National Institute for Public Health
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RIVM Letter Report 601357007/2011

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Abstract

Environmental risk limits for phenanthrene

RIVM has derived environmental risk limits (ERLs) for phenanthrene. This derivation has been performed because the current ERLs have not been derived according to the current valid methodology. Phenanthrene is a substance belonging to the group of PAHs and is included in the Dutch decree on water quality objectives in the context of the Water Framework Directive (WFD). The ERLs in this report are advisory values that serve as a scientific background for the Dutch Steering Committee for Substances, which is responsible for setting those standards.

The maximum permissible concentration in water ($\mathrm{MPC}_{\mathrm{water}}$) is the level at which no harmful effects are expected, based on annual concentrations. This MPC is based on three routes: direct toxicity, secondary poisoning and consumption of fish by humans. Direct toxicity is the most critical of these three routes and determines the overall MPC for fresh- and saltwater (1.1 microgram per liter). The Maximum Acceptable Concentration ($\mathrm{MAC}_{\mathrm{water,\ eco}}$), that protects the ecosystem from effects of short term concentration peaks, is 6.7 microgram per liter for fresh- and saltwater.

The newly derived ERLs for water, suspended matter and sediment are higher than the currently valid ERLs. These differences are due to a more extensive dataset on ecotoxicology in combination with the more recent methodology for derivation of ERLs. Monitoring data indicate that the new MPC and $\mathrm{MAC}_{\mathrm{eco}}$ for water, suspended matter and sediment are not being exceeded. In this observation, mixture toxicity for the total of PAHs has not been included.

Trefwoorden / Key words:
environmental risk limits, maximum permissible concentration, negligible concentration, phenanthrene

Rapport in het kort

Milieurisicogrenzen voor fenantreen

Het RIVM heeft in opdracht van het ministerie van Infrastructuur en Milieu (I&M), milieurisicogrenzen voor fenantreen bepaald. Dit was nodig omdat de huidige norm voor fenantreen voor waterkwaliteit niet is afgeleid volgens de meest recente methodiek. Fenantreen is een stof die behoort tot de stofgroep PAK's. De stof is opgenomen in de Regeling Monitoring Kader Richtlijn Water, waarin staat aan welke eisen oppervlaktewater in Nederland moet voldoen. De Stuurgroep Stoffen stelt de nieuwe normen vast op basis van de wetenschappelijke advieswaarden in dit rapport.

Het Maximaal Toelaatbaar Risiconiveau (MTR) is de concentratie in water waarbij geen schadelijke effecten te verwachten zijn, gebaseerd op jaargemiddelde concentraties. Hiervoor zijn drie routes onderzocht: directe effecten op waterorganismen, indirecte effecten op vogels en zoogdieren via het eten van prooidieren, en indirecte effecten op mensen via het eten van vis. De eerste van de drie levert de laagste waarde en bepaalt daarmee het MTR voor zoet- en zoutwater (1,1 microgram per liter). De Maximaal Aanvaardbare Concentratie ($MAC_{water,\ eco}$), die het ecosysteem beschermt tegen kortdurende concentratiepieken, is 6,7 microgram per liter.

De nieuw afgeleide milieurisicogrenzen voor water, in water zwevend stof en sediment zijn hoger dan de nu geldende milieurisicogrenzen. Dit komt doordat er meer gegevens beschikbaar zijn over de directe effecten van fenantreen op waterorganismen en door het gebruik van een nieuwere methodiek. Gebaseerd op monitoringsgegevens worden de nieuwe MTR en MAC_{eco} voor water, zwevend stof en sediment naar verwachting niet overschreden. Bij deze beoordeling is de giftige aard voor het totaal aantal PAK's nog niet in beschouwing genomen.

Trefwoorden:
milieukwaliteitsnormen, milieurisicogrenzen, maximaal toelaatbaar risiconiveau, verwaarloosbaar risiconiveau, fenantreen

Contents

Summary

Environmental risk limits are derived using ecotoxicological, physicochemical, and human toxicological data. They represent environmental concentrations of a substance offering different levels of protection to man and ecosystems. It should be noted that the ERLs are scientifically derived values. They serve as advisory values for the Dutch Steering Committee for Substances, which is appointed to set the Environmental Quality Standards (EQSs) from these ERLs. ERLs should thus be considered as preliminary values that do not have an official status.

This report contains ERLs for phenanthrene in water, groundwater, sediment and soil. The following ERLs are derived: Negligible Concentration (NC), Maximum Permissible Concentration (MPC), Maximum Acceptable Concentration for ecosystems (MAC$_{eco}$), and Serious Risk Concentration for ecosystems (SRC$_{eco}$). The risk limits were mostly based on data presented in the RIVM report "Environmental risk limits for polycyclic aromatic hydrocarbons (PAHs)" (Verbruggen, in prep.).

For the derivation of the MPC and MAC$_{eco}$ for water and the MPC for sediment, the methodology used is in accordance with the Water Framework Directive. For the derivation of ERLs for air, no specific guidance is available. However, as much as possible the basic principles underpinning the ERL derivation for the other compartments are followed for the derivation of atmospheric ERL. For the MPCs for soil, and the NCs and the SRCs$_{eco}$ in general, the guidance developed for the project 'International and National Environmental Quality Standards for Substances in the Netherlands' was used (Van Vlaardingen and Verbruggen, 2007). An overview of the derived environmental risk limits is given in Table 1. The MPCs for water and suspended matter are higher than the current EQSs, in which the routes secondary poisoning and fish consumption were not included. The MPC for sediment is higher than the current EQS. These differences are due to a more extensive dataset on ecotoxicology in combination with the more recent methodology for derivation of ERLs.

Table 1 Derived MPC, NC, MAC$_{eco}$, and SRC$_{eco}$ values for phenanthrene

ERL	**unit**	**value**			
		MPC	**NC**	**MAC$_{eco}$**	**SRC$_{eco}$**
freshwater [a]	μg.L^{-1}	1.1	1.1 x10^{-2}	6.7	43
freshwater susp. matter [b]	mg.kg$_{dwt}^{-1}$	2.5			
drinking water human health [c]	mg.L^{-1}	0.14			
saltwater	μg.L^{-1}	1.1	1.1 x10^{-2}	6.7	43
saltwater susp. Matter	mg.kg$_{dwt}^{-1}$	2.5			
freshwater sediment [d]	mg.kg$_{dwt}^{-1}$	0.78	7.8 x10^{-3}		63
saltwater sediment [d]	mg.kg$_{dwt}^{-1}$	0.78	7.8 x10^{-3}		63
soil [e]	mg.kg$_{dwt}^{-1}$	1.9	1.9 x10^{-2}		90
groundwater	μg.L^{-1}	1.1	1.1 x10^{-2}		43
air	mg.m^{-3}	n.d.			

[a] From the MPC$_{fw, eco}$, MPC$_{fw, secpois}$ and MPC$_{fw, hh food}$ the lowest one is selected as the 'overall' MPC$_{water}$.

[b] Expressed on the basis of Dutch standard suspended matter.

[c] As stated in the new WFD guidance, the MPC$_{dw, hh}$ is not included in the selection of the final MPC$_{fw}$. Therefore, the MPC$_{dw, hh}$ is presented as a separate value.

[d] Expressed on the basis of Dutch standard sediment.

[e] Expressed on the basis of Dutch standard soil.

n.d. = not derived.

Monitoring data for phenanthrene indicate that currently the NC_{water} derived in this report is exceeded in all Dutch surface waters and that the $MPC_{susp, water}$ and $MPC_{susp, sw}$ are likely to be exceeded at many locations. Also, the $MPC_{sediment}$ could be exceeded in some cases and the $NC_{sediment}$ is likely to be exceeded in most cases. For this observation, the additive mixture toxicity for all PAHs has not been taken into account.

1 Introduction

1.1 Project framework

In this report environmental risk limits (ERLs) for surface water (freshwater and marine), soil, groundwater and air are derived for phenanthrene. Phenanthrene is listed in the Dutch decree on WFD-monitoring (*Regeling monitoring Kaderrichtlijn water*) as a specific pollutant. The aim of this report is to present updated risk limits that can be used to set water quality standards in accordance with the WFD. Phenanthrene is relevant for other compartments as well, therefore, ERLs for soil and air have also been derived. MPCs for direct ecotoxicity have already been derived by Verbruggen (in prep.). Additional ERLs, including those considering secondary poisoning and human health through fish consumption, are derived in this report. The derivation of the ERLs is performed in the context of the project National Policy on Substances. The following ERLs are considered:

- Maximum Permissible Concentration (MPC) – defined in VROM (1999, 2004) as the standard based on scientific data which indicates the concentration in an environmental compartment for which:
  1 no effect to be rated as negative is to be expected for ecosystems;
  2a no effect to be rated as negative is to be expected for humans (for non-carcinogenic substances);
  2b for humans no more than a probability of 10^{-6} per year of death can be calculated (for carcinogenic substances). Within the scope of the Water Framework Directive (WFD), a probability of 10^{-6} on a life-time basis is used.

  The MPCs for water and soil should not result in risks due to secondary poisoning (considered as part of the ecosystem in the definition above) and/or risks for human health aspects. These aspects are therefore also addressed in the MPC derivation. Separate MPC-values are derived for the freshwater and saltwater environment.

- Negligible Concentration (NC) – the concentration at which effects to ecosystems are expected to be negligible and functional properties of ecosystems are safeguarded fully. It defines a safety margin which should exclude combination toxicity. The NC is derived by dividing the MPC by a factor of 100.

- Maximum Acceptable Concentration (MAC_{eco}) for aquatic ecosystems – the concentration protecting aquatic ecosystems from effects due to short-term exposure or concentration peaks. The MAC_{eco} is derived for freshwater and saltwater ecosystems.

- Serious Risk Concentration for ecosystems (SRC_{eco}) – the concentration in water at which possibly serious ecotoxicological effects are to be expected. This value should be compared with the Serious Risk Concentration for humans (SRC_{human}), which is not derived elsewhere (Lijzen et al., 2001).

- Maximum Permissible Concentration for surface water that is used for drinking water abstraction ($MPC_{dw,\ hh}$). This is the concentration in surface water that meets the requirements for use of surface water for drinking water production. The $MPC_{dw,\ hh}$ specifically refers to locations that are used for drinking water abstraction.

The quality standards in the context of the WFD refer to the absence of any impact on community structure of aquatic ecosystems. Hence, not the potential to recover after transient exposure, but long-term undisturbed function is the protection objective under the WFD. Recovery in a test situation, after a limited exposure time, is therefore not included in the derivation of the MPC and MAC.

