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Maximum Permissible Concentrations and Negligible Concentrations for metals, taking background concentrations into account

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*on page 105, Table 8.1, the last column: The values given in this column are the **MPA(sed)** instead of the **MPC(sed)**. This means that the background concentrations should be added. The MPC(sed) values in Table 8.2 (third column) are the correct values.

*on page 127, Table 9.5: Although the heading says that the MPC(water) is expressed as the total concentration, the values given in table 9.5 are the dissolved concentrations. The MPC(water) expressed as total concentration is for arsenic 32 μg/l, cadmium 2.1 μg/l, chromium 84 μg/l, copper 3.8 μg/l, lead 220 μg/l, inorganic mercury 1.5 μg/l, methyl-mercury 0.1 μg/l, nickel 6.3 μg/l and zinc 40 μg/l . The comparisons with measured concentrations are performed with the total concentrations, so the results given are correct

*on page 227 in Table 5.8.1, fourth column: The value with note g should be 3 (which is the value corrected for the background concentration) instead of 12. The calculations in the report are performed with the corrected value of 3.

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PREFACE

This report contains results obtained in the framework of the project "Setting Integrated Environmental Quality Objectives". The results have been discussed in an advisory group. The members are M. Beek (National Institute of Inland Water Management), M.M.H.E. van den Berg (Health Council of the Netherlands), J. de Bruijn (National Institute of Public Health and the Environment), T. Crommentuijn (National Institute of Public Health and the Environment), C. Denneman (Ministry of Housing, Spatial Planning and the Environment), J. Deneer (Winand Staring Centre for Integrated Land, Soil and Water Research), J. Faber (Institute for Forestry and Nature Research), M. Janssen (National Institute of Public Health and the Environment), E. van de Plassche (National Institute of Public Health and the Environment), J. Struijs (National Institute of Public Health and the Environment), M.E.J. van der Weiden (Ministry of Housing, Spatial Planning and the Environment), J. van Wensem (Technical Soil Protection Committee) and A.P. van Wezel (National Institute for Coastal and Marine Management).

Results have been discussed within the "Peer Review Committee" of the Centre for Substances and Risk Assessment. Members were J.B.H.J. Linders, R. Luttik, M. Van den Hoop and J.A. Janus.

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EXECUTIVE SUMMARY

This report contains Maximum Permissible Concentrations (MPCs) and Negligible Concentrations (NCs) for seventeen metals. It is one of the series of reports on the project "Setting Integrated Environmental Quality Objectives" and is produced at the request of the Ministry of Housing, Spatial Planning and the Environment (VROM). The MPCs and NCs have been derived using "state of the art" risk assessment methodology. The presented MPCs and NCs, in combination with other relevant information, allow VROM to set Environmental Quality Objectives (EQOs). The metals for which MPCs and NCs are derived are: antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), thallium (Tl), tin (Sn), vanadium (V) and zinc (Zn).

The present report updates MPCs and NCs for these metals taking into account existing background concentrations in the Netherlands following the so-called "added risk approach". The need to update the MPCs and NCs stems from the observation that MPCs and/or NCs reported by previous studies were lower than the background concentration in the Dutch environment. In those cases the EQOs were set at the level of the background concentration, but this was not considered an acceptable solution in the longer term. In addition, it was recognised that the difference in the bioavailability of metals in laboratory tests compared to the field situation might be an issue when setting risk levels.

The added risk approach is used to derive MPCs and NCs for the different environmental compartments. The basic starting point for this approach is the calculation of a Maximum Permissible Addition (MPA) using available laboratory test data on organisms that are representative of the Dutch situation. This MPA is used as the amount of the metal in a specific compartment that may originate from anthropogenic sources and be considered acceptable when added to the background concentration (Cb). The Maximum Permissible Concentration (MPC) is subsequently defined as the sum of the Maximum Permissible Addition (MPA) and the background concentration (Cb). In formula:

$$\mathrm{MPC} = \mathrm{MPA} + Cb$$

where:

MPC = Maximum Permissible Concentration
MPA = Maximum Permissible Addition
Cb = background concentration

The added risk approach follows the same rationale as is used for radiation objectives where the Maximum Permissible Addition is defined as the amount of radiation due to anthropogenic sources that is allowed on top of the background radiation.

By adding the MPA to the background concentration of metals the added risk approach ignores the fact that the bioavailable fraction of the background concentration may have negative effects on some organisms in the ecosystem. From an environmental policy point of view such negative effects from the background concentration may be ignored and may even be regarded as desirable, since these effects may in theory even lead to an increase in ecosystem differentiation or biodiversity. It should be noted that the added risk approach is in

agreement with the definition of the MPC for substances with no background concentration (C*b* = 0), i.e. MPC = MPA.

The Negligible Addition (NA) is derived by dividing the MPA by 100. This factor of 100 is applied to take into account combination toxicity and other uncertainties in risk assessment. The Negligible Concentration (NC) is then defined as the sum of the background concentration C*b* and the Negligible Addition (i.e. NC = NA + C*b*). Again note that the added risk approach is in agreement with the definition of the NC for substances with no background concentration (C*b* = 0): NC = NA.

Like the MPC values in previous reports the MPA values for the metals covered by this report have been derived using either fixed assessment factors (modified EPA-method) or a statistical extrapolation technique (Aldenberg and Slob method). However, special attention has been paid to the evaluation and selection of the toxicity data used in these extrapolation methods. For instance, data on species that are not considered representative for the Dutch environment have not been included. In addition, special attention has been paid to the background concentrations present in the test media in order to be sure that the test results explicitly represent the amount of the substance causing effects in addition to the amount already present of natural origin.

From a policy point of view the possible effects due to the (bioavailable fraction of the) background may be ignored. However the statistical extrapolation technique which calculates an MPA similar to a 95% protection level for all species in the environment, can be applied to a more scientific investigation of the effect on MPC values where the bioavailable fraction of the metal in the background concentration is taken into account when calculating the MPA. Throughout this report such an evaluation is made using assumptions on different levels of bioavailability of the background concentrations.

It is realised that bioavailability is a key factor that must be included when setting environmental quality objectives for metals. Bioavailability for metals depends on a complex set of factors, such as water, soil or sediment chemistry, biological factors, and environmental factors. Some of these factors have a significant influence on bioavailability and enough scientific knowledge is available to describe quantitatively this influence and to take it into consideration in the actual risk limits. For example, a differentiation is made between dissolved and total concentrations in water to correct for the sorption of metals to suspended particles. The influence of some other factors is less pronounced (water hardness) or not enough knowledge is available to set up quantitative correction routines (pH in soil). Therefore, certain assumptions need to be made in order to derive MPCs and NCs plus general environmental quality objectives. It is for instance assumed that concentrations added in laboratory experiments are completely bioavailable to the test organisms. It is also assumed that the bioavailable fraction in the field behaves the same as the added concentration in laboratory experiments.

It is presumed that the added risk approach as presented in this report can also be applied to essential metals provided that in the data evaluation phase special attention is given to the nature of the effects that are observed in the toxicity studies. If this is assured the added risk approach should not lead to levels of MPCs and NCs that may result in deficiencies, because included in these risk limits are background concentrations that are assumed to provide the organisms in a given ecosystem with sufficient essential metals.

