National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

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RIVM Letter Report 601357009/2011
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Abstract

Environmental risk limits for benz[*a*]anthracene

RIVM has derived environmental risk limits (ERLs) for benz[*a*]anthracene. This derivation has been performed because the current ERLs have not been derived according to the current valid methodology. Benz[*a*]anthracene 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 (MPC_{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. The latter of the three routes is the most critical of these three routes and determines the overall MPC for fresh- and saltwater (0.23 nanogram per liter). The Maximum Acceptable Concentration ($MAC_{water,\ eco}$), that protects the ecosystem from effects of short term concentration peaks, is 0.1 microgram per liter for freshwater and 0.01 microgram per liter for saltwater.

The newly derived ERLs for water and suspended matter are lower than the currently valid ERLs. This can be explained by the fact that the risk through exposure of humans by consumption of fish and exposure of birds and mammals by consumption of water animals have been considered for these new ERLs. Monitoring data indicate that the new MPC and MAC_{eco} for water, suspended matter and sediment are being exceeded. In this observation, mixture toxicity for the total of PAHs has not been included.

Keywords:
environmental quality standard, benz[*a*]anthracene, maximum permissible concentration, negligible concentration

Rapport in het kort

Milieurisicogrenzen voor benz[*a*]antraceen

Het RIVM heeft in opdracht van het ministerie van Infrastructuur en Milieu (I&M), milieurisicogrenzen voor benz[*a*]antraceen bepaald. Dit was nodig omdat de huidige norm voor benz[*a*]antraceen voor waterkwaliteit niet is afgeleid volgens de meest recente methodiek. Benz[*a*]antraceen 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 deze 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 visserijproducten. De laatste van de drie levert de laagste waarde en bepaalt daarmee het MTR voor zoet- en zoutwater (0,23 nanogram per liter). De Maximaal Aanvaardbare Concentratie ($MAC_{water, eco}$), die het ecosysteem beschermt tegen kortdurende concentratiepieken, is 0,1 microgram per liter voor zoetwater en 0,01 microgram per liter voor zoutwater.

De nieuw afgeleide milieurisicogrenzen voor water en in water zwevend stof zijn lager dan de nu geldende milieurisicogrenzen. Dit kan direct worden verklaard doordat consumptie van waterdieren door vogels and zoogdieren en menselijke visconsumptie in de nieuwe norm zijn meegewogen. Gebaseerd op monitoringsgegevens worden de nieuwe MTR en MAC_{eco} voor water, zwevend stof en sediment naar verwachting overschreden. Bij deze beoordeling is mengseltoxiciteit voor het totaal aantal PAK's nog niet in beschouwing genomen.

Trefwoorden:
milieukwaliteitsnormen, milieurisicogrenzen, benz[*a*]anthraceen, maximaal toelaatbaar risiconiveau, verwaarloosbaar risiconiveau

Contents

Summary

Environmental risk limits are derived using ecotoxicological, physico-chemical, 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 benz[*a*]anthracene in water, groundwater, sediment, soil and air. 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 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. An overview of the derived environmental risk limits is given in Table 1. The newly derived ERLs are lower than the current valid ERLs, in which the routes secondary poisoning and fish consumption were not included.

Monitoring data suggests that currently the ERLs for water and sediment derived in this report might be exceeded in the Netherlands. For this observation, the additive mixture toxicity of all PAHs has not been taken into account.

*Table 1. Derived MPC, NC, MAC_{eco}, and SRC_{eco} values for benz[*a*]anthracene*

ERL	**unit**	**value**			
		MPC	**NC**	**MAC_{eco}**	**SRC_{eco}**
freshwater [a]	$ng.L^{-1}$	0.23	0.0023	100	3.1×10^3
freshwater susp. matter [b]	$\mu g.kg_{dwt}^{-1}$	14			
drinking water human health [c]	$ng.L^{-1}$	180			
saltwater	$ng.L^{-1}$	0.23	0.0023	10	3.1×10^3
saltwater susp. matter	$\mu g.kg_{dwt}^{-1}$	14			
freshwater sediment [d]	$\mu g.kg_{dwt}^{-1}$	350	3.5		9.1×10^4
saltwater sediment [d]	$\mu g.kg_{dwt}^{-1}$	35	0.35		9.1×10^4
soil [e]	$\mu g.kg_{dwt}^{-1}$	2.3	2.3×10^{-2}		9.1×10^4
groundwater	$ng.L^{-1}$	12	0.12		3.1×10^3
air	$ng.m^{-3}$	1.0	1.0×10^{-2}		

[a] From the $MPC_{fw, eco}$, $MPC_{fw, secpois}$ and $MPC_{fw, hf food}$,the lowest one is selected as the 'overall' MPC_{fw}.
[b] Expressed on the basis of Dutch standard suspended matter.
[c] As stated in ths 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 in this report.
[d] Expressed on the basis of Dutch standard sediment.
[e] Expressed on the basis of Dutch standard soil.
n.d. = not derived.

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 benz[*a*]anthracene. Benz[*a*]anthracene 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. Benz[*a*]anthracene 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 or 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 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 benz[*a*]anthracene are 0.03 $\mu g.L^{-1}$ for water-total, 0.01 $\mu g.L^{-1}$ for water-dissolved, 0.8 $mg.kg_{dwt}^{-1}$ for suspended matter and 0.4 $mg.kg_{dwt}^{-1}$ for sediment. The derivation of these values is reported by Kalf et al. (1995). For air there is an indicative MPC of 0.0629 $ng.m^{-3}$. Derivation of this value is described by Hansler et al. (2008).