1.2 Current MPCs

The current MPCs for phenanthrene are 0.3 $\mu g.L^{-1}$ for water, 1 $mg.kg_{dwt}^{-1}$ for suspended matter and 0.5 $mg.kg_{dwt}^{-1}$ for sediment. The derivation of these values is reported by Kalf et al. (1995). For air there is an indicative MPC of 9.6 $ng.m^{-3}$. Derivation of this value is described by Hansler et al. (2008).

1.3 Sources of phenanthrene

There is no production of phenanthrene as a pure product. Phenanthrene, like most other polycyclic aromatic hydrocarbons (PAHs), is however present in fossil fuels and derived products; human use of these products is one of the main sources of phenanthrene in the environment. Other important anthropogenic sources are industrial processes, such as iron steel works, coke manufacturing, asphalt production, wood preservation, ship protection and petroleum cracking. Most of these industries have however improved their processes or reduced or stopped the use of PAH containing products and current emissions are highly reduced as compared to the past. Apart from anthropogenic sources, there are also natural sources like vegetation fires and volcanic emissions.

1.4 Methodology

The methodology for risk limit derivation is described in detail in the INS-guidance document (Van Vlaardingen and Verbruggen, 2007), which is further referred to as the INS-Guidance. The methodology is based on the Technical Guidance Document (TGD), issued by the European Commission and developed in support of the risk assessment of new notified chemical substances, existing substances and biocides (EC, 2003) and on the Manual for the derivation of Environmental Quality Standards in accordance with the Water Framework Directive (Lepper, 2005). The European guidance under the framework of WFD has been revised, and the updated guidance has been published recently (EC, 2011). The risk limits in this report will be used for setting water quality standards that will become effective after the new guidance has come in to force. Therefore, the terminology is harmonised as much as possible and the new guidance is followed in the case it deviates from the INS-guidance. This specifically applies to the derivation of the MAC (see section 3.5), for which the new methodology is used. This also holds for the MPC for surface waters intended for the abstraction of drinking water ($MPC_{dw,\ hh}$, see section 3.4). In the INS-guidance, this is one of the MPCs from which the lowest value should be selected as the general MPC_{water} (see section 3.1.6 and 3.1.7 of the INS-Guidance). According to the new guidance, the $MPC_{dw,\ hh}$ is not taken into account for the derivation of the general MPC_{water}, but specifically refers to locations that are used for drinking water abstraction. For the derivation of ERLs for air, no specific guidance is available. However, as much as possible, the basic principles underpinning the ERL derivation for the other compartments are followed for the derivation of an atmospheric ERL.

1.4.1 Data sources

The RIVM report “Environmental risk limits for polycyclic aromatic hydrocarbons (PAHs)” (Verbruggen, in prep.) is used as the source of physicochemical and (eco)toxicity data. Information given in this report is checked thoroughly and approved by the scientific committee of the project 'International and National Environmental Quality Standards for Substances in the Netherlands' (INS). Therefore, no additional evaluation of data is performed for the ERL derivation. Only valid data combined in an aggregated data table are presented in the current report. Occasionally, key studies are discussed when relevant for the derivation of a certain ERL. Since in the report of Verbruggen only ERLs for direct toxicity are reported, the additional ERLs to be derived according to the INS guidance are derived in this report.

1.4.2 Data evaluation

Ecotoxicity studies were screened for relevant endpoints (i.e. those endpoints that have consequences at the population level of the test species) and thoroughly evaluated with respect to the validity (scientific reliability) of the study. A detailed description of the evaluation procedure is given in section 2.2.2 and 2.3.2 of the INS-Guidance and in the Annex to the draft EQS-guidance under the WFD. In short, the following reliability indices were assigned, based on Klimisch et al. (1997):

Ri 1: Reliable without restriction
’Studies or data … generated according to generally valid and/or internationally accepted testing guidelines (preferably performed according to GLP) or in which the test parameters documented are based on a specific (national) testing guideline … or in which all parameters described are closely related/comparable to a guideline method.’

Ri 2: Reliable with restrictions
’Studies or data … (mostly not performed according to GLP), in which the test parameters documented do not totally comply with the specific testing guideline, but are sufficient to accept the data or in which investigations are described which cannot be subsumed under a testing guideline, but which are nevertheless well documented and scientifically acceptable.’

Ri 3: Not reliable
’Studies or data … in which there are interferences between the measuring system and the test substance or in which organisms/test systems were used which are not relevant in relation to the exposure (e.g., unphysiologic pathways of application) or which were carried out or generated according to a method which is not acceptable, the documentation of which is not sufficient for an assessment and which is not convincing for an expert judgment.’

Ri 4: Not assignable
’Studies or data … which do not give sufficient experimental details and which are only listed in short abstracts or secondary literature (books, reviews, etc.).’

Citations
In case of (self-)citations, the original (or first cited) value is considered for further assessment, and an asterisk is added to the Ri of the endpoint that is cited.

All available studies are summarised in data-tables that are included as Annexes to this report. These tables contain information on species characteristics, test conditions and endpoints. Explanatory notes are included with respect to the assignment of the reliability indices. In the aggregated data table only one effect value per species is presented. When for a species several effect data are available, the geometric mean of multiple values for the same endpoint is calculated where possible. Subsequently, when several endpoints are available for one species, the lowest of these endpoints (per species) is reported in the aggregated data table.

1.5 Status of the results

The results presented in this report have been discussed by the members of the scientific advisory group for the INS-project (WK-INS). It should be noted that the ERLs in this report are scientifically derived values, based on (eco)toxicological, fate and physicochemical data. They serve as advisory values for the Dutch Steering Committee for Substances, which is appointed to set the Environmental Quality Standards (EQSs). ERLs should thus be considered as advisory values that do not have an official status.

2 Substance properties, fate human toxicology and trigger values

2.1 Identity

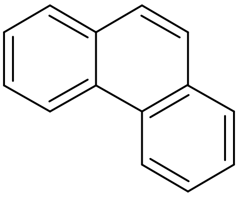

Figure 1. Structural formula of phenanthrene

Table 2. Identification of phenanthrene

Parameter	**Name or number**
Chemical name	phenanthrene
Common/trivial/other name	phenanthrene; *o*-diphenyleneethylene
CAS number	85-01-8
EC number	201-581-5
Molecular formula:	$C_{14}H_{10}$
SMILES code	c12ccccc1c3ccccc3cc2

2.2 Physicochemical properties

Table 3. Physicochemical properties of phenanthrene from Verbruggen (in prep.)

Parameter	**Unit**	**Value**	**Remark**
Molecular weight	[$g.mol^{-1}$]	178.23	
Water solubility	[$\mu g.L^{-1}$]	1034	Geometric mean of seven values by the generator-column method
log K_{OW}	[-]	4.502	Geometric mean of three values by the slow-stirring method
log K_{OC}	[$L.kg^{-1}$]	4.292	QSAR
Vapour pressure	[Pa]	0.018	Geometric mean of five values by the gas saturation method
Melting point	[°C]	99.2	
Boiling point	[°C]	340	
Henry’s law constant	[$Pa.m^3.mol^{-1}$]	3.8	Geometric mean of seven values by the gas stripping method, one by the headspace method and one by the wetted-wall method

2.3 Bioconcentration and biomagnification

Bioconcentration data (based on lab studies) and bioaccumulation data (based on field studies) for phenanthrene are given in Table 4. The data in this table are based on studies reviewed by Bleeker and Verbruggen (2009) according to the Ri classification of Klimisch et al. (1997) and considered reliable (Ri1 or 2). A full overview of these studies is given in Appendix 1

Table 4. Overview of bioaccumulation data for phenanthrene

Parameter	Unit	Value	Remark
BCF (fish)	[L.kg^{-1}]	1750	Geometric mean of most reliable BCF value for for *Cyprinodon variegatus* (1149) and *Pimephales promelas*, all data normalized to 5% fat. Species geometric mean for *Pimephales promelas* was first calculated from five values.
BCF (molluscs)	[L.kg^{-1}]	1260	Geometric mean of the BCF values for *Mya arenaria* and *Mytilus edulis*. These BCFs could not be normalized to 5% fat
BCF (crustaceans - human consumption)	[L.kg^{-1}]	210	BCF for *Crangon septemspinosa*, this is the only BCF for a crustacean suitable for human consumption
BCF (crustaceans)	[L.kg^{-1}]	648	Geometric mean of BCF values for all crustacean species. Species geometric mean was calculated first for *Diporeia* sp. Only one of the BCF values could be normalized to 5% fat
BCF (insects)	[L.kg^{-1}]	1340	Geometric mean of all BCF values for *Hexagenia limbata* normalized to 5% fat
BCF (worms)	[L.kg^{-1}]	1616	Geometric mean of the BCF values for *Stylodrilus heringianus* and *Nereis virens*. These BCFs could not be normalized to 5% fat
BCF (plants)	[L.kg^{-1}]	30	Geometric mean of all BCF values for *Lemna gibba* not normalized to 5% fat
BMF	[kg.kg^{-1}]	1	Biomagnification has not been observed (Nfon et al., 2008, Wan et al., 2007, Takeuchi et al., 2009) [a]

[a] In a study into foodweb distribution of PAHs (Vives et al., 2005), a biomagnification factor of 1.5 kg.kg^{-1} is reported. This value was based on phenanthrene concentrations in the fish diet and a fat normalized concentration in the fish liver. Since the phenanthrene concentration in the fish liver is in general higher than in the whole fish, this reported value supports the use of a BMF of 1.

