Methods for the Development of Risk-Based Threshold Concentrations for the Lower Duwamish Waterway, Seattle, WA

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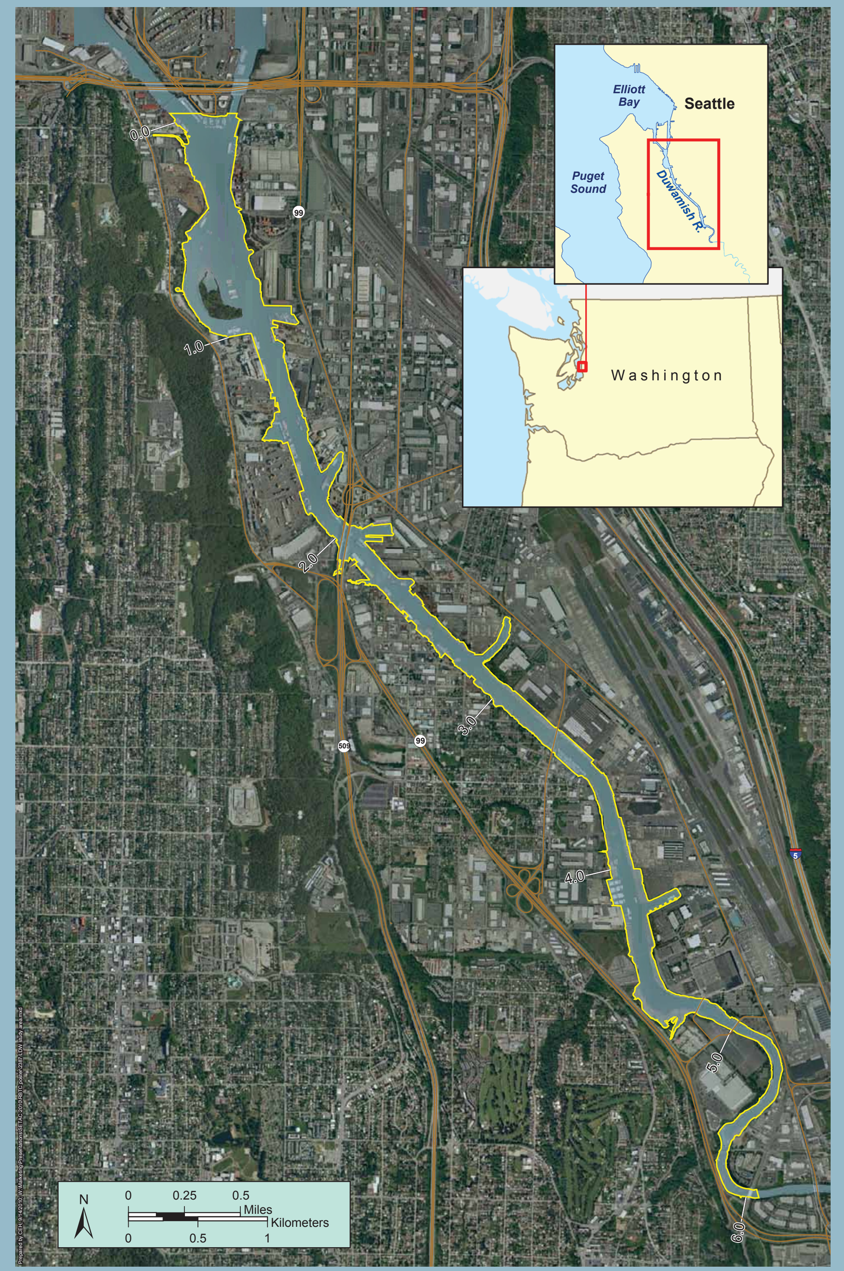

