RIVM report 607880006/2006

Environmental effect indicators for priority pollutants

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In the context of the projects M/607880 and M/607010, 'Chemical Substance Dispersion', this study was performed at the expense of the Netherlands Ministry of Housing, Spatial Planning and the Environment, Directorate-General for Environmental Protection, Directorate for Chemicals, Waste and Radiation.

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Rapport in het kort

Milieueffectindicatoren voor prioritaire stoffen

Dit rapport beschrijft een methode die de effecten schat van Nederlandse emissies van prioritaire stoffen op de volksgezondheid en ecosystemen. Prioritaire stoffen vormen een dusdanig gevaar voor het milieu, dat met voorrang emissiereducerende maatregelen zijn getroffen om dat gevaar te verminderen. De methode berekent zogenaamde MilieuEffectIndicatoren (MEI) en is ontwikkeld om te toetsen of de doelstellingen van het Nederlandse milieubeleid gehaald zijn.

De eerste milieueffectindicator, de MEI_{ECO}, schat het verlies van soorten organismen in het Nederlandse oppervlaktewater als gevolg van emissies van prioritaire stoffen. Uit een toetsing blijkt dat het effect van prioritaire stoffen op de soortensamenstelling in de periode 1990-2003 ongeveer is gehalveerd. Op basis van de Nederlandse emissies wordt het verlies van soorten in 1990 geschat op 3,2% en in 2003 op 1,8%. De MEI_{ECO} wordt berekend op basis van geschatte blootstelling, de gevoeligheid van soorten voor bepaalde stoffen en de giftigheid van bepaalde stofmengsels.

De tweede milieueffectindicator, de MEI_{VGZ}, schat het effect van emissies van prioritaire stoffen op de volksgezondheid. Uit een analyse van de situatie in Nederland blijkt dat de impact van de prioritaire stoffen op de volksgezondheid met ongeveer eenderde is afgenomen. Het effect wordt uitgedrukt in het verlies aan DALY's (Disability Adjusted Life Years), ofwel het aantal gezonde levensjaren dat een populatie verliest door ziekten of voortijdig overlijden. Het effect van de Nederlandse emissies wordt geschat op een verlies van 59.000 DALY in 1990 en 42.000 DALY in 2003. De MEI_{VGZ} wordt berekend op basis van geschatte blootstelling, de ziekteverwekkende eigenschappen van bepaalde stoffen en epidemiologische gegevens.

Abstract

Environmental effect indicators for priority pollutants

Here a method is described for estimating public health and ecosystem effects due to the emission of priority pollutants in the Netherlands. Priority pollutants are subject to measures of emission reduction because of their immediate threat to the environment. The method proposed calculates so-called environmental effect indicators (MEI in Dutch) and is designed to test the effectiveness of the environmental policy in the Netherlands.

The first indicator, for ecological environmental effect (MEI_{ECO}), estimates the impact of priority pollutant emissions on the relative loss of species from surface waters in the Netherlands. Evaluation of historical data reveals the impact of priority pollutants on the composition of aquatic species was to have approximately halved between 1990 and 2003. When considering only the impact of emissions originating from the Netherlands, the loss of species was estimated at 3.2% in 1990 and 1.8% in 2003. The calculation of the MEI_{ECO} is based on estimated exposure, pollutant-specific species-sensitivity distributions and considerations on mixture toxicity.

The second indicator, the public health effect indicator (MEI_{VGZ}), estimates the impact of priority pollutant emissions on the health of the Dutch population. Evaluation of historical data reveals an impact reduction of approximately one-third of the priority pollutants on public health in the Netherlands between 1990 and 2003. The impact is expressed as the loss of Disability Adjusted Life Years (DALY), which is the population loss of healthy life years due to disease and untimely death. If we consider only the emissions originating from the Netherlands, the health impact is estimated at a loss of 59,000 DALY in 1990 and 41,000 DALY in 2003. The calculation of the MEI_{VGZ} is based on estimated exposure, the pathogenic properties of priority pollutants and epidemiological considerations.

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Samenvatting

Dit rapport beschrijft methoden waarmee twee afzonderlijke Milieu Effect Indicatoren (MEI) voor Nederlandse emissies van prioritaire stoffen kunnen worden berekend. De methoden schatten de gemiddelde effecten die in Nederland respectievelijk worden verwacht op de volksgezondheid (MEI_{VGZ}) en op de biodiversiteit in ecosystemen (MEI_{ECO}). De milieueffectindicatoren vormen de derde schakel in een stelsel van milieubeleidsindicatoren, waarmee eerst het behalen van emissiedoelstellingen wordt afgemeten aan de Milieu Druk Indicator (MDI) en op de tweede plaats het behalen van milieukwaliteitsdoelstellingen in termen van concentraties wordt afgemeten aan de Milieu Kwaliteits Indicator (MKI).
De neergaande trends in de MEI-evaluatie wijzen erop dat het Nederlands milieubeleid ten aanzien van emissiereducerende maatregelen van prioritaire stoffen in de periode tussen 1990 en 2003 belangrijke successen heeft geboekt.

MEI_{ECO}

De MEI_{ECO} schat het gemiddelde relatieve verlies van soorten in Nederlandse oppervlaktewateren als gevolg van Nederlandse emissies van 48 prioritaire stoffen waarvoor op dit moment emissiegegevens beschikbaar zijn. De MEI_{ECO} is beperkt tot de effecten op waterorganismen omdat voor bodem-, land- en luchtsoorten niet voldoende gevoeligheidsgegevens bekend zijn. Echter, door de aard van de concentratieberekeningen zijn overeenkomstige effecten te verwachten in de milieucompartimenten water, waterbodem, droge bodem en lucht. De MEI_{ECO} is berekend met behulp van de gevoeligheidsverdeling van soorten (Species Sensitivity Distribution – SSD) op basis van de mediaan acuut dodelijke concentraties (EC_{50}). Door de onzekerheden in de SSD-methode en de analyse via de ruimtelijk gemiddelde blootstelling dient de MEI_{ECO} niet gebruikt worden als een absolute maat voor het werkelijke verlies aan soorten. De methode kan echter wel gebruikt worden als relatieve indicator bij prioriteitstelling en beleidsevaluaties. Het effect van prioritaire stoffen op de soortensamenstelling is in de periode tussen 1990 en 2003 ongeveer gehalveerd. Op basis van alleen de Nederlandse emissies wordt het verlies van soorten in 1990 geschat op 3,2% en in 2003 op 1,8%. Wanneer ook de Europese emissies bij de berekeningen worden betrokken neemt het geschatte verlies van soorten toe tot 4,1%in 1990 en 2,2% in 2003. Hiermee zijn de Nederlandse emissies verantwoordelijk te stellen voor ongeveer 75% van de geschatte effecten. De geschatte effecten worden in gelijke mate veroorzaakt door de emissies van koper en PAK's, en in mindere mate door de emissies van zink. De sterkste daling vindt plaats in de periode tussen 1995 en 2002. Er moet worden opgemerkt dat de hier gepresenteerde evaluatie slechts een klein deel van de potentieel aanwezige stoffen betreft. Verwacht wordt dat een uitbreiding van het aantal stoffen waarvoor emissiegegevens beschikbaar zijn slechts zal resulteren in een marginale toename van de geschatte effecten.

MEI_{VGZ}

De MEI_{VGZ} drukt het effect van emissies van prioritaire stoffen op de volksgezondheid uit in de maat 'Disability Adjusted Life Years' (DALY), ofwel het verlies aan gezondheid gewogen levensjaren voor de gehele Nederlandse populatie. De DALY weegt de mate van ongemak die wordt veroorzaakt door een aandoening, de duur van de aandoening en een eventueel te vroeg overlijden. Alhoewel de opname van milieucontaminanten op talrijke manieren plaats kan vinden (lucht, voedsel, drinkwater, huidcontact, etcetra) is de berekening van de MEI_{VGZ} gebaseerd op de landelijk mediane kwaliteit van de ingeademde buitenlucht als enige

blootstellingsroute. Deze keuze is gemaakt om nauwelijks te modelleren verschillen in locatie van voedselherkomst, voedselkeuze en drinkwaterbehandeling uit te sluiten. De MEI_{VGZ} is, door gebrek aan beschikbare data, slechts voor 11 carcinogene stoffen en voor Particulair Materiaal met een diameter tot 10 micrometer (fijn stof - PM_{10}) en ozon berekend. Door de grote onzekerheden in de DALY-methode en de analyse via de ruimtelijk gemiddelde blootstelling dient de MEI_{VGZ} niet gebruikt worden als een absolute maat voor het werkelijke verlies aan gewogen levensjaren. De methode kan echter wel gebruikt worden als relatieve indicator bij prioriteitstelling en beleidsevaluaties. De geschatte impact op de volksgezondheid van de set van stoffen is in de periode tussen 1990 en 2003 met 31% afgenomen. De belangrijkste veroorzaker van gezondheidseffecten is de emissie van PM_{10} met een effect dat wordt geschat op verlies van 86000 DALY in 2003, als de emissies in Europa en in Nederland worden samengenomen. Het effect van Nederlandse emissies wordt geschat op een verlies van 59000 tot 42000 DALY. Het aandeel van de set van carcinogene stoffen en van ozon is met een verlies van slechts 143 tot 55 DALY relatief verwaarloosbaar. Ook voor de MEI_{VGZ} wordt verwacht dat een uitbreiding van het aantal stoffen waarvoor emissies naar het buitenmilieu en gezondheidsschade bekend zijn slechts aanleiding zal geven tot een marginale toename van de geschatte effecten op de volksgezondheid.

Summary

This report describes newly developed methods to quantify two separate environmental effect indicators (MEI) for emissions of priority pollutants in the Netherlands. The methods estimate the average effects that are expected to occur on public health (MEI_{VGZ}) and on biodiversity in ecosystems (MEI_{ECO}), respectively. The MEI indicators are the third in a series of environmental policy indicators, where firstly the environmental pressure indicator (MDI) quantifies whether the emission reduction objectives are met, and where secondly the environmental quality indicator (MKI) verifies whether environmental quality standards are met.
The down-going trends in the MEI evaluations indicate that environmental policy in the Netherlands with respect to emission reduction of priority pollutants was rather successful in the period between 1990 and 2003.

MEI_{ECO}

The MEI_{ECO} estimates the average relative loss of species from surface waters in the Netherlands as a consequence of the emissions of 48 priority pollutants for which emission data were available, The MEI_{ECO} is limited to the effects on freshwater organisms, because the sensitivity patterns for soil, sediment and air exposed organisms are not sufficiently known. However, due to the fact that the predicted concentrations in different compartments are based on steady state equilibrium partitioning, the ecological effects in different compartments are expected to be about equal. The MEI_{ECO} is evaluated using Species Sensitivity Distributions (SSD) based on acute median lethal concentrations (EC50). The results of the MEI_{ECO} calculation should not be interpreted as an absolute loss of species, because of the spatial average of the exposure and the large uncertianties in the SSD-method. However, the results may be useful as an indicator in a comparative sense. Over the past 10 years, the impact on the loss of species diminished by approximately 50%. Restricted to the modeled effects caused by emissions in the Netherlands only, the loss of species is estimated to be 3.2% in 1990 and 1.8% in 2003. Including the European emissions, the estimated effects increase to 4.1% and 2.2%, respectively. The emissions in the Netherlands are considered responsible for approximately 75% of the overall effects in aquatic ecosystems. Both for isolated emissions in the Netherlands as well as the overall European emissions and for all years, the effects are mainly attributed to the emissions of copper and PAH, and to a lesser extent by the emissions of zinc. The presented evaluation is only concerned with a limited number of the toxicants that are potentially entering the environment. However, even if the number of toxicants for which emission data are available is considerably extended beyond the hard-core priority pollutants that now take part in the evaluation, it is not expected that the MEI_{ECO} would increase more than marginally.

MEI_{VGZ}

The MEI_{VGZ} expresses the public health effects as ‘Disability Adjusted Life Years’ (DALY), or in other words the loss of health weighted life years for the entire population of the Netherlands. The DALY weights the amount of discomfort caused by a disease, the duration of a disease and the life years lost by untimely death. Public exposure to environmental contaminants may be accomplished by a variety of exposure routes. The calculation of the MEI_{VGZ} is solely based on the inhalation of the Netherlands median quality of the outside air. This partial exposure was preferred to exclude hard to model differences in origin of food,

food habits and drinking water preparation processes. Due to a lack of data, the MEI_{VGZ} is calculated for the combined action of 11 carcinogenic compounds, ozone and fine particulate matter. The results of the MEI_{VGZ} calculation should not be interpreted as the absolute loss of life years, because of the spatial average of the exposure and the large uncertainties in the DALY method. However, the results may be useful as an indicator in a comparative sense. Over the years 1990 to 2003, the public health impact of the combined set of included substance emissions decreased with 31%. The major proportion of effects is modeled to be caused by the emissions of PM_{10} in Europe and the Netherlands together (loss of 86000 DALY in 2003). Restricted to the isolated emissions in the Netherlands the modeled effects diminish to approximately 50% of that (loss of 59000 to 42000 DALY). The health risk contribution caused by the emissions of the set of carcinogenic compounds and ozone (loss of 143 to 55 DALY) is relatively negligible compared to the health risk of PM_{10}. Also for the MEI_{VGZ} only a marginal increase is expected with an extension of the number of compounds for which emissions and health risk status could be quantified.

1. Introduction

Environmental policy in the Netherlands has a thematic approach. Themes recognized are:

- Climate change
- Acidification
- Eutrophication
- Toxic and hazardous substances
- Contaminated land
- Waste disposal
- Disturbance
- Groundwater depletion.

With the preparation, formulation and implementation of environmental policy, the question has risen what type of indicators we need to demonstrate the effectivity of the measures taken. To answer this question for the problem of exposure to toxicants and hazardous substances, the Directorate General for Environmental Protection from the Netherlands Ministry of Housing, Spatial Planning and the Environment identified the need to formulate a series of policy indicators to reveal progress with respect to a variety of policy targets set:

- Emission reduction targets formulated for priority pollutants require an environmental pressure indicator (Milieu Druk Indicator - MDI) to reveal whether the reductions in actual emissions meet these targets. The MDI, developed in 1999 (Van de Bovekamp et al., 1999), is considered to be the most important indicator, because it directly relates to the primary policy objective of emission reduction.
- Environmental quality standards formulated for priority pollutants require an environmental quality indicator (Milieu Kwaliteits Indicator - MKI) that verifies whether the actual concentrations measured in the environment meet these standards. The MKI, developed in 2000 (Sterkenburg et al., 2000), is considered an indicator to refine the evaluation with respect to environmental quality objectives.
- The environmental effect indicator (Milieu Effect Indicator – MEI) quantifies the effects that actually may occur in the exposed ecosystems and on public health. As such, the MEI is considered a less influential indicator that may become obsolete when the primary policy targets are about to be met.

In the present report the MEI is formulated for the effects on the ecosystem (MEI_{ECO}) and the effects on public health (MEI_{VGZ}) separately.

The goals of this study are:

1) to design and formulate methods to derive both MEI indicators,
2) to illustrate the method with real examples, evaluating the estimated effects of emission of priority pollutants for the years 1990, 1995, 2002 and 2003, and
3) to evaluate the effectivity of environmental policy in the Netherlands, with respect to the measures taken for reduction of priority pollutant emissions.

2. MEI definition: outline and choices

Derivation of any effect indicator requires a number of steps as depicted in Figure 1.

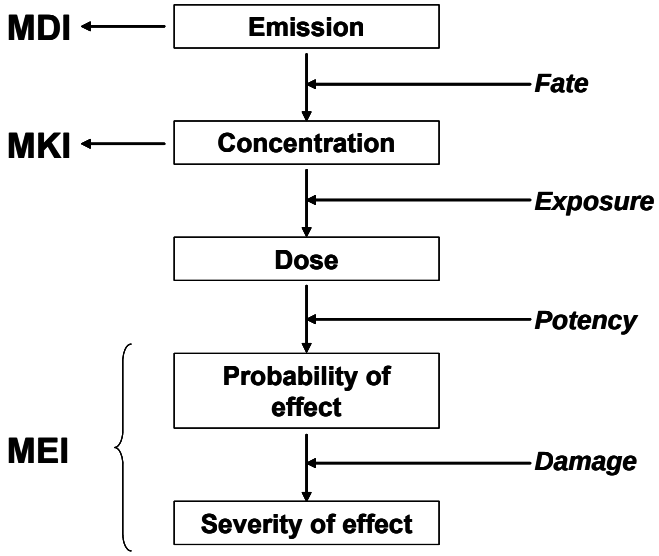

Figure 1 *Illustrative outline of stages for the calculation of characterization factors for both human health and ecosystem effects (after Krewitt et al., 2002)*

Exposure to substances in the environment may lead to effects. The impact of a substance depends on fate, exposure, the likelihood of an effect and the consequences of an effect. The likelihood of an effect is described by the toxicological potency (a quantitative measure related to the dose–response of a substance, such as the relative risk in a cohort study or an aquatic toxicity test conducted in a laboratory). The consequences of an effect can be described as toxicological severity (a measure or description, qualitative or quantitative, of the effect incurred, such as bladder cancer, skin irritation, the reproduction success or mortality observed in a test species).

In the following subchapters an overview is given of options for the different modeling steps that have to be taken to derive environmental effect indicators.

2.1 Exposure modeling

Effects of environmental contamination are generally caused by concentrations of contaminants in the environment. Due to limited availability of measured concentrations for a wide variety of priority pollutants, it was decided to base the MEI on environmental concentrations predicted from emission data. Using emission data as the primary input to the analysis allows us to separate the influence of the emissions in the Netherlands from the influence of the emissions abroad. This may be a valuable asset for the evaluation of the MEI for the effectivity of the Dutch environmental policy. Substances are emitted in the environment and spread throughout the environment where people and the ecosystem are exposed to them. The first step in the process of MEI estimation converts emissions in the

Netherlands and in the rest of Europe to national median environmental concentrations in different compartments. The concentration of the substances in various media and exposure to these substances in the various media can be estimated with fate, transport and exposure modelling.

2.2 MEI for ecosystem effects

Due to limited availability of toxicity values for soil and air exposure to toxicants, the MEI for the ecosystem (MEI_{ECO}) is restricted to quantify the effects that may occur in a generic community of freshwater organisms. The concentration predictions performed by the exposure modeling are based on principles of equilibrium partitioning (EP). If it is assumed that both water and soil organisms are mainly exposed through the water phase, EP theory dictates that the exposure of water and sediment organisms is about equal. From the limited amount of data available, it can not be concluded that soil organisms have a sensitivity pattern that is grossly different from that of water organisms. Under these assumptions, the MEI_{ECO} based on soil exposure will be similar to the MEI_{ECO} based on aquatic exposure. For ecotoxicity in water, the emissions and concentrations of Ozone and PM_{10} are not considered influential.

Given the estimates of ambient concentrations, the calculation of the MEI_{ECO} is based on pollutant-specific species-sensitivity distributions and considerations on mixture toxicity.

2.2.1 Species sensitivity distributions

Analyzing the results of the world's resources on laboratory derived toxicity observations learnt that species differ in their sensitivity towards a single chemical (Hoekstra et al., 1994; Notenboom et al., 1995; Vaal et al., 1997a; Vaal et al., 1997b; Vaal et al., 2000). This may be due to differences in life history, physiology, morphology and behavior. Without attempting to explain the cause of variability in species sensitivity, this recognition led to attempts to describe the variation with statistical distribution functions, thereby putting the concept of Species Sensitivity Distribution (SSD) into existence (Stephan et al., 1985; Van Straalen and Denneman, 1989; Posthuma et al., 2002). The basic assumption of the SSD concept is that the sensitivities of a set of species can be described by some kind of statistical distribution. Usually a parametric distribution function is applied, such as the triangular (e.g. Stephan, 1985), normal (e.g. Wagner and Løkke, 1991) or logistic distribution (e.g. Van Straalen and Denneman, 1989). Non-parametric methods are used as well (e.g. Jagoe and Newman, 1997). The available ecotoxicological data are seen as a sample from this distribution and are used to estimate the moment parameters of the SSD. The moments of the statistical distribution are used to calculate a concentration that is expected to be safe for most species of interest (e.g., the HC_5, see Figure 2), which in turn can be used to set a regulatory Environmental Quality Criterion. A more recent application is the use of SSDs in Ecological Risk Assessment of contaminated ecosystems. Since their introduction, the importance of SSDs in ecotoxicity evaluations has steadily grown until they are now used world wide. Intensive discussions have taken place on principles, statistics, assumptions, data limitations, and applications (e.g. Forbes and Forbes, 1993; Hopkin, 1993; Smith and Cairns, 1993; Chapman et al., 1998; Posthuma et al., 2002). So far, the SSD method is the only significant basis to predict toxic risks for a multitude of toxicants on natural ecosystems with multiple species, including the assessment of mixture risks.

The process of calculating toxic risk, or the Potentially Affected Fraction of species (PAF) from an SSD is depicted in Figure 2.

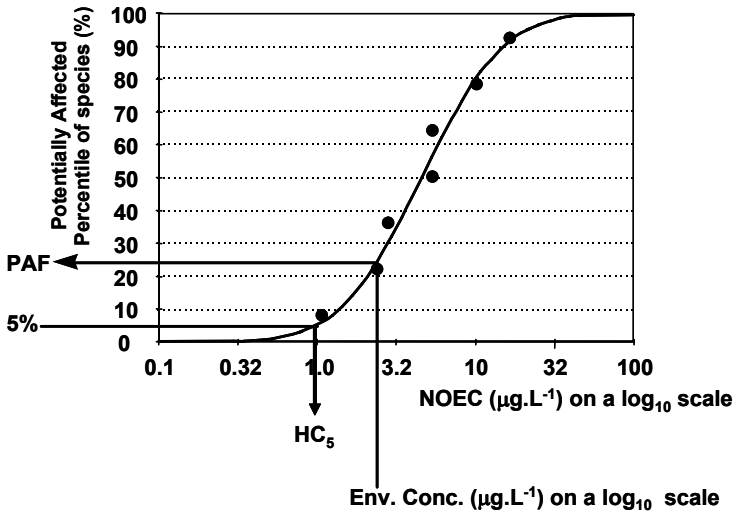

Figure 2 *Exemplary cumulative distribution function of species sensitivity fitted (curve) to observed chronic toxicity values (NOEC; dots). The arrows indicate the inference of a Potentially Affected Fraction of species (PAF-value) and the HC_5.*

2.2.2 Mixture toxicity evaluation

Methods to assess the joint action of components in a mixture of toxicants are largely based on the conceptual groundwork laid by Bliss (1939), and are mathematical rather than biological in nature. Plackett and Hewlett (1952) expanded Bliss's scheme with the possible types of interactions that can occur between chemical components of mixtures (Table 1).

Table 1 *The four possible types of joint action for mixtures as defined by Plackett and Hewlett (1952).*

	Similar Joint Action	Dissimilar Joint Action
Non-Interactive	Simple similar action (concentration addition)	Independent joint action (response addition)
Interactive	Complex similar action	Dependent joint action

For the non-interactive or independent types of joint action it is assumed that the chemicals in the mixture do not affect the toxicity of one another. Two different models are available, depending on the Toxic Modes of Action (TMoA) of the chemicals in the mixture. The modeling approach commonly known as Concentration Addition (CA) relates to Simple Similar Action (SSA), and concerns mixtures of chemicals with the same TMoA. The modeling approach called Response Addition (RA) is related to Independent Joint Action (IJA) and is used to predict the combined effect of toxicants with dissimilar TMoA. No models other than empirical observations are available for the prediction of interactive joint action (either for similar or dissimilar TMoA), where the constituents of the mixture influence each other in the expression of their toxicity.

