National Institute for Public Health
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RIVM Letter Report 601357008/2011
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Abstract

Environmental risk limits for chrysene

RIVM has derived environmental risk limits (ERLs) for chrysene. This derivation has been performed because the current ERLs have not been derived according to the current valid methodology. Chrysene 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 (1.2 nanogram per liter). The Maximum Acceptable Concentration ($MAC_{water,\ eco}$), that protects the ecosystem from effects of short term concentration peaks, is 0.07 microgram per liter for freshwater and 0.007 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.

Trefwoorden / Key words:
environmenal quality standard, chrysene, maximum permissible concentration, negligible concentration

Rapport in het kort

Milieurisicogrenzen voor chryseen

Het RIVM heeft in opdracht van het ministerie van Infrastructuur en Milieu (I&M), milieurisicogrenzen voor chryseen bepaald. Dit was nodig omdat de huidige norm voor chryseen voor waterkwaliteit niet is afgeleid volgens de meest recente methodiek. Chryseen 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 vis. De laatste van de drie levert de laagste waarde en bepaalt daarmee het MTR voor zoet- en zoutwater (1,2 nanogram per liter). De Maximaal Aanvaardbare Concentratie ($MAC_{water,\ eco}$), die het ecosysteem beschermt tegen kortdurende concentratiepieken, is 0,07 microgram per liter voor zoetwater en 0,007 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 / Key words:
milieukwaliteitsnormen, milieurisicogrenzen, chryseen, maximaal toelaatbaar risiconiveau, verwaarloosbaar risiconiveau

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 chrysene 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 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 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 newly derived ERLs are lower than the current EQSs, in which the routes secondary poisoning and fish consumption were not included.

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

Table 1. Derived MPC, NC, MAC_{eco}, and SRC_{eco} values for chrysene

ERL	**unit**	**value**			
		MPC	**NC**	**MAC_{eco}**	**SRC_{eco}**
freshwater [a]	$ng.L^{-1}$	1.2	1.2×10^{-2}	70	1.6×10^{3}
freshwater susp. matter [b]	$\mu g.kg_{dwt}^{-1}$	56			
drinking water human health [c]	$\mu g.L^{-1}$	1.8			
saltwater	$ng.L^{-1}$	1.2	1.2×10^{-2}	7.0	1.6×10^{3}
saltwater susp. matter	$\mu g.kg_{dwt}^{-1}$	56			
freshwater sediment [d]	$mg.kg_{dwt}^{-1}$	1.6	1.6×10^{-2}		38
saltwater sediment [d]	$mg.kg_{dwt}^{-1}$	0.16	1.6×10^{-3}		38
soil [e]	$\mu g.kg_{dwt}^{-1}$	23	0.23		38×10^{3}
groundwater	$ng.L^{-1}$	70	0.70		1.6×10^{3}
air	$ng.m^{-3}$	10	0.10		

[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 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 saltwater), soil, groundwater and air are derived for chrysene. Chrysene 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. Chrysene 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 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 chrysene are 0.9 μg.L^{-1} for water-total, 0.03 μg.L^{-1} for water-dissolved, 22 mg.kg$_{dwt}^{-1}$ for suspended matter and 11 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 0.255 ng.m^{-3}. Derivation of this value is described by Hansler et al. (2008).

1.3 Sources of chrysene

There is no production of chrysene as a pure product. Chrysene, 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 source of chrysene 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. (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

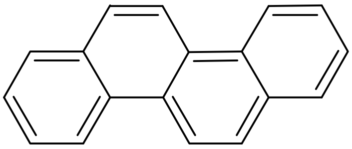

Figure 1. Structural formula of chrysene

Table 2. Identification of chrysene

Parameter	Name or number
Chemical name	Chrysene
Common/trivial/other name	Chrysene
CAS number	218-01-9
EC number	205-923-4
Molecular formula:	$C_{18}H_{12}$
SMILES code	c12ccccc1ccc3c4ccccc4ccc23

2.2 Physicochemical properties

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

Parameter	Unit	Value	Remark
Molecular weight	[g.mol^{-1}]	228.29	
Water solubility	[µg.L^{-1}]	1.61	Geometric mean of six values by the generator-column method
log K_{OW}	[-]	5.81	Slow-stirring method
log K_{OC}	[L.kg^{-1}]	5.60	QSAR
Vapour pressure	[Pa]	$2.11*10^{-6}$	Gas saturation method
Melting point	[°C]	155.5	
Boiling point	[°C]	448	
Henry's law constant	[Pa.m^3.mol^{-1}]	0.247	Geometric mean of one value by the gas stripping method and one by the headspace method

2.3 Bioconcentration and biomagnification

Bioconcentration data (based on lab studies) and bioaccumulation data (based on field studies) for chrysene 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). These data are supplemented with a few additional studies from the public literature which were published after publication of Bleeker and Verbruggen (2009) or were not considered relevant for that report. A full overview of these studies is given in Appendix 1.