A wide range of BCFs is available. In addition, BAFs are available. These BAFs (derived from field samples) indicate that the BCFs (derived from laboratory studies) are comparable to the bioaccumulation in the field. The BAF values are presented in Appendix 1. The low lipid content of most organisms from the field carries some additional uncertainty in comparison to the laboratory BCF values. Therefore, the BCF data normalized to 5% lipids will be used in the calculation of the MPCs for secondary poisoning of mammals and birds ($MPC_{fw,\ secpois}$ and $MPC_{sw,\ secpois}$) and the MPC for human food consumption ($MPC_{water,\ hh\ food}$).
When deciding which BCF should be used for calculation of the MPCs for secondary poisoning of mammals and birds ($MPC_{fw,\ secpois}$ and $MPC_{sw,\ secpois}$) and the MPC for human food consumption ($MPC_{water,\ hh\ food}$), it should be considered that humans have a more specific food choice (fishery products) than mammals and birds, for which diets can vary considerably amongst different species. Therefore different BCFs should be used when deriving the different MPCs.
For the $MPC_{water,\ hh\ food}$, the relative human consumption of fish, molluscs and crustaceans is used to determine the BCF. The human food consumption pattern used to determine the BCF is based on the Dutch food consumption survey for 1998 (Anonymous, 1998). The relative consumption of fish, molluscs and crustacean is 90% : 7% : 3% for fish : molluscs : crustaceans. On the basis of this relative consumption, a weighted average is calculated from the BCFs for fish, molluscs and the crustacean that is suitable for human consumption. The calculated BCF is: 1664 L.kg^{-1} based on geometric mean values for fish and molluscs, normalized to 5% lipids if possible. It should be noted that this approach is not the most conservative. A person having an equal daily consumption of fish only might not entirely be protected by this BAF. On the

other hand, the derivation of the $MPC_{water,\ hh\ food}$ is already precautionary for the general Dutch population, because of the relatively high daily intake (115 g fishery prodcucts) and the fact that the contribution of the consumption of fishery products to the total daily exposure is only 10%. Therefore, a large risk for such a person is considered unlikely.
For the BCF to calculate the $MPC_{fw,\ secpois}$, it is presumed that some predatory species have strong preference for the one of the three groups (fish, crustaceans or molluscs) or another group (e.g. worms) for their diet. The selected BCF for the $MPC_{fw,\ secpois}$ is the highest of the available groups and is the geometric mean of the BCF values for fish which is 1750 $L.kg^{-1}$.

2.4 Human toxicological threshold limits and carcinogenicity

Phenanthrene has not been classified in EU framework. The U.S. EPA (IRIS) concluded that phenanthrene is not classifiable for human carcinogenicity. RIVM concluded that phenanthrene is probably carcinogenic, but the relative carcinogenic potential is extremely low. For oral toxicity, a Tolerable Daily Intake (TDI) of 0.040 $mg.kg_{bw}^{-1}.day^{-1}$ was derived based on a threshold approach (Baars et al., 2001). This value is adopted as TDI in this report.
For inhalation toxicity no individual TCA (Tolerable Concentration in Air) is available for phenanthrene. A limit value of 0.01 $ng.m^{-3}$ has been proposed by the EU working group on PAHs (EC, 2001) for a lifetime exposure risk of 10^{-6} for benzo[*a*]pyrene (BaP) as indicator for the total PAHs and this value has been adopted in EU legislation (EU, 2004). To obtain an limit value for benzo[*a*]pyrene as an individual substance, the limit value can be increased with a factor of 10 (a factor that is used to estimate the risk of total PAHs on the risk of BaP only) to 0.1 $ng.m^{-3}$. TCAs for other PAHs can be derived from this value on the basis of their relative carcinogenic potency. The relative carcinogenic potency of phenanthrene is considered to be negligible and has been set at <0.001 (Baars et al., 2001). With this value the TCA for phenanthrene will be > 0.1 $\mu g.m^{-3}$, no bound value can be derived. With a daily breathing volume of about 10,000 L air, it is can be calculated that this value of 0.1 $\mu g.m^{-3}$ would still be very stringent compared to the TDI.

2.5 Trigger values

This section reports on the trigger values for ERL_{water} derivation (as demanded in WFD framework) as reported in Verbruggen (in prep.).

Table 5. Phenanthrene: collected properties for comparison to MPC triggers

Parameter	Value	Unit	Method/Source
Log $K_{p,susp\text{-}water}$	3.29	[-]	$K_{OC} \times f_{OC,susp}$[a]
BCF	1664 / 1750[b]	[$L.kg^{-1}$]	
BMF	1	[kg,kg^{-1}]	
Log K_{OW}	4.50	[-]	
R-phrases	n.a.	[-]	
A1 value	n.a.	[$\mu g.L^{-1}$]	
DW standard	n.a.	[$\mu g.L^{-1}$]	

[a] $f_{OC,susp}$ = 0.1 $kg_{OC}.kg_{solid}^{-1}$ (EC, 2003).
[b] Different BCF values are given to be used separately for calculation of the $MPC_{water,\ hh\ food}$ and the $MPC_{fw,\ secpois}$ respectively.
n.a. = not available.

○ phenanthrene has a log $K_{p,\ susp\text{-}water}$ > 3; derivation of $MPC_{sediment}$ is triggered.

- phenanthrene has a log $K_{\mathrm{p,\ susp\text{-}water}}$ > 3; expression of the $\mathrm{MPC_{water}}$ as $\mathrm{MPC_{susp,\ water}}$ is required.
- phenanthrene has a BCF > 100 $\mathrm{L.kg^{-1}}$; assessment of secondary poisoning is triggered.
- phenanthrene is only marginally carcinogenic but given the low TDI and the fact that the BCF is above 100 $\mathrm{L.kg^{-1}}$, an $\mathrm{MPC_{water}}$ for human health via food (fish) consumption ($\mathrm{MPC_{water,\ hh\ food}}$) should be derived.

3 Toxicity data and derivation of ERLs for water

3.1 Toxicity data

The selected freshwater toxicity data for phenanthrene as reported by Verbruggen (in prep.) are given in Table 6 and marine toxicity data are shown in Table 7.

Table 6. Phenanthrene: selected freshwater toxicity data for ERL derivation

Chronic Taxonomic group	**NOEC/EC$_{10}$ (µg.L^{-1})**	**Acute Taxonomic group**	**L(E)C$_{50}$ (µg.L^{-1})**
		Cyanophyta	
		Anabaena flos-aqua	1300
Algea		**Algea**	
Pseudokirchneriella subcapitata	15 [a]	*Nitzschia palea*	870
Scenedesmus vacuolatus	150	*Pseudokirchneriella subcapitata*	233 [f]
		Scenedesmus vacuolatus	590
Crustacea		**Crustacea**	
Ceriodaphnia dubia	13	*Daphnia magna*	700
Daphnia magna	18 [b]	*Daphnia pulex*	100
Daphnia pulex	13 [c]	*Diporeia* spp.	74 [g]
Hyalella azteca	155	*Gammarus minus*	460
		Insecta	
Pisces		*Chironomus riparius*	41 [h]
Danio rerio	14 [d]		
Micropterus salmoides	11		
Oncorhynchus mykiss	23 [d]		
Oryzias latipes	93 [e]		

[a] Geometric mean of 10 and 24 µg.L^{-1} for the growth rate (most relevant parameter) under optimal growth conditions (2 d, pH restricted to 7.0-7.3).

[b] Most sensitive parameter (reproduction) determined under most reliable exposure regime (intermittent flow).

[c] Most sensitive parameter (reproduction).

[d] Most sensitive parameter (weight).

[e] Most sensitive parameter (malformations).

[f] Geometric mean of 180 and 302 µg.L^{-1} for the growth rate (most relevant parameter) under optimal growth conditions (2 d, pH restricted to 7.0-7.3).

[g] Longest exposure time of 5 d.

[h] Most sensitive life-stage (1st instar) illuminated with a mercury light source 330-800 nm, including some UV-A.

Table 7. Phenanthrene: selected marine toxicity data for ERL derivation

Chronic Taxonomic group	**NOEC/EC$_{10}$ (µg.L^{-1})**	**Acute Taxonomic group**	**L(E)C$_{50}$ (µg.L^{-1})**
		Bacteria	
		Vibrio fischeri	310 [d]
Mollusca		**Mollusca**	
Mytilus galloprovincialis	29 [a]	*Mytilus edulis*	148
		Annelida	
		Neanthes arenaceodentata	187
Crustacea		**Crustacea**	
Acartia tonsa	69 [b]	*Acartia tonsa*	422
		Artemia salina	520
		Oithona davisae	522 [e]
		Palaemonetes pugio	360

Chronic Taxonomic group	NOEC/EC_{10} ($\mu g.L^{-1}$)	Acute Taxonomic group	L(E)C_{50} ($\mu g.L^{-1}$)
Echinodermata			
Arbacia punctulata	164		
Paracentrotus lividus	105 [c]		
Urochordata			
Ciona intestinalis	262 [c]		

[a] determined in the dark.

[b] most sensitive parameter (recruitment) determined under most reliable exposure regime (intermittent flow).

[c] determined with a photoperiod 14:10 h light:dark by cool daylight lamps (380-780nm, PAR) with an intensity of 70 $\mu E.m^{-2}.s^{-1}$.

[d] Geometric mean of 530, 530, 510, 520, 144, 142, and 182 $\mu g.L^{-1}$ for standard exposure time (15 min).

[e] Most sensitive endpoint (mortality).

3.1.1 *Mesocosm studies*

No mesocosm studies are available.

3.2 Treatment of fresh- and saltwater toxicity data

As stated by Verbruggen (in prep.), there is no significant difference between the freshwater and marine acute toxicity data. Therefore the datasets can be combined. Chronic data for marine organisms appeared to be significantly higher than data for freshwater organisms. This was considered due to the inclusion of typically marine taxonomic groups (Echinodermata and Urochordata), which appeared to be relatively tolerant to phenanthrene. Therefore, the chronic data sets were combined as well.

3.3 Derivation of MPC_{fw} and MPC_{sw}

3.3.1 *$MPC_{fw, eco}$ and $MPC_{sw, eco}$*

The following derivation of the $MPC_{fw, eco}$ and $MPC_{sw, eco}$ is cited from Verbruggen (in prep.). Because acute and chronic toxicity data are available for algae, *Daphnia*, and fish, an assessment factor of 10 can be applied to the lowest NOEC or EC_{10}. This is the EC_{10} of 11 $\mu g.L^{-1}$ for *Micropterus salmoides*. The resulting $MPC_{fw, eco}$ is 1.1 $\mu g.L^{-1}$. Because chronic data are available for additional taxonomic groups for the marine environment, the same assessment factor can be applied for the $MPC_{sw, eco}$, which is 1.1 $\mu g.L^{-1}$ too.

3.3.2 *$MPC_{fw, secpois}$ and $MPC_{sw, secpois}$*

Phenanthrene has a BCF > 100 $L.kg^{-1}$, thus assessment of secondary poisoning is triggered. Therefore, toxicological data on birds and mammals should be used to derive an $MPC_{oral, min}$ from which the $MPC_{fw, secpois}$ and $MPC_{sw, secpois}$ can be derived. However no studies with population relevant endpoints for mammals and birds could be found. The EPA ECOTOX Database does contain NOELs for birds and mammals, but the underlying studies did not examine population relevant endpoints and/or only applied the PAH in a single dose and mostly only one concentration was tested.