Location of Lower Duwamish Waterway site

Abstract

Four chemicals or chemical groups (arsenic, polychlorinated biphenyls [PCBs], carcinogenic polycyclic aromatic hydrocarbons [cPAHs], and dioxins and furans) were identified as risk drivers for the Lower Duwamish Waterway (LDW) Superfund site in Seattle, Washington, based on the results of the human health risk assessment. Risk drivers identified based on the ecological risk assessment included PCBs for river otter and 41 chemicals for benthic invertebrates. Sediment risk-based threshold concentrations (RBTCs) were developed for both human health and ecological risk drivers. Risk equations were used to derive sediment RBTCs for all human health risk driver chemicals for the direct sediment contact scenarios. RBTCs for benthic invertebrates were based on the Washington State Sediment Management Standards. To derive sediment RBTCs for seafood consumption scenarios, it was necessary to model the relationship between chemical concentrations in seafood tissue and sediment. For PCBs, this relationship was established using a site-specific food web model. For arsenic and cPAHs, tissue and sediment relationships were explored using regression models, but the relationships were considered too uncertain for the development of sediment RBTCs. Sediment RBTCs based on seafood consumption were not estimated for dioxins and furans because there were no dioxin and furan tissue data from the LDW when the risk assessments were conducted.

Introduction

The Lower Duwamish Waterway (LDW) in Seattle, Washington, was listed as a Superfund site in September 2001 and as a Washington State cleanup site under the Model Toxics Control Act in 2002. A remedial investigation (RI), including human health and ecological risk assessments, was completed in 2010 (Windward 2010), and a feasibility study (FS) is in progress (AECOM 2010). Certain chemicals were selected as risk drivers in the risk assessments in order to focus the FS on chemicals of concern that posed the highest risk (Figure 1).

Sediment RBTCs are chemical concentrations that equate to specific human health or ecological risk thresholds. RBTCs were an important component in the derivation of preliminary remediation goals (PRGs) in the draft final FS (AECOM 2010). PRGs were based on RBTCs unless the RBTCs were below background concentrations or below concentrations that could be quantified by chemical analysis.

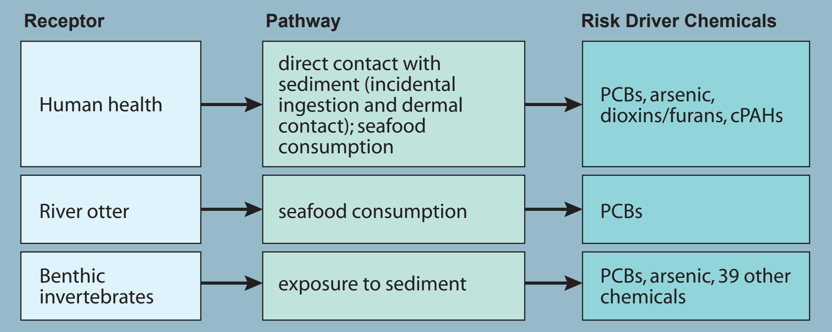

Figure 1. Risk driver chemicals selected based on human health and ecological risk assessments

Overview of Methods for Deriving RBTCs

Methods for deriving sediment RBTCs were dependent upon the receptor, exposure pathway, and chemical, as detailed below and presented in Table 1.

- Direct sediment contact – The derivation of sediment RBTCs for risks from sediment contact was straightforward because risks were directly related to sediment concentrations.
- Seafood consumption – A mechanistic food web model designed for hydrophobic chemicals was developed to derive sediment polychlorinated biphenyl (PCB) RBTCs for human health and river otter seafood consumption. The model was not appropriate for arsenic or carcinogenic polycyclic aromatic hydrocarbons (cPAHs), so regression models were evaluated for those risk drivers.

Table 1. Methods for deriving RBTCs

Exposure Pathway	Receptor	Chemical-Specific RBTC Calculation Method			
		PCBs	Arsenic	Dioxins/Furans	cPAHs[a]
Direct sediment contact	humans	back-calculated from risk equation	back-calculated from risk equation	back-calculated from risk equation	back-calculated from risk equation
	benthic invertebrates	SMS	SMS	na	na[b]
Seafood consumption	humans	food web model	regression	model not developed for dioxins/furans[c]	regression
	river otter	food web model	na	na	na