Table 4. Overview of bioaccumulation data for chrysene

Parameter	Unit	Value	Remark
BCF (crustacean)	[L.kg^{-1}]	6088	Not normalized to 5% fat
BCF (fish)	[L.kg^{-1}]	13	Not normalized to 5% fat
BAF (molluscs)	[L.kg^{-1}]	145000	Geometric mean of the BAF values for molluscs.
BAF (crustacean)	[L.kg^{-1}]	30800	
BAF (fish)	[L.kg^{-1}]	21700	
BMF	[kg.kg^{-1}]	1	Default value since biomagnification has not been observed (Nfon et al., 2008, Wan et al., 2007, Takeuchi et al., 2009)

BCFs are only available for crustaceans and fish. In addition BAFs are available. These BAFs (derived from field samples) indicate that the BCFs (derived from laboratory studies) are most likely underestimating bioaccumulation in the field. For example, the BCF for fish is very low compared to the BCFs for crustacean while this difference is smaller for the BAFs. The BAF values for whole animals presented in Appendix 1 show a difference of only a factor 1.4 between crustaceans and fish. This difference does not support the observations of the lab studies in Table 4 and suggests that the low BCF for the fish is underestimating the BAF in the field. In the original report (Hooftman and Evers-de Ruiter, 1992), the low BCF value is explained by metabolism to more polar metabolites and subsequent depuration. However, given the lifestage tested (embryo-larval), this is not very likely as young fish are known to have less metabolic capacities than juvenile and adult fish. The value of 13 L.kg^{-1} should therefore be considered as an outlier.
These findings are supported by three trophic magnification studies, 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 were higly consistent (0.26 in Bohai Bay, North China (Wan et al., 2007); 0.23 in the Bothnian Gulf, Baltic Sea (Nfon et al., 2008); 0.22 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 20.
Therefore, the BAF data will be used in the calculation of the MPCs for secondary poisoning of mammals and birds (MPC$_{\text{fw, secpois}}$ and MPC$_{\text{sw, secpois}}$) and the MPC for human food consumption (MPC$_{\text{water, hh food}}$) that are triggered in Section 2.5.

When deciding which BAF should be used for calculation of the MPC$_{\text{fw, secpois}}$ MPC$_{\text{sw, secpois}}$ and the MPC$_{\text{water, hh food}}$, it should be considered that humans have a much more selective food choice (fishery products) than mammals and birds, for which diets can vary considerably amongst different species. Therefore different BAFs should be used when deriving the different MPCs.
Therefore, the BAF to be used to calculate the MPC$_{\text{water, hh food}}$ should be 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: crustacean. On the basis of this relative consumption, a weighted average is calculated from the BAFs for fish, molluscs and the crustacean that is suitable for human consumption.
The calculated BAF is: 26000 L.kg^{-1}, based on a geometric mean value for molluscs and other 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 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 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 these three groups and is the geometric mean of the BAF values for molluscs, normalized to 5% lipids, which is 145000 $L.kg^{-1}$.

2.4 Human toxicological threshold limits and carcinogenicity

Chrysene has been classified in EU framework with the R phrases R45, R68 and R50-53. The U.S. EPA (IRIS) concluded that chrysene is probably a human carcinogen. RIVM concluded that chrysene is a suspected carcinogen and has derived a human toxicological limit of 0.050 $mg.kg_{bw}^{-1}.day^{-1}$. 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 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 risk limit for human health (TL_{hh}) of 0.50 $\mu g.kg_{bw}^{-1}.day^{-1}$ is used.
For inhalation toxicity, no individual TCA (Tolerable Concentration in Air) is available for chrysene. 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 can be 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 chrysene is set at 0.01 (Baars et al., 2001). With this value the TCA for chrysene is 10 $ng.m^{-3}$.

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. Chrysene: collected properties for comparison to MPC triggers

Parameter	Value	Unit	Method/Source
Log $K_{p,susp-water}$	4.60	[-]	$K_{OC} \times f_{OC,susp}$ [a]
BCF	26000 / 145000 [b]	[$L.kg^{-1}$]	
BMF	1	[$kg.kg^{-1}$]	
Log K_{OW}	5.81	[-]	
R-phrases	45, 68, 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 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.