For calculating the combined added toxic risk of the evaluated priority pollutants as the MEI_{ECO}, a mixed model is used where the combined toxicity of groups of substances with the same TMoA is first evaluated with the CA model, producing a multiple substance concentration additive Potentially Affected Fraction of species for a single TMoA ($msPAF_{TMoA}$). After this first step the risk contributions of groups of compounds with

different TMoA are combined according to the RA model, to produce a $msPAF_{Overall}$. The procedures used are detailed in De Zwart and Posthuma (2005).

2.2.3 MEI_{ECO} based on msPAF evaluation

For the MEI_{ECO}, the ecosystem effects in relation to a calculated concentrations in surface water result in effects will be quantified as the msPAF based on acute LC_{50} exceedance. This measure is considered an estimate of the proportion of species lost from the aquatic ecosystem (Posthuma and De Zwart, 2006).

Interpretation of the MEI_{ECO}

Because of the uncertainties, it should be noted that the MEI_{ECO} should be used as a relative measure for policy evaluation and priority setting only, and not as an absolute quantification of ecosystem effects.

2.3 MEI for public health effects

Human exposure to substances in the environment may lead to health effects. The human population can be exposed to substances in the environment via three different routes of exposure: the inhalation route, the oral route and, to a lesser extend, the dermal route. The focus in this study is on the direct route of exposure for priority air pollutants by inhalation of ambient air. Exposure to priority air pollutants via the oral or dermal route is not within the scope of this study because of modeling difficulties related to unpredictable regional differences in food preferences, human behavior and drinking water treatment.

2.3.1 Options for integrated health measures

Mortality rates, morbidity, healthy life expectancy, attributable burden of disease measures, and monetary valuation are common health measures as pointed out by Knol and Staatsen (2005). All methods have several associated difficulties, such as imprecision of the population exposure assessment; uncertain shapes of the exposure-response curves for the low environmental exposure levels; insufficient (quality of) epidemiological data; extrapolation from animal to man or from occupational to the general population; generalization of exposure-response relations from locally collected data for use on regional, national or global scale; combined effects in complex mixtures, etcetera.
It should be noted that comparing public health problems, whether in terms of discomfort, monetary implications or some other measure, should never be the only criterion on which to base policy. Other important factors not captured in these methods include for example solidarity and equity, and certain social impacts. However, the measures can provide valuable information as part of the whole decision making process. The following description of integrated health measures is based on Knol and Staatsen (2005).

Mortality and morbidity figures

The annual mortality risk or the number of deaths related to a certain (environment-related) disease can be compared with this risk or number in another region or country, or with data from another period in time. A serious disadvantage is that non-fatal health outcomes are not incorporated in the calculations. For non-fatal health outcomes, morbidity numbers (i.e. prevalence or incidence rates based on hospital admissions or doctor visits) can be used to evaluate a (population) health state. The mortality and morbidity rates are easy to comprehend and because everyone is treated equal, there don't seem to be ethical questions attached. But the fact that everyone is treated equal can also be considered a drawback,

because the death of young and healthy people is getting the same weight as the death of elderly or ill people. Furthermore, there is no indication of the severity of diseases. In addition, both mortality and morbidity figures are difficult to attribute to their exact causes. *Therefore, mortality and morbidity figures only reveal part of a public health problem and are not very useful for complex policy questions related to environmental health.*

Healthy life expectancy
Using mortality tables, the total average life expectancy can be calculated for different age groups in a population. This measure is especially useful to review the generic health state in a country for the long term.

However, healthy life expectancy does not give insight into specific health effects, effects of specific policy interventions, or trends in certain subgroups.

Monetary valuation
Another approach to health impact assessment is monetary valuation. In this measure, money is used as a unit to express health loss or gain, thereby facilitating the comparison of policy costs and benefits. It can help policy makers in allocating limited (health care) resources and setting priorities. There are different approaches to monetary valuation:
The *cost of illness* (COI) approach estimates the material costs related to mortality and morbidity. Costs for the whole society are included and it considers loss of income, productivity and medical costs. Immaterial costs, such as impact of disability (pain, fear) or decrease in quality of life, are not included. Therefore, this could lead to an underestimation of the health costs. Furthermore, individual preferences are not considered.
The *willingness to pay* (WTP) approach measures how much money one would be willing to pay for improvement of a certain health state or for a reduction in health risk. The *willingness to accep*t (WTA) approach measures how much money one wants to receive to accept an increased risk. WTP and WTA can be estimated by observing the individual's behavior and expenditures on related goods (revealed preference). For example, the extra amount of money people are willing to pay for safer or healthier products (e.g. cars with air bags), or the extra salary they accept for compensation of a risky occupation (De Hollander, 2004).
Another similar method is *contingent valuation* (CV), in which people are asked directly how much money they would be willing to pay (under hypothetical circumstances) for obtaining a certain benefit (e.g. clean air or good health). Advantages of these approaches are that the values represent individual preferences and include certain indefinable costs (e.g. pain, quality of life). The values also appear to be fairly stable in Western countries (De Hollander, 2004). A disadvantage is that the values are restricted to individual costs. Social costs are not incorporated. The reliability of the answers obtained in contingent valuation studies can be discussed, as people are spending 'hypothetical' money for 'hypothetical' health benefits. In addition, willingness-to-pay values have shown to be dependent on income.
Results of monetary valuation of health problems provide policy makers with crude estimations of the costs and benefits associated with certain policy decisions.

However, expressing health in terms of money is complicated and many uncertainties are involved.

Attributable burden of disease
Health impact assessments can also be executed by calculating the attributable burden of disease. The burden of disease attributable to an (environmental) factor can be expressed in QALYs and DALYs. Quality Adjusted Life Years, QALY, combines both the quality and

quantity elements of health in one indicator. Essentially, time spent in ill health (measured in years) is multiplied by a weight measuring the relative (un)desirability of the illness state. Thereby a number is obtained which represents the equivalent number of expected life years in full health. QALYs are commonly used for cost-utility analysis and to appraise different forms of health care. To do that, QALYs combine life years *gained* as a result of these health interventions/health care programs with a judgment about the quality of these gained life years.
Disability Adjusted Life Years, DALY, also combines information on quality and quantity of life in one indicator. However, contrary to QALYs, DALYs give an indication of the (potential) number of healthy life years *lost* due to premature mortality or morbidity. The DALYs are estimated for particular diseases, instead of a health state. Morbidity is weighted for the severity of the disorder. The concept was first introduced by Murray and Lopez (1996) as part of the Global Burden of Disease study, which was launched by the World Bank. Since then, the World Health Organization has endorsed the procedure, and the DALY approach has been used in various studies on a global, national and regional level.
With QALY, the focus is on assessing individual preference for different non-fatal health outcomes that might result from a specific intervention, whereas the DALY was developed primarily to compare relative burdens among different diseases and among different populations (Morrow and Bryant, 1995).

DALYs are suitable for analyzing particular disorders or specific factors that influence health.

Problems associated with the DALY approach include the difficulty of estimating the duration of the effects (which have hardly been studied) and the severity of a disease; and allowing for combined effects in the same individual (first you have symptoms, then you go to a hospital and then you may die). Therefore, there are still many disadvantages involved in these kinds of calculations, since very complex information has to be reduced to one single value.

The results should therefore be handled with care, but can be very useful with proper explanation and clear description of the uncertainties involved.

2.3.2 MEI_{VGZ} based on DALY evaluation

For the MEI_{VGZ}, the health effects in relation to a calculated concentrations in ambient air will be quantified as the population loss of healthy life years expressed in DALYs. Health effects from air pollution comprize de development of different carcinoma, aggravation of asthma, and even premature mortality. This depends on the extent of exposure and the substances to which people are exposed. Because of the divergence in magnitude, duration and severity of these health effects, the DALY method that converts all effects to a comparable unit can be very useful for the interpretation and comparison of different (environmental) health problems. This is especially useful for evaluating and comparing different policy options and assessing cost effectiveness of mitigating measures or prevention.

Interpretation of the MEI_{VGZ}

Experience with integrated health measures in environmental health decision-making is limited to the use of monetary cost estimates of health impacts, the Years of Life Lost (YLL) due to mortality and the total amount of healthy life lost expressed in Disability Adjusted Life Years (DALYs). The MEI_{VGZ} will be expressed in terms of the integrated health measure DALY. Because of the uncertainties, it should be noted that the MEI_{VGZ} should be used as a relative measure for policy evaluation and priority setting only, and not as an absolute quantification of the health burden.

3. Technical description of data and methods

3.1 Available emission data

For a limited set of the priority pollutants specified in the Netherlands, total emission data for the Netherlands were available for the years 1990, 1995, 2002 and 2003. For these years, the emissions of single chemicals and groups of chemicals (summary emissions) to air, water and soil were separately quantified (Alkemade et al., 2006). Summary emission data are available for groups of compounds that are identified as: Chlorobenzenes, Poly Chlorinated Biphenyls (PCB), Phenols, Polycyclic Aromatic Hydrocarbons (PAH), Chlorophenols, Poly Chlorinated Dioxins and Dibenzufuranes (PCDB), and Phtalate esters. For most emissions of contaminants specified as a summary emissions, the total emission for the group was attributed to each of the individual chemicals belonging to that group of chemicals. After calculation of the environmental concentrations and the estimation of risk, the worst case mixture was considered to be fully represented by the single compound with the highest calculated risk (see Annex 4). Another approach was chosen for the emission of the unspecified group of PAH compounds The emissions of 10 individual PAH substances were divided based on the distribution of measured air concentrations in the Netherlands (Buijsman, 1999). This was done because all individual PAH compounds contributed considerably to the overall MEI_{ECO}. The average distribution of individual PAH constituents measured in air is given in Table 2, where for Benzo(a)pyrene and Fluoranthene separate emission estimates are available.
The group of phtalate esters was considered to be solely composed of Di-(2-ethylhexyl) phthalate, because this compound constitutes approximately 80% of all phtalate esters used (personal communication J. Struijs, RIVM, LER). The different approaches for the treatment of emission data for groups of pollutants is summarized in Table 3.

Table 2 Average relative proportion of 10 individual PAH compounds in air in the Netherlands.

PAH	Relative proportion in ambient air mixture
Naphthalene	34%
Phenanthrene	55%
Anthracene	5%
Benzo[a]Anthracene	2%
Chyrsene	2%
Benzo[k]fluoranthene	1%
Benzo[ghi]perylene	1%
Indeno[1,2,3-cd]pyrene	1%
Benzo(a)pyrene	1%
Fluoranthene	15%

Table 3 Different methods of representation for grouped pollutant emissions.

Group of pollutants	Method of representation	Compound selected
Chlorobenzenes	Entire group emission attributed to compound with highest risk (PAF)	1,2-Dichlorobenzene
Poly Chlorinated Biphenyls (PCB)	Entire group emission attributed to compound with highest risk (PAF)	PCB-153
Phenols	Phenol is only compound in database	Phenol
Polycyclic Aromatic Hydrocarbons (PAH)	All divided according to measured concentration in air	10 different PAH compounds
Chlorophenols	Entire group emission attributed to compound with highest risk (PAF)	2,3,4,6-Tetrachlorophenol
Poly Chlorinated Dioxins and Dibenzufuranes (PCDB)	Entire group emission attributed to compound with highest risk (PAF)	2,3,4,7,8-Pentachlorodibenzofurane
Phtalate esters	Entire group emission attributed to compound that constitutes approx. 80% of phtalate use	Di-(2-ethylhexyl) phthalate

The emission data that are used for SimpleBox modeling (see paragraph 3.2.1) are summarized in Annex 1, where the summary emissions for the groups of compound are separated by bold horizontal lines. These data are derived from Alkemade et al. (2006).

The spatially explicit (gridcell) emissions in the Netherlands and in Europe of primary and secondary particulate matter up to 10 micrometers in size (PM_{10}, NO_x, SO_x, NH_3) and compounds that act in the formation of ozone (Non-Methane Volatile Organic Compounds (NMVOC) and NO_x) were obtained from 'The Netherlands Environmental Assessment Agency' (MNP). The emission files for NMVOC, NO_x, SO_x and NH_3 reflect the 2003 EMEP 'expert emissions' (http://webdab.emep.int/). The PM_{10}-file contains the 1995 CEPMEIP (Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance) data.

3.2 Calculation of environmental concentrations from emission data

Three models were used for the calculation of environmental concentrations in surface water and air from priority pollutant emission data.

1. For well defined organic and inorganic contaminants that are emitted as single compounds or mixtures, the model SimpleBox 3.23 is used to calculated the steady state environmental concentrations in water and air.
2. For the generation and distribution of fine particulate material in air from emissions of PM_{10} and the presence of NO_x, SO_x and NH_3, the spatial-explicit linear model OPS is used. PM_{10} concentrations are calculated for 1990, 1995 and 2003.
3. For the generation and distribution of ozone in air from the emission of NMVOC and NO_x the spatial explicit non-linear model LOTOS-EUROS is used. For reasons of feasibility, the change of the ozone concentration as a result of a hypothetical 100% reduction of respectively NMVOC and NO_x has been calculated for the year 2000 only.

3.2.1 SimpleBox model

SimpleBox was created as a research tool in environmental risk assessment. SimpleBox (Brandes et al., 1996) is implemented in the regulatory EU model EUSES (Vermeire et al., 1997) that is used for risk assessment of new and existing chemicals. Dedicated SimpleBox applications have been used for the derivation of integrated environmental quality criteria for air, water, and soil in the Netherlands. Spreadsheet versions of SimpleBox are used for multi media chemical fate modeling by scientists at universities and research institutes in various countries. SimpleBox predicts equilibrium exposure concentrations in various environmental media, assuming steady-state concentrations that result from a long term constant emission.

SimpleBox is a multimedia mass balance model of the so-called Mackay type. It represents the environment as a series of well-mixed boxes of air, water, sediment, soil, and vegetation (compartments). Calculations start with user-specified emission fluxes into the compartments (obtained from paragraph 3.1). Intermedia mass transfer fluxes and degradation fluxes are calculated by the model on the basis of user-specified mass transfer coefficients and degradation rate constants. The model performs a simultaneous mass balance calculation for all the compartments, and produces steady-state concentrations in the compartments as output. SimpleBox defines three partially nested spatial scales: a regional and continental scale nested in a temperate northern hemisphere scale, plus tropical and arctic northern

hemisphere scales. Applicability is limited to environmental situations where spatial differences in concentrations within compartments or boxes are negligible or unimportant. The model is fully described in publicly available RIVM-reports (Van de Meent, 1993; Brandes et al., 1996; Bakker et al., 2003). Advantages and limitations of multimedia fate models are described and evaluated in a SETAC publication (Cowan et al., 1995).

The SimpleBox model was defined to represent the Netherlands on the regional scale. In order to account for emissions in the remaining part of Europe, 1/3 of the Dutch emissions per unit area were assumed to be emitted in the rest of Europe on the continental scale (personal communication D. van de Meent). Both the dimensions of the regional scale (Netherlands) and the continental scale (rest of Europe) are given in Table 4.

Table 4 *Modeling dimensions of the SimpleBox model applied to calculate the concentrations in water and air in the Netherlands.*

REGIONAL SCALE (Netherlands)	Unit	Value
Area land	km^2	4.00E+04
Area sea	km^2	4.00E+02
Length sea box	km	4.00E+01
Fraction fresh water	-	3.00E-02
Fraction natural soil	-	2.70E-01
Fraction agricultural soil	-	6.00E-01
Fraction urban/industrial soil	-	1.00E-01
Depth fresh water	m	3.00E+00
Temperature	^oC	1.20E+01
Wind speed	$m.s^{-1}$	3.00E+00
Average precipitation	$mm.yr^{-1}$	7.00E+02
Fraction infiltration	-	2.50E-01
Fraction run off	-	2.50E-01
Soil erosion	$mm.yr^{-1}$	3.00E-02

CONTINENTAL SCALE (Rest of Europe)	Unit	Value
Area land	km^2	7.04E+06
Area sea	km^2	7.04E+06
Fraction fresh water	-	3.00E-02
Fraction natural soil	-	2.70E-01
Fraction agricultural soil	-	6.00E-01
Fraction urban/industrial soil	-	1.00E-01
Depth fresh water	m	3.00E+00
Temperature	^oC	1.20E+01
Wind speed	$m.s^{-1}$	3.00E+00
Average precipitation	$mm.yr^{-1}$	7.00E+02
Fraction infiltration	-	2.50E-01
Fraction run off	-	2.50E-01
Soil erosion	$mm.yr^{-1}$	3.00E-02

In order to calculate the steady state concentrations in the Netherlands for the different priority pollutants, the model requires estimates of physico-chemical compound properties. The model also requires degradation constants and ecotoxicity data for the ecological risk calculation. Estimated values for these types of input data are given in Annexes 2 and 3, respectively.

To single out the contribution of the emissions in the Netherlands to the environmental concentrations in water and air in the Netherlands, two SimpleBox calculations have been conducted:

1. The concentrations in the Netherlands are calculated as a result of the emissions both in Europe and in the Netherlands.
2. The concentrations in the Netherlands are calculated as a result of the emissions in Europe only.

This approach allows for a separation of the added effects of the emissions in the Netherlands in a later stage of the MEI calculations.

3.2.2 OPS model

For the purpose of the PM_{10} modeling OPS-Pro 4.1, the latest version of the Operational Priority Substances (OPS) model was used. OPS is a model that simulates the atmospheric process sequence of emission, dispersion, transport, chemical conversion and finally deposition. The model is originally designed to calculate the deposition of acidifying compounds for the Netherlands as a whole using a high spatial resolution. The model is, however, set up as a universal framework supporting the modeling of other pollutants such as fine particles and persistent organic pollutants (Van Jaarsveld, 2004).

From the emissions, the concentrations of the secondary components nitrate, sulphate, and ammonium were modeled. The 1990 and 2003 PM_{10}-results were obtained by multiplying the model results (1995) by a conversion factor that reflects the difference in emission quantity per country and sector between 1995 and the years of interest. The typical concentration of the various PM_{10} species in the Netherlands was reflected by a weighted concentration average over the Dutch grid cells. Weights of the grids are based on population density numbers.

Similar to the SimpleBox calculation, the OPS model has been run twice with different input emissions (1 - Europe including the Netherlands, and 2 – Europe without the Netherlands) in order to estimate the PM_{10} concentrations that would result from the emissions in the Netherlands only.

3.2.3 LOTOS/EUROS model

The regional chemistry transport model LOTOS-EUROS was used to calculate ozone formation in air due to emissions of NO_x and NMVOC (Schaap et al., 2005; Schaap et al., 2006). LOTOS-EUROS is a combination of the models LOng Term Ozone Simulation (LOTOS) and EURopean Operational Smog (EUROS) and is used to calculate dispersion and chemical transformation of air pollutants in the lower troposphere over Europe. It extends in vertical direction to about 3.5 km above sea level, following the dynamic mixing layer approach. LOTOS-EUROS is a dynamic model and the main prognostic equation is the continuity equation that describes the change in time of the concentration of a component as a result of transport and diffusion, chemistry, dry and wet deposition, emission and entrainment. Europe was divided in 25x25 km grids. To calculate ozone over Europe a gas phase chemistry scheme is used, describing photochemistry. Meteorological data of 1997 were used and emission data of the year 2000.

For reasons of feasibility, the change of the ozone concentration as a result of a reduction of respectively NMVOC and NO_x has been calculated for the year 2000 only. We calculated the pollutant-specific influence on O_3 by reducing the emissions in the Netherlands of respectively NO_x and NMVOC with a hypothetical 100%. To get an indication of the presumed non-linearity in the concentration-emission relationship of O_3 and respectively NO_x and NMVOC, we investigated whether 4 times a 25% reduction of emissions gives the same change in O_3 concentrations as a 100% emission reduction.

Similar to the SimpleBox and the OPS calculations, the LOTOS-EUROS estimates required multiple model runs with variable emissions in the Netherlands and constant emissions in the rest of Europe.

3.3 Available data on measured concentrations

3.3.1 Water

From the WaterStat application of the Netherlands Ministry of Transport, Public Works and Water Management available on the internet (http://www.waterstat.nl/), the median concentrations of the substances for which emission data were available were retrieved for all available fresh water stations in the Netherlands for the years 1990, 1995 and 2002. A nation-wide median concentration was calculated per year by taking the geometrical average over the stations. To validate the modelled water concentrations, the median measured water concentrations were statistically compared to the water concentrations predicted from emissions in the Netherlands in combination with the emissions estimated for Europe.

3.3.2 Air

Measured air concentration data for the years 1990, 1995, 2002 and 2003 were likewise retrieved from the website of the National Air Quality Monitoring Network (Landelijk Meetnet Luchtkwaliteit - LML) (http://www.lml.rivm.nl/data_val/index.html) operated by RIVM. To validate the modelled air concentrations, the average measured air concentrations of emitted substances were also statistically compared with the air concentrations predicted from the emissions in the Netherlands in combination with the emissions estimated for Europe.

3.4 Calculation procedure for MEI_{ECO}

The procedure to derive MEI_{ECO} boils down to the following.

3.4.1 SSD and mixture toxicity

For the MEI_{ECO} the risk of individual priority pollutants is calculated with the log-normal SSD. The log-normal SSD curve is fully characterized by the mu (μ), or log transformed toxicity endpoint concentrations averaged over species and the sigma (σ), or the standard deviation of the same data. Both moments of the log-normal SSD for the selected priority pollutants based on chronic No Observed Effect Concentrations (NOEC) are given in Annex 3.

For each of the priority pollutant (i) concentrations ($Concentration_i$) in the Netherlands surface waters, calculated by SimpleBox, the exposure concentration is recalculated to Hazard Units by dividing this concentration by the exponentiated μ_i value:

$$HU_i = \frac{Concentration_i}{10^{\mu_i}}$$

The HU_i values are added for substances with corresponding $TMoA_i$ and corresponding slope (σ_i):

$$HU_{TmoA} = \sum_i HU_i$$

The log-normal CA model gives the toxic risk for mixture constituents with the same TMoA by applying the Microsoft Excel function:

$$msPAF_{TMoA} = \text{NORMDIST}\left({}^{10}\log\left(HU_{TMoA}\right), 0, \overline{\sigma}, 1\right)$$

The combination effect for compounds with different modes of action is calculated analogous to the probability of two non-excluding processes (Hewlett and Plackett, 1979). For the present use in SSDs, it is assumed that sensitivities are uncorrelated in RA. For more than two chemicals or groups of chemicals with different TMoA, this leads to:

$$\mathrm{msPAF}_{\mathrm{Overall}} = 1 - \prod_{\mathrm{TMoA}} (1 - \mathrm{msPAF}_{\mathrm{TMoA}})$$

3.4.2 $\mathbf{MEI_{ECO}}$ based on species loss

Generally, ecosystem risk is conservatively expressed as the proportion of species for which the chronic NOEC is exceeded. The exceedance of no effect concentrations is not a straight-forward indication for the loss of species. The loss of species is generally corresponding to concentrations that are an order of magnitude higher. As has been demonstrated in Posthuma and De Zwart (2006), the actual loss of species is more closely related to the SSD risk calculation based on acute median lethal concentrations (LC_{50}). Therefore, the final MEI_{ECO} calculations are founded on LC_{50} SSD curves that are right shifted from the NOEC based curves by a factor of 10 (log 10 = 1, $\mu_{\text{acute LC50}} = \mu_{\text{chronic NOEC}} + 1$) on the concentration axis (De Zwart, 2002).

