

ANNEX 8A BIOACCUMULATION ASSESSMENT

8A.1.1 Introduction

This *Annex* presents the methodology for the bioaccumulation assessment and the findings of the assessment for the concentrations of Contaminants of Concern (COCs) in seafood.

8A.1.2 Background

The objective of the bioaccumulation assessment is to predict the likely concentrations of COCs in selected marine organisms due to contaminant exposure through disposal operations at the proposed WL Facility.

8A.1.3 Literature Review of Bioaccumulation of COCs

Contamination in aquatic ecosystems has become one of the major environmental concerns worldwide. COCs are released from point sources to river/estuarine and coastal waters as a result of increased industrialization. Sediment is a potentially important source of COC for the overlying water, due to sediment resuspension (contributing to the particulate load) or sediment remobilisation and diagenesis (contributing to the dissolved load). Once in the water column, COCs are then partitioned between the dissolved and particulate phases and this is controlled by adsorption/desorption and precipitation/dissolution. Many physico-chemical and biological factors (e.g., particle type / concentration, salinity, dissolved organic carbon concentration, and biological uptake) can influence the partitioning in the water column. Thus, COCs can become available to marine benthic invertebrates through uptake from the dissolved phase and ingestion of suspended particles and sediments (i.e. particulate phase).

The bioaccumulation of COCs in aquatic organisms has received extensive attention over the last several decades because toxicity is dependent on their accumulation. The bioavailability is defined as the fraction of total COCs in the environment that is available for accumulation in organisms. Many factors can control bioavailability of the COCs, including the biological characteristics of the organisms (e.g. assimilation, feeding rate and pattern, size/age, and reproductive condition) and the geochemistry of the COCs (e.g. contaminant partitioning in the water column and speciation). Further, these can be influenced by physico-chemical factors, such as temperature, salinity, dissolved organic carbon (DOC) concentration, and suspended solids (SS).

In general, there are two approaches to predict pollutant concentrations in aquatic organisms ⁽¹⁾⁽²⁾:

- Partitioning equilibrium (EqP); and
- Kinetic modelling.

The approaches are well developed and have been used in the development of water quality criteria and sediment quality criteria in the US and elsewhere (i.e. using the equilibrium partitioning method and the bioconcentration factor to predict the concentrations in aquatic organisms) ⁽³⁾⁽⁴⁾. The approach has been applied to the situation in southern China where marine organisms are exposed to contaminated sediment ⁽⁵⁾⁽⁶⁾ and is thus applicable and relevant to the Hong Kong situation. Although there has been no experimental validation of these models in the Hong Kong context, the Trophic Trace model which is a comparable bioconcentration modelling tool, is endorsed by the USEPA and

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- (1) Landrum PF, Lee H II, Lydy MJ (1992) Toxicokinetics in aquatic systems: model comparisons and use in hazard assessment. *Environ Toxicol Chem* 11:1709-1725
 - (2) Luoma SN, Fisher NS (1997) Uncertainties in assessing contaminant exposure from sediments. In: Ingersoll CG, Dillon T, Biddinger GR (eds) *Ecological risk assessment of contaminated sediments*. SETAC Special Publication Series, Pensacola, FL, p 211-237
 - (3) Connell DW (1989) *Bioaccumulation of xenobiotic compounds*. CRC Press, Boca Raton, FL.
 - (4) US EPA (2000) *Bioaccumulation testing and interpretation for the purpose of sediment quality assessment*. EPA-823-R-00-001. Office of Water (4305) and Office of solid waste (5307W).
 - (5) Wang WX, Yan Q, Fan W, Xu Y (2002) Bioavailability of sedimentary metals from a contaminated bay. *Marine Ecology Progress Series* 240: 27-38.
 - (6) Wang WX (2013) Prediction of metal toxicity in aquatic organisms. *Chinese Science Bulletin* 58(2). pp194-202.

the US Army Corps of Engineers and is an internationally accepted standard for modelling bioconcentration in aquatic and marine environments ⁽⁷⁾. The approach adopted here is therefore considered appropriate and scientifically valid.

8A.1.3.1 Equilibrium Partitioning (EqP) Approach

The EqP approach assumes only one phase (waterborne) of uptake and a constant exposure. Mathematically, this can be expressed by:

$$BCF = C / C_w \quad (\text{Equation 1})$$

where BCF is the COC bioconcentration factor ($L\ g^{-1}$); C is the COC concentration ($\mu g\ g^{-1}$) in the animals; and C_w is the COC concentration in the dissolved phase ($\mu g\ L^{-1}$). Thus, the likely concentration of COC in the animals due to uptake of desorbed COC can be directly calculated by:

