentrations. Results are summarized for LDW-wide averages to reflect the spatial area for TTLs (which are LDW-wide). Details for the statistical tests, including temporal differences for each reach individually, are presented in Appendix B[56] and the results are summarized below.

- Based on Aroclor analyses:
  - LDW-wide, total PCB concentrations in fillet tissues from 2017 were significantly lower than those from 2007 (259 µg/kg ww in 2017 vs. 361 µg/kg ww in 2007; p =0.010) (Figure 4-2).
  - Total PCB concentrations in LDW-wide whole-body tissues from 2017 were slightly higher than those from 2007 (750 µg/kg ww in 2017 vs. 709 µg/kg ww in 2007; p = 0.62) (Figure 4-3).
- Based on PCB congeners:
  - Insufficient PCB congener data were available to conduct a temporal comparison for English sole fillet (Figure 4-2).
  - Total PCB concentrations in whole-body tissues were significantly lower in 2017 than in 2007 (808 µg/kg ww in 2017 vs. 1,640 µg/kg ww in 2007; p = 0.034) (Figure 4-3).

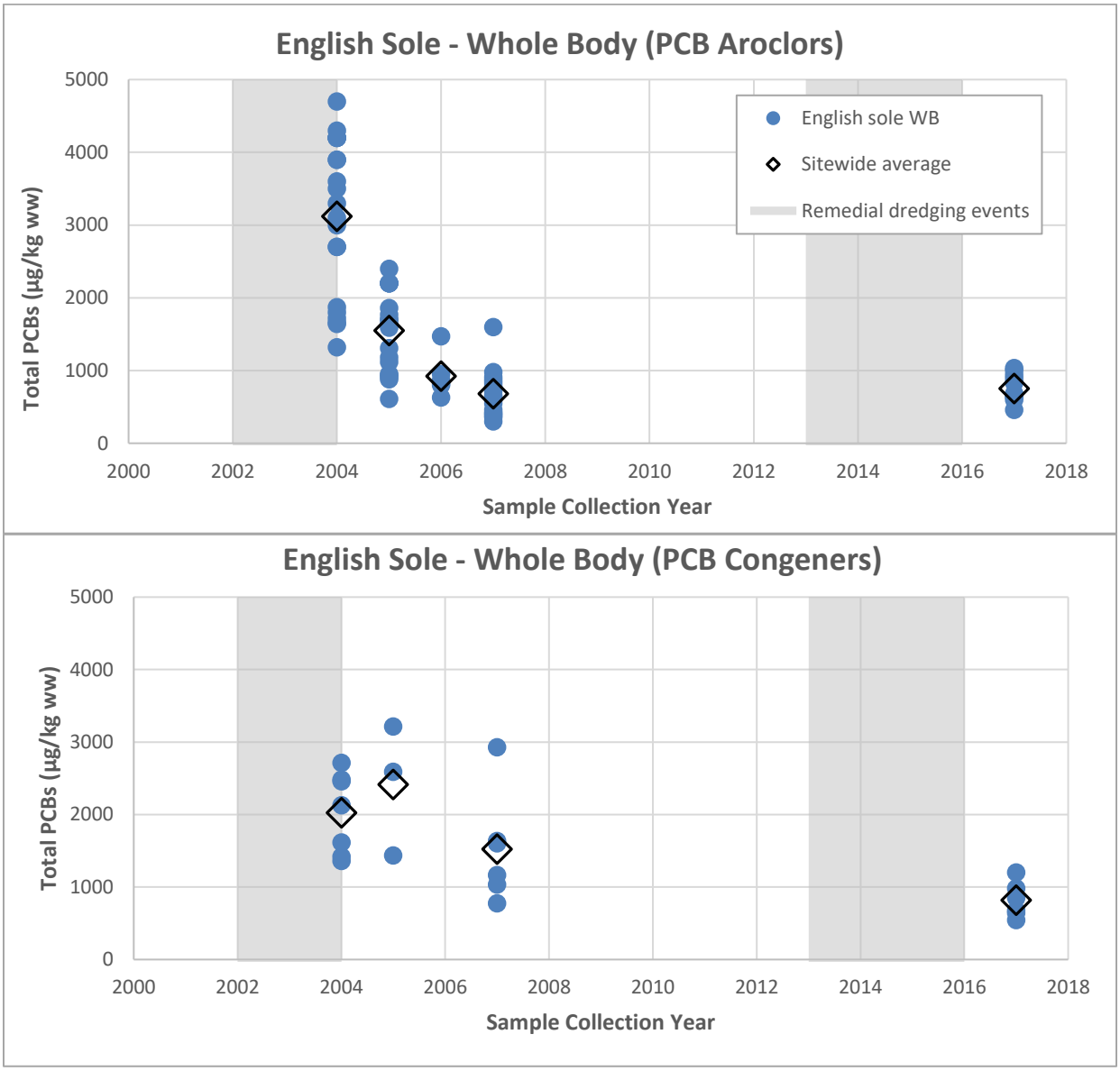
[56] Statistical comparisons were done using a crossed two-factor ANOVA design (Appendix B, Section B4.3.1). If the interaction between year and reach was strong, the magnitude of change in concentration by reach was estimated (Table B4-3).





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

Figure 4-2. Total PCB concentrations in English sole fillet tissue over time



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

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

Based on Aroclor data, total PCB concentrations in tissue were higher after the 2003/2004 dredge operations, which were followed by decreases in concentrations in 2005 and 2007; this trend is less clear when looking at the available total PCB congener data (Figures 4-2 and 4-3). The extent to which the 2017 data were influenced by the 2013–2015 dredge events is uncertain.

To better evaluate how these datasets compare, the ratio of the total PCB sum based on Aroclors to that based on congeners was calculated for samples for which both Aroclor

and congener data were available (Table 4-5 and Figure 4-4). The ratios can be interpreted as follows:

- A ratio of 1 (or samples close to the 1:1 line) indicates that the total PCB Aroclor and total PCB congener sums are equal, as was the case for the 2017 samples.
- A ratio greater than 1 (or samples below the 1:1 line) indicates that the Aroclor sum is greater, as was the case for the 2004 samples.
- A ratio less than 1 (or samples above the 1:1 line) indicates that the congener sum is greater, as was the case for the 2007 samples.

Table 4-5. Comparison of Aroclor-to-congener total PCB ratios

Species and Tissue Type	Average Ratio of Total PCB Aroclors to Total PCB Congeners			
	2004	2005	2007	2017
English sole – fillet	1.48 (n=7)	-	-	0.78 (n=6)
English sole – whole body	1.62 (n=7)	0.66 (n=3)	0.51 (n=6)	0.93 (n=6)
Shiner surfperch – whole body	1.39 (n=9)	1.13 (n=3)	0.60 (n=6)	0.90 (n=8)
Crab – edible meat[a]	1.53 (n=8)	-	0.43 (n=4)	1.09 (n=8)
Crab – whole body[a]	1.72 (n=6)	-	0.43 (n=1)	0.98 (n=8)
Summary	**Aroclors > congeners**	**limited data (no clear trend)**	**Aroclors < congeners**	**Aroclors and congeners generally similar**

[a] Includes both graceful and Dungeness crab.

PCB – polychlorinated biphenyl

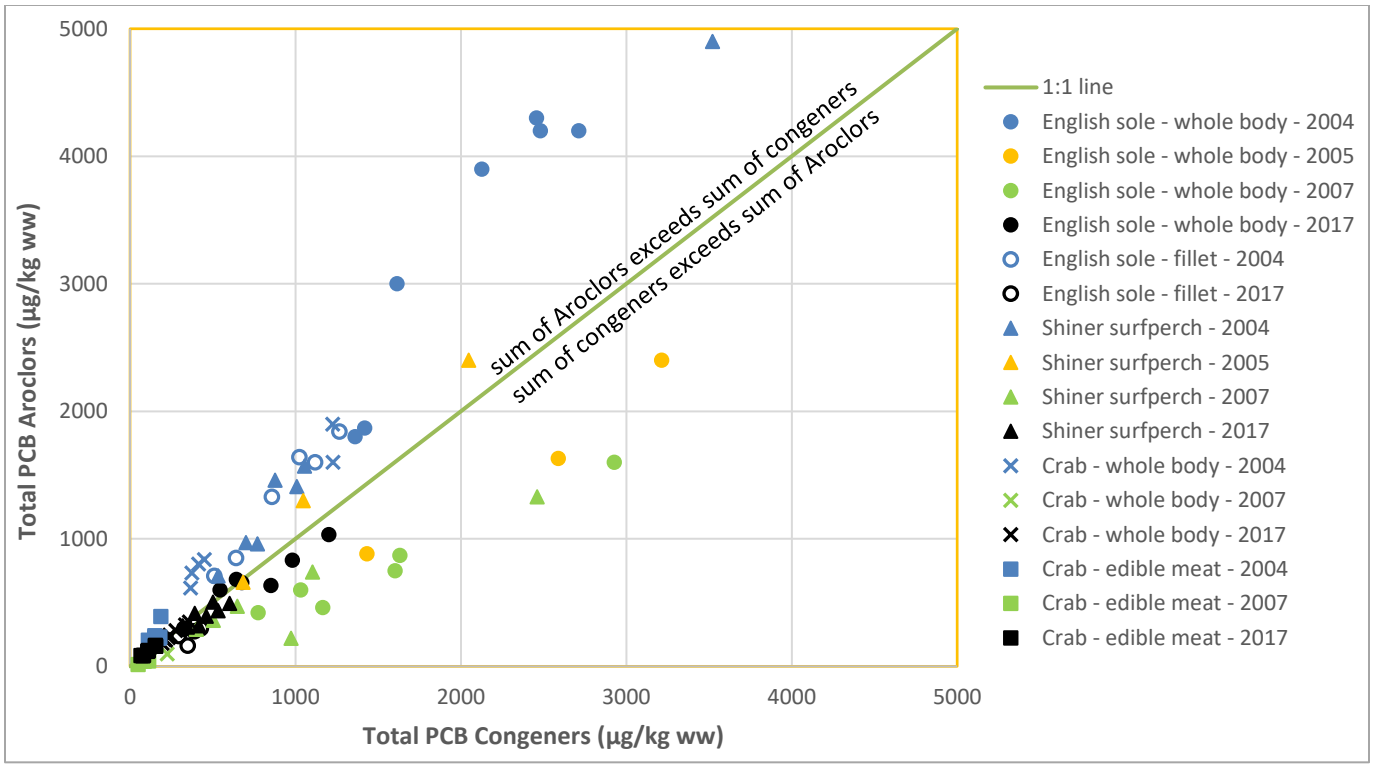


Figure 4-4. Comparison of total PCB Aroclor and congener sums for whole body tissue

This evaluation suggests that the 2003/2004 dredge operations likely resulted in increased tissue concentrations (although perhaps not to the extent indicated by the Aroclor data), and that concentrations remained high in 2005. Total PCB concentrations were lower in 2006 and 2007. Differences in the Aroclor methods[57] used in the different years likely contributed to the differences observed in Aroclor and congener data.

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 Table 4-6 and Figure 4-5. Differences exist in the sampling area, sample preparation, and analytical methods used for these datasets relative to both each other and to the LDWG sampling events. For example, total PCBs were calculated as the sum of 17 PCB congeners multiplied by a factor of two for the monitoring data from 2007 to 2017 presented by West et al. (2017); other studies reported the sum of PCB Aroclors or the sum of 209 PCB congeners. In addition, many of the pre-RI datasets presented data for skin-off English sole fillets (pre-2004 data in Figure 4-2), 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

[57] ARI used EPA method 8081 for the analysis of Aroclors for all samples. However, there were significant method modifications between 2004 and 2017, including changes in extraction protocols, analytical equipment, and data interpretation that improved the performance of the method.

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 affect existing data comparisons (Windward 2010b).[58] Lastly, uncertainty associated with the movement of the fish included in each composite (and thus the concentrations to which they were exposed) further complicates this comparison.

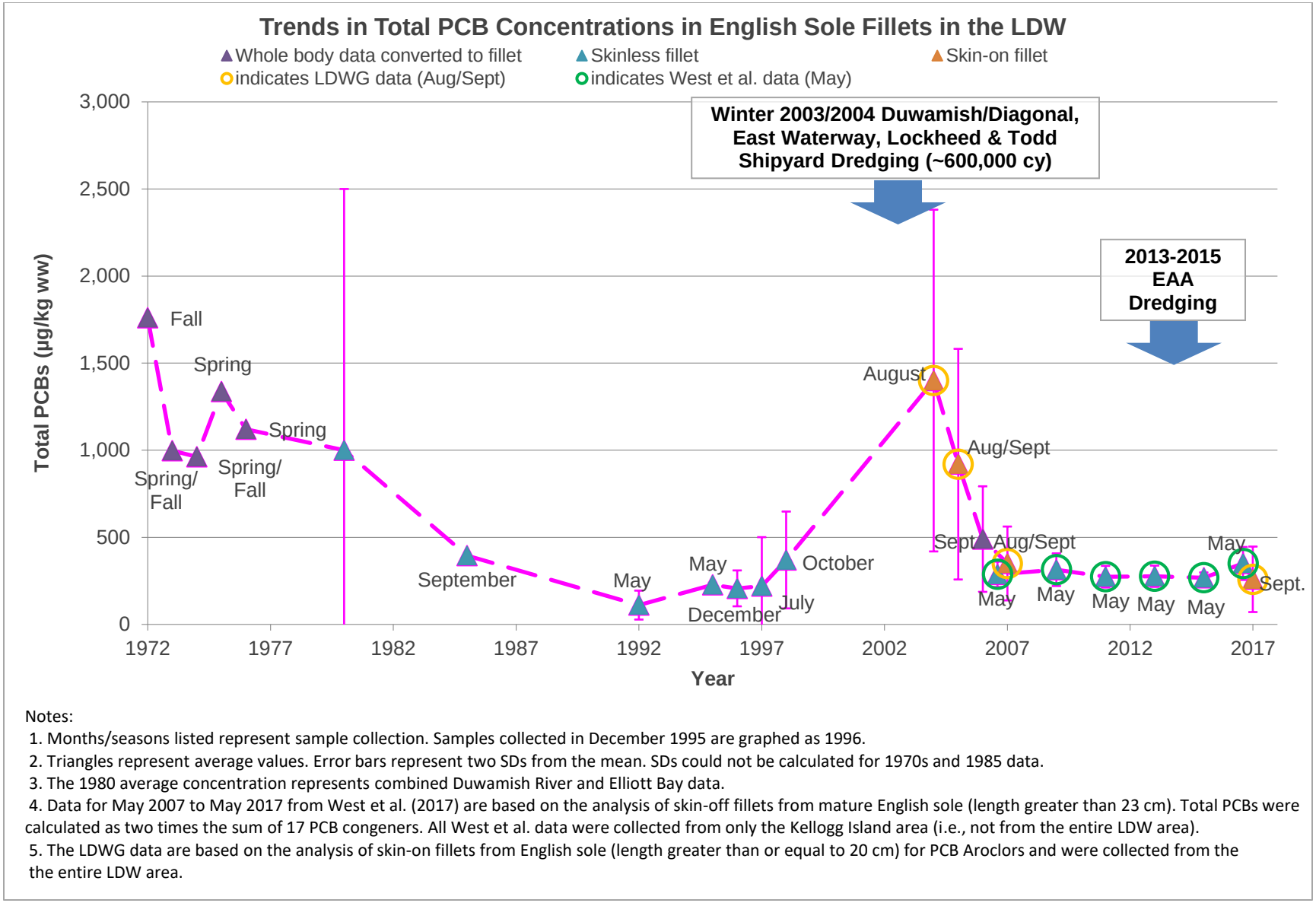
Table 4-6. Summary of existing English sole fillet data

Sampling Timing		Count of Samples	Fillet Type	No. of Fish per Composite	Average Lipid (%)	Sampling Area	Sampling Program
Year	Month or Season						
1972	fall	2	skin-on[a]	25	na	na	Butler and Schutzmann (1978)
1973	spring/fall	4	skin-on[a]	25	na	na	
1974	spring/fall	4	skin-on[a]	25	na	na	
1975	spring	2	skin-on[a]	25	na	na	
1976	spring	2	skin-on[a]	25	na	na	
1980	na	5	skin-on	na	na	near Kellogg Island only	Malins et al. (1982)
1985	September	2	skinless	na	1.9	near Kellogg Island only	EBAP
1992	May	3	skinless	10	0.48	near Kellogg Island only	PSAMP
1995	May	3	skinless	20	0.35	near Kellogg Island only	PSAMP
1995	December	3	skinless	6	11	near RM 1 only	EVS 1995
1997	May	3	skinless	20	0.30	near Kellogg Island only	King County WQA
1998	October	3	skinless	5	na	RM 2.1 and RM 3.6	WSOU
2004	August	7	skin-on	5	2.9	site-wide	LDW RI
2005	Aug/Sept	10	skin-on	5	3.5	site-wide	LDW RI
2007	September	19	skin-on	5	3.0	site-wide	LDW RI
2007	May	6	skinless	20	0.50	near Kellogg Island only	West et al. (2017)
2009	May	6	skinless	20	0.23	near Kellogg Island only	
2011	May	5	skinless	9 - 20	0.44	near Kellogg Island only	
2013	May	3	skinless	17 - 18	0.43	near Kellogg Island only	
2015	May	6	skinless	16 - 17	0.34	near Kellogg Island only	
2017	May	6	skinless	na	na	near Kellogg Island only	
2017	Aug/Sept	12	skin-on	10	2.3	site-wide	LDW Pre-Design Studies

[a] Converted from whole body using the relationship developed as part of the LDW RI.

EVS – EVS Environment Consultants
LDW – Lower Duwamish Waterway
na – not available (unknown)
PSAMP – Puget Sound Ambient Monitoring Program
RI – remedial investigation
RM – river mile
WQA – water quality assessment
WSOU – Waterway Sediment Operable Unit

[58] Skin-off and skin-on information is provided in the tables and figures for completeness only, since the RI showed that this did not significally affect the results.



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 for May 2007 to May 2017 from West et al. (2017) are based on the analysis of skin-off fillets from mature English sole (length greater than 23 cm). Total PCBs were calculated as two times the sum of 17 PCB congeners. All West et al. data were collected from only the Kellogg Island area (i.e., not from the entire LDW area).
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 the entire LDW area.

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

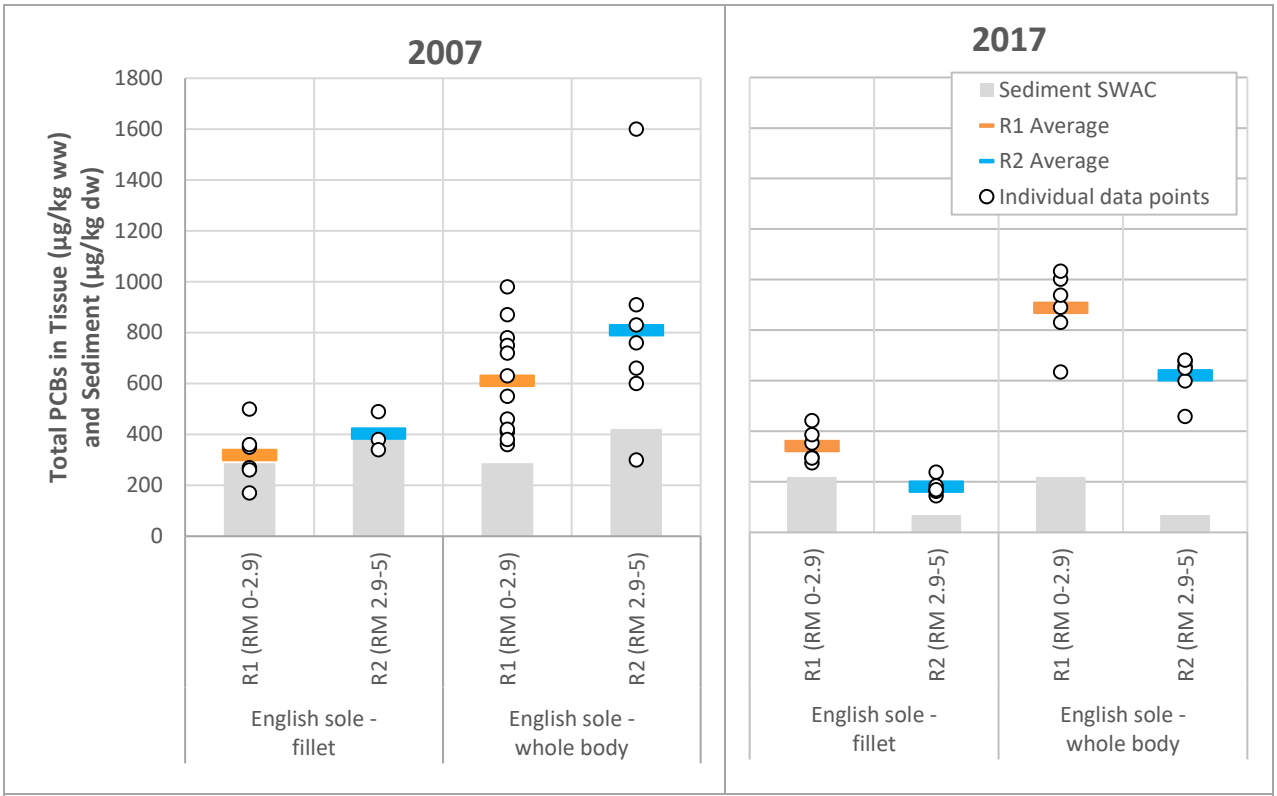
Other differences in the datasets shown on Figure 4-5 include collection location, season, lipid fraction, compositing details, and analytical methods (see notes on Figure 4-5). These differences are important to consider when interpreting these data, since they may impact some of the year-to-year variation 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 and the uncertainty in the total PCB concentrations, 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. Spatial patterns within these two sampling years were explored non-statistically using arithmetic means and concentration ranges. 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 (RM 2.9 to RM 4.8) than in Reach 1 (RM 0 to RM 2.8). 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. This comparison is complicated by the uncertainty associated with the extent to which the 2017 tissue data were influenced by the 2013–2015 dredge events.



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	621
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

Temporal Evaluation

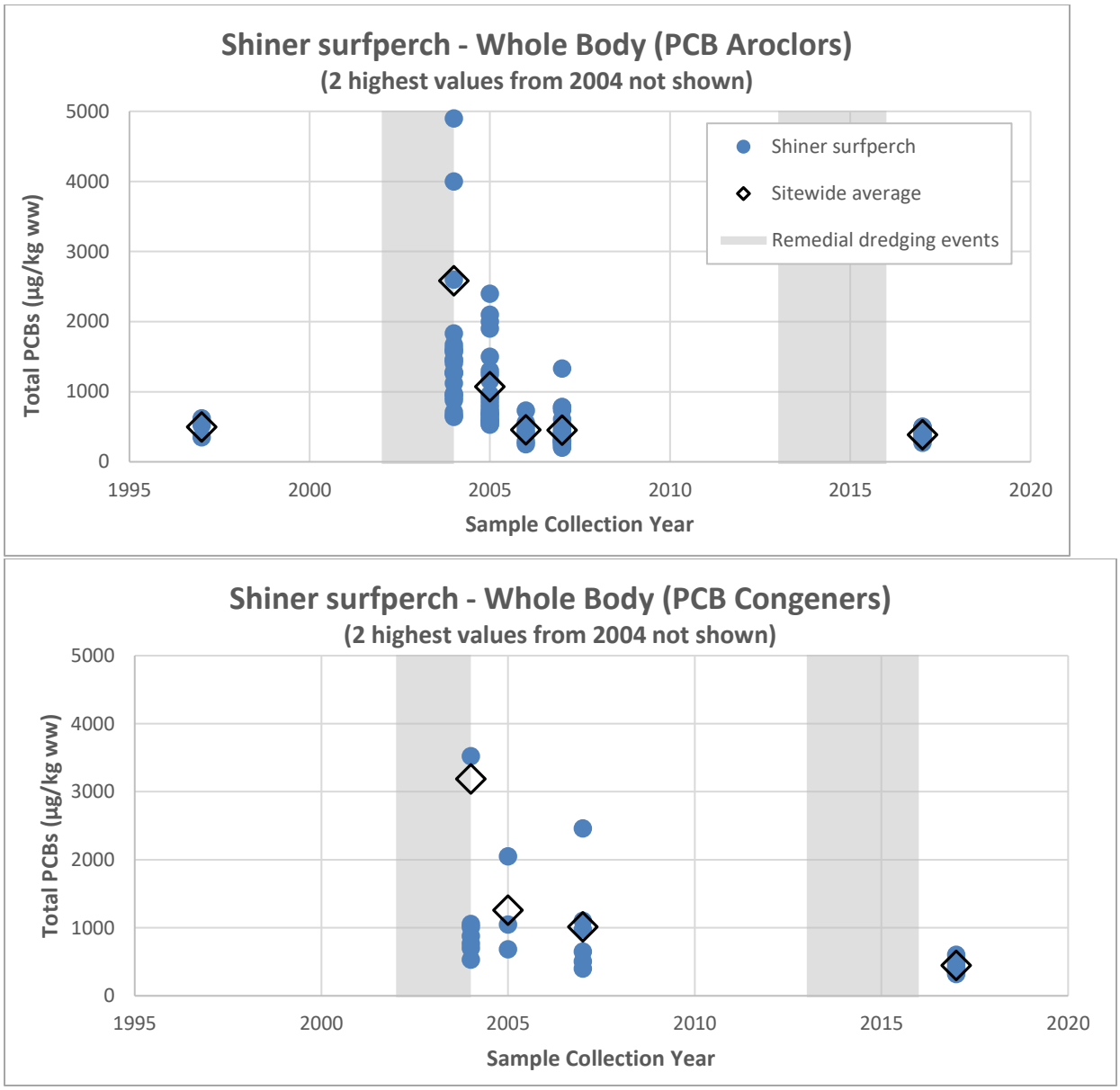
Total PCB concentrations in shiner surfperch have also been monitored over time. Data included in the RI dataset were reported for 1997, 2004, 2005, 2006, and 2007 prior to the baseline sampling in 2017; the events for which data are available are summarized in Table 4-7.