3.4.3 Separation of $\mathbf{MEI_{ECO}}$ for Dutch emissions

The previous toxic risk calculations for freshwater organisms produce two sets of toxic risk estimates in the Netherlands for the emissions of Europe alone and the combined emissions of Europe and the Netherlands. The risk estimates for individual TMoA ($\mathrm{msPAF}_{\mathrm{TMoA}}$) of these two sets are called $\mathrm{msPAF}_{\mathrm{TMoA,\ Eur\text{-}NL}}$ and $\mathrm{msPAF}_{\mathrm{TMoA,\ Eur+NL}}$. The risk of individual TMoA added by the Dutch emissions (Added $\mathrm{msPAF}_{\mathrm{TMoA,NL}}$) is defined as (Klepper et al., 1999):

$$Added\ msPAF_{TMoA,NL} = \left(msPAF_{TMoA,Eur+NL} - msPAF_{TMoA,Eur-NL}\right) / \left(1 - msPAF_{TMoA,Eur-NL}\right)$$

The Added $\mathrm{msPAF}_{\mathrm{TMoA,NL}}$ values for different TMoA are again combined to form the MEI_{ECO} according to:

$$MEI_{eco} = 1 - \prod_{TMoA} (1 - Added\ msPAF_{TMoA,NL})$$

With this calculation, the MEI_{ECO} expresses the proportion of species that is exposed to a concentration higher than the endpoint effect level as a result of the combined emissions in the Netherlands only. Due to the emissions in Europe, the actual proportion of species suffering effects will be higher.

3.5 Calculation procedure for $\mathbf{MEI_{VGZ}}$

3.5.1 $\mathbf{MEI_{VGZ}}$ and DALY formulae

The public health indicator for priority air pollutants MEI_{VGZ} is calculated as follows:

$$MEI_{VGZ} = \sum_{x} \sum_{e} AB_{x,e} \times DALY_{e}$$

MEI_{VGZ}: Indicator for Human Health Effects due to emission of all substances evaluated (years lost per year of exposure).

$AB_{x,e}$: Population Attributable Burden of getting disease type *e* due to exposure to a substance *x* (per year of exposure).

$DALY_{e}$: Disability Adjusted Life Years, lost due to getting disease type *e* (years).

Attributable burden of disease

The attributable burden of disease can be calculated based on relative risks for PM_{10} and ozone and based on unit risk factors for carcinogenic substances.

PM_{10} and ozone

The attributable burden of disease is calculated based on relative risks for PM_{10} and ozone as follows (based on Knol and Staatsen, 2005; De Hollander et al., 1999):

$$AB_{x,e} = \left(\frac{RR'_{e,x} - 1}{RR'_{e,x}} \right) \times F_{\exp,x,e} \times F_{inc,e} \times N_{pop}$$

$$RR'_{e,x} = \left((RR_{x,e} - 1) \times C_x \right) + 1$$

$AB_{x,e}$: Population Attributable Burden of getting disease type *e* due to exposure to a substance *x* per year of exposure (per year of exposure).
$F_{inc,e}$: Incidence Fraction of the population for disease type *e* (-).
$F_{exp,x,e}$: Fraction of the population exposed to substance *x* and that can get disease type *e* (-).
N_{pop}: Number of persons living in the Netherlands (-).
$RR_{x,e}$: Adjusted Relative Risk to get disease type *e* after exposure to substance *x* (per year of exposure).
$RR_{x,e}$: Relative Risk to get disease type *e* after exposure to substance *x* (per $\mu g/m^3$ per year of exposure).
C_x: Concentration of substance *x* (mg/m^3).

Carcinogenic substances

The attributable burden of disease is calculated based on unit risk factors of carcinogenic substances as follows:

$$AB_{x,e} = \frac{UR_x}{ALE} \times C_x \times F_{\exp,x,e} \times N_{pop}$$

$AB_{x,e}$: Population Attributable Burden of getting disease type *e* due to exposure to a substance *x* per year of exposure (per year of exposure).
UR_x: Unit Risk factor of substance *x*: cancer risk estimate for lifetime exposure to a concentration of 1 $\mu g/m^3$ of substance *x* ($m^3/\mu g$).
ALE: Average Life Expectancy (year)
C_x: Concentration of substance *x* ($\mu g/m^3$).
$F_{exp,x,e}$: Fraction of the population exposed to substance *x* and that can get disease type *e* (-).
N_{pop}: the number of persons living in the Netherlands (-).

DALYs

The health burden, expressed in DALYs is calculated as follows (Murray and Lopez, 1996):

$$DALY_e = \sum_e YLL_e + YLD_e$$

$$YLD_e = D_e \times w_e$$

$DALY_e$: Disability Adjusted Life Years, lost due to getting disease type *e* (years).
YLD_e: Years of life disabled due to disease type *e* per incidence case (years).
YLL_e: Years of life lost due to disease type *e* per incidence case (years).
D_e: Duration of disease type *e* (years).
w_e: Weighting factor for disease type *e* (-).

3.5.2 Data selection

Evaluation over time
The impact of emissions of air pollutants is evaluated for the years 1990, 1995, 2002 and 2003. Next to the modelled air concentrations, other parameters are also of influence on the quantification of indicator MEI_{VGZ}. To rule out these influences, typical values have been set for all parameters other than emission:

- The exposed population is the Dutch population. The population number alters over time and consequently will the number of people affected and the MEI_{VGZ}. To rule out the influence of the alterations in population number, it is set to a typical value of 15 864 000, the population number for the year 2000 (CBS, 2006).
- The fraction of the population exposed is set to 1, assuming exposure of the total population to the concentrations in the air.
- The incidence fraction is the fraction of the population that develops a specific disease. The incidence fractions alter over time and consequently will the MEI_{VGZ}. To rule out the influence of the alterations in incidence fractions, they are set to the values for the year 2000 based on Knol and Staatsen (2005), see Table 5.
- The duration and severity of a disease dependent on the treatments and with advancing medical science the weighting factors for severity and the duration may differ per year. Therefore the values of Knol and Staatsen (2005) and De Hollander et al. (1999) are used, see Table 5 and Table 6.
- The average life expectancy has increased over time. To rule out the influence of increased life expectancy, the average life expectancy is set to 80 years.

Chemical selection
In 1988 a list of 50 priority substances is drawn up in the first National Environmental Policy Plan. The substances on this list implied a risk for the public and/or environmental health. In 2004 this list was supplemented with 162 substances. The list of priority substances is the starting point of this study. For a limited set of the priority pollutants specified in the Netherlands, emission data were available for the years 1990, 1995, 2002 and 2003 (Annex 1). For these years, the emissions of single chemicals and pollutant groups to air, water and soil were separately quantified (Alkemade et al., 2006).

For only a very limited set of priority substances there is data available on emissions as well as on potency as well as on health burden.

Data on potency of pollutants
For a very limited set of priority substances there was epidemiological data available on relative risks and unit risk factors.

PM_{10} and ozone
We used epidemiological data on relative risks for air pollutants PM_{10} and ozone as given by Knol and Staatsen (2005). They investigated the effects of PM_{10} and ozone on the health of the Dutch population. PM_{10} can be regarded as an indicator of a more complex mixture of urban air pollutants. For the effects of short-term PM_{10} exposure, health effects taken into account include mortality (total and subdivided in cardiovascular and respiratory mortality, including Chronic Obstructive Pulmonary Diseases (COPD), and hospital admissions for cardiovascular and respiratory disease (total and separately for COPD and asthma). Time spent outside the hospital while still suffering from the disease or disability is not included in our DALY outcomes due to lack of data. For long-term PM_{10} exposure, they analyzed total

mortality. The health effects of short-term ozone exposure that they considered are mortality (total and subdivided in cardiovascular mortality). The contribution of other health effects of exposure to ozone, like hospital admission for cardiovascular disease, respiratory disease, COPD and asthma was not statistically significant and therefore not considered here.
We considered health effects from primary PM_{10}, secondary aerosols NH_4^+, NO_3^- and SO_4^{2-} and secondary ozone. The secondary aerosols are formed from emissions of NH_3, NO_x and SO_2. Ozone is formed from emissions of NO_x and NMVOC.
The incidence fractions on hospital admission for 2000 are based on Knol and Staatsen (2005). The incidence fractions on mortality for 2000 are based on statistics from CBS (2006). The incidence fractions and relative risks are listed in Table 5.

Carcinogenic substances
For carcinogenic substances we used unit risk factors. The unit risk estimate for an air pollutant is defined as 'the additional lifetime cancer risk occurring in a hypothetical population in which all individuals are exposed continuously from birth throughout their lifetimes to a concentration of 1 $\mu g/m^3$ of the agent in the air they breathe' (WHO, 2001). The unit risk factors are used from the Air Quality Guidelines for Europe 2000 of the World Health Organization (2001) or the IRIS database of the USEPA (2006). If both databases reported different air unit risk factors for the same agent, preference was given to the WHO unit risk factors. The available unit risk factors for priority substances used are listed in Table 6.
For chromium the unit risk factor is available for hexavalent chromium, whereas the air concentrations are calculated for total chromium. Mennen et al. (1998) measured chromium concentrations at a regional site in Bilthoven in the Netherlands. They found that the ratio of Cr VI to total Cr did not exceed 8% and the average value was at most 5%, which they state is probably an overestimate. These results agree with the theoretical predictions of Seigneur and Constantinou (1996). Therefore to estimate the MEI_{VGZ} for chromium, we assumed a ratio of Cr VI to total Cr of 5%.

Selection of critical endpoints
For every substance we selected one critical endpoint, although substances may cause a variety of disease. If no human endpoint was mentioned with the unit risk factor, we chose the corresponding endpoint of the animal studies. It is obvious that the list of endpoints is not comprehensive, and it might be criticized that it reflects what is quantifiable rather than what is relevant for decision making. Although this is true in principal, we strongly believe that the underlying epidemiological studies have addressed health endpoints that are of direct social concern. So, we suggest as a pragmatic approach to assume that the list of morbidity endpoints is incomplete, but provides a reasonable approximation of the most important effects known today which are of direct social concern (as listed by Krewitt et al., 2002).

Data on health burden
We used data on weighting factors for the Netherlands on severity and duration for air pollutants PM_{10} and ozone as given by Knol and Staatsen (2005). For that exercise, they used the weighting factors as used by the Department of Public Health Status and Forecasting (RIVM, 2004), the background report for the Public Health Status and Forecast 1997 (Melse and Kramers, 1998), and the Global Burden of Disease study (Murray and Lopez, 1996). If severity weights were not available from the abovementioned sources they used weights from De Hollander et al. (1999). We used data on weighting factors for the Netherlands on severity and duration for carcinogenic substances as given by De Hollander et al. (1999). When there is no data on the weighting factors for a substance but it causes the same disease type as other

substances, we used the same weighting factors for severity and duration. For chloroform and formaldehyde there were no data available on weighting factors neither for bladder cancer nor for nose and throat cancer in the Netherlands. Therefore we used weighting factors for the Established Market Economies (EME) from the Global Burden of Disease study (Murray and Lopez, 1996). The weighting factors are presented in Table 5 and Table 6.

Table 5 Health outcomes, relative risks, incidence fractions and weighting factors for PM_{10} and ozone (Knol and Staatsen, 2005)

Substance	CAS-nr.	Health outcome	Relative risk per mg/m^3 (95%CI)	Incidence fraction	YLL	D	w
PM_{10}	-	Total mortality long term	1.0043 (1.0026 – 1.0061)	8.9E-03	10		
		Total mortality short term	1.00036 (1.00025 – 1.00046)	8.9E-03	0.25		
		Respiratory disease mortality (short term)	1.00114 (1.00084 – 1.00157)	9.3E-04	0.25		
		Cardiovascular disease mortality (short term)	1.00025 (1.00009 – 1.00041)	3.1E-03	0.25		
		COPD mortality (short term)	1.00106 (1.00062 – 1.00150)	4.2E-04	0.25		
		Hospital admission: respiratory	1.00047 (1.00025 – 1.00067)	3.1E-03		0.038	0.64
		Hospital admission: cardiovascular	1.00032 (1.00019 – 1.00044)	5.3E-03		0.038	0.71
		Hospital admission: COPD	1.00084 (1.00053 – 1.00115)	1.3E-03		0.038	0.53
Ozone	10028-15-6	Mortality (total)	1.00026 (1.00016 – 1.00038)	8.9E-03	0.25		
		Cardiovascular disease mortality (short term)	1.00021 (1.00002 – 1.00040)	3.1E-03	0.25		

Table 6 Health outcomes, IARC Classifications, unit risk factors and weighting factors for carcinogenic substances

Substance	CAS-nr.	Health outcome	IARC *	Unit Risk Factor (m^3/µg)	Species, Ref.	YLL	YLD	D	w	Ref.
1,2-Dichloroethane	107-06-2	Hemangiosarcoom	2b	2.60E-05	R, y	13.3		4.4	0.53	b
Benzo [a] pyrene (BaP)	50-32-8	Lung cancer	2a	8.70E-02	H, x	13.5		2.9	0.43	b
Benzene	71-43-2	Leukemia	1	6.00E-06	H, x	21.2		2.7	0.83	b
Acrylonitrilee	107-13-1	Lung cancer	2b	2.00E-05	H, x	13.5		2.9	0.43	b
Vinyl chloride	75-01-4	Hepato-angiosarcoom	1	1.00E-06	H, x	13.3		4.4	0.53	b
Chloroform	67-66-3	Bladder cancer	2b	2.30E-05	M, y	2.8	0.4			c
Trichloroethylene	79-01-6	Liver cancer	2a	4.30E-07	R, x	13.3		4.4	0.53	b ¥
Cd & Cd compounds	7440-43-9	Lung cancer	1	1.80E-03	H, y	13.5		2.9	0.43	b ¥
Cr VI & Cr VI compounds	7440-47-3	Lung cancer	1	4.00E-02	H, x	13.5		2.9	0.43	b ¥
Formaldehyde	50-00-0	Nose and throat cancer	1	1.30E-05	R, y	5.1	0.387			c
Nil & Ni compounds	7440-02-0	Lung cancer	2b	3.80E-04	H, x	13.5		2.9	0.43	b ¥

** IARC classification: group 1: carcinogenic to humans; group 2a: probably carcinogenic to humans; group 2b: possibly carcinogenic to humans; H=human; R=rat; M=mouse; x) Air Quality Guidelines (WHO, 2001); y) IRIS- database ;. a) Knol and Staatsen, (2005); b) De Hollander et al., (1999); c) Murray and Lopez, (1996), for EME; ¥ Adopted from other substance with same disease type.*

4. Results and discussion

4.1 Validation of predicted concentrations

4.1.1 Water

For the water compartment in the Netherlands, measured concentrations are available for a considerable number of substances (Table 7) represented in the list of emission data (Annex 1).

Table 7 Available yearly data on measured and modelled concentrations in Dutch surface waters.

Compound	Year	Measured concentration µg/L	Modelled concentration µg/L
1,1,1-trichloroethane	1990	7.2E-02	2.0E-02
1,1,1-trichloroethane	1995	3.3E-02	4.9E-03
1,1,1-trichloroethane	2002	1.5E-02	5.3E-04
1,2 dichloroethane	1990	1.0E-01	4.3E-02
1,2 dichloroethane	1995	1.5E-01	1.0E-02
1,2 dichloroethane	2002	9.5E-02	1.4E-02
1,4-dichlorobenzene	2002	2.2E-02	7.3E-03
1,4-dichlorobenzene	2002	2.2E-02	7.3E-03
2,4,5-Trichlorophenol	1990	2.0E-02	1.2E-02
2,4,5-Trichlorophenol	1995	1.0E-02	8.2E-03
2,4,5-Trichlorophenol	2002	2.0E-02	6.5E-03
2,4,6-trichlorophenol	1990	2.1E-02	1.1E-02
2,4,6-trichlorophenol	1995	1.0E-02	7.6E-03
2,4,6-trichlorophenol	2002	2.0E-02	6.1E-03
Ammonia	1990	2.2E+02	1.9E+00
Ammonia	1995	1.2E+02	1.4E+00
Ammonia	2002	1.3E+02	1.0E+00
anthracene	1995	1.0E-02	2.9E-02
anthracene	2002	1.0E-02	1.5E-02
Arsenic	1990	2.3E+00	2.3E-01
Arsenic	1995	2.4E+00	2.2E-01
Arsenic	2002	1.3E+00	2.1E-01
Benzene	1990	1.0E-01	1.9E-01
Benzene	1995	1.2E-02	1.1E-01
Benzene	2002	1.3E-02	6.7E-02
Benzo(a)pyrene	1990	2.0E-02	2.2E-02
Benzo(a)pyrene	1995	1.1E-02	1.9E-02
Benzo(a)pyrene	2002	1.0E-02	9.5E-03
Benzo[a]anthracene	1995	1.0E-02	1.6E-02
Benzo[a]anthracene	2002	1.0E-02	8.8E-03
Benzo[ghi]perylene	1990	2.0E-02	1.8E-02
Benzo[ghi]perylene	1995	1.5E-02	1.2E-02
Benzo[ghi]perylene	2002	1.5E-02	6.6E-03
Benzo[k]fluoranthene	1990	1.0E-02	1.5E-02
Benzo[k]fluoranthene	1995	1.0E-02	9.8E-03
Benzo[k]fluoranthene	2002	1.0E-02	5.3E-03
Cadmium	1990	7.0E-02	1.9E-02
Cadmium	1995	5.0E-02	9.3E-03
Cadmium	2002	8.0E-02	7.6E-03
Chromium	1990	1.5E+00	5.3E-02
Chromium	1995	1.5E+00	4.0E-02
Chromium	2002	8.3E-01	3.6E-02
chyrsene	1995	1.0E-02	2.7E-02
chyrsene	2002	1.1E-02	1.5E-02
Copper	1990	2.5E+00	2.3E+00
Copper	1995	2.7E+00	2.1E+00
Copper	2002	3.1E+00	1.4E+00
di-(2-ethylhexyl)-phthalate	2002	1.0E+00	4.9E-03
Fluoranthene	1990	4.0E-02	1.6E-01
Fluoranthene	1995	2.6E-02	1.4E-01
Fluoranthene	2002	1.4E-02	9.6E-02
HCH (water)	1990	7.7E-03	4.8E-03
HCH (water)	1995	4.2E-03	2.0E-03

Compound	Year	Measured concentration µg/L	Modelled concentration µg/L
HCH (water)	2002	2.3E-03	2.1E-07
hexachlorobenzene	1990	3.2E-03	1.2E-02
hexachlorobenzene	1995	1.5E-03	8.2E-03
hexachlorobenzene	2002	1.6E-03	9.0E-03
Indeno[1,2,3-cd]pyrene	1990	1.0E-02	9.0E-03
Indeno[1,2,3-cd]pyrene	1995	1.5E-02	6.0E-03
Indeno[1,2,3-cd]pyrene	2002	1.5E-02	3.3E-03
Lead	1990	9.3E-01	1.5E-01
Lead	1995	1.2E+00	1.0E-01
Lead	2002	1.2E+00	8.8E-02
Mercury	1990	1.9E-02	2.8E-03
Mercury	1995	1.5E-02	1.8E-03
Mercury	2002	7.6E-03	8.0E-04
Nickel	1990	2.9E+00	4.1E+00
Nickel	1995	2.9E+00	3.9E+00
Nickel	2002	2.6E+00	3.3E+00
pentachlorophenol	1990	1.7E-02	2.4E-02
pentachlorophenol	1995	1.1E-02	1.7E-02
pentachlorophenol	2002	2.0E-02	1.4E-02
phenanthrene	1995	2.0E-02	3.4E-01
phenanthrene	2002	1.2E-02	1.8E-01
Styrene	1990	1.0E-01	4.6E-04
Styrene	1995	1.0E-02	1.7E-03
Styrene	2002	1.4E-02	1.6E-04
Tetrachloroethene (PER)	1990	6.7E-02	5.8E-03
Tetrachloroethene (PER)	1995	1.2E-01	1.4E-03
Tetrachloroethene (PER)	2002	5.6E-02	7.4E-04
Tetrachloromethane (Tetra)	1990	1.1E-02	2.8E-03
Tetrachloromethane (Tetra)	1995	1.3E-02	8.8E-04
Tetrachloromethane (Tetra)	2002	1.4E-02	1.0E-04
Toluene	1990	1.0E-01	1.2E-02
Toluene	1995	1.0E-02	7.2E-03
Toluene	2002	1.5E-02	3.4E-03
Trichloroethene	1990	1.0E-01	1.7E-02
Trichloroethene	1995	4.6E-02	1.4E-03
Trichloroethene	2002	3.7E-02	4.0E-04
Trichloromethane	1990	9.9E-02	3.5E-03
Trichloromethane	1995	5.5E-02	5.2E-03
Trichloromethane	2002	3.5E-02	1.8E-03
Zinc	1990	8.7E+00	1.3E+00
Zinc	1995	9.6E+00	4.8E+00
Zinc	2002	9.4E+00	4.3E+00
Total number of entries	**95**		

Figure 3 presents a comparison and regression analysis of the 95 corresponding pairs of measured and predicted concentrations in Dutch surface waters.

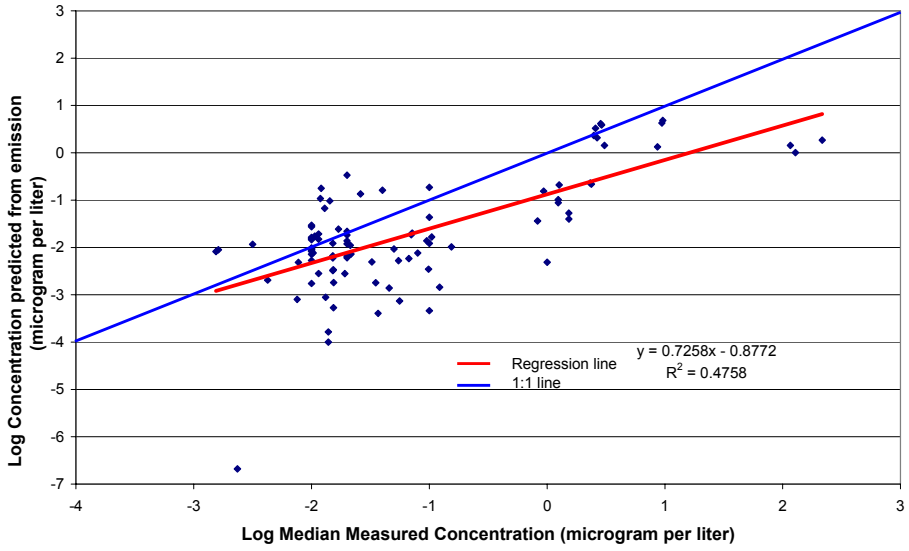

Figure 3 Graphical comparison of measured and predicted concentrations in Dutch surface waters.

The evaluation of measured and predicted water concentrations indicates that there is a clear and significant relationship between the predicted and the observed water concentrations. However, the predicted concentrations are slightly below the observed concentrations. This may be due to the selection of monitoring stations in main national water bodies with a relatively high exposure. Furthermore, the measured concentrations may reflect local emission peaks, while the modelled concentrations are calculated under the assumption of long term constant emissions as a nation-wide and European average.

4.1.2 Air

Available data on measured air concentrations are scarce (16 compounds) as depicted in Table 8.

Table 8 Available yearly data on modelled and measured air concentrations in the Netherlands.