1.3 Sources of benz[*a*]anthracene

There is no production of benz[*a*]anthracene as a pure product. Benz[*a*]anthracene, 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 benz[*a*]anthracene 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 is currently being 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

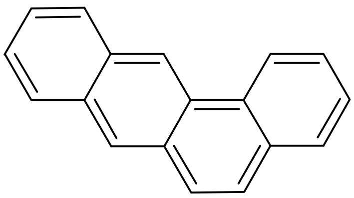

*Figure 1. Structural formula of benz[*a*]anthracene*

*Table 2. Identification of benz[*a*]anthracene*

Parameter	Name or number
Chemical name	1,2-benzanthracene
Common/trivial/other name	benz[*a*]anthracene, 1,2-benzanthracene, 2,3-benzophenanthrene, naphthanthracene, tetraphene
CAS number	56-55-3
EC number	200-280-6
Molecular formula:	$C_{18}H_{12}$
SMILES code	c12ccccc1cc3ccc4ccccc4c3c2

2.2 Physicochemical properties

*Table 3. Physicochemical properties of benz[*a*]anthracene from Verbruggen (in prep.)*

Parameter	Unit	Value	Remark
Molecular weight	[g.mol^{-1}]	228.29	
Water solubility	[µg.L^{-1}]	10.2	Geometric mean of seven values by the generator-column method
log K_{OW}	[-]	5.91	Slow-stirring method
log K_{OC}	[L.kg^{-1}]	5.70	QSAR
Vapour pressure	[Pa]	2.71 x 10^{-5}	Gas saturation method
Melting point	[°C]	160.5	
Boiling point	[°C]	438	
Henry's law constant	[Pa.m^3.mol^{-1}]	0.47	Geometric mean of two values by the gas stripping method and one by the headspace method

2.3 Bioconcentration and biomagnification

Bioconcentration data (based on lab studies) for benz[*a*]anthracene 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 (Klimisch et al., 1997) and considered reliable (Ri1 or 2). These data are supplemented with a few additional studies from the public literature which were not taken up in Bleeker and Verbruggen (2009) but considered reliable. A full overview of these studies is given in Appendix 1.

Table 4. Overview of bioaccumulation data for benz[a]anthracene

Parameter	Unit	Value	Remark
BCF (fish)	[$L.kg^{-1}$]	260	Not normalised to 5% lipid
BCF (crustaceans)	[$L.kg^{-1}$]	15100	Geometric mean of all BCF values for crustaceans. Only one of the BCF values has been normalized to 5% fat
BAF (molluscs)	[$L.kg^{-1}$]	32800	Geometric mean of the BAF values for molluscs.
BAF (crustacean)	[$L.kg^{-1}$]	12700	
BAF (fish)	[$L.kg^{-1}$]	12400	
BMF	[$kg.kg^{-1}$]	1	Biomagnification has not been observed (Nfon et al., 2008, Wan et al., 2007, Takeuchi et al., 2009)

BCFs are only available for fish and crustaceans. In addition, BAFs for fish are available (see Appendix 1). These BAFs (derived from field samples) suggest that the reliable BCF of 260 $L.kg^{-1}$ for the fish (derived from a laboratory study) is underestimating the BAF in the field. Furthermore, three trophic magnification studies are available in which both molluscs and/or crustaceans and fish were included. In all three studies there appeared to be a dilution with trophic level. TMF values on lipid weight basis calculated from the studies varied from 0.20 to 0.52 (0.20 in Bohai Bay, North China (Wan et al., 2007); 0.37 in the Bothnian Gulf, Baltic Sea (Nfon et al., 2008); 0.52 in Tokyo Bay (Takeuchi et al., 2009)). Because the difference between the species from these taxa is less than two trophic levels, the difference in BAF values is at most a factor of 25, but possibly much less, e.g. a factor of 4 to 8. Although the low lipid content of most organisms from the field study by Takeuchi et al. (2009) carries some extra uncertainty, it is clear that BAF values for fish caught in the field studies are higher than the BCF for fish. As precautionary values the BAF 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 BAF 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 BAFs are used when deriving the different MPCs.

The BAF for the $MPC_{water, hh food}$ is based on a human food consumption pattern. The human food consumption pattern used to determine the BAF 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 BAFs for fish, molluscs and the crustacean from the study by Takeuchi et al. (2009). The calculated BAF is 13000 $L.kg^{-1}$, based on a geometric mean value for molluscs and BAF values normalized to 5% lipids. It should be noted that this approach is not the most conservative. A person having an equal daily consumption of molluscs only might not be protected by this BAF. On the other hand, the derivation of the $MPC_{water, hh food}$ is already very precautionary for the general Dutch population, because of the relatively high daily intake (115 g fishery products) 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 BAF to calculate the $MPC_{fw, secpois}$, it is presumed that some predatory species have strong preference for one of the three groups (fish, crustaceans, molluscs) for their diet. The selected BAF for the $MPC_{fw, secpois}$ is the highest of the BCFs available for the three groups and is the geometric mean of the BCF values for molluscs which is 33000 $L.kg^{-1}$ normalised to 5% lipids.