[a] cPAHs were expressed as TEQ based on the relative toxicity of individual cPAHs to benzo(a)pyrene.
[b] RBTCs for individual PAHs were derived from SMS, which provided the RBTCs for all of the risk driver chemicals for benthic invertebrates, including those not listed in this table.
[c] Risk was assumed to be unacceptable.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
na – not applicable (not a risk driver)
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
SMS – Washington State Sediment Management Standards
TEQ – toxic equivalent

Direct Sediment Contact RBTCs

- **Human health RBTCs** – Risks from direct contact were calculated using a risk equation for three direct contact scenarios (Box 1). To derive RBTCs, the risk equation was used to back-calculate sediment concentrations when the excess cancer risk threshold was set at either 1×10^{-6}, 1×10^{-5}, or 1×10^{-4} (Box 2; Table 2). RBTCs for non-cancer hazards were not calculated from direct sediment contact because none of the reasonable maximum exposure (RME) scenarios had hazard quotients (HQs) greater than 1.
- **Benthic invertebrate RBTCs** – For benthic invertebrates, 41 chemicals were identified as risk drivers. Sediment RBTCs for these 41 chemicals were set equal to the sediment quality standards and cleanup screening levels of the Washington State Sediment Management Standards (SMS) (Ecology 1995).

Box 1. Key exposure parameters for the direct contact RME scenarios

Netfishing – Site-wide exposure for 119 days/year for 44 years

Child beach play – Exposure at eight beaches for 65 days/year for 6 years

Tribal clamming – Exposure in clamming areas for 120 days/year for 64 years

Box 2. Equation for deriving direct sediment contact RBTCs

$$RBTC = \frac{TR}{(E_{dermal} + E_{ingestion}) \times SF}$$

Where:
RBTC = risk-based threshold concentration in sediment
TR = target excess cancer risk (i.e., 1×10^{-6}, 1×10^{-5}, 1×10^{-4})
E_{dermal} = exposure via dermal absorption calculated using scenario-specific parameters (e.g., exposure frequency/duration, exposed surface area, body weight)
$E_{ingestion}$ = exposure via incidental ingestion calculated using scenario-specific parameters (e.g., exposure frequency/duration, incidental sediment ingestion rate, body weight)
SF = cancer slope factor

Table 2. Human health sediment RBTCs based on the direct contact RME scenarios compared with site concentrations

Risk Driver	Risk Threshold (Excess Cancer Risk)	Sediment RBTC		
		Netfishing	Beach Play	Tribal Clamming
Arsenic (mg/kg dw)	1×10^{-6}	3.7	2.8	1.3
	1×10^{-5}	37	28	13
	1×10^{-4}	370	280	130
cPAH TEQ (µg/kg dw)	1×10^{-6}	380	90	150
	1×10^{-5}	3,800	900	1,500
	1×10^{-4}	38,000	9,000	15,000
Dioxin and furan TEQ (ng/kg dw)	1×10^{-6}	37	28	13
	1×10^{-5}	370	280	130
	1×10^{-4}	3,700	2,800	1,300
Total PCBs (µg/kg dw)	1×10^{-6}	1,300	1,700	500
	1×10^{-5}	13,000	17,000	5,000
	1×10^{-4}	130,000	170,000	50,000

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
TEQ – toxic equivalent

Seafood Consumption RBTCs for PCBs

A food web model calibrated to LDW environmental conditions and resident seafood species was used to estimate sediment RBTCs for PCBs for three seafood consumption RME scenarios. Details regarding specific input parameters, calibration, and performance of the food web model are presented in the LDW RI (Windward 2010). Steps for calculating RBTCs using the food web model are as follows:

- **Step 1.** Total PCB concentrations in surface water were estimated as a function of PCB concentrations in LDW sediment and concentrations in upstream and downstream surface water. Paired sediment and surface water PCB concentrations were important model input parameters.
- **Step 2.** The food web model was used to estimate total PCB concentrations in each tissue type for a range of sediment PCB concentrations.
- **Step 3.** Tissue concentrations that corresponded with sediment concentrations used in the food web model runs were entered into the human health and ecological risk assessment equations, and risks were estimated.
- **Step 4.** Sediment RBTCs were derived as sediment concentrations associated with risk thresholds. A best-fit RBTC was estimated using the food web model parameter set that most closely fit the empirical PCB tissue data for all seafood species combined. RBTCs were also estimated for each seafood exposure scenario using upper- and lower-bound parameter sets.