- chrysene has a log $K_{\mathrm{p,\ susp\text{-}water}} > 3$; derivation of $\mathrm{MPC}_{\mathrm{sediment}}$ is triggered.
- chrysene has a log $K_{\mathrm{p,\ susp\text{-}water}} > 3$; expression of the $\mathrm{MPC}_{\mathrm{water}}$ as $\mathrm{MPC}_{\mathrm{susp,\ water}}$ is required.
- chrysene has a BCF > 100 $\mathrm{L.kg^{-1}}$; assessment of secondary poisoning is triggered.
- chrysene is classified as R45 (may cause cancer, therefore, an $\mathrm{MPC}_{\mathrm{water}}$ for human health via food (fish) consumption ($\mathrm{MPC}_{\mathrm{water,\ hh\ food}}$) should be derived.

3 Toxicity data and derivation of ERLs for water

3.1 Toxicity data

The available saltwater and freshwater toxicity data for chrysene as reported by Verbruggen (in prep.) are given in Table 6 and discussed in Section 3.3.1.

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

Chronic[a] **Taxonomic group**	**NOEC/EC_{10} ($\mu g.L^{-1}$)**	**Acute[a]** **Taxonomic group**	**$L(E)C_{50}$ ($\mu g.L^{-1}$)**
		Algea	> water solubility
		Crustacea	
		Daphnia magna	0.7
		Fish	> water solubility

3.1.1 Mesocosm studies

No mesocosm studies are available.

3.2 Treatment of fresh- and saltwater toxicity data

No comparison between saltwater and freshwater could be made, because of the lack of effects in the majority of the studies. 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.).
Reliable chronic toxicity studies were performed with algae (Bisson et al., 2000), daphnids (both *Daphnia magna* (Hooftman, 1991) and *Ceriodaphnia dubia* (Bisson et al., 2000)) and fish (Hooftman and Evers-de Ruiter, 1992), but no significant effects were observed for any species in a regular toxicity experiment around or below the aqueous solubility. The only study that showed a considerable effect of chrysene, was a determination of the median lethal time for neonates of *Daphnia magna* (Newsted and Giesy, 1987). In this experiment, the daphnids were exposed to one concentration of chrysene (measured concentration of 0.7 $\mu g.L^{-1}$). The test was performed as a static-renewal acute toxicity test. After 24 hours of exposure with a 16:8 light:dark photoperiod, the animals were exposed to UV-light with an intensity of 25 ± 3 $\mu W.cm^{-2}$ UV-B (310 ± 36 nm), 120 ± 5 $\mu W.cm^{-2}$ UV-A (365 ± 36 nm), and 680 ± 10 $\mu W.cm^{-2}$ visible light (400 to 700 nm). The median lethal time after UV-radiation started was 24 hours. Thus, after 48 hours, of which the last 24 hours were with UV radiation, 50% mortality of the daphnids occurred at 0.7 $\mu g.L^{-1}$.

For marine species acute toxicity studies were performed with bacteria, annelids and crustaceans. No significant effects at or below the aqueous solubility were observed in any of these toxicity studies as well. Moreover, only one study with the luminescent bacterium species *Vibrio fischeri* can be considered as reliable (Loibner et al., 2004).
No acute toxicity data for algae and fish are available. However, for algae the EC_{10} and thus the EC_{50} for growth of *Pseudokirchneriella subcapitata* is higher than 1 $\mu g.L^{-1}$. Due to the limited solubility of chrysene, no acute effects are

expected for fish either. Besides that, an ELS study with the zebra fish *Brachydanio rerio* is available. Chronic studies were performed with algae, daphnids (two species) and fish. Therefore an assessment factor of 10 to the lowest NOEC or EC_{10} can be applied. However, no effects were observed at all, although in the test with *Ceriodaphnia dubia* the highest tested measured concentration was 0.09 $\mu g.L^{-1}$ which means that this species was not tested up to the water solubility of chrysene. The only study with a significant effect below the aqueous solubility was 50% mortality after 48 hours at 0.7 $\mu g.L^{-1}$. In this study, toxicity of chrysene was enhanced by irradiation with UV-light, although the intensity was considerably less than natural sunlight. Sunlight or UV-light comparable with sunlight was also used in the case of the lowest effect concentrations for anthracene and fluoranthene. Similar to these compounds an assessment factor of 10 is applied to the lowest effect concentration. The resulting $MPC_{fw,\ eco}$ is thus 0.07 $\mu g.L^{-1}$. No additional chronic toxicity data for typically marine species are available. Therefore, an assessment factor of 100 will be applied to derive the $MPC_{sw,\ eco}$. This $MPC_{sw,\ eco}$ thus is 0.007 $\mu g.L^{-1}$.

The final $MPC_{fw,\ eco}$ is 0.07 $\mu g.L^{-1}$ and the final $MPC_{sw,\ eco}$ is 0.007 $\mu g.L^{-1}$.