2.4 Human toxicological threshold limits and carcinogenicity

Benz[*a*]anthracene has been classified in EU framework with the R phrases R45 and R50-53. Also, the U.S. EPA (IRIS) concluded that benz[*a*]anthracene is probably a human carcinogen. The RIVM concluded that benz[*a*]anthracene is a suspected carcinogen and has derived an human toxicological threshold limit on basis of non-threshold effects of 0.0050 $mg.kg_{bw}^{-1}.day^{-1}$. This value is based on a cancer risk of 10^{-4} per lifetime for non-treshold toxicity (Baars et al., 2001). As this risk under the WFD is reduced to 10^{-6} per lifetime (a factor of 100 lower) (Lepper, 2005, Van Vlaardingen and Verbruggen, 2007), this value should be divided by 100. Therefore, in this report a threshold limit for human health (TL_{hh}) of 0.050 $\mu g.kg_{bw}^{-1}.day^{-1}$ is used.
For inhalation toxicity no individual TCA (Tolerable Concentration in Air) is available for benz[*a*]anthracene. 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 a limit value for benzo[*a*]pyrene as an individual substance, the limit value is increased with a factor 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 benz[*a*]anthracene is set at 0.1 (Baars et al., 2001). With this value the TCA for benz[*a*]anthracene is 1 $ng.m^{-3}$.

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. Benz[a]anthracene: collected properties for comparison to MPC triggers

Parameter	Value	Unit	Method/Source
Log $K_{p,susp-water}$	4.70	[-]	$K_{OC} \times f_{OC,susp}$ [a]
BCF	13000 / 33000 [b]	[$L.kg^{-1}$]	
BMF	1	[$kg.kg^{-1}$]	
Log K_{OW}	5.91	[-]	
R-phrases	45, 50-53	[-]	
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 BAF 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.

- benz[*a*]anthracene has a log $K_{p, susp-water}$ > 3; derivation of $MPC_{sediment}$ is triggered.
- benz[*a*]anthracene has a log $K_{p, susp-water}$ > 3; expression of the MPC_{water} as $MPC_{susp, water}$ is required.
- benz[*a*]anthracene has BCFs and BAFs > 100 $L.kg^{-1}$; assessment of secondary poisoning is triggered.

- benz[*a*]anthracene is suspected or probably carcinogenic, therefore, an MPC_{water} for human health via food (fish) consumption ($MPC_{water,\ hh\ food}$) should be derived.

3 Toxicity data and derivation of ERLs for water

3.1 Toxicity data

The selected freshwater toxicity data for benz[*a*]anthracene as reported by Verbruggen (in prep.) are given in Table 6. For the marine environment no reliable toxicity data are available. In addition to the data in Table 6, a study with fathead minnows (*Pimephales promelas*) is presented in which the median lethal time was determined. Larvae were exposed to measured concentrations of 1.8 μg.L^{-1} benz[*a*]anthracene for an incubation period of 120 h. The median lethal time was 65 h, which means that more than 50% mortality occurred in the test period of 120 h.

Table 6. Benz[a]anthracene: 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})**
Algea		**Algea**	
Pseudokirchneriella subcapitata	1.2		
Scenedesmus vacuolatus	8.0	*Scenedesmus vacuolatus*	14
		Crustacea	
		Daphnia pulex	10

3.1.1 *Mesocosm studies*

No mesocosm studies are available.

3.2 Treatment of fresh- and saltwater toxicity data

There are no valid marine toxicity data, therefore ERLs for the marine environment will be based on freshwater toxicity data.

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.).
The determination of the lethal time for *Pimephales promelas* is an acute fish toxicity study, which completes the base-set, although no LC_{50} can be derived from the study. Chronic toxicity data are available for algae and crustaceans. Fish are possibly the most sensitive species of the base-set in acute toxicity tests. Therefore, an assessment factor of 100 should be applied to derive the $MPC_{fw, eco}$ from the lowest chronic toxicity value. The lowest NOEC or EC_{10} is the EC_{10} of 1.2 μg.L^{-1} for *Pseudokirchneriella subcapitata*. The $MPC_{fw, eco}$ for fresh water is 0.012 μg.L^{-1}. Because no studies with additional marine species are available, the $MPC_{sw, eco}$ is derived by applying an assessment factor of 1000. The $MPC_{sw, eco}$ is 0.0012 μg.L^{-1}.

The final $MPC_{fw, eco}$ is 12 ng.L^{-1} and the final $MPC_{sw, eco}$ is 1.2 ng.L^{-1}.

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

Benz[*a*]anthracene has BCFs > 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 relevant studies with population relevant endpoints for mammals and birds could be found. Also the EPA ECOTOX database does not contain NOELs for birds and mammals.

Considering the fact that benz[*a*]anthracene is a suspected carcinogen and that the risk of the MPR is reduced to 10^{-6} per lifetime, the $MPC_{water, hh food}$ should be much more protective than the MPCs for secondary poisoning. Therefore, derivation of the $MPC_{fw, secpois}$ and $MPC_{sw, secpois}$ is not deemed necessary.