$$C = BCF * C_w \quad (\text{Equation 2})$$

A more complicated EqP model has been developed for sediment quality criteria by assuming equilibrium partitioning of chemicals (mainly non-ionic organic) among the aqueous phase, sediment and organisms ⁽⁸⁾. Sediments in aquatic systems presently contain large amounts of contaminants and can be a potentially significant source for COC accumulation in benthic fauna. Correlations based on sediment concentration are now viewed as better predictors of tissue residues than predictions based on water ⁽⁹⁾. This approach is normally exploited by normalizing chemical concentrations based on the lipid content of organisms and the organic carbon content of sediments. Thus the biota-sediment accumulation factor (BSAF) can be calculated by:

$$BSAF = C_a(l) / C_s(c) \quad (\text{Equation 3})$$

where $C_a(l)$ is the chemical concentration in the animals normalized to their lipid content, $C_s(c)$ is the chemical concentration in sediments normalized to organic carbon content. These BSAF values are considered to be independent of the type of sediments ⁽¹⁰⁾.

8A.1.3.2 Kinetic Modelling Approach

Kinetic models are required for non-steady state, non-equilibrium accumulation due to varying exposure in the field. Such an approach is not constrained by assuming constant exposure/thermodynamic equilibrium. Various kinetic models used in aquatic systems and hazard assessments were reviewed, including the physiologically-based pharmacokinetic model (PBPK) and bioenergetic-based toxicokinetic model (BE). BE models describe toxicant accumulation and loss in terms of an animals' energy requirements and usually treat the animal as a single compartment ⁽¹¹⁾.

Assuming that the COC is accumulated only from the water, the accumulation of COC can be described by a simple kinetic equation:

$$dC / dt = k_u * C_w - k_e * C \quad (\text{Equation 4})$$

where C is the COC concentration in the animals at time t; k_u is the uptake rate constant from the dissolved phase; k_e is the efflux rate constant (d^{-1}). Under steady-state condition, C can be directly calculated as:

$$C = k_u * C_w / k_e \quad (\text{Equation 5})$$

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- (7) ERDC (2003) Trophic trace models contaminant bioaccumulation, trophic transfer, and risk. Dredging Research 6 (1):1-2
- (8) Di Toro DM, Zarba CS, Hansen DJ, Berry WJ, Swartz RC, Cowan CE, Pavlou SP, Allen HE, TGThomas NA, Paquin PR (1991) Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. Environmental Toxicology and Chemistry 10: 1541-1583
- (9) Di Toro DM, Zarba CS, Hansen DJ, Berry WJ, Swartz RC, Cowan CE, Pavlou SP, Allen HE, TGThomas NA, Paquin PR (1991) *Op cit.*
- (10) Thomann RV, Mahony JD, Mueller R (1995) Steady-state model of biota sediment accumulation factor for metals in two marine bivalves. Environmental Toxicology and Chemistry 14: 1989-1998.
- (11) Landrum PF, Lee H II, Lydy MJ (1992) *Op cit.*

In this model, the BCF can similarly be calculated as:

$$\text{BCF} = k_u / k_e \quad (\text{Equation 6})$$

For sediment-ingesting animals, the accumulation of COC can be similarly modeled using the kinetic equation:

$$dC / dt = AE * IR * C_s - k_e * C \quad (\text{Equation 7})$$

where AE is the COC assimilation efficiency from the ingested sediment, IR is the ingestion rate ($\text{g g}^{-1} \text{d}^{-1}$); C_s is the COC concentration in the ingested sediment (mg g^{-1}). Under steady-state condition, C can be directly calculated as:

$$C = AE * IR * C_s / k_e \quad (\text{Equation 8})$$

Thus, to assess the possible COC accumulation (due to desorption from sediments) by the bivalves/ molluscs and fish, parameters required in the modelling calculation are the BCFs or the uptake rate constant k_u , efflux rate constant k_e , and COC concentrations in the water. To assess the possible COC accumulation by sediment-ingesting animals, parameters required in the modelling calculation are the assimilation efficiency (AE), ingestion rate (IR) of the animals, COC concentration in the sediment (C_s), and efflux rate constant k_e . If these parameters are not available for the animals, another approach will be to use the BSAF, as described in Equation 3.

To further predict the COC concentration in the predators, the trophic transfer factor (TTF) needs to be introduced:

$$C_n = C_{n-1} \times \text{TTF} \quad (\text{Equation 9})$$

where C_n is the COC concentration in the predator, and C_{n-1} is the COC concentration in the prey.

8A.1.4 Selection of Contaminants of Concern (COCs) and Species for Bioaccumulation Assessment

The bioaccumulation assessment is based on the water quality modeling simulation of the release (i.e., desorption) of pollutants from the sediments disturbed during disposal. The COCs investigated are those used in the water quality modelling.

There is a lack of bioaccumulation and bioconcentration factors available in the literature for TBT and it is therefore not included in the risk assessment. This limitation does not limit the conservative nature of the assessment because background levels of TBT in sediment and dredged materials in Hong Kong are generally very low or undetectable. This statement is backed up by monitoring data collected for ESC CMPs and SB CMPs since 1997 which has consistently recorded TBT in sediment and tissue samples below levels of concern.