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

Chrysene 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 relevant studies with population relevant endpoints for mammals and birds could be found. The EPA ECOTOX Database does contain NOELs for birds and mammals. However, 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.

Considering the fact that chrysene is a suspected carcinogen and that the risk of the MPR is 10^{-6} per lifetime, the $MPC_{water,\ hh\ food}$ is expected to be much more protective than the MPCs for secondary poisoning based on endpoints derived with the threshold approach. 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 chrysene is triggered (Table 5). This derivation is based on the TL_{hh} of 0.50 $\mu g.kg_{bw}^{-1}.day^{-1}$. $MPC_{hh,\ food} = 0.1 * 0.50*70/0.115 =$ 30 $\mu g.kg_{food}^{-1}$. The resulting $MPC_{water,\ hh\ food}$ is then: 30 / (26000*1) = 1.2×10^{-3} $\mu g.L^{-1}$ = 1.2 $ng.L^{-1}$.

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

The MPC_{fw} and the MPC_{sw} are determined by the lowest MPC_{water} derived, this is the $MPC_{water,\ hh\ food}$. Therefore the MPC_{fw}. and the MPC_{sw} are 1.2 $ng.L^{-1}$.

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

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

For this calculation, $K_{p,susp\text{-}water,Dutch\ standard}$ is calculated from the log Koc of 5.6 as given in Table 3. With an $f_{OC,susp,\ Dutch\ standard}$ of 0.1176 the $K_{p,\ susp\text{-}water,\ Dutch\ standard}$ can be calculated to 46800 $L.kg^{-1}$. With this value the $MPC_{susp,\ fw}$ and $MPC_{susp\ sw}$ are 56 $\mu g.kg_{dwt}^{-1}$.

3.4 Derivation of $MPC_{dw, hh}$

No A1 value and DW standard are available for chrysene. With the TL_{hh} of 0.50 $\mu g.kg_{bw}^{-1}.day^{-1}$ 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 limit for human health, 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 0.50 x 70 / 2 = 1.8 $\mu g.L^{-1}$.

3.5 Derivation of MAC_{eco}

The following derivation of the MAC_{eco} originates from Verbruggen (in prep.). Because the MPC values are based on an acute study with *Daphnia* and no further information is available, the $MAC_{fw, eco}$ and $MAC_{sw, eco}$ are set equal to their corresponding MPC values: 0.07 $\mu g.L^{-1}$, and 0.007 $\mu g.L^{-1}$ respectively.

3.6 Derivation of NC

Negligible concentrations are derived by dividing the MPCs by a factor 100. This gives an NC_{fw} of 12 $pg.L^{-1}$ and an NC_{sw} of 12 $pg.L^{-1}$.

3.7 Derivation of $SRC_{water, eco}$

The following derivation of the $SRC_{water, eco}$ is cited from Verbruggen (in prep.). Because no toxicity was observed up to the solubility in chronic studies, the $SRC_{water, eco}$ is set equal to the aqueous solubility. The $SRC_{water, eco}$ thus is 1.6 $\mu g.L^{-1}$.

The final $SRC_{water, eco}$ is 1.6 $\mu g.L^{-1}$. The $SRC_{water, eco}$ is valid for the marine and the 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 0.058 $\mu g.L^{-1}$ was calculated after application of an assessment factor of 5 to the HC_5. The HC_{50} of 3.3 $\mu g.L^{-1}$ was taken over as the $SRC_{water, eco}$. These values are comparable to the derived ERLs values for freshwater.

4 Toxicity data and derivation of ERLs for sediment

4.1 Toxicity data

According to Verbruggen (in prep.) no ecotoxicity data for benthic organisms are available.

4.2 Derivation of $MPC_{sediment}$

Verbruggen (in prep.) derived the $MPC_{sediment}$ by means of equilibrium partitioning. The $MPC_{sediment,\ fw}$ is 1.6 $mg.kg_{dwt}^{-1}$ for Dutch standard sediment. For the $MPC_{sediment,\ sw}$, this number is a factor of 10 lower, 0.16 $mg.kg_{dwt}^{-1}$ for Dutch standard sediment.

The final $MPC_{sediment,\ fw}$ is 1.6 $mg.kg_{dwt}^{-1}$ for Dutch standard sediment and the final $MPC_{sediment,\ sw}$ is 0.16 $mg.kg_{dwt}^{-1}$ for Dutch standard sediment

4.3 Derivation of $NC_{sediment}$

The $NC_{sediment,\ fw}$ is set a factor of 100 lower than de $MPC_{sediment}$ at 16 $\mu g.kg_{dwt}^{-1}$ and the $MPC_{sediment,\ sw}$ at 1.6 $\mu g.kg_{dwt}^{-1}$ for Dutch standard sediment.