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

Derivation of $MPC_{water, hh food}$ for benz[*a*]anthracene is triggered (Table 5). This derivation is based on the TL_{hh} of 0.050 µg.kg_{bw}^{-1}.day^{-1}. $MPC_{hh, food}$ = 0.1 * 0.050*70/0.115 = 3.0 µg.kg_{food}^{-1}. The resulting $MPC_{water, hh food}$ is then: 3.0 / 13000 = 0.23 ng.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 $MPCf_{w/sw}$ derived. Therefore the MPC_{fw} and the MPC_{sw} are 0.23 ng.L^{-1}

Benz[*a*]anthracene 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 5.7 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 58940 L.kg^{-1}. With this value the $MPC_{susp, fw}$ and the $MPC_{susp, sw}$ are 14 µg.kg_{dwt}^{-1}.

3.4 Derivation of $MPC_{dw, hh}$

No A1 value and DW standard are available for benz[*a*]anthracene. With the TL_{hh} of 0.050 µg.$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 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 0.050 x 70 / 2 = 0.18 µg.L^{-1}.

3.5 Derivation of MAC_{eco}

The following derivation of the MAC_{eco} originates from Verbruggen (in prep.). Two acute EC50s have been selected. However, from other non valid acute toxicity studies, it is clear that for fish and daphnids acute toxic effects due to phototoxicity occur at concentrations that lie in the same range as the chronic effects, which is about one order of magnitude below the selected acute toxicity data. Phototoxicity can be considered as a very sensitive acute effect. An assessment factor of 100 on the lowest selected acute value seems to be protective for the phototoxic effects on fish and daphnids as well. The $MAC_{fw, eco}$ then becomes 0.10 µg.L^{-1}. Because there are no reliable marine data, an additional factor of 10 is applied. The resulting $MAC_{sw, eco}$ is 10 ng.L^{-1}.

3.6 Derivation of NC

Negligible concentrations are derived by dividing the MPCs by a factor 100. This gives an NC_{fw} and an NC_{sw} of 0.0023 ng.L^{-1}.

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

The following derivation of the $SRC_{water,\ eco}$ is cited from Verbruggen (in prep.). The value of the $SRC_{fw,\ eco}$ could be taken equal to the geometric mean of the two available NOECs and is 3.1 μg.L^{-1}. The $SRC_{fw,\ eco}$ should represent the HC_{50}. With fish probably being the most sensitive taxonomic group and crustaceans showing no effects up to (almost) the water solubility, the geometric mean of the two algae species seems a good representative for the HC_{50}.

The final $SRC_{water,\ eco}$ is 3.1 μg.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 $MPC_{fw,\ eco}$ for benz[*a*]anthracene of 0.050 μg.L^{-1} was calculated after application of an assessment factor of 5 to the HC_5. The HC_{50} of 2.8 μg.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 benz[*a*]anthracene as reported by Verbruggen (in prep.) is given in Table 7. These values are recalculated to standard sediment with 10% organic matter.

*Table 7. Benz[*a*]anthracene: selected chronic sediment toxicity data for ERL derivation*

Chronic Taxonomic group	**NOEC/EC$_{10}$ (mg.kg$_{dwt}^{-1}$)**
Crustacea	
Rhepoxynius abronius	≥ 64

4.2 Derivation of MPC$_{sediment}$

The following derivation of the MPC$_{sediment}$ is cited from Verbruggen (in prep.). The only available study with benthic organisms is a 10-d study with the marine crustacean *Rhepoxynius abronius* (Boese et al., 1998). No effects on reburial and mortality were observed up to concentrations of 64 mg.kg$_{dwt}^{-1}$, normalized to Dutch standard sediment with 10% organic matter. Therefore, the ERLs are derived by means of equilibrium partitioning. The MPC$_{sediment, fw}$ is 0.35 mg.kg$_{dwt-}^{1}$ for standard sediment. The MPC$_{sediment, sw}$, is a factor of 10 lower, 0.035 mg.kg$_{dwt}^{-1}$ for standard sediment.

The final MPC$_{sediment, fw}$ is 0.35 mg.kg$_{dwt}^{-1}$ for standard sediment and the final MPC$_{sediment, sw}$ is 0.035 mg.kg$_{dwt}^{-1}$ for standard sediment.

4.3 Derivation of NC$_{sediment}$

The NC$_{sediment, fw}$ is set a factor of 100 lower than the MPC$_{sediment, fw}$ at 3.5 µg.kg$_{dwt}^{-1}$ for standard sediment. The NC$_{sediment, sw}$ is 0.35 µg.kg$_{dwt}^{-1}$ for standard sediment.

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

Verbruggen (in prep.) derived an SRC$_{sediment, eco}$ of 91 mg.kg$_{dwt}^{-1}$ for standard sediment based on equilibrium partitioning.

The final SRC$_{sediment, eco}$: 91 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 1.5 mg.kg $_{dwt}^{-1}$ after application of an assessment factor of 5 to the HC$_5$. The HC$_{50}$ of 84 mg.kg $_{dwt}^{-1}$ was taken over as the SRC$_{sediment, fw}$. 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 benz[*a*]anthracene as reported by Verbruggen (in prep.) is given in Table 8. Unbound values are not presented in this table.

*Table 8. Benz[*a*]anthracene: selected chronic soil toxicity data for ERL derivation*

Chronic Taxonomic group	**NOEC/EC_{10} ($mg.kg_{standard\ soil}^{-1}$)**
Crustacea	
Oniscus asellus	1.9 [a]

[a] Most sensitive parameter (growth of females).