The resulting MPAs, NAs, MPCs, NCs and C*b*s, for water, soil and sediment are shown in Tables 1 and 2. The MPAs and NAs for water are proposed to be used for freshwater, saltwater and groundwater. Although salinity may influence metal toxicity no differences in sensitivity between freshwater and saltwater species were observed and the data were pooled to obtain more reliable MPA values to be used for both extrapolations. Note, however, that for some metals a different background concentration is available for the three types of water, which automatically results in distinct MPCs and NCs. It must also be noted that the MPC and NC values for the different water types pertain to the dissolved fraction. When EQOs for the total concentration are set the values in the table need to be corrected by the fraction adsorbed to suspended matter using default values for the suspended matter/water partition coefficients.

The MPC and NC values in Tables 1 and 2 are calculated based on one single background concentration of each metal for the Dutch situation. It is of course realised that background concentrations vary from site to site, which must be taken into account when evaluating actual risks at a specific site, if this information is available. The added risk approach enables the user of the MPA values to do so. For water, however, it may be difficult to find information on the true background concentration at a specific site. For soil and sediment it is recommended to use the so-called reference-lines to adjust the C*b*/MPC and NC values for the organic carbon and clay content of the soil under study, although it is realised that the scientific evidence for using this method to correct risk limits is limited.

For most metals the proposed NC value is almost similar to the background concentration, which is due to the fact that the MPA values are often low compared to the background concentration. The NA, defined as 1/100 of the MPA, will then of course also be low and the NC (=NA + C*b*) will automatically be close to the background concentration.

With respect to water chemistry, hardness is often considered one of the main factors affecting aquatic toxicity. Hardness, however, is disregarded when setting environmental risk limits in the present report. Based on evaluations of chronic aquatic toxicity of metals, the influence of hardness on aquatic toxicity, and thus on environmental risk limits, is regarded as less pronounced. These evaluations have shown that in most cases fish and seldom species from other taxonomic groups were studied. Besides this hardness is usually related to a number of other abiotic factors (pH, alkalinity, ionic strength), which makes the precise effect of hardness difficult to assess. Therefore, the relationship between hardness and chronic toxicity of metals appears to be much less consistent than that between hardness and acute toxicity, and, furthermore, it can be assumed that the effect of hardness on chronic toxicity is species dependent.

The setting of reliable environmental risk limits for metals is seriously hampered by the lack of reliable ecotoxicological data, although the data availability differs greatly for different substances and compartments. For water it was feasible to apply the statistical extrapolation method to 12 of the 18 (including methyl-mercury) metals considered. For the remaining six metals the modified EPA-method had to be applied. For soil it was feasible to apply the statistical extrapolation method to only five of the metals considered and the modified EPA-method to four of the metals. MPAs for the remaining metals had to be based on equilibrium partitioning using soil/water partition coefficients. All MPCs and NCs for sediment are based on equilibrium partitioning. Considering the use of equilibrium partitioning it must be noted that MPCs derived using equilibrium partitioning are regarded as less reliable than MPCs based on ecotoxicological data for the considered compartment and that there is a great need for adequate soil and sediment toxicity data.

It can be stated that in general the reliability of MPCs and NCs decreases in the order of: statistical extrapolation and experimental results > modified EPA-method and experimental results. In addition, it has to be borne in mind that the reliability of the experimental data needs to be considered as well. The use of the equilibrium partitioning method may introduce further uncertainty. This uncertainty is considered much less in the case of sediment MPCs than of soil MPCs, due to the fact that the sediment/water partition coefficients show much less variation. This is also one of the reasons why this report gives separate MPC values for soil and sediment.

It should be noted that MPCs and NCs have not been adjusted for the possible effects of secondary poisoning. Although it was recognised that for some metals (Cd, Zn, Hg) secondary poisoning is an important process to take into account, the available toxicity and bioconcentration data were not considered reliable enough to be applied in the methodology developed over the past few years.

Despite the fact that the aim of the project is to derive harmonised MPCs and NCs for the different environmental compartments this harmonisation process could be sustained to only a limited extent. The main reason for this was the limited data available, which resulted in reasonably reliable MPCs for water only. These MPCs were subsequently used for soil and sediment MPCs using equilibrium partitioning. In such cases harmonisation is no longer an issue. In some cases where direct toxicity data for soil organisms were available the resulting MPC values were, however, not harmonised with MPC values for water due to the fact that underlying soil/water partition coefficients show a very high variation which introduces too much uncertainty into the calculation. Harmonisation of available MPCs for soil and MPCs for air, although feasible by calculating steady-state concentration ratios using the SIMPLEBOX model, has been evaluated in this report, but the results must be seen as very provisional and should be used with care.

A comparison of 'old' MPCs with MPCs derived in this report shows that all the 'new' MPCs are higher than the 'old' ones. This is a result of taking into account the background concentrations. From a preliminary comparison of concentrations measured in the environment for some of the metals considered in this report with derived MPCs, it can be concluded that in water the measured concentrations copper and zinc are higher than the MPC. It can be concluded that for soil the mean of the measured concentrations is below the MPC for all the metals considered, but it must be noted that the measurements do show a large variation.

This report represents MPCs following the state of the art of risk assessment methodology. It is realised, however, that some of the assumptions made are debatable and that new scientific knowledge may lead to further improvement of this methodology. For example, the discrepancy between the bioavailability of metals in laboratory tests and field situations has not been solved. Further research is required to develop methods to determine the actual and/or potential bioavailable fractions of metals in soil, in the field and in the laboratory. When such methods are available, a more accurate estimate of the risks imposed by (heavy) metals may be possible. However, we feel confident that with the introduction of the added risk approach some of the previously observed problems in applying MPC values for metals have been solved in an acceptable manner.

table 1: Maximum Permissible Addition (MPA), Negligible Addition (NA), background concentration (C*b*) in freshwater (fresh), saltwater (marine) and groundwater (grw), Maximum Permissible Concentration (MPC) and Negligible Concentration (NC) for metals. Values are given as dissolved concentrations in µg/l.

Metal	MPA(fresh)	NA(fresh)	C*b*(fresh)	MPC(fresh)	NC(fresh)	C*b*(marine)	MPC(marine)	NC(marine)	C*b*(grw)	MPC(grw)	NC(grw)
antimony(Sb)	6.2 (b)	0.062	0.29	6.5	0.35				0.09	6.3	0.15
arsenic (As)	24 (a)	0.24	0.77	25	1.0				7.0	31	7.2
barium (Ba)	150 (b)	1.5	73	220	75				197	350	190
beryllium (Be)	0.16 (a)	0.0016	0.02	0.18	0.022				0.05	0.21	0.052
cadmium (Cd)	0.34 (a)	0.0034	0.08	0.42	0.083	0.025	0.37	0.028	0.06	0.40	0.063
chromium (Cr)	8.5 (a)	0.085	0.17	8.7	0.26				2.4	11	2.5
cobalt (Co)	2.6 (a)	0.026	0.20	2.8	0.23				0.63	3.2	0.66
copper (Cu)	1.1 (a)	0.011	0.44	1.5	0.45	0.25	1.4	0.26	1.3	2.4	1.3
lead (Pb)	11 (a)	0.11	0.15	11	0.26	0.02	11	0.13	1.6	13	1.7
mercury (Hg)	0.23 (a)	0.0023	0.01	0.24	0.012	0.0025	0.23	0.0048			
methyl-mercury	0.01 (a)	0.0001	0.01	0.02	0.01	0.0025	0.013	0.0026			
molybdenum (Mo)	290 (b)	2.9	1.4	290	4.3				0.69	290	3.6
nickel (Ni)	1.8 (a)	0.018	3.3	5.1	3.3				2.1	3.9	2.1
selenium (Se)	5.3 (a)	0.053	0.04	5.3	0.093				0.02	5.3	0.073
thallium (Tl)	1.6 (b)	0.016	0.04	1.6	0.056				<2	3.6	2.0
tin (Sn)	18 (b)	0.18	0.0002	18	0.18				<2	20	2.2
vanadium (V)	3.5 (b)	0.035	0.82	4.3	0.86				1.2	4.7	1.2
zinc (Zn)	6.6 (a)	0.066	2.8	9.4	2.9	0.35	7.0	0.42	24	31	24