Compound	Year	Measured regional concentration µg/m^3	Modelled concentration µg/m^3
1,1,1-trichloroethane	1995	6.1E-01	1.5E+00
1,1,1-trichloroethane	2002	2.0E-01	1.5E-01
1,1,1-trichloroethane	2003	1.3E-01	1.5E-01
Arsenic	1990	1.5E-03	1.0E-04
Arsenic	1995	9.8E-04	8.1E-05
Arsenic	2002	8.5E-04	8.1E-05
Arsenic	2003	9.8E-04	6.7E-05
Benzene	1995	9.8E-01	3.5E-01
Benzene	2002	8.4E-01	2.3E-01
Benzene	2003	6.0E-01	2.2E-01
Cadmium	1990	4.9E-04	1.4E-04
Cadmium	1995	3.9E-04	7.5E-05
Cadmium	2002	2.7E-04	1.5E-04
Cadmium	2003	2.7E-04	1.6E-04
Koolmonoxide	1995	3.9E+02	3.6E+03
Koolmonoxide	2002	3.1E+02	2.7E+03
Koolmonoxide	2003	3.1E+02	2.6E+03
Lead	1990	5.3E-02	2.3E-02
Lead	1995	2.4E-02	1.1E-02
Lead	2002	1.1E-02	2.5E-03
Lead	2003	1.2E-02	2.4E-03
Nitrogenoxides	1995	2.2E+01	3.4E+01
Nitrogenoxides	2002	2.0E+01	2.8E+01
Nitrogenoxides	2003	2.3E+01	2.8E+01
Ozone	2000	4.0E+01	1.9E+01
PM_{10}	2003	3.3E+01	1.5E+01
Styrene	1995	1.3E-01	2.2E-02
Styrene	2002	1.6E-01	1.1E-02
Sulfurdioxide	1995	5.6E+00	2.3E+01
Sulfurdioxide	2002	2.6E+00	1.7E+01
Sulfurdioxide	2003	2.7E+00	1.7E+01
Tetrachloromethane (Tetra)	1995	8.2E-01	1.6E-01
Tetrachloromethane (Tetra)	2002	5.9E-01	1.3E-02
Tetrachloromethane (Tetra)	2003	4.7E-01	1.3E-02
Toluene	1995	2.4E+00	1.1E+00
Toluene	2002	2.9E+00	5.3E-01
Trichloroethene	1995	3.4E-01	1.9E-01
Trichloroethene	2002	1.0E-01	1.4E-02
Trichloroethene	2003	3.4E-01	7.3E-03
Trichloromethane	1995	1.2E-01	1.3E-02
Trichloromethane	2003	1.0E-01	3.5E-03
Zinc	1990	6.8E-02	1.5E-02
Zinc	1995	4.3E-02	9.8E-03
Zinc	2002	3.2E-02	6.1E-03
Zinc	2003	3.1E-02	6.2E-03
Total number of entries	**45**		

Figure 4 presents a comparison and regression analysis of the 45 corresponding pairs of measured and predicted air concentrations in the Netherlands.

The evaluation of measured and predicted air concentrations indicates that there is a clear and highly significant relationship between the predicted and the observed concentrations. However, especially for the lower concentrations, the predicted concentrations are slightly below the observed concentrations. This may be due to taking the arithmetic average of the observed concentrations that will be slightly higher than the median of the observed concentrations calculated in the prediction. Furthermore, the SimpleBox model used for predicting the concentrations of most pollutants assumes a steady-state situation with relatively low concentrations that especially for the air compartment may not be reached in reality.

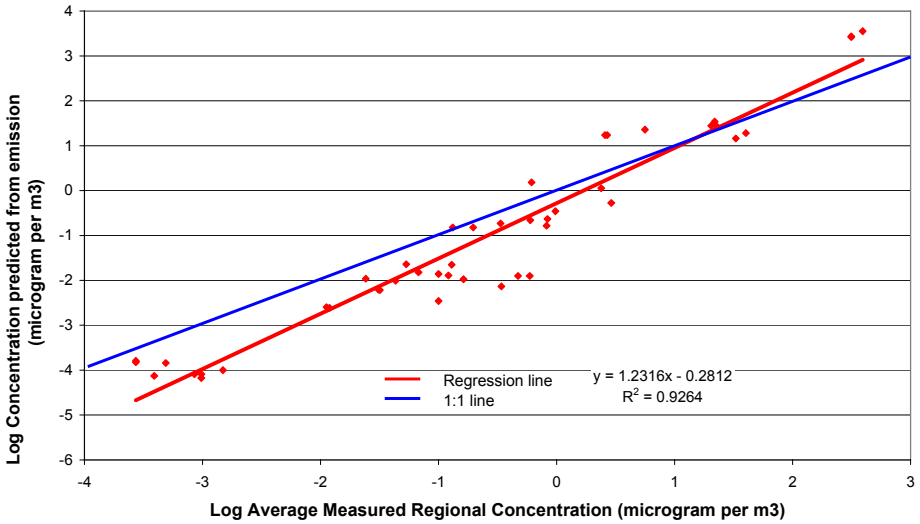

Figure 4 *Graphical comparison of measured and predicted air concentrations in the Netherlands.*

4.1.3 Conclusions on the use of modelled concentrations

The planned use of modelled exposure concentrations instead of the measured concentrations of the priority pollutants for the MEI evaluation has the advantage of allowing for the eventual separation of the impact of emissions in the Netherlands from the impact of emissions in the rest of Europe. The use of modelled concentrations is only valid if a clear relationship can be established between the modelled and measured concentrations. For the purpose of the MEI evaluation, a full one-to-one relationship is however not required. The use of the MEI as a relative and comparative indicator may only require a clear and possitive correlation between modelled and measured concentrations. For both water and air, the analyses presented in the paragraphs 4.1.1 and 4.1.2 demonstrated a reasonably positive correlation with a slope that is statistically not far from unity. Hence, modelled concentrations were used for all MEI calculations.

4.2 MEI_{ECO} evaluation and trends

4.2.1 Ecosystem exposure to priority pollutants in water

Annex 4 contains a table where the predicted concentrations in fresh surface waters of all priority pollutants (including the individual constituents of summary emissions) are given as a result of the emissions in Europe and the Netherlands together. This table also contains the conversion of concentrations to toxic risk per compound, expressed as the Potentially Affected Fraction of species (PAF) based on chronic NOEC exceedance. The PAF values per

compound lead to the selection of a single hypothetical worst case constituent of the summary emissions, as indicated in the table (first column).

4.2.2 Assessment of ecological risk

Intermediate results of the ecotoxic risk calculations based on chronic NOEC exceedance for emissions in Europe with and without the Netherlands is presented in Annex 5. Here the individual priority pollutants are grouped to represent Toxic Modes of Action (TMoA), because pollutants with the same mode of action can be regarded as a single toxicant (De Zwart and Posthuma, 2005).

Annex 6 further elaborates the data in Annex 5 to represent the overall toxic risk based on NOEC exceedance for freshwater organisms as a consequence of emissions in Europe with and without the emissions in the Netherlands.

Based on chronic NOEC exceedance for organisms in the average surface water of the Netherlands, Table 9 gives the risks that are added by the Netherlands emissions of the selected priority pollutants grouped to TMoA and in total.

Table 9 *The toxic risk for freshwater organisms added by the emissions of priority pollutants grouped to TMoA in the Netherlands (Added msPAF$_{TMoA,NL}$), culminating in the overall toxic risk in the bottom row. The highlighted figures contribute more than 1% to the overall effects. The evaluation is based on chronic NOEC exceedance.*

TMoA	**Added msPAF$_{TMoA,NL}$ 1990**	**Added msPAF$_{TMoA,NL}$ 1995**	**Added msPAF$_{TMoA,NL}$ 2002**	**Added msPAF$_{TMoA,NL}$ 2003**
Ah-receptor	0.01%	0.00%	0.00%	0.00%
As	0.00%	0.00%	0.00%	0.00%
Cd	0.11%	0.05%	0.04%	0.04%
Cr	0.01%	0.01%	0.00%	0.00%
Cu	**12.01%**	**11.19%**	**8.71%**	**8.44%**
Diester toxicity	0.00%	0.00%	0.00%	0.00%
F	**3.87%**	0.01%	0.05%	0.02%
H2S	0.00%	0.00%	0.00%	0.00%
Hg	0.00%	0.00%	0.00%	0.00%
NH3	0.10%	0.07%	0.04%	0.03%
Ni	0.59%	0.55%	0.46%	0.45%
Nonpolar narcosis (mainly PAH)	**14.07%**	**10.50%**	**6.05%**	**7.56%**
NOx	1.38%	1.18%	0.94%	0.94%
Pb	0.00%	0.00%	0.00%	0.00%
pH	0.00%	0.00%	0.00%	0.00%
Polar narcosis	0.00%	0.00%	0.00%	0.00%
Zn	**1.42%**	**4.52%**	**4.09%**	**4.03%**
Unc. oxidative phosphorylation	0.97%	0.51%	0.39%	0.38%
Alkylation / arylation reactivity	0.00%	0.00%	0.00%	0.00%
Carbonyl reactivity	0.00%	0.00%	0.00%	0.00%
Neurotox: Cyclodiene-type	0.05%	0.02%	0.00%	0.00%
msPAF-Overall	**30.63%**	**25.91%**	**19.31%**	**20.27%**

Based on chronic NOEC exceedance, Figure 5 gives the different types of overall risk for freshwater organisms estimated to be caused by the emissions in Europe and the Netherlands, separate and in combination.

A declining trend from 31% to 19% of emission related risk for the aquatic ecosystem can be observed in the toxic risk based on chronic NOEC exceedance over the years 1990-2002. The priority pollutants contributing most to the toxic risk are PAH (included in the TMoA of non polar narcosis) and Copper (both with a risk varying between 14-12% in 1990 and 8% in 2003. The next influential priority pollutant is Zinc (4 to 5%). The relatively high predicted risk of fluorides in 1990 (4%) is caused by an unlikely high outlier emission to water for that year (37500 Tonnes in 1990 as opposed to 1810 Tonnes for the year 1995). The relatively low

predicted risk of zinc in 1990 (1.4% in 1990 and approximately 4% in the other years) is caused by missing zinc emission data to water for that year.

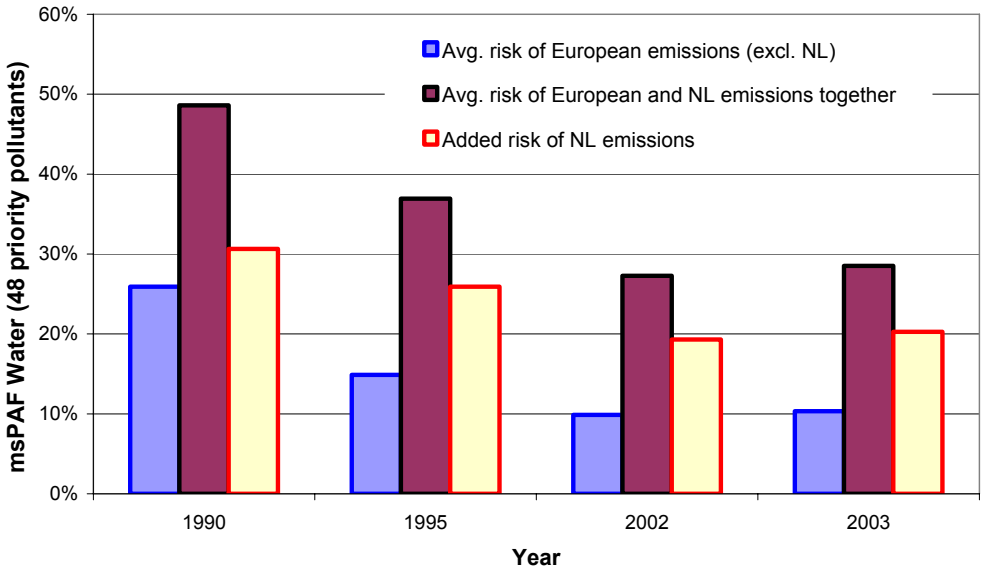

Figure 5 *The different types of overall risk for freshwater organisms based on chronic NOEC exceedance.*

The final risk evaluations for the MEI_{ECO} are based on acute LC_{50} exceedances, and the calculated risk can be interpreted as being related to the loss of species (Posthuma and De Zwart, 2006). The modelled loss of freshwater species is depicted in Figure 6.

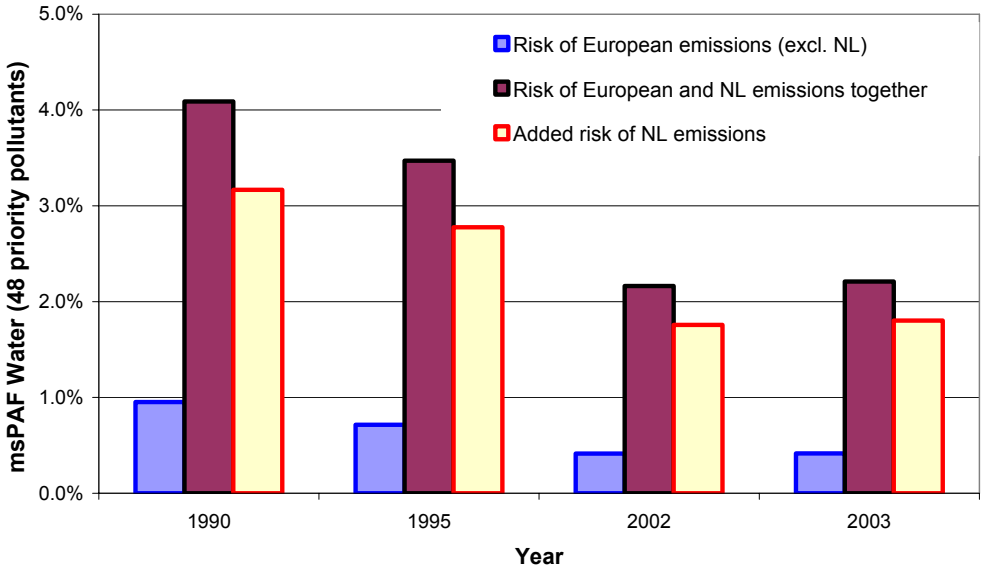

Figure 6 *The different types of overall risk for freshwater organisms based on acute LC50 exceedance, or the loss of species.*

Over the entire period of the years 1990 to 2003, the loss of species that would occur as a consequence of steady state exposure caused by the average emission of a variety of priority pollutants is estimated to be well below the 5% level. The substances contributing most to the estimated loss of species are in the same order as for the evaluation based on exceedance of chronic NOEC values (see Table 10). The MEI_{ECO} decreases from 3.2% in 1990 to 1.8% in

2003. The emissions in the Netherlands contribute about 75% to the overall effects caused by emissions in the Netherlands and the rest of Europe.

Table 10 *The toxic risk for freshwater organisms added by the emissions of priority pollutants grouped to TMoA in the Netherlands (Added $msPAF_{TMoA,NL}$), culminating in the overall toxic risk for the loss of species in the bottom row. The bottom row is the proposed MEI_{ECO}. The highlighted figures contribute to the overall effects. The evaluation is based on acute LC_{50} exceedance.*

TMoA	**Added $msPAF_{TMoA,NL}$ 1990**	**Added $msPAF_{TMoA,NL}$ 1995**	**Added $msPAF_{TMoA,NL}$ 2002**	**Added $msPAF_{TMoA,NL}$ 2003**
Ah-receptor	0.00%	0.00%	0.00%	0.00%
As	0.00%	0.00%	0.00%	0.00%
Cd	0.01%	0.00%	0.00%	0.00%
Cr	0.00%	0.00%	0.00%	0.00%
Cu	**1.79%**	**1.59%**	**1.05%**	**0.99%**
Diester toxicity	0.00%	0.00%	0.00%	0.00%
F	**0.07%**	0.00%	0.00%	0.00%
H2S	0.00%	0.00%	0.00%	0.00%
Hg	0.00%	0.00%	0.00%	0.00%
NH3	0.00%	0.00%	0.00%	0.00%
Ni	0.02%	0.02%	0.01%	0.01%
Nonpolar narcosis (mainly PAH)	**1.10%**	**0.63%**	**0.23%**	**0.34%**
NOx	0.08%	0.06%	0.04%	0.04%
Pb	0.00%	0.00%	0.00%	0.00%
pH	0.00%	0.00%	0.00%	0.00%
Polar narcosis	0.00%	0.00%	0.00%	0.00%
Zn	**0.09%**	**0.49%**	**0.42%**	**0.41%**
Unc. oxidative phosphorylation	0.04%	0.01%	0.01%	0.01%
Alkylation / arylation reactivity	0.00%	0.00%	0.00%	0.00%
Carbonyl reactivity	0.00%	0.00%	0.00%	0.00%
Neurotox: Cyclodiene-type	0.00%	0.00%	0.00%	0.00%
msPAF-Overall - MEI_{ECO}	**3.17%**	**2.78%**	**1.76%**	**1.80%**

4.3 MEI_{VGZ} evaluation and trends

4.3.1 Human exposure to priority pollutants in ambient air

An overview of the air concentrations of priority substances for MEI_{VGZ} is presented in Table 11. The concentrations of all mentioned substances, except cadmium, have decreased in the period 1990-2003. The concentration of cadmium is increased with 11%.

Table 11 *Calculated air concentrations for 1990, 1995, 2002 and 2003*

Substance	**CAS-nr.**	**Calculated Air concentration (µg/m3)**							
		1990		**1995**		**2002**		**2003**	
		EU+NL	**NL**	**EU+NL**	**NL**	**EU+NL**	**NL**	**EU+NL**	**NL**
Primary PM_{10}	-	-	4.7E+00	-	4.4E+00	-	-	6.3E+00	3.8E+00
$PM_{10}[NH4]^{+}$	-	-	1.1E+00	-	9.1E-01	-	-	1.2E+00	6.1E-01
$PM_{10}[NO3]^{-}$	-	-	3.6E+00	-	3.0E+00	-	-	5.0E+00	2.3E+00
$PM_{10}[SO4]^{2-}$	-	-	5.8E-01	-	4.3E-01	-	-	2.0E+00	2.0E-01
1,2-Dichloroethane	107-06-2	4.6E-01	6.5E-02	5.7E-02	8.1E-03	1.4E-01	2.0E-02	1.4E-01	2.0E-02
Benzo [a] pyrene (BaP)	50-32-8	3.2E-04	1.8E-04	1.8E-04	9.9E-05	1.8E-04	9.9E-05	1.3E-04	7.4E-05
Benzene	71-43-2	4.7E-01	3.2E-01	3.5E-01	2.3E-01	2.3E-01	1.6E-01	2.2E-01	1.5E-01
Acrylonitrilee	107-13-1	2.0E-02	7.8E-03	1.4E-02	5.3E-03	3.5E-03	1.4E-03	2.3E-03	9.0E-04
Vinyl chloride	75-01-4	2.7E-02	1.2E-02	8.6E-03	3.7E-03	4.3E-03	1.8E-03	5.0E-03	2.2E-03
Chloroform	67-66-3	2.8E-02	3.5E-03	1.3E-02	1.6E-03	3.2E-03	4.1E-04	3.5E-03	4.3E-04
Trichloroethylene	79-01-6	1.7E-01	4.3E-02	1.9E-01	4.8E-02	1.4E-02	3.6E-03	7.3E-03	1.9E-03
Cd & Cd compounds	7440-43-9	1.4E-04	7.8E-05	7.5E-05	4.0E-05	1.5E-04	8.1E-05	1.6E-04	8.7E-05
Cr VI & Cr VI compounds	7440-47-3	3.8E-05	2.1E-05	2.8E-05	1.5E-05	1.7E-05	9.1E-06	1.6E-05	8.7E-06
Formaldehyde	50-00-0	5.9E-02	5.4E-02	4.2E-02	3.9E-02	2.7E-02	2.5E-02	2.6E-02	2.4E-02
Ni & Ni compounds	7440-02-0	5.2E-03	2.8E-03	6.0E-03	3.2E-03	9.1E-04	4.9E-04	9.4E-04	5.1E-04

EU + NL: concentrations due to European and Dutch emissions; NL: concentrations due to Dutch emissions.

Table 12 shows the change in ozone concentrations as result of hypothetical 100% reductions of the emissions of NO_2 and NMVOC for the year 2000.

Table 12 Reduction or increase of secondary ozone as result of reduction of emission of NO2 and NMVOC for 2000.

Scenario	Emission reduction NO_2 in NL		Emission reduction NMVOC in NL	
	- 4*25 %	- 100 %	- 4*25 %	- 100 %
Δ concentration O_3 (µg/m^3)	+ 4.36	+ 5.66	- 0.20	- 0.19

The strongest reduction of the concentrations caused by both emissions in the Netherlands and and emissions in the rest of European emissions for carcinogenic substances took place in the period 1990-1995.

4.3.2 Assessment of human health risk

Assuming a direct relationship between the modelled concentrations caused by emissions and total health burden, the results for the MEI_{VGZ} are represented in Table 13 and Table 14. The total health burden (MEI_{VGZ}) due to the emissions of the selected priority pollutants in the Netherlands has decreased with 31% over the period 1990-2003 (59000 to 42000 DALY). For the entire period, PM_{10} is the largest contributor to the total MEI_{VGZ} (more than 99%), mainly caused by primary PM_{10} and $PM_{10}[NO_3]^+$. The contribution of carcinogenic substances to the overall MEI_{VGZ} is lower than 0.1%. The contribution of secondary ozone formation to the overall MEI_{VGZ} changes slightly as a result of hypothetical 100% reductions in the Dutch emissions of NMVOC (about -0.1%) and NO_2 (about + 0.2%), respectively. In 2003, approximately 50% of the public health risk is attributable to the emissions in the netherlands (42000 DALY), compared to the overall emissions in Europe (86000 DALY). An overview of the total health burden from Dutch and European emissions is presented in Figure 7.

Table 13 MEI_{VGZ} for 1990, 1995, 2002 and 2003.

Substance	**CAS-nr.**	**MEI_{VGZ} (DALYs)**							
		1990		**1995**		**2002**		**2003**	
		EU+NL	**NL**	**EU+NL**	**NL**	**EU+NL**	**NL**	**EU+NL**	**NL**
Primary PM_{10}	-	-	2.8E+04	-	2.6E+04	-	-	3.7E+04	2.3E+04
$PM_{10}[NH4]^+$	-	-	6.6E+03	-	5.5E+03	-	-	7.5E+03	3.7E+03
$PM_{10}[NO3]^-$	-	-	2.1E+04	-	1.8E+04	-	-	2.9E+04	1.4E+04
$PM_{10}[SO4]^{2-}$	-	-	3.5E+03	-	2.6E+03	-	-	1.2E+04	1.2E+03
1,2-Dichloroethane	107-06-2	3.7E+01	5.2E+00	4.6E+00	6.5E-01	1.1E+01	1.6E+00	1.1E+01	1.6E+00
Benzo [a] pyrene (BaP)	50-32-8	8.0E+01	4.5E+01	4.6E+01	2.5E+01	4.5E+01	2.5E+01	3.4E+01	1.9E+01
Benzene	71-43-2	1.3E+01	8.9E+00	9.7E+00	6.5E+00	6.5E+00	4.4E+00	6.1E+00	4.1E+00
Acrylonitrilee	107-13-1	1.2E+00	4.6E-01	7.9E-01	3.1E-01	2.0E-01	8.0E-02	1.3E-01	5.2E-02
Vinyl chloride	75-01-4	8.5E-02	3.7E-02	2.7E-02	1.2E-02	1.3E-02	5.7E-03	1.6E-02	6.7E-03
Chloroform	67-66-3	4.1E-01	5.1E-02	1.9E-01	2.3E-02	4.7E-02	5.9E-03	5.0E-02	6.2E-03
Trichloroethylene	79-01-6	2.2E-01	5.8E-02	2.5E-01	6.4E-02	1.9E-02	4.8E-03	9.8E-03	2.5E-03
Cd & Ca compounds	7440-43-9	7.6E-01	4.1E-01	3.9E-01	2.1E-01	7.9E-01	4.3E-01	8.5E-01	4.6E-01
Cr VI & Cr VI compounds	7440-47-3	4.5E+00	2.4E+00	3.3E+00	1.8E+00	2.0E+00	1.1E+00	1.9E+00	1.0E+00
Formaldehyde	50-00-0	8.4E-01	7.6E-01	6.0E-01	5.5E-01	3.9E-01	3.6E-01	3.7E-01	3.4E-01
Nil & Ni compounds	7440-02-0	5.8E+00	3.1E+00	6.6E+00	3.6E+00	1.0E+00	5.5E-01	1.0E+00	5.7E-01
Total	-	-	5.9E+04	-	5.2E+04	-	-	8.6E+04	4.2E+04

EU + NL: Health burden due to European and Dutch emissions; NL: Health burden due to Dutch emissions.