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.). Toxicity tests with five terrestrial species from three taxonomic groups are available for benz[*a*]anthracene. In the tests with the pot worm *Enchytraeus crypticus* (Bleeker et al., 2003, Droge et al., 2006) and the springtails *Folsomia candida* (Bleeker et al., 2003, Droge et al., 2006) and *Folsomia fimetaria* (Sverdrup et al., 2002) no effects were observed on reproduction and survival at measured concentrations of 2400 $mg.kg_{dwt,\ standard\ soil}^{-1}$ and above, normalized to Dutch standard soil with 10% organic matter. Pore water concentrations are possibly already saturated at concentrations around 300 $mg.kg_{dwt}^{-1}$. At the levels used in the test increasing or decreasing the concentrations has no effect anymore on the uptake of the substance from pore water. Also for the isopod *Porcellio scaber*, exposed through contaminated litter (van Brummelen et al., 1996), no effects were observed up to concentrations normalized to 10% organic matter of 26 $mg.kg_{dwt,\ standard\ soil}^{-1}$. Only for the isopod *Oniscus asellus*, also exposed through contaminated litter (van Brummelen et al., 1996), significant effects were observed. The NOEC normalized to 10% organic matter was 1.0 $mg.kg_{dwt,\ standard\ soil}^{-1}$ for the growth of females. From the presented data a reliable EC_{10} can be derived as well. Taking account of loss of the substance in between renewal of the food, the EC_{10} is 1.9 $mg.kg_{dwt,\ standard\ soil}^{-1}$ and still slightly higher than the NOEC reported in the study, based on initial concentrations. This value has been selected (Table 8). There data discussed are for five species, but all species are invertebrates that can be considered as primary consumers (springtails) and decomposers. Therefore, an assessment factor of 50 should be applied in principle. However, given the fact that five species are tested and *Oniscus asellus* appears to be a very sensitive species, an assessment factor of 10 seems justified. A value of 0.19 $mg.kg_{dwt}^{-1}$ for Dutch standard soil is derived for the $MPC_{soil,\ eco}$.

The final $MPC_{soil,\ eco}$ is 0.19 $mg.kg_{dwt}^{-1}$ for standard soil.

5.2.2 $MPC_{soil,\ secpois}$

Benz[*a*]anthracene has a BCF > 100 $L.kg^{-1}$ and therefore secondary poisoning is triggered. However no relevant studies with population relevant endpoints for mammals and birds could be found. Considering the fact that benz[*a*]anthracene is a suspected carcinogen and that the Maximum Permissible Risk (MPR) is reduced to 10^{-6} per lifetime, the $MPC_{soil, hh food}$ should be much more protective than the MPC for secondary poisoning. Therefore, derivation of the $MPC_{soil, secpois}$ is not deemed necessary.

5.2.3 *$MPC_{soil, hh food}$*

For the derivation of the $MPC_{soil, hh food}$, the MPR of 0.050 $\mu g.kg_{bw}^{-1}.day^{-1}$ 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 to 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 2.3 $\mu g.kg_{dwt}^{-1}$ 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 2.3 $\mu g.kg_{dwt}^{-1}$ 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 23 $ng.kg_{dwt}^{-1}$ 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.). Of the five species tested, three showed no signs of toxicity up to concentrations that may be assumed to correspond with saturated pore water concentrations. It seems not justified to base the $SRC_{soil, eco}$ on one very sensitive species, because the $SRC_{soil, eco}$ should represent the HC_{50}. Therefore, the $SRC_{soil, eco}$ is derived from the $SRC_{water, eco}$ by equilibrium partitioning and is 91 $mg.kg_{dwt}^{-1}$ for Dutch standard soil.

The final $SRC_{soil, eco}$ is 91 $mg.kg_{dwt}^{-1}$ 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 1.5 $mg.kg_{dwt}^{-1}$, after application of an assessment factor of 5 to the HC_5. The HC_{50} of 84 $mg.kg_{dwt}^{-1}$ 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 $MPC_{gw,\ eco}$ = $MPC_{fw,\ eco}$ = 0.012 µg.L^{-1}.

6.1.2 $MPC_{gw,\ hh}$

The $MPC_{gw,\ hh}$ is set equal to the $MPC_{dw,\ hh}$: 0.18 µg.L^{-1}.

6.1.3 Selection of the MPC_{gw}

The lowest MPC_{gw} sets the MPC_{gw} this is the $MPC_{gw,\ eco}$: 0.012 µg.L^{-1}.

6.2 Derivation of NC_{gw}

The NC_{gw} is set a factor 100 lower than the MPC_{gw}: 0.12 ng.L^{-1}.

6.3 Derivation of $SRC_{gw,\ eco}$

The $SRC_{gw,\ eco}$ is set equal to the $SRC_{water,\ eco}$: 3.1 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 $MPC_{air, hh}$

The $MPC_{air, hh}$ is set by the TCA of 1 $ng.m^{-3}$ given in Section 2.4.

7.1.3 Selection of the MPC_{air}

The MPC_{air} will be determined by the only MPC_{air} derived, the $MPC_{air, hh}$: 1 $ng.m^{-3}$.

7.2 Derivation of NC_{air}

The MPC_{air} divided by 100 is the NC_{air}: 0.01 $ng.m^{-3}$.