(a): MPA based on statistical extrapolation
(b): MPA based on modified EPA-method

table 2: Maximum Permissible Addition (MPA), Negligible Addition (NA), background concentration (C*b*) in soil and sediment (sed), Maximum Permissible Concentration (MPC) and Negligible Concentration (NC) for metals. Values are given as concentrations in mg/kg standard soil/sediment (soil/sediment containing 10% organic matter and 25% clay.

Metal	MPA(soil)	NA(soil)	C*b*(soil)	MPC(soil)	NC(soil)	MPA(sed) (c)	NA(sed)	C*b*(sed)	MPC(sed)	NC(sed)
antimony (Sb)	0.53 (c)	0.0053	3.0	3.5	3.0	16	0.16	3.0	19	3.2
arsenic (As)	4.5 (c)	0.045	29	34	29	160	1.6	29	190	31
barium (Ba)	9.0 (c)	0.09	155	165	155	150	1.5	155	300	157
beryllium (Be)	0.0061 (c)	0.000061	1.1	1.1	1.1	0.096	0.00096	1.1	1.2	1.1
cadmium (Cd)	0.76 (a)	0.0076	0.8	1.6	0.81	29	0.29	0.8	30	1.1
chromium (Cr)	3.8 (b)	0.038	100	100	100	1620	16	100	1720	116
cobalt (Co)	24 (b)	0.24	9.0	33	9.2	10	0.10	9.0	19	9.1
copper (Cu)	3.5 (a)	0.035	36	40	36	37	0.37	36	73	36
lead (Pb)	55 (a)	0.55	85	140	86	4700	47	85	4800	132
mercury (Hg)	1.9 (a)	0.019	0.3	2.2	0.32	26	0.26	0.3	26	0.56
methyl-mercury	0.37 (b)	0.0037	0.3	0.67	0.30	1.1	0.011	0.3	1.4	0.31
molybdenum (Mo)	253 (c)	2.5	0.5	254	3.0	250	2.5	0.5	250	3.0
nickel (Ni)	2.6 (b)	0.026	35	38	35	9.4	0.094	35	44	35
selenium (Se)	0.11 (c)	0.0011	0.7	0.81	0.70	2.2	0.022	0.7	2.9	0.72
thallium (Tl)	0.25 (c)	0.0025	1.0	1.3	1.0	1.6	0.016	1.0	2.6	1.0
tin (Sn)	34 (c)	0.34	19	53	19	22000	220	19	22000	239
vanadium (V)	1.1 (c)	0.011	42	43	42	14	0.14	42	56	42
zinc (Zn)	16 (a)	0.16	140	160	140	480	4.8	140	620	145

Notes:

(a): MPA based on statistical extrapolation,

(b): MPA based on modified EPA-method,

(c): MPA based on equilibrium partitioning.

UITGEBREIDE SAMENVATTING

Dit rapport over Maximaal Toelaatbare Risico niveaus (MTR's) en Verwaarloosbare Risico niveaus (VR's) voor metalen is onderdeel van de reeks studies in het kader van het project "Integrale Normstelling Stoffen". Het rapport is gemaakt op verzoek van het Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (VROM). De hier gepresenteerde MTR's en VR's voor metalen zijn afgeleid op basis van de huidige wetenschappelijke stand van zaken en worden samen met andere relevante informatie door VROM gebruikt om normen vast te stellen. De metalen waarvoor hier de MTR's en VR's zijn afgeleid, zijn: antimoon (Sb), arseen (As), barium (Ba), beryllium (Be), cadmium (Cd), chroom (Cr), kobalt (Co), koper (Cu), lood (Pb), kwik (Hg), molybdeen (Mo), nikkel (Ni), selenium (Se), thallium (Tl), tin (Sn), vanadium (V) en zink (Zn).

Het onderhavige rapport herziet de bestaande MTR's en VR's voor de genoemde metalen en houdt daarbij rekening met de bestaande achtergrond concentraties in Nederland volgens de zogenaamde "Toegevoegd Risico Methode". De noodzaak om de eerder afgeleide MTR's en VR's voor metalen aan te passen, was dat sommige van de eerdere MTR's en/of VR's lager uitkwamen dan de achtergrond concentraties in het Nederlandse milieu. In die gevallen werden de normen gelijk gesteld aan deze achtergrond concentratie, maar deze benadering werd onvoldoende bevonden. Verder werd erkend dat de verschillen in biologische beschikbaarheid tussen laboratorium studies en het veld mee dienen te worden genomen bij het afleiden van risiconiveaus.

In het huidige rapport is de zogenaamde "toegevoegd risico benadering" gebruikt voor de afleiding van de MTR's en VR's voor de verschillende milieu compartimenten. Het uitgangspunt van deze benadering is dat een Maximaal Toelaatbare Toevoeging (MTT) wordt berekend, die is gebaseerd op beschikbare laboratorium testen, uitgevoerd met organismen die representatief zijn voor de Nederlandse situatie. De MTT, van antropogene oorsprong, wordt vervolgens opgeteld bij de natuurlijke achtergrond concentratie van het metaal. Het Maximaal Toelaatbare Risico niveau (MTR) is dus gelijk aan de som van de Maximaal Toelaatbare Toevoeging (MTT) en de achtergrond concentratie (C*b*). In formule:

$$\mathrm{MTR} = \mathrm{MTT} + \mathrm{C}b$$

waarin:

MTR = Maximaal Toelaatbare Risico niveau
MTT = Maximaal Toelaatbare Toevoeging
C*b* = achtergrond concentratie

De toegevoegd risico benadering volgt dezelfde filosofie als die gebruikt wordt bij de stralingsnormen, waarin de Maximaal Toelaatbare Toevoeging is gedefinieerd als de hoeveelheid straling afkomstig van antropogene bronnen die is toegestaan bovenop de achtergrondstraling.

Door de MPA toe te voegen aan de achtergrond concentratie worden de mogelijke effecten van de metalen vanuit het beschikbare deel van achtergrond concentratie niet meegenomen. Vanuit een milieubeleidsoogpunt kunnen deze effecten worden verwaarloosd of zelfs als nuttig worden gezien, omdat die tot een grotere ecosysteem differentiatie of biodiversiteit kunnen leiden. Verder stemt de toegevoegde risico benadering overeen met de afleiding voor stoffen zonder (een natuurlijke) achtergrond concentratie ($Cb = 0$): MTR = MTT.