4.4 Derivation of $SRC_{sediment,\ eco}$

Verbruggen (in prep.) derived an $SRC_{sediment,\ eco}$ of 38 $mg.kg_{standard\ sediment}^{-1}$ by mean of equilibrium partitioning from the $SRC_{water,\ eco}$.

The final $SRC_{sediment,\ eco}$ is 38 $mg.kg_{dwt}^{-1}$ 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 1.4 $mg.kg_{dwt}^{-1}$ was calculated, after application of an assessment factor of 5 to the HC_5. The HC_{50} of 77 $mg.kg_{dwt}^{-1}$ 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

The soil toxicity data for chrysene as reported by Verbruggen (in prep.) are discussed in Section 5.2.1.

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.). For soil, two studies with three species are available. No effects were observed in a 14-d study with the earthworm *Eisenia fetida* (Bowmer et al., 1993), a 21-d study with the springtail *Folsomia candida* (Bowmer et al., 1993), and a 28-d study with the springtail *Folsomia fimetaria* (Sverdrup et al., 2002). However, pore water concentrations are possibly already saturated below 50 $mg.kg_{dwt\ standard\ soil}^{-1}$. Therefore, the ERLs are derived by means of equilibrium partitioning from the $MPC_{fw, eco}$. The $MPC_{soil, eco}$ is 1.6 $mg.kg_{dwt}^{-1}$ for Dutch standard soil.

The final MPC_{eco} for soil is 1.6 $mg.kg_{dwt}^{-1}$ for Dutch standard soil.

5.2.2 $MPC_{soil, secpois}$

Chrysene 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 chrysene is a suspected carcinogen and that the risk of the TL_{hh} is reduced to 10^{-6} per lifetime, the $MPC_{soil, hh\ food}$ is expected to 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 TL_{hh} of 0.50 $\mu g.kg_{bw}^{-1}.day^{-1}$ can be used (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 23 $\mu g.kg_{dwt}^{-1}$ 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 23 $\mu g.kg_{dwt}^{-1}$ 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 0.23 $ug.kg_{dwt}^{-1}$ for Dutch standard soil.

5.4 Derivation of $SRC_{soil, eco}$

Verbruggen (in prep.) derived the $SRC_{soil, eco}$ through equilibrium partitioning from the $SRC_{water, eco}$. The $SRC_{soil, eco}$ is 38 $mg.kg_{dwt\ soil}^{-1}$ 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 1.4 $mg.kg_{dwt}^{-1}$, after application of an assessment factor of 5 to the HC_5. The HC_{50} of 77 $mg.kg_{dwt}^{-1}$ was taken over as the $SRC_{soil,\ eco}$. Both values were normalised for Dutch standard soil. These values are comparable to the derived ecotoxicological 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 $MPC_{gw, eco} = MPC_{fw, eco} = 0.07$ μg.L^{-1}.

6.1.2 $MPC_{gw, hh}$

The $MPC_{gw, hh}$ is set equal to the $MPC_{dw, hh}$: 1.8 μg.L^{-1}.

6.1.3 Selection of the MPC_{gw}

The lowest MPC_{gw} sets the MPC_{gw} this is the $MPC_{gw, eco}$: 0.07 μg.L^{-1}.

6.2 Derivation of NC_{gw}

The NC_{gw} is set a factor 100 lower than the MPC_{gw}: 0.7 ng.L^{-1}.

6.3 Derivation of $SRC_{eco, gw}$

The $SRC_{gw, eco}$ is set equal to the $SRC_{water, eco}$: 1.6 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 10 $ng.m^{-3}$ 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 $MPC_{air, hh}$: 10 $ng.m^{-3}$.

7.2 Derivation of NC_{air}

The MPC_{air} divided by 100 is the NC_{air}: 0.1 $ng.m^{-3}$.

8 Comparison of derived ERLs with monitoring data

Surface water

The RIWA (Dutch Association of River Water companies) reports monitoring data for chrysene in the Rhine and Meuse basins. The concentrations for the years 2006-2010 are given in Table 7. 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$_{\text{p, susp-water, Dutch standard}}$ given in Section 3.3.4, the fraction of the total concentration sorbed to suspended matter is 40 to 60%. Nevertheless, the limit of quantification reported by the RIWA (0.01 µg.L^{-1}) is already higher than the MPC$_{\text{water}}$ of 0.0012 µg.L^{-1} derived in this report. Therefore, all reported annual average concentrations exceed the MPC$_{\text{water}}$ and in the other cases, where the concentrations were below the detection limit, it is unknown if the MPC$_{\text{water}}$ is being exceeded. In 2007, even with 60% of the total concentration sorbed to suspended matter, one of the maximum concentrations in the Rhine basin exceeds the MAC$_{\text{fw, eco}}$ of 0.07 µg.L^{-1} derived in this report. In the Meuse basin, based on the concentration of suspended matter measured at the same time, this occurred one times in 2010 at Heel. Considering the facts that the reported concentrations exceeding the MPC$_{\text{water}}$ and MAC$_{\text{fw, eco}}$ are from recent years and the fact that the detection limit is higher than the MPC$_{\text{water}}$, it is likely that the new ERLs are currently being exceeded.