A range of sediment RBTCs for total PCBs was derived for three human health seafood consumption RME scenarios (Box 3) and for river otter seafood consumption (Table 3).

Box 3. Key exposure parameters for the seafood ingestion RME scenarios

Adult tribal – Ingestion rate of 97.5 g/day for 70 years
Child tribal – Ingestion rate of 39 g/day for 6 years
Adult Asian and Pacific Islander – Ingestion rate of 51.5 g/day for 30 years

- Sediment RBTCs for RME scenarios (adult tribal, child tribal, and adult Asian and Pacific Islander [API]) could not be derived for 1×10^{-5} or 1×10^{-6} risk thresholds (excess cancer risks) or for HQs = 1 (non-cancer hazards) because the contribution from water alone (even at concentrations similar to those in upstream surface water) resulted in estimated total PCB concentrations in tissue greater than these risk thresholds, even in the absence of any contribution from sediment.
- At the 1×10^{-4} risk threshold, best-fit RBTCs ranged from 7.3 to 185 µg/kg dw for the three human health seafood consumption RME scenarios.
- Best-fit RBTCs for river otter were 128 and 159 µg/kg dw.

Table 3. Sediment RBTCs for total PCBs for human health and river otter exposure scenarios

RME Scenario	Risk Threshold	Sediment PCB RBTC (µg/kg dw)		
		Lower Bound	Best Fit	Upper Bound
Adult tribal	1×10^{-4} (excess cancer risk)	< 1	7.3	25
Child tribal		109	185	301
Adult API		67	100	167
Adult tribal	1×10^{-5} or 1×10^{-6} (excess cancer risk) or HQ = 1 (non-cancer hazard)	< 1	< 1	< 1
Child tribal		< 1	< 1	< 1
Adult API		< 1	< 1	< 1
River otter (lowest observed effect level, without juvenile fish)	HQ = 1	91	128	217
River otter (lowest observed effect level, with juvenile fish)		100	159	250

API – Asian and Pacific Islander
dw – dry weight
HQ – hazard quotient
PCB – polychlorinated biphenyl
RBTC – risk-based sediment concentration
RME – reasonable maximum exposure

Seafood Consumption RBTCs for Arsenic and cPAHs

Empirical regressions are commonly used to describe the relationship between chemical concentrations in sediment and biota at contaminated sites. Regression models are considered superior to simple uptake factors (e.g., biota-sediment accumulation factors, bioaccumulation factors, or bioconcentration factors) because of their ability to address thresholds and other non-linear properties associated with bioaccumulation. Clam consumption was responsible for 95% or more of the human health risk associated with inorganic arsenic and 95% or more of the risk associated with cPAH TEQ in each of the three RME scenarios. Relationships between chemical concentrations in composite clam samples and co-located sediment samples were evaluated for the derivation of potential RBTCs.

- **Arsenic regression** – Various regression models were evaluated, including log-normalization (of only sediment concentrations or of both sediment and tissue concentrations) and the exclusion of potential outliers. A marginal positive association between inorganic arsenic in clams and total arsenic in co-located sediment was observed for one of the models, as shown in Figure 2. The low R^2 value indicated that the linear regression model should not be relied upon for the establishment of a sediment RBTC. In addition, confidence intervals around the regression line indicated a high level of uncertainty in the relationship. Scatter in the data points was particularly pronounced at the low end of the sediment range, where sediment cleanup goals may be set.
- **cPAH TEQ regression** – As with arsenic, various regression models were investigated for cPAH TEQ (Figure 3). The uncertainties associated with cPAH TEQ were the same as those for arsenic, making this approach unacceptable for the establishment of a sediment RBTC. In addition, a single high data point was responsible for the significance of the regression.

Because of uncertainty in these regressions, sediment RBTCs were not calculated for arsenic and cPAH TEQ for the seafood consumption scenarios.