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

LDW – Lower Duwamish Waterway
RI – remedial investigation
WQA – water quality assessment

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 (Figure 4-7). These samples were collected and analyzed using similar methods throughout this time period (Windward 2004b, 2005, 2017a), and have similar lipid fractions (lipid fractions are generally higher in late summer than in spring) (Table 4-7), allowing for clear temporal comparisons.



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

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 more consistent and slightly lower than those in 2007, but the change was not significant.[59]

However, as shown in Table 4-5 and Figure 4-4, the comparison of total PCB Aroclor and congener sums suggests that the initial spike in PCB concentrations following the 2003/2004 dredge event may have been lower than indicated by the Aroclor data, and that the subsequent recovery in tissue may have been slower (i.e., concentrations remained similar [or perhaps decreased slightly] in 2005 and 2007). This evaluation supports the conclusion that concentrations and variability in the 2017 baseline samples have decreased since 2007, consistent with the removal of the highest PCB concentrations from the LDW.

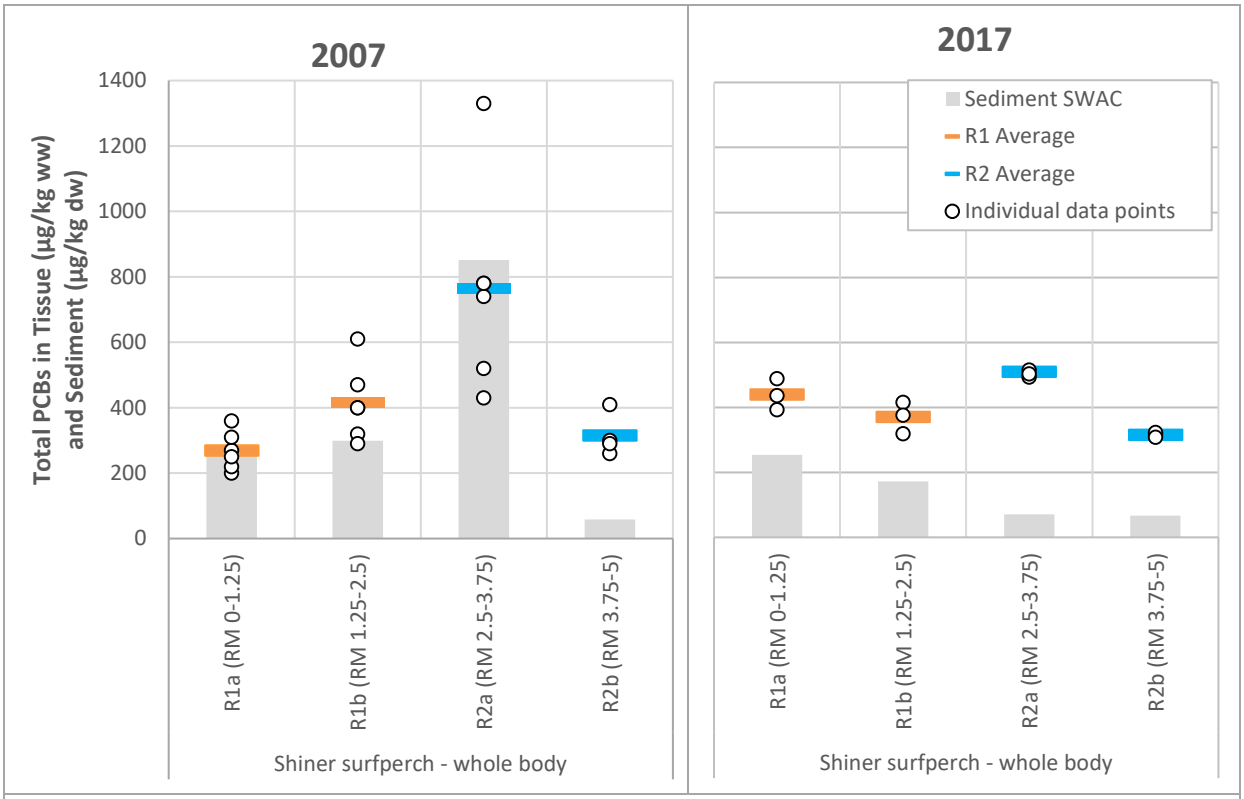
Spatial Evaluation

Figure 4-8 presents shiner surfperch tissue and surface sediment total PCB Aroclor data by reach for 2007 and 2017. Spatial patterns within these two sampling years were explored non-statistically using arithmetic means and concentration ranges. 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. This

[59] 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 = 0.55). The decrease in PCB congener concentrations from 2007 (1,016 µg/kg ww) to 2017 (446 µg/kg ww) was large in magnitude but non-significant (p = 0.051). See Appendix B, Section B4.3.1.2 for details.

comparison is complicated by the uncertainty associated with the extent to which the 2017 tissue data were influenced by the 2013–2015 dredge events.



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

Temporal Evaluation

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

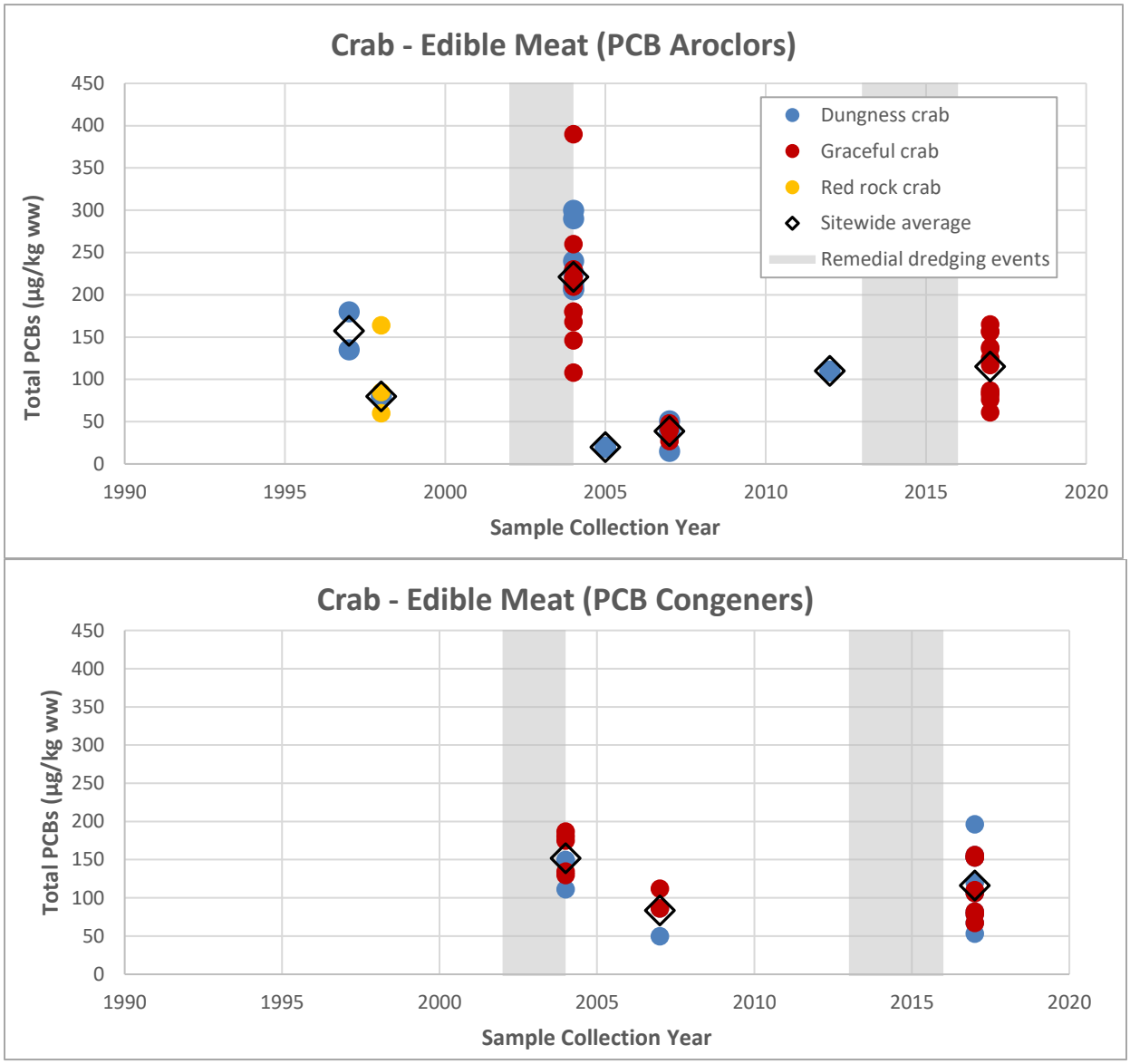
[a] Concentrations in all whole-body samples were calculated from edible meat and hepatopancreas samples.

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

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 2004b, 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 Aroclor 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

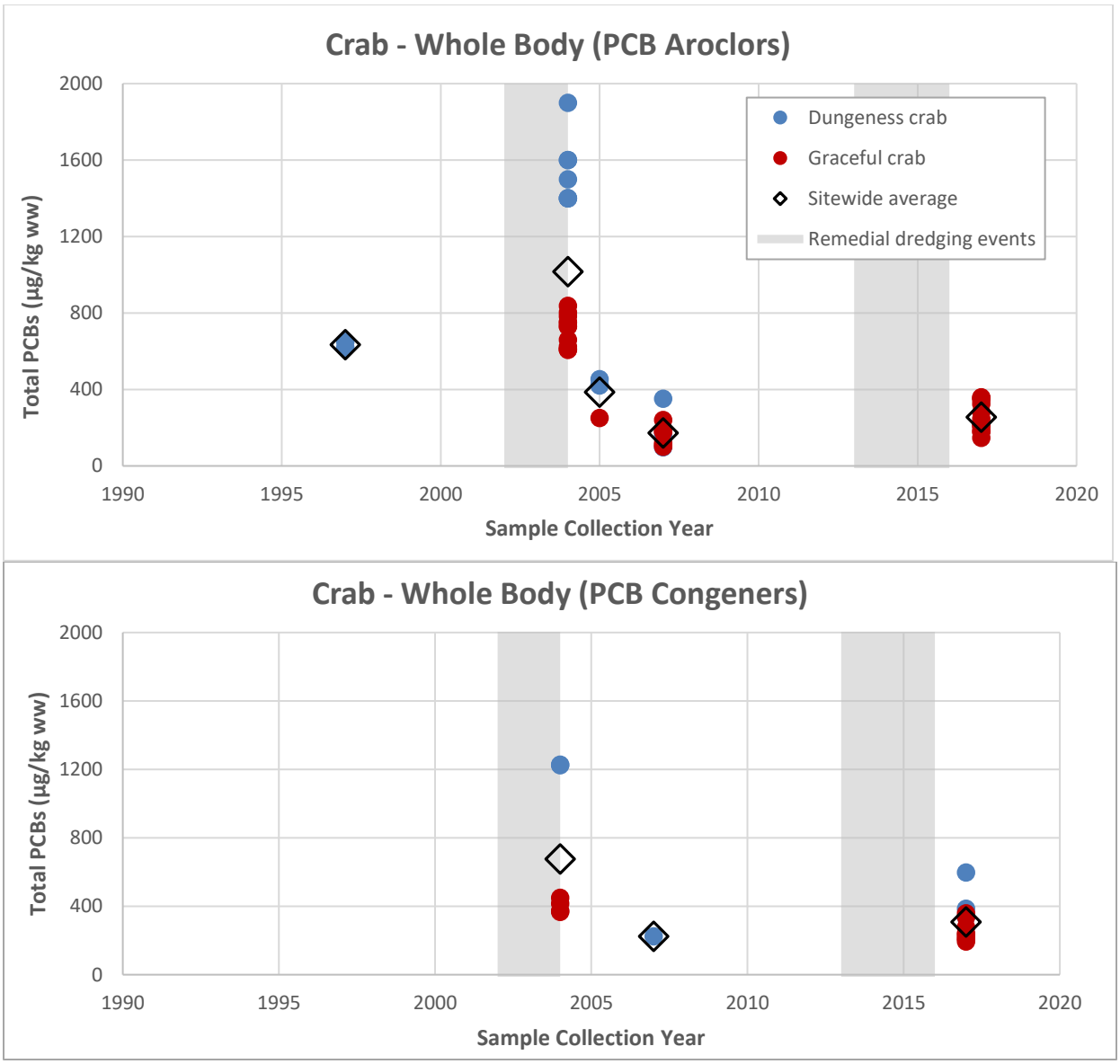
in samples prior to this time were only collected from the area near Kellogg Island (i.e., they are not representative of site-wide conditions). The 2012 Dungeness crab data from the WDFW study[60] fall within the range of concentrations observed in 2017 baseline sampling.



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

[60] 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.



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

A statistical evaluation was conducted to compare the 2007 and 2017 crab tissue data. To account for differences between 2007 and 2017 in species collected and the areas where most crabs were collected, this statistical evaluation was conducted using only graceful crab in Reach 1 for both years. Data for this analysis were limited. The statistical results are meant to simply provide information about the magnitude and statistical significance of observed changes; the results do not provide definitive statements about temporal trends. Total PCB Aroclor concentrations in both edible meat

and whole-body tissue were significantly higher in 2017 than in 2007.[61] Insufficient data are available to conduct additional statistical comparisons (e.g., comparisons using Dungeness crab, congener data, or data from Reach 2).

There are several possible factors that could help explain why PCB concentrations in crab tissue appear to have increased over this time period, whereas concentrations in English sole and shiner surfperch tissue have decreased or were similar. These factors may include the following:

- **Movement of crab** – Crab (or their prey) may move in and out of the LDW more than other species, which may complicate the comparison of their tissue concentrations between 2007 and 2017.
- **Area of evaluation** – While total PCB concentrations in sediment decreased over this time period (i.e., 2007 to 2017), the majority of that decrease was associated with EAA remediation in Reach 2; concentrations of PCBs in sediment in 2017 were about 25% lower in Reach 1 and 85% lower in Reach 2 than in 2007.[62] The statistical comparison for crab described above included only crab from Reach 1 (whereas this evaluation was conducted LDW-wide for English sole and shiner surfperch). Thus a less noticeable difference between concentrations in 2007 and 2017 might have been expected for crab.
- **Recovery from dredging** – As discussed for English sole and shiner surfperch, there is uncertainty regarding the extent to which the 2013–2015 dredging impacted the 2017 data. Dredging may have affected different species differently.
- **Aroclor vs. congener sums** – Another factor that could help to explain the crab data relates to the comparison of total PCB Aroclor and congener sums in 2007 and 2017 (Table 4-5 and Figure 4-4). The 2007 Aroclor sums were lower than the corresponding congener sums in crab tissue, whereas the 2017 Aroclor and congener sums were similar. The congener data suggest less of a difference between the two years than the Aroclor data.

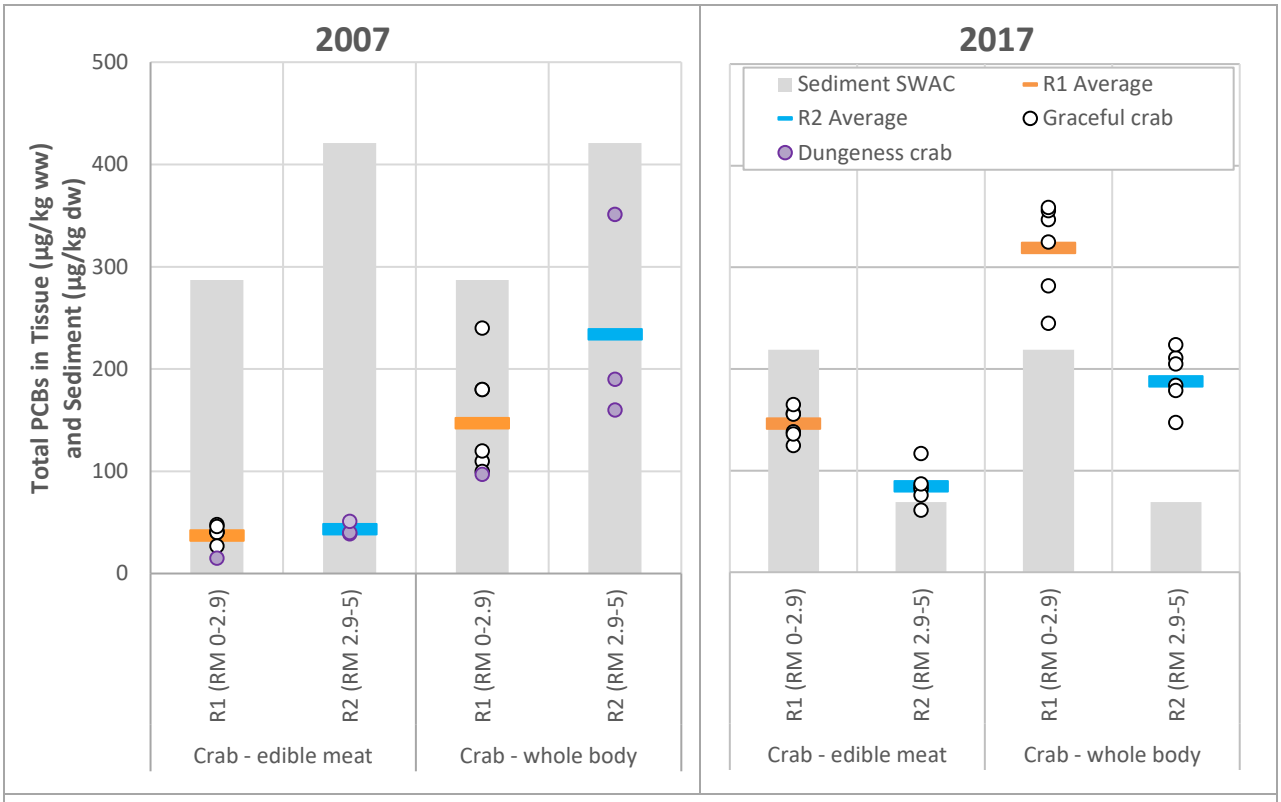
Spatial Evaluation

Figure 4-11 presents crab tissue and surface sediment total PCB Aroclor data by reach for 2007 and 2017. Spatial patterns within these two sampling years were explored non-statistically using arithmetic means and concentration ranges. General conclusions are:

[61] 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 tissue types significantly increased from 2007 to 2017: Edible meat concentrations increased from 41 µg/kg ww in 2007 to 146 µg/kg ww in 2017 ($p<<0.001$), and whole body tissues increased from 155 µg/kg ww in 2007 to 319 µg/kg ww in 2017 ($p<0.001$). (More details in Appendix B, Section B4.3.1.3).

[62] For comparison, sediment SWACs decreased from 287 to 219 µg/kg dw from 2007 to 2017 in Reach 1 and from 421 to 69 µg/kg from 2007 to 2017 in Reach 2.

- 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. This comparison is complicated by the uncertainty associated with the extent to which the 2017 tissue data were influenced by the 2013–2015 dredge events.



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 crab tissues 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.

Total PCB Homolog Patterns

PCB homolog patterns were also assessed across tissue types. Patterns were similar across all crab samples (i.e., both Dungeness and graceful crab) and were generally similar across samples for fish (i.e., English sole and shiner surfperch). Figure 4-12 presents the average homolog pattern for crab and fish, along with the pattern for clams (which are discussed in Section 5). Clams have a higher percent contribution from the lower-weight homologs (i.e., tri, tetra, and penta-CBs) than do crab and fish, perhaps reflecting differing pathways of exposure or uptake mechanisms.

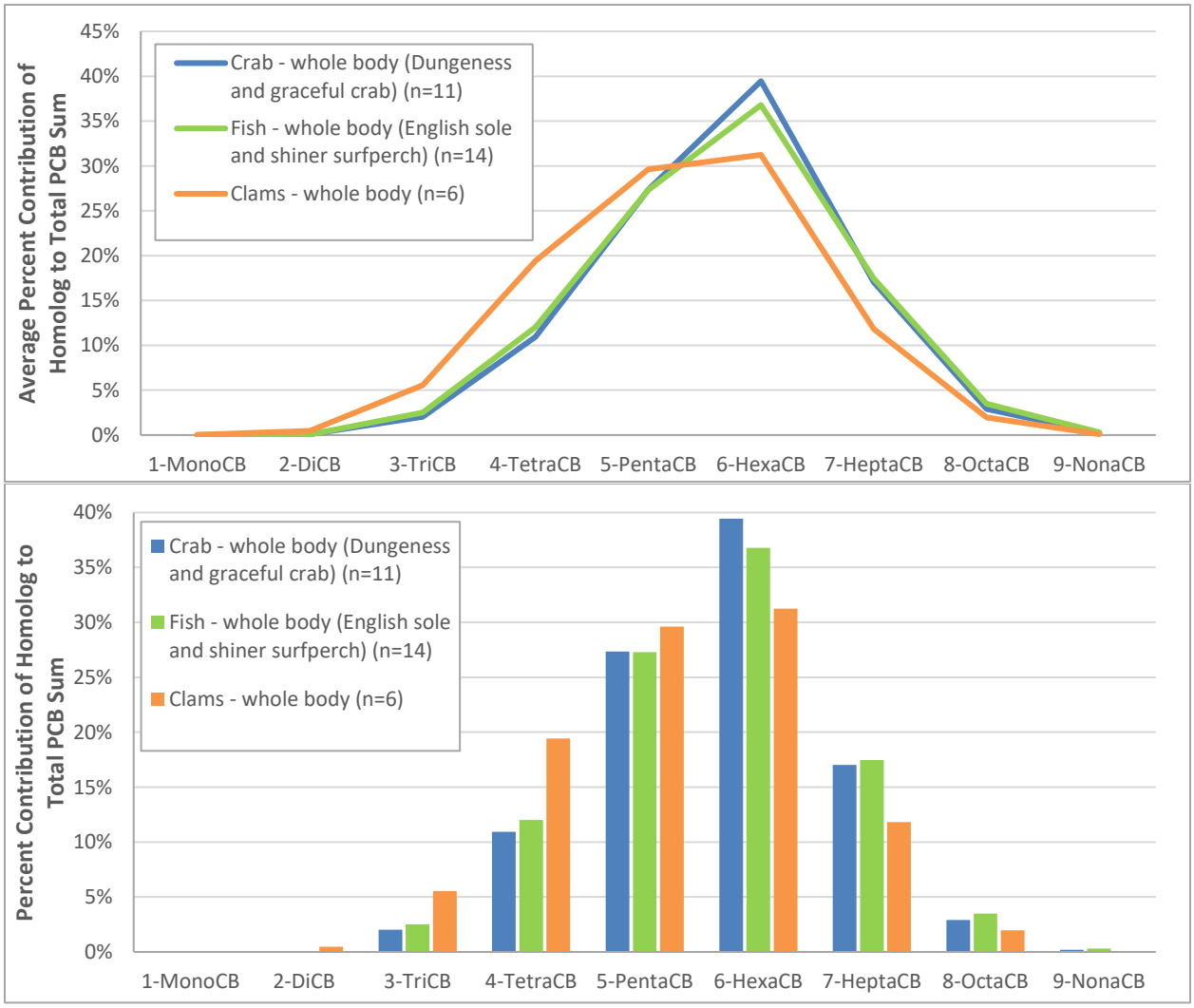


Figure 4-12. Average homolog patterns for fish, crab, and clams in 2017 baseline samples

One other observation of note regarding homolog patterns can be seen by comparing the homolog patterns for shiner surfperch from the four different areas from which they were collected (Map 4-1). Two composites of 15 fish each were analyzed in each of the four areas. As shown on Figure 4-13, the patterns for Reaches 1a and 1b are nearly identical, and the pattern for Reach 2b is relatively similar. However, the average pattern for the two samples collected from Reach 2a had greater contributions from the higher chlorinated biphenyls (i.e., hexa, hepta, and octa), potentially indicating a different pattern in this area.

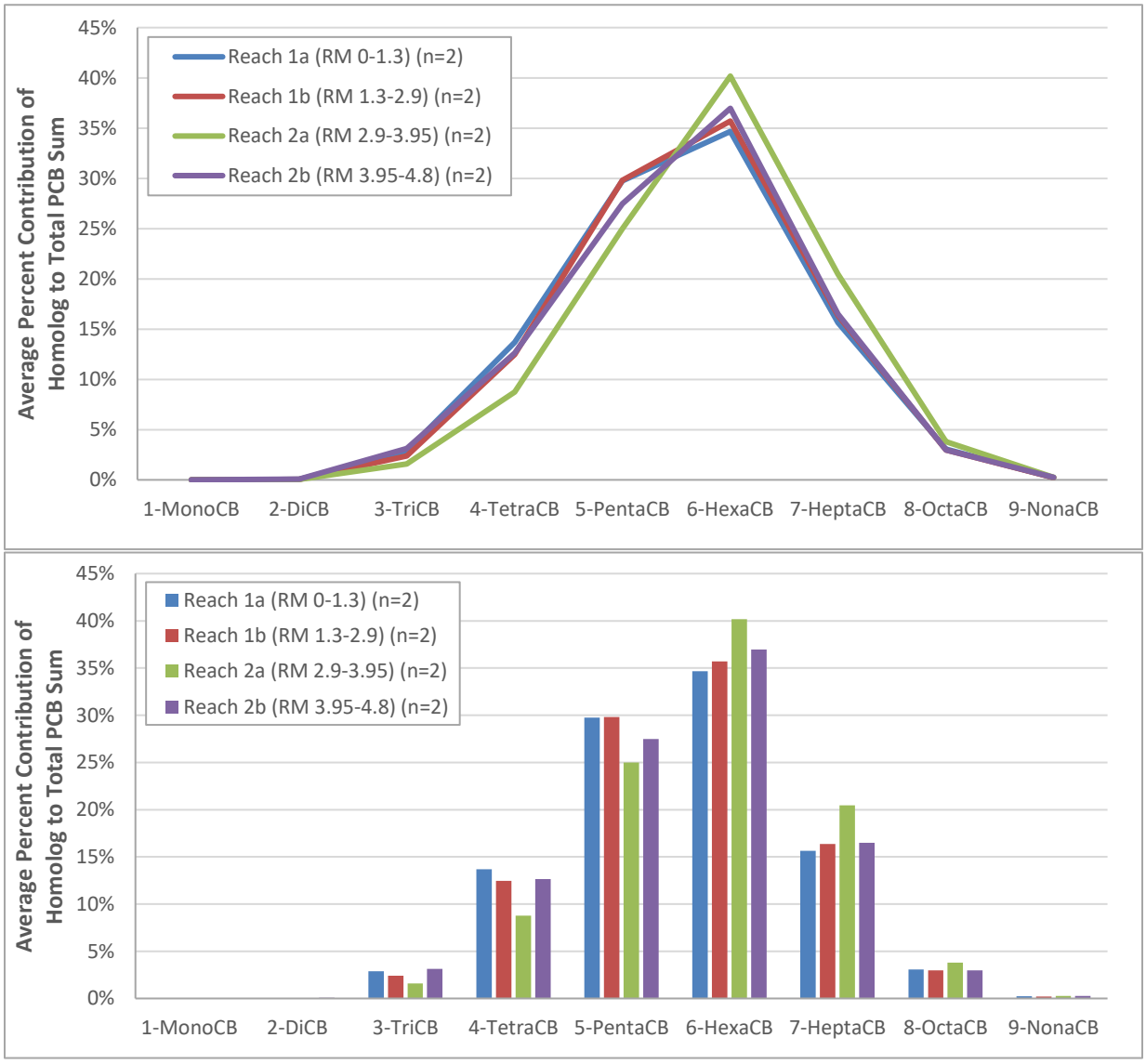


Figure 4-13. Average homolog patterns by area for shiner surfperch in 2017 baseline samples

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/FS (Windward 2010b; AECOM 2012). 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 that was developed and calibrated[63] for the LDW using site-specific data. The FWM is intended to represent average values in the LDW, and thus the model uses parameter values that are averages (e.g., for PCB concentrations in sediment, water, and tissue). 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).[64] 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

[63] 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.