De Verwaarloosbare Toevoeging (VT) is afgeleid door deling van de MTT door 100. Deze factor 100 is genomen om rekening te houden met mengsel toxiciteit en onzekerheden in de risico beoordeling. Vervolgens is het Verwaarloosbaar Risico niveau (VR) gedefinieerd als de som van de Verwaarloosbare Toevoeging (VT) en de achtergrond concentratie (Cb): VR = VT + Cb. Voor het VR geldt ook dat de toegevoegd risico benadering overeen komt met de afleiding voor stoffen zonder (een natuurlijke) achtergrond concentratie ($Cb = 0$): VR = VT.

MTT-waarden worden op een vergelijkbare wijze als eerdere MTR's afgeleid, waarbij gebruik gemaakt wordt van ofwel vaste veiligheidsfactoren (aangepaste EPA-methode), ofwel een statistische extrapolatie methode (Aldenberg en Slob methode). Hierbij moet worden opgemerkt dat er speciale aandacht is besteed aan de evaluatie en selectie van de data die voor de extrapolaties gebruikt zijn. Soorten die niet als representatief voor de Nederlandse situatie kunnen worden beschouwd, zijn bijvoorbeeld niet meegenomen. Daarnaast is er speciale aandacht besteed aan de achtergrond concentraties in het test medium, om er zeker van te zijn dat de waargenomen effecten een gevolg zijn van de toegevoegde concentratie.

Vanuit een beleidsmatig oogpunt kunnen de effecten veroorzaakt door (het beschikbare deel van) de achtergrond concentratie genegeerd worden. Desondanks kan de statistische extrapolatie methode, die een 95% beschermingsniveau voor alle soorten in het milieu berekent, worden toegepast om de mogelijke effecten van de beschikbare fractie van de metalen van de achtergrond concentratie op het MTR, te onderzoeken. In het onderhavige rapport is zo'n evaluatie uitgevoerd, waarbij verschillende niveaus van beschikbaarheid worden aangenomen.

In dit rapport wordt onderkend dat biologische beschikbaarheid een centrale rol speelt en dat hiermee rekening dient te worden gehouden bij het afleiden van milieukwaliteitsdoelstellingen voor metalen. Biologische beschikbaarheid is afhankelijk van een complexe set van factoren, zoals de chemische samenstelling van water, bodem of sediment, en van biologische- en milieufactoren. Sommige van deze factoren hebben een significant effect op de beschikbaarheid waarbij wetenschappelijke kennis voorhanden is om kwantitatief rekening mee te houden. Bijvoorbeeld: de differentiatie tussen opgeloste en totale concentraties in water om te corrigeren voor de sorptie van metalen aan gesuspendeerde deeltjes. De invloed van andere factoren is minder uitgesproken (hardheid) of er is onvoldoende kennis is voorhanden om kwantitatieve rekenregels te geven (pH in bodem). Gezien de onzekerheden is het nodig om aannames te maken voor de afleiding van MTR's en VR's, als ook generieke milieukwaliteitsdoelstellingen. Er wordt bijvoorbeeld aangenomen dat de concentraties die worden toegevoegd in het laboratorium volledig beschikbaar zijn voor de test organismen. Daarnaast wordt er aangenomen dat het beschikbare deel in het veld zich hetzelfde gedraagt als de in het laboratorium toegevoegde concentratie.

De in dit rapport gebruikte methodologie in het kader van "Integrale Normstelling" behoeft met name voor essentiële metalen geen aparte benadering onder de voorwaarde dat er tijdens de data evaluatie fase speciale aandacht wordt besteed aan de aard van de waargenomen effecten in toxiciteit studies. Indien hiermee rekening wordt gehouden zullen de met de toegevoegd risico benadering afgeleide MTR's en VR's niet tot deficiënties leiden. Immers, de achtergrond concentraties, die worden verondersteld aan de organismen voldoende van de benodigde essentiële metalen te kunnen leveren, zijn bij de afleiding meegenomen.

De resulterende *Cb*'s, MTT's, VT's, MTR's en VR's voor water, bodem en sediment staan vermeld in tabellen 1 en 2. De MTR's en VR's worden aanbevolen voor zoet-, zout en grondwater. Ondanks dat saliniteit de toxiciteit kan beïnvloeden, zijn er geen verschillen in gevoeligheid tussen zoet en zoutwater organismen gevonden en de data voor zoet en zout zijn gecombineerd. Hierbij moet worden opgemerkt dat, indien er sprake is van een verschillende achtergrond concentratie in de genoemde watertypes, dit wel tot verschillende MTR's en VR's leidt. Ook moet worden opgemerkt dat de genoemde MTR's en VR's betrekking hebben op opgeloste concentraties. Dit betekent dat indien milieukwaliteitsdoelstellingen worden vergeleken met totaal gemeten concentraties, de getallen eerst nog moeten worden omgerekend gebruik makende van "default" waarden voor de zwevend stof/water partitie coëfficiënt.

De MTR's en VR's in tabel 1 en 2 zijn berekend op basis van één enkele waarde voor elk metaal voor de achtergrond concentratie voor Nederland. Er wordt uiteraard gerealiseerd dat achtergrond concentraties variëren van plaats tot plaats. De toepassing van de toegevoegd risico methode maakt dit mogelijk. Dit is een aspect dat bij het bepalen van het actuele risico op een bepaalde plaats in acht genomen dient te worden, indien de informatie voorhanden is. Voor water echter zal het zeer moeilijk zijn om informatie te vinden over de achtergrond concentraties op een bepaalde locatie. Voor bodem en sediment wordt geadviseerd om de *Cb*/MTR's en VR's te corrigeren voor organisch materiaal en kleigehalte van de bodem met behulp van de zogenaamde referentielijnen. De wetenschappelijke onderbouwing van deze referentielijnen voor deze toepassing is echter zeer zwak.

Voor de meeste metalen zijn de voorgestelde VR's bijna gelijk aan de achtergrond concentraties ten gevolge van het feit dat MTT waarden vaak erg laag zijn in vergelijking met de achtergrond concentratie. Het VT gedefinieerd als de MTT/100 is dan natuurlijk ook laag en het VR (=VT + *Cb*) ligt dan automatisch dicht bij de achtergrond concentratie.

De hardheid van het water wordt vaak gezien als een van de belangrijkste factoren die de aquatische toxiciteit beïnvloeden. In dit rapport is de hardheid van het water echter niet meegenomen bij het afleiden van milieukwaliteitsdoelstellingen. Op basis van een evaluatie van de invloed van hardheid op de chronische toxiciteit van metalen is geconcludeerd dat deze invloed op de toxiciteit en dus op de milieukwaliteitsdoelstellingen niet eenduidig is. Deze evaluaties laten zien dat in de meeste gevallen vissen zijn bestudeerd en zelden soorten uit andere taxonomische groepen. Daarnaast hangt de hardheid ook samen met een aantal andere factoren (pH, alkaliniteit, ion-sterkte) zodat de invloed van hardheid alleen moeilijk vast te stellen is. Daardoor blijkt de relatie tussen hardheid en chronische toxiciteit minder duidelijk te zijn dan voor acute toxiciteit en bovendien kan er aangenomen worden dat de invloed van hardheid soortspecifiek is.