Table 7 Total concentrations (µg.L^{-1}) of chrysene 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]	0.03	0.0515	0.49	0.0107	0.04	<	<	<	0.02
Nieuwegein [a]	0.0135	0.03	<	0.01	<	0.01	0.0137	0.02	<	0.02
Nieuwersluis [b]	<	0.02	<	0.01	<	<	<	0.02	<	0.03
Meuse										
Eijsden	- [e]	-	<	0.02	0.0123	0.03	-	-	-	-
Heel	<	<	<	<	<	<	<	<	0.0286	0.17
Brakel	<	<	<	<	<	<	<	<	<	<
Keizersveer	<	0.03	<	0.02	<	0.02	<	<	0.0254	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 chrysene on their website (www.waterbase.nl). For the years 2001 to 2010 maximum peak values for surface waters are reported up to 1.4 µg.L^{-1}. In several cases, even with 60% of the total concentration sorbed to suspended matter, the MAC$_{\text{fw, eco}}$ derived in this report has been exceeded, for example at Lobith in June 2007 and in Nederweert in December 2009 and April 2010.

Similarly, the $MAC_{sw, eco}$ has been exceeded in many occasions in marine and brackish waters, for example at Huibertsgat oost, July 2009; Haringvlietsluis, April 2005 and Lauwersoog havenmond, September 2007. For suspended matter, the average of the concentrations for almost all Dutch sampling locations reported for 2008, 2009 and 2010 do exceed the $MPC_{susp, fw}$ or $MPC_{susp, sw}$ with exception of the locations Markermeer (2008, 2009 and 2010), Pampus oost (2009 and 2010) and Vrouwenzand (2009 and 2010).

For remote mountain lakes, dissolved water concentrations for chrysene in combination with triphenylene are 21, 24 and 105 $pg.L^{-1}$ for the Pyrenees, alps and central Norway, respectively (Vilanova et al., 2001). In these water samples chrysene counted for 7 to 19% 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 chrysene and triphenylene together ranges from 0.036 to 0.057 $ng.L^{-1}$ (OSPAR, 2005).

Sediment

For sediment, over the years 2001 to 2010 the reported concentrations exceeded the new derived $MPC_{sediment, fw}$ only in one location. The $MPC_{sediment, sw}$ is also exceeded in one location. Almost all of the other reported values exceed the newly derived $NC_{sediment, fw}$ or $NC_{sediment, sw}$. Concentrations in North Sea sediment are also collected for the OSPAR convention. Actual concentrations are not report for chrysene 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 20 $\mu g.kg_{dwt}^{-1}$ normalised to 2.5% TOC (OSPAR, 2009a). Normalised to Dutch standard sediment, this value would be a factor 3 lower than the $MPC_{sediment}$ derived in this report but higher than the $NC_{sediment}$. The trends for concentrations of chrysene 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 chrysene in the upper soil (0-0.1 m) was determined at 14 $\mu g.kg_{dwt}^{-1}$ for Dutch standard soil. In the lower soil (0.5-1.0 m) the median was determined at 4 $\mu g.kg_{dwt}^{-1}$ 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 chrysene and triphenylene together, the average concentrations were 120 $\mu g.kg^{-1}$, 27 $\mu g.kg^{-1}$, 125 $\mu g.kg^{-1}$ and 176 $\mu g.kg^{-1}$ 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 0.741 $mg.kg_{dwt}^{-1}$ and 0.083 $mg.kg_{dwt}^{-1}$ for the upper and lower soil respectively normalised to Dutch standard soil. These values exceed the derived MPC value for soil. The 80% level in the upper soils was 0.029 $mg.kg_{dwt}^{-1}$ meaning that at least 20% of the uppers soil samples exceed the MPC_{soil}. In the lower soils, the 95% level of 0.024 was higher than the MPC_{soil}. From this 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 background concentrations 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 chrysene alone. It should be considered that chrysene 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 chrysene 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 chrysene in water, groundwater, sediment, soil and air. Monitoring data suggests that currently the MPC_{fw}, the MPC_{sw} the $MPC_{susp,\ fw}$ and the $MPC_{susp,\ sw}$ derived in this report are likely to be exceeded in the Dutch surface waters. The MPCs for sediment could be exceeded in some cases and the NCs for sediment are likely to be exceeded in many cases. Also, the MPC_{soil} will be exceeded in many cases including soils with a relatively low exposure to PAHs. Besides that, it should be mentioned that chrysene 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 NC_{soil} should be mentioned that it might not be representative (too low) for soils with a natural exposure to PAHs.