As an alternative approach the $MPC_{fw, secpois}$ is derived in a similar way as the TDI for phenanthrene.
The TDI of phenanthrene was based on the toxicity of the aromatic C_{9-16} fraction of TPH (Total Petroleum Hydrocarbon) because phenanthrene is part of this fraction (Baars et al., 2001). On the same grounds, it can be presumed that the underlying studies can be used to derive an $MPC_{oral, min}$ for phenanthrene. The

TDI is based on studies with 90 days administration of naphthalene, fluorene, anthracene, fluoranthene and pyrene (TPHCWG, 1997). Considering population relevant endpoints, the lowest NOEL for rats from these studies was 50 $mg.kg_{bw}^{-1}.d^{-1}$ for changes in body weight from a study with naphthalene. With a conversion factor of 20 to calculate a $NOEC_{oral}$ in $mg.kg_{food}^{-1}$ and an assessment factor of 90 for 90 days studies the MPC_{oral} is 11 $mg.kg_{food}^{-1}$. The lowest NOEL for mice was 250 $mg.kg_{bw}^{-1}.d^{-1}$ for changes in body weight and food consumption from a study with fluoranthene. With a conversion factor of 8.3 to calculate a $NOEC_{oral}$ in $mg.kg_{food}^{-1}$ and an assessment factor of 90, the MPC_{oral} is 23 $mg.kg_{food}^{-1}$. The $MPC_{oral, min}$ of 11 $mg.kg_{food}^{-1}$ is used to calculate the $MPC_{fw, secpois}$ and $MPC_{sw, secpois}$. With the BCF of 1750 $L.kg^{-1}$and BMF1 and BMF2 of 1, the $MPC_{fw, secpois}$ and $MPC_{sw, secpois}$ are both 6.3 $\mu g.L^{-1}$.

3.3.3 *$MPC_{water, hh food}$*

Derivation of $MPC_{water, hh food}$ for phenanthrene is triggered (Table 5). This derivation is based on the TDI of 0.040 $mg.kg_{bw}^{-1}.day^{-1}$. $MPC_{hh, food} = 0.1 \times TL_{hh} \times BW / 0.115 = 2.4$ $mg.kg_{food}^{-1}$, where the TL_{hh} is the TDI, BW is a body weight of 70 kg, 0.115 kg is the daily consumption of fishery products. With a BCF of 1664 $L.kg^{-1}$ and a BMF1 of 1, the resulting $MPC_{water, hh food}$ is then: 2.4 / (1664*1) = 1.5 $\mu g.L^{-1}$. The $MPC_{water, hh food}$ is valid for the freshwater and saltwater compartment.

3.3.4 *Selection of the MPC_{fw} and MPC_{sw}*

The MPC_{fw} and the MPC_{sw} are determined by the lowest $MPC_{fw/sw}$ derived. Therefore, both the MPC_{fw} and the MPC_{sw} are 1.1 $\mu g.L^{-1}$.

Phenanthrene has a log $K_{p, susp-water} \geq 3$; expression of the MPC_{water} as $MPC_{susp, water}$ is required. The $MPC_{susp, water}$ is calculated according to:

$MPC_{susp, water} = MPC_{water, dissolved} \times K_{p, susp-water, Dutch standard}$

For this calculation, $K_{p,susp-water,Dutch standard}$ is calculated from the log Koc of 4.292 as given in Table 3. With an $f_{OC,susp, Dutch standard}$ of 0.1176 the $K_{p, susp-water, Dutch standard}$ can be calculated to 2305 $L.kg^{-1}$. With this value, both the $MPC_{susp, fw}$ and the $MPC_{susp, sw}$ are 2.5 $mg.kg_{dwt}^{-1}$.

3.4 Derivation of $MPC_{dw, hh}$

No A1 value and DW standard are available for phenanthrene. With the TDI of 0.040 $mg.kg_{bw}^{-1}.day^{-1}$ an $MPC_{dw, hh, provisional}$ can be calculated with the following formula: $MPC_{dw, hh, provisional} = 0.1 \times TL_{hh} \times BW / uptake_{dw}$ where the TL_{hh} is the TDI, BW is a body weight of 70 kg, and $uptake_{dw}$ is a daily uptake of 2 L. As described in section 2.2 water treatment is currently not taken into account. Therefore the $MPC_{dw, hh}$ = the $MPC_{dw, hh, provisional}$ and becomes: 0.1 x 0.040 x 70 / 2 = 0.14 $mg.L^{-1}$.

3.5 Derivation of MAC_{eco}

The following derivation of the MAC_{eco} is cited from Verbruggen (in prep.). There are no reliable acute toxicity data for fish or other vertebrates and for aquatic plants. However, from two fish species tested and one aquatic plant (i.e. studies that were considered unreliable because only nominal concentrations were reported), these groups do not appear particularly sensitive. Therefore, the $MAC_{fw, eco}$ and the $MAC_{sw, eco}$ can be derived from a species sensitivity distribution (Figure 2). The HC5 of the acute toxicity data is 67 $\mu g.L^{-1}$, which is above the lowest value of 41 µg.L^{-1} for *Chironomus riparius*. The HC_{50} is 307 µg.L^{-1}. The goodness-of-fit is accepted at all significance levels. The number of toxicity data and the taxonomic diversity is high and the differences in species sensitivity are low, which is characteristic of narcotic effects. The $MAC_{fw, eco}$ should be protective of any acute effects. However, the values used in the SSD are 50% effective concentration. Therefore, an assessment is made between the 50% and 10% effective concentrations (EC_{50} and EC_{10}). A direct comparison can be made for eight species from four taxonomic groups (Table 8). The ratio between the EC_{50} and EC_{10} varies widely. Moreover, such data have not been generated for the most sensitive taxonomic group, which are the insects. Therefore, an assessment factor of 10 is applied to the HC5 (acute) to derive the $MAC_{fw, eco}$. The $MAC_{fw, eco}$ is thus 6.7 µg.L^{-1}. Because of the number of marine data, including non standard species such as annelids and molluscs, an extra assessment factor for the $MAC_{sw, eco}$ is not necessary. The $MAC_{sw, eco}$ is 6.7 µg.L^{-1} too.

Table 8 Ratio of acute no effect levels (10% cut-off by means of EC_{10}) versus 50% effect levels (EC_{50}) for phenanthrene

Taxon	**Species**	**EC_{50}/EC_{10} or LC_{50}/LC_{10}**
Algae	*Pseudokirchneriella subcapitata*	6.5-18
Algae	*Scenedesmus vacuolatus*	3.9
Bacteria	*Vibrio fischeri*	3.7-24
Crustacea	*Daphnia magna*	1.3-2.6
Crustacea	*Daphnia pulex*	2.5
Crustacea	*Acartia tonsa*	1.3
Crustacea	*Oithona davisae*	2.1-2.7
Cyanophyta	*Anabaena flos-aqua*	2.5

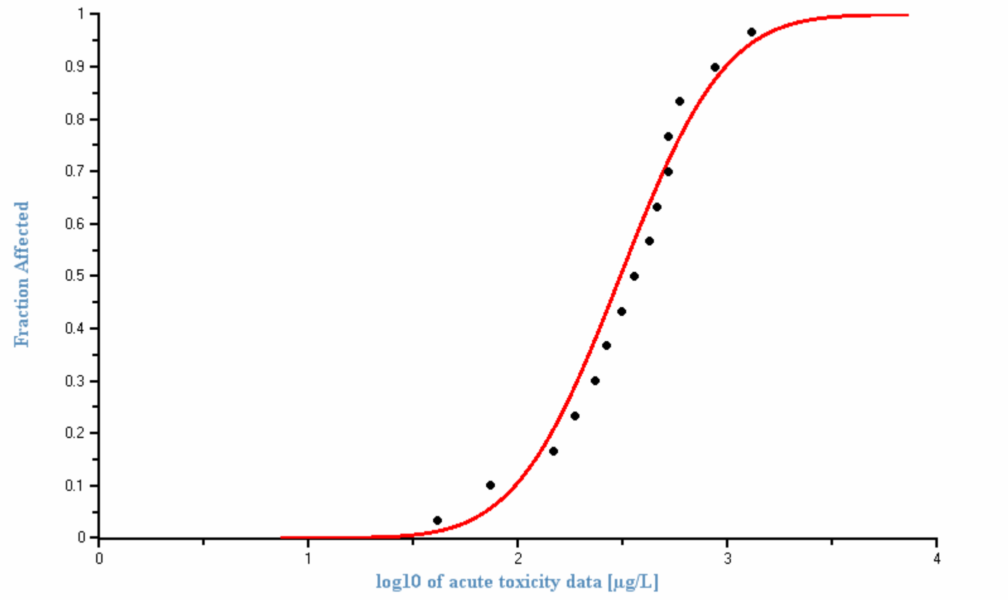

Figure 2 Species sensitivity distribution for the acute toxicity of phenanthrene to aquatic organisms

3.6 Derivation of the NC

Negligible concentrations are derived by dividing the MPCs by a factor of 100. This gives an NC_{fw} of 11 ng.L^{-1} and an NC_{sw} of 11 ng.L^{-1}

3.7 Derivation of the $SRC_{water, eco}$

The following derivation of the $SRC_{water, eco}$ is cited from Verbruggen (in prep.). The $SRC_{water, eco}$ is equal to the geometric mean of the chronic toxicity data and is 43 $\mu g.L^{-1}$. The $SRC_{water, eco}$ is valid for the salt- and freshwater environment.

3.8 Lipid approach

In Verbruggen (in prep.), ERLs were also calculated on the basis of internal lipid concentrations. In this approach all individual toxicity data for all examined PAHs were recalculated to internal lipid concentrations and concentrations were expressed on a molar basis. The obtained dataset was set out in a species sensitivity distribution and the values for HC_5 and HC_{50} have been recalculated to concentrations for the individual PAHs in water, sediment and soil. More details on this approach can be found in Verbruggen (in prep.). With this method an $MPC_{fw, eco}$ of 0.68 $\mu g.L^{-1}$ was calculated after application of an assessment factor of 5 to the HC_5. The HC_{50} of 38 $\mu g.L^{-1}$ was taken over as the $SRC_{water, eco}$. These values are comparable to the derived ERL values for freshwater.

4 Toxicity data and derivation of ERLs for sediment

4.1 Toxicity data

An overview of the selected sediment toxicity data for phenanthrene as reported by Verbruggen (in prep.) is given in Table 9. These values are recalculated to standard sediment with 10% organic matter. The crustaceans *Rhepoxynius abronius* and *Schizopera knabeni* are marine species while the annelid *Limnodrilus hoffmeisteri* inhabits mostly brackish sediments. The rest of the species live in freshwater sediments.