Het afleiden van milieukwaliteitsdoelstellingen voor metalen wordt ernstig bemoeilijkt door het gebrek aan betrouwbare toxiciteits data. Voor water is het mogelijk om de statistische extrapolatie methode toe te passen voor 12 van de 18 (inclusief methylkwik) metalen. Voor de overige zes metalen is de aangepaste EPA-methode toegepast. Voor bodem is het mogelijk de toegevoegde risico benadering met behulp van de statistische extrapolatie methode toe te passen voor vijf metalen. Voor vier metalen is de aangepaste EPA-methode toegepast. Voor de overige metalen is het evenwichtspartitieconcept gebruikt voor de afleiding van de MTT. Voor sediment zijn alle MTR's en VR's gebaseerd op het evenwichtspartitieconcept. Wat het evenwichtspartitieconcept betreft kan worden opgemerkt dat de MTR's als minder betrouwbaar beschouwd worden dan MTR's afgeleid op een directe manier op basis van ecotoxicologische gegevens voor het betreffende compartiment en dat er een grote behoefte is aan toxiciteits data voor bodem en sediment.

Wat betreft de betrouwbaarheid van de afgeleide MTR's en VR's wordt er over het algemeen aangenomen dat de volgorde aan betrouwbaarheid als volgt is: statistische extrapolatie en experimentele resultaten > aangepaste EPA-methode en experimentele resultaten. Ook moet worden opgemerkt dat met de betrouwbaarheid van de experimentele resultaten rekening dient te worden gehouden. Het gebruik van het evenwichtspartitieconcept introduceert daarnaast een extra onzekerheid. De grootte van deze onzekerheid wordt veel minder geacht in het geval van sediment in vergelijking met bodem ten gevolge van het feit dat de sediment/water partitiecoëfficiënten minder spreiding vertonen.

De MTR's en VR's zijn niet aangepast voor doorvergiftiging, ondanks het feit dat wordt erkend dat voor sommige metalen dit een belangrijke route is. De gebruikte toxiciteits data en bioconcentratiefactoren worden echter minder betrouwbaar geacht om in de afgelopen jaren ontwikkelde methoden gebruikt te worden.

Ondanks het feit dat het doel van het project is om de MTR's en VR's te harmoniseren, kon deze stap slechts beperkt worden uitgevoerd. De belangrijkste reden is dat alleen voor water redelijk betrouwbare MTR's voorhanden zijn. Deze MTR's zijn vervolgens gebruikt voor bodem en sediment door het toepassen van het evenwichtspartitieconcept. In het geval de MTR's voor bodem gebaseerd zijn op directe blootstelling van organismen is ook geen harmonisatie toegepast aangezien de partitiecoëfficiënten een grote variatie vertonen en daardoor een extra onzekerheid in de berekening introduceren. Harmonisatie van de MTR voor bodem met die voor lucht kan worden bereikt door met behulp van het SIMPLEBOX model zogenaamde "steady-state concentraties" te berekenen. Echter, de berekeningen voor metalen worden te prematuur geacht om de MTR's aan te passen.

De vergelijking van de "oude" met de MTR's afgeleid in dit rapport laat zien dat alle 'nieuwe' MTR's hoger zijn dan de 'oude'. Dit is een gevolg van het feit dat de achtergrond concentratie wordt meegenomen. Uit een voorlopige vergelijking van gemeten concentraties in het milieu voor sommige in dit rapport opgenomen metalen met MTR's kan geconcludeerd worden dat vooral voor koper en zink de gemeten concentraties hoger zijn dan het MTR. Voor de bodem kan geconcludeerd worden dat het gemiddelde van de gemeten concentraties onder het MTR ligt, maar het moet worden opgemerkt dat de metingen een grote spreiding vertonen.

Dit rapport is gebaseerd op de huidige stand van zaken betreffende risicobeoordelingsmethoden. Er wordt gerealiseerd dat sommige aannames bediscussieerd kunnen worden en dat door verbeterde kennis en nieuwe wetenschappelijke ontwikkelingen sommige aannames in de toekomst beter kunnen worden onderbouwd. In de huidige toegevoegde risico benadering is bijvoorbeeld de lacune in kennis tussen de beschikbaarheid van de metalen in het laboratorium en het veld nog niet opgelost. Verdere studies zijn noodzakelijk voor een betere bepaling van de actuele biologisch beschikbare fracties van metalen in bodem, in het veld en in het laboratorium. Als er methoden beschikbaar komen om de potentiële en actuele biologisch beschikbare metaal concentraties te bepalen, zal een betere schatting van de risico's door metalen mogelijk zijn. Ondanks deze beperkingen, hebben zijn wij ervan overtuigd dat door het toepassen van de toegevoegd risico methode enkele bestaande problemen met betrekking tot de afleiding van MTR's voor metalen op een aanvaardbare wijze zijn opgelost.

tabel 1: Maximaal Toelaatbare Toevoeging (MTT), Verwaarloosbare Toevoeging (VT), achtergrond concentratie (AC) in zoetwater (zoet), zoutwater (zout)en grondwater (gw), Maximaal Toelaatbaar Risiconiveau (MTR) en Verwaarloosbaar Risiconiveau (VR) voor metalen in water. Waarden zijn weergegeven als opgeloste concentraties in µg/l.

Metaal	**MTT$_{(water)}$**	**VT$_{(water)}$**	**AC$_{(zoet)}$**	**MTR$_{(zoet)}$**	**VR$_{(zoet)}$**	**AC$_{(zout)}$**	**MTR$_{(zout)}$**	**VR$_{(zout)}$**	**AC$_{(gw)}$**	**MTR$_{(gw)}$**	**VR$_{(gw)}$**
antimoon(Sb)	6.2 (b)	0.062	0.29	6.5	0.35				0.09	6.3	0.15
arseen (As)	24 (a)	0.24	0.77	25	1.0				7.0	31	7.2
barium (Ba)	150 (b)	1.5	73	220	75				197	350	190
beryllium (Be)	0.16 (a)	0.0016	0.02	0.18	0.022				0.05	0.21	0.052
cadmium (Cd)	0.34 (a)	0.0034	0.08	0.42	0.083	0.025	0.37	0.028	0.06	0.40	0.063
chroom (Cr)	8.5 (a)	0.085	0.17	8.7	0.26				2.4	11	2.5
kobalt (Co)	2.6 (a)	0.026	0.20	2.8	0.23				0.63	3.2	0.66
koper (Cu)	1.1 (a)	0.011	0.44	1.5	0.45	0.25	1.4	0.26	1.3	2.4	1.3
lood (Pb)	11 (a)	0.11	0.15	11	0.26	0.02	11	0.13	1.6	13	1.7
kwik (Hg)	0.23 (a)	0.0023	0.01	0.24	0.012	0.0025	0.23	0.0048			
methyl-kwik	0.01 (a)	0.0001	0.01	0.02	0.01	0.0025	0.013	0.0026			
molybdeen (Mo)	290 (b)	2.9	1.4	290	4.3				0.69	290	3.6
nikkel (Ni)	1.8 (a)	0.018	3.3	5.1	3.3				2.1	3.9	2.1
seleen (Se)	5.3 (a)	0.053	0.04	5.3	0.093				0.02	5.3	0.073
thallium (Tl)	1.6 (b)	0.016	0.04	1.6	0.056				<2	3.6	2.0
tin (Sn)	18 (b)	0.18	0.0002	18	0.18				<2	20	2.2
vanadium (V)	3.5 (b)	0.035	0.82	4.3	0.86				1.2	4.7	1.2
zink (Zn)	6.6 (a)	0.066	2.8	9.4	2.9	0.35	7.0	0.42	24	31	24