Table 14 *MEI_{VGZ} for secondary ozone as result of emission of NOx and NMVOC for 2000.*

Scenario	NO_x decrease in NL		NMVOC decrease in NL	
	4*25 %	100 %	4*25 %	100 %
MEI_{VGZ} –ozone (DALYs)	+ 5.2E+01	+ 6.6E+01	- 2.2E+00	- 2.3E+00

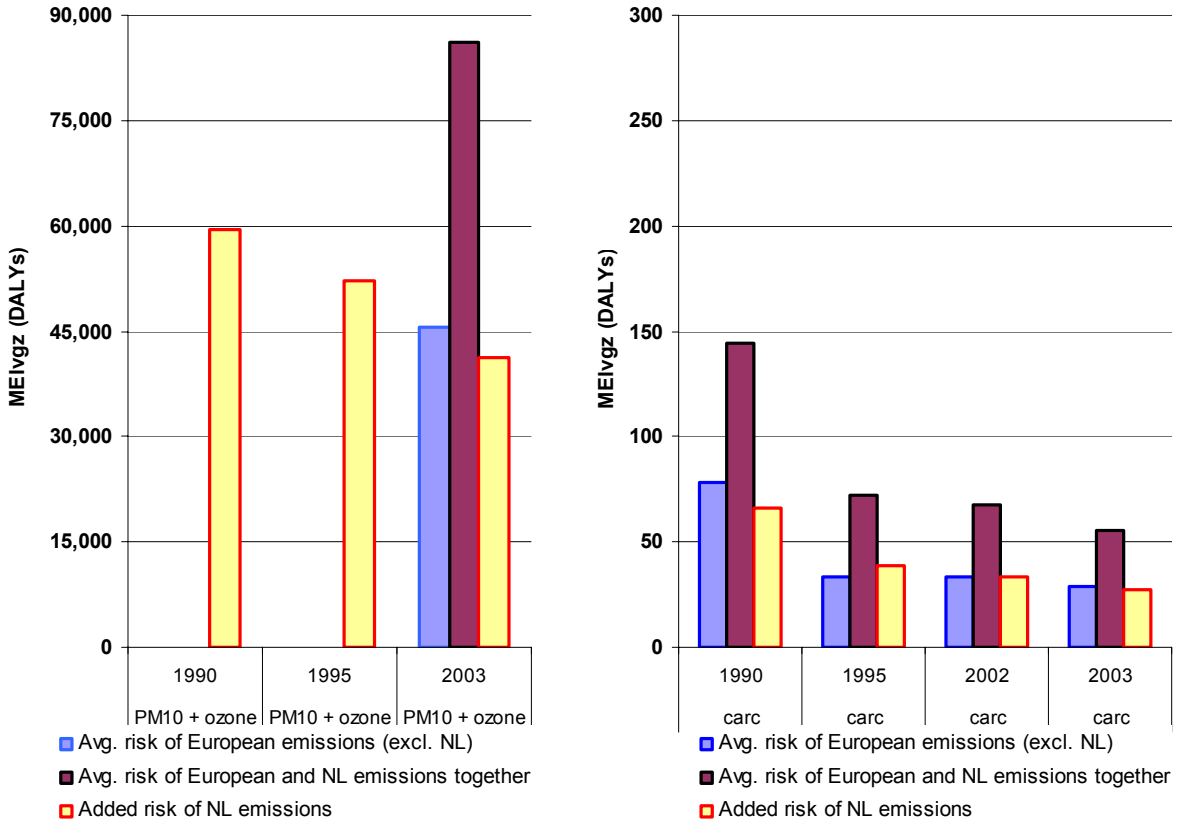

Figure 7 *The MEI_{VGZ} based on European and Dutch emissions for the period 1990-2003. The left figure summarizes the MEI_{VGZ} estimates for PM_{10} and ozone. The right figure summarizes the MEI_{VGZ} for the selected carcinogenic priority pollutants.*

Of the carcinogenic substances, benzo[a]pyrene is the substance of most importance from Dutch emissions, followed by benzene and 1,2-dichloroethane. Dutch emissions of B[a]P account for about 0.05% of the total health burden. Together B[a]P, benzene and 1,2-dichloroethane account for about 0.07% of the health burden from Dutch emissions.

5. Evaluation of uncertainties and MEI

The derivation of both MEI variables depends on models and data. This implies that uncertainties may be introduced by incomplete and/or uncertain data, but also by the application of inappropriate and/or over simplified modelling techniques. Following the cause-effect chain, uncertainties are separately listed for the two MEI indicators. Each of the uncertainty issues is discussed, and in the end the entire procedure is evaluated.

MEI_{ECO}

- With the inclusion of emissions for 48 priority pollutants, the MEI_{ECO} does not reflect the full set of 212 priority pollutants adopted in 2004 (VROM, 2004). This is solely due to the lack of emission data. For the remaining priority pollutants it is very well possible to generate the required information on physico-chemical and toxicological properties. Inclusion of the remaining pollutants, will certainly lead to an increase in the reported value of the MEI_{ECO}. However, even if the number of toxicants for which emission data are available is considerably extended beyond the hard-core priority pollutants that now take part in the evaluation, it is not expected that the MEI_{ECO} would increase more than marginally.
- The predicted water concentrations of the priority pollutants correspond remarkably well to the measured concentrations. This implies that the estimates generated by the SimpleBox model are based on properly estimated physico-chemical compound properties and distribution processes (partitioning coefficients and degradation constants).
- The SSD data for some of the priority pollutants evaluated are based on insufficient toxicity observations. However, the estimates used are based on expert judgement, as well as extrapolations from data available for comparable compounds with the same mode of action. It is not expected that the SSD data used for these compounds are far off from reality.

Even if the SSD estimates would deviate from reality, the MEI_{ECO} can still be used as a relative indicator to quantify the average change of probable environmental effects on the aquatic ecosystem over years.

MEI_{VGZ}

- With the inclusion of emissions for 11 carcinogenic priority pollutants and the emission and formation of PM_{10} and ozone, the MEI_{VGZ} does not reflect the full set of 212 priority pollutants adopted in 2004 (VROM, 2004). Next to the lack of emission data, this is in part due to the fact that information on health effects potentially associated with priority substances is generally lacking. Inclusion of the remaining pollutants, will certainly lead to an increase in the reported value of the MEI_{VGZ}. In view of the comparatively enormous health risk of PM_{10}, only a marginal increase is expected for the MEI_{VGZ} with an extension of the number of compounds for which emissions and health risk status could be quantified.
- The predicted air concentrations of the priority pollutants correspond remarkably well with the measured concentrations. This implies that the estimates generated by the different exposure models are based on properly estimated physico-chemical compound properties and distribution processes (transport phenomena, partitioning coefficients and degradation constants).

- Concentration uncertainties only influence the results over time. This is not the case for other substance-specific parameters, they can influence the relative importance between chemicals.
- At current NO_x and NMVOC emission rates, NO_x emission reduction will lead to an increase of ozone concentrations in the Netherlands and thereby an increase in human health effects. The lack of linearity in the emission-concentration relationship causes an uncertainty in the ozone burden of disease calculations of a maximum factor of 1.3 for NO_x.
- When calculating the MEI_{VGZ}, average exposure concentrations and average sensitivities determine the final outcome on the population level. But in reality, the variation in exposure and intraspecies variation of sensitivity determine the final outcome on the individual level. For example, for ozone especially the exposure to peak concentrations (smog) leads to health effects, but these peak concentrations are not considered here. Therefore, for health effects due to exposure to peak concentrations, the MEI_{VGZ} may lead to an underestimation of effects and further study is therefore recommended.
- We included the influence of Dutch and/or European emissions on the environmental and human health burden in the Netherlands only. This implies that burdens caused by Dutch emissions in other countries than the Netherlands are not included in the MEI. It is expected that for chemicals with the ability to transport over large distances, total environmental and human health impacts are underestimated by the calculation procedure adopted.
- For most substances no epidemiological information is available, therefore it is considered preferable to develop a human health assessment method based on toxicological data obtained from animal studies. This would enable us to evaluate the impact on public health for far more substances.

Even if the DALY estimates would deviate from reality, the MEI_{VGZ} can still be used as a relative indicator to quantify the average change of probable environmental health effects on the Netherlands population.

6. Conclusions

The goals of this study were:
1) to design and formulate methods to derive MEI to assess the effects of priority pollutant emissions on the ecosystem and on public health,
2) to illustrate the method with examples, evaluating the trends in the MEI evaluation for the years 1990, 1995, 2002 and 2003, and
3) to evaluate the effectivity of environmental policy in the Netherlands, with respect to the measures taken for reduction of priority pollutant emissions.

6.1 Design of MEI indicators

For the entire range of priority pollutants it proved to be possible to formulate methods to estimate the effects of emissions in the Netherlands on public health and the ecosystem. The actual limitation to a limited number of priority pollutants (48 for ecosystem effects and 13 for public health effects) is mainly caused by a lack of emission data for the remaining priority pollutants. For the estimation of public health effects the inclusion of additional priority pollutants is further restricted by a lack of compound and disease specific data on pathogenicity. The methods can be used for relative analyses of temporal trends, but they do not support any direct physical interpreation.

6.2 Trends in the MEI evaluation

The evaluation of both MEI for the years 1990 to 2003 demonstrates down-going trends. Except for the public health impact of fine particulate material (PM_{10}), the priority pollutants evaluated did not contribute excessively to the effects predicted for both public health and the ecosystem. PM_{10} on the other hand is by far (99%) the largest contributor to the public health effects that are estimated to be considerable. The priority pollutant emissions in the Netherlands contribute between 50% (PM_{10} - public health) and 75% (ecosystem) to the overall effects estimated to be caused by emissions in the Netherlands and the rest of Europe together.

6.3 Effectivity of environmental policy in the Netherlands

The down-going trends in both MEI coincide with down-going trends in the emissions of priority pollutants in the Netherlands and the resulting environmental concentrations. Assuming a direct relationship between the policy measures taken for emission reduction and the down-going trends in both MEI indicators, it can be concluded that the Netherlands environmental policy has been quite effective over the past 15 years, not only in reducing emissions, but also in reducing environmental concentrations and the associated probability and magnitude of impacts as inddicated by the MEI. The latter is evidently the ultimate driving force behind the formulation of environmental policies.

Literature

Alkemade, G. E. M., Peek, C. J., and Ruyssenaars, P. G. 2006. Prioritaire stoffen in de EmissieRegistratie: Emissies naar lucht, kwaliteit en aanbevelingen voor de verbetering van de EmissieRegistratie. MNP Report 500055003/2005 (in Dutch), Netherlands Environmental Assessment Agency, Bilthoven, the Netherlands.

Bakker, J., Brandes, L. J., Den Hollander, H. A., Van de Meent, D., and Struijs, J. 2003. Validating SimpleBox-Computed Steady-State Concentration Ratios. RIVM report 607220010, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

Bliss, C. I. 1939. The toxicity of poisons applied jointly. Annals of Applied Biology 26:585-615.

Brandes, L. H., den Hollander, H., and van de Meent, D. 1996. SimpleBox 2.0: a nested multimedia fate model for evaluating the environmental fate of chemicals. 719101029, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

Buijsman, E. 1999. Assessment of air quality for Polycyclic Aromatic Hydrocarbons in the Netherlands. RIVM Report 729999001, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

CBS. 2006. CBS StatLine, Central database of Statistics Netherlands. Accession date: April 2006. http://statline.cbs.nl. Voorburg/Heerlen, the Netherlands

Chapman, P. M., Fairbrother, A., and Brown, D. 1998. A critical evaluation of safety (uncertainty) factors for ecological risk assessment. Environmental Toxicology and Chemistry 17:99-108.

Cowan, C. E., Mackay, D., Feijtel, T. C. J., van de Meent, D., Di Guardo, A., Davies, J., and Mackay, D. N., editors. 1995. The multi-media fate model: A vital tool for predicting the fate of chemicals. SETAC Press, Pensacola, FL.

De Hollander, A. E. M. 2004. Assessing and evaluating the health impact of environmental exposures 'Deaths, DALYs or Dollars?' Utrecht University, Utrecht, the Netherlands.

De Hollander, A. E. M., Melse, J. M., Lebret, E., and Kramers, P. G. N. 1999. An Aggregate Public Health Indicator to Represent the Impact of Multiple Environmental Exposures. Epidemiology 10:606-617.

De Zwart, D. 2002. Observed regularities in SSDs for aquatic species. Pages 133-154 in Posthuma, L., Suter, G. W., II, and Traas, T. P., editors. Species Sensitivity Distributions in Ecotoxicology. Lewis Publishers, Boca Raton, FL, USA.

De Zwart, D., and Posthuma, L. 2005. Complex mixture toxicity for single and multiple species: proposed methodologies. Environmental Toxicology and Chemistry 24:2665–2676.

Forbes, T. L., and Forbes, V. E. 1993. A critique of the use of distribution-based extrapolation models in ecotoxicology. Functional Ecology 7:249-254.

Hewlett, P. S., and Plackett, R. L. 1979. The Interpretation of Quantal Responses in Biology. Edward Arnold, London, UK.

Hoekstra, J. A., Vaal, M. A., Notenboom, J., and Slooff, W. 1994. Variation in the sensitivity of aquatic species to toxicants. Bulletin of Environmental Contamination and Toxicology 53:98-105.

Hopkin, S. P. 1993. Ecological implications of 95% protection levels for metals in soil. Oikos 66:137-141.

Jagoe, R. H., and Newman, M. C. 1997. Bootstrap estimation of community NOEC values. Ecotoxicology 6:293-306.

Klepper, O., Traas, T. P., Schouten, A. J., Korthals, G. W., and De Zwart, D. 1999. Estimating the effect on soil organisms of exceeding no-observed effect concentrations (NOECs) of persistent toxicants. Ecotoxicology 8:9-21.

Knol, A. B., and Staatsen, B. A. M. 2005. Trends in the environmental burden of disease in the Netherlands 1980 – 2020. RIVM report 500029001, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

Krewitt, W., Pennington, D. W., Olsen, S. I., Crettaz, P., and Jolliet, O. 2002. Life-Cycle Impact Assessment: Striving Towards Best Practice. in Udo de Haes, H., Jolliet, O., Finnveden, G., Goedkoop, M., Hauschild, M., Hertwich, E., Hofstetter, P., Klöpffer, W., Krewitt, W., Lindeijer, E., Mueller-Wenk, R., Olson, S., Pennington, D., Potting, J., and Steen, B., editors. Towards best available practice in life cycle impact assessment. SETAC Europe Press, Brussels, Belgium.

Melse, J. M., and Kramers, P. G. N. 1998. Berekeningen van de ziektelast in Nederland. Achtergronddocument bij VTV-1997 deel III, hoofdstuk 7. RIVM report 431501028, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

Mennen, M. G., Koot, W., Van Putten, E. M., Ritsema, R., S., P., Knol-de Vos, T., Fortezza, F., and Kliest, J. J. G. 1998. Hexavalent chromium in ambient air in the Netherlands. Results of measurements near wood preservation plants and at a regional site. RIVM report 723101031, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

Morrow, R. H., and Bryant, J. H. 1995. Health Policy Approaches to Measuring and Valuing Human Life: Conceptual and Ethical Issues. American Journal of Public Health 85:1356-1360.

Murray, C. J. L., and Lopez, A. D., editors. 1996. The Global Burden of Disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. Harvard University Press, Cambridge, Massachusetts, USA.

Notenboom, J., Vaal, M. A., and Hoekstra, J. A. 1995. Using comparative ecotoxicology to develop quantitative species sensitivity relationships (QSSR). Environmental Science and Pollution Research 2:242-243.

Plackett, R. L., and Hewlett, P. S. 1952. Quantal responses to mixtures of poisons. Journal of the Royal Statistical Society B 14:141-163.

Posthuma, L., and De Zwart, D. 2006. Predicted effects of toxicant mixtures are confirmed by changes in fish species assemblages in Ohio, USA rivers. Environmental Toxicology and Chemistry 25:1094-1105.

Posthuma, L., Suter, G. W., II, and Traas, T. P., editors. 2002. Species Sensitivity Distributions in Ecotoxicology. Lewis Publishers, Boca Raton, FL, USA.

RIVM. 2004. Nationaal Kompas Volksgezondheid. Volksgezondheid Toekomst Verkenning. Accession date: November 2004. http://www.nationaalkompas.nl. Bilthoven, the Netherlands

Schaap, M., Roemer, M., Sauter, F. J., Boersen, M., Timmermans, R. M. A., and Builtjes, P. J. H. 2005. LOTOS-EUROS: Documentation. 2005/297, TNO, Apeldoorn, the Netherlands.

Schaap, M., Timmermans, R. M. A., Roemer, M., Boersen, M., Builtjes, P. J. H., Sauter, F. J., Velders, G. J. M., and Beck, J. P. 2006. The LOTOS-EUROS model: description, validation and latest developments. International Journal of Environment and Pollution In Press.

Seigneur, C., Wrobel, J., and Constantinou, E. 1996. A Chemical Kinetic Mechanism for Atmospheric Inorganic Mercury. Environmental Science & Technology 30:2421–2426.

Smith, E. P., and Cairns, J., Jr. 1993. Extrapolation methods for setting ecological standards for water quality, statistical and ecological concerns. Ecotoxicology 2:203-219.

Stephan, C. E. 1985. Are the 'Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Life and Its Uses' Based on Sound Judgments? Pages 515-526 in Cardwell, R. D., Purdy, R., and Bahner, R. C., editors. Aquatic Toxicology and Hazard Assessment, Seventh Symposium. American Society for Testing and Materials, Philadelphia, PA.

Stephan, C. E., Mount, D. I., Hansen, D. J., Gentile, J. H., Chapman, G. A., and Brungs, W. A. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB 85-227049, United States EPA ORD ERL, Duluth MN.

Sterkenburg, A., Van de Bovekamp, A., Den Hollander, H. A., and Van de Meent, D. 2000. Milieukwaliteitsindicator Verspreiding. RIVM report 607880001, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

USEPA. 2006. Integrated Risk Information System (IRIS). Accession date: April 2006. http://www.epa.gov/iriswebp/iris/.

Vaal, M. A., Van der Wal, J. T., Hermens, J., and Hoekstra, J. 1997a. Pattern analysis of the variation in the sensitivity of aquatic species to toxicants. Chemosphere 35:1291-1309.

Vaal, M. A., Van der Wal, J. T., Hoekstra, J., and Hermens, J. 1997b. Variation in the sensitivity of aquatic species in relation to the classification of environmental pollutants. Chemosphere 35:1311-1327.

Vaal, M. A., Van Leeuwen, C. J., Hoekstra, J. A., and Hermens, J. L. M. 2000. Variation in sensitivity of aquatic species to toxicants: practical consequences for effect assessment of chemical substances. Environmental Management 25:415-423.

Van de Bovekamp, A., Sterkenburg, A., and Wesselink, L. G. 1999. Milieudrukindicator Verspreiding. RIVM report 601503018, National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands.

Van de Meent, D. 1993. SimpleBox: A generic multimedia fate evaluation model. RIVM report 672720001, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

Van Jaarsveld, J. A. 2004. The Operational Priority Substances model: description and validation of OPS-Pro 4.1. RIVM report 500045001, National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

Van Straalen, N. M., and Denneman, C. A. J. 1989. Ecotoxicological evaluation of soil quality criteria. Ecotoxicology and Environmental Safety 18:241-251.

Vermeire, T. G., Jager, D. T., Bussian, B., Devillers, J., Den Haan, K., Hansen, B., Lundberg, I., Niessen, H., Robertson, S., Tyle, H., and Van der Zandt, P. T. 1997. European Union System for the Evaluation of Substances (EUSES). Principles and Structure. Chemosphere 34:1823-1836.

VROM. 2004. Nederlands stoffenbeleid in internationaal perspectief. Uitvoeringsnota SOMS. Netherlands Ministry of Housing, Spatial Planning and the Environment (VROM), The Hague, the Netherlands.

Wagner, C., and Løkke, H. 1991. Estimation of ecotoxicological protection levels from NOEC toxicity data. Water Research 25:1237-1242.

WHO. 2001. Air quality guidelines for Europe. Regional publications, European series No. 91, World Health Organization, Copenhagen, Denmark.

Annex 1

Table of emissions from Alkemade et al.(2006). Summary emissions identified as a group of individual pollutants are separated by bold lines.