[64] 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

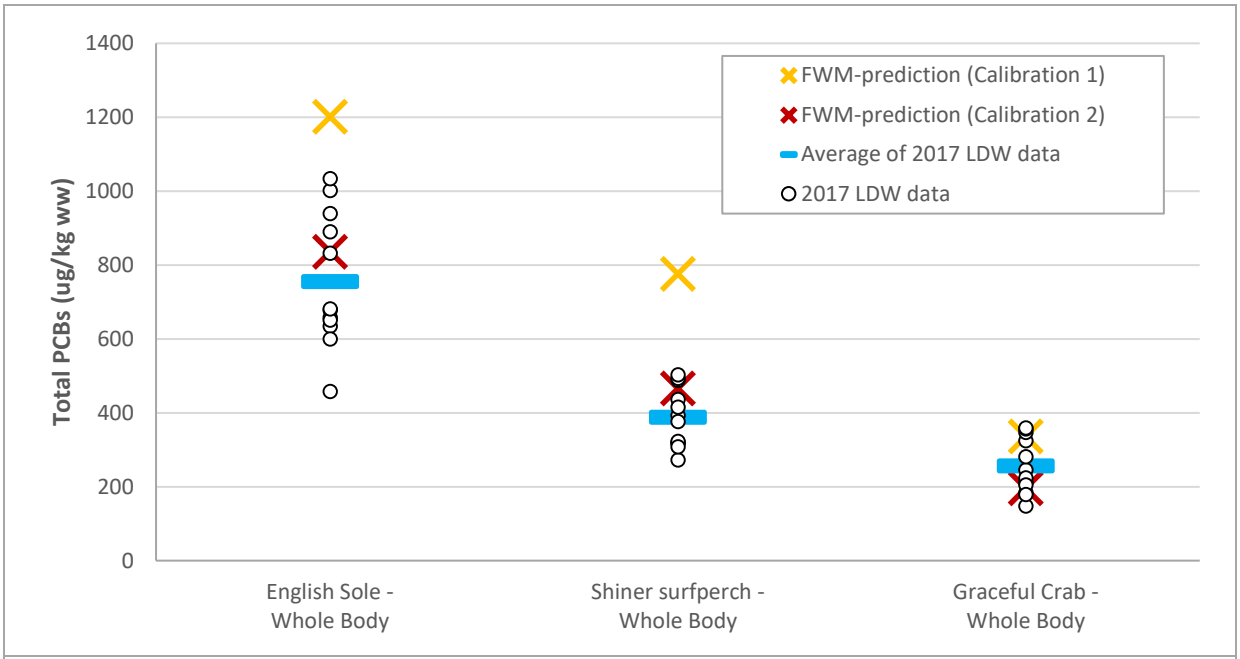
concentration divided by the lower of these two values. If the predicted concentrations were higher than the LDW average, a plus sign (+) was added before the SPAF to indicate that the model was over-predicting concentrations. Conversely, if the predicted concentration was lower than the LDW average, 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 4-14. 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.[65] 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.

fish/crab are exposed. The FWM represents average conditions, so storm sample concentrations were excluded because they are not representative of the typical conditions to which the fish are exposed.

[65] 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 4-14. 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 4-14). 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 4-15. The model over-predicted in the downstream reaches and subreaches and under-predicted in the upstream reaches for English sole and shiner surfperch (Figure 4-15); 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 (µg/kg dw)	219	69	254	172	71	67
Water[a] (ng/L)	0.9	0.9	0.9	0.9	0.9	0.9
SPAFs						
English sole	+1.1	-1.3	-	-	-	-
Shiner surfperch	-	-	+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

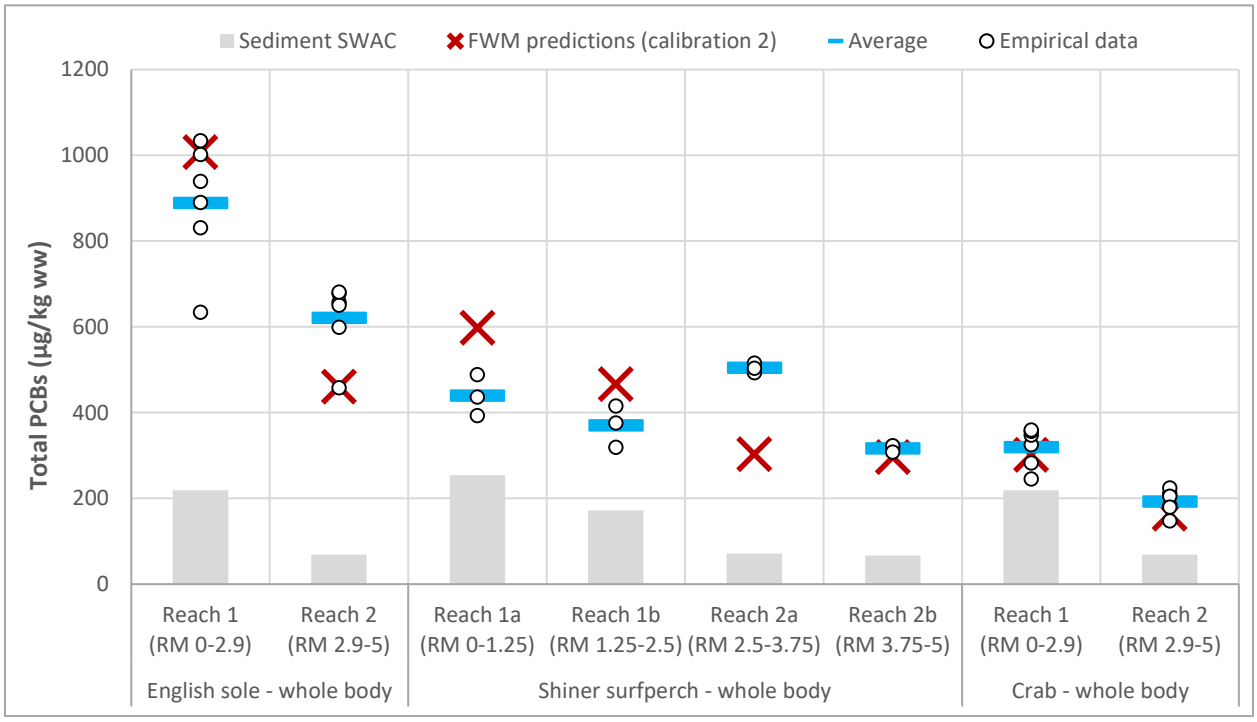
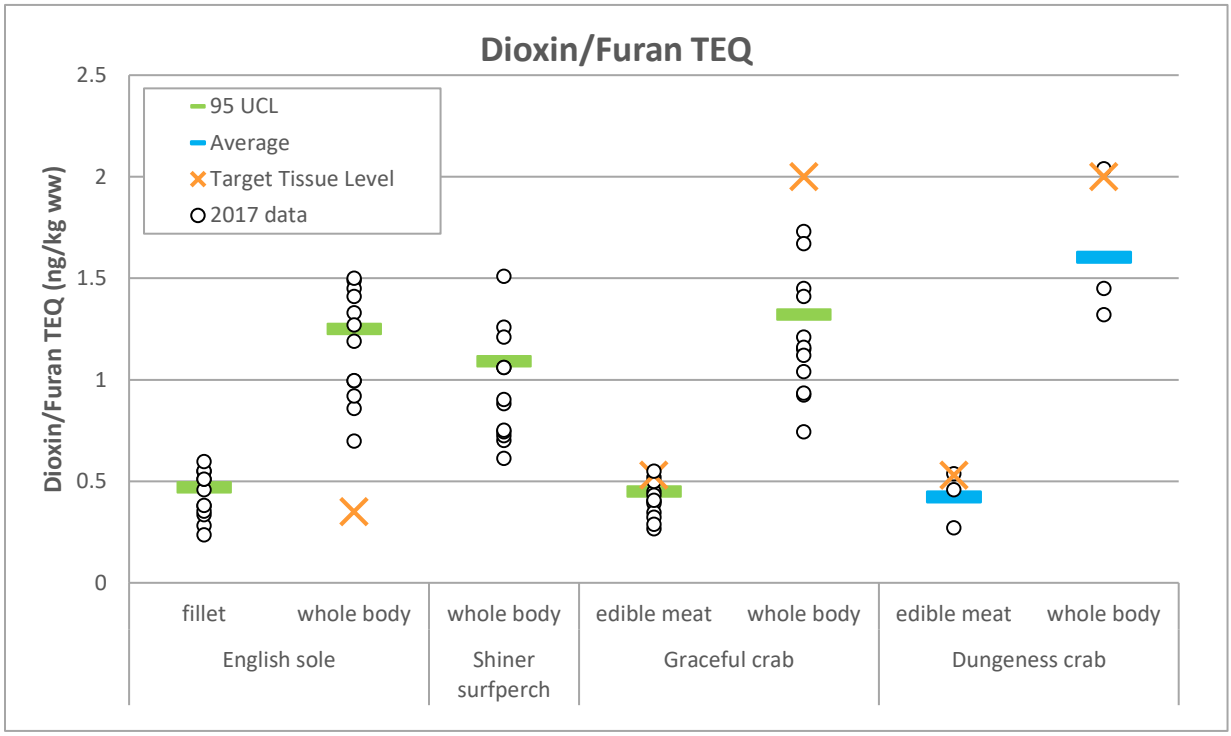


Figure 4-15. FWM results by reach for Pre-Design Studies baseline data

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 suggests that tissue concentrations are generally responding as expected due to changes in sediment and surface water concentrations.

4.2.1.3 Dioxins/furans

This section provides additional discussion of the dioxin/furan baseline tissue data. Figure 4-16 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.

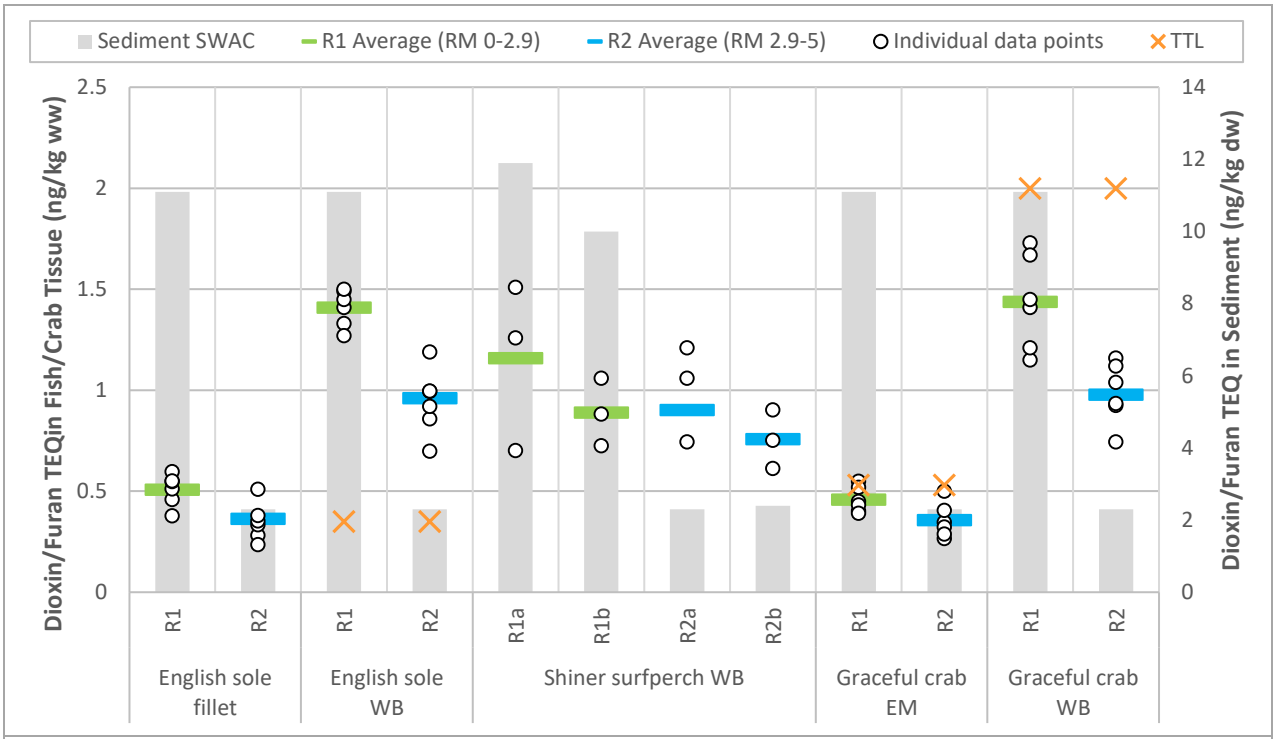


Notes: TTLs are available for all species/tissue types, with the exception of English sole fillet and shiner surfperch (for which no non-urban background data were available to develop a TTL). The TTL in the ROD is for Dungeness crab but is compared with both graceful and Dungeness crab data in this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

Figure 4-16. Dioxin/furan TEQs in Pre-Design Studies baseline fish/crab tissue compared with TTLs

Figure 4-17 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, although results were not statistically evaluated. 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 4-17. 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 inorganic arsenic and cPAHs compared with the tissue dataset used in the HHRA, which included data collected between 1992 and 2005 (Windward 2007). Depending on tissue type, concentrations of inorganic arsenic in the 2017 baseline samples were relatively similar to or higher (by a factor of 2 to 4) than those used to evaluate risks to human health in the HHRA (statistical comparisons of these data are reported in Appendix B, Section B4.3.2). cPAHs were not detected in any of the 2017 baseline crab samples.

Table 4-10. Comparison of inorganic arsenic concentrations and cPAH TEQs in fish and crab tissue in HHRA and baseline datasets

Analyte and Tissue Type	Summary of HHRA Data			Summary of 2017 Data		
	Detection Frequency	Range of Values	Average[a]	Detection Frequency	Range of Values	Average[a]
Inorganic arsenic (mg/kg ww)						
English sole – fillet[b]	6/8	0.003–0.006 J	0.004	1/12	0.005 J–0.010 U	0.005
English sole – whole body[b]	8/8	0.020–0.090	0.056	12/12	0.056–0.369	0.122
Shiner surfperch – whole body[c]	8/10	0.010 U–0.160	0.057	12/12	0.028–0.076	0.046
Crab – edible meat[d]	6/6	0.010–0.030	0.023	12/12	0.031–0.251	0.097
Crab – whole body[d]	6/6	0.022 J–0.123	0.075	12/12	0.070–0.253	0.114
cPAH TEQ (µg/kg ww)[e]						
Crab – edible meat	8/19	0.33 J–0.84 J	0.44	0/12	0.91 U[f]	nc
Crab – whole body	19/19	0.45–2.4 J	0.75	0/12	0.91 U[f]	nc

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

[b] In addition to English sole, the HHRA dataset includes starry flounder data.

[c] In addition to shiner surfperch, the HHRA dataset includes pile perch and striped perch data and a mix of tissue types.

[d] The HHRA dataset includes a mix of crab species (i.e., Dungeness, graceful, and red rock crab), whereas the baseline dataset includes only graceful crab.

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

[f] Values calculated as the ½ MDL. Although the Work Plan (Windward and Integral 2017c) specified the use of ½ RLs for non-detected values, cPAH TEQs calculated using ½ MDLs are presented herein because of the high RLs for PAHs. Using the ½ RL, values for crab edible meat and whole body would range from 2.25 U to 2.27 U µg/kg ww.

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
TEQ – toxic equivalent
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. Thus, there is too much uncertainty to draw conclusions from this comparison.
- **Pesticides –** Concentrations of pesticides in the 2017 baseline tissue samples were generally similar to or lower than concentrations in the HHRA dataset. The RI tissue dataset and the baseline dataset were analyzed using the same high-resolution analytical method (EPA 8270D/1699mod). However, older data in the HHRA dataset that were analyzed using other methods had elevated pesticide results that were qualified as tentatively identified (JN qualification) because of probable analytical interference associated with the presence of PCBs. 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 HHRA Data			Summary of 2017 Baseline Data		
	Detection Frequency	Range of Values	Average[a]	Detection Frequency	Range of Values	Average[a]
Vanadium (mg/kg ww)						
English sole – fillet[b]	0 / 8	0.25 U	nc	2/2	0.0461–0.0480	0.0471
English sole – whole body[b]	24 / 24	0.2 J–0.5	0.4	2/2	0.336–0.357	0.347
Shiner surfperch – whole body[c]	22 / 26	0.21 J–1.23	0.4	2/2	0.761–0.821	0.791
Crab – edible meat[d]	0 / 19	0.21 U	nc	2/2	0.199–0.241	0.220
Crab – whole body[d]	12 / 19	0.11 U–0.2 J	0.1	2/2	0.202–0.235	0.219

Analyte and Tissue Type	Summary of HHRA Data			Summary of 2017 Baseline Data		
	Detection Frequency	Range of Values	Average[a]	Detection Frequency	Range of Values	Average[a]
TBT (mg/kg ww)						
English sole – fillet[b]	10 / 17	0.74 U–5.7	2.0	0/2	3.84 U–3.85 U	nc
English sole – whole body[b]	18 / 23	1.5 U–15	5.7	0/2	3.82 U–3.84 U	nc
Shiner surfperch – whole body[c]	31 / 31	4.8–180	51	2/2	8.44–12.1	10.3
Crab – edible meat [d]	9 / 25	1.5 U–82	6.2	0/2	3.84 U–3.85 U	nc
Crab – whole body[d]	15 / 21	0.75 U–75	9.9	0/2	3.84 U–3.85 U	nc

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

[b] In addition to English sole, the HHRA dataset includes starry flounder data.

[c] In addition to shiner surfperch, the HHRA dataset includes pile perch and striped perch data and a mix of tissue types.

[d] The HHRA dataset includes a mix of crab species (i.e., Dungeness, graceful, and red rock crab), whereas the baseline dataset includes only graceful crab.

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 HHRA Data			Summary of 2017 Baseline Data		
	Detection Frequency	Range of Values[a]	Average[b]	Detection Frequency	Range of Values	Average[b]
BEHP (µg/kg ww)						
English sole – fillet[c]	2/14	3.6 U–1,300 J	190	0/2	49.6 U	nc
English sole – whole body[c]	0/24	66 U–3,600 U	nc	2/2	340–341	341
Shiner surfperch – whole body[d]	5/29	24 U–3,600 J	740	2/2	495–496	496
Crab – edible meat[e]	0/21	16 U–260 U	nc	2/2	49.7–49.9	49.8
Crab – whole body[e]	3/21	9.2 U–100 U	30	2/2	77.6–78.0	77.8
Carbazole (µg/kg ww)						
English sole – fillet[c]	0/14	3.6 U–2,900 U	nc	0/2	19.8 U	nc
English sole – whole body[c]	0/24	1,500 U–2,900 U	nc	2/2	16.6	16.6
Shiner surfperch – whole body[d]	2/29	40 U–14,000	1,200	2/2	19.8	19.8
Crab – edible meat[e]	0/21	27 U–2,900 U	nc	2/2	19.9–20.0	20.0
Crab – whole body[e]	0/21	16 U–1,500 U	nc	2/2	19.9–20.0	20.0

Analyte and Tissue Type	Summary of HHRA Data			Summary of 2017 Baseline Data		
	Detection Frequency	Range of Values[a]	Average[b]	Detection Frequency	Range of Values	Average[b]
HCB (µg/kg ww)						
English sole – fillet[c]	1/14	1.1 JN–18 U	5.5	0/2	19.8 U	nc
English sole – whole body[c]	4/24	4.4 JN–10 U	4.5	2/2	16.6	16.6
Shiner surfperch – whole body[d]	1/29	1.5 U–24 U	2.5	2/2	19.8	19.8
Crab – edible meat[e]	1/21	0.93 JN–16 U	2.3	2/2	19.9–20.0	20.0
Crab – whole body[e]	4/21	0.75 U–9.2 U	2.0	2/2	19.9–20.0	20.0
PCP (µg/kg ww)						
English sole – fillet[c]	0/14	3.3 U–5,800 U	nc	0/2	99.2 U	nc
English sole – whole body[c]	6/24	1.1 J–2,900 U	610	2/2	82.9	82.9
Shiner surfperch – whole body[d]	2/29	2.8 U–2,900 U	63	2/2	99.0–99.2	99.1
Crab – edible meat[e]	0/21	3.3 U–580 U	nc	2/2	99.4–99.8	99.6
Crab – whole body[e]	0/21	1.7 J–2,000 U	nc	2/2	99.4–99.7	99.6

[a] RLs are sample specific and affected by sample dilution. The highest RL values reflect samples that were diluted in order to get target SVOC concentrations within calibration ranges.

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

[c] In addition to English sole, the HHRA dataset includes starry flounder data.

[d] In addition to shiner surfperch, the HHRA dataset includes pile perch and striped perch data and a mix of tissue types.

[e] The HHRA dataset includes a mix of crab species (i.e., Dungeness and graceful crab), whereas the baseline dataset includes only graceful crab.