Opmerkingen:

(a): MTT gebaseerd op statistische extrapolatie

(b): MTT gebaseerd op gemodificeerde EPA-methode

tabel 2: Maximaal Toelaatbare Toevoeging (MTT), Verwaarloosbare Toevoeging (VT), achtergrond concentratie (AC) en Maximaal Toelaatbaar Risiconiveau (MTR) voor metalen in bodem en sediment. Waarden zijn weergegeven als een concentratie in standaardbodem/sediment (bodem/sediment met 10% organisch materiaal en 25% klei).

Metaal	MTT$_{(bodem)}$		VT$_{(bodem)}$	AC$_{(bodem)}$	MTR$_{(bodem)}$	VR$_{(bodem)}$	MTT$_{(sediment)}$ (c)	VT$_{(sediment)}$	AC$_{(sediment)}$	MTR$_{(sediment)}$	VR$_{(sediment)}$
antimoon (Sb)	0.53	(c)	0.0053	3.0	3.5	3.0	16	0.16	3.0	19	3.2
arseen (As)	4.5	(c)	0.045	29	34	29	160	1.6	29	190	31
barium (Ba)	9.0	(c)	0.09	155	165	155	150	1.5	155	300	157
beryllium (Be)	0.0061	(c)	0.000061	1.1	1.1	1.1	0.096	0.00096	1.1	1.2	1.1
cadmium (Cd)	0.76	(a)	0.0076	0.8	1.6	0.81	29	0.29	0.8	30	1.1
chroom (Cr)	3.8	(b)	0.038	100	100	100	1620	16	100	1720	116
kobalt (Co)	24	(b)	0.24	9.0	33	9.2	10	0.10	9.0	19	9.1
koper (Cu)	3.5	(a)	0.035	36	40	36	37	0.37	36	73	36
lood (Pb)	55	(a)	0.55	85	140	86	4700	47	85	4800	132
kwik (Hg)	1.9	(a)	0.019	0.3	2.2	0.32	26	0.26	0.3	26	0.56
methyl-kwik	0.37	(b)	0.0037	0.3	0.67	0.30	1.1	0.011	0.3	1.4	0.31
molybdeen (Mo)	253	(c)	2.5	0.5	254	3.0	250	2.5	0.5	250	3.0
nikkel (Ni)	2.6	(b)	0.026	35	38	35	9.4	0.094	35	44	35
seleen (Se)	0.11	(c)	0.0011	0.7	0.81	0.70	2.2	0.022	0.7	2.9	0.72
thallium (Tl)	0.25	(c)	0.0025	1.0	1.3	1.0	1.6	0.016	1.0	2.6	1.0
tin (Sn)	34	(c)	0.34	19	53	19	22000	220	19	22000	239
vanadium (V)	1.1	(c)	0.011	42	43	42	14	0.14	42	56	42
zink (Zn)	16	(a)	0.16	140	160	140	480	4.8	140	620	145

Opmerkingen:

(a): MTT gebaseerd op statistische extrapolatie

(b): MTT gebaseerd op gemodificeerde EPA-methode

(c): gebaseerd op equilibrium partitie

CHAPTER 1 INTRODUCTION

1.1 The project Setting Integrated Environmental Quality Objectives

This report is produced in the context of the project 'Setting Integrated Environmental Quality Objectives'. The project started in 1989 as a result of the actions proposed in the National Environmental Policy Plan (NEPP) (VROM[1], 1989a). The aim of the project is to derive concentration limits for substances in the environment for the different compartments, air, water, sediment and soil based on the risk philosophy of the Ministry of Housing, Spatial Planning and the Environment (Ministry of VROM). This philosophy is laid down in the policy document "Premises for Risk Management" (VROM, 1989b). These concentration limits are referred to as Environmental Quality Objectives (EQOs) in Dutch Environmental Policy.

The EQOs (MPCs and target values) set by the Ministry of VROM are based on risk limits, the Maximum Permissible Concentration (MPC) and Negligible Concentration (NC)[2], the latter are presented in this report. The MPC for the different compartments is derived using (eco)toxicological data and represents the potential risk of the substance in question. The NC is obtained by dividing the MPC by 100. The derivation of the risk limits MPC and NC is performed at the National Institute of Public Health and the Environment (RIVM[3]). To ensure that the MPC in one compartment does not lead to exceedance of the MPC in other compartments, due to intercompartmental exchange processes, MPCs have to be harmonised. The process of deriving integrated EQOs is shown schematically in figure 1.1.

The project has been divided into subprojects. The first subproject, MILBOWA[4], resulted in the report "Desire for Levels" (Van de Meent et al., 1990). In this report a methodology was proposed for deriving MPCs and NCs for several compounds such as heavy metals, chlorophenols, pesticides and polycyclic aromatic hydrocarbons (PAHs). Based on Van de Meent et al. (1990) EQOs for water, sediment and soil were set by the Minister of VROM (VROM, 1991). The second subproject resulted in proposals for MPCs and NCs for nine trace metals (Van de Plassche and De Bruijn, 1992), several volatile compounds (Van de Plassche and Bockting, 1993) and substances with potential for secondary poisoning (Van de Plassche, 1994). The MPCs for PAHs derived in Van de Meent et al. (1990), have been updated recently by Kalf et al. (1995; 1997).

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[1] Abbreviation in Dutch for "Ministry of Housing, Spatial Planning and the Environment",

[2] Besides the EQOs derived in the project "Setting Integrated Environmental Quality Objectives", the intervention value for soil clean-up is used in the Netherlands. This intervention value is based on an ecotoxicological serious soil contamination concentration or ECOTOX SCC (derived in a comparable way as the MPC) and a human toxicological serious soil contamination concentration or HUM-TOX SCC (see Kreule et al., 1995),

[3] Abbreviation in Dutch for "National Institute of Public Health and the Environment",

[4] Abbreviation in Dutch for "Environmental Quality Objectives for soil and water"