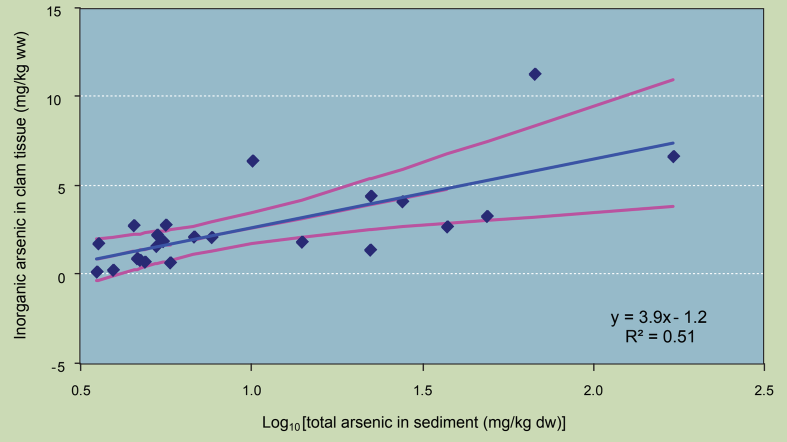

Figure 2. Regression relationship for inorganic arsenic in clam tissue relative to total arsenic in co-located sediment

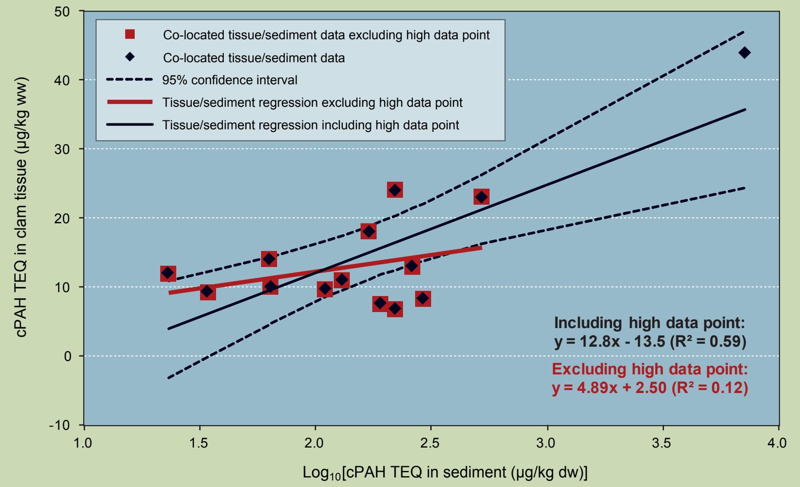

Figure 3. Regression relationship for cPAH TEQ in clam tissue relative to cPAH TEQ in co-located sediment

Comparison of RBTCs with Natural Background and Upstream Area Concentrations

A comparison of sediment RBTCs with natural background (i.e., Puget Sound reference areas) and upstream concentrations is important for risk management decisions because cleanup to concentrations below natural background and upstream concentrations is not practicable. For informational purposes, sediment RBTCs were compared with data from Puget Sound reference areas (90th percentile concentrations from a comprehensive survey conducted in 2008) and data from areas upstream of the LDW (estimated concentrations developed in the draft final FS [AECOM 2010] from multiple lines of evidence).

- Sediment RBTCs for total PCBs for the human seafood consumption RME scenarios were undefined at concentrations below natural background and upstream concentrations for all scenarios at risk thresholds of 1×10^{-6} and 1×10^{-5} (excess cancer risks) and for an HQ = 1 (non-cancer hazard) (Figure 4).
- RBTCs for PCBs, cPAH TEQ, and dioxins and furans for the human direct sediment contact RME scenarios were above natural background and upstream concentrations (Figure 5).
- RBTCs for arsenic for the human direct sediment contact RME scenarios were below natural background and upstream concentrations at the 1×10^{-6} risk threshold (Figure 5).
- RBTCs for river otter were above total PCB concentrations in sediment from natural background and upstream areas.