BEHP – bis(2-ethylhexyl) phthalate
HCB – hexachlorobenzene
HHRA – human health risk assessment
J – estimated concentration
JN – tentative identification of estimated concentration
nc – not calculated
PCP – pentachlorophenol
RL – reporting limit
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 HHRA Data			Summary of 2017 Baseline Data		
	Detection Frequency	Range of Values	Average[a]	Detection Frequency	Range of Values	Average[a]
Aldrin (µg/kg ww)						
English sole – fillet[b]	0/17	0.5 U–7.2 U	nc	0/2	0.77 U–0.89 U	nc
English sole – whole body[b]	1/24	6.2 JN–10 U	4.2	0/2	0.79 U–0.91 U	nc
Shiner surfperch – whole body[c]	1/26	1.4 JN–7.2 U	1.0	0/2	0.88 U–0.92 U	nc
Crab – edible meat[d]	0/19	1.5 U–7.2 U	nc	1/2	0.34 J–0.96 U	0.41
Crab – whole body[d]	0/19	0.75 U–3.6 U	nc	1/2	0.37 J–0.94 U	0.42

Analyte and Tissue Type	Summary of HHRA Data			Summary of 2017 Baseline Data		
	Detection Frequency	Range of Values	Average[a]	Detection Frequency	Range of Values	Average[a]
alpha-BHC (µg/kg ww)						
English sole – fillet[b]	1/17	0.38 JN–7.2 U	1.6	2/2	0.42 J–0.83 J	0.63
English sole – whole body[b]	0/24	1.0 U–10 U	nc	2/2	0.49 J–0.68 J	0.59
Shiner surfperch – whole body[c]	2/26	0.45 JN–7.2 U	1.2	2/2	0.55 J–1.1 J	0.83
Crab – edible meat[d]	0/19	1.5 U–7.2 U	nc	2/2	0.60 J–0.61 J	0.61
Crab – whole body[d]	3/19	0.75 U–3.6 U	1.0	2/2	0.56 J–0.57 J	0.57
beta-BHC (µg/kg ww)						
English sole – fillet[b]	2/17	0.5 U–7.2 U	1.6	0/2	0.77 U–0.89 U	nc
English sole – whole body[b]	9/24	4.0 JN–10 U	4.6	0/2	0.79 U–0.91 U	nc
Shiner surfperch – whole body[c]	16/26	1.5 U–15 JN	5.7	0/2	0.88 U–0.92 U	nc
Crab – edible meat[d]	0/19	1.5 U–8.2 U	nc	0/2	0.92 U–0.96 U	nc
Crab – whole body[d]	0/19	0.75 U–3.6 U	nc	0/2	0.91 U–0.94 U	nc
gamma-BHC (µg/kg ww)						
English sole – fillet[b]	0/17	0.5 U–7.2 U	nc	1/2	0.25 J–0.89 U	0.35
English sole – whole body[b]	2/24	2.3 JN–10 U	4.1	1/2	0.35 J–0.91 U	0.41
Shiner surfperch – whole body[c]	7/26	0.59 JN–7.2 U	1.4	2/2	0.22 J–0.47 J	0.35
Crab – edible meat[d]	1/19	1.5 U–7.2 U	1.8	2/2	0.31 J–0.38 J	0.35
Crab – whole body[d]	1/19	0.75 U–3.6 U	1.4	2/2	0.35 J–0.40 J	0.38
Total chlordane (µg/kg ww)						
English sole – fillet[b]	11/17	1.6 J–28 JN	8.6	2/2	1.04 J–1.31 J	1.18
English sole – whole body[b]	24/24	6.3 JN–59 JN	33	2/2	3.4 J–4.5 J	4.0
Shiner surfperch – whole body[c]	26/26	3.9 JN–330	31	2/2	1.27 J–2.26 J	1.77
Crab – edible meat[d]	19/19	2.0 JN - 63 JN	4	1/2	0.11 J–2.3 U	0.66
Crab – whole body[d]	19/19	9.0 JN–26 JN	16	2/2	0.20 J–0.46 J	0.33
Total DDTs (µg/kg ww)						
English sole – fillet[b]	15/17	1.1–103 JN	37	2/2	3.0 J–6.3 J	4.7
English sole – whole body[b]	24/24	51 JN–280 JN	170	2/2	11.3 J–15.4 J	13.4
Shiner surfperch – whole body[c]	26/26	10 JN–1,020 JN	170	2/2	3.9 J–7.9 J	5.9
Crab – edible meat[d]	19/19	11 JN–32 JN	21	2/2	0.94 J–1.7 J	1.3
Crab – whole body[d]	19/19	48 JN–150 JN	90	2/2	3.9 J	3.9
Dieldrin (µg/kg ww)						
English sole – fillet[b]	0/17	1.0 U -7.2 U	nc	1/2	0.30 J–0.89 U	0.38
English sole – whole body[b]	0/24	2.0 U–10 U	nc	2/2	0.66 J–0.79	0.73
Shiner surfperch – whole body[c]	0/26	1.5 U–7.2 U	nc	0/2	0.88 U–0.92 U	nc
Crab – edible meat[d]	1/19	1.3 JN–7.2 U	1.9	0/2	0.92 U–0.96 U	nc
Crab – whole body[d]	1/19	1.6 U–7.8 U	1.7	0/2	0.91 U–0.94 U	nc

Analyte and Tissue Type	Summary of HHRA Data			Summary of 2017 Baseline Data		
	Detection Frequency	Range of Values	Average[a]	Detection Frequency	Range of Values	Average[a]
Heptachlor (µg/kg ww)						
English sole – fillet[b]	0/17	0.5 U–7.2 U	nc	2/2	0.14 J–0.20 J	0.17
English sole – whole body[b]	2/24	1.0 U–10 U	4.2	2/2	0.11 J–0.20 J	0.16
Shiner surfperch – whole body[c]	1/26	1.5 U–9.7 JN	1.7	2/2	0.25 J -0.27 J	0.26
Crab – edible meat[d]	0/19	1.5 U–7.2 U	nc	2/2	0.24 J–0.25 J	0.25
Crab – whole body[d]	0/19	1.5 U–9.7 U	nc	2/2	0.22 J–0.23 J	0.23
Heptachlor epoxide (µg/kg ww)						
English sole – fillet[b]	0/17	0.5 U–7.2 U	nc	0/2	0.77 U–0.89 U	nc
English sole – whole body[b]	13/24	7.2 U–45 JN	16	1/2	0.29 J–0.91 U	0.38
Shiner surfperch – whole body[c]	5/26	1.5 U–10 JN	2.6	0/2	0.88 U–0.92 U	nc
Crab – edible meat[d]	15/19	0.93 JN–7.2 U	1.9	1/2	0.19 J–0.92 U	0.33
Crab – whole body[d]	15/19	1.0 U–5.5 JN	3.2	1/2	0.26 J–0.91 U	0.36

[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.

[b] In addition to English sole, the HHRA dataset includes starry flounder data.

[c] In addition to shiner surfperch, the HHRA dataset includes pile perch and striped perch data and a mix of tissue types.

[d] The HHRA dataset includes a mix of crab species (i.e., Dungeness and graceful crab), whereas the baseline dataset includes only graceful crab.

BHC – benzene hexachloride
DDT – dichlorodiphenyltrichloroethane
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	• The ROD includes TTLs 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. • An evaluation of trends in total PCB tissue concentrations (using Aroclor data) found that concentrations in 2017 baseline samples were lower than concentrations in 2007 for English sole fillet, similar to 2007 concentrations for English sole whole body and shiner surfperch tissue, and higher than concentrations in 2007 for crab (both whole-body and edible meat tissue). However, this comparison is uncertain because of Aroclor method differences and the extent to which the 2013–2015 dredge events may have affected the 2017 results. • 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, except for shiner surfperch in subreach 2a). • The LDW FWM predictions (using Calibration 2) and the Pre-Design Studies dataset are similar, suggesting that the tissue concentrations are responding as expected to the ongoing remediation in the LDW.
Dioxin/ furan TEQ	• The ROD includes TTLs for three fish/crab seafood categories (English sole whole body, crab edible meat, and crab whole body). • The site-wide 95UCL for English sole (whole body) was above the TTL. • The 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	• The ROD does not include a fish or crab TTL for cPAH. • cPAHs were not detected in baseline crab tissue samples.
Inorganic arsenic	• The ROD does not include a fish or crab TTL for 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. However, the presence of non-detected values and changes in analytical methods (e.g., for pesticides) may complicate this comparison in some cases.

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
ROD – Record of Decision
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 2018e).

5.1 DQOs and Data Collected

As described in the clam tissue QAPP (Windward 2018e), 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 from clam tissue collection areas in the LDW (Map 5-1), as described in Table 5-1. The targeted intertidal areas included the areas from which clams were collected in 2004 and 2007 as part of the RI sampling program, which were generally areas identified as having high-quality clam habitat in the 2003 LDW clam abundance survey (Windward 2004a).[66] The clam tissue QAPP (Windward 2018e) discussed 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 (Slip 4) and C09 (RM 2.9 to RM 3.4 W) to create a composite sample.	9 whole-body samples

[66] As in the RI, clam collection was not attempted in all of the potential intertidal clamming areas discussed in Section 2 (Map 2-8). Rather, sampling was focused on the high-quality habitat areas, which were designated as clam tissue collection areas (Map 5-2).

Composite Type	Summary of Sampling Design	Total No. of 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 (Appendix H). 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
RM – river mile
ROD – record of decision
SVOC – semivolatile organic compound
TBT – tributyltin
TEQ – toxic equivalent

Clam tissue was collected as described in the QAPP (Windward 2018e) 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. However, there was considerable uncertainty in the calculation of cPAH TEQs because of the low detection frequencies for the PAH compounds. Therefore, the clam tissue samples were re-analyzed using the ultra-trace modified method (EPA method 8270/1625). The re-analysis with the more sensitive method resulted in detected results for all the PAHs in all clam tissue composite samples.

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 (Slip 4 and RM 2.9 to RM 3.3 W, respectively;[67] Table 5-1), the absence of composites from these areas did not impact the usability of the baseline dataset to define current site-wide conditions. The prevalence of clams in each clam tissue collection area will change over

[67] As anticipated, clam abundance was low in these areas. C07 is located in Slip 4, which was recently remediated, and C09 is an area that was qualified as having low-quality clam habitat in the 2003 clam abundance survey (Windward 2004a).

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. Future clam tissue monitoring will continue to collect clam tissue in the 11 areas targeted during baseline sampling, to the extent possible.

Variance within the dataset represents differences in COC concentrations in clam tissue 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 Triangle), 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)[a]					
All data	9	lognormal	5.94	4.29	38%
Excluding highest value from area C05 (Slip 2)	8	normal	4.31	3.62	19%
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 Triangle])	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)[b]	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] cPAH TEQs were calculated using the results of a re-analysis of the clam tissue samples performed using the ultra-trace modified method (EPA method 8270/1625).

[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 concentration in the sample from area C11 (RM 3.8 E, just downstream from RARE study plots) was more than nine times higher than that in the next highest sample. Based on the RI/FS dataset, sediment arsenic concentrations are elevated in this area. For the whole-body without siphon skin dataset, inorganic arsenic concentrations in samples from areas C04 (Glacier Triangle) and C11 (RM 3.8 E) 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
RARE – Regional Applied Research Effort
RI/FS – remedial investigation/feasibility study
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 species-specific 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 (i.e., if concentrations in one tissue type decreased by 50%, concentrations in all tissue types would also be assumed to have decreased by 50%) (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			
			Detection Frequency	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)	0.24[a]	1×10^{-6} RBTC	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[68] and 21) (EPA 2014, 2015a).

[a] The RBTC based on EPA's 2017 update of the benzo(a)pyrene slope factor is 1.8µg/kg ww.

[b] Insufficient data were available to 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
EPA – US Environmental Protection Agency
LDW – Lower Duwamish Waterway
na – not applicable
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 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 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	Detection Frequency	Mean Value	Min. Detect	Max. Detect	95UCL[a]	TTL	95UCL < TTL?
Total PCBs (µg/kg ww)							
Total PCB Aroclors	9/9	13.1	8.0	19.6 J	15.1	0.42	no
Total PCB congeners	6/6	22.3	16.126 J	27.810 J	25.7		no
cPAH TEQ (µg/kg ww)							
All data[b]	9/9	4.29	2.36	9.58	5.94	0.24[c]	no
Dioxin/furan TEQ (ng/kg ww)							
All data	9/9	0.87	0.192 J	5.55 J	3.42	0.71	no

[68] 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.*

Risk Driver	Detection Frequency	Mean Value	Min. Detect	Max. Detect	95UCL[a]	TTL	95UCL < TTL?
Inorganic arsenic (mg/kg ww)							
Whole body	11/11	5.4	0.7	37.4	19.4	0.09	no
Whole body without siphon skin	11/11	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] cPAH TEQs were calculated using the results of a re-analysis of the clam tissue samples by ultra-trace modified method (EPA method 8270/1625).

[c] The RBTC based on EPA's 2017 update of the benzo(a)pyrene slope factor (EPA 2017) is 1.8 µg/kg ww.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EPA – US Environmental Protection Agency
MDL – method detection limit
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

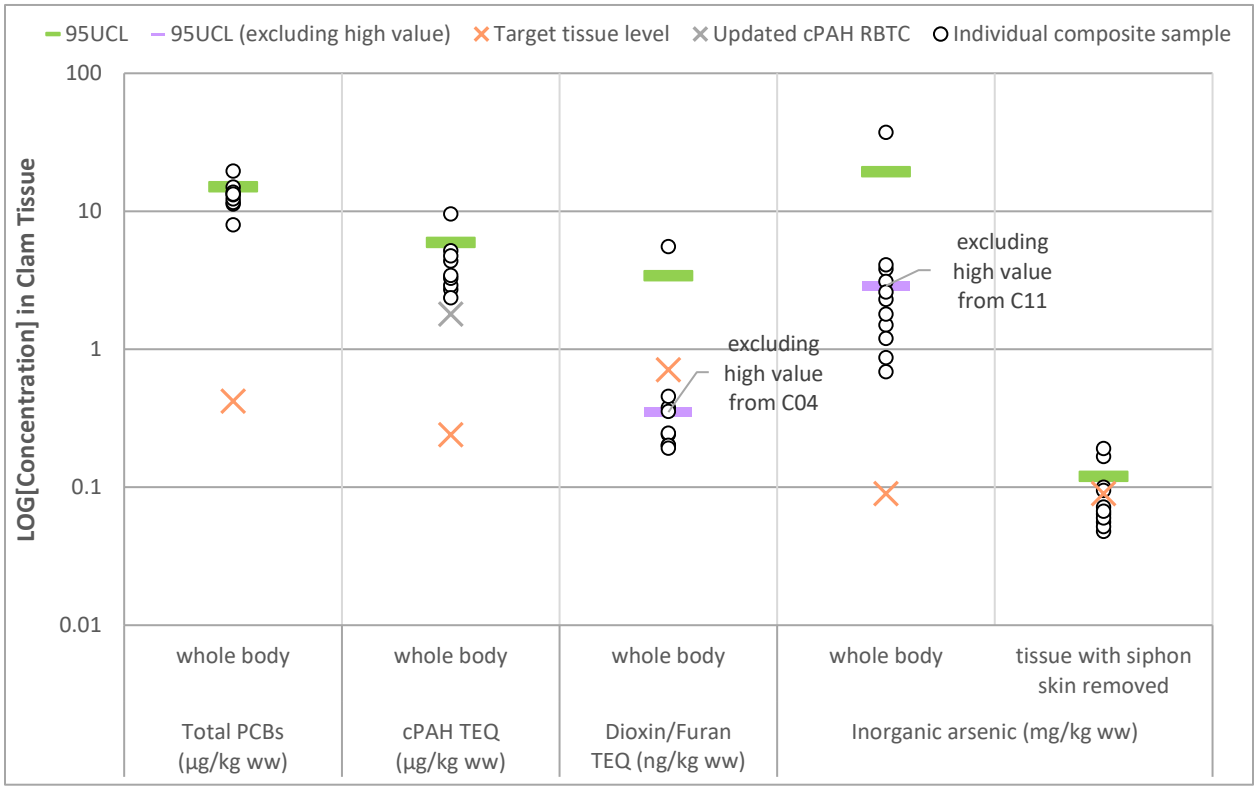


Figure 5-1. Comparison of clam tissue concentrations and TTLs for risk drivers

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. Table 5-5 and Figure 5-2 provide spatial comparisons of clam tissue concentrations for the risk driver chemicals, and Figure 5-3 provides temporal comparisons. For the temporal evaluation, details

regarding each event that are relevant when assessing trends are summarized in Table 5-6. 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 existing data).

Table 5-5. Risk driver concentrations in clam composite samples across areas

Location ID	Total PCBs (µg/kg ww)		cPAH TEQ[a] (µg/kg ww)	Dioxin/Furan TEQ (ng/kg ww)	Inorganic Arsenic (mg/kg ww)	
	Aroclors	Congeners			Whole Body	Whole Body minus Siphon Skin
C01	13.3 J	16.126 J	3.44 J	0.192 J	2.6	0.067
C02	11.3 J	20.020 J	2.72 J	0.379 J	1.5	0.048
C03	11.6 J	nd	4.36 J	0.456 J	1.8	0.072
C04	19.6 J	22.660 J	5.17 J	5.55 J	3.82	0.167
C05	15.0	nd	9.58	0.242 J	0.69	0.056
C06	12.3 J	27.810 J	4.75 J	0.354 J	0.87	0.052
C07	nd	nd	nd	nd	4.1	0.10
C08	13.8 J	25.520 J	2.91 J	0.201 J	1.2	0.064
C09	nd	nd	nd	nd	2.3	0.060
C10	8.0	nd	2.36 J	0.247 J	3.1	0.095
C11	13.2 J	21.760 J	3.28 J	0.201 J	37.4	0.191
95UCL[b]	15.1	26.7	5.94	3.42	19.4	0.12
TTL	0.42		0.24[c]	0.71	0.09 (whole body)	

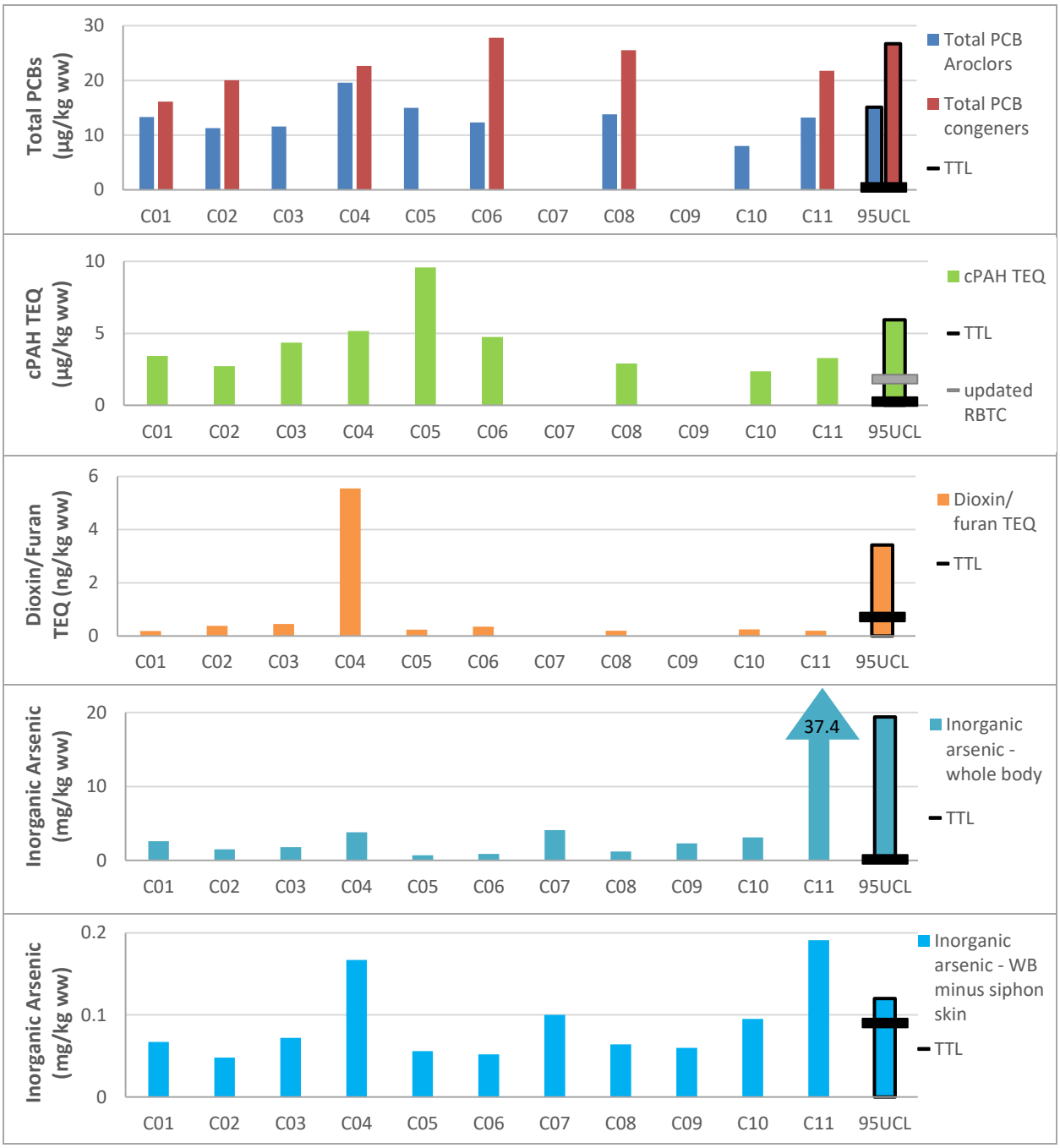
Note: Tissue type is whole body unless otherwise specified.

[a] cPAH TEQs are based on the re-analyzed clam tissue samples using the ultra-trace method.

[b] 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.

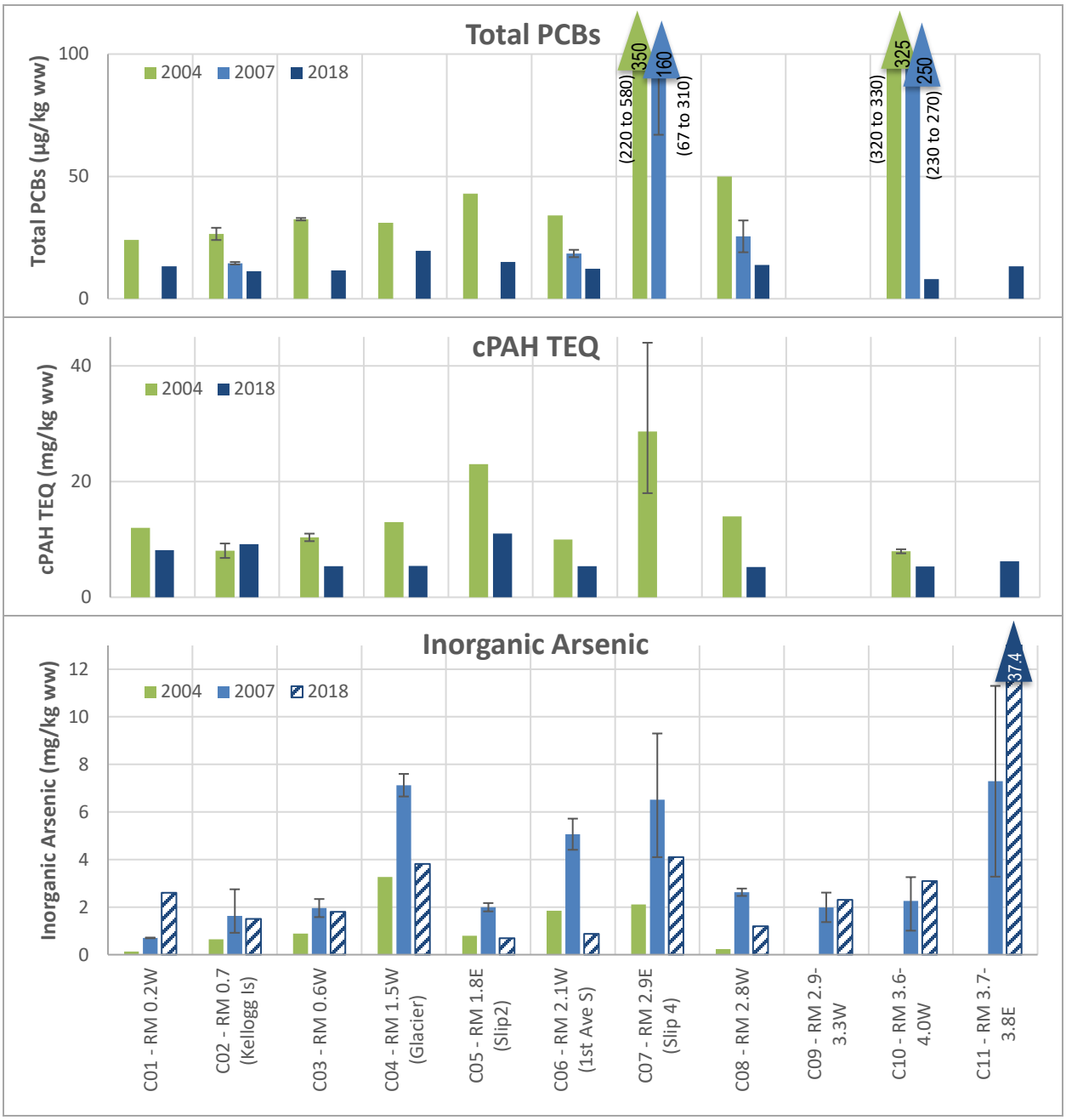
[c] The RBTC based on EPA's 2017 update of the benzo(a)pyrene slope factor (EPA 2017) is 1.8 µg/kg ww.

95UCL – 95% upper confidence limit (on the mean)
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EPA – US Environmental Protection Agency
J – estimated concentration
nd – no data
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
TEQ – toxic equivalent
TTL – target tissue level
U – not detected at given concentration
ww – wet weight



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.
The TTL is a site-wide value and is thus only compared with the site-wide 95UCL. For inorganic arsenic, the TTL applies to whole-body concentrations but is shown on the plot for whole body minus siphon skin for informational purposes.

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 with error bars indicating the range. Where no bar is shown, no clam tissue data were collected for that year-chemical combination (see Table 5-6 for details). The striped pattern for the 2018 data for inorganic arsenic indicates that the comparison of these data is uncertain. The 2004 and 2007 composites generally included 20 to 30 clams, whereas the 2018 composites included 3 clams (Table 5-6).

Figure 5-3. Comparison of RI/FS clam tissue data from 2004/2007 with 2018 baseline data

Table 5-6. Overview of available LDW clam tissue data by year

Location Description	Sampling Year		
	2004	2007	2018[a]
Mean values by Sampling Year:			
Total PCBs (µg/kg ww)	140	105[b] (6 locations only)	13.1 ± 3.13
cPAH TEQ (µg/kg ww)	15.1	na (no data)	4.29 ± 2.20
Dioxin/furan TEQ (ng/kg ww)	na (no data)	na (no data)	0.87 ± 1.76 (0.28 ± 0.10 excluding high value from area C04)
Inorganic arsenic (mg/kg ww)	1.2 (no sample collected from area C11[c])	2.7[b]	5.4 ± 11 (2.2 ± 1.2 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*[d]	*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 Triangle)	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] SDs denoted by ±.

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

[c] 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.

[d] 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
SD – standard deviation
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). The sum of PCB congeners ranged from 16.126 to 27.810 µg/kg for the tissue samples. In general, tissue congener patterns differ from Aroclor standard patterns because congener-specific properties (i.e., solubility and partition coefficients) that affect bioaccumulation result in altered PCB congener patterns in tissues. In addition, at lower concentrations, congeners are more likely to be detected than are Aroclors because the PCB congener method is more sensitive than the Aroclor method (Windward 2018f).

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 RI/FS 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). No clams were collected in the T-117 EAA footprint in 2018. 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 of 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 total PCB concentration in clams decreased by an order of magnitude from a mean of 140 µg/kg ww in 2004 to a mean of 13.1 µg/kg ww in 2018 (Table 5-6). 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

cPAH TEQs in clam tissue were greater than the TTL of 0.24 µg/kg ww for clam tissue samples collected in all nine areas (Figure 5-2), and they were also above the updated RBTC of 1.8 µg/kg ww calculated using the 2017 benzo(a)pyrene slope factor. Using the ultra-trace analysis for PAHs, the detection of the individual cPAHs used to calculate the cPAH TEQ was 100% in all of the clam tissue samples.

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 similar 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 all eight areas by a factor of approximately 2 to 5 (Figure 5-3). 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 Triangle) 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 Triangle) 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 Triangle])	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[69]). Dioxins/furans were not analyzed in 2004 and 2007, so comparison to RI/FS 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 whole-body TTL (Figure 5-2). 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).

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 (Glacier Triangle) and C11 (RM 3.8 E) 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 5-4). In other words, concentrations in siphon skin tissue were approximately 160 to 1,600 times higher than

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

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.