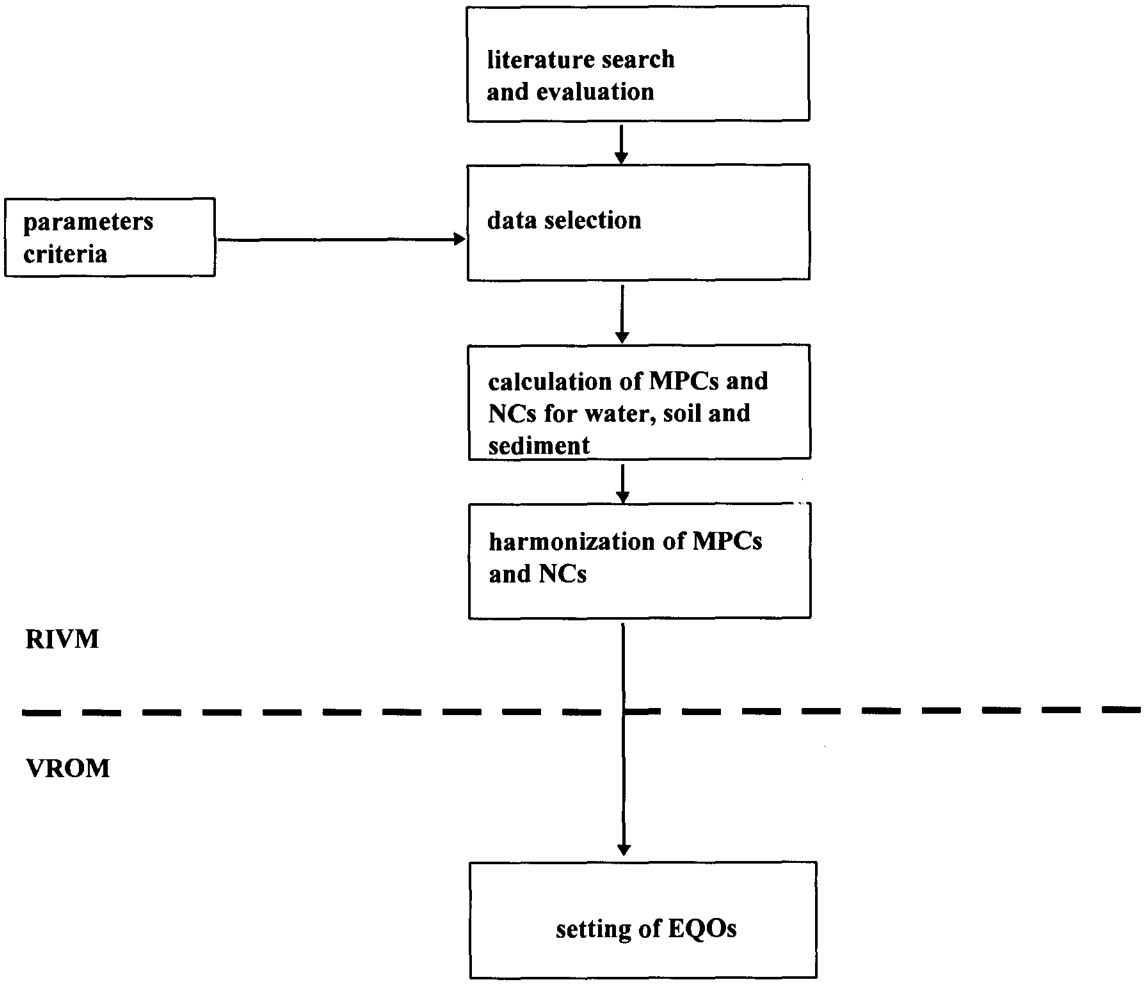

Figure 1.1 The process of deriving Integrated Environmental Quality Objectives.

1.2 Environmental Quality Objectives for metals

1.2.1 History

In the Netherlands MPCs and NCs for metals were first derived by Van de Meent et al. (1990) on the basis of the available ecotoxicological information without taking into account that metals are naturally present in the different environmental compartments. In most cases the methodology resulted in MPCs and/or NCs lower than what was considered to be the background concentration in the environment. In those cases the EQOs were set equal to the level of the background concentration but this was not considered as an acceptable solution at the longer term.

It was later realised that in the methodology proposed by Van de Meent et al. (1990) the discrepancy between availability of metals in laboratory tests and field conditions is ignored. The actual effect of naturally occurring substances may be lower under field conditions than expected on the basis of laboratory tests, because of the lower bioavailability in the field. In order to develop MPCs it may be important to account also for the bioavailability of natural and anthropogenic concentrations, anticipating that only the bioavailable part of the total concentration may cause an effect.

1.2.2 The added risk approach

The RIVM-project ECOROUTING has focused on the question 'how to deal with quality objectives of metals in relation to the background concentrations' (Peijnenburg et al., 1996). The main goal of this project was to study alternative methods that incorporate the background concentration. The alternative methods should be based on the existing approximation but should further incorporate a modification on the basis of bioavailability. On the basis of an extensive consultation of experts and following discussions, "The added risk approach"[1] was proposed. This method, which is described in detail by Struijs et al. (1997) is an elaboration of the existing statistical extrapolation method to be used for all substances, naturally occurring or anthropogenic.

In the present report the so-called "added risk approach" is adopted to calculate risk limits for the different environmental compartments. The basic starting point for this approach is the calculation of a maximum permissible addition (MPA) on the basis of the available data from laboratory toxicity tests. This MPA is considered as the maximum concentration to be added on top on the background concentration due to anthropogenic activities. The MPC is regarded as the sum of the MPA and the background or *Cb*. In formula: MPC = MPA + *Cb*.[2] Traditionally MPC values are calculated using either fixed assessment factors or by applying a statistical extrapolation technique. The MPA can be calculated using a similar approach. In the "added risk approach" as elaborated by Struijs et al. (1997) the possible effects of the bioavailable fraction of the metal in the background are taken into account.

In the present report one single background concentration for each metal is considered. This assumption was necessary to enable the derivation of MPCs for the Netherlands in general. It is however realised that background concentrations vary from site to site, which must be taken into account when using the MPCs in practice.

From a policy point of view the possible effects due to the (bioavailable fraction of the) natural background may be ignored. A more scientific investigation of the resulting outcome

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[1] The added risk approach subsequently served as the starting point for a project entitled "Risk Assessment of Heavy Metals", which is still in progress and the results are therefore not yet available. In this project attention is paid to the question how to determine the bioavailable concentrations of heavy metals in soil, in the field and in the laboratory. Methods for calculating and measuring potentially and actually (bio)available metal concentrations in soils will be developed and validated, to enable a better estimate of the risks imposed by heavy metals in the future.

[2] The terminology as proposed by Struijs et al. (1997) has been modified in the present report. In the present report the MPC is defined as the sum of the background concentration *Cb* and the so-called Maximum Permissible Addition (MPA), i.e., MPC= *Cb* + MPA. In the original proposal by Struijs et al. (1997), the MPC is defined as the concentration allowed to be added on top of the background concentration. In both cases, the MPC in the original proposal and the MPA as used in the present report, is based on the fraction of species which may be affected due to the (bioavailable) concentration of the substance considered. This modification in terminology has been performed for two reasons: Firstly, this approach follows the reasoning used for radiation objectives, in which a Maximum Permissible Addition is defined as the amount of radiation that is allowed on top of the background radiation. Secondly, this approach is in agreement with the definition of the MPC for substances with no background concentration, for which MPCs are comparable with measured concentrations in the environment. In spite of this change in terminology the concept of the added risk approach stays the same.

of the approach as published by Struijs et al. (1997), assuming different availabilities of the background concentration, may however be warranted. The statistical extrapolation technique which calculates an MPA similar to a 95% protection level for all species in the environment, can be applied for a more scientific investigation of the effect on MPC values where (the bioavailable fraction of) the metal in the background concentration is taken into account when calculating the MPA. Throughout this report such an evaluation is made using assumptions on different levels of bioavailability of the background concentrations.