Table 9. Phenanthrene: selected chronic sediment toxicity data for ERL derivation

Chronic[a] **Taxonomic group**	**NOEC/EC$_{10}$** **(mg.kg$_{dwt}^{-1}$)**
Annelida	
Limnodrilus hoffmeisteri	168 [a]
Lumbriculus variegatus	26
Crustacea	
Hyalella azteca	167 [b]
Rhepoxynius abronius	122 [c]
Schizopera knabeni	7.8 [d]
Insecta	
Chironomus riparius	91 [e]

[a] most sensitive parameter (sediment egestion).

[b] geometric mean of 339, 113, and 122 mg.kg$_{dw,\ standard\ sed}^{-1}$, recalculated to standard sediment with 10% organic matter, for the most sensitive parameter (length).

[c] geometric mean of 125 and 120 mg.kg$_{dw,\ standard\ sed}^{-1}$, recalculated to standard sediment with 10% organic matter.

[d] most sensitive parameter (reproduction).

[e] geometric mean of 84, 114, and 79 mg.kg$_{dw,\ standard\ sed}^{-1}$, recalculated to standard sediment with 10% organic matter for the parameter emergence/mortality in a 28-d study.

4.2 Derivation of MPC$_{sediment}$

The following derivation of the MPC$_{sediment}$ is cited from Verbruggen (in prep.). With six chronic data from three taxonomic groups equally distributed over freshwater and marine species, a minimum assessment factor of 10 can be applied to derive the MPC$_{sediment,\ fw}$ and MPC$_{sediment,\ sw}$. The resulting value is 0.78 mg.kg$_{dwt}^{-1}$ for Dutch standard sediment.

Both the MPC$_{sediment,\ fw}$ and the MPC$_{sediment,\ sw}$ are 0.78 mg.kg$_{dwt}^{-1}$ for Dutch standard sediment.

4.3 Derivation of NC$_{sediment}$

The NC$_{sediment,\ fw}$ is set a factor of 100 lower than de MPC$_{sediment,\ fw}$ at 7.8 µg.kg$_{dwt}^{-1}$ for Dutch standard sediment. The NC$_{sediment,\ sw}$ is 7.8 µg.kg$_{dwt}^{-1}$ for Dutch standard sediment.

4.4 Derivation of SRC$_{sediment,\ eco}$

The following derivation of the SRC$_{sediment,\ eco}$ is cited from Verbruggen (in prep.). The SRC$_{sediment,\ eco}$ is derived from the geometric mean of the benthic data and is 63 mg.kg$_{dwt}^{-1}$ for Dutch standard sediment.

The $SRC_{sediment, eco}$ is 63 $mg.kg_{dwt}^{-1}$ for Dutch standard sediment. The $SRC_{sediment, eco}$ is valid for the marine and the freshwater environment.

4.5 Lipid approach

With the lipid approach as briefly described in Section 3.8, Verbruggen (in prep.) calculated an $MPC_{sediment, fw}$ of 0.78 $mg.kg_{dwt}^{-1}$, after application of an assessment factor of 5 to the HC5. An HC50 of 44 $mg.kg_{dwt}^{-1}$ was taken over as the $SRC_{sediment, eco}$. Both values were normalised for Dutch standard sediment. These values are comparable to the derived ERL values for sediment.

5 Toxicity data and derivation of ERLs for soil

5.1 Toxicity data

An overview of the selected soil toxicity data for phenanthrene as reported by Verbruggen (in prep.) is given in Table 10.

Table 10. Phenanthrene: selected chronic soil toxicity data for ERL derivation

Chronic[a] **Taxonomic group**	**NOEC/EC$_{10}$** **(mg.kg$_{standard\ soil}^{-1}$)**
Bacteria	
nitrification	154
Macrophyta	
Sinapsis alba	98 [a]
Trifolium pretense	88 [a]
Lolium perenne	645 [a]
Annelida	
Eisenia fetida	36 [b]
Eisenia veneta	92
Enchytraeus crypticus	87 [c]
Insecta	
Folsomia candida	37 [d]
Folsomia fimetaria	72 [c]

[a] Most sensitive endpoint (fresh weight).

[b] Most sensitive endpoint (total offspring) derived from presented data based on time weighted average concentrations.

[c] Most sensitive endpoint (reproduction) corrected for time weighted average concentrations.

[d] Geometric mean of 33 and 41 mg.kg$_{dwt}^{-1}$ for most sensitive endpoint (reproduction) corrected for time weighted average concentrations.

5.2 Derivation of MPC$_{soil}$

5.2.1 *MPC$_{soil,\ eco}$*

The following derivation of the MPC$_{soil,\ eco}$ is cited from Verbruggen (in prep.). Chronic toxicity data for phenanthrene in soil are available for annelids, collembola, terrestrial plants, and microbial processes. The EC$_{10}$ for reproduction of *Eisenia fetida* is the lowest EC$_{10}$ or NOEC. This value is almost equal to the geometric mean of 33 and 41 mg.kg$_{dwt,\ standard\ soil}^{-1}$ for the springtail *Folsomia candida*. Because chronic data are available for 8 species and 1 terrestrial process, covering all trophic levels, an assessment factor of 10 can be applied to derive the MPC$_{soil,\ eco}$. The MPC$_{soil,\ eco}$ is thus 3.6 mg.kg$_{dwt}^{-1}$ for Dutch standard soil.

The MPC$_{eco}$ for soil is 3.6 mg.kg$_{dwt}^{-1}$ for Dutch standard soil.

5.2.2 *MPC$_{soil,\ secpois}$*

Phenanthrene has a BCF > 100 L.kg^{-1} and therefore secondary poisoning is triggered.

An indicative MPC$_{soil,\ secpois}$ can be calculated from the indicative MPC$_{oral}$ of 11 mg.kg$_{food}^{-1}$ as calculated in Section 3.3.2. The MPC$_{soil,\ secpois,\ TGD}$ can be calculated with the method as described in Van Vlaardingen and Verbruggen (2007). This calculation has been performed with an estimated BCF value of 380 L.kg^{-1}, based on the log K$_{ow}$. The calculated MPC$_{soil,\ secpois,\ TGD}$ is: 11.4 mg.kg$_{dwt}^{-1}$. Conversion to Dutch standard soil gives 33.7 mg.kg$_{dwt}^{-1}$ for

Dutch standard soil. Jager (Jager, 1998) reported BCF values for earthworms ranging from 9 to 40 L.kg^{-1}. This indicates that the calculated MPC$_{soil,\ secpois}$ is most likely a worst case estimate.

5.2.3 *MPC$_{soil,\ hh\ food}$*

For the derivation of the MPC$_{soil,\ hh\ food}$, the TDI of 0.040 mg.kg$_{bw}^{-1}$.day^{-1} can be used as TL$_{hh}$. With the method as described in van Vlaardingen and Verbruggen (2007), specific human intake routes are allowed to contribute 10% of the human toxicological threshold limit. Four different routes contributing to human exposure have been incorporated: consumption of leafy crops, root crops, milk and meat. Uptake via root crops was determined to be the critical route. The calculated MPC$_{soil,\ hh\ food}$ is 1.85 mg.kg$_{dwt}^{-1}$ for Dutch standard soil.

5.2.4 *Selection of the MPC$_{soil}$*

The lowest MPC$_{soil}$ is the MPC$_{soil,\ hh\ food}$, this sets the MPC$_{soil}$ to 1.9 mg.kg$_{dwt}^{-1}$ for Dutch standard soil.

5.3 Derivation of NC$_{soil}$

The NC$_{soil}$ is set a factor of 100 lower than de MPC$_{soil}$ at 0.019 mg.kg$_{dwt}^{-1}$ for Dutch standard soil.

5.4 Derivation of SRC$_{soil,\ eco}$

The following derivation of the SRC$_{soil,\ eco}$ is cited from Verbruggen (in prep.). The SRC$_{soil,\ eco}$ is derived from the geometric mean of the data for the eight species and is 90 mg.kg$_{dwt}^{-1}$ for Dutch standard soil.

5.5 Lipid approach

With the lipid approach as briefly described in Section 3.8, Verbruggen (in prep.) calculated an MPC$_{soil,\ eco}$ of 0.76 mg.kg $_{dwt}^{-1}$ was calculated, after application of an assessment factor of 5 to the HC5. The HC50 of 44 mg.kg $_{dwt}^{-1}$ was taken over as the SRC$_{soil,\ eco}$. Both values are normalised for Dutch standard soil. These values are comparable to the derived ERL values for soil.

6 Derivation of ERLs for groundwater

6.1 Derivation of MPC_{gw}

6.1.1 $MPC_{gw, eco}$

Since groundwater-specific ecotoxicological ERLs are absent, the surface water $MPC_{fw, eco}$ is taken as a substitute. Thus the $MPC_{gw, eco}$ = $MPC_{fw, eco}$ = 1.1 µg.L^{-1}.

6.1.2 $MPC_{gw, hh}$

The $MPC_{gw, hh}$ is set equal to the $MPC_{dw, hh}$: 0.14 mg.L^{-1}.

6.1.3 Selection of the MPC_{gw}

The lowest MPC_{gw} sets the MPC_{gw} this is the $MPC_{gw, eco}$: 1.1 µg.L^{-1}.

6.2 Derivation of NC_{gw}

The NC_{gw} is set a factor 10 lower than the MPC_{gw}: 11 ng.L^{-1}.

6.3 Derivation of $SRC_{gw, eco}$

The $SRC_{gw, eco}$ is set equal to the $SRC_{water, eco}$: 43 µg.L^{-1}.

7 Derivation of ERLs for air

7.1 Derivation of MPC_{air}

7.1.1 $MPC_{air, eco}$

No data are available to derive an $MPC_{air, eco}$.

7.1.2 $MPC_{air, hh}$

Since only an unbound TCA for phenanthrene in air is available, an $MPC_{air, hh}$ cannot be derived.

7.1.3 *Selection of the* MPC_{air}

No MPC_{air} can be derived.

7.2 Derivation of NC_{air}

Since there is no MPC_{air}, an NC_{air} can also not be derived.