		Emission to air (T.yr^{-1})				Emission to water (T.yr^{-1})				Emission to soil (T.yr^{-1})			
CAS	**Name**	**1990**	**1995**	**2002**	**2003**	**1990**	**1995**	**2002**	**2003**	**1990**	**1995**	**2002**	**2003**
608-93-5	Pentachlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
634-66-2	1,2,3,4-Tetrachlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
87-61-6	1,2,3-Trichlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
106-46-7	1,4-dichlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
108-90-7	Chlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
118-74-1	Hexachlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
634-90-2	1,2,3,5-Tetrachlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
95-94-3	1,2,4,5-Tetrachlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
120-82-1	1,2,4-Trichlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
95-50-1	1,2-Dichlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
108-70-3	1,3,5-Trichlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
541-73-1	1,3-Dichlorobenzene	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
25321-22-6	Dichlorobenzene (mixed isomers)	84.5	43.8	59.5	41.1	1.94	1.42	1.51	1.54	-	-	-	-
1336-36-3	PCB-Total	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
11097-69-1	PCB-1254	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
37680-73-2	PCB-101	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
2050-68-2	PCB-15	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
35065-27-1	PCB-153	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
2051-24-3	PCB-209	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
15862-07-4	PCB-29	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
35693-99-3	PCB-52	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
33284-50-3	PCB-7	-	0.0000153	-	3.1E-09	0.00656	0.00244	0.0019	0.000905	-	-	-	-
108-95-2	Phenol	456	260	151	146	0.474	1.93	5.16	5.22	-	-	-	-
91-20-3	Naphthalene	199.7136	158.5756	130.4725	127.9566	34.62359	22.76191	11.65633	15.45958	-	-	-	-
85-01-8	Phenanthrene	325.5034	258.45456	212.6506	208.5502	56.43128	37.09852	18.99807	25.19681	-	-	-	-
120-12-7	Anthracene	31.59648	25.08808	20.64191	20.24388	5.477762	3.601138	1.844135	2.445844	-	-	-	-
56-55-3	Benzo[a]Anthracene	9.53856	7.57376	6.23152	6.11136	1.653664	1.087136	0.55672	0.738368	-	-	-	-
218-01-9	Chyrsene	10.13472	8.04712	6.62099	6.49332	1.757018	1.155082	0.591515	0.784516	-	-	-	-
207-08-9	Benzo[k]fluoranthene	3.57696	2.84016	2.33682	2.29176	0.620124	0.407676	0.20877	0.276888	-	-	-	-
191-24-2	Benzo[ghi]perylene	8.34624	6.62704	5.45258	5.34744	1.446956	0.951244	0.48713	0.646072	-	-	-	-
193-39-5	Indeno[1,2,3-cd]pyrene	7.75008	6.15368	5.06311	4.96548	1.343602	0.883298	0.452335	0.599924	-	-	-	-
50-32-8	Benzo(a)pyreen	4.84	2.74	2.73	2.04	0.976	0.884	0.415	0.472	-	-	-	-
206-44-	Fluorantheen	102	64.9	38.8	38	6.67	5.87	4.29	4.78	-	-	-	-
87-86-5	Pentachlorophenol	34	29	22.7	22.1	0.268	0.0839	0.0724	0.0717	-	-	-	-
106-48-9	4-Chlorophenol	34	29	22.7	22.1	0.268	0.0839	0.0724	0.0717	-	-	-	-
120-83-2	2,4-Dichlorophenol	34	29	22.7	22.1	0.268	0.0839	0.0724	0.0717	-	-	-	-
58-90-2	2,3,4,6-Tetrachlorophenol	34	29	22.7	22.1	0.268	0.0839	0.0724	0.0717	-	-	-	-
88-06-2	2,4,6-Trichlorophenol	34	29	22.7	22.1	0.268	0.0839	0.0724	0.0717	-	-	-	-
95-57-8	2-Chlorophenol	34	29	22.7	22.1	0.268	0.0839	0.0724	0.0717	-	-	-	-
95-95-4	2,4,5-Trichlorophenol	34	29	22.7	22.1	0.268	0.0839	0.0724	0.0717	-	-	-	-

CAS	Name	Emission to air (T.yr^{-1})				Emission to water (T.yr^{-1})				Emission to soil (T.yr^{-1})			
		1990	1995	2002	2003	1990	1995	2002	2003	1990	1995	2002	2003
51207-31-9	2,3,7,8-Tetrachlorodibenzofurane	.000743	.0000662	2.88E-05	2.76E-05	1.31E-06	4.84E-07	1.09E-07	1.47E-07	-	-	-	-
39001-02-	Octachlorodibenzofurane	.000743	.0000662	2.88E-05	2.76E-05	1.31E-06	4.84E-07	1.09E-07	1.47E-07	-	-	-	-
5409-83-6	2,8-Dichlorodibenzofurane	.000743	.0000662	2.88E-05	2.76E-05	1.31E-06	4.84E-07	1.09E-07	1.47E-07	-	-	-	-
57117-31-4	2,3,4,7,8-Pentachlorodibenzofurane	.000743	.0000662	2.88E-05	2.76E-05	1.31E-06	4.84E-07	1.09E-07	1.47E-07	-	-	-	-
67562-39-4	1,2,3,4,6,7,8-Heptachlorodibenzofurane	.000743	.0000662	2.88E-05	2.76E-05	1.31E-06	4.84E-07	1.09E-07	1.47E-07	-	-	-	-
70648-26-9	1,2,3,4,7,8-Hexachlorodibenzofurane	.000743	.0000662	2.88E-05	2.76E-05	1.31E-06	4.84E-07	1.09E-07	1.47E-07	-	-	-	-
117-81-7	Di-(2-ethylhexyl) phthalate	103	40	4.46	.001	1.11	0.808	0.525	0.512	-	-	-	-
131-11-3	Dimethylphthalate	103	40	4.46	.001	1.11	0.808	0.525	0.512	-	-	-	-
28553-12-	Di-isononyl phthalate	103	40	4.46	.001	1.11	0.808	0.525	0.512	-	-	-	-
84-61-7	Dicyclohexyl phthalate	103	40	4.46	.001	1.11	0.808	0.525	0.512	-	-	-	-
84-66-2	Diethylphthalate	103	40	4.46	.001	1.11	0.808	0.525	0.512	-	-	-	-
84-69-5	Di-isobutyl phthalate	103	40	4.46	.001	1.11	0.808	0.525	0.512	-	-	-	-
84-74-2	Dibutyl phthalate	103	40	4.46	.001	1.11	0.808	0.525	0.512	-	-	-	-
85-68-7	Butyl benzyl phthalate	103	40	4.46	.001	1.11	0.808	0.525	0.512	-	-	-	-
107-06-2	1,2-Dichloroethane	1250	156	381	381	5.9	1.87	1.94	1.06	-	-	-	-
127-18-4	Tetrachloroethene (PER)	1190	1050	741	766	1.12	0.15	0.0411	0.0223	-	-	-	-
67-66-3	Trichloromethane	67.8	30.1	7.49	7.74	0.717	1.17	0.405	0.721	-	-	-	-
71-43-2	Benzene	10600	7760	5230	4890	55.4	31.8	19.8	18.8	-	-	-	-
79-01-6	Trichloroethene	916	1010	75.7	40	3.79	0.136	0.0816	0.0459	-	-	-	-
107-13-1	Acrylonitrile	175	118	30.5	20	-	-	-	-	-	-	-	-
7440-43-9	Cadmium	2.11	1.09	2.2	2.35	7.29	3.7	2.88	2.62	6.01	2.82	2.12	2.42
7440-47-3	Chromium	11.2	8.22	4.9	4.73	34	18	8.63	8.33	69.3	73	89.2	93.8
50-00-	Formaldehyde	4690	3350	2180	2060	17.2	27.2	20.4	19.1	-	-	-	-
7439-92-1	Lead	334	159	36.9	35.5	225	155	137	132	497	334	320	321
7440-02-	Nickel	76	87.6	13.3	13.8	165	153	137	133	27.2	26.4	28.3	28.6
75-01-4	Vinylchloride	285	89.6	44.5	51.9	-	-	-	.0248	-	-	-	-
75-21-8	Oxirane	186	40.2	13.2	21.8	-	-	-	-	-	-	-	-
100-42-5	Styrene	1980	1250	593	567	-	0.41	0.0073	0.0135	-	-	-	-
108-88-3	Toluene	43100	25300	11900	10900	-	-	-	-	-	-	-	-
56-23-5	Tetrachloromethane (Tetra)	313	131	10	10	0.47	0.132	0.0172	0.0129	-	-	-	-
75-09-2	Dichloromethane	2460	2000	360	348	0.148	0.901	0.143	0.159	-	-	-	-
107-02-8	Acroleïne	867	686	540	524	-	-	-	-	-	-	-	-
74-85-1	Ethene	18600	12300	8180	8090	-	-	-	-	-	-	-	-
7440-50-8	Copper	19.2	20.3	22.1	21.5	180	180	120	109	934	775	542	535
7439-97-6	Mercury	3.41	1.14	0.717	0.695	1.36	1.06	0.434	0.471	0.147	0.0146	0.0137	0.0136
75-56-9	Methyloxirane	1E-08	3.23	0.326	0.231	-	-	-	-	-	-	-	-
7440-66-6	Zinc	221	144	89	90.6	-	1600	1530	1490	1790	1680	1100	1130
7440-38-2	Arsenic	1.46	1.19	1.19	0.975	12	11.4	11	10.9	-	-	-	-
7664-41-7	Ammonia	249000	193000	136000	130000	-	-	-	-	-	-	-	-
630-08-	Carbonmonoxide	1180000	907000	692000	672000	-	-	-	-	-	-	-	-
71-55-6	1,1,1-Trichloroethane	4810	1050	104	104	0.12	0.146	0.0242	0.00804	-	-	-	-
10102-44-	Nitrogendioxide	592000	507000	410000	409000	-	-	-	-	-	-	-	-
7664-93-9	Sulfurdioxide	242000	183000	138000	138000	-	-	-	-	-	-	-	-
7783-06-4	Hydrogensulfide	3110	2430	2110	2090	-	-	-	-	-	-	-	-
58-89-9	HCH (water)	-	-	-	-	0.132	0.0556	5.69E-06	3.32E-05	-	-	-	-
7681-49-4	Fluorides	1580	940	1040	1060	37500	1810	2950	2300	-	-	-	-

Annex 2

Table of physico-chemical properties for priority pollutants. The columns MW, Kh', Pvap25, SOL25 and K_{OW} quantify molecular weight, the dimensionless Henri coefficient, the vapor pressure at 25 ºC, water solubility at 25 ºC and the octanol-water partitioning coefficient for organic substances, respectively. For non-organic pollutants, the different Kp columns quantify water-particulate material partitioning coefficients in soil, sediment and suspended matter, respectively.

ID #	Name	MW $g.mol^{-1}$	Tm °C	KpSoil -	KpSed -	KpSusp -	Kh' -	Pvap25 Pa	Sol25 $mg.L^{-1}$	K_{OW} -
608-93-5	Pentachlorobenzene	250.3	86				2.8E-02	2.2E-01	6.5E-01	1.0E+05
634-66-2	1,2,3,4-Tetrachlorobenzene	215.9	47.5				3.1E-02	5.2E+00	7.8E+00	3.2E+04
87-61-6	1,2,3-Trichlorobenzene	181.5	53				5.0E-02	2.8E+01	2.1E+01	1.3E+04
106-46-7	1,4-dichlorobenzene	147	53.1				9.7E-02	1.5E+02	7.2E+01	2.5E+03
108-90-7	Chlorobenzene	112.6	-46				1.3E-01	1.6E+03	4.8E+02	6.3E+02
118-74-1	Hexachlorobenzene	284.8	228				6.9E-02	2.3E-03	5.0E-03	3.2E+05
634-90-2	1,2,3,5-Tetrachlorobenzene	215.9	54.5				4.7E-02	9.8E+00	3.6E+00	3.2E+04
95-94-3	1,2,4,5-Tetrachlorobenzene	215.9	140				4.0E-02	7.2E-01	1.3E+00	3.2E+04
120-82-1	1,2,4-Trichlorobenzene	181.5	17				5.7E-02	6.1E+01	4.0E+01	1.3E+04
95-50-1	1,2-Dichlorobenzene	147	-17				7.7E-02	2.0E+02	1.2E+02	2.5E+03
108-70-3	1,3,5-Trichlorobenzene	181.5	64				7.1E-02	3.2E+01	5.3E+00	1.3E+04
541-73-1	1,3-Dichlorobenzene	147	-25				1.1E-01	3.1E+02	1.2E+02	2.5E+03
25321-22-6	Dichlorobenzene (mixed isomers)	147	-25				8.1E-09	3.1E+02	1.2E+02	3.0E+03
1336-36-3	PCB-Total	292	122				1.7E-02	1.2E-02	2.8E-01	1.3E+07
11097-69-1	PCB-1254	326.4	100				1.1E-02	1.0E-03	5.5E-02	3.2E+06
37680-73-2	PCB-101	326.4	135				3.7E-03	3.4E-03	1.5E-02	6.3E+06
2050-68-2	PCB-15	223.1	149				8.1E-03	7.1E-02	6.2E-02	1.7E+05
35065-27-1	PCB-153	360.9	103				9.4E-04	4.6E-04	1.0E-03	7.9E+06
2051-24-3	PCB-209	498.7	306				3.8E-01	1.4E-05	1.0E-06	1.8E+08
15862-07-4	PCB-29	257.6	76.3				8.2E-03	1.3E-01	1.6E-01	6.5E+05
35693-99-3	PCB-52	292	87				8.2E-03	4.9E-03	3.0E-02	1.3E+06
33284-50-3	PCB-7	223.1	81.5				1.1E-02	1.8E-01	1.2E+00	1.4E+05
108-95-2	Phenol	94.1	41				1.3E-05	4.7E+01	8.8E+04	2.9E+01
91-20-3	Naphthalene	128.2	80.5				1.8E-02	1.0E+01	3.1E+01	2.3E+03
85-01-8	Phenanthrene	178.2	101				1.7E-03	2.0E-02	1.1E+00	3.7E+04
120-12-7	Anthracene	178.2	216				2.2E-03	1.0E-03	4.5E-02	2.8E+04
56-55-3	Benzo[a]Anthracene	228.3	160				4.8E-04	2.8E-05	1.1E-02	8.1E+05
218-01-9	Chyrsene	228.3	255				2.1E-04	5.7E-07	2.0E-03	4.1E+05
207-08-9	Benzo[k]fluoranthene	252.3	217				2.4E-05	5.2E-08	8.0E-04	1.0E+06
191-24-2	Benzo[ghi]perylene	276.3	277				1.3E-05	1.4E-08	2.6E-04	3.2E+06
193-39-5	Indeno[1,2,3-cd]pyrene	276.3	163				1.4E-05	1.3E-08	6.2E-02	5.0E+06
50-32-8	Benzo(a)pyreen	252.3	177				1.8E-05	7.1E-07	2.1E-03	1.1E+06
206-44-0	Fluorantheen	202.3	111				3.6E-04	1.2E-03	2.6E-01	1.7E+05
87-86-5	Pentachlorophenol	266.3	190				9.9E-07	4.2E-03	1.4E+01	1.1E+05
106-48-9	4-Chlorophenol	128.6	42.7				2.5E-05	1.2E+01	2.4E+04	2.5E+02
120-83-2	2,4-Dichlorophenol	163	44				8.8E-05	1.2E+01	4.5E+03	1.6E+03

ID #	Name	MW g.mol^{-1}	Tm °C	KpSoil -	KpSed -	KpSusp -	Kh' -	Pvap25 Pa	Sol25 mg.L^{-1}	K_{ow} -
58-90-2	2,3,4,6-Tetrachlorophenol	231.9	70				1.4E-04	2.8E-01	1.8E+02	2.8E+04
88-06-2	2,4,6-Trichlorophenol	197.5	69.5				1.0E-04	1.3E+00	4.3E+02	4.9E+03
95-57-8	2-Chlorophenol	128.6	9				4.5E-04	1.3E+02	2.5E+04	1.4E+02
95-95-4	2,4,5-Trichlorophenol	197.5	69				6.5E-05	2.5E+00	9.5E+02	5.2E+03
51207-31-9	2,3,7,8-Tetrachlorodibenzofurane	306	227				6.8E-04	2.0E-04	4.2E-04	1.3E+06
39001-02-0	Octachlorodibenzofurane	443.8	258				7.7E-05	5.0E-10	1.2E-06	1.0E+08
5409-83-6	2,8-Dichlorodibenzofurane	237.1	184				2.6E-03	3.9E-04	1.5E-02	2.8E+05
57117-31-4	2,3,4,7,8-Pentachlorodibenzofurane	340.4	196				2.0E-04	1.7E-05	2.4E-04	3.2E+06
67562-39-4	1,2,3,4,6,7,8-Heptachlorodibenzofurane	409.3	236				5.8E-04	5.7E-07	1.4E-06	2.5E+07
70648-26-9	1,2,3,4,7,8-Hexachlorodibenzofurane	374.9	226				5.9E-04	3.1E-06	8.2E-06	1.0E+07
117-81-7	Di-(2-ethylhexyl) phthalate	390.5	-47				5.9E-04	1.3E-05	3.0E-03	1.3E+05
131-11-3	Dimethylphthalate	194.2	5				4.2E-06	2.5E-01	4.2E+03	1.3E+02
28553-12-0	Di-isononyl phthalate	418.6	84.9				6.1E-05	7.2E-05	2.0E-01	2.3E+09
84-61-7	Dicyclohexyl phthalate	330.4	66				4.1E-06	1.2E-04	4.0E+00	1.6E+06
84-66-2	Diethylphthalate	222.3	-41				1.8E-05	8.2E-02	1.1E+03	3.0E+02
84-69-5	Di-isobutyl phthalate	278.4	17.6				5.0E-05	3.2E-01	6.2E+00	1.3E+04
84-74-2	Dibutyl phthalate	278.3	-35				7.3E-05	2.7E-03	1.1E+01	5.2E+04
85-68-7	Butyl benzyl phthalate	312.4	-35				5.1E-05	8.6E-04	2.7E+00	4.8E+04
107-06-2	1,2-Dichloroethane	98.96	-35				4.8E-02	1.1E+04	8.5E+03	3.0E+01
127-18-4	Tetrachloroethene (PER)	165.8	-19				7.1E-01	2.6E+03	2.6E+02	7.6E+02
67-66-3	Trichloromethane	119.4	-64				1.5E-01	2.6E+04	8.2E+03	9.3E+01
71-43-2	Benzene	78.11	5.53				2.2E-01	1.3E+04	1.8E+03	1.3E+02
79-01-6	Trichloroethene	131.4	-84				4.0E-01	9.7E+03	1.4E+03	3.4E+02
107-13-1	Acrylonitrile	53.06	-84				5.6E-03	1.1E+04	7.6E+04	1.8E+00
7440-43-9	Cadmium	112.4	321	2.0E+02	8.5E+04	1.3E+05	8.1E-26			
7440-47-3	Chromium	52	1900	1.1E+02	1.9E+05	2.9E+05	8.1E-26			
50-00-0	Formaldehyde	30.03	-92				1.4E-05	5.2E+05	1.2E+06	2.2E+00
7439-92-1	Lead	207.2	327	1.9E+03	4.3E+05	6.5E+05	8.1E-26			
7440-02-0	Nickel	58.69	1455	3.6E+02	5.2E+03	7.9E+03	8.1E-26			
75-01-4	Vinylchloride	62.5	-154				1.1E+00	3.5E+05	2.8E+03	2.4E+01
75-21-8	Oxirane	44.05	-111				6.0E-03	1.8E+05	3.6E+08	5.0E-01
100-42-5	Styrene	104.1	-31				1.1E-01	8.0E+02	3.0E+02	1.1E+03
108-88-3	Toluene	92.13	-95				2.7E-01	3.8E+03	5.2E+02	4.9E+02
56-23-5	Tetrachloromethane (Tetra)	153.8	-23				1.1E+00	1.5E+04	8.0E+02	4.4E+02
75-09-2	Dichloromethane	84.94	-95				1.3E-01	2.6E+04	1.3E+04	1.8E+01
107-02-8	Acroleïne	56.04	-87				4.9E-03	3.7E+04	2.1E+05	9.8E-01
74-85-1	Ethene	28.05	-169				9.2E+00	2.7E+09	2.6E+02	1.3E+01
7440-50-8	Copper	63.55	1083	2.2E+02	3.4E+04	5.0E+04	8.1E-26			
7439-97-6	Mercury	200.6	-39	1.7E+02	1.1E+05	1.7E+05	2.8E-05			
75-56-9	Methyloxirane	58.08	-112				2.8E-03	7.1E+04	4.8E+05	1.1E+00
7440-66-6	Zinc	65.39	420	3.3E+02	7.2E+04	1.1E+05	8.1E-26			
7440-38-2	Arsenic	74.92	817	3.3E+03	6.6E+03	1.0E+04	8.1E-26			
7664-41-7	Ammonia	17.03	-78				6.5E-04	9.2E+05	5.7E+05	4.2E-02
630-08-0	Carbonmonoxide	28.01	-205					2.1E+10	4.0E+01	6.0E+01
71-55-6	1,1,1-Trichloroethane	133.4	-30				6.9E-01	1.7E+04	1.5E+03	3.1E+02
10102-44-0	Nitrogendioxide	46.02	-11					1.4E+05	1.0E+06	2.6E-01
7664-93-9	Sulfurdioxide	64.06	-76					3.1E+05	1.1E+05	6.3E-03

ID #	Name	MW $g.mol^{-1}$	Tm °C	KpSoil -	KpSed -	KpSusp -	Kh' -	Pvap25 Pa	Sol25 $mg.L^{-1}$	K_{ow} -
7783-06-4	Hydrogensulfide	34.08	-86				3.5E-01	2.0E+06	2.9E+03	4.2E-02
58-89-9	HCH (water)	290.9	113				2.1E-04	3.7E-03	7.3E+00	5.0E+03
7681-49-4	Fluorides	41.99	993	1.0E-04	1.0E-04	1.0E-04	1.0E-06	2.0E-06	5.0E+03	

Annex 3

Table of degradation constants and ecotoxicological properties based on chronic NOEC data. The four columns kdeg(x) give degradation constants in air, water, sediments and soil, respectively. TMoA identifies the toxic mode of action. Mu (μ) and sigma (σ) quantify the centre and the slope of the SDD on a log concentration scale, respectively.