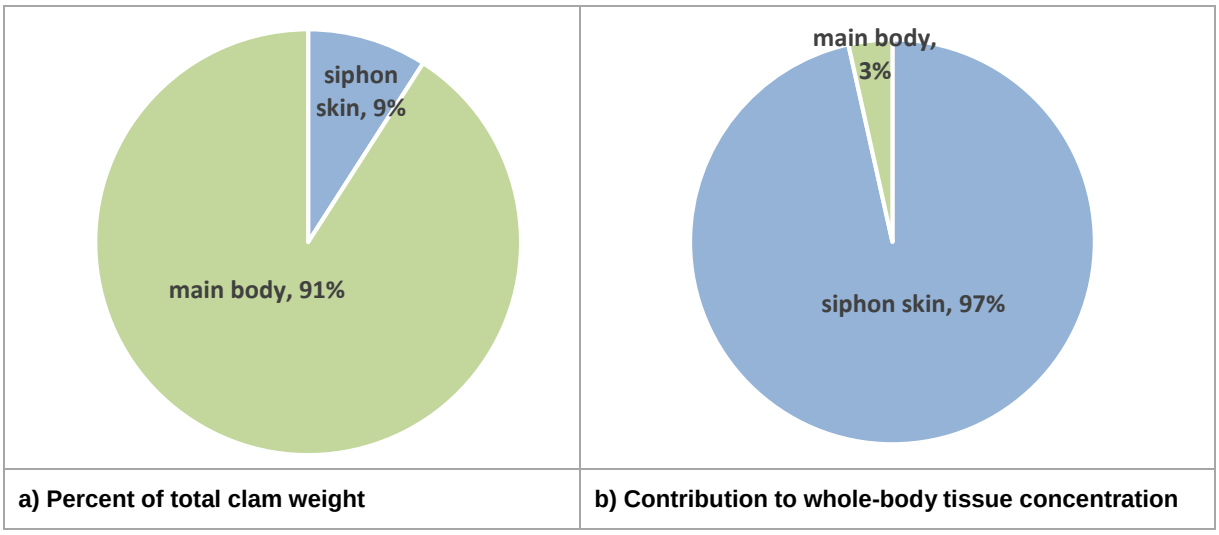


Figure 5-4.*M. arenaria* clam siphon skin results for inorganic arsenic

The TTL for inorganic arsenic (0.09 mg/kg ww) was based on the 95UCL of inorganic arsenic concentrations in six whole-body (i.e., including siphon skin) *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 Triangle) and C11 (RM 3.8E). Concentrations of arsenic in sediments in both of these areas are known to be elevated. 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 site-wide temporal pattern exists with regard to inorganic arsenic concentrations in clam tissue (Figure 5-3). In all clam tissue collection areas where both

2004 and 2007 data were available, concentrations in the 2004 samples were lower than those in 2007 samples by a factor of 2.2 to 11.3. No consistent pattern is present in clam tissue when comparing 2007 and 2018 data:

- **Concentrations were similar in 2007 and 2018** – For areas C02, C03, C09, and C10, inorganic arsenic concentrations in the 2007 and 2018 samples were similar to one another (i.e., concentrations were within a factor of 1.4).
- **Concentrations in 2018 samples were higher** – In areas C01 and C11, inorganic arsenic concentrations were higher in the 2018 composite tissue sample (higher than the 2007 samples by a factor of 3.7 to 5.1);
- **Concentrations in 2007 samples were higher** – In areas C04, C05, C06, C07,[70] and C08, the inorganic arsenic concentrations were higher in the 2007 composite tissue samples (higher than the 2018 samples by a factor of 1.6 to 5.8).

As noted in Table 5-6, the 2018 composites analyzed for inorganic arsenic represented 3 individual clams, whereas the 2004 and 2007 samples represented between 19 and 52 clams, adding to the uncertainty associated with this comparison. In addition, analytical variability likely contributes to some of the differences (the laboratory precision for inorganic arsenic has a relative percent difference of +/- 35% [similar to values that are within a factor of 1.4 of one another]).

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. Detection frequencies 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).

[70] Clams were collected within C07 (the Slip 4 EAA) in 2004 and 2007 (before EAA remediation) from the head of the slip and along the southern shoreline, and in 2018 (after remediation) from the head of the slip.

Table 5-9. Non-risk driver baseline chemistry results for clam tissue compared with 2004 data

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

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

[b] RLs for HCB were higher in the baseline dataset than in the HHRA dataset. For the HHRA dataset, HCB was analyzed as part of the pesticide group (EPA method 8081), whereas for the baseline dataset, HCB was analyzed as part of the SVOC group (EPA method 8270), which involves a less-sensitive analytical method.

BEHP – bis(2-ethylhexyl) phthalate
BHC – benzene hexachloride
DDT – dichlorodiphenyltrichloroethane
EPA – US Environmental Protection Agency
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 (both site wide and at all locations throughout the LDW for which both RI/FS and baseline data are available). Nonetheless, the site-wide 95UCL remains above the TTL for clams. •
cPAH TEQ	• cPAH TEQs in clam tissue have decreased since the HHRA was performed. However, the site-wide 95UCL for clams remains above the TTL in the ROD (0.24 µg/kg ww) and the updated 2017 RBTC for clams (1.8 µg/kg ww).
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 Triangle]), 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
RI/FS – remedial investigation/feasibility study
ROD – Record of Decision
SVOC – semivolatile organic compound
T-117 – Terminal 117
TBT – tributyltin
TEQ – toxic equivalent
TTL – target tissue level
ww – wet weight

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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**[71] **–** 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. The technical basis for calculating porewater concentrations from passive samplers is the subject of ongoing research by the scientific community. Therefore, the decision was made to use LDW

[71] 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).

sediment concentrations and literature partition coefficients to estimate porewater concentrations of dioxins/furans to address DQO 2 at this time.

The study design to address DQO 1 for cPAHs in porewater was detailed in the clam QAPP (Windward 2018e). 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 of the 16 sediment samples (i.e., those from areas A01, A02, A04, A06, A07, A08, A10, A11, A17, and A18) were selected for the *ex situ* 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 2019b). 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 mislabeled at some point in the analytical process (Windward 2019b). Because there was no way to definitively identify all the passive samplers that had been affected, it was agreed that the *ex situ* exposures would be redone using archived sediment from the same 10 locations (the archived sample material was stored, frozen, at Analytical Resources, Inc.).

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).[72] 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 2019c). 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 following equilibration with sediment. The PCB porewater data were validated and no issues were identified that would limit the use of this data.

[72] 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.

6.2 POREWATER DATA INTERPRETATION

6.2.1 cPAH porewater investigation

A porewater cPAH investigation was conducted to address DQO 1. Co-located clam tissue and surface sediment samples were collected at 16 potential clamming locations across a range of cPAH TEQs (Windward 2018e, 2019b). At 10 of the locations, the freely dissolved cPAH porewater concentrations (C_{free}) were estimated using passive samplers exposed *ex situ* in a laboratory to the sediment collected with the clams (Windward 2018e). The relationships among cPAH TEQs in clam tissue, sediment and porewater were evaluated. In addition to the evaluation of the 10 paired sediment, porewater and clam tissue samples presented here, an additional analysis of the 16 paired sediment and clam tissue samples is presented in Appendix G.

All of the cPAHs were detected frequently in the sediment and porewater samples whereas detection frequencies were lower in the clam tissue samples (Table 6-1). To reduce the confounding influence of non-detects, relationships were considered for only individual cPAHs with high detection frequencies in tissue samples. Data were evaluated for three cPAHs: benzo(a)anthracene, benzo(b)fluoranthene, and chrysene. Benzo(a)pyrene, dibenzo(a,h)anthracene, and indeno(g,h,i) were infrequently detected in the tissue samples. All of these cPAH compounds were detected in all of the sediment and porewater samples.

Table 6-1. Detection frequencies of individual cPAHs in clam tissues, co-located sediments and porewater from the LDW Pre-Design Studies

cPAH Compound	PEF	Detection Frequency n=10		
		Sediment	Tissue	Porewater[a]
Benzo(a)pyrene	1.0	100%	20%	100%
Dibenzo(a,h)anthracene	0.4	94%	0%	80%
Benzo(a)anthracene	0.1	100%	90%	100%
Indeno(1,2,3-cd)pyrene	0.1	100%	10%	90%
Benzo(b)fluoranthene	0.1	100%	100%	100%
Benzo(j,k)fluoranthene	0.1	100%	70%	100%
Chrysene	0.01	100%	90%	100%

[a] Freely dissolved porewater concentrations (C_{free}) were calculated from passive sampler concentrations.
Grey shaded PAHs were selected for assessment of relationships among sediment, tissue, and porewater.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
PEF – potency equivalency factor

The relationships among the clam tissue, sediment, and porewater cPAH concentrations were evaluated using scatterplots and Spearman's rank correlations. These tools were applied to the following data pairs:

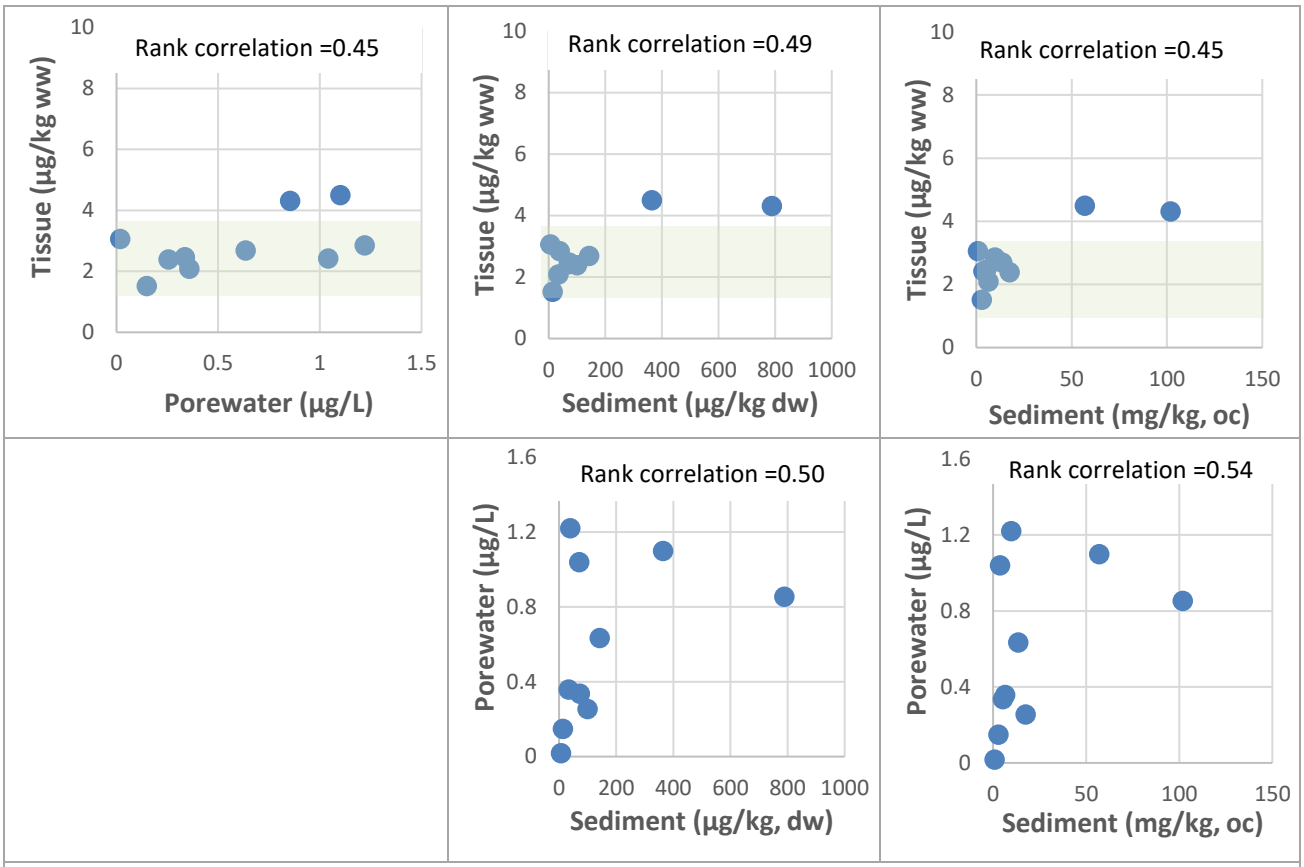
- Tissue vs. sediment (both dry weight and OC normalized),

- Tissue vs. porewater
- Porewater vs. sediment (both dry weight and OC normalized).

Spearman's rank correlation was used to summarize the relationships among these data pairs.[73] The Spearman's rank correlation coefficient summarizes any monotonic correlation (e.g., Y tends to increase whenever X increases). Possible values of Spearman's rank correlation range from -1 to +1. A rank correlation of 0.5 indicates moderate association between the two variables. Spearman's rank correlation is not directly tied to a specific model form and requires only that the model be monotonic (i.e., linear, log-linear, etc.).

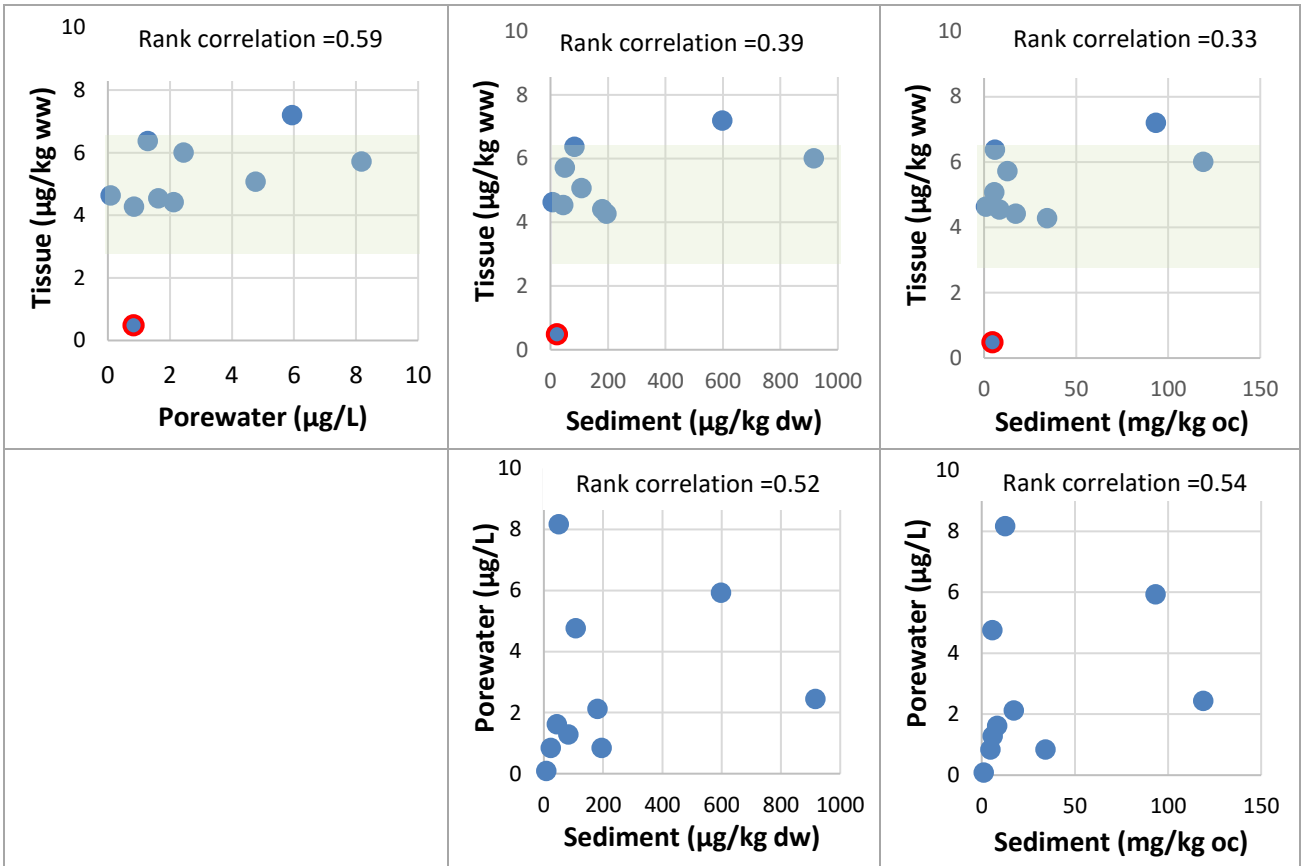
The correlations among cPAH concentrations in clam tissue, sediment, and porewater are moderate at best (Table 6-2). The sediment cPAH concentrations are not predictive of tissue or porewater concentrations.

For eight locations with sediment cPAH TEQ values less than approximately 200 µg/kg dw, the tissue concentrations were similar (Figures 6-1 and 6-2). This limits the ability to make inferences about the relationships between tissue and sediment or porewater. Porewater data were only moderately correlated with sediment concentrations, both on a dry weight and OC-normalized basis (correlations ranging from 0.50 to 0.54, Table 6-2). The relationship between cPAH concentrations in porewater and sediment was similar for both the dry weight concentrations and the OC-normalized concentrations.



Note: Shaded bar indicates the range of laboratory analytical variability for tissues (+/- 35% of the mean).

Figure 6-1. Benzo(b)fluoranthene compared among clam tissue, sediment, and porewater (C_{free})



Note: Data point outlined in red is a non-detect, plotted at the MDL.
Shaded bar indicates the range of laboratory analytical variability for tissues (+/- 35% of the mean).

Figure 6-2.Chrysene compared among clam tissue, sediment, and porewater (C_{free})

Table 6-2. Spearman's rank correlation coefficients (and p-values) for individual cPAHs with high detection frequencies in clam tissues and co-located sediments and porewater

Paired Data[a]	Spearman's Rank Correlation Coefficients (p-values)		
	Benzo(b)fluoranthene	Chrysene	Benzo(a)anthracene
Tissue vs. porewater	0.45 (p=0.19)	0.59 (p=0.08)	0.43 (p=0.22)
Tissue vs. sediment (dry weight)	0.49 (p=0.15)	0.39 (p=0.26)	0.26 (p=0.47)
Tissue vs. sediment (OC normalized)	0.45 (p=0.19)	0.33 (p=0.35)	0.39 (p=0.26)
Porewater vs. sediment (dry weight)	0.50 (p=0.14)	0.52 (p=0.13)	0.53 (p=0.12)
Porewater vs. sediment (OC normalized)	0.54 (p=0.11)	0.54 (p=0.11)	0.50 (p=0.14)

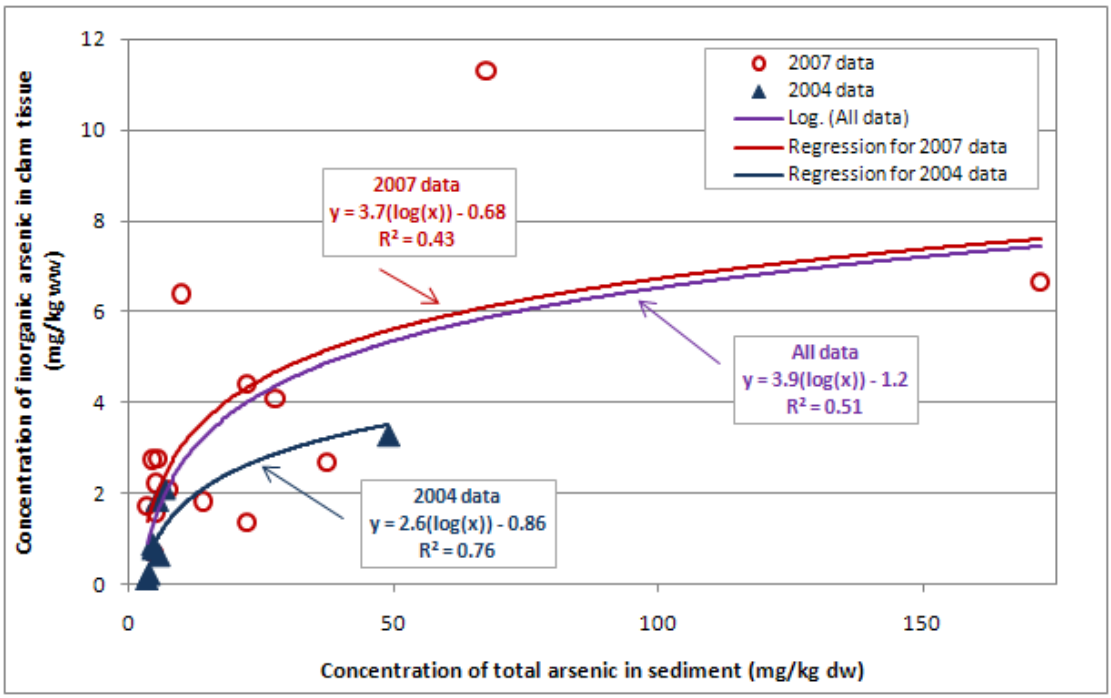
[a] Sample size is 10 for all pairwise comparisons.
cPAH – carcinogenic polycyclic aromatic hydrocarbon
OC – organic carbon

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:

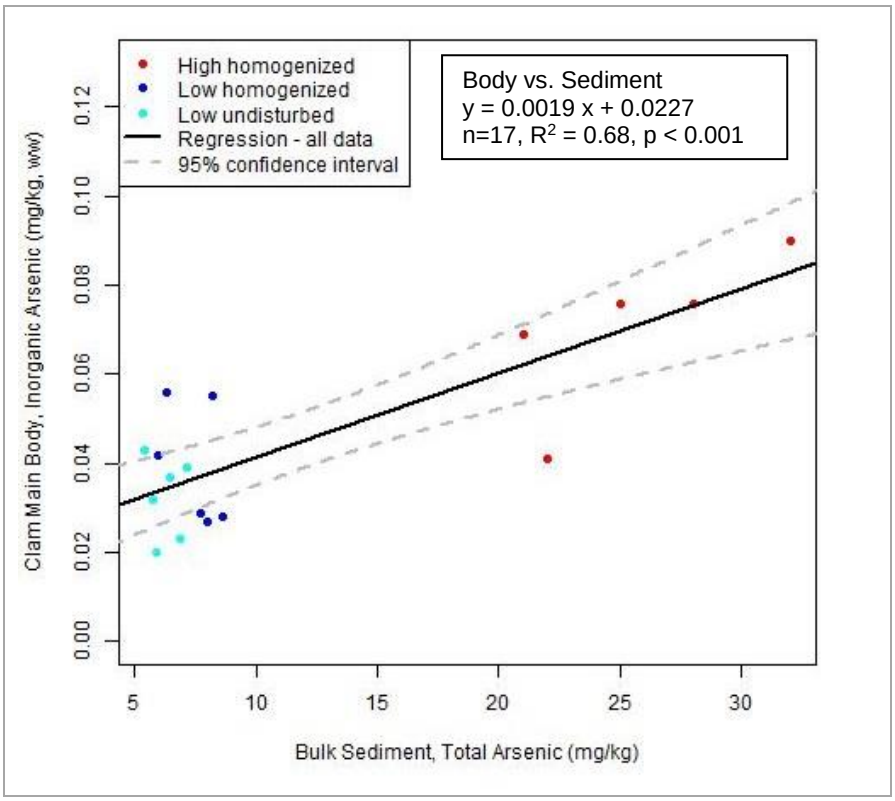
- **The available porewater data did not help to explain the bioaccumulation of inorganic arsenic by *M. arenaria***. The RARE study demonstrated that concentrations of total arsenic in porewater were closely related to those in sediment, and that the relationship between clam tissue and sediment was 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 6-3, and from the RARE study (Kerns et al. 2017), as presented in Figure 6-4. The moderate relationships suggest that, in addition to sediment, exposures through the water column contribute to arsenic levels in clam tissue. The RARE study indicated that arsenic concentrations were higher in siphon skin than in the rest of the clam tissue.
- **The background-based sediment cleanup level for arsenic may not achieve the TTL for clams.** As discussed in the RARE study (Kerns et al. 2017), inorganic arsenic concentrations in clam tissue minus siphon skin are predicted to reach 0.09 mg/kg (the inorganic arsenic concentration used as a TTL) at a sediment concentration of 36 mg/kg total arsenic. However, by definition, the TTL applies

to whole clams (i.e., tissue including the siphon skin); concentrations in whole-body clam are not predicted to reach the TTL at the site-wide sediment cleanup level of 7 mg/kg dw.



Source: Windward (2010a)

Figure 6-3. 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 6-4. 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.
- Removal of clam siphon skins reduced the clam whole body arsenic concentrations significantly.
- 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.

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. This information confirmed the PCB partition coefficient used in the RI FWM (Windward 2010a) and also would be helpful in future predictions of PCB concentrations in porewater.