8 Comparison of derived ERLs with monitoring data

Surface water

The RIWA (Dutch Association of River Water companies) reports monitoring data for benz[*a*]anthracene in the Rhine and Meuse basins. The concentrations for the years 2006-2010 are given in Table 9. These values cannot be directly compared with the ERLs derived in this report since they are expressed as dissolved concentrations. Presuming a concentration of suspended matter in surface water varying between 15 and 30 mg.L^{-1} and the $K_{p,\ susp\text{-}water,\ Dutch\ standard}$ given in Section 3.3.4, the fraction of the total concentration sorbed to suspended matter is 50 to 70%.The limit of quantification reported by the RIWA (0.01 µg.L^{-1}) is already higher than the MPC_{water} of 0.0012 µg.L^{-1} derived in this report. Therefore, all reported annual average concentrations exceed the MPC_{water} and in the other cases, where the concentrations were below the detection limit, it is unknown if the MPC_{water} is being exceeded. In 2010, based on the concentration of suspended matter measured at the same time, one of the maximum concentrations in the Meuse basin (at Heel) exceeds the $MAC_{fw,\ eco}$ of 0.1 µg.L^{-1} derived in this report. Considering the facts that the reported concentrations exceeding the MPC_{water} and $MAC_{fw,\ eco}$ are from recent years and the fact that the detection limit is higher than the MPC_{water}, it is likely that the new ERLs are currently being exceeded.

Table 9 Total concentrations (µg.L^{-1}) of benz[a]anthracene 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]	<	0.0277	0.3	<	<	<	<	<	0.02
Nieuwegein [a]	0.0154	0.04	<	0.0104	<	0.01	0.0175	0.03	0.0129	0.03
Nieuwersluis [b]	- [e]	-	-	-	<	<	<	0.02	<	0.02
Meuse										
Eijsden	-	<	<	<	<	0.02	-	-	-	-
Heel	<	<	<	<	<	<	<	<	0.0386	0.24
Brakel	<	<	<	<	<	<	<	<	<	<
Keizersveer	<	0.03	<	0.02	<	0.02	<	<	0.0258	0.14
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 benz[*a*]anthracene on their website (www.waterbase.nl). For the years 2001 to 2010 maximum peak values for surface water were reported up to 1.7 µg.L^{-1}. In the highest case, even with 70% of the total concentration sorbed to suspended matter, the $MAC_{fw,\ eco}$ derived in this report has been exceeded. In the other cases, whether the $MAC_{fw,\ eco}$ has been exceeded depends on the concentration of the suspended matter at that time. The $MAC_{sw,\ eco}$ has been exceeded in many occasions in marine and brackish waters even with 70% of the total concentration sorbed to suspended mater, for example Huibertsgat oost, July 2009; Haringvlietsluis, April 2005 and Terschelling, Januari 2007. For suspended matter, the average of the concentrations reported for 2008, 2009 and 2010 did exceed $MPC_{susp, fw}$ or $MPC_{susp, sw}$ for all of the 35 Dutch sampling locations.

For remote mountain lakes in the Pyrenees, alps and central Norway, dissolved water concentrations for benz[*a*]anthracene are reported ranging from 3.1 to 5.9 $pg.L^{-1}$ (Vilanova et al., 2001). In these water samples, benz[*a*]anthracene counted for about 1.0-1.4% 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 benz[*a*]anthracene ranges from 0.001 to 0.004 $ng.L^{-1}$ (OSPAR, 2005).

Sediment
For sediment, over the years 2001 to 2010 the reported concentrations exceeded the newly derived MPCs for sediment in 16 occasions. All of the other reported values exceed the newly derived NCs for sediment. Concentrations in North Sea sediment are also collected for the OSPAR convention. Actual concentrations are not report for benz[a]anthracene but in the assessment report for 2008/2009 (OSPAR, 2009b) can be seen that the concentration in all samples exceed the OSPAR "Background Assessment Concentration" of 16 $\mu g.kg_{dwt}^{-1}$ normalised to 2.5% TOC (OSPAR, 2009a). For Dutch standard sediment, this value would be comparable to the $MPC_{sediment}$ derived in this report. The trends for concentrations of benz[a]anthracene in north sea sediment over the period 2003-2007 are in general stabile and at some locations 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 benz[*a*]anthracene in the upper soil (0-0.1 m) was determined at 6 $\mu g.kg_{dwt}^{-1}$ for Dutch standard soil. This value already exceed the derived MPC_{soil} of 2.3 $\mu g.kg_{dwt}^{-1}$. For the lower soil (0.5-1.0 m) the median could not be determined. The value for the upper soil is 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 benz[*a*]anthracene, the average concentrations were 50 $\mu g.kg^{-1}$, 81 $\mu g.kg^{-1}$, 50 $\mu g.kg^{-1}$ and 52 $\mu g.kg^{-1}$ for Montseny (Spain), Pyrenees (French-Spanish border), Alps (Austria) and Tatras (Slovakia), 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 0.318 $mg.kg_{dwt}^{-1}$ and 0.264 $mg.kg_{dwt}^{-1}$ for the upper and lower soil respectively normalised to Dutch standard soil. From this and the fact that the median was already higher than the MPC_{soil}, can be concluded that the newly derived MPC_{soil} will be exceeded in many areas with a relatively low exposure of PAHs. It can also be concluded that the concentrations in remote areas are most likely not only from natural sources, application of the added risk approach is therefore not appropriate. Considering the NC_{soil}, it should be mentioned that the NC_{soil} is

much lower than the backgroundconcentrations determined by Lamé et al. (2004b) and Wilcke (2000) but since these values might not be fully caused by natural sources alone, it is unsure if the NC_{soil} is representing a system with no pollution or that it is too low.