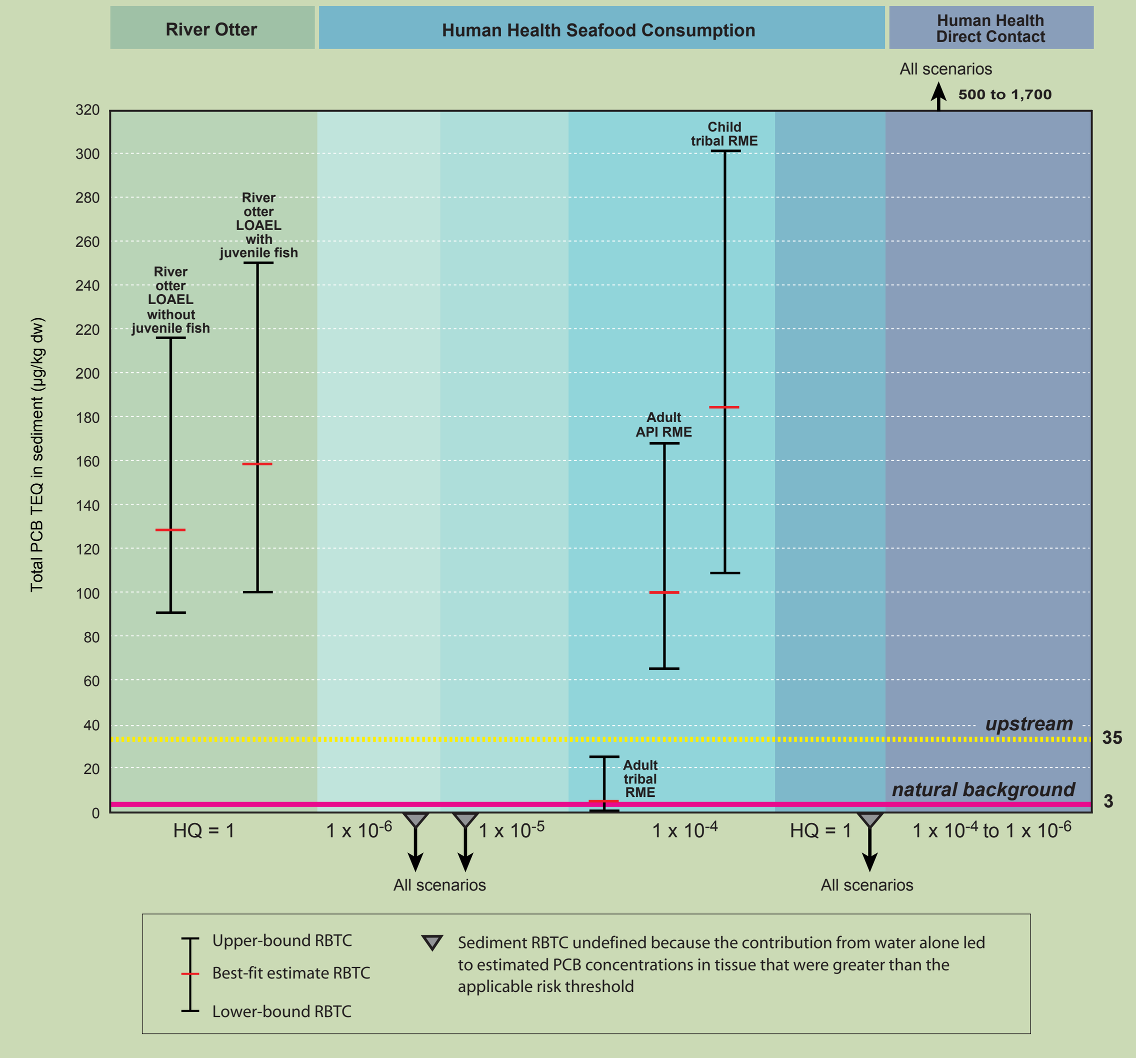

Figure 4. Sediment RBTCs for total PCBs for human health seafood consumption and direct contact RME scenarios and for river otter