ID #	Name	kdeg(air) s^{-1}	kdeg(water) s^{-1}	kdeg(sed) s^{-1}	kdeg(soil) s^{-1}	TMoA -	μ Log $g.L^{-1}$	σ Log $g.L^{-1}$
608-93-5	Pentachlorobenzene	3.5E-08	1.1E-08	1.1E-08	1.1E-08	Nonpolar narcosis	-2.12	0.71
634-66-2	1,2,3,4-Tetrachlorobenzene	1.1E-07	3.5E-08	1.1E-08	3.5E-08	Nonpolar narcosis	-0.45	0.71
87-61-6	1,2,3-Trichlorobenzene	3.5E-07	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-3.48	0.71
106-46-7	1,4-dichlorobenzene	3.5E-07	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-3.02	0.71
108-90-7	Chlorobenzene	1.1E-06	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-1.99	0.71
118-74-1	Hexachlorobenzene	2.6E-08	3.5E-09	3.5E-09	3.5E-09	Nonpolar narcosis	-1.79	0.71
634-90-2	1,2,3,5-Tetrachlorobenzene	4.2E-08	1.1E-07	1.0E-07	1.1E-07	Nonpolar narcosis	-3.05	0.71
95-94-3	1,2,4,5-Tetrachlorobenzene	1.1E-07	3.5E-08	1.1E-08	3.5E-08	Nonpolar narcosis	-3.66	0.71
120-82-1	1,2,4-Trichlorobenzene	3.5E-07	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-2.10	0.71
95-50-1	1,2-Dichlorobenzene	3.5E-07	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-4.79	0.71
108-70-3	1,3,5-Trichlorobenzene	2.5E-07	1.1E-07	1.0E-07	1.1E-07	Nonpolar narcosis	-2.42	0.71
541-73-1	1,3-Dichlorobenzene	3.5E-07	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-1.83	0.71
25321-22-6	Dichlorobenzene (mixed isomers)	2.1E-07	1.1E-07	1.3E-07	1.1E-07	Nonpolar narcosis	-2.31	0.71
1336-36-3	PCB-Total	4.1E-07	5.7E-07	1.4E-07	5.7E-07	Ah-receptor	-3.11	0.91
11097-69-1	PCB-1254	1.7E-07	2.9E-08	6.0E-10	8.5E-09	Ah-receptor	-3.11	0.91
37680-73-2	PCB-101	1.7E-07	2.1E-07	9.9E-08	1.1E-07	Ah-receptor	-3.00	0.91
2050-68-2	PCB-15	1.0E-06	5.3E-07	2.5E-07	2.7E-07	Ah-receptor	-3.00	0.91
35065-27-1	PCB-153	3.5E-08	3.5E-09	3.5E-09	3.5E-09	Ah-receptor	-6.89	0.91
2051-24-3	PCB-209	3.5E-09	3.5E-09	3.5E-09	3.5E-09	Ah-receptor	-6.89	0.91
15862-07-4	PCB-29	6.5E-07	5.3E-07	2.5E-07	2.7E-07	Ah-receptor	-3.60	0.91
35693-99-3	PCB-52	1.1E-07	3.5E-09	3.5E-09	3.5E-09	Ah-receptor	-5.52	0.91
33284-50-3	PCB-7	1.3E-06	5.3E-07	2.5E-07	2.7E-07	Ah-receptor	-3.00	0.91
108-95-2	Phenol	1.5E-05	8.6E-06	4.5E-07	1.5E-06	Polar narcosis	-3.67	0.85
91-20-3	Naphthalene	1.1E-05	1.1E-06	3.5E-08	1.1E-07	Nonpolar narcosis	-3.73	0.71
85-01-8	Phenanthrene	3.5E-06	3.5E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-4.79	0.71
120-12-7	Anthracene	3.5E-06	3.5E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-5.48	0.71
56-55-3	Benzo[a]Anthracene	1.1E-06	1.1E-07	3.5E-09	1.1E-08	Nonpolar narcosis	-6.02	0.71
218-01-9	Chyrsene	1.1E-06	1.1E-07	3.5E-09	1.1E-08	Nonpolar narcosis	-5.72	0.71
207-08-9	Benzo[k]fluoranthene	1.1E-06	1.1E-07	3.5E-09	1.1E-08	Nonpolar narcosis	-6.09	0.71
191-24-2	Benzo[ghi]perylene	1.1E-06	1.1E-07	3.5E-09	1.1E-08	Nonpolar narcosis	-6.52	0.71
193-39-5	Indeno[1,2,3-cd]pyrene	3.2E-05	1.2E-08	1.2E-08	1.2E-08	Nonpolar narcosis	-6.72	0.71
50-32-8	Benzo(a)pyreen	1.1E-06	1.1E-07	3.5E-09	1.1E-08	Nonpolar narcosis	-5.82	0.71
206-44-0	Fluorantheen	1.1E-06	1.1E-07	3.5E-09	1.1E-08	Nonpolar narcosis	-5.38	0.71
87-86-5	Pentachlorophenol	3.5E-07	3.5E-07	3.5E-08	1.1E-07	Unc. oxidative phosphorylation	-3.27	0.82
106-48-9	4-Chlorophenol	3.5E-06	3.5E-06	1.1E-07	3.5E-07	Unc. oxidative phosphorylation	-2.69	0.82
120-83-2	2,4-Dichlorophenol	3.5E-06	3.5E-06	1.1E-07	3.5E-07	Unc. oxidative phosphorylation	-3.40	0.82
58-90-2	2,3,4,6-Tetrachlorophenol	3.5E-07	3.5E-07	3.5E-08	1.1E-07	Unc. oxidative phosphorylation	-6.10	0.82
88-06-2	2,4,6-Trichlorophenol	1.1E-06	1.1E-06	3.5E-08	1.1E-07	Unc. oxidative phosphorylation	-2.63	0.82
95-57-8	2-Chlorophenol	4.9E-06	2.6E-07	2.6E-07	2.3E-06	Unc. oxidative phosphorylation	-4.10	0.82

ID #	Name	kdeg(air) s^{-1}	kdeg(water) s^{-1}	kdeg(sed) s^{-1}	kdeg(soil) s^{-1}	TMoA -	μ Log $g.L^{-1}$	σ Log $g.L^{-1}$
95-95-4	2,4,5-Trichlorophenol	1.1E-06	1.1E-06	3.5E-08	1.1E-07	Unc. oxidative phosphorylation	-3.67	0.82
51207-31-9	2,3,7,8-Tetrachlorodibenzofurane	1.3E-07	3.5E-07	1.1E-08	1.1E-08	Ah-receptor	-8.91	0.91
39001-02-0	Octachlorodibenzofurane	3.5E-07	3.5E-08	3.5E-09	3.5E-09	Ah-receptor	-10.65	0.91
5409-83-6	2,8-Dichlorodibenzofurane	1.1E-06	3.5E-07	1.1E-08	3.5E-08	Ah-receptor	-8.36	0.91
57117-31-4	2,3,4,7,8-Pentachlorodibenzofurane	5.7E-08	3.5E-07	1.1E-08	1.1E-08	Ah-receptor	-9.26	0.91
67562-39-4	1,2,3,4,6,7,8-Heptachlorodibenzofurane	1.2E-08	1.1E-07	1.1E-08	1.1E-08	Ah-receptor	-10.08	0.91
70648-26-9	1,2,3,4,7,8-Hexachlorodibenzofurane	5.9E-08	2.0E-08	1.9E-09	2.0E-09	Ah-receptor	-9.72	0.91
117-81-7	Di-(2-ethylhexyl) phthalate	3.5E-06	1.1E-06	1.1E-07	3.5E-07	Diester toxicity	-2.27	1.19
131-11-3	Dimethylphthalate	1.1E-06	1.1E-06	1.1E-07	3.5E-07	Diester toxicity	-3.29	1.19
28553-12-0	Di-isononyl phthalate	1.2E-05	9.5E-07	4.3E-07	4.6E-07	Diester toxicity	-2.58	1.19
84-61-7	Dicyclohexyl phthalate	1.2E-05	3.5E-06	1.6E-06	1.7E-06	Diester toxicity	-3.77	1.19
84-66-2	Diethylphthalate	1.1E-06	1.1E-06	1.1E-07	3.5E-07	Diester toxicity	-4.55	1.19
84-69-5	Di-isobutyl phthalate	4.6E-06	3.5E-06	1.6E-06	1.7E-06	Diester toxicity	-2.94	1.19
84-74-2	Dibutyl phthalate	3.5E-06	1.1E-06	1.1E-07	3.5E-07	Diester toxicity	-4.89	1.19
85-68-7	Butyl benzyl phthalate	3.5E-06	1.1E-06	1.1E-07	3.5E-07	Diester toxicity	-3.72	1.19
107-06-2	1,2-Dichloroethane	1.1E-07	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-1.60	0.71
127-18-4	Tetrachloroethene (PER)	3.5E-07	3.5E-07	3.5E-08	1.1E-07	Nonpolar narcosis	-2.01	0.71
67-66-3	Trichloromethane	1.1E-07	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-1.43	0.71
71-43-2	Benzene	1.1E-05	1.1E-06	1.1E-07	3.5E-07	Nonpolar narcosis	-2.09	0.71
79-01-6	Trichloroethene	1.1E-06	3.5E-07	3.5E-08	1.1E-07	Nonpolar narcosis	-2.01	0.71
107-13-1	Acrylonitrile	1.9E-06	1.5E-06	1.5E-06	1.5E-06	Alkylation / arylation reactivity	-2.76	0.44
7440-43-9	Cadmium	1.0E-20	1.0E-20	1.0E-20	1.0E-20	Cd	-4.10	1.21
7440-47-3	Chromium	1.0E-20	1.0E-20	1.0E-20	1.0E-20	Cr	-3.15	1.10
50-00-0	Formaldehyde	5.3E-05	2.0E-06	5.0E-07	2.0E-06	Carbonyl reactivity	-2.28	0.51
7439-92-1	Lead	1.0E-20	1.0E-20	1.0E-20	1.0E-20	Pb	-3.28	0.68
7440-02-0	Nickel	1.0E-20	1.0E-20	1.0E-20	1.0E-20	Ni	-3.31	0.89
75-01-4	Vinylchloride	3.5E-06	3.5E-07	3.5E-08	1.1E-07	Nonpolar narcosis	-1.00	0.71
75-21-8	Oxirane	3.8E-08	7.2E-07	3.1E-08	7.2E-07	Alkylation / arylation reactivity	-1.86	0.44
100-42-5	Styrene	3.9E-05	1.1E-06	1.1E-07	3.5E-07	Alkylation / arylation reactivity	-2.60	0.44
108-88-3	Toluene	1.1E-05	3.5E-07	3.5E-08	1.1E-07	Nonpolar narcosis	-2.44	0.71
56-23-5	Tetrachloromethane (Tetra)	1.1E-08	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-1.46	0.71
75-09-2	Dichloromethane	1.1E-07	1.1E-07	1.1E-08	3.5E-08	Nonpolar narcosis	-1.50	0.71
107-02-8	Acroleïne	1.0E-05	5.7E-07	1.1E-07	5.7E-07	Alkylation / arylation reactivity	-5.07	0.44
74-85-1	Ethene	6.2E-06	5.5E-07	1.4E-07	5.5E-07	Nonpolar narcosis	-3.15	0.71
7440-50-8	Copper	1.0E-20	1.0E-20	1.0E-20	1.0E-20	Cu	-4.79	0.92
7439-97-6	Mercury	1.0E-20	1.0E-20	1.0E-20	1.0E-20	Hg	-4.62	0.90
75-56-9	Methyloxirane	2.6E-07	1.0E-06	1.4E-07	1.0E-06	Alkylation / arylation reactivity	-1.77	0.44
7440-66-6	Zinc	1.0E-20	1.0E-20	1.0E-20	1.0E-20	Zn	-3.73	1.02
7440-38-2	Arsenic	1.0E-20	1.0E-20	1.0E-20	1.0E-20	As	-3.62	0.73
7664-41-7	Ammonia	4.0E-06	5.0E-05	5.0E-05	4.0E-06	NH3	-3.16	0.85
630-08-0	Carbonmonoxide	3.4E-09	4.0E-06	3.7E-06	4.0E-06	Nonpolar narcosis	-2.60	0.71
71-55-6	1,1,1-Trichloroethane	6.5E-09	4.1E-08	9.7E-09	4.1E-08	Nonpolar narcosis	-1.84	0.71
10102-44-0	Nitrogendioxide	5.5E-06	1.0E-20	1.0E-20	1.0E-20	NOx	-2.65	0.91
7664-93-9	Sulfurdioxide	2.2E-06	1.0E-40	1.0E-40	1.0E-40	pH	-1.99	0.31
7783-06-4	Hydrogensulfide	2.4E-06	2.0E-06	5.0E-07	2.0E-06	H2S	-5.68	0.62
58-89-9	HCH (water)	1.9E-07	1.1E-08	3.5E-09	1.1E-08	Neurotox: Cyclodiene-type	-4.88	1.11
7681-49-4	Fluorides	1.0E-40	1.0E-40	1.0E-40	1.0E-40	F	-1.85	0.54

Annex 4

Table of predicted water concentrations for individual priority pollutants resulting from emissions in Europe, including the Netherlands (Cw_{Eur+NL}). The resulting risk for freshwater organisms based on chronic NOEC exceedance is given in the columns marked PAF_{EUR+NL}. For summary emissions identified as a group of individual pollutants (separated by bold lines) the table also shows the worst case selection of individual compounds as a counter in the first column.

Selected	ID #	Name	Cw_{Eur+NL} g/L 1990	PAF_{Eur+NL} % 1990	Cw_{Eur+NL} g/L 1995	PAF_{Eur+NL} % 1995	Cw_{Eur+NL} g/L 2002	PAF_{Eur+NL} % 2002	Cw_{Eur+NL} g/L 2003	PAF_{Eur+NL} % 2003
	608-93-5	Pentachlorobenzene	1.3E-08	0.00%	9.0E-09	0.00%	9.9E-09	0.00%	9.5E-09	0.00%
	634-66-2	1,2,3,4-Tetrachlorobenzene	1.2E-08	0.00%	8.5E-09	0.00%	9.3E-09	0.00%	9.0E-09	0.00%
	87-61-6	1,2,3-Trichlorobenzene	1.0E-08	0.00%	7.4E-09	0.00%	8.0E-09	0.00%	7.9E-09	0.00%
	106-46-7	1,4-dichlorobenzene	9.4E-09	0.00%	6.8E-09	0.00%	7.3E-09	0.00%	7.3E-09	0.00%
	108-90-7	Chlorobenzene	8.6E-09	0.00%	6.2E-09	0.00%	6.6E-09	0.00%	6.7E-09	0.00%
	118-74-1	Hexachlorobenzene	1.2E-08	0.00%	8.2E-09	0.00%	9.0E-09	0.00%	8.8E-09	0.00%
	634-90-2	1,2,3,5-Tetrachlorobenzene	1.1E-08	0.00%	7.7E-09	0.00%	8.4E-09	0.00%	8.3E-09	0.00%
	95-94-3	1,2,4,5-Tetrachlorobenzene	1.2E-08	0.00%	8.1E-09	0.00%	8.9E-09	0.00%	8.7E-09	0.00%
	120-82-1	1,2,4-Trichlorobenzene	1.0E-08	0.00%	7.3E-09	0.00%	7.9E-09	0.00%	7.9E-09	0.00%
1	95-50-1	1,2-Dichlorobenzene	9.5E-09	0.00%	6.8E-09	0.00%	7.4E-09	0.00%	7.4E-09	0.00%
	108-70-3	1,3,5-Trichlorobenzene	1.0E-08	0.00%	7.1E-09	0.00%	7.7E-09	0.00%	7.7E-09	0.00%
	541-73-1	1,3-Dichlorobenzene	9.3E-09	0.00%	6.7E-09	0.00%	7.2E-09	0.00%	7.3E-09	0.00%
	25321-22-6	Dichlorobenzene (mixed isomers)	3.6E-07	0.00%	2.1E-07	0.00%	2.6E-07	0.00%	2.1E-07	0.00%
	1336-36-3	PCB-Total	6.3E-12	0.00%	2.3E-12	0.00%	1.8E-12	0.00%	8.6E-13	0.00%
	11097-69-1	PCB-1254	3.2E-11	0.00%	1.2E-11	0.00%	9.3E-12	0.00%	4.4E-12	0.00%
	37680-73-2	PCB-101	1.2E-11	0.00%	4.3E-12	0.00%	3.4E-12	0.00%	1.6E-12	0.00%
	2050-68-2	PCB-15	3.1E-11	0.00%	1.2E-11	0.00%	9.0E-12	0.00%	4.3E-12	0.00%
2	35065-27-1	PCB-153	3.3E-11	0.00%	1.2E-11	0.00%	9.7E-12	0.00%	4.6E-12	0.00%
	2051-24-3	PCB-209	3.3E-12	0.00%	1.2E-12	0.00%	9.7E-13	0.00%	4.6E-13	0.00%
	15862-07-4	PCB-29	2.5E-11	0.00%	9.2E-12	0.00%	7.2E-12	0.00%	3.4E-12	0.00%
	35693-99-3	PCB-52	3.7E-11	0.00%	1.4E-11	0.00%	1.1E-11	0.00%	5.1E-12	0.00%
	33284-50-3	PCB-7	3.0E-11	0.00%	1.1E-11	0.00%	8.7E-12	0.00%	4.2E-12	0.00%
3	108-95-2	Phenol	2.4E-08	0.00%	1.8E-08	0.00%	2.0E-08	0.00%	2.0E-08	0.00%
4	91-20-3	Naphthalene	1.4E-07	0.00%	9.0E-08	0.00%	4.6E-08	0.00%	6.1E-08	0.00%
5	85-01-8	Phenanthrene	5.1E-07	1.65%	3.4E-07	0.85%	1.8E-07	0.27%	2.3E-07	0.44%
6	120-12-7	Anthracene	4.4E-08	0.41%	2.9E-08	0.19%	1.5E-08	0.05%	2.0E-08	0.09%
7	56-55-3	Benzo[a]Anthracene	2.5E-08	1.22%	1.6E-08	0.62%	8.8E-09	0.20%	1.1E-08	0.32%
8	218-01-9	Chyrsene	4.1E-08	0.92%	2.7E-08	0.46%	1.5E-08	0.14%	1.9E-08	0.23%
9	207-08-9	Benzo[k]fluoranthene	1.5E-08	0.68%	9.8E-09	0.33%	5.3E-09	0.10%	6.8E-09	0.16%
10	191-24-2	Benzo[ghi]perylene	1.8E-08	4.33%	1.2E-08	2.49%	6.6E-09	0.97%	8.5E-09	1.43%
11	193-39-5	Indeno[1,2,3-cd]pyrene	9.0E-09	3.09%	6.0E-09	1.72%	3.3E-09	0.63%	4.2E-09	0.96%
12	50-32-8	Benzo(a)pyreen	2.2E-08	0.47%	1.9E-08	0.37%	9.5E-09	0.09%	1.0E-08	0.12%
13	206-44-0	Fluorantheen	1.6E-07	2.30%	1.4E-07	1.77%	9.6E-08	1.04%	1.1E-07	1.21%
	87-86-5	Pentachlorophenol	2.4E-08	0.00%	1.7E-08	0.00%	1.4E-08	0.00%	1.3E-08	0.00%
	106-48-9	4-Chlorophenol	6.5E-09	0.00%	4.7E-09	0.00%	3.7E-09	0.00%	3.7E-09	0.00%
	120-83-2	2,4-Dichlorophenol	3.9E-09	0.00%	2.5E-09	0.00%	2.0E-09	0.00%	2.0E-09	0.00%

Selected	ID #	Name	Cw_{Eur+NL} g/L 1990	PAF_{Eur+NL} % 1990	Cw_{Eur+NL} g/L 1995	PAF_{Eur+NL} % 1995	Cw_{Eur+NL} g/L 2002	PAF_{Eur+NL} % 2002	Cw_{Eur+NL} g/L 2003	PAF_{Eur+NL} % 2003
14	58-90-2	2,3,4,6-Tetrachlorophenol	1.8E-08	2.23%	1.2E-08	1.33%	9.4E-09	0.97%	9.2E-09	0.93%
	88-06-2	2,4,6-Trichlorophenol	1.1E-08	0.00%	7.6E-09	0.00%	6.1E-09	0.00%	5.9E-09	0.00%
	95-57-8	2-Chlorophenol	9.5E-09	0.00%	5.8E-09	0.00%	4.6E-09	0.00%	4.5E-09	0.00%
	95-95-4	2,4,5-Trichlorophenol	1.2E-08	0.00%	8.2E-09	0.00%	6.5E-09	0.00%	6.4E-09	0.00%
	51207-31-9	2,3,7,8-Tetrachlorodibenzofurane	9.5E-14	0.00%	1.2E-14	0.00%	4.2E-15	0.00%	4.4E-15	0.00%
	39001-02-0	Octachlorodibenzofurane	1.2E-14	0.01%	1.4E-15	0.00%	5.1E-16	0.00%	5.2E-16	0.00%
	5409-83-6	2,8-Dichlorodibenzofurane	5.8E-14	0.00%	7.8E-15	0.00%	2.7E-15	0.00%	2.9E-15	0.00%
15	57117-31-4	2,3,4,7,8-Pentachlorodibenzofurane	7.7E-14	0.00%	9.5E-15	0.00%	3.4E-15	0.00%	3.6E-15	0.00%
	67562-39-4	1,2,3,4,6,7,8-Heptachlorodibenzofurane	2.0E-14	0.00%	2.4E-15	0.00%	8.6E-16	0.00%	9.0E-16	0.00%
	70648-26-9	1,2,3,4,7,8-Hexachlorodibenzofurane	6.1E-14	0.01%	7.3E-15	0.00%	2.7E-15	0.00%	2.8E-15	0.00%
16	117-81-7	Di-(2-ethylhexyl) phthalate	2.1E-08	0.00%	1.1E-08	0.00%	4.9E-09	0.00%	4.3E-09	0.00%
	131-11-3	Dimethylphthalate	1.2E-07	0.12%	5.4E-08	0.04%	1.2E-08	0.00%	7.2E-09	0.00%
	28553-12-0	Di-isononyl phthalate	2.3E-11	0.00%	1.4E-11	0.00%	7.4E-12	0.00%	6.9E-12	0.00%
	84-61-7	Dicyclohexyl phthalate	5.9E-09	0.01%	3.2E-09	0.00%	1.5E-09	0.00%	1.3E-09	0.00%
	84-66-2	Diethylphthalate	6.7E-08	1.33%	3.1E-08	0.63%	9.5E-09	0.17%	7.1E-09	0.12%
	84-69-5	Di-isobutyl phthalate	1.0E-08	0.00%	6.0E-09	0.00%	3.0E-09	0.00%	2.7E-09	0.00%
	84-74-2	Dibutyl phthalate	2.4E-08	1.05%	1.4E-08	0.60%	6.6E-09	0.28%	6.0E-09	0.25%
	85-68-7	Butyl benzyl phthalate	2.5E-08	0.05%	1.4E-08	0.03%	6.8E-09	0.01%	6.2E-09	0.01%
17	107-06-2	1,2-Dichloroethane	4.3E-08	0.00%	1.0E-08	0.00%	1.4E-08	0.00%	1.0E-08	0.00%
18	127-18-4	Tetrachloroethene (PER)	5.8E-09	0.00%	1.4E-09	0.00%	7.4E-10	0.00%	6.7E-10	0.00%
19	67-66-3	Trichloromethane	3.5E-09	0.00%	5.2E-09	0.00%	1.8E-09	0.00%	3.2E-09	0.00%
20	71-43-2	Benzene	1.9E-07	0.00%	1.1E-07	0.00%	6.7E-08	0.00%	6.4E-08	0.00%
21	79-01-6	Trichloroethene	1.7E-08	0.00%	1.4E-09	0.00%	4.0E-10	0.00%	2.3E-10	0.00%
22	107-13-1	Acrylonitrile	5.0E-09	0.00%	3.4E-09	0.00%	8.7E-10	0.00%	5.7E-10	0.00%
23	7440-43-9	Cadmium	1.9E-08	0.14%	9.3E-09	0.06%	7.6E-09	0.05%	7.3E-09	0.04%
24	7440-47-3	Chromium	5.3E-08	0.01%	4.0E-08	0.01%	3.6E-08	0.01%	3.7E-08	0.01%
25	50-00-0	Formaldehyde	6.2E-07	0.00%	5.8E-07	0.00%	4.0E-07	0.00%	3.7E-07	0.00%
26	7439-92-1	Lead	1.5E-07	0.00%	1.0E-07	0.00%	8.8E-08	0.00%	8.6E-08	0.00%
27	7440-02-0	Nickel	4.1E-06	1.01%	3.9E-06	0.94%	3.3E-06	0.76%	3.2E-06	0.73%
28	75-01-4	Vinylchloride	4.4E-11	0.00%	1.4E-11	0.00%	6.8E-12	0.00%	9.6E-11	0.00%
29	75-21-8	Oxirane	1.1E-08	0.00%	2.3E-09	0.00%	7.7E-10	0.00%	1.3E-09	0.00%
30	100-42-5	Styrene	4.6E-10	0.00%	1.7E-09	0.00%	1.6E-10	0.00%	1.8E-10	0.00%
31	108-88-3	Toluene	1.2E-08	0.00%	7.2E-09	0.00%	3.4E-09	0.00%	3.1E-09	0.00%
32	56-23-5	Tetrachloromethane (Tetra)	2.8E-09	0.00%	8.8E-10	0.00%	1.0E-10	0.00%	8.0E-11	0.00%
33	75-09-2	Dichloromethane	1.5E-08	0.00%	1.5E-08	0.00%	2.7E-09	0.00%	2.7E-09	0.00%
34	107-02-8	Acroleïne	1.3E-08	0.00%	1.0E-08	0.00%	8.0E-09	0.00%	7.7E-09	0.00%
35	74-85-1	Ethene	2.4E-10	0.00%	1.6E-10	0.00%	1.0E-10	0.00%	1.0E-10	0.00%
36	7440-50-8	Copper	2.3E-06	17.98%	2.1E-06	16.62%	1.4E-06	12.63%	1.4E-06	12.19%
37	7439-97-6	Mercury	2.8E-09	0.00%	1.8E-09	0.00%	8.0E-10	0.00%	8.5E-10	0.00%
38	75-56-9	Methyloxirane	8.1E-19	0.00%	2.6E-10	0.00%	2.6E-11	0.00%	1.9E-11	0.00%
39	7440-66-6	Zinc	1.3E-06	1.81%	4.8E-06	6.08%	4.3E-06	5.45%	4.2E-06	5.37%
40	7440-38-2	Arsenic	2.3E-07	0.00%	2.2E-07	0.00%	2.1E-07	0.00%	2.1E-07	0.00%
41	7664-41-7	Ammonia	1.9E-06	0.12%	1.4E-06	0.08%	1.0E-06	0.04%	9.7E-07	0.04%
42	630-08-0	Koolmonoxide	2.0E-07	0.00%	1.5E-07	0.00%	1.2E-07	0.00%	1.1E-07	0.00%
43	71-55-6	1,1,1-Trichloroethane	2.0E-08	0.00%	4.9E-09	0.00%	5.3E-10	0.00%	4.6E-10	0.00%
44	10102-44-0	Nitrogendioxide	4.0E-05	2.65%	3.4E-05	2.23%	2.8E-05	1.74%	2.7E-05	1.74%

Selected	ID #	Name	Cw_{Eur+NL} g/L 1990	PAF_{Eur+NL} % 1990	Cw_{Eur+NL} g/L 1995	PAF_{Eur+NL} % 1995	Cw_{Eur+NL} g/L 2002	PAF_{Eur+NL} % 2002	Cw_{Eur+NL} g/L 2003	PAF_{Eur+NL} % 2003
45	7664-93-9	Sulfurdioxide	2.4E-06	0.00%	1.8E-06	0.00%	1.4E-06	0.00%	1.4E-06	0.00%
46	7783-06-4	Hydrogensulfide	1.6E-09	0.00%	1.2E-09	0.00%	1.1E-09	0.00%	1.1E-09	0.00%
47	58-89-9	HCH (water)	4.8E-09	0.10%	2.0E-09	0.03%	2.1E-13	0.00%	1.2E-12	0.00%
48	7681-49-4	Fluorides	3.6E-03	13.63%	1.9E-04	0.03%	3.0E-04	0.10%	2.4E-04	0.05%

Annex 5

Intermediate results of the ecotoxic risk calculation for Dutch surface waters based on chronic NOEC exceedance. The individual pollutants are grouped to represent Toxic Modes of Action (TMoA). The last two columns pertain to the risk that is added by the emissions in the Netherlands.