Sum of PAHs
The observations reported above are based on the reported concentrations for benz[*a*]anthracene alone. It should be considered that benz[*a*]anthracene 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 benz[*a*]anthracene 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 benz[*a*]anthracene in water, groundwater, sediment, soil and air. The newly derived ERLs are lower than the current EQSs, due to the inclusion of the route human fish consumption. Monitoring data suggests that currently the MPC_{fw}, the $MPC_{sup, fw}$ and the $MPC_{susp, sw}$ derived in this report are exceeded in the Dutch surface waters. Also, the MPCs for sediment could be exceeded in some cases and the NCs for sediment are likely to be exceeded in many cases. Besides that, it should be mentioned that benz[*a*]anthracene 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 MPC_{soil} should be mentioned that it is comparable to the estimated background concentration, the NC_{soil} might therefore not be representative (too low) for soils with a natural exposure to PAHs.

Table 10. Derived MPC, NC, MAC_{eco}, and SRC_{eco} values for benz[a]anthracene

ERL	**unit**	**value**			
		MPC	**NC**	**MAC_{eco}**	**SRC_{eco}**
freshwater [a]	$ng.L^{-1}$	0.23	0.0023	100	3.1×10^3
freshwater susp. matter [b]	$\mu g.kg_{dwt}^{-1}$	14			
drinking water human health [c]	$ng.L^{-1}$	180			
saltwater	$ng.L^{-1}$	0.23	0.0023	10	3.1×10^3
saltwater susp. matter	$\mu g.kg_{dwt}^{-1}$	14			
freshwater sediment [d]	$\mu g.kg_{dwt}^{-1}$	350	3.5		9.1×10^4
saltwater sediment [d]	$\mu g.kg_{dwt}^{-1}$	35	0.35		9.1×10^4
soil [e]	$\mu g.kg_{dwt}^{-1}$	2.3	2.3×10^{-2}		9.1×10^4
groundwater	$ng.L^{-1}$	12	0.12		3.1×10^3
air	$ng.m^{-3}$	1.0	1.0×10^{-2}		

[a] From the $MPC_{fw, eco}$, $MPC_{fw, secpois}$ and $MPC_{fw, hf food}$,the lowest one is selected as the 'overall' MPC_{fw}.

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

[c] As stated in ths 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 in this report.

[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 benz[a]anthracene taken over from RIVM report 601779002 (Bleeker and Verbruggen, 2009). Studies for additional endpoints are indicated with a **

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
Algae																				
Chlorella fusca				S										3180	wet weight		equi.	3	18	Freitag et al. (1985)
Annelida																				
Capitella capitata														3.6	wet weight		equi.	4	16	Bayona et al. (1991)
Lumbriculus variegates				S										3090000	wet weight		equi.	3	17	Jonker and van der Heijden (2007)
Polychaete so.														9.4	wet weight		equi.	4	16	Bayona et al. (1991)
Crustacea																				
Daphnia magna	< 24 h		HPLC	R				23±1	1	1.8				10226	whole animal		equi.	2	2	Newsted and Giesy (1987)
Daphnia magna				S										2920	wet weight		kinetic	3	12	McCarthy et al. 1985
Daphnia pulex			flu.	S				25	1	6				10109±507	whole animal		equi.	2	2	Southworth et al. (1978)
Daphnia pulex			C14											803-1106	wet weight		equi.	4	14	Trucco et al. (1983)
Pontoporeia hoyi		>98	C14	F				4	0.25+14	0.62-1.11	9.4	138.6 ±26.2	0.0022 ±0.0023	63000	whole animal	33457	kinetic	1	3	Landrum (1988)
Rhepoxynius abronius				SD										2832-25465	wet weight		equi.	4	15	Boese et al. (1999)
Pisces																				
Leuciscus idus melanotus				S										350	wet weight		equi.	3	10	Freitag et al. (1985)
Oncorhynchus mykiss				D										325	wet weight		kinetic	4	13	Rantamäki (1997)
Pimephales promelas	0.52±0.21 g	95	HPLC-Flu	S	tw			20±1	4	4.5		2300	11.3	200	whole fish ww		kinetic	2	4,6,7	De Maagd (1996) *
Pimephales promelas	0.52±0.21 g	95	HPLC-Flu	S	tw			20±1	4	4.5		1600	9.3	170	whole fish ww		kinetic	2	1,4,6,7	De Maagd (1996) *
Pimephales promelas	0.42±0.18 g	95	HPLC-Flu	CF	tw			20.5±1	14+4.2	8.7±3.4 (1.7-20.8)		405	1.53	260	whole fish ww		kinetic	2	4,5,8	De Maagd et al. (1998)
Pimephales promelas	0.42±0.18 g	95	HPLC-Flu	CF	tw			20.5±1	14+4.2	8.7±3.4 (1.7-20.8)		405.45	1.53	265	whole fish ww		equi.	2	4,5,9	De Maagd et al. (1998) *
Scophthalmus maximus				F										>10000	lipid weight		equi.	3	11	Baussant et al. (2001)

Notes
1 Based on fish data only.
2 Exposure duration ≤4d, but steady state reported.