Surface sediment samples were exposed *ex situ* to PE strips in order to determine total PCB C_{free}[74] in porewater associated with total PCB concentrations and organic matter in sediment (Table 6-3). Total PCB concentrations in porewater increased with increased OC-normalized total PCB sediment concentrations (Figure 6-5). 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 6-3. 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

[74] 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 2019c). 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-SS177	4.134 J	385.5 J	12.1	3.19 J	0.051 J
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

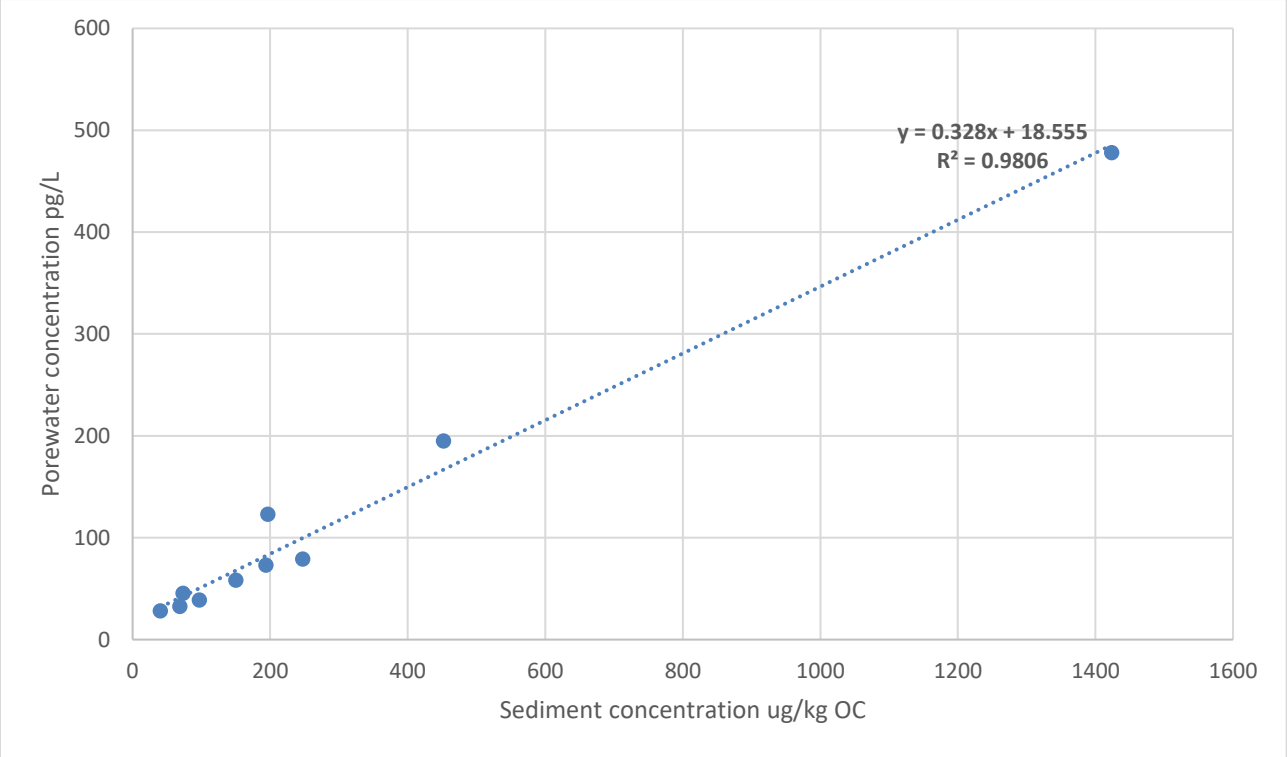


Figure 6-5. Total PCB C_{free} in porewater as a function of OC-normalized total PCB concentrations in LDW sediment

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. For each individual PCB congener, the congener concentration and fraction of OC in sediment is combined with the congener-specific partition coefficient to calculate the corresponding freely dissolved PCB congener concentration in porewater. The porewater total PCB concentration is calculated as the sum of the detected freely dissolved individual PCB congener concentrations.

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

Where:

C_S = bulk sediment PCB congener concentration

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

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

C_W = freely dissolved PCB congener 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).

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

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 congener-specific 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 6-6.

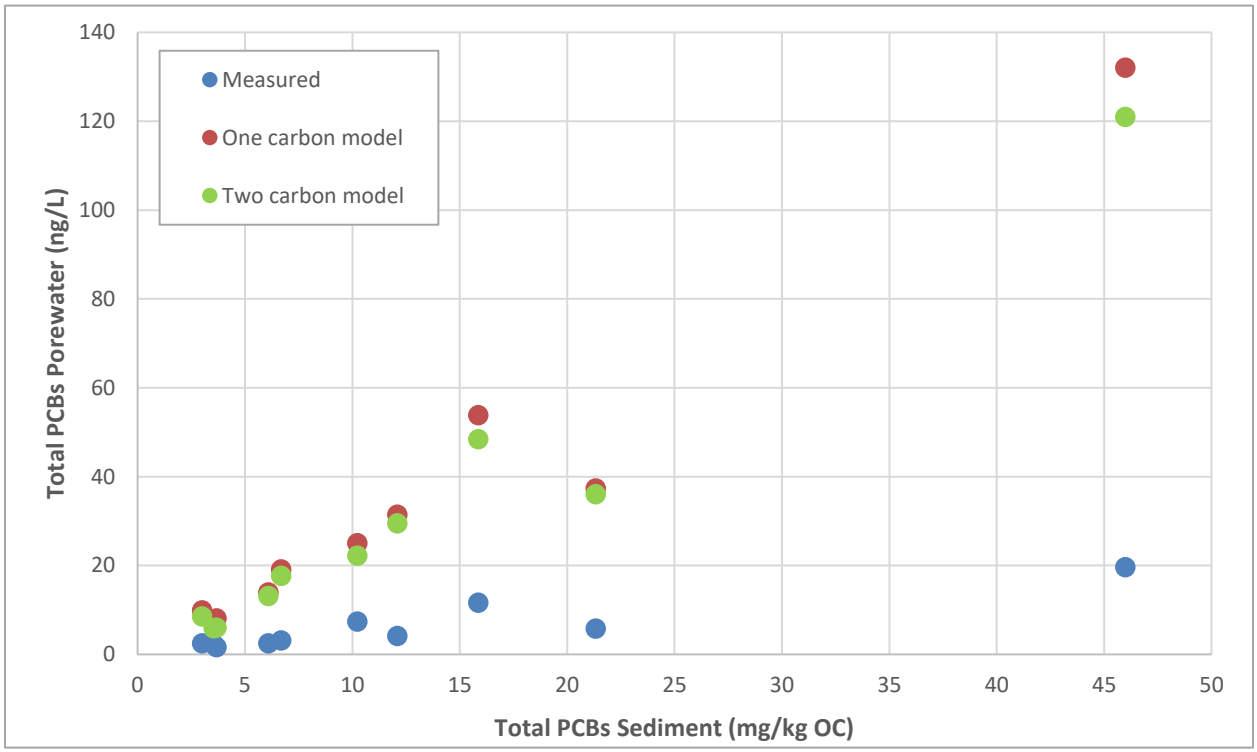


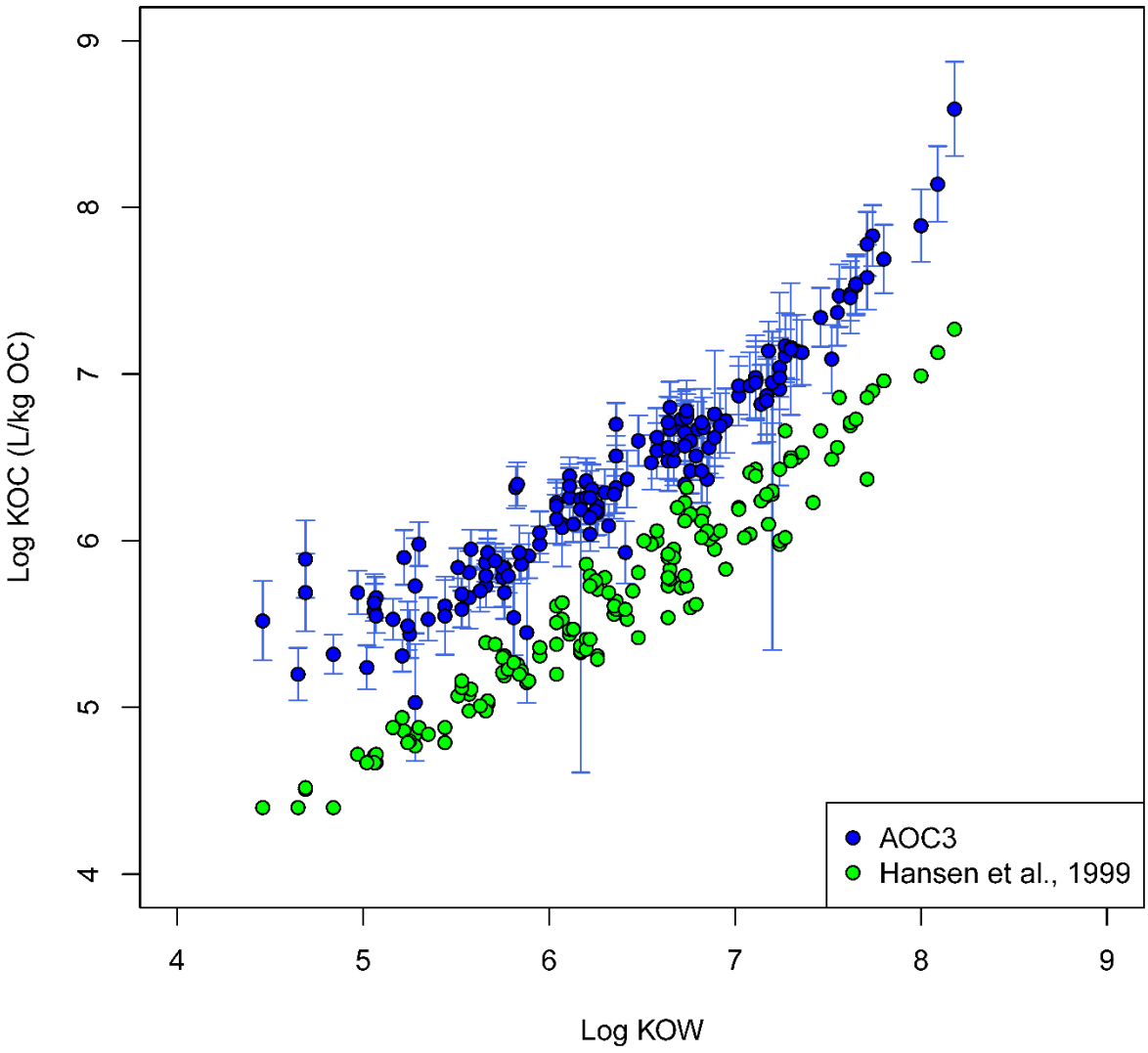
Figure 6-6. Comparison of LDW measured and predicted total PCB concentrations in porewater using one- and two-carbon models.

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 6-6). 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 using literature congener-specific K_{OC} values. 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.[75]

[75] 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.

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 were 6.5 times higher than the 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 6-7) 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 $\text{Log } K_{OC} = 0.77 \times \text{Log } K_{OW} + 1.5$.



Note: Error bars represent SD

Figure 6-7. 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 6-4, 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 6-4. 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.[76] 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.

[76] 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,[77] 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).[78]

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 literature dioxin/furan congener partition coefficients may result in conservative estimates of actual porewater dioxin/furan concentrations. The literature PCB congener partition coefficients underestimated the sorption of PCB congeners to OC in LDW sediment (Section 6.2.3), and the same may be true for the dioxin/furan congeners. This is the greatest uncertainty associated with the use of the one-carbon equilibrium partitioning model.

The one-carbon model predicts a linear relationship between sediment and porewater concentrations for each congener. The ranges of sediment concentrations and modelled porewater concentrations for the dioxin/furan congeners are provided in Table 6-5.

Table 6-5. 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

[77] 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.

[78] 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).

Dioxin/Furan Congener	Range of Sediment Concentrations (ng/kg)	Range of Predicted Porewater Concentrations (pg/L)
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
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). The use of equilibrium partitioning models likely overestimates the porewater dioxin/furan concentrations, similar to the results for porewater PCB congener concentrations.

6.3 SUMMARY AND KEY POINTS

The cPAH porewater data met DQO 1 by assessing the relationship among PAH concentrations in porewater, sediment, and tissue. 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 2017c).

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

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

DQO	Chemical	Summary of Key Conclusions
DQO 1	cPAH TEQ	• Porewater data were only moderately correlated with sediment concentrations. • The relationship between cPAH concentrations in porewater and sediment was similar for dry weight and OC-normalized sediment concentrations.
	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, potentially with field validation, 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 2019c)). The results of these analyses are presented in the surface sediment data report.

The results of the analyses of the near-outfall sediment samples were compared to the sediment RALs—which include the Recovery Category 1 and 2/3 surface sediment RALs from Tables 27 and 28 of the ROD (EPA 2014)—to assist Ecology in identifying drainage basins of potential interest for additional source control investigations.[79] To provide a comprehensive analysis, this comparison was extended to include all detected 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) (excluding field replicates). Table 7-1 provides the results of this comparison. Maps 7-1a through 7-1d show the outfall and sediment sample locations.

[79] For this data evaluation report, results of the analyses of near-outfall sediment samples collected between RM 4.8 and RM 5.0 were compared to Recovery Category 2/3 RALs. Recovery categories in this area will be recommended in the LDW Upper Reach Pre-Design Investigation QAPP.

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

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Detected Concentrations > Surface Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Surface Sediment RALs[a] (Sample Dates in Parentheses)		
					RI/FS	Post-FS	Pre-Design Studies
2149	L1505	0.0 W	50	1	ns	BBP, total PCBs (4/20/2011)	ns
2233	L1508	0.1 W	50	1	cPAH TEQ (3/14/2005)	ns	ns
2157	L1514	0.4 W	50	1	ns	benzyl alcohol (3/24/2011)	ns
Siphon-West CSO (Duwamish West CSO)	L1515	0.4 W	100	3	total PCBs (3/8/2005)	fluoranthene, phenanthrene, BEHP, benzyl alcohol (2) (4/8/2011)	ns
2225	L0205	0.6 E	50	1	BBP (8/20/1994)	ns	ns
2245	L0309	0.9 E	100	4	ne	benzyl alcohol (3) (4/8/2011), total PCBs (6/4/2015)	ns
2246	L0306	0.9 E	50	1	ne	benzyl alcohol (3/21/2011)	ns
2247	L0307	0.9 E	50	2	ne	benzyl alcohol (2) (3/21/2011)	ns
5000	L0308	0.9 E	100	3	ns	benzyl alcohol (3) (4/8/2011)	ns
5001	L0310	0.9 E	100	4	ne	benzyl alcohol (3) (4/8/2011), total PCBs (6/4/2015)	ns
2244	L0401	1.1 E	50	2	ns	acenaphthene, dibenzofuran, fluorene, phenanthrene, benzyl alcohol (2) (3/21/2011)	ns
2223 (Brandon CSO)	L0402	1.1 E	50	1	ns	BBP, total PCBs (8/29/2011)	ns
2008	L0501	1.2 E	50	1	ns	benzyl alcohol (3/8/2011)	ns
5003	L1607	1.2 W	100	4	ne	arsenic (2), benzyl alcohol (4), total PCBs (2) (3/24/2011)	ns
5004	L1608	1.2 W	100	3	ne	arsenic (2), benzyl alcohol (3), total PCBs (2) (3/24/2011)	ns

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

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Detected Concentrations > Surface Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Surface Sediment RALs[a] (Sample Dates in Parentheses)		
					RI/FS	Post-FS	Pre-Design Studies
5005	L1701	1.2 W	100	1	ns	benzyl alcohol (3/24/2011)	ns
2009	L0502	1.3 E	50	1	ns	benzyl alcohol (3/8/2011)	ns
AML-DP2	L1704	1.3 W	50	1	arsenic, copper, zinc (3/10/2005)	ns	ns
2130	L1712	1.4 W	50	1	ns	arsenic, zinc, dioxin/furan TEQ (5/23/2012)	ns
2127 (SW Kenny St Storm Drain/T115 CSO)	L1802	1.5 W	100	3	cPAH TEQ (9/15/1998), dioxin/furan TEQ (3/14/2005)	benzyl alcohol (5/22/2012)	ns
2015	L0508	1.6 E	50	1	ns	benzyl alcohol (3/8/2011)	ns
6146	L1803	1.6 W	50	3	ns	benzyl alcohol (3) (3/8/2011 and 3/21/2011)	ns
2019	L0603	1.7 E	50	2	total PCBs (11/4/1997)	benzyl alcohol (4/15/2011)	ns
2022	L0607	1.9 E	50	3	total PCBs (3/16/2005)	benzyl alcohol (2), total PCBs (3/24/2011)	ns
2501	L0610	1.9 E	100	1	total PCBs (3/15/2005)	ne	ns
2502	L0609	1.9 E	100	1	total PCBs (3/15/2005)	ne	ns
2125	L1806	1.9 W	100	1	BEHP, BBP, dimethyl phthalate, total PCBs (10/15/1997)	ns	ns
2122	L1808	1.9 W	50	2	ns	benzyl alcohol (2) (3/8/2011)	ns
2506	L1810	2.0 W	100	2	ne	BEHP (2), benzyl alcohol (3/7/2011)	ns
2025	L0705	2.1 E	50	1	ns	arsenic, zinc, benzo(g,h,i)perylene, dibenzo(a,h)anthracene,	ns

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

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Detected Concentrations > Surface Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Surface Sediment RALs[a] (Sample Dates in Parentheses)		
					RI/FS	Post-FS	Pre-Design Studies
						indeno(1,2,3-cd)pyrene, cPAH TEQ (4/15/2011)	
S Brighton St Storm Drain	L0706	2.1 E	100	3	ns	cPAH TEQ, benzyl alcohol (3), hexachlorobenzene (3/14/2011)	ns
2508	L2001	2.1 W	50	1	ns	ns	total PCBs (3/2/2018)
2118	L2005	2.2 W	50	3	ns	chromium, lead, zinc, 2-methylnaphthalene, acenaphthene, 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, 1,2-dichlorobenzene, 2,4-dimethylphenol, benzyl alcohol, n-nitrosodiphenylamine, PCP, phenol, total PCBs (3) (7/3/2012)	ns
Dawn Foods	L0801	2.3 E	50	1	ne	ns	cPAH TEQ, total PCBs (2/28/2018)
2117	L2006	2.3 W	50	1	ns	total PCBs (7/2/2012)	ns
2116	L2007	2.3 W	50	1	total PCBs (12/16/2009)	ns	ns
2028	L0806	2.4 E	50	1	dioxin/furan TEQ (1/24/2005)	ns	ns
2026	L0808	2.4 E	100	2	dioxin/furan TEQ (1/24/2005)	mercury, zinc, BEHP, BBP, benzoic acid, benzyl alcohol, total PCBs (3/24/2011)	ns

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

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Detected Concentrations > Surface Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Surface Sediment RALs[a] (Sample Dates in Parentheses)		
					RI/FS	Post-FS	Pre-Design Studies
2035	L0810	2.5 E	100	4	ns	acenaphthene, dibenzofuran, benzyl alcohol (3) (3/7/2011); total PCBs (3/16/2015)	ns
5thAveS	L2012	2.5 W	50	1	ne	ns	dioxin/furan TEQ (2/23/2018)
Clean-ScapesB	L0816	2.7 E	50	1	ns	ns	cPAH TEQ, total PCBs (2/28/2018)
2112	L2102	2.7 W	100	3	cPAH TEQ (10/4/2006); acenaphthene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, cPAH TEQ, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, phenanthrene, total HPAHs, total LPAHs, total PCBs, dioxin/furan TEQ (12/15/2009)	mercury, benzyl alcohol, total PCBs (4/8/2011)	ns
2042	L0901	2.8 E	50	1	ns	BEHP, total PCBs (7/23/2013)	ns
5006	L0902	2.8 E	50	1	ne	total PCBs (3/12/2015)	ns
5008	L0904	2.8 E	50	1	ns	total PCBs, dioxin/furan TEQ (7/23/2013)	ns

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

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Detected Concentrations > Surface Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Surface Sediment RALs[a] (Sample Dates in Parentheses)		
					RI/FS	Post-FS	Pre-Design Studies
5009	L0905	2.8 E	50	7	ns	benzyl alcohol (2), total PCBs (2) (8/24/2011); benzyl alcohol, total PCBs (2/1/2012); acenaphthene, dibenzofuran, fluorene, phenanthrene, benzyl alcohol, total PCBs (2/2/2012); total PCBs (3/5/2013); total PCBs (7/24/2013); benzyl alcohol (12/10/2014)	ns
2107 (8th Avenue CSO)	L2103	2.8 W	100	6	total PCBs (10/24/1997)	1,4-dichlorobenzene, benzyl alcohol (2), total PCBs (3/4/2011); benzyl alcohol (3), total PCBs (3/7/2011)	ns
2106	L2104	2.8 W	50	3	ns	benzyl alcohol, total PCBs (3/4/2011); benzyl alcohol (2), total PCBs (3/7/2011)	ns
2108	L2105	2.8 W	50	4	ns	benzyl alcohol and total PCBs (3/4/2011), benzyl alcohol (3), total PCBs (3/7/2011)	ns
2052	L0920	2.9 E	100	1	total PCBs (10/7/1997)	ne	ns
2053	L0919	2.9 E	100	1	total PCBs (10/7/1997)	ne	ns
2214	L2203	3.5 W	50	5	total PCBs (9/14/2004), total PCBs (8/29/2008)	4-methylphenol, benzyl alcohol (3), total PCBs (2) (3/7/2011)	ns
T117	L2204	3.5 W	50	3	total PCBs (9/14/2004); total PCBs (8/29/2008)	4-methylphenol, benzyl alcohol, total PCBs (3/7/2011)	ns
2062	L1102	3.8 E	100	5	arsenic, cPAH TEQ, dibenzo(a,h)anthracene, phenanthrene, benzo(g,h,i)perylene, indeno(1,2,3-cd)pyrene, fluoranthene, total PCBs (10/8/1997); benzo(a)anthracene,	ne	ns

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

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

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

Ecology Outfall ID	Leidos Outfall ID	Approximate RM	Buffer Size (ft)	No. Samples Within Buffer with Detected Concentrations > Surface Sediment RALs[a]	Chemicals with Detected Concentrations Greater Than the Surface Sediment RALs[a] (Sample Dates in Parentheses)		
					RI/FS	Post-FS	Pre-Design Studies
					(10/25/2006); lead, zinc, BBP, total PCBs (2/11/2008)		
2073	L1204	4.0 E	50	1	total PCBs (12/5/2006)	ns	ns
2080	L1208	4.2 E	100	2	cPAH TEQ, phenol (8/24/2004)	dimethyl phthalate (3/21/2011)	ns
2081	L1209	4.2 E	100	1	benzo(g,h,i)perylene, cPAH TEQ, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, BEHP (8/25/2004)	ns	ns
2082	L1210	4.2 E	50	2	ne	benzyl alcohol (2) (3/17/2011)	ns
DeltaMarine	L2301	4.2 W	50	1	ns	ns	benzyl alcohol (3/8/2018)
2089	L1301	4.3 E	50	3	cPAH TEQ (10/13/1997)	benzyl alcohol (2) (3/17/2011)	ns
2099	L2402	4.4 W	50	1	ns	benzyl alcohol (3/3/2011)	ns
2085	L1306	4.5 E	100	1	ne	benzyl alcohol (3/17/2011)	ns
2090	L1307	4.5 E	100	3	total PCBs (10/15/1997)	benzyl alcohol (2) (3/17/2011)	ns
2200	L2405	4.5 W	100	2	ne	benzyl alcohol (2) (3/18/2011)	ns
BDC-3	L1309	4.7 E	50	1	ns	benzyl alcohol (3/17/2011)	ns
2092	L1401	4.8 E	50	2	total PCBs (12/6/1995)	benzyl alcohol (3/18/2011)	ns
BDC-5	L1403	4.9 E	50	3	total PCBs (2) (12/5/1995), total PCBs (12/6/1995)	ns	ns
2097	L1402	4.9 E	50	5	benzoic acid, total PCBs (3) (12/6/1995); total PCBs (1/26/2005)	benzyl alcohol (3/18/2011)	ns

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

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

Note: Only detected results are included in this table. Field replicates 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 surface sediment RALs from Tables 27 and 28 of the ROD (EPA 2014). Note that the 0–10-cm cPAH TEQ RAL in the ROD is under EPA review. Because excess cancer risks from cPAHs for netfishing using the new benzo(a)pyrene slope factor are less than 1×10^{-6} (Appendix G), cPAHs would no longer be a COC for this pathway and the locations with cPAH TEQ RAL exceedances in this table would not be exceedances for cPAHs. .

BBP – butyl benzyl phthalate
BEHP – bis(2ethylhexyl)phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
COC – contaminant of concern
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
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).[80] 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.[81] Of these 135 outfalls, 76 were located outside of EAAs and had surface sediment samples with detected COC concentrations greater than the surface sediment RALs. 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 surface sediment RAL. Maps 7-2a through 7-2d show EFs of RALs in surface sediment samples for the four human health risk drivers relative to outfall locations.

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

COC	No. of Outfalls with Nearby Sediment Concentrations > Surface Sediment RAL	Range of Concentrations in Nearby Sediment > Surface Sediment RAL
Total PCBs	44	13–10,600 mg/kg OC
cPAH TEQ[a]	14	1,060–110,000 µg/kg
Dioxin/furan TEQ	7	25.3 J–247 J ng/kg
Arsenic	6	67–269 mg/kg
Other	57	see Appendix E

[a] EPA has revised the benzo(a)pyrene slope factor and is considering eliminating the 0–10-cm RAL for cPAHs because excess cancer risks would be less than 1 x 10^{-6} for netfishing with the updated slope factor (see Appendix G).

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. The most likely cause of the increase in benzyl alcohol detections and concentrations since 2010 is changes in the analytical methods used for

[80] 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.

[81] 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.

the analysis of semi-volatile organic compounds (SVOCs) (Fourie and Fox 2016) (see the draft Pre-Design Work Plan (Windward and Anchor 2019) for more discussion).

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 in past studies, 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 in 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 7-3a) 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 2019c)). The results of these additional analyses are presented in the surface sediment data report and discussed herein.

As a conservative screen, results of bank sample analyses were compared to the lowest surface sediment RALs[82] 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 7-3a through 7-3c), the Terminal 108 (T-108) bank samples collected in 2012 and 2015 (8 samples) (Windward and Integral 2018b), and the Duwamish/Diagonal bank samples collected in 2005 (2 samples) (Windward 2010a). Bank samples with COC concentrations greater than the lowest surface sediment RALs from the LDW ROD are shown on Maps 7-3a through 7-3c and summarized in Table 7-3.

[82] 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).