Conclusions

- Sediment RBTCs for total PCBs for the three human health seafood consumption RME scenarios were undefined at < 1 µg/kg dw for the 1×10^{-5} and 1×10^{-6} risk thresholds (excess cancer risks) and for an HQ = 1 (non-cancer hazard) because the contribution from water alone resulted in estimated total PCB concentrations in tissue greater than these risk thresholds for these relatively high seafood consumption rates, even in the absence of any contribution from sediment. At a 1×10^{-4} risk threshold, best-fit RBTCs for PCBs ranged from 7.3 to 185 µg/kg dw for the three human health seafood consumption RME scenarios.
- Sediment RBTCs could not be developed for the human health seafood consumption RME scenarios for arsenic and cPAHs because of uncertainty in tissue-sediment regression models.
- Sediment RBTCs were below natural background and upstream concentrations for human direct sediment contact RME scenarios for arsenic at the 1×10^{-6} risk threshold. In addition, sediment RBTCs were undefined at concentrations below natural background and upstream concentrations for human seafood consumption RME scenarios for total PCBs at risk thresholds of 1×10^{-6} and 1×10^{-5} (excess cancer risks) and for HQs = 1 (non-cancer hazards).

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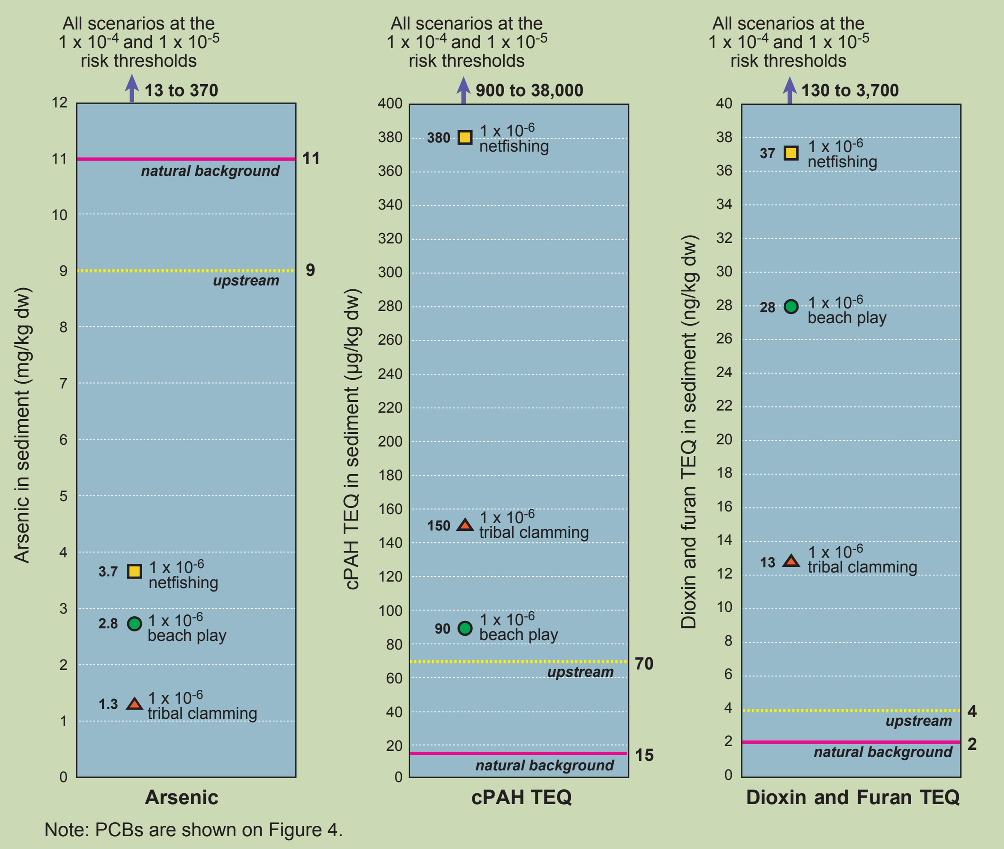

Note: PCBs are shown on Figure 4.

Figure 5. Sediment RBTCs for human health direct sediment contact RME scenarios compared with background and upstream concentrations