3 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.
4 12:12 photoperiod.
5 Fish loading about 0.7 g.L^{-1}.
6 Corrected for control volatilisation; recovery from fish fitted to data.
7 Kinetic adjusted Banerjee method.
8 Only kinetics of the uptake phase used.
9 Based on concentrations determined at 10, 24, 72 and 336 h.
10 No food, no aeration; exposure concentration above water solubility.
11 Exposure to oil, PAH concentration above water solubility; BCF based on lipid weight.
12 Static exposure; constant exposure unlikely.
13 Exposed via diet.
14 Based on total radioactivity.
15 Exposure via sediment.
16 Exposed in the field.
17 Static exposure; sediment present; steady state unlikely.
18 Static exposure; steady state unlikely.

Table A1.2. Bioaccumulation factors for benz[a]anthracene calculated from concentrations in field samples

Species	Species properties	Analysis	Test water	pH	Hardness / Salinity [g.L^{-1}]	Temp. [°C]	Exp. conc. [pg.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				130 (100-180)	1.03	10000	whole body	48000	2		Takeuchi et al. (2009)
Mercenaria stimpsoni	7.07 g	GC-MS	Tokyo Bay, Japan				130 (100-180)	0.38	3600	whole body	47000	2		Takeuchi et al. (2009)
Mytilopsis sallei	0.38 g	GC-MS	Tokyo Bay, Japan				130 (100-180)	1.28	8700	whole body	34000	2		Takeuchi et al. (2009)
Mytilus galloprovincialis	3.35 g	GC-MS	Tokyo Bay, Japan				130 (100-180)	1.41	10000	whole body	37000	2		Takeuchi et al. (2009)
Perna viridis	4.83 g	GC-MS	Tokyo Bay, Japan				130 (100-180)	0.73	2800	whole body	19000	2		Takeuchi et al. (2009)
Xenostrobus secures	0.56 g	GC-MS	Tokyo Bay, Japan				130 (100-180)	0.83	3700	whole body	22000	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	50000		180	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	<1000			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	48000		<2.1	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	<1000		>1400	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	24000		167	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	31000		97	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	6.6±0.1 cm, 0.48±0.02 g_{dw}	HPLC fluorescence	Izmit Bay, Turkey				<20	0.87±0.26	>9000	whole body	>52000	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	3.8±0.3 cm, 0.21±0.02 g_{dw}	HPLC fluorescence	İzmit Bay, Turkey				890	1.41±0.20	380	whole body	1400	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	5.1±0.2 cm, 0.19±0.02 g_{dw}	HPLC fluorescence	İzmit Bay, Turkey				290	1.30±0.32	4400	whole body	17000	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	6.1±0.3 cm, 0.165±0.01 g_{dw}	HPLC fluorescence	İzmit Bay, Turkey				1570	0.49±0.47	640	whole body	6500	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	5.6±0.3 cm, 0.20±0.03 g_{dw}	HPLC fluorescence	İzmit Bay, Turkey				2280	0.37±0.28	640	whole body	8700	3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	4.6±0.3 cm, 0.19±0.02 g_{dw}	HPLC fluorescence	İzmit Bay, Turkey				<20	0.27±0.14		whole body		3	7	Telli-Karakoc et al. (2002)
Mytilus galloprovincialis	5.1±0.4 cm, 0.18±0.02 g_{dw}	HPLC fluorescence	İzmit Bay, Turkey				480	0.64±0.21	35000	whole body	140000	3	7	Telli-Karakoc et al. (2002)
Radix ovata		GC-MS	Lake Redon, Pyrenees, Spain				~3			whole body	360000	4	4,5	Vives et al. (2005)
Pisidium sp.		GC-MS	Lake Redon, Pyrenees, Spain				~3			whole body	280000	4	4,5	Vives et al. (2005)
Crustacea														
Daphnia pulicaria		GC-MS	Lake Redon, Pyrenees, Spain				~3			whole body	6900	4	1,5	Vives et al. (2005)
Hemigrapsus penicillatus	0.42 g	GC-MS	Tokyo Bay, Japan				130 (100-180)	2.76	7000	whole body	13000	2		Takeuchi et al. (2009)
Monoporeia affinis		HPLC fluo (water) GC-MS (biota)	Baltic Sea, Bothnian Sea		7.5±0.5	2.0±0.5	76±26	1.13	12000	whole body	54000	3	8	Nfon et al. (2008); Witt (2002)
Mysis sp.		HPLC fluo (water) GC-MS (biota)	Baltic Sea, Bothnian Sea		7.5±0.5	2.0±0.5	76±26	0.51	130	whole body	1300	3	8	Nfon et al. (2008); Witt (2002)
Saduria entomon		HPLC fluo (water) GC-MS (biota)	Baltic Sea, Bothnian Sea		7.5±0.5	2.0±0.5	76±26	0.21	270	whole body	6400	3	8	Nfon et al. (2008); Witt (2002)
Pisces														
Acanthogobius flavimanus	9.12 g	GC-MS	Tokyo Bay, Japan				130 (100-180)	0.30	750	whole body	12000	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	180	whole body	1600	3	8	Nfon et al. (2008); Witt (2002)
Salmo trutta	286±26mm, 230±58g, 11±4years	GC-MS	Lake Redon, Pyrenees, Spain				~3	1.2	51000	liver	220000	4	1,2,3,5	Vives et al. (2005)
Salvelinus namaycush siscowet	527±18mm, 1.3±0.1kg, 9.2±0.9years		Lake Superior, USA				160±150	20.5	9550	fillet	2330	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 seems 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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