Table 8. Derived MPC, NC, MAC_{eco}, and SRC_{eco} values for chrysene

ERL	**unit**	**value**			
		MPC	**NC**	**MAC_{eco}**	**SRC_{eco}**
freshwater [a]	$ng.L^{-1}$	1.2	1.2×10^{-2}	70	1.6×10^{3}
freshwater susp. matter [b]	$\mu g.kg_{dwt}^{-1}$	56			
drinking water human health [c]	$\mu g.L^{-1}$	1.8			
saltwater	$ng.L^{-1}$	1.2	1.2×10^{-2}	7.0	1.6×10^{3}
saltwater susp. matter	$\mu g.kg_{dwt}^{-1}$	56			
freshwater sediment [d]	$mg.kg_{dwt}^{-1}$	1.6	1.6×10^{-2}		38
saltwater sediment [d]	$mg.kg_{dwt}^{-1}$	0.16	1.6×10^{-3}		38
soil [e]	$\mu g.kg_{dwt}^{-1}$	23	0.23		38×10^{3}
groundwater	$ng.L^{-1}$	70	0.70		1.6×10^{3}
air	$ng.m^{-3}$	10	0.10		

[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 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/BAF data

*Table A1.1. Bioconcentration factors for chrysene 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
Mollusca																				
Mytilus galloprovincialis	field collected	HPLCgr.	flu.	R	nw		22‰	22	7d	1	-			1372	whole animal	-	equi.	3	4	Okay and Karacik (2008) *
Mytilus galloprovincialis	field collected	HPLCgr.	flu.	R	nw		22‰	22	7d	1.8	-			2090	whole animal	-	equi.	3	4	Okay and Karacik (2008) *
Rangia cuneata														8.2	wet weight		equi.	3	7	Neff et al. (1976)
Annelida																				
Capitella capitata				F										6.2	wet weight		equi.	4	12	Bayona et al. (1991)
Lumbriculus variegatus				S										3020000	wet weight		equi.	3	9	Jonker and Vander Heijden (2007)
Polychaete sp.				F										14.7	wet weight		equi.	4	12	Bayona et al. (1991)
Crustacea																				
Daphnia magna	< 24 h		HPLC	R				23±1	1	0.70				6088	whole animal		equi.	2	1	Newsted and Giesy (1987)
Daphnia magna				S										5500	wet weight		equi.	4	10	Eastmond et al.(1984)
Eurytemora affinis			GC/MS	CF	nw/dw		15	10	3.6	0.06	-			950	whole animal		equi.	4	2	Cailleaud et al. (2009)
Rhepoxynius abronius				S										1141	wet weight		equi.	3	8	Chen et al. (2008)
														1560-21080	wet weight		equi.	4	11	Boese et al. (1999)
Pisces																				
Danio rerio	fertilized eggs		HPLC-flu	F	nw	7.8-8.2	204	25	42 d	0.91				13	whole animal	-	equi.	2	3	Hooftman and Evers-de Ruiter (1992) *
Oryzias javanicus				F										10	wet weight		equi.	3	5	Cheikyula et al. (2008)
Pagrus major				F										15	wet weight		equi.	3	5	Cheikyula et al. (2008)
Scophthalmus maximus				F										>10000	lipid weight		equi.	3	6	Baussant et al. (2001a)
Scophthalmus maximus				F										54	lipid weight		kinetic	3	6	Baussant et al. (2001b)

Notes

1 Exposure duration ≤ 4d, but steady state reported.
2 Concentration Factor based on dry weight.
3 Flow-through system was an intermittent flow-through system: Automatic renewal of the medium every hour.
4 BCF based on nominal concentrations, highest test concentration probably toxic.
5 Exposure concentration above water solubility.
6 Exposure to oil, PAH concentration above water solubility; BCF based on lipid weight.
7 Exposure type not reported; steady state unlikely.
8 Exposure via sediment; exposure concentration above water solubility.
9 Static exposure; sediment present; steady state unlikely.
10 Based on total radioactivity.
11 Exposure via sediment.
12 Exposed in the field.