8 Comparison of derived ERLs with monitoring data

Surfacewater

The RIWA (Dutch Association of River Water companies) reports monitoring data for phenanthrene in the Rhine and Meuse basins. The total concentrations for the years 2006-2010 are given in Table 11. These values cannot be directly compared with the ERLs derived in this report that expressed as dissolved concentrations. However, presuming a concentration of suspended matter in surface water varying between 15 and 30 mg.L^{-1} and the $K_{p,\ \text{susp-water, Dutch standard}}$ given in Section 3.3.4, the fraction of the total concentration sorbed to suspended matter is only 3 to 6%. The total concentration is therefore representative for the dissolved fraction. It can be concluded that none of these values exceeds the newly derived MPC or MAC for freshwater, but the NC_{water} of 11 ng.L^{-1} is exceeded in many cases.

Table 11 Total concentrations (µg.L^{-1}) of phenanthrene in surface water of the Rhine and Meuse for the years 2006-2010. Source: RIWA

location	**2006**		**2007**		**2008**		**2009**		**2010**	
	aa.[c]	max	aa.	max	aa.	max	aa.	max	aa.	max
Rhine										
Lobith	<[d]	<	0.0896	1	0.015	0.04	<	<	<	0.01
Nieuwegein[a]	0.0319	0.07	0.0147	0.02	0.0187	0.03	0.03	0.05	0.0107	0.03
Nieuwersluis[b]	0.0223	0.06	0.0137	0.04	<	0.02	0.0137	0.02	0.0233	0.08
Meuse										
Eijsden	-[e]	-	0.02	0.05	0.0154	0.04	-	-	-	-
Heel	<	<	<	<	<	<	<	0.0062	0.0129	0.05
Brakel	<	0.02	<	0..03	<	0.02	<	0.02	<	0.02
Keizersveer	0.01	0.04	0.01	0.03	<	0.02	<	0.01	0.0235	0.11
Stellendam	<	<	<	<	<	<	<	<	<	<

[a] Lek canal.

[b] Amsterdam-Rhine canal.

[c] aa. = annual average.

[d] < = below limit of detection/quantification.

[e] - = not reported.

The Dutch Ministry of Infrastructure and Environment does present monitoring data for total concentrations of phenanthrene in water and sediment on their website (www.waterbase.nl). For the years 2001 to 2010 maximum peak values for surface water were reported up to 3.1 µg.L^{-1}. These values do not exceed the MAC_{eco} derived in this report. For suspended matter, the average of the concentrations reported for 2001 to 2010 did not exceed the $MPC_{susp,\ fw}$ or $MPC_{susp,\ sw}$.

For remote mountain lakes in the Pyrenees, alps and central Norway, dissolved water concentration for phenanthrene are reported ranging from 0.096 to 0.176 ng.L^{-1} (Vilanova et al., 2001). In these water samples, phenanthrene counted for 31 to 45% of the total PAH concentration. For the marine environment, background concentrations have been agreed for several regions of the North-East Atlantic. The background concentration of phenanthrene ranges from 0.262 to 0.636 ng.L^{-1} (OSPAR, 2005). These values are lower than the NCs for fresh- and saltwater.

Sediment

For sediment, over the years 2001 to 2010 the reported concentrations exceeded the new derived $MPC_{sediment}$ in four occasions: 3.39 $mg.kg_{dwt}^{-1}$ (Sas van Gent, 2001), 1.2 $mg.kg_{dwt}^{-1}$ (Sas van Gent 2006), 2.7 $mg.kg_{dwt}^{-1}$ (Sas van Gent, 2009) and 0.79 $mg.kg_{dwt}^{-1}$ (Bovensluis, 2002). Most of the other reported values exceed the newly derived $NC_{sediment}$. Concentrations in North Sea sediment are also collected for the OSPAR convention. Actual concentrations are not report for phenanthrene but in the assessment report for 2008/2009 (OSPAR, 2009b) it can be seen that the concentration in almost all samples exceed the OSPAR "Background Assessment Concentration" of 32 $\mu g.kg_{dwt}^{-1}$ normalised to 2.5% TOC (OSPAR, 2009a). Normalised to Dutch standard sediment, this value would be about a factor 10 lower than the $MPC_{sediment}$ derived in this report but exceeding the $NC_{sediment}$. The trends for concentrations of phenanthrene in North Sea sediment over the period 2003-2007 are in general stable and rarely declining.

Soil

In the year 2000, the AW2000 project examined the concentrations of many contaminants in agricultural soil and soils in nature reserves in the Netherlands, which were not exposed to local sources of contamination, in order to determine their background values in the Netherlands (Lamé et al., 2004b). The median concentration of phenanthrene in the upper soil (0-0.1 m) was determined at 10 $\mu g.kg_{dwt}^{-1}$ for Dutch standard soil. In the lower soil (0.5-1.0 m) the median was determined at 0.004 $\mu g.kg_{dwt}^{-1}$ for Dutch standard soil. These values are comparable to the estimated natural background concentration of 1-10 $\mu g.kg_{soil}^{-1}$ for individual PAHs as determined by Wilcke (2000). It seems in contradiction that soils in European high mountain areas, recently examined on their PAH concentration (Quiroz et al., 2011) showed higher concentrations. For phenanthrene, the average concentrations were 117 $\mu g.kg^{-1}$, 72 $\mu g.kg^{-1}$, 256 $\mu g.kg^{-1}$ and 120 $\mu g.kg^{-1}$ for Montseny (Spain), Pyrenees (French-Spanish border), Alps (Austria) and Tatras (Slovania) respectively. However, the actual concentration is correlated to the altitude and these high concentrations are attributed to condensation effects at higher altitudes caused by the lower temperatures. When this correlation is extrapolated to sea level, the estimated value is comparable to those determined within the AW2000 project (Lamé et al., 2004a) and by Wilcke (2000). The maximum concentrations monitored in the AW2000 project are 1.16 $mg.kg_{dwt}^{-1}$ and 0.093 $mg.kg_{dwt}^{-1}$ for the upper and lower soil respectively normalised to Dutch standard soil. These values do not exceed the derived MPC value for soil but are higher than the NC_{soil}. The 80% level in the upper soils was 0.022 $mg.kg_{dwt}^{-1}$ meaning that at least 20% of the uppers soil samples exceed the NC_{soil}. In the lower soils, the 90% level of 0.018 $mg.kg_{dwt}^{-1}$ was close to the NC_{soil}. From this can be concluded that the newly derived NC_{soil} will be exceeded in many areas with a relatively low exposure of PAHs.

Sum of PAHs

The observations reported above are based on the reported concentrations for phenanthrene alone. It should be considered that phenanthrene will not occur on its own but as part of the mixture of PAHs. Therefore, the occurrence of mixture toxicity should be considered when performing a risk assessment. PAHs are a large group of substances of which the mechanisms of toxicity are comparable. Therefore, the risk assessment for every environmental compartment should be based on concentration addition for every PAH determined and not on a single PAH like phenanthrene alone.

9 Conclusions

In this report, the risk limits Negligible Concentration (NC), Maximum Permissible Concentration (MPC), Maximum Acceptable Concentration for ecosystems (MAC_{eco}), and Serious Risk Concentration for ecosystems (SRC_{eco}) are derived for phenanthrene in water, groundwater, sediment and soil. The MPC for water and suspended matter are higher than the current valid ERLs. The MPC for sediment is also higher than the current valid ERL. These differences are due to a more extensive dataset on ecotoxicology in combination with the more recent methodology for derivation of ERLs. Monitoring data suggests that currently the NC_{water} derived in this report will be exceeded in the Dutch surface waters. Also, the $MPC_{sediment}$ could be exceeded in some cases and the $NC_{sediment}$ is likely to be exceeded in many cases. Besides that, it should be mentioned that phenanthrene will not occur on its own but as part of the mixture of PAHs. For a substance group like PAHs, additive effects (mixture toxicity) should not be ruled out and the total group of PAHs should be assessed by application of concentration addition, at least for ecotoxic effects. The ERLs that were obtained are summarised in the table below. For the soil compartment, it can be concluded that the NC_{soil} will be exceeded in many cases, including soils with a relatively low exposure to PAHs.

Table 12. Derived MPC, NC, MAC_{eco}, and SRC_{eco} values for phenanthrene

ERL	**unit**	**value**			
		MPC	**NC**	**MAC_{eco}**	**SRC_{eco}**
freshwater [a]	$\mu g.L^{-1}$	1.1	1.1 x10^{-2}	6.7	43
freshwater susp. matter [b]	$mg.kg_{dwt}^{-1}$	2.5			
drinking water human health [c]	$mg.L^{-1}$	0.14			
saltwater	$\mu g.L^{-1}$	1.1	1.1 x10^{-2}	6.7	43
saltwater susp. matter	$mg.kg_{dwt}^{-1}$	2.5			
freshwater sediment [d]	$mg.kg_{dwt}^{-1}$	0.78	7.8 x10^{-3}		63
saltwater sediment [d]	$mg.kg_{dwt}^{-1}$	0.78	7.8 x10^{-3}		63
soil [e]	$mg.kg_{dwt}^{-1}$	1.9	1.9 x10^{-2}		90
groundwater	$\mu g.L^{-1}$	1.1	1.1 x10^{-2}		43
air	$mg.m^{-3}$	n.d.			

[a] From the $MPC_{fw, eco}$, $MPC_{fw, secpois}$ and $MPC_{fw, hh food}$ the lowest one is selected as the 'overall' MPC_{water}.
[b] Expressed on the basis of Dutch standard suspended matter.
[c] As stated in the new WFD guidance, the $MPC_{dw, hh}$ is not included in the selection of the final MPC_{fw}. Therefore, the $MPC_{dw, hh}$ is presented as a separate value.
[d] Expressed on the basis of Dutch standard sediment.
[e] Expressed on the basis of Dutch standard soil.
n.d. = not derived.