Table 7-3. Bank samples 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/Total No. of Samples within RM Range[b]	Chemicals with Concentrations > Lowest RAL[c]
0.1–0.2 W	5 samples collected at Riverside Marina bank for Ecology in 2011	2/5	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	2/11	mercury, acenaphthene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, dibenzofuran, fluorene, indeno(1,2,3-cd)pyrene, phenanthrene, 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)	5/7	arsenic (5), lead (5), zinc (5)
0.7–2.9 E[d]	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	10/18	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, dioxin/furan TEQ (2)
2.1–2.5 W	4 samples collected at Boyer Trotsky street end for Ecology in 2011	2/4	total PCBs, dioxin/furan TEQ (2)
4.7–5.0 W	2 Pre-Design Studies samples from Bank 6 (LDW18-BNK6-1 and LDW18-BNK6-2)	1/2	total PCBs

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] There is uncertainty in distinguishing between intertidal samples and bank samples. The bank samples have been identified based on the sample classification in the original study.

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

[d] 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 7-3a and 7-3b).

BBP – butyl benzyl phthalate
CKD – cement kiln dust
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
Ecology – Washington State Department of Ecology
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RAL – remedial action level
RM – river mile
ROD – Record of Decision

HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
T-107 – Terminal 107
T-108 – Terminal 108
TEQ – toxic equivalent

A total of 66 bank samples were evaluated, 22 of which had detected COC concentrations greater than the lowest surface sediment RALs. The following is a summary of these bank areas:

- Total PCBs: Four 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: Three 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: Four bank areas had concentrations greater than the lowest sediment RALs for chemicals other than the risk-drivers listed above. These areas are located in the lower two-thirds of 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.[83] Seeps sampled 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 7-4).

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

[83] Based on an assessment presented in an appendix to the surface sediment data report (Windward 2019c), 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.

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. Nearby surface sediment data were also considered.

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.[84] 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.[85] 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 7-4. This map and Table 7-4 identify seep locations with detected concentrations that were greater than groundwater PCULs. Three chemicals (acenaphthene, BEHP, and cPAH TEQ) in the Pre-Design Studies seep dataset and three chemicals (arsenic, 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-76	RI/FS	1.0 E	arsenic

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

[85] There is no groundwater PCUL protective of sediment for total chromium. As a conservative screen, total chromium results were compared to the trivalent chromium PCUL of 76 µ/L. None of the seep results for total chromium included in the screen were greater than this PCUL.

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-77	Pre-Design Studies	1.1 E	acenaphthene, cPAH TEQ
SP-79	Pre-Design Studies	1.5 E	BEHP
SP-80	RI/FS	1.6 E	copper
SEEP82	post-FS	1.8 E	copper
SP-01	Pre-Design Studies	2.2 E	cPAH TEQ
SP-05	Pre-Design Studies	2.6 E	cPAH TEQ
SP-24	Pre-Design Studies	4.2 E	cPAH TEQ
SP-33	Pre-Design Studies	4.8 E	BEHP, cPAH TEQ
SP-66	Pre-Design Studies	0.9 W	cPAH TEQ
SP-54	RI/FS	2.2 W	total PCB Aroclors

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, 11 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)
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

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.

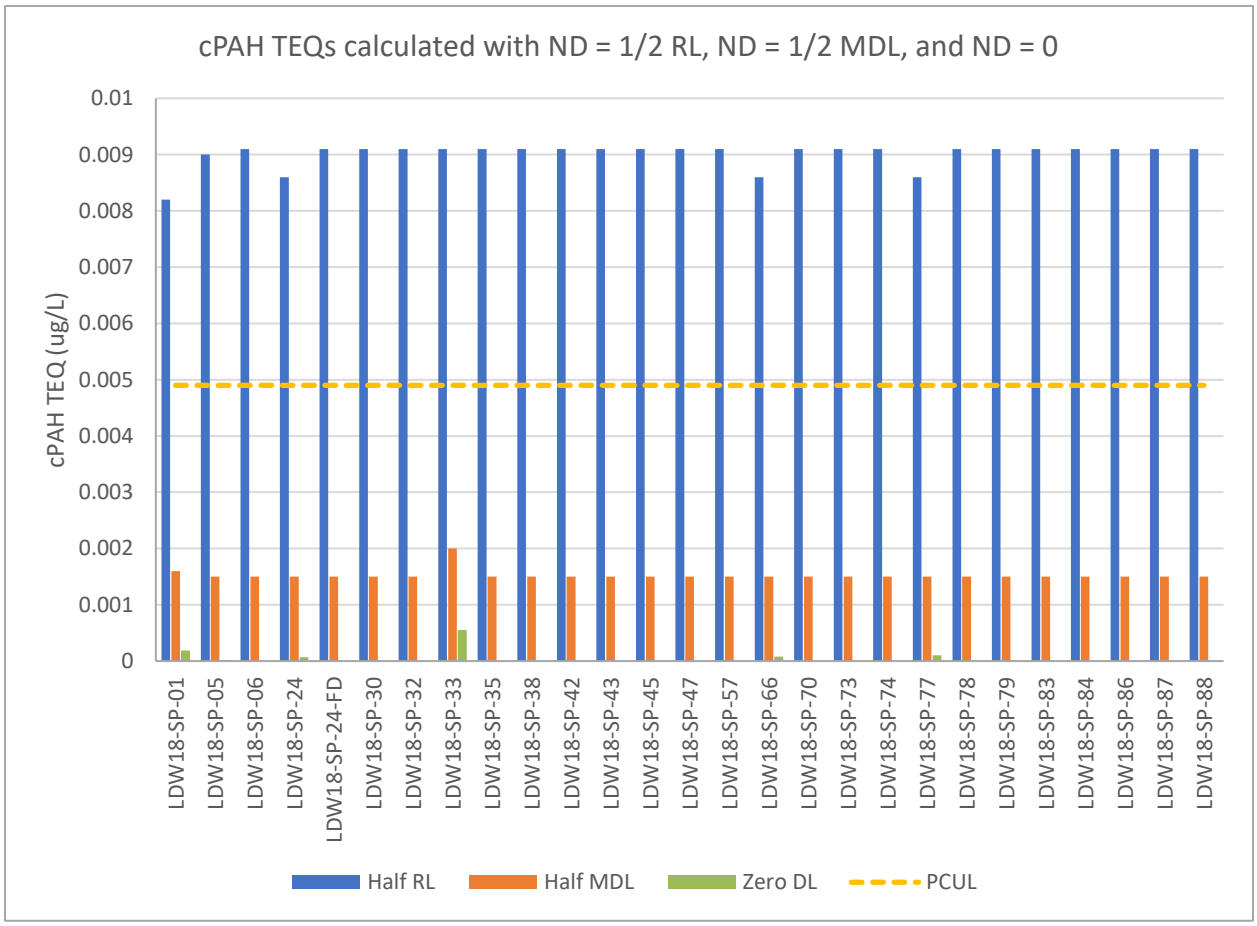


Figure 7-1. Contribution of detected and non-detected values to cPAH TEQs in seep samples collected during the Pre-Design Studies

In 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 2017c), 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 (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 (mid) input value – Pragmatic assessment of what might be achieved in the next decade[86] 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,[87] 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.

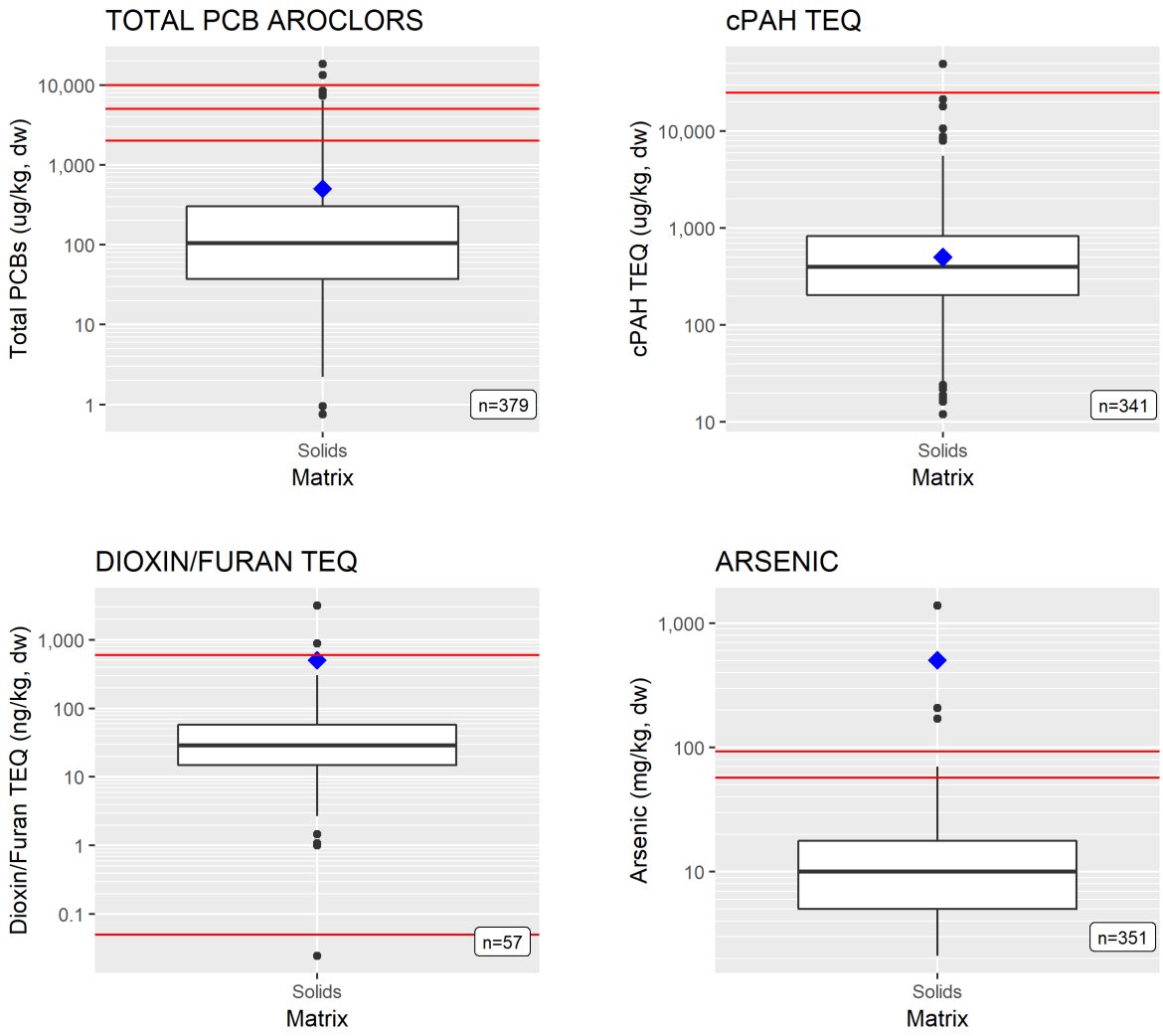
Box plots summarizing the updated datasets are displayed in Figure 8-1 (all data combined, using ½ detection limit [DL] for the data below detection). Summary statistics from the lateral input datasets are provided in Table 8-1. To determine updated lateral input values, the same summary statistics used 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.

[86] At the time of the FS, the next decade was 2012 to 2022.

[87] 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 updated 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, mean, 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 (red lines) are identified in Table 8-1. 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	Screening Values Applied[b]	No. Total	No. Non-detects	Detection Frequency (%)	Min. Detect	Min. Non-detect	Max. Detect	Max. Non-detect	Summary Statistics[a]						
									Percentile						
									25th	75th	10th	90th	Median	Mean	95UCL
Total PCB Aroclors (µg/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 (µg/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 (µg/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 (µg/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 (µg/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 (µg/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). Screening values of 2,000 and 10,000 µg/kg dw were selected to define the low and high BCM sensitivity values, respectively. The high value is not intended to represent potential sources throughout the drainage basins tributary to the LDW. Rather, the high value is used only to determine sensitivity of the model; it is not an estimate of actual source loads or a target value for source control work. The screening value of 5,000 µg/kg dw was chosen to account for the presence of PCBs in building materials of older structures that may exist within the drainage basins tributary to the LDW. These types of sources will be difficult to identify and control in the near term (AECOM 2012); this was the assumption used during the LDW FS.
- For cPAHs, a single screening value (25,000 µg TEQ/kg dw) was used based on best professional judgment (AECOM 2012, Appendix C). cPAHs are present at TEQs > 25,000 µg/kg dw at various locations throughout the drainage basins tributary to the LDW, typically in on-site drainage structures (catch basins and oil/water separators) at sites engaged in transportation-related activities (e.g., bus and airport operations), maintenance facilities, service stations, foundries, and fast food facilities. This screening value is considered an appropriate representation of source control effectiveness in controlling significant sources (AECOM 2012); this was the assumption used during the LDW FS.
- 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), to reflect different potential levels of source control (AECOM 2012). This was the assumption used during the LDW FS.

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
DL – detection limit
dw – dry weight
FS – feasibility study
LDW – Lower Duwamish Waterway
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 updated 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. Screening 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 screening 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 (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 (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 (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).[88] The updated dataset had more source tracing solids data collected within the LDW drainage basins over a large area (n = 57). With the updated dataset and exclusion of greater Seattle metropolitan area sediment data, the base case (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 (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) (Map 8-5). 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)

[88] Of the 21 lateral input samples for dioxins/furans, 12 were from sediments near outfalls in the Greater Seattle metropolitan area.

- Upstream surface sediment data from RM 5.0 to RM 7.0 collected by several parties (1994 to 2008)
- 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.[89] The following more recent datasets have been identified:

- Filtered solids collected upstream at RM 10.4 next to Foster Links Golf Course by King County (2013 to 2015)
- Solids collected in sediment traps upstream at RM 10.4 next to Foster Links Golf Course by King County (2013 to 2015)
- Centrifuged solids collected upstream at RM 10.4 next to Foster Links Golf Course by US Geological Survey (USGS) (2013, 2015, and 2017)
- Fine-grained (< 62.5 µm) bedded sediments collected upstream at RM 10.4 along Foster Links Golf Course 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.

[89] 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[c,e] (µg/kg)	n = 7 8 (median) 15 (mean) 67 (95UCL[d])	n = 3, 5, 4 7, 59, 5 (median) 8, 49, 6 (mean) 66 (95UCL[d])	n = 5, 4 1, 9 (median) 5, 13 (mean) 15 (95UCL[d])	n = 10, 17, 10 8, 18, 2 (median) 8, 25,3 (mean) 24 (95UCL[d])	n = 30 2 (median) 5 (mean) 10 (95UCL[d])	n = 7 6 (median) 6 (mean) 9 (95UCL[d])	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[d:] 2008 - 2017); 43 (95UCL[d:] 2011, 2017)			
cPAH TEQ[c,f] (µg/kg)	n = 7 53 (median) 138 (mean) 640 (95UCL[d])	n = 2, 3, 4 36, 350, 39 (median) 36, 315, 44 (mean) 415 (95UCL[d])	n = 4, 4 35, 45 (median) 45, 54 (mean) 80 (95UCL[d])	n = 5, 17, 10 33, 141, 14 (median) 53, 156, 28 (mean) 157 (95UCL[d])	n = 31 16 (median) 37 (mean) 72 (95UCL[d])	n = 7 18 (median) 23 (mean) 31 (95UCL[d])	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[d:] 2008 - 2017); 30 (95UCL[c] 2011, 2017)			
Dioxin/furan TEQ[c,f] (ng/kg)	n = 6 3 (median) 6 (mean) 10 (95UCL[d])	n = 3, 3, 4 3, 8, 3 (median) 3, 12, 4 (mean) 11 (95UCL[d])	n = 3, 2 1, 3 (median) 2, 3 (mean) 5 (95UCL[d])	n = 11, 17, 10 3, 9, 1 (median) 4, 10, 2 (mean) 9 (95UCL[d])	n = 31 2 (median) 2 (mean) 2 (95UCL[d])	n = 7 3 (median) 3 (mean) 4 (95UCL[d])	n = 2 3 (median) 3 (mean)	no data	n = 5 1 (median) 1 (mean)	n = 5 3 (median) 3 (mean)
							3 (95UCL[d:] 2008 - 2017); 3 (95UCL[d:] 2011, 2017)			
Arsenic[c] (mg/kg)	n = 7 14 (median) 17 (mean) 22 (95UCL[d])	n = 3, 3, 4 37, 17, 11 (median) 40, 19 11 (mean) 30 (95UCL[d])	n = 5, 2 5, 13 (median) 9, 13 (mean) 20 (95UCL[d])	n = 8, 17, 10 21, 15, 10 (median) 20, 18, 10 (mean) 20 (95UCL[d])	n = 31 9 (median) 9 (mean) 10 (95UCL[d])	n = 7 10 (median) 10 (mean) 11 (95UCL[d])	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[d:] 2008 - 2017); 11 (95UCL[d:] 2011, 2017)			

[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] If the sample result was non-detected, then ½ DL was used to calculate the summary statistics presented in this table.

[d] 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.

[e] PCBs were calculated as the sum of detected congeners when available; otherwise, PCBs were calculated as the sum of detected Aroclors.

[f] cPAH and dioxin/furan TEQs were calculated using ½ DL for non-detected results.

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[d,e](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[d,f](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[d] (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[d,f] 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.

[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).

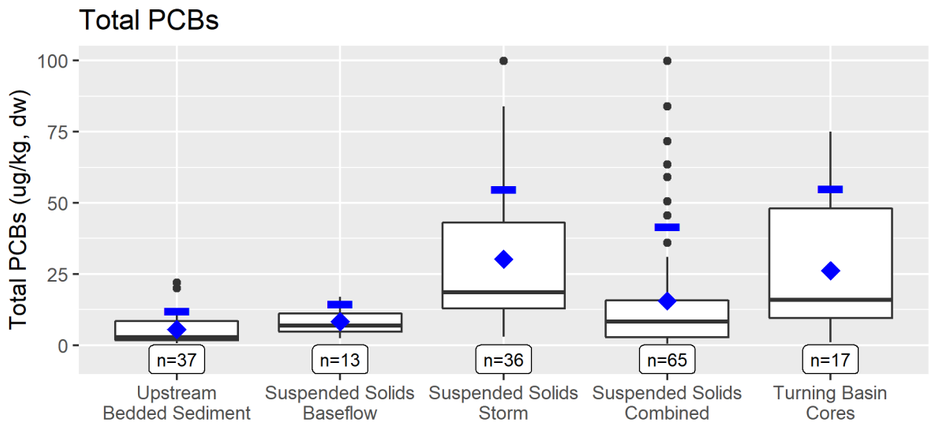
[c] All baseflow and storm events (with and without significant dam releases) were included in combined calculations.

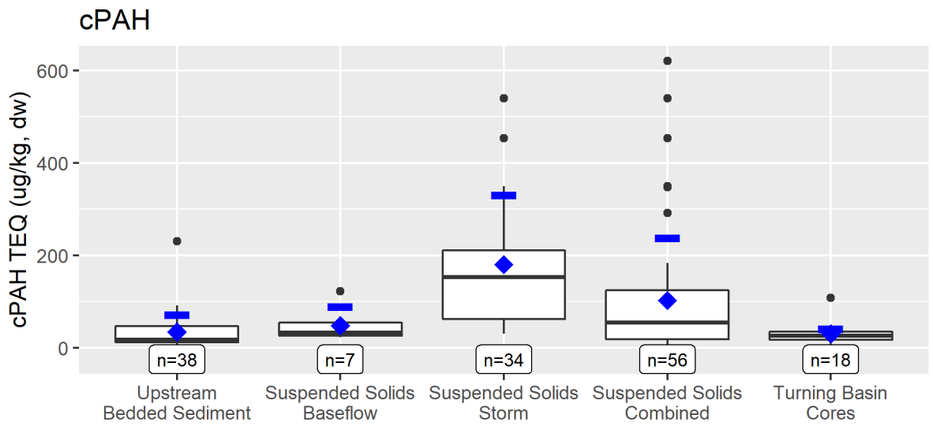
[d] If the sample result was non-detected, then ½ DL was used to calculate the summary statistics presented in this table.

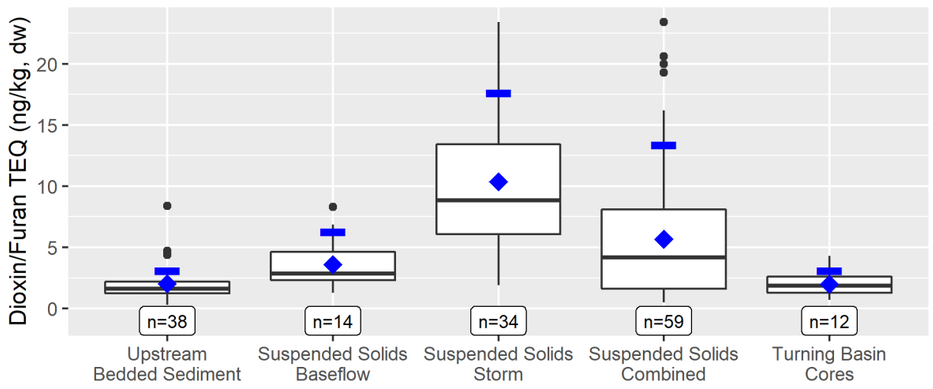
[e] Total PCBs were calculated as the sum of detected congeners when available; otherwise, total PCBs were calculated as the sum of detected Aroclors.

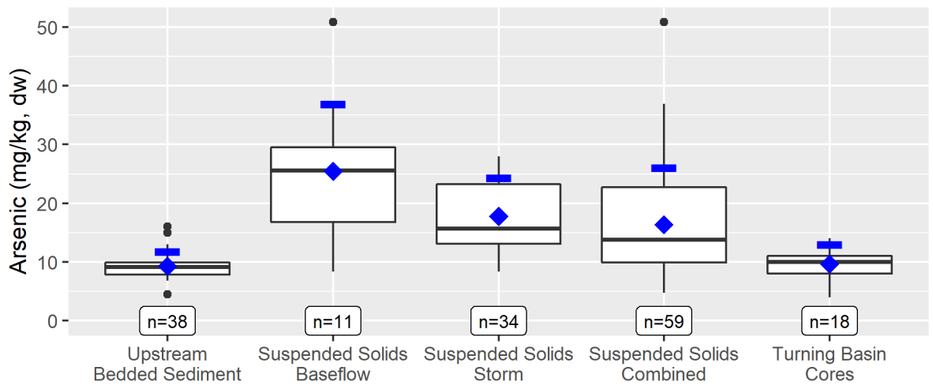
[f] cPAH and dioxin/furan TEQs were calculated using ½ DL for non-detected results.

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
RM – river mile
TEQ – toxic equivalent
USGS – US Geological Survey









Note: Blue diamonds are the mean, and blue lines are the 95UCL for the mean.

Figure 8-2.Distributions of upstream sediment data by dataset

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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 upstream. 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 (AECOM 2012) was followed for the updated values. 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 (see Appendix C (part 3b) in the FS (AECOM 2012)). For this reason, all lines of evidence were considered in selecting input values, each line of evidence having some level of uncertainty as to how well it represents sediment depositing throughout the LDW. For this reason, as in the FS, a base case (mid) value as well as low and high values are presented. An example of uncertainty in one of the lines of evidence would be that while the suspended solids data from upstream provide a measurement of contaminant concentrations in those particles, 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 (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 updated values based on the updated dataset

COC	Estimation Approach and Values					
	Input (Base Case 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 combined suspended storm solids)
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 upstream 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 (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 combined suspended storm solids as well as 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 (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. All three selected upstream input values for cPAH TEQ were lower than those used in the FS (Table 8-5) (AECOM 2012), consistent with the lower-than-expected baseline SWAC of 147 µg/kg (relative to the 220 to 360 µg/kg cPAH TEQ base case predictions in Years 0 and 5).

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 (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 (AECOM 2012) were also selected for arsenic. The base case (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. Higher arsenic concentrations are associated with suspended solids, which have higher proportions of finer grain particles (Conn et al. 2015), but not all finer particles settle in

the LDW (AECOM 2012, Section 5.1.1), Section 5.1.1).[90] For these reasons and consideration of the baseline LDW SWAC, the suspended solids data for arsenic were not used. 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[91]) were estimated based on 95UCL values from the 2008 EPA ocean survey vessel (OSV) *Bold* survey. For this 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). The *Bold* Plus dataset includes data in the *Bold* dataset plus additional data from Ecology-approved reference areas (Ecology 2019).

[90] Approximately 50% of the total solids load entering the LDW from upstream is predicted to be deposited in the LDW, which requires regular dredging of the Turning Basin; of the clay and silt suspended load, approximately 10% of the clay-sized particles and 76% of the silt-sized particles are predicted to settle in the LDW (AECOM 2012; QEA 2008).

[91] When dredging is performed in intertidal areas, the sediment bed is returned to existing elevations through backfill of clean material.

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
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 the 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 (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). The BCM may be used in future modeling to refine natural recovery predictions. A summary of the updated values is presented in Table 8-7, and a comparison of updated base case (mid) values relative to mid, low, and high values included in the FS is presented in Table 8-8. The updated base case (mid) input parameters for total PCBs, cPAHs, and arsenic are within the uncertainty range expected in the FS:

- 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. All recommended base case (mid) values were within the low-to-high range presented in the FS.
- cPAH TEQ – All input values were lower, but all recommended base case (mid) values were still within the low-to-high range presented in the FS.
- Arsenic – Input values were relatively unchanged, and all recommended base case (mid) values were within the low-to-high range presented in the FS.

For dioxins and furans, the Pre-Design Studies datasets are larger than those available for the FS. The larger datasets indicate that base case (mid) input values for laterals and bed replacement are higher and outside of the uncertainty range in the FS, whereas the upstream base case (mid) input value did not change.

Table 8-7. Summary of updated BCM input parameters based on updated data

COC	Updated 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

Table 8-8. Comparison of updated mid-BCM input parameters with range in FS

COC	Lateral				Upstream				Bed Replacement Value			
	Updated	FS			Updated	FS			Updated	FS		
	Mid	Mid	Low	High	Mid	Mid	Low	High	Mid	Mid	Low	High
Total PCBs (µg/kg)	300	300	100	1,000	20	35	5	80	72	60	30	90
cPAH TEQ (µg/kg)	830	1,400	500	3,400	55	70	40	270	111	140	70	200
Dioxin/furan TEQ (ng/kg)	50	20	10	40	4	4	2	8	8	4	2	6
Arsenic (mg/kg)	13	13	9	30	9	9	7	10	10	10	9	11

BCM – bed composition model
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
FS – feasibility study
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

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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. 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. With respect to source-related sampling, LDWG will continue to work with Ecology as it continues its source-sufficiency evaluations.