Table A1.2. Bioaccumulation factors for chrysene calculated from concentrations in field samples

Species	Species properties	Analysis	Test water	pH	Hardness / Salinity [g.L^{-1}]	Temp. [°C]	Exp. concn. [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	GCMS	Tokyo Bay, Japan				0.1 (0.04-0.25)	1.03	36500	whole body	177000	2		Takeuchi et al. (2009)
Mercenaria stimpsoni	7.07 g	GCMS	Tokyo Bay, Japan				0.1 (0.04-0.25)	0.38	10100	whole body	133000	2		Takeuchi et al. (2009)
Mytilopsis sallei	0.38 g	GCMS	Tokyo Bay, Japan				0.1 (0.04-0.25)	1.28	26400	whole body	103000	2		Takeuchi et al. (2009)
Mytilus galloprovincialis	3.35 g	GCMS	Tokyo Bay, Japan				0.1 (0.04-0.25)	1.41	45000	whole body	160000	2		Takeuchi et al. (2009)
Perna viridis	4.83 g	GCMS	Tokyo Bay, Japan				0.1 (0.04-0.25)	0.73	24700	whole body	169000	2		Takeuchi et al. (2009)
Xenostrobus secures	0.56 g	GCMS	Tokyo Bay, Japan				0.1 (0.04-0.25)	0.83	23500	whole body	142000	2		Takeuchi et al. (2009)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS flu	Gulf of Rijeka, Adriatic Sea, Croatia	8.11-8.13	36.04-36.53	14.2-15.6	58		517	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS flu	Gulf of Rijeka, Adriatic Sea, Croatia	8.18	36.04-35.28	14.3-15.6	<1		>35000	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS flu	Gulf of Rijeka, Adriatic Sea, Croatia	7.99-8.07	18.05-20.60	12.8-13.5	16		<6.25	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS flu	Gulf of Rijeka, Adriatic Sea, Croatia	8.18-8.19	36.11-36.90	14.2-16.0	<1		>2000	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS flu	Gulf of Rijeka, Adriatic Sea, Croatia	8.01-8.18	20.80-24.20	13.1-14.2	<1		>3000	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	4-5 cm	HPLC UV-VIS flu	Gulf of Rijeka, Adriatic Sea, Croatia	8.20-8.22	36.53-37.57	14.5-16.4	32		94	whole body		3	7	Bihari et al. (2007)
Mytilus galloprovincialis	6.6±0.1cm, 0.48±0.02g$_{dw}$	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±0.3cm, 0.21±0.02g$_{dw}$	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±0.2cm, 0.19±0.02g$_{dw}$	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±0.3cm, 0.17±0.01g$_{dw}$	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±0.3cm, 0.20±0.03g$_{dw}$	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±0.3cm, 0.19±0.02g$_{dw}$	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±0.4cm, 0.18±0.02g$_{dw}$	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				~0.021			whole body	190000	4	4,5,9	Vives et al. (2005)
Pisidium sp.		GC-MS	Lake Redon, Pyrenees, Spain				~0.021			whole body	190000	4	4,5,9	Vives et al. (2005)
Crustacea														
Daphnia pulicaria		GC-MS	Lake Redon, Pyrenees, Spain				~0.021			whole body	2100	4	1,5,9	Vives et al. (2005)
Hemigrapsus penicillatus	0.42 g	GCMS	Tokyo Bay, Japan				0.1 (0.04-0.25)	2.76	17000	whole body	30800	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	0.158±0.064	1.13	39000	whole body	170000	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	0.158±0.064	0.51	1100	whole body	10000	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	0.158±0.064	0.21	870	whole body	21000	3	8	Nfon et al. (2008); Witt (2002)
Pisces														
Acanthogobius flavimanus	9.12 g	GCMS	Tokyo Bay, Japan				0.1 (0.04-0.25)	0.3	1300	whole body	21700	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	0.158±0.064	1.13	140	whole body	1200	3	8	Nfon et al. (2008); Witt (2002)

Species	Species properties	Analysis	Test water	pH	Hardness / Salinity [g.L^{-1}]	Temp. [°C]	Exp. concn. [ng.L^{-1}]	lipid content [%]	BAF [L.kg$_{ww}$$^{-1}$]	BAF type	Norm. BAF [L.kg$_{ww}$$^{-1}$]	Ri	Notes	Ref
Salmo trutta	286±26mm, 230±58g, 11±4years	GC-MS	n.a.				0.022	4.6	28704	liver	31200	3	2,4,5,9	Vives et al. (2005)
Salvelinus namaycush siscowet	527±18mm, 1.3±0.1kg, 9.2±0.9years		Lake Superior, USA				0.37±0.21	20.5	760	fillet	190	3	6,9	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}).
9 Chrysene was not separated from triphenylene.

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