There are two possible pathways for the accumulation of contaminants due to sediment resuspension:

- desorption of contaminants into the water column following sediment resuspension followed by uptake from the water; and
- ingestion of contaminated sediments.

Thus, the selection of species for assessment is based on the availability of parameters to quantify the exposure pathways as well as the ecological significance. They can be separated into the following feeding groups:

- Pelagic fish – to assess the potential uptake of desorbed contaminants in the water column;
- A filter-feeding mollusc – to assess the potential uptake of desorbed contaminants in overlying waters and from contaminated sediments;
- A deposit-feeding worm (polychaete or sipunculan) - to assess the potential uptake of contaminants from sediment ingestion; and

- Predatory fish, crab and shrimp that specifically prey on the above animals.

The selection of the species under these feeding groups is based on available literature and experience in bioaccumulation assessment. Where possible, local species are selected. There have been a number of studies on the bioaccumulation of COCs in local species such as green mussels, clams, sea bream and mangrove snapper. However, there is a lack of information on the uptake of contaminants by local polychaete species, but studies on other deposit-feeding invertebrates such as sipunculans are available. Where data gaps appear, information is supplemented with reference to international studies. It should be noted that, where no information is available on the uptake of the COCs in marine organisms within either local or international literature, an assessment of bioaccumulation potential of this parameter is not possible. In the later risk assessment work that has been conducted ambient values have been substituted where these data gaps occur.

8A.1.5 Modelling of Contaminant Release

Concentrations of the COCs in water (dissolved phase) and in sediment are determined from the results of the water quality modelling.

8A.1.5.1 Dissolved Phase

Contaminants adsorbed to sediment particles can be expected to either remain adsorbed to the sediment, settling or dispersing in direct proportion to suspended sediment concentrations, or desorb from the sediment particles and enter solution.

Values of the partition coefficients (K_d) have been determined. The majority of the K_d values have been derived from the Chemical Database developed by the Dutch Ministry for Transport, Public Works and Water Management with the remainder taken from the EIA for New Contaminated Mud Marine Disposal Facility at Airport East / East Sha Chau Area. For the organic compounds the K_d value is related to Total Organic Carbon (TOC) rather than Total Particulate Matter (TPM). In those cases a reference ratio TOC:TPM needs to be used. Since this ratio is highly variable both in space and in time, it is proposed to derive this value from the model output, rather than to prescribe a value.

The input data for SS are determined as the depth averaged value within an area 400 m from the Key Area. The 400 m value is taken from the review of environmental monitoring data for the CMPs at the East of Sha Chau, which have indicated that the majority of the previous monitoring programmes regarded the “impact” area to be from 400m of the CMP boundary. The value was 5.3 mg L⁻¹. Average values have been used in the assessment because the risk assessment presented in **Annex 8B** focuses on chronic risk and not acute. The use of maximum SS levels would bring an unwarranted level of conservativeness to this assessment, which would result in misleading results.

The selected K_d values and the dissolved concentrations of each COCs are shown in **Table 8A.1**. It is assumed that COCs in the dissolved phase originate from desorption from the re-suspended sediments with 100% desorption.

Table 8A.1 Partitioning Coefficients Utilised in the Bioaccumulation Assessment and the Dissolved Concentrations of COCs

COCs	K_d	Upper Chemical Exceedance Level (UCEL)	Dissolved Concentrations ($\mu\text{g L}^{-1}$)
Arsenic	130 L/g	42 mg/kg	0.028938
Cadmium	100 L/g	4 mg/kg	0.002120
Chromium	290 L/g	160 mg/kg	0.245920
Copper	122 L/g	110 mg/kg	0.071126
Lead	130 L/g	110 mg/kg	0.075790

COCs	K _d	Upper Chemical Exceedance Level (UCEL)	Dissolved Concentrations (µg L ⁻¹)
Mercury	700 L/g	1 mg/kg	0.003710
Nickel	40 L/g	40 mg/kg	0.008480
Silver ⁽¹⁾	200 L/g	2 mg/kg	0.002120
Zinc	100 L/g	270 mg/kg	0.143100
Total PCBs	1585 L/gOC ⁽²⁾	180 µg/kg	0.001512
LMW PAH	0.075 L/g	3.16 mg/kg	0.000001
HMW PAH	1.14 L/g	9.6 mg/kg	0.000058

Remarks:

(1) Wen LS, Santschi PH, Paternostro CL, Lehman RD, 1997. Colloidal and particulate silver in river and estuarine waters of Texas. Environ Sci Technol 31: 723-731.

(2) OC = 0.012 gOC/g

8A.1.5.2 Particulate Phase (Sediment Ingestion)

The water quality modeling provides estimates of sediment deposition in and around the pits. Although K_d values have been used to determine desorption for the purposes of the sediment ingestion assessment it was assumed that 0% of contaminants desorb. Such an assumption indicates that the bioaccumulation assessment is inherently conservative.