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Appendix 1 Detailed BCF data

Table A1.1. Bioconcentration factors for phenanthrene adopted from RIVM report 601779002 (Bleeker and Verbruggen, 2009)

Species	Species properties	Purity	Analysis	Test type	Test water	pH	Hardness/ Salinity	Temp.	Exposure time	Exp. concn.	lipid content	Uptake rate constant	Depuration rate constant	BCF	BCF type	Norm. BCF	Method	Ri	Notes	Ref
		[%]					[g.L^{-1}]	[°C]	[d]	[µg.L^{-1}]	[%]	[h^{-1}]		[L.kg$_{ww}^{-1}$]		[L.kg$_{ww}^{-1}$]				
Algae																				
Chlorella fusca				S										1760	wet weight		equi.	3	22	Geyer et al. (1984)
Pseudokirchneriella subcapitata				S										10620	wet weight		equi.	3	22	Casserly et al. (1983)
Pseudokirchneriella subcapitata			C14	S										4.22 – 4.47	dry weight		equi.	3	22,25	Halling-Sørensen et al. (2000)
Thalassiosira pseudonana			C14	S										17	dry weight		equi.	3	22,25	Fan and Reinfelder (2003)
Thalassiosira pseudonana			C14	S										38.3	dry weight		equi.	3	22,25	Fan and Reinfelder (2003)
Macrophyta																				
Lemna gibba		>95	C14	S					3+1	25	-	18.4	0.268	69	whole plant	-	kinetic	2	1	Duxbury et al. (1997)
Lemna gibba		>95	C14	S					3+1	25	-	8.66	0.35	25	whole plant	-	kinetic	2	1	Duxbury et al. (1997)
Lemna gibba		>95	C14	S					3+1	25	-	6.55	0.453	14	whole plant	-	kinetic	2	1	Duxbury et al. (1997)
Lemna gibba		>95	C14	S					3+1	35	-	19.6	0.212	92	whole plant	-	kinetic	2	1	Duxbury et al. (1997)
Lemna gibba		>95	C14	S					3+1	35	-	9.55	0.314	30	whole plant	-	kinetic	2	1	Duxbury et al. (1997)
Lemna gibba		>95	C14	S					3+1	35	-	6.09	0.546	11	whole plant	-	kinetic	2	1	Duxbury et al. (1997)
Mollusca																				
Modiola modiolus				S										3.1	wet weight		equi.	3	20	Palmork and Solbakken (19981)
Mya arenaria			HPLC	F				10	4+14	4.3±0.4	-	0.0064	8.2	1280	whole animal	-	kinetic	1	1	McLeese and Burridge (1987)
Mytilus edulis			HPLC	F				10	4+14	4.3±0.4	-	0.013	16.1	1240	whole animal	-	kinetic	1	1	McLeese and Burridge (1987)
Mytilus edulis				F										2932	wet weight		equi.	4	26	Baussant et al. (2001a)
Mytilus galloprovincialis	field collected	HPLCgrade	flu	R	nw		22‰	22	7d	100	-			100	whole animal	-	equi.	3	13	Okay and Karacik (2008)
Mytilus galloprovincialis	field collected	HPLCgrade	flu	R	nw		22‰	22	7d	400	-			279	whole animal	-	equi.	3	13	Okay and Karacik (2008)
Rangia cuneata														240	wet weight		kinetic	3	21	Neff et al. (1976)
Annelida																				
Capitella capitata				F										30.7	wet weight		equi.	4	28	Lu et al. (1977)
Lumriculus variegatus				S										34700	lipid weight		equi.	3	23	Jonker and Van der Heijden (2007)
Nereis virens			HPLC	F				10	4+14	4.3±0.4	-	3	0.006	500	whole animal	-	kinetic	2	1	McLeese and Burridge (1987)
Stylodrilus heringianus		>98	C14	F				4	0.25+8	-	-	94.0±12.9	0.018±0.003	5222	whole animal	-	kinetic	2	1	Frank et al. (1986)

Species	Species properties	Purity	Analysis	Test type	Test water	pH	Hardness/ Salinity	Temp.	Exposure time	Exp. concn.	lipid content	Uptake rate constant	Depuration rate constant	BCF	BCF type	Norm. BCF	Method	Ri	Notes	Ref
		[%]					[g.L^{-1}]	[°C]	[d]	[µg.L^{-1}]	[%]	[h^{-1}]		[L.kg$_{ww}^{-1}$]		[L.kg$_{ww}^{-1}$]				
Crustacea																				
Asellus aquaticus				S										1300	wet weight		equi.	3	22	Van Hattum and Cid Montanes (1999)
Crangon septemspinosa			HPLC	F				10	4+14	4.3±0.4	-	6.8	0.032	210	whole animal	-	kinetic	1	1	McLeese and Burridge (1987)
Daphnia magna	< 24h		HPLC	R				23±1	1	40.1	-			324	whole animal	-	equi.	2	1	Newsted and Giesy (1987)
Daphnia magna			C14	S										600	wet weight		equi.	4	27	Eastmond et al. (1984)
Daphnia pulex			C14											1165-1424	wet weight		equi.	4	27,29	Trucco et al. (1983)
Daphnia pulex			flu.	S				25	1	30	-			325	whole animal	-	equi.	2	1	Southworth et al.(1978)
Diporeira sp.	juvenile 5-11 months	>98	C14	R				4	28+nr	57.1	-	62.5±12.8	0.006±0.002	10417	whole animal	-	kinetic	2	1	Landrum et al. (2003)
Diporeira sp.	juvenile 5-11 months	>98	C14	R				4	28+nr	104.6	-	79.4±23.2	0.009±0.003	8822	whole animal	-	kinetic	2	1	Landrum et al. (2003)
Diporeira sp.	juvenile 5-11 months	>98	C14	R				4	28+nr	214.4	-	57.2±11.3	0.005±0.001	11440	whole animal	-	kinetic	2	1	Landrum et al. (2003)
Diporeira sp.	juvenile 5-11 months	>98	C14	R				4	28+nr	383	-	51.9±20.2	0.005±0.0042	10380	whole animal	-	kinetic	2	1	Landrum et al. (2003)
Diporeira sp.	juvenile 5-11 months	>98	C14	R				4	28+nr	637.8	-	44.1±9.4	0.008±0.003	5513	whole animal	-	kinetic	2	1	Landrum et al. (2003)
Eurytemora affinis			GC/MS	CF	nw/dw		15	10	3.6	0.06	-			530	whole animal	-	equi.	2	1,12	Cailleaud et al. (2009)
Hyalella azteca			C14	R										440-504	wet weight		equi.	4	27,29	Lee et al. (2002)
Pontoporeia hoyi		>98	C14	F				4	0.25+14	0.07-7.1	9.4	129.0±31	0.0046±0.0027	28043	whole animal	14893	kinetic	1	2	Landrum (1988)
Insecta																				
Hexagenia limbata		>98	C14	F				10	0.25+14	0.07-7.1	7.8±1.9	131.1±46.8	0.032±0.004	4097	whole animal	2626	kinetic	2	1	Landrum and Poore (1988)
Hexagenia limbata		>98	C14	F				15	0.25+14	0.07-7.1	15.1±2.6	43.3±12.0	0.0076±0.0016	5697	whole animal	1880	kinetic	2	1	Landrum and Poore (1988)
Hexagenia limbata		>98	C14	F				15	0.25+14	0.07-7.1	9.1±3.4	57.5±5.0	0.029±0.002	1983	whole animal	1090	kinetic	2	1	Landrum and Poore (1988)
Hexagenia limbata		>98	C14	F				20	0.25+14	0.07-7.1	6±2.4	56.3±6.8	0.032±0.004	1759	whole animal	1466	kinetic	2	1	Landrum and Poore (1988)
Hexagenia limbata		>98	C14	F				20	0.25+14	0.07-7.1	3.7±1.2	33.0±8.0	0.067±0.008	493	whole animal	666	kinetic	2	1	Landrum and Poore (1988)
Hexagenia limbata		>98	C14	F				10	0.25+14	0.07-7.1	6±1.4	34.2±7.2	0.026±0.002	1315	whole animal	1096	kinetic	2	1	Landrum and Poore (1988)
Pisces																				
Brachidanio rerio				S										11446	wet weight		kinetic	3	14	Djomo et al. (1996)
Brachidanio rerio				R										7943-9120	dry weight		equi.	3	15	Petersen and Kristensen (1998)
Culpea harengus				R										20893	dry weight		equi.	3	15	Petersen and Kristensen (1998)
Cyprinodon variegatus	2.5±1.2 g, 4.7±0.8 cm		GC-MS	CF	sw		34	25	36+8	0.12±0.030		680	0.84	810	whole fish ww	418	kinetic	2	3	Jonsson et al. (2004)
Cyprinodon variegatus	2.5±1.2 g, 4.7±0.8 cm		GC-MS	CF	sw		34	25	36+8	0.12±0.030	9.7			8351	whole fish lw	418	kinetic	2	3	Jonsson et al. (2004)
Cyprinodon variegatus	2.5±1.2 g, 4.7±0.8 cm		GC-MS	CF	sw		34	25	36+8	1.12±0.32		1783	0.8	2229	whole fish ww	1149	kinetic	2		Jonsson et al. (2004)
Cyprinodon variegatus	2.5±1.2 g, 4.7±0.8 cm		GC-MS	CF	sw		34	25	36+8	1.12±0.32	9.7			22977	whole fish lw	1149	kinetic	2		Jonsson et al. (2004)
Cyprinodon variegatus	2.5±1.2 g, 4.7±0.8 cm		GC-MS	CF	sw		34	25	36+8	0.12±0.030				700	whole fish ww	361	equi.	2	3,9	Jonsson et al. (2004)
Cyprinodon variegatus	2.5±1.2 g, 4.7±0.8 cm		GC-MS	CF	sw		34	25	36+8	1.12±0.32				1623	whole fish ww	837	equi.	2	9	Jonsson et al. (2004)
Gadus morhua				R										10715	dry weight		equi.	3	15	Petersen and Kristensen (1998)
Leuciscus idus melanotus				S										1760	wet weight		equi.	3	16	Freitag et al. (1985)
Oncorhynchus mykiss				D										613	wet weight		kin	4	25	Niimi and Palazzo (1986)
Oryzias javanicus				F										150	wet weight		equi.	3	17	Cheikyula et al. (2008)
Pagrus major				F										180	wet weight		equi.	3	17	Cheikyula et al. (2008)
Pagrus major				F										173, 737	values for different tissues		equi.	3	17,18	Cheikyula et al. (2008)