TMoA	Emission locations	Year	#Chemicals	Sum HU	Log Sum HU	σ see Annex 3	$msPAF_{TMoA}$	Added $msPAF_{TMoA,NL}$
Ah-receptor	Europe, excl. NL	1990	2	1.6E-04	-3.81	0.91	0.00%	
Ah-receptor	Europe, incl. NL	1990	2	4.0E-04	-3.40	0.91	0.01%	0.01%
Ah-receptor	Europe, excl. NL	1995	2	3.5E-05	-4.46	0.91	0.00%	
Ah-receptor	Europe, incl. NL	1995	2	1.1E-04	-3.95	0.91	0.00%	0.00%
Ah-receptor	Europe, excl. NL	2002	2	2.4E-05	-4.62	0.91	0.00%	
Ah-receptor	Europe, incl. NL	2002	2	8.0E-05	-4.09	0.91	0.00%	0.00%
Ah-receptor	Europe, excl. NL	2003	2	1.3E-05	-4.88	0.91	0.00%	
Ah-receptor	Europe, incl. NL	2003	2	4.2E-05	-4.38	0.91	0.00%	0.00%
As	Europe, excl. NL	1990	1	4.6E-04	-3.34	0.73	0.00%	
As	Europe, incl. NL	1990	1	9.5E-04	-3.02	0.73	0.00%	0.00%
As	Europe, excl. NL	1995	1	4.3E-04	-3.36	0.73	0.00%	
As	Europe, incl. NL	1995	1	9.0E-04	-3.05	0.73	0.00%	0.00%
As	Europe, excl. NL	2002	1	4.2E-04	-3.38	0.73	0.00%	
As	Europe, incl. NL	2002	1	8.7E-04	-3.06	0.73	0.00%	0.00%
As	Europe, excl. NL	2003	1	4.1E-04	-3.38	0.73	0.00%	
As	Europe, incl. NL	2003	1	8.6E-04	-3.07	0.73	0.00%	0.00%
Cd	Europe, excl. NL	1990	1	6.0E-05	-4.22	1.21	0.02%	
Cd	Europe, incl. NL	1990	1	2.4E-04	-3.63	1.21	0.14%	0.11%
Cd	Europe, excl. NL	1995	1	3.0E-05	-4.52	1.21	0.01%	
Cd	Europe, incl. NL	1995	1	1.2E-04	-3.93	1.21	0.06%	0.05%
Cd	Europe, excl. NL	2002	1	2.6E-05	-4.58	1.21	0.01%	
Cd	Europe, incl. NL	2002	1	9.6E-05	-4.02	1.21	0.05%	0.04%
Cd	Europe, excl. NL	2003	1	2.6E-05	-4.59	1.21	0.01%	
Cd	Europe, incl. NL	2003	1	9.3E-05	-4.03	1.21	0.04%	0.04%
Cr	Europe, excl. NL	1990	1	1.8E-05	-4.75	1.10	0.00%	
Cr	Europe, incl. NL	1990	1	7.6E-05	-4.12	1.10	0.01%	0.01%
Cr	Europe, excl. NL	1995	1	1.3E-05	-4.88	1.10	0.00%	
Cr	Europe, incl. NL	1995	1	5.7E-05	-4.25	1.10	0.01%	0.01%
Cr	Europe, excl. NL	2002	1	1.2E-05	-4.93	1.10	0.00%	
Cr	Europe, incl. NL	2002	1	5.2E-05	-4.29	1.10	0.01%	0.00%
Cr	Europe, excl. NL	2003	1	1.2E-05	-4.92	1.10	0.00%	
Cr	Europe, incl. NL	2003	1	5.3E-05	-4.27	1.10	0.01%	0.00%
Cu	Europe, excl. NL	1990	1	4.2E-02	-1.38	0.92	6.78%	
Cu	Europe, incl. NL	1990	1	1.4E-01	-0.85	0.92	17.98%	12.01%
Cu	Europe, excl. NL	1995	1	3.7E-02	-1.43	0.92	6.12%	
Cu	Europe, incl. NL	1995	1	1.3E-01	-0.90	0.92	16.62%	11.19%
Cu	Europe, excl. NL	2002	1	2.6E-02	-1.59	0.92	4.29%	
Cu	Europe, incl. NL	2002	1	8.7E-02	-1.06	0.92	12.63%	8.71%
Cu	Europe, excl. NL	2003	1	2.5E-02	-1.61	0.92	4.10%	

TMoA	Emission locations	Year	#Chemicals	Sum HU	Log Sum HU	σ see Annex 3	msPAF$_{TMoA}$	Added msPAF$_{TMoA,NL}$
Cu	Europe, incl. NL	2003	1	8.4E-02	-1.08	0.92	12.19%	8.44%
Diester toxicity	Europe, excl. NL	1990	1	1.6E-06	-5.80	1.19	0.00%	
Diester toxicity	Europe, incl. NL	1990	1	3.8E-06	-5.42	1.19	0.00%	0.00%
Diester toxicity	Europe, excl. NL	1995	1	7.5E-07	-6.13	1.19	0.00%	
Diester toxicity	Europe, incl. NL	1995	1	2.1E-06	-5.69	1.19	0.00%	0.00%
Diester toxicity	Europe, excl. NL	2002	1	2.3E-07	-6.63	1.19	0.00%	
Diester toxicity	Europe, incl. NL	2002	1	9.0E-07	-6.04	1.19	0.00%	0.00%
Diester toxicity	Europe, excl. NL	2003	1	1.8E-07	-6.75	1.19	0.00%	
Diester toxicity	Europe, incl. NL	2003	1	7.9E-07	-6.10	1.19	0.00%	0.00%
F	Europe, excl. NL	1990	1	2.0E-01	-0.69	0.54	10.15%	
F	Europe, incl. NL	1990	1	2.5E-01	-0.60	0.54	13.63%	3.87%
F	Europe, excl. NL	1995	1	1.1E-02	-1.97	0.54	0.01%	
F	Europe, incl. NL	1995	1	1.3E-02	-1.88	0.54	0.03%	0.01%
F	Europe, excl. NL	2002	1	1.7E-02	-1.77	0.54	0.06%	
F	Europe, incl. NL	2002	1	2.1E-02	-1.68	0.54	0.10%	0.05%
F	Europe, excl. NL	2003	1	1.4E-02	-1.87	0.54	0.03%	
F	Europe, incl. NL	2003	1	1.7E-02	-1.78	0.54	0.05%	0.02%
H2S	Europe, excl. NL	1990	1	5.1E-04	-3.30	0.62	0.00%	
H2S	Europe, incl. NL	1990	1	7.6E-04	-3.12	0.62	0.00%	0.00%
H2S	Europe, excl. NL	1995	1	4.0E-04	-3.40	0.62	0.00%	
H2S	Europe, incl. NL	1995	1	5.9E-04	-3.23	0.62	0.00%	0.00%
H2S	Europe, excl. NL	2002	1	3.4E-04	-3.46	0.62	0.00%	
H2S	Europe, incl. NL	2002	1	5.2E-04	-3.29	0.62	0.00%	0.00%
H2S	Europe, excl. NL	2003	1	3.4E-04	-3.47	0.62	0.00%	
H2S	Europe, incl. NL	2003	1	5.1E-04	-3.29	0.62	0.00%	0.00%
Hg	Europe, excl. NL	1990	1	4.0E-05	-4.40	0.90	0.00%	
Hg	Europe, incl. NL	1990	1	1.2E-04	-3.93	0.90	0.00%	0.00%
Hg	Europe, excl. NL	1995	1	2.2E-05	-4.66	0.90	0.00%	
Hg	Europe, incl. NL	1995	1	7.6E-05	-4.12	0.90	0.00%	0.00%
Hg	Europe, excl. NL	2002	1	1.0E-05	-4.98	0.90	0.00%	
Hg	Europe, incl. NL	2002	1	3.3E-05	-4.48	0.90	0.00%	0.00%
Hg	Europe, excl. NL	2003	1	1.1E-05	-4.96	0.90	0.00%	
Hg	Europe, incl. NL	2003	1	3.5E-05	-4.45	0.90	0.00%	0.00%
NH3	Europe, excl. NL	1990	1	1.1E-03	-2.97	0.85	0.02%	
NH3	Europe, incl. NL	1990	1	2.7E-03	-2.58	0.85	0.12%	0.10%
NH3	Europe, excl. NL	1995	1	8.3E-04	-3.08	0.85	0.01%	
NH3	Europe, incl. NL	1995	1	2.1E-03	-2.69	0.85	0.08%	0.07%
NH3	Europe, excl. NL	2002	1	5.8E-04	-3.23	0.85	0.01%	
NH3	Europe, incl. NL	2002	1	1.4E-03	-2.84	0.85	0.04%	0.04%
NH3	Europe, excl. NL	2003	1	5.6E-04	-3.25	0.85	0.01%	
NH3	Europe, incl. NL	2003	1	1.4E-03	-2.86	0.85	0.04%	0.03%
Ni	Europe, excl. NL	1990	1	4.5E-03	-2.35	0.89	0.42%	
Ni	Europe, incl. NL	1990	1	8.5E-03	-2.07	0.89	1.01%	0.59%
Ni	Europe, excl. NL	1995	1	4.2E-03	-2.37	0.89	0.39%	
Ni	Europe, incl. NL	1995	1	8.0E-03	-2.10	0.89	0.94%	0.55%
Ni	Europe, excl. NL	2002	1	3.5E-03	-2.45	0.89	0.30%	
Ni	Europe, incl. NL	2002	1	6.8E-03	-2.17	0.89	0.76%	0.46%

TMoA	Emission locations	Year	#Chemicals	Sum HU	Log Sum HU	σ see Annex 3	$msPAF_{TMoA}$	Added $msPAF_{TMoA,NL}$
Ni	Europe, excl. NL	2003	1	3.4E-03	-2.47	0.89	0.29%	
Ni	Europe, incl. NL	2003	1	6.6E-03	-2.18	0.89	0.73%	0.45%
Nonpolar narcosis	Europe, excl. NL	1990	23	1.1E-01	-0.98	0.71	8.40%	
Nonpolar narcosis	Europe, incl. NL	1990	23	2.7E-01	-0.56	0.71	21.29%	14.07%
Nonpolar narcosis	Europe, excl. NL	1995	23	7.6E-02	-1.12	0.71	5.64%	
Nonpolar narcosis	Europe, incl. NL	1995	23	1.9E-01	-0.72	0.71	15.55%	10.50%
Nonpolar narcosis	Europe, excl. NL	2002	23	4.4E-02	-1.36	0.71	2.77%	
Nonpolar narcosis	Europe, incl. NL	2002	23	1.1E-01	-0.96	0.71	8.65%	6.05%
Nonpolar narcosis	Europe, excl. NL	2003	23	5.3E-02	-1.28	0.71	3.55%	
Nonpolar narcosis	Europe, incl. NL	2003	23	1.3E-01	-0.87	0.71	10.84%	7.56%
NOx	Europe, excl. NL	1990	1	9.5E-03	-2.02	0.91	1.29%	
NOx	Europe, incl. NL	1990	1	1.8E-02	-1.75	0.91	2.65%	1.38%
NOx	Europe, excl. NL	1995	1	8.1E-03	-2.09	0.91	1.06%	
NOx	Europe, incl. NL	1995	1	1.5E-02	-1.82	0.91	2.23%	1.18%
NOx	Europe, excl. NL	2002	1	6.6E-03	-2.18	0.91	0.81%	
NOx	Europe, incl. NL	2002	1	1.2E-02	-1.91	0.91	1.74%	0.94%
NOx	Europe, excl. NL	2003	1	6.6E-03	-2.18	0.91	0.81%	
NOx	Europe, incl. NL	2003	1	1.2E-02	-1.91	0.91	1.74%	0.94%
Pb	Europe, excl. NL	1990	1	7.3E-05	-4.14	0.68	0.00%	
Pb	Europe, incl. NL	1990	1	2.9E-04	-3.53	0.68	0.00%	0.00%
Pb	Europe, excl. NL	1995	1	4.6E-05	-4.33	0.68	0.00%	
Pb	Europe, incl. NL	1995	1	1.9E-04	-3.71	0.68	0.00%	0.00%
Pb	Europe, excl. NL	2002	1	3.6E-05	-4.44	0.68	0.00%	
Pb	Europe, incl. NL	2002	1	1.7E-04	-3.78	0.68	0.00%	0.00%
Pb	Europe, excl. NL	2003	1	3.6E-05	-4.45	0.68	0.00%	
Pb	Europe, incl. NL	2003	1	1.6E-04	-3.79	0.68	0.00%	0.00%
pH	Europe, excl. NL	1990	1	1.6E-04	-3.79	0.31	0.00%	
pH	Europe, incl. NL	1990	1	2.4E-04	-3.63	0.31	0.00%	0.00%
pH	Europe, excl. NL	1995	1	1.2E-04	-3.91	0.31	0.00%	
pH	Europe, incl. NL	1995	1	1.8E-04	-3.75	0.31	0.00%	0.00%
pH	Europe, excl. NL	2002	1	9.3E-05	-4.03	0.31	0.00%	
pH	Europe, incl. NL	2002	1	1.4E-04	-3.87	0.31	0.00%	0.00%
pH	Europe, excl. NL	2003	1	9.3E-05	-4.03	0.31	0.00%	
pH	Europe, incl. NL	2003	1	1.4E-04	-3.87	0.31	0.00%	0.00%
Polar narcosis	Europe, excl. NL	1990	1	2.6E-05	-4.58	0.85	0.00%	
Polar narcosis	Europe, incl. NL	1990	1	1.1E-04	-3.95	0.85	0.00%	0.00%
Polar narcosis	Europe, excl. NL	1995	1	1.6E-05	-4.79	0.85	0.00%	
Polar narcosis	Europe, incl. NL	1995	1	8.3E-05	-4.08	0.85	0.00%	0.00%
Polar narcosis	Europe, excl. NL	2002	1	1.3E-05	-4.90	0.85	0.00%	
Polar narcosis	Europe, incl. NL	2002	1	9.4E-05	-4.03	0.85	0.00%	0.00%
Polar narcosis	Europe, excl. NL	2003	1	1.2E-05	-4.91	0.85	0.00%	
Polar narcosis	Europe, incl. NL	2003	1	9.3E-05	-4.03	0.85	0.00%	0.00%
Zn	Europe, excl. NL	1990	1	1.9E-03	-2.72	1.02	0.39%	
Zn	Europe, incl. NL	1990	1	7.2E-03	-2.14	1.02	1.81%	1.42%
Zn	Europe, excl. NL	1995	1	6.5E-03	-2.18	1.02	1.64%	
Zn	Europe, incl. NL	1995	1	2.6E-02	-1.58	1.02	6.08%	4.52%
Zn	Europe, excl. NL	2002	1	5.7E-03	-2.24	1.02	1.42%	

TMoA	Emission locations	Year	#Chemicals	Sum HU	Log Sum HU	σ see Annex 3	$msPAF_{TMoA}$	Added $msPAF_{TMoA,NL}$
Zn	Europe, incl. NL	2002	1	2.3E-02	-1.64	1.02	5.45%	4.09%
Zn	Europe, excl. NL	2003	1	5.6E-03	-2.25	1.02	1.40%	
Zn	Europe, incl. NL	2003	1	2.3E-02	-1.65	1.02	5.37%	4.03%
Unc. oxidative phosphorylation	Europe, excl. NL	1990	1	1.4E-02	-1.84	0.82	1.28%	
Unc. oxidative phosphorylation	Europe, incl. NL	1990	1	2.2E-02	-1.65	0.82	2.23%	0.97%
Unc. oxidative phosphorylation	Europe, excl. NL	1995	1	1.1E-02	-1.98	0.82	0.82%	
Unc. oxidative phosphorylation	Europe, incl. NL	1995	1	1.5E-02	-1.83	0.82	1.33%	0.51%
Unc. oxidative phosphorylation	Europe, excl. NL	2002	1	8.3E-03	-2.08	0.82	0.58%	
Unc. oxidative phosphorylation	Europe, incl. NL	2002	1	1.2E-02	-1.93	0.82	0.97%	0.39%
Unc. oxidative phosphorylation	Europe, excl. NL	2003	1	8.1E-03	-2.09	0.82	0.56%	
Unc. oxidative phosphorylation	Europe, incl. NL	2003	1	1.2E-02	-1.94	0.82	0.93%	0.38%
Alkylation / arylation reactivity	Europe, excl. NL	1990	5	6.0E-04	-3.22	0.44	0.00%	
Alkylation / arylation reactivity	Europe, incl. NL	1990	5	1.5E-03	-2.82	0.44	0.00%	0.00%
Alkylation / arylation reactivity	Europe, excl. NL	1995	5	4.7E-04	-3.33	0.44	0.00%	
Alkylation / arylation reactivity	Europe, incl. NL	1995	5	1.2E-03	-2.92	0.44	0.00%	0.00%
Alkylation / arylation reactivity	Europe, excl. NL	2002	5	3.7E-04	-3.43	0.44	0.00%	
Alkylation / arylation reactivity	Europe, incl. NL	2002	5	9.4E-04	-3.03	0.44	0.00%	0.00%
Alkylation / arylation reactivity	Europe, excl. NL	2003	5	3.6E-04	-3.44	0.44	0.00%	
Alkylation / arylation reactivity	Europe, incl. NL	2003	5	9.1E-04	-3.04	0.44	0.00%	0.00%
Carbonyl reactivity	Europe, excl. NL	1990	1	2.6E-05	-4.59	0.51	0.00%	
Carbonyl reactivity	Europe, incl. NL	1990	1	1.2E-04	-3.93	0.51	0.00%	0.00%
Carbonyl reactivity	Europe, excl. NL	1995	1	2.4E-05	-4.62	0.51	0.00%	
Carbonyl reactivity	Europe, incl. NL	1995	1	1.1E-04	-3.96	0.51	0.00%	0.00%
Carbonyl reactivity	Europe, excl. NL	2002	1	1.7E-05	-4.78	0.51	0.00%	
Carbonyl reactivity	Europe, incl. NL	2002	1	7.6E-05	-4.12	0.51	0.00%	0.00%
Carbonyl reactivity	Europe, excl. NL	2003	1	1.6E-05	-4.80	0.51	0.00%	
Carbonyl reactivity	Europe, incl. NL	2003	1	7.1E-05	-4.15	0.51	0.00%	0.00%
Neurotox: Cyclodiene-type	Europe, excl. NL	1990	1	2.2E-04	-3.66	1.11	0.05%	
Neurotox: Cyclodiene-type	Europe, incl. NL	1990	1	3.7E-04	-3.43	1.11	0.10%	0.05%
Neurotox: Cyclodiene-type	Europe, excl. NL	1995	1	9.3E-05	-4.03	1.11	0.01%	
Neurotox: Cyclodiene-type	Europe, incl. NL	1995	1	1.6E-04	-3.81	1.11	0.03%	0.02%
Neurotox: Cyclodiene-type	Europe, excl. NL	2002	1	9.5E-09	-8.02	1.11	0.00%	
Neurotox: Cyclodiene-type	Europe, incl. NL	2002	1	1.6E-08	-7.80	1.11	0.00%	0.00%
Neurotox: Cyclodiene-type	Europe, excl. NL	2003	1	5.5E-08	-7.26	1.11	0.00%	
Neurotox: Cyclodiene-type	Europe, incl. NL	2003	1	9.3E-08	-7.03	1.11	0.00%	0.00%

Annex 6

The overall toxic risk based on chronic NOEC exceedance for freshwater organisms as a consequence of the emissions of priority pollutants in Europe, with and without the emissions in the Netherlands.The individual pollutants are grouped to represent Toxic Modes of Action (TMoA).

	Resulting from emissions in Europe, including the Netherlands				Resulting from emissions in Europe, excluding the Netherlands			
TMoA	**$msPAF_{TMoA,Eur+NL}$ 1990**	**$msPAF_{TMoA,Eur+NL}$ 1995**	**$msPAF_{TMoA,Eur+NL}$ 2002**	**$msPAF_{TMoA,Eur+NL}$ 2003**	**$msPAF_{TMoA,Eur-NL}$ 1990**	**$msPAF_{TMoA,Eur-NL}$ 1995**	**$msPAF_{TMoA,Eur-NL}$ 2002**	**$msPAF_{TMoA,Eur-NL}$ 2003**
Ah-receptor	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
As	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Cd	0.14%	0.06%	0.05%	0.04%	0.02%	0.01%	0.01%	0.01%
Cr	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
Cu	17.98%	16.62%	12.63%	12.19%	6.78%	6.12%	4.29%	4.10%
Diester toxicity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
F	13.63%	0.03%	0.10%	0.05%	10.15%	0.01%	0.06%	0.03%
H2S	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Hg	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
NH3	0.12%	0.08%	0.04%	0.04%	0.02%	0.01%	0.01%	0.01%
Ni	1.01%	0.94%	0.76%	0.73%	0.42%	0.39%	0.30%	0.29%
Nonpolar narcosis	21.29%	15.55%	8.65%	10.84%	8.40%	5.64%	2.77%	3.55%
NOx	2.65%	2.23%	1.74%	1.74%	1.29%	1.06%	0.81%	0.81%
Pb	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
pH	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Polar narcosis	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Zn	1.81%	6.08%	5.45%	5.37%	0.39%	1.64%	1.42%	1.40%
Unc. oxidative phosphorylation	2.23%	1.33%	0.97%	0.93%	1.28%	0.82%	0.58%	0.56%
Alkylation / arylation reactivity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Carbonyl reactivity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Neurotox: Cyclodiene-type	0.10%	0.03%	0.00%	0.00%	0.05%	0.01%	0.00%	0.00%
msPAF-Overall	**49%**	**37%**	**27%**	**29%**	**26%**	**15%**	**10%**	**10%**