Following a similar approach to that for determining average SS values across the “impact area” adjacent to the pits the average rate of sediment deposition was determined. This value was then fed into a series of equations, which are detailed in **Table 8A.2**. The end result of the calculations was a series of values for COC elevation in sediment for the Study Area.

Table 8A.2 Methodology for Predicting Increase in Sediment Concentrations of COCs

	Unit	Ref	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	Total PCBs	LMW PAH	HMW PAH
Deposition Rate (SS)	kg/m ² /day	A	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Concentration in Disposal Material (UCEL)	mg/kg	B	42.00	4.00	160.00	110.00	110.00	1.00	40.00	2.00	270.00	0.18	3.16	9.60
Bioturbation Depth	m	C	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Volume of Sediment	m ³	D	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Typical Density of Sediment	kg/m ³	E	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00	750.00
Ambient Sediment Concentration	mg/kg	F	8.15	0.25	33.65	30.65	40.60	0.14	21.25	0.15	102.20	0.02	0.09	0.06
<i>In situ</i> Sediment Mass	kg	D x E = G	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
<i>In situ</i> COC Mass	mg	G x F = H	611.25	18.75	2523.75	2298.75	3045.00	10.13	1593.75	11.25	7665.00	1.13	6.75	4.80
Deposition of COC	mg/m ² /day	A x B = I	0.92	0.09	3.52	2.42	2.42	0.02	0.88	0.04	5.94	0.00	0.07	0.21
Day 1 <i>In situ</i> COC Mass	mg	H + I = J	612.17	18.84	2527.27	2301.17	3047.42	10.15	1594.63	11.29	7670.94	1.13	6.82	5.01
Day 1 <i>In situ</i> COC Concentration	mg/kg	J / G = K	8.16	0.25	33.70	30.68	40.63	0.14	21.26	0.15	102.28	0.02	0.09	0.07
Total Disposal Days (20Mm ³ = 26,700m ³ /d)	day	L	187.27	187.27	187.27	187.27	187.27	187.27	187.27	187.27	187.27	187.27	187.27	187.27
Deposition of COC over Facility Lifetime	mg/m ²	L x I = M	173.03	16.48	659.18	453.18	453.18	4.12	164.79	8.24	1112.36	0.74	13.02	39.55
Lifetime <i>in situ</i> COC Mass (COC)	mg	M + H = N	784.28	35.23	3182.93	2751.93	3498.18	14.24	1758.54	19.49	8777.36	1.87	19.77	44.35
<i>In situ</i> Lifetime Sediment Mass	kg	(L * A) + G = P	79.12	79.12	79.12	79.12	79.12	79.12	79.12	79.12	79.12	79.12	79.12	79.12
Change in Volume	m ³	P / E = Q	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Change in Height	cm	Q / 1m / 1m = R	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Overall Lifetime <i>In situ</i> COC Concentration	mg/kg	N / P = S	9.91	0.45	40.23	34.78	44.21	0.18	22.23	0.25	110.94	0.02	0.25	0.56

8A.1.6 Detailed Assessment of Bioaccumulation

8A.1.6.1 Pelagic Fish

In assessing COC bioaccumulation by the marine pelagic fish, it is assumed that the COCs are predominantly accumulated from the dissolved phase and uptake from the sediment particles is negligible. COCs in the dissolved phase originate from desorption from the resuspended sediments with 100% desorption. Two approaches are therefore used to predict the likely COC concentrations in marine pelagic fish, including the EqP approach and the kinetic approach. For the EqP approach, the COC concentration is directly calculated as the BCF times the desorbed COC concentration using Equation 2. The mean BCFs of metals (Cr, Pb and Ni) are referred from International Atomic Energy Agency ⁽¹²⁾. For other COCs, the BCF is calculated by the kinetic equation (Equation 6) with known uptake rate constant k_u and efflux rate constant k_e from the local fish species (mangrove snappers, sweetlips and seabreams) ⁽¹³⁾⁽¹⁴⁾⁽¹⁵⁾. The BCF of Cu is calculated from the field data of Gibbs and Miskowicz ⁽¹⁶⁾.

As comprehensive biota data within and in the vicinity of the Study Area are not available, ambient concentrations have been calculated from a review of biota data collected in reference areas between January 2016 and February 2021 as part of the biomonitoring programme under the EM&A of ESC CMP (**Table 8A.3**) ⁽¹⁷⁾. Using these two approaches, the calculated COC concentrations in the fish as a result of uptake of desorbed metals are shown in **Table 8A.4**, together with the BCFs used in the calculations. The predictions were made based on the shortnose ponyfish *Leiognathus brevisrostris*.