Species	Species properties	Purity [%]	Analysis	Test type	Test water	pH	Hardness/ Salinity [g.L^{-1}]	Temp. [°C]	Exposure time [d]	Exp. concn. [µg.L^{-1}]	lipid content [%]	Uptake rate constant [h^{-1}]	Depuration rate constant	BCF [L.kg$_{ww}^{-1}$]	BCF type	Norm. BCF [L.kg$_{ww}^{-1}$]	Method	Ri	Notes	Ref
Parlychthys olivaceus				F										75	wet weight		equi.	3	17	Cheikyula et al. (2008)
Parlychthys olivaceus				F										10, 181	values for different tissues		equi.	3	17,18	Cheikyula et al. (2008)
Pimephales promelas	5-6 w, 4.8% lipid		GC-PID	(C)F	nw			24±1	28+5	2.63±0.83	4.8			1733	whole fish ww	1805	kinetic	2	4,5,10	Carlson et al. (1979)
Pimephales promelas	5-6 w, 3.8% lipid		GC-PID	(C)F	nw			24±1	28+5	2.55±0.44	3.8			3611	whole fish ww	4751	kinetic	2	4,10	Carlson et al. (1979)
Pimephales promelas	5-6 w, 4.1% lipid		GC-PID	(C)F	nw			24±1	28+5	2.53±0.44	4.1			2086	whole fish ww	2544	kinetic	2	4,6,10	Carlson et al. (1979)
Pimephales promelas	5-6 w, 4.3% lipid		GC-PID	(C)F	nw			24±1	28+5	2.34±0.54	4.3			2084	whole fish ww	2423	kinetic	2	4,10	Carlson et al. (1979)
Pimephales promelas	5-6 w, 4.4% lipid		GC-PID	(C)F	nw			24±1	28+5	2.20±0.25	4.4			2240	whole fish ww	2546	kinetic	2	4,7,10	Carlson et al. (1979)
Pimephales promelas	0.52±0.21 g	>96	HPLC-Flu	S	tw			20±1	4	626		2000	0.3	6761	whole fish ww		kinetic	3	8,11	De Maagd (1996)
Scophthalmus maximus				F										10300	wet weight		equi.	3	19	Baussant et al. (2001a)
Scophthalmus maximus				F										936	wet weight		kinetic	3	19	Baussant et al. (2001b)
Scophthalmus maximus				R										11220	dry weight		equi.	3	15	Petersen and Kristensen (1998)

Notes

1 BCF is based on the parent compound.
2 In this study lipid content was expressed only as percentage of dry weight (35%). In addition the ratio between total wet weight and dry weight was given (0.269). For lipid normalization it was assumed that the same ratio holds for lipids, resulting in a lipid content of 9.4% based on wet weight; BCF is based on the parent compound. This species is the same as *Diporeia* sp.
3 Curve fitting not significant.
4 16:8 photoperiod; extracted with C18 solid phase; MeOH 10 µl.L^{-1}.
5 Tested together with α-naphthaflavone.
6 Tested together with 9-chlorophenanthrene.
7 Tested together with dibenzofuran, fluorene, 1methyl-phenanthrene, fluoranthene, and pyrene.
8 12:12 photoperiod; corrected for control volatilisation; recovery from fish fitted to data.
9 BCF assessed at days 4, 7 and 36.
10 Simultaneous kinetic method used.
11 Kinetic adjusted Banerjee method.
12 BCF based on dry weight.
13 BCF based on nominal concentration, highest concentration and possibly both concentrations are toxic.
14 Exposure via sediment for less than 96 h.
15 BCF values based on dry weight; early life stages used.
16 No air or food was provided; exposure 72 h.
17 Exposure to oversaturated PAH mixture.
18 BCF values in different tissues.
19 Exposure to oil, PAH concentration appears to be above water solubility.
20 Low on experimental detail, exposure concentration unclear.
21 Low on experimental detail, exposure type not reported, steady state not reached.
22 Short, static exposure; steady state unlikely.
23 Static exposure; sediment present; steady state unlikely.
24 BCF value based on dry weight and total radioactivity.
25 Exposed via diet.
26 Exposed to oil.
27 Based on total radioactivity.
28 Exposed in the field.
29 Values represent (a range of) BCF values from (a range of) different exposure concentrations.

Table A1.2. Bioaccumulation factors for phenanthrene

Species	Species properties	Analysis	Test water	pH	Hardness/ Salinity $[g.L^{-1}]$	Temp. [°C]	Exp. conc. $[ng.L^{-1}]$	lipid content [%]	BAF $[L.kg_{ww}^{-1}]$	BAF type	Norm. BAF $[L.kg_{ww}^{-1}]$	Ri	Notes	Ref
Mollusca														
Crassostrea gigas	6.94 g	GC-MS	Tokyo Bay, Japan				12.3 (9.94-15.24)	1.03	595	whole body	2887	2		Takeuchi et al. (2009)
Mercenaria stimpsoni	7.07 g	GC-MS	Tokyo Bay				12.3 (9.94	0.38	167	whole body	2202	2		Takeuchi et al. (2009)
Mytilopsis sallei	0.38 g	GC-MS	Tokyo Bay				12.3 (9.94	1.28	466	whole body	1822	2		Takeuchi et al. (2009)
Mytilus galloprovincialis	3.35 g	GC-MS	Tokyo Bay				12.3 (9.94	1.41	622	whole body	2207	2		Takeuchi et al. (2009)
Perna viridis	4.83 g	GC-MS	Tokyo Bay				12.3 (9.94	0.73	549	whole body	3762	2		Takeuchi et al. (2009)
Xenostrobus securis	0.56 g	GC-MS	Tokyo Bay				12.3 (9.94	0.83	606	whole body	3651	2		Takeuchi et al. (2009)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS fluorescence	Gulf of Rijeka, Adriatic Sea, Croatia	8.11-8.13	36.04-36.53	14.2-15.6	5		2000	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS fluorescence	Gulf of Rijeka, Adriatic Sea, Croatia	8.18	36.04-35.28	14.3-15.6	52		210	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS fluorescence	Gulf of Rijeka, Adriatic Sea, Croatia	7.99-8.07	18.05-20.60	12.8-13.5	<1		>7000	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS fluorescence	Gulf of Rijeka, Adriatic Sea, Croatia	8.18-8.19	36.11-36.90	14.2-16.0	<1		>15000	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS fluorescence	Gulf of Rijeka, Adriatic Sea, Croatia	8.01-8.18	20.80-24.20	13.1-14.2	6		3000	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS fluorescence	Gulf of Rijeka, Adriatic Sea, Croatia	8.20-8.22	36.53-37.57	14.5-16.4	5		1600	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	6.6±0.1 cm, 0.48±0.02 g_{dw}	HPLC flu.	İzmit Bay, Turkey				0.28	0.87±0.26	8100	whole body	46000	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	3.8±0.3 cm, 0.21±0.02 g_{dw}	HPLC flu.	İzmit Bay, Turkey				0.47	1.41±0.20	21000	whole body	75000	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	5.1±0.2 cm, 0.19±0.02 g_{dw}	HPLC flu.	İzmit Bay, Turkey				0.19	1.30±0.32	27000	whole body	103000	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	6.1±0.3 cm, 0.17±0.01 g_{dw}	HPLC flu.	İzmit Bay, Turkey				2.47	0.49±0.47	540	whole body	6000	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	5.6±0.3 cm, 0.20±0.03 g_{dw}	HPLC flu.	İzmit Bay, Turkey				<0.01	0.37±0.28	>320000	whole body	>4.4E6	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	4.6±0.3 cm, 0.19±0.02 g_{dw}	HPLC flu.	İzmit Bay, Turkey				<0.01	0.27±0.14	>27000	whole body	>5.0E5	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	5.1±0.4 cm, 0.18±0.02 g_{dw}	HPLC flu.	İzmit Bay, Turkey				1.31	0.64±0.21	2700	whole body	11000	3	7	Telli-Karakoc et al. (2002)
Radix ovata		GC-MS	Lake Redon, Pyrenees, Spain				~0.096			whole body	3.5E6	4	4,5	Vives et al. (2005)
Pisidium sp.		GC-MS	Lake Redon, Pyrenees, Spain				~0.096			whole body	160000	4	4,5	Vives et al. (2005)
Crustacea														
Daphnia pulicaria		GC-MS	Lake Redon, Pyrenees, Spain				~0.096			whole body	8900	4	1,5	Vives et al. (2005)
Hemigrapsus penicillatus	0.42 g	GC-MS	Tokyo Bay, Japan				12.3 (9.94-15.24)	2.76	438	whole body	793	2		Takeuchi et al. (2009)
Monoporeia affinis		HPLC flu. (water) GC-MS (biota)	Baltic Sea, Bothnian Sea		7.5±0.5	2.0±0.5	0.381±0.070	1.13	1200	whole body	5400	3	8	Nfon et al. (2008); Witt (2002)
Mysis sp.		HPLC flu. (water) GC-MS (biota)	Baltic Sea, Bothnian Sea		7.5±0.5	2.0±0.5	0.381±0.070	0.51	990	whole body	9700	3	8	Nfon et al. (2008); Witt (2002)
Saduria entomon		HPLC flu. (water) GC-MS (biota)	Baltic Sea, Bothnian Sea		7.5±0.5	2.0±0.5	0.381±0.070	0.21	200	whole body	4900	3	8	Nfon et al. (2008); Witt (2002)
Pisces														
Acanthogobius flavimanus	9.12 g	GC-MS	Tokyo Bay, Japan				12.3 (9.94-15.24)	0.3	63	whole animal	1043	2		Takeuchi et al. (2009)
Clupea harengus		HPLC flu. (water) GC-MS (biota)	Baltic Sea, Bothnian Sea		7.5±0.5	2.0±0.5	76±26	0.58	480	whole body	4100	3	8	Nfon et al. (2008); Witt (2002)
Salmo trutta	field sampled, 286±26mm, 230±58 g, 11±4 years	GC-MS	Lake Redon, Pyrenees, Spain				~0.096	1.2	110000	liver	470000	4	1,2,3,5	Vives et al. (2005)
Salvelinus namaycush siscowet	527±18 mm, 1.3±0.1 kg, 9.2±0.9 years		Lake Superior, USA				3.49±1.71	20.5	18	fillet	4.4	3	6	Burkhard and Lukasewycz (2000)

Notes

1 Lipid normalized BAF read from figure.
2 Lipid content of 4.6% is for the liver based on dry weight, the lipid content in the muscles was 3%.
3 Average water content in brown trout tissue of 74.2% used to recalculate to fresh weight BAF (not normalized).
4 Based on ratios of reported concentrations in organisms and lipid contents and the BAF for brown trout.
5 Not clear if biota and water were sampled at the same time. Water concentrations are averages over 1.5 year. Concentrations show some (possibly seasonal) variation (Vilanova et al., 2001).
6 Trout sampled in 1991, water sampled in 1986. Sampling location in Lake Superior were not the same as well.
7 Samples were collected and extracted unfiltered. Therefore, the aqueous concentrations do not represent dissolved concentrations. This may explain the variable and sometimes very high water concentrations and BAFs.
8 Biota samples collected in 1991-1993, water sampled from 1992-1998 (Witt, 2002). Water samples not exactly the same location as the biota samples. Nevertheless, water concentrations seem rather constant over time and over water. Total water concentrations monitored, but particulate organic carbon is low (~0.25 $mg.L^{-1}$).

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