All recommendations made in this section are for future consideration in long-term monitoring. EPA approval of the data evaluation report does not necessarily indicate EPA agreement with the recommendations.

9.1 SEDIMENT

As part of the Pre-Design Studies, sediment was collected and analyzed for site-wide 0–10-cm composite samples, site-wide 0–45-cm potential clamming area composite samples, and individual beach play area 0–45-cm composite samples to represent baseline conditions following early actions and before the site-wide sediment remedy. Future sediment data will be collected for remedial design and following remedy construction activities as part of MNR and long-term monitoring. This section discusses the study design performance and, where applicable, refinements to be considered for long-term monitoring.

9.1.1 Site-wide surface sediment (0–10-cm) samples

As discussed in Section 2.1, the sampling design for site-wide surface sediment (0–10-cm sediment) included composite samples (each composed of 7 individual grab samples) collected from 24 equally sized areas throughout the LDW (see Map 2-1). Excluding several composite samples wherein elevated concentrations of human health risk drivers have been documented, the data for the four human health risk drivers were normally distributed with CVs of approximately 0.6 or less, leading to an RME for the mean of 21% or less. These distributional results are consistent with the assumptions made in the study design development (i.e., data from a Normal distribution with CVs of 0.7 or less). The individual composite samples that skewed the distributions for arsenic, cPAH TEQ and dioxin/furan TEQ were collected from areas that are expected to be remediated, so the mean and variance from the post-remedy sampling event are

expected to be less than the baseline mean and variance. Thus, no changes to the study design are recommended.

9.1.2 Potential clamming area sediments

As discussed in Section 2.3.1, the sampling design for the potential clamming area sediments called for three site-wide composites, each with 68 grab samples collected from 0–45-cm sediment from intertidal potential clamming areas (see Map 2-8). 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%) and higher 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.

Site-wide heterogeneity after remediation is expected to decrease, resulting in less variance among the three site-wide composites during post-remediation sampling. The approach for future sediment sampling in potential clamming areas will be developed in the long-term monitoring plan. This approach may involve elements of Incremental Sampling Methodology (ITRC 2012).

9.1.3 Beach play area sediments

As discussed in Section 2.3.2, the sampling design for the beach play area sediments called for three beach-wide composites for each of the eight beaches, with three to nine samples from 0–45-cm sediment per composite (proportional to the size of each beach) (see Map 2-9). To estimate the 95UCL, Chebyshev's inequality was used. The conservativeness of Chebyshev's inequality coupled with sampling variance for all four risk drivers meant that RMEs were as high as 362% for cPAHs.

The 95UCL was below the RBTC at all eight beaches for total PCBs, above the RBTC at seven of the eight beaches for arsenic, above the RBTC at three of the eight beaches for dioxins/furans, and above the updated RBTC[92] at three or four of the beaches (depending on treatment of replicate results) for cPAHs. Remediation is expected in most of the beach play areas (either in part or the entire beach), which is expected to reduce risk driver concentrations and variance in these beaches. Future monitoring in these beach play areas will be developed in the long-term monitoring plan and will be modified to address the small- and large-scale variability observed in this dataset. Evaluation of the best approach to meet study objectives, achieve a target RME, or provide sufficient statistical power for the comparison tests to cleanup levels in the ROD will be evaluated prior to future sampling, using the most recent and relevant estimates of variance at that time.

[92] RBTC updated based on EPA's 2017 update of the benzo(a)pyrene slope factor (EPA 2017).

9.2 SURFACE WATER

Baseline concentrations in surface water were assessed using whole-water composite-grab samples for COCs with ARARs and passive samplers for PCBs. As described in Section 3.1.1, composite-grab samples were collected from two locations within the LDW and one location just upstream (see Map 3-1) under a variety of conditions (e.g., storm, base flow, and dam flow rate). These samples were analyzed for PCBs and other COCs with surface water quality ARARs. Composite-grab surface water samples will be collected again following construction of the remedy to assess progress toward meeting ARARs.

As discussed in Section 3.1.2, passive samplers were deployed twice at two locations within the LDW to assess the freely dissolved concentrations of total PCBs. These samplers were allowed to equilibrate for one month (August) and then analyzed for PCB congeners. These data will be used with data from future monitoring events to assess trends in PCBs. The next deployment of the passive samplers is scheduled to occur in 2023 (EPA 2018). This section discusses recommended refinements for the composite-grab sample and passive sampler approaches following the remedy.

9.2.1 Composite-grab samples

Key components of the composite-grab surface water sampling design include the number and timing of sampling events and chemicals to be analyzed in the samples. Refinements to these components are discussed in this section.

9.2.1.1 Number of sampling events

Based on the results of the composite-grab sampling events, it is recommended that 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	Detection Frequency	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
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 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, h), 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. While the analyte list for surface water samples may focus on the chemical groups listed above, periodic full-suite analysis may be required by EPA as cleanup and source control progress.

9.2.2 Passive samplers

Key components of the passive sampler portion of the surface water sampling design include 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 (74% of the total) and across replicates (25% of the total). Variability across locations accounted for essentially 0% of the variance, with the difference in freely dissolved PCB concentrations between the two locations of 0.029 ng/L (95% CI = 0.0267, 0.0322).

Additional passive sampling will be conducted in 2023 at the same two locations monitored during baseline sampling. Beyond that effort, it is recommended that consideration be given to monitoring only a single location, likely at location PS1 (South Park Bridge), for consistency with the location of previous sampling and because the structure is permanent. For determining the number of locations going forward,

considerations should include an evaluation of variance from the three years of sampling (two years of baseline and one year in 2023) and the location and timing of remediation.

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 per location 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%.[93] 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 per location 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 per location 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, as described in Section 4.1, involved the collection of English sole, shiner surfperch, and Dungeness and graceful crabs throughout the LDW (see Map 4-1 and Table 4-1). This design is also intended for use in future monitoring events in order to collect comparable data to assess trends and to evaluate concentrations relative to TTLs. The tissue sampling is scheduled for 2023 and will use the same sampling design that was used in baseline. This section proposes potential refinements to two components of the tissue sampling design for sampling events that will occur after 2023: analyte list and crab species.

9.3.1 Analyte list

Continued monitoring of the human health risk drivers total PCBs, dioxins/furans, and inorganic arsenic is recommended at this time. However, continued monitoring of cPAHs in crab tissue should be evaluated following the 2023 sampling event. There is

[93] This MDD was calculated assuming a single location and depth.

no TTL for cPAHs in crab, and while cPAHs were detected in RI/FS samples of crab, they were not detected in the baseline samples.[94]

Following the 2023 sampling event, the need to continue monitoring non-risk driver chemicals should be evaluated as part of long-term monitoring plan development.

9.3.2 Target crab species

Based on the results of the stable isotope evaluation (Appendix I), 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 to collect Dungeness crab to the extent that it is available.

9.4 CLAM TISSUE

The study design for the collection of clam tissue samples, as discussed in Section 5.1, 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. The tissue variance was skewed by tissue samples from one or more areas with higher sediment concentrations for all analytes, except total PCBs (Appendix B.5).

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 is expected to 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.

[94] The DLs associated with the detected results for crab in the RI/FS samples were lower (0.12 to 0.36 µg/kg) than the baseline DLs (0.5 to 1.0 µg/kg). The ultra-trace method for cPAHs will be considered for crabs in the upcoming 2023 monitoring event.

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 due to the number of clams available for analysis. 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[95] 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.

With respect to cPAHs, significant efforts have been made in the RI and Pre-Design Studies (Section 6.2.1) to better understand the relationship between cPAH concentrations in sediment and those in clam tissue. Based on the work done to date, it appears likely that both sediment and surface water exposure pathways are important. Because the cPAH concentrations in clam tissue have declined since the RI and sediment remediation and source control efforts are more likely to further reduce the concentrations than increase them, no further targeted studies are recommended. Clam tissue concentrations are still above the TTLs for cPAHs, however, so periodic monitoring is recommended.

9.4.2 Analyte list

Continued monitoring of the risk drivers total PCBs, cPAHs, dioxins/furans, and inorganic arsenic is recommended. In the 10 clam composite tissue samples re-analyzed for cPAHs using the ultra-trace modified method (EPA method 8270/1625), the cPAH detection frequency was 100% for all samples (Section 5.1). It is recommended that future monitoring continue to use this method, which has 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 initial Pre-Design Studies dataset). This method would enable a determination of whether cPAH TEQs in clam tissue are below the TTL of 0.24 µg/kg ww,[96] even if all cPAHs were undetected.

Most of the non-risk driver chemicals were either not detected in clam tissue, or were detected at concentrations lower than those in the HHRA dataset samples. Thus, the need to continue monitoring non-risk driver chemicals should be evaluated as part of long-term monitoring plan development. Of the non-risk driver chemicals analyzed in clam tissue, only vanadium, TBT, and BEHP were detected; none of the three other

[95] As shown in Table 5-2, the variance in total PCBs and dioxins/furans was acceptable (excluding the composite from the Glacier Triangle area). Future cPAH variance will depend on the ability to detect cPAHs in clam tissue.

[96] The RBTC based on EPA's 2017 update of the benzo(a)pyrene slope factor (EPA 2017) is 1.8 µg/kg ww.

SVOCs or pesticides were detected, and RLs for these chemicals were generally lower than those for the HHRA database samples (see Table 5-8). 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 about 50 times lower than those in the HHRA (Windward 2007) (Table 5-9),[97] meaning that human risks from TBT would be well below the non-cancer threshold (hazard quotient [HQ] less than 1) for all three reasonable maximum seafood consumption exposure scenarios.

In summary, the following recommendations are made for the future 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.
- Discuss in the long-term monitoring plan which non-risk driver chemicals should continue to be monitored based on the RI, baseline, and 2023 data.

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. The study designs used in the baseline sampling are generally well suited for long-term monitoring, although refinements are recommended for future monitoring efforts. Specific monitoring requirements will be determined as the long- term monitoring plan is developed. 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.

[97] The 14 clam tissue concentrations of TBT in the HHRA dataset ranged from 150 to 660 µg/kg ww, while TBT concentrations in the three Pre-Design Studies composite samples ranged from 5.34 to 7.44 µg/kg ww.

10 References

Accardi-Dey A, Gschwend PM. 2002. Assessing the combined roles of natural organic matter and black carbon as sorbents in sediments. Environ Sci Tech 36:21-29.

AECOM. 2012. Final feasibility study, Lower Duwamish Waterway. Prepared for Lower Duwamish Waterway Group. AECOM, Seattle, WA.

AMEC, DOF, Ramboll Environ, FloydSnider, Geosyntec. 2016. Quality assurance project plan. Enhanced Natural Recovery/Activated Carbon Pilot Study, Lower Duwamish Waterway. Amec Foster Wheeler Environment & Infrastructure, Inc.; Dalton, Olmsted & Fuglevand, Inc.; Ramboll Environ; Floyd|Snider; and Geosyntec Consultants.

Amec Foster Wheeler. 2016. Post-construction surface sediment monitoring report - year 1. Amec Foster Wheeler Environment & Infrastructure, Inc., Seattle, WA.

Amec Foster Wheeler. 2017. Quality assurance project plan addendum 1. Enhanced natural recovery/activated carbon pilot study Lower Duwamish Waterway *ex situ* SPME sampling at the subtidal plot. Amec Foster Wheeler Environment & Infrastructure, Inc.

Anchor, Windward. 2019. Remedial design work plan for the Lower Duwamish Waterway upper reach. Revised draft final. Submitted to EPA October 28, 2019. Anchor QEA, Inc. and Windward Environmenal LLC, Seattle, WA.

Apell JN, Gschwend PM. 2016. In situ passive sampling of sediments in the Lower Duwanish Wateray Superfund site: replicability, comparison with ex situ measurements, and use of data. Environ Pollut 218:95-101.

Apell JN, Gschwend PM. 2017. The atmosphere as a source/sink of polychlorinated biphenyls to/from the Lower Duwamish Waterway Superfund site. Environ Pollut 227:263-270.

Apell JN, Shull DH, Hoyt AM, Gschwend PM. 2018. Investigating the effect of bioirrigation on in situ porewater concentrations and fluxes of polychlorinated biphenyls using passive samplers. Environ Sci Tech 52:4565-4573.

Baltz DM. 1984. Life history variation among female surfperches (Perciformes: Embiotocidae). Environ Biol Fish 10(3):159-171.

Butler PA, Schutzmann RL. 1978. Residues of pesticides and PCBs in estuarine fish, 1972-76 -- National Pesticide Monitoring Program. Pestic Monit J 12(2):51-59.

Conn KE, Black RW, Vanderpool-Kimura AM, Foreman JR, Peterson NT, Senter CA, Sissel SK. 2015. Chemical concentrations and instantaneous loads, Green River to the Lower Duwamish Waterway near Seattle, Washington, 2013-15. US Geological Survey, Reston, VA.

EC. 2002. Opinion of the Scientific Committee on Food on benzyl alcohol. SCF/CS/ADD/FLAV/78 Final. European Commission, Health and Consumer Protection Directorate-General, Scientific Committee on Food.

Ecology. 2013. Model Toxics Control Act Regulation and Statute. Publication No. 94-06. Washington State Department of Ecology, Olympia, WA.

Ecology. 2015. Sediment cleanup users manual II. Guidance for implementing the Cleanup Provisions of the Sediment Management Standards, Chapter 173-204 WAC. March 2015. Pub. no. 12-09-057. Toxics Cleanup Program, Washington State Department of Ecology, Olympia, WA.

Ecology. 2016. Lower Duwamish Waterway source control strategy. Publication No. 16-09-339. Washington State Department of Ecology, Olympia, WA.

Ecology. 2017. Sediment cleanup user's manual II. Guidance for implementing the cleanup provisions of the sediment management standards, Chapter 173-204 WAC. Draft for review and comment through July 7, 2017. Pub. No. 12-09-057. Revised April 2017. Toxics Cleanup Program, Washington State Department of Ecology, Olympia, WA.

Ecology. 2018a. Lower Duwamish Waterway preliminary cleanup level workbook supplemental information. Washington State Department of Ecology.

Ecology. 2018b. Lower Duwamish Waterway preliminary cleanup level workbook. Excel data. Washington State Department of Ecology.

Ecology. 2019. Sediment cleanup user's manual. Guidance for implementing the cleanup provisions of the sediment management standards, Chapter 173-204 WAC. Second revision December 2019. Pub. No. 12-09-057. Toxics Cleanup Program, Washington State Department of Ecology, Olympia, WA.

EPA. 2012. Equilibrium partitioning sediment benchmarks (ESBs) for the protection of benthic organisms: procedures for the determination of the freely dissolved interstitial water concentrations of nonionic organics. EPA/600/R-02/012. US Environmental Protection Agency.

EPA. 2014. Record of Decision. Lower Duwamish Waterway Superfund Site. US Environmental Protection Agency.

EPA. 2015a. Lower Duwamish Waterway Record of Decision Table and Figure Revisions. Environmental Protection Agency, Seattle, WA.

EPA. 2015b. ProUCL version 5.1.002 user guide. Statistical software for environmental applications for data sets with and without nondetect observations. EPA/600/R-07/041. US Environmental Protection Agency.

EPA. 2016. Third Amendment to the Administrative Order on Consent for remedial investigation/feasibility study (AOC) for the Lower Duwamish Waterway (LDW), CERCLA-10-2001-0055. US Environmental Protection Agency, Region 10, Olympia, WA.

EPA. 2017. Toxicological review of benzo[a]pyrene (BaP). CASRN 50-32-8. EPA/635/R-17/003Fa. US Environmental Protection Agency, Washington, DC.

EPA. 2018. Remedial design statement of work, LDW Upper Reach, Lower Duwamish Waterway Superfund site. Attachment to the *Fourth Amendment of the Administrative Order on Consent for Remedial Investigation/Feasibility Study*. US Environmental Protection Agency, Region 10, Seattle, WA.

Fourie HW, Fox D. 2016. Revised evaluation guidelines for benzyl alcohol in marine sediments. 2016 Sediment Management Annual Review Meeting, May 4, 2016. DMMP Agencies. pp 96-106.

Ghosh U, Zimmerman JR, Luthy RG. 2003. PCB and PAH speciation among particle types in contaminated harbor sediments and effects on PAH bioavailability. Environ Sci Tech 37:2209-2217.
Gordon CD. 1965. Aspects of the life-history of *Cymatogaster aggregata* gibbons. Master of Science. Zoology, The University of British Columbia, British Columbia. 107 pp.
Hansen BG, Paya-Perez AB, Rahman M, Larsen BR. 1999. QSARs for Kow and Koc of PCB congeners: a critical examination of data, assumptions and statistical approaches. Chemosphere 39(13):2209-2228.
Hart Crowser. 2012a. Lower Duwamish Waterway bank sampling summary report. Hart Crowser, Inc., Seattle, WA.
Hart Crowser. 2012b. Lower Duwamish Waterway bank sampling summary report, Seattle, Washington. Prepared for Washington State Department of Ecology. Hart Crowser, Inc., Seattle, WA.
Integral, Anchor QEA, Windward. 2019. Recovery category recommendations report. Final. Integral Consulting Inc., Anchor QEA, and Windward Environmental LLC, Seattle, WA.
ITRC. 2012. Technical and regulatory guidance. Incremental sampling methodology. Interstate Technology and Regulatory Council, Washington, DC.
Iverson SJ, Frost KJ, Lang SLC. 2002. Fat content and fatty acid composition of forage fish and invertebrates in Prince William Sound, Alaska: factors contributing to among and within species variability. Mar Ecol Prog Ser 241:161-181.
Jalalizadeh M, Ghosh U. 2017. Analysis of measurement errors in passive sampling of porewater PCB concentrations under static and periodically vibrated conditions. Environ Sci Tech 51(12):7018-7027.
Kerns K, Michalsen M, Lotufo GR, Adams K, Duncan B, Hale E. 2017. Controlled field exposures suggest modes of arsenic accumulation in adult eastern softshell clams. Final. US Army Corps of Engineers and US Environmental Protection Agency, Seattle, WA.
King County. 1999. Subappendix G-H. King County combined sewer overflow water quality assessment for the Duwwamish River and Elliott Bay. King County, WA.
King County, Anchor. 2008. Duwamish/Diagonal sediment remediation project 2006/2007 monitoring report. Prepared for the Elliott Bay Duwamish Restoration Program Panel. King County Department of Natural Resources and Anchor Environmental LLC, Seattle, WA.
Koelmans AA, Jonker MTO, Cornelissen G, Buchelli TD, Van Noort PCM, Gustafsson O. 2006. Black carbon: the reverse of its dark side. Chemosphere 63:365-377.
Lambert MK, Friedman CL, Luey P, Lohmann R. 2011. Role of black carbon in the sorption of polychlorinated dibenzo-p-dioxins and dibenzofurans at the Diamond Alkali Superfund site, Newark Bay, New Jersey. Environ Sci Tech 45:4331-4338.
Lassuy DR. 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest). English sole. USFW

biological report 82(11.101). Coastal Ecology Group, US Army Corps of Engineers, Vicksburg, MS and National Wetlands Research Center, US Fish and Wildlife Service, Slidell, LA.
Leidos. 2014a. LDW technical support: sediment outfall sampling - Phase 2 scoping (draft). Leidos, Bothell, WA.
Leidos. 2014b. Lower Duwamish Waterway. Outfall inventory update January 2012 - February 2014. Leidos, Bothell, WA.
Louis Berger. 2010. Hudson River PCBs site EPA Phase 1 evaluation report. Prepared for US Environmental Protection Agency, Region 2, and US Army Corps of Engineers, Kansas City District. The Louis Berger Group, Inc.
Malins DC, McCain BB, Brown DW, Sparks AK, Hodgins HO, Chan S. 1982. Chemical contaminants and abnormalities in fish and invertebrates from Puget Sound. Environmental Conservation Division, National Marine Fisheries Service, Seattle, WA.
Mickelson S. 2013. Receiving water characterization study. King County NPDES monitoring program. Final report. King County Department of Natural Resources and Parks, Marine and Sediment Assessment Group, Seattle, WA.
Mraz J. 2012. Lipids in common carp (*Cyprinus carpio*) and effects on human health. PhD. Food Science, Swedish University of Agricultural Sciences, 68 pp.
Oregon DEQ. 2015. Oregon Coast softshell clam (*Mya arenaria*) health advisory related to inorganic arsenic. Oregon Department of Environmental Quality.
Patmont C, LaRosa P, Narayanan R, Forrest C. 2018. Environmental Dredging Residual Generation and Management. Int Environ Asses and Manag 14(3):335-343.
QEA. 2008. Lower Duwamish Waterway sediment transport modeling report. Prepared for Lower Duwamish Waterway Group. Quantitative Environmental Analysis, LLC, Montvale, NJ.
SAIC. 2011. Surface sediment sampling at outfalls in the lower Duwamish Waterway. Science Applications International Corporation, Bothell, WA.
Stern JH. 2015. PCB cycling in an urban river/estuary. Eighth International Conference on Remediation and Management of Contaminated Sediments, New Orleans, LA, January 2015.
West JE, O'Neill SM, Ylitalo GM. 2017. Time trends of persistent organic pollutants in benthic and pelagic indicator fishes from Puget Sound, Washington, USA. Arch Environ Contam Toxicol 73(2):207-229.
Windward. 2004a. Lower Duwamish Waterway remedial investigation. Intertidal clam survey data report. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.
Windward. 2004b. Lower Duwamish Waterway remedial investigation. Quality assurance project plan: Fish and crab tissue collection and chemical analyses. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.
Windward. 2005. Lower Duwamish Waterway remedial investigation. Quality assurance project plan: Fish and crab tissue collection and chemical analyses.

Addendum for additional fish and crab sampling in the Lower Duwamish Waterway. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.
Windward. 2007. Lower Duwamish Waterway remedial investigation. Baseline human health risk assessment. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.
Windward. 2010a. Lower Duwamish Waterway remedial investigation. Remedial investigation report. Final. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.
Windward. 2010b. Lower Duwamish Waterway remedial investigation. Remedial investigation report. Final. Prepared for Lower Duwamish Waterway Group. Appendix I. Source control area-related facility information. Windward Environmental LLC, Seattle, WA.
Windward. 2017a. Baseline fish and crab tissue collection and chemical analyses - quality assurance project plan. Final. Submitted to EPA on July 19, 2017. Lower Duwamish Waterway Pre-Design Studies. Windward Environmental LLC, Seattle, WA.
Windward. 2017b. Baseline surface water collection and chemical analyses - quality assurance project plan. Final. Submitted to EPA on August 2, 2017. Lower Duwamish Waterway Pre-Design Studies. Windward Environmental LLC, Seattle, WA.
Windward, Integral. 2017a. Pre-design studies work plan - porewater addendum. Final. Submitted to EPA August 28, 2017. Windward Environmental LLC and Integral Consulting Inc., Seattle, WA.
Windward, Integral. 2017b. Pre-design studies work plan. Appendix C. Data management plan. Lower Duwamish Waterway Superfund site. Final. Prepared for the Lower Duwamish Waterway Group for submittal to EPA Region 10. Windward Environmental LLC and Integral Consulting Inc., Seattle, WA.
Windward, Integral. 2017c. Pre-design studies work plan. Lower Duwamish Waterway Superfund site. Final. Prepared for the Lower Duwamish Waterway Group for submittal to EPA Region 10 on August 28, 2017. Windward Environmental LLC and Integral Consulting Inc., Seattle, WA.
Windward. 2018a. Baseline surface water collection and chemical analyses - quality assurance project plan - addendum. Final. Submitted to EPA on March 2, 2018. Lower Duwamish Waterway Pre-Design Studies. Windward Environmental LLC, Seattle, WA.
Windward. 2018b. Lower Duwamish Waterway baseline seep collection and chemical analyses - quality assurance project plan. Final. Windward Environmental LLC, Seattle, WA.
Windward. 2018c. Lower Duwamish Waterway baseline seep data report. Final. Submitted to EPA December 7, 2018. Windward Environmental LLC, Seattle, WA.

Windward. 2018d. Lower Duwamish Waterway baseline surface sediment collection and chemical analyses - quality assurance project plan. Final. Windward Environmental LLC, Seattle, WA.
Windward. 2018e. Lower Duwamish Waterway clam collection and chemical analyses - quality assurance project plan - addendum. Final. Windward Environmental LLC, Seattle, WA.
Windward. 2018f. Lower Duwamish Waterway clam collection and chemical analyses - quality assurance project plan. Final. Windward Environmental LLC, Seattle, WA.
Windward. 2018g. Lower Duwamish Waterway fish and crab data report. Final. Windward Environmental, LLC, Seattle, WA.
Windward. 2018h. Surface water analyte evaluation. Windward Environmental LLC, Seattle, WA.
Windward, Integral. 2018a. Technical memorandum: compilation of existing data. Final. Submitted to EPA November 19, 2018. Windward Environmental LLC and Integral Consulting Inc., Seattle, WA.
Windward, Integral. 2018b. Technical memorandum: Compilation of existing data. Final. Submitted to EPA on November 19, 2018. Windward Environmental LLC and Integral Consulting Inc., Seattle, WA.
Windward. 2019a. Lower Duwamish Waterway baseline surface water collection and chemical analyses data report. Final. Submitted to EPA on April 2, 2019. Lower Duwamish Waterway Pre-Design Studies. Windward Environmental LLC, Seattle, WA.
Windward. 2019b. Lower Duwamish Waterway clam data report. Final. Submitted to EPA on February 28, 2019. Windward Environmental LLC, Seattle, WA.
Windward. 2019c. Lower Duwamish Waterway surface sediment data report. Final. Submitted to EPA February 8, 2019. Windward Environmental LLC, Seattle, WA.
Windward, Anchor. 2019. Pre-design investigation work plan for the Lower Duwamish Waterway upper reach. Draft final. Submitted to EPA December 16, 2019. Windward Environmental LLC and Anchor QEA, Seattle, WA.