Table 8A.3 Averaged Concentrations of Contaminants of Concern in Marine Biota Collected in Reference Areas from EM&A of ESC CMP between January 2016 and February 2021

COC	Averaged Concentrations for Pelagic Fish (mg kg ⁻¹)	Averaged Concentrations for Molluscs (mg kg ⁻¹)	Averaged Concentrations for Predatory Crab (mg kg ⁻¹)	Averaged Concentrations for Predatory Fish (mg kg ⁻¹)	Averaged Concentrations for Predatory Shrimp (mg kg ⁻¹)
Arsenic	0.033	0.278	0.198	0.106	0.134
Cadmium	0.025	0.379	0.086	0.025	0.347
Chromium	0.260	6.456	0.207	0.320	0.290
Copper	0.857	22.841	8.079	0.555	8.185
Lead	0.049	1.522	0.044	0.081	0.061
Mercury	0.058	0.054	0.054	0.049	0.045
Nickel	1.269	38.087	0.282	0.300	0.566
Silver	0.027	1.099	0.149	0.047	0.183
Zinc	9.530	75.766	23.034	5.025	12.435

- (12) IAEA (International Atomic Energy Agency) (2000) Sediment k_d s and concentration factors for radionuclides in the marine environment. Technical report series, No. 247 Vienna
- (13) Xu Y, Wang WX. (2002) Exposure and food chain transfer factor of Cd, Se, and Zn in a marine fish, *Lutjanus argentimaculatus*. Mar Ecol Prog Ser 238: 173-186.
- (14) Wang WX, Wong RSK (2003) Bioaccumulation kinetics and exposure pathways of inorganic mercury and methylmercury in a marine fish, the sweetlips *Plectorhinchus gibbosus*. Mar Ecol Prog Ser 261: 257-268.
- (15) Long A, Wang WX (2005) Assimilation and bioconcentration of Ag and Cd by the marine black bream after waterborne and dietary metal exposure. Environ Toxicol Chem 24(3): 709-16.
- (16) Gibbs PJ, Miskiewicz AG (1995) Heavy metals in fish near a major primary treatment sewage plant outfall. Mar Pollut Bull 30: 667-675.
- (17) A review of EPD long-term sediment quality data has been conducted and it is noticed that sediments at North Western Water Control Zone (WCZ) where ESC CMPs are located were generally with higher contaminant levels than those at Southern WCZ where the proposed Project is located. As such, it is conservative to adopt the recent ambient data from the EM&A programme of the ESC CMPs.

COC	Averaged Concentrations for Pelagic Fish (mg kg ⁻¹)	Averaged Concentrations for Molluscs (mg kg ⁻¹)	Averaged Concentrations for Predatory Crab (mg kg ⁻¹)	Averaged Concentrations for Predatory Fish (mg kg ⁻¹)	Averaged Concentrations for Predatory Shrimp (mg kg ⁻¹)
Total PCBs	0.001	0.001	0.001	0.001	0.001
LMW PAH	0.025	0.025	0.025	0.025	0.025
HMW PAH	0.050	0.050	0.050	0.050	0.050

Notes:

Pelagic Fish: *Leiognathus brevis*

Molluscs: *Turritella* sp.

Predatory Crab: *Charybdis* sp.

Predatory Fish: *Cynoglossus* sp., *Trypauchen vagina*

Predatory Shrimp: *Metapenaeus* sp., *Oratosquilla* sp.

Table 8A.4 Predicted Concentrations of COCs in Pelagic Fish

COC	Concentrations of COCs in Dissolved Phase (µg L ⁻¹)	BCF (L kg ⁻¹)	Elevated Concentration in Pelagic Fish (mg kg ⁻¹)	Ambient Concentration in Pelagic Fish (mg kg ⁻¹)	Total Concentration in Pelagic Fish (mg kg ⁻¹)
Arsenic	0.029	350	0.010	0.033	0.043
Cadmium	0.002	200	0.000	0.025	0.025
Chromium	0.246	200	0.049	0.260	0.309
Copper	0.071	2200	0.156	0.857	1.013
Lead	0.076	200	0.015	0.049	0.064
Mercury	0.004	6800	0.025	0.058	0.083
Nickel	0.008	1000	0.008	1.269	1.278
Silver	0.002	500	0.001	0.027	0.028
Zinc	0.143	700	0.100	9.530	9.630
Total PCBs	0.002	100000	0.151	0.001	0.152
LMW PAH	0.000001	1000	0.000	0.025	0.025
HMW PAH	0.000058	10000	0.001	0.050	0.051

References:

- (1) EPA (1980) Ambient water quality criteria for Arsenic. Washington DC, US EPA, Office of Water Regulations and Standards. EPA 440/5-80-021
- (2) Xu Y, Wang W-X. (2002) Exposure and food chain transfer factor of Cd, Se, and Zn in a marine fish, *Lutjanus argentimaculatus*. Mar Ecol Prog Ser 238: 173-186.
- (3) Wang W-X, Wong RSK (2003) Bioaccumulation kinetics and exposure pathways of inorganic mercury and methylmercury in a marine fish, the sweetlips *Plectorhinchus gibbosus*. Mar Ecol Prog Ser 261: 257-268.
- (4) Long A, Wang WX (2005) Assimilation and bioconcentration of Ag and Cd by the marine black bream after waterborne and dietary metal exposure. Environ Toxicol Chem 24(3): 709-16.
- (5) Gibbs PJ, Miskiewicz AG (1995) Heavy metals in fish near a major primary treatment sewage plant outfall. Mar Pollut Bull 30: 667-675.
- (6) IAEA (International Atomic Energy Agency) (2000) Sediment kds and concentration factors for radionuclides in the marine environment. Technical report series, No. 247 Vienna
- (7) Veith GD, Kosian P (1983) Estimating bioconcentration potential from octanol/water partition coefficients. In: Mackay D, Patterson S, Eisenreich SJ (eds) Physical behavior of PCBs in the Great Lakes. Ann Arbor Sci Publ, Ann Arbor, MI. pp 269-282.

8A.1.7 Molluscs

In assessing the bioaccumulation by filter-feeding molluscs, only the uptake from the dissolved uptake was modelled and sediment ingestion was not modelled. The kinetic equation of Equation 6 is used to predict the accumulation from the dissolved phase as a result of COC desorption from the sediment. The k_u and k_e measured in the local green mussels (*Perna viridis*) are used to calculate the likely BCF. Alternatively, the BCF is directly referred from IAEA ⁽¹⁸⁾. The predicted COC concentrations in filter-feeding molluscs due to uptake of desorbed COCs are shown in **Table 8A.5**. The predictions were made based on the gastropod *Turritella* sp..

Table 8A.5 Predicted Concentrations of COCs in Molluscs

COC	Concentrations of COCs in Dissolved Phase ($\mu\text{g L}^{-1}$)	BCF (L kg^{-1})	Elevated Concentration in Molluscs (mg kg^{-1})	Ambient Concentration in Molluscs (mg kg^{-1})	Total Concentration in Molluscs (mg kg^{-1})
Arsenic	0.029	350	0.010	0.278	0.288
Cadmium	0.002	10000	0.021	0.379	0.400
Chromium	0.246	1000	0.246	6.456	6.702
Copper	0.071	2000	0.142	22.841	22.983
Lead	0.076	2570	0.195	1.522	1.717
Mercury	0.004	2000	0.007	0.054	0.061
Nickel	0.008	2000	0.017	38.087	38.104
Silver	0.002	60000	0.127	1.099	1.227
Zinc	0.143	22000	3.148	75.766	78.915
Total PCBs	0.002	100000	0.151	0.001	0.153
LMW PAH	0.000001	1000	0.000	0.025	0.025
HMW PAH	0.000058	10000	0.001	0.050	0.051

References:

- (1) EPA (1980) Ambient water quality criteria for Arsenic. Washington DC, US EPA, Office of Water Regulations and Standards. EPA 440/5-80-021
- (2) Wang WX (2003) Metal bioaccumulation in bivalve mollusks: Recent progress. In: Molluscan Shellfish Safety. A. Villalba, B. Reguera, J. L. Romalde and R. Beiras (eds), Intergovernmental Oceanographic Commission of UNESCO and Consellería de Pesca e Asuntos Marítimos da Xunta de Galicia. Santiago de Compostela, Spain. pp 503-520.
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- (4) Wang W-X, Fisher NS, Luoma SN (1996) Kinetic determinations of trace element bioaccumulation in the mussel, *Mytilus edulis*. Mar Ecol Prog Ser 140: 91-113.
- (5) IAEA (International Atomic Energy Agency) (2000) Sediment kds and concentration factors for radionuclides in the marine environment. Technical report series, No. 247 Vienna
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8A.1.8 Polychaete and Other Deposit-Feeding Worms (Sipunculans)

Similar to marine molluscs ingesting sediments, the accumulation of COCs by the deposit-feeding polychaetes and other worms such as sipunculans is also predicted using the kinetic equation (Equation 8). However, the AE of COCs has been measured only for a few metals with good techniques (e.g., Cd, Cr, Zn). The extraction of metals (e.g., Cu, Pb, Ni, Hg) from the sediments by the gut juices has been measured in a few polychaete species. In order to predict the likely accumulation of these metals in the polychaetes, it is inherently assumed that the AE of these metals

(18) IAEA (International Atomic Energy Agency) (2000) *Op cit*.

is comparable to the extraction efficiency. Such assumption is based that all the extracted metals are assimilated by the animals, and extraction represents the maximum rate of uptake. Thus, prediction of metal accumulation based on the extraction efficiency can be considered as a conservative estimate of the metal accumulation in the deposit-feeding animals. For these animals, the maximum ingestion rate is assumed to be 200% of the tissue dry weight each day ⁽¹⁹⁾⁽²⁰⁾. The influx rate of the metals from ingested sediments is then calculated using Equation 7.

To predict the accumulation of organic contaminants such as PAH and PCBs, again the approach of BSAF is used. In these calculations, the lipid content of the animals and the organic carbon content of the sediments are also considered. The BSAFs of PAHs (0.2) and PCBs (0.68) have been quantified in marine polychaetes in several previous studies ⁽²¹⁾⁽²²⁾, and these measurements were based on the lipid content and the sediment organic carbon content. To convert these values for the total sediments and the whole individual animal, it is assumed that the organic carbon content in the sediment is 2% and the lipid content of the polychaetes is 1.6% ⁽²³⁾. These predictions are shown in **Table 8A.6**.

Table 8A.6 Predicted Concentrations of COCs in Polychaetes

COC	Concentrations in Sediment (i.e. Particulate Phase) (mg kg ⁻¹)	AE x IR / k _e	BSAF	Elevated Concentration in Polychaetes (mg kg ⁻¹)
Arsenic	9.913	0.25	-	2.478
Cadmium	0.445	1 ⁽¹⁾	-	0.445
Chromium	40.229	0.5 ⁽¹⁾	-	20.115
Copper	34.782	1 ⁽²⁾	-	34.782
Lead	44.214	0.5 ⁽²⁾	-	22.107
Mercury	0.180	2 ⁽³⁾⁽⁴⁾	-	0.360
Nickel	22.226	0.5 ⁽²⁾	-	11.113
Silver	0.246	0.5	-	0.123
Zinc	110.938	1 ⁽¹⁾	-	110.938
Total PCBs	0.024	-	0.68 ⁽⁵⁾	0.016
LMW PAH	0.250	-	0.2 ⁽⁶⁾	0.050
HMW PAH	0.561	-	0.2 ⁽⁶⁾	0.112

References:

- (1) Wang W-X, Yan Q, Fan W, Xu Y (2002) Bioavailability of sedimentary metals from a contaminated bay. *Mar Ecol Prog Ser* 240: 27-38.
- (2) Peng S-H, Wang W-X, Li X, Yen YF (2004) Metal partitioning in estuarine sediments measured by sequential extraction and biomimetic approaches. *Chemosphere*
- (3) Lawrence AL, Mcaloon KM, Mason RP, Mayer LM (1999) Intestinal solubilization of particle-associated organic and inorganic mercury as a measure of bioavailability to benthic invertebrates. *Environ Sci Technol* 33: 1871-1876.
- (4) Assuming extraction = assimilation, ke=0.02 d⁻¹, and IR=2 g g⁻¹ d⁻¹.
- (5) Kaag NHBM, Foekema EM, Scholten MCTh, Van Straalen NM (1997) Comparison of contaminant accumulation in three species of marine invertebrates with different feeding habits. *Environ Toxicol Chem* 16: 837-842.
- (6) Maruya KA, Risebrough RW, Horne AJ (1997) The bioaccumulation of polynuclear aromatic hydrocarbons by benthic invertebrates in an intertidal marsh. *Environ Toxicol Chem* 16: 1087-1097.

- (19) Cammen LM (1980) Ingestion rate: An empirical model for aquatic deposit feeders and detritivores. *Oecologia* 44: 303-310.
- (20) Wang WX, Stupakoff I, Fisher NS (1999) Bioavailability of dissolved and sediment-bound metals to a marine deposit-feeding polychaete. *Mar Ecol Prog Ser* 178: 281-293.
- (21) Maruya KA, Risebrough RW, Horne AJ (1997) The bioaccumulation of polynuclear aromatic hydrocarbons by benthic invertebrates in an intertidal marsh. *Environ Toxicol Chem* 16: 1087-1097.
- (22) Kaag NHBM, Foekema EM, Scholten MCTh, Van Straalen NM (1997) Comparison of contaminant accumulation in three species of marine invertebrates with different feeding habits. *Environ Toxicol Chem* 16: 837-842.
- (23) Maruya KA, Risebrough RW, Horne AJ (1997) *Op cit*.

8A.1.9 *Predatory Fish, Crabs and Shrimps*

To predict the likely COC concentrations in the predatory fish, crabs, and shrimps, the trophic transfer factor (TTF) is used (Equation 9). Specifically, the TTF is the ratio of COC concentrations in the predator to those in the preys. The TTF has been measured in a few specific predator-prey systems, but the data are relatively scattered. The TTF of COCs in aquatic ecosystems have been reported and these values are then used in the model calculation ⁽²⁴⁾. To predict the concentration in the predatory fish, the prey fish is assumed. To predict the COC concentrations in the crabs and shrimps, the prey polychaetes are assumed. The COC concentrations in the prey fish and in the polychaetes are referred from the model calculations, again assuming that the COCs are accumulation in the prey fish from the dissolved phase (due to desorption), and in the prey polychaetes from the ingested sediments (due to contaminated sediment deposition). **Table 8A.7** shows the model predictions.

(24) Suedel BC, Boraczek JA, Peddicord RK, Clifford PA, Dillon TM (1994) Trophic transfer and biomagnification potential of contaminants in aquatic ecosystems. Rev Environ Contam Toxicol 136: 21-89

Table 8A.7 Predicted Concentrations of COCs in Predatory Fish, Crabs and Shrimps

COC	TTF ⁽¹⁾ ⁽²⁾			Elevated Concentration in (mg kg ⁻¹)			Ambient Concentration in (mg kg ⁻¹)			Total Concentration in (mg kg ⁻¹)		
	Predatory Fish	Crabs	Shrimps	Predatory Fish	Crabs	Shrimps	Predatory Fish	Crabs	Shrimps	Predatory Fish	Crabs	Shrimps
Arsenic	0.25	0.25	0.25	0.003	0.620	0.620	0.106	0.198	0.134	0.109	0.818	0.754
Cadmium	0.1	0.01	2.4	0.000	0.004	1.069	0.025	0.086	0.347	0.025	0.090	1.415
Chromium	0.7			0.034			0.320	0.207	0.290	0.354	0.207	0.290
Copper	0.5			0.078			0.555	8.079	8.185	0.633	8.079	8.185
Lead	0.7			0.011			0.081	0.044	0.061	0.091	0.044	0.061
Mercury	0.4	0.8	0.8	0.010	0.288	0.288	0.049	0.054	0.045	0.059	0.342	0.334
Nickel	0.7			0.006			0.300	0.282	0.566	0.306	0.282	0.566
Silver	0.5			0.001			0.047	0.149	0.183	0.047	0.149	0.183
Zinc	1	1.2	0.7	0.100	133.125	77.656	5.025	23.034	12.435	5.125	156.159	90.091
Total PCBs	4	1.2	1.2	0.605	0.019	0.019	0.001	0.001	0.001	0.606	0.020	0.020
LMW PAH	0.2	0.2	0.2	0.000	0.010	0.010	0.025	0.025	0.025	0.025	0.035	0.035
HMW PAH	0.2	0.2	0.2	0.000	0.022	0.022	0.050	0.050	0.050	0.050	0.072	0.072

Remarks:

- (1) Suedel BC, Boraczek JA, Peddicord RK, Clifford PA, Dillon TM (1994) Trophic transfer and biomagnification potential of contaminants in aquatic ecosystems. Rev Environ Contam Toxicol 136: 21-89
- (2) USEPA (2000) Bioaccumulation testing and interpretation for the purpose of sediment quality assessment. EPA-823-R-00-001. Office of Water (4305) and Office of solid waste (5307W).
- (3) Empty Cells are when no data are present.

8A.1.10 Summary

A summary of predicted body burden (i.e. tissue) concentrations of COCs in the target species is presented in **Table 8A.8**.

Table 8A.8 Summary of Body Burden (i.e. Tissue) Concentrations of Contaminants in the Target Species

COC	Total Concentration (mg kg ⁻¹)				
	Pelagic Fish (mg kg ⁻¹)	Molluscs (mg kg ⁻¹)	Predatory Fish (mg kg ⁻¹)	Predatory Crabs (mg kg ⁻¹)	Predatory Shrimps (mg kg ⁻¹)
Ambient					
Arsenic	0.033	0.278	0.106	0.198	0.134
Cadmium	0.025	0.379	0.025	0.086	0.347
Chromium	0.260	6.456	0.320	0.207	0.290
Copper	0.857	22.841	0.555	8.079	8.185
Lead	0.049	1.522	0.081	0.044	0.061
Mercury	0.058	0.054	0.049	0.054	0.045
Nickel	1.269	38.087	0.300	0.282	0.566
Silver	0.027	1.099	0.047	0.149	0.183
Zinc	9.530	75.766	5.025	23.034	12.435
Total PCBs	0.001	0.001	0.001	0.001	0.001
LMW PAH	0.025	0.025	0.025	0.025	0.025
HMW PAH	0.050	0.050	0.050	0.050	0.050
Study Area					
Arsenic	0.043	0.288	0.109	0.818	0.754
Cadmium	0.025	0.400	0.025	0.090	1.415
Chromium	0.309	6.702	0.354	0.207	0.290
Copper	1.013	22.983	0.633	8.079	8.185
Lead	0.064	1.717	0.091	0.044	0.061
Mercury	0.083	0.061	0.059	0.342	0.334
Nickel	1.278	38.104	0.306	0.282	0.566
Silver	0.028	1.227	0.047	0.149	0.183
Zinc	9.630	78.915	5.125	156.159	90.091
Total PCBs	0.152	0.153	0.606	0.020	0.020
LMW PAH	0.025	0.025	0.025	0.035	0.035
HMW PAH	0.051	0.051	0.050	0.072	0.072