As the added risk approach as originally proposed by Struijs et al. (1997) discriminates between bioavailable and unavailable fractions of the background, the results from toxicity tests should, ideally, be based on the fraction of the concentration that is bioavailable. As methods to determine these fractions are not yet available the assumption is made that concentrations added in laboratory experiments are considered to be completely bioavailable. Besides this it is assumed that the bioavailable fraction in the field behaves the same as the added concentration in laboratory experiments.

It is realised that the bioavailability of metals is influenced by several physico-chemical parameters like pH, alkalinity and hardness and probably differs for each metal. For instance, in the United States and Canada, water hardness related Quality Objectives are derived and correction formulas are being used. Whether these parameters should be included in deriving one standard value, which is considered representative for the Dutch situation, will be evaluated in chapter 9.

1.2.3 Essential metals

Some of the metals considered in this report are essential elements. Being an essential element means that some organisms may have a minimum requirement that supplies the needs, and a maximum above which the element is toxic (Scheinberg, 1991). This minimum requirement is necessary because trace metals play an essential role in the metabolism of the organism (Rainbow, 1993). The range between the minimum and maximum is often called the window of essentiality (Hopkin, 1993).

According to Begon et al. (1990) Mg, Mn, Fe, Cu, Zn and Mo are essential for all living organisms while Cr, Co, Se and V are essential for restricted groups of organisms. These elements are considered essential as they form for instance an integral part of at least one enzyme. Since the primary action of these essential metals is as catalysts, only trace amounts are necessary for optimal cellular function (Clarckson, 1986). Organisms have evolved mechanisms to be able to supply the needs independent of the external concentration by regulating an essential element to a constant level (Rainbow and Dallinger, 1993).

When organisms are exposed to such a low level of an essential metal at which it is unable to regulate the internal concentration to cope with its needs, effects due to deficiency may occur. One should therefore be aware that risk limits do not represent a concentration that may lead to effects due to deficiency. It must be reminded however that deficiency levels are species dependent which results in one of the key-elements of biological diversity.

1.3 Aim of this report

This report is produced at the request of the Ministry of VROM, who asked for generic risk limits for metals based on the "state of the art" risk assessment. The aim of the report is to update MPCs and NCs for metals using the added risk approach and the background concentrations proposed by Van den Hoop (1995a) following the methodology commonly used in the project "Setting Integrated Environmental Quality Objectives" (figure 1.1).

The metals considered are: antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), thallium (Tl), tin (Sn), vanadium (V) and zinc (Zn).

Considering the methodology used as presented in figure 1.1, the following remarks have to be made:

- On the methodology used for literature search, evaluation and selection:
  - For most of the metals considered the ecotoxicological data have been taken from reports published in the project "Setting Integrated Environmental Quality Objectives" and other RIVM projects. Especially if other recent RIVM documents on a certain metal are available, these data are included in this report. Therefore not all data are updated until the same date. Because the methodology used to evaluate and select the data is constantly in development, the methodology used for the different metals may therefore be slightly different. We are however convinced that, with the exception of some aspects (see below), most of the differences are only of minor influence for the outcome of the MPC,
  - In this report the *added* risk approach is used and the data should therefore be based on concentrations added to the test media in the laboratory. Especially for ecotoxicological data which result in values close to the background concentration, it is critical to know if the data include or exclude the background of the test medium. Therefore for *all* the metals, the original reference on ecotoxicological data with a value less than ten times the background concentration have been re-evaluated,
  - Special attention is paid to the representativeness of the tested species for the Dutch situation. On the basis of existing data-sheets on species occurring in the Netherlands and the information on the occurrence of the species supplied in the original manuscripts the decision is made to include or exclude the species in the data. In the discussion some examples will be given (chapter 9).

In summary the following information is used to derive MPCs and NCs:
1. Methods used in previous reports of the project "Setting Integrated Environmental Quality Objectives",
2. Proposal for the adjusted methodology to be used for xenobiotic and naturally occurring substances (Struijs et al., 1997), using the modified definition for the MPC,
3. Results from the literature survey on background concentrations in water, soil and sediment in the Netherlands (Van den Hoop, 1995a),
4. Updates of ecotoxicological data performed in the context of "Setting Integrated Environmental Quality Objectives" and other RIVM-projects,
5. Evaluation procedures to test the coherence of independently derived MPCs and NCs for air, water and soil (DiToro et al., 1991; Van de Meent and De Bruijn, 1995),

6. Proposals for MPCs and NCs taking secondary poisoning into account for cadmium, copper and mercury (Van de Plassche, 1994),
7. Working documents and reports on the partitioning of metals between particulate matter and marine/fresh surfacewater, between soil and water, and between sediment and fresh/marine surface water (Venema, 1994; Venema, 1996; Yland, 1996; Yland and Smedes, 1996).

1.4 Outline of this report

In chapter 2 an overview is given of Maximum Permissible Concentrations (MPCs), Negligible Concentrations (NCs) and background concentrations (*Cb*) in the Netherlands as published in the framework of the project Setting Integrated Environmental Quality Objectives and other RIVM projects since 1990 and before this report.

Chapter 3 describes the methodology that will be followed in this report to derive "new" MPCs and NCs. Attention is paid to the methodology used for selection and evaluation of the literature (3.2), selection of the data used for extrapolation (3.3), the existing extrapolation methods (3.4) and the elaboration of these methods into the added risk approach (3.5), the harmonisation methods used (3.6); equilibrium partitioning (3.6.1) and calculation of critical concentrations in air (3.6.2). Section 3.7 summarises the methodology used in the present report for water, soil and sediment.

Chapter 4 presents the partition coefficients that are used in this report. A summary of the literature survey on background concentrations in water, soil and sediment in the Netherlands (Van den Hoop, 1995a) is presented in chapter 5.

Chapter 6, 7 and 8 present the MPCs and NCs derived for water, soil and sediment, respectively. In chapter 9 the added risk approach and the results assuming different percentages of availability are discussed.

The appendices I to IV present the data for the metals for which an update has been made (cadmium, arsenic, chromium and copper; for all other metals data are presented elsewhere, see table 3.1). The data that are used in the extrapolations are shown in appendices V and VI. Appendix VII presents results from tests in sediment-water systems.

CHAPTER 2 OVERVIEW OF PREVIOUSLY PUBLISHED MPCS, NCS AND BACKGROUND CONCENTRATIONS

Table 2.1 gives an overview of the Maximum Permissible Concentrations (MPCs), the Negligible Concentrations (NCs) and background concentrations (C*b*) in the environment for metals that have been published in the context of the project "Setting Integrated Environmental Quality Objectives" and other RIVM projects since 1990 but before this report was published. The notes in table 2.1 indicate which methodology is used (see also chapter 3) and in which report the MPCs and NCs with the underlying ecotoxicological data have been published. The MPCs and NCs for water in table 2.1 are expressed as dissolved concentrations. No discrimination is made for different types of water. The MPCs and NCs for water apply for fresh surface water, marine water and groundwater.

It is important to realise that it is impossible to derive background concentrations by analysing water, soil or sediment samples anywhere in the Netherlands. No sampling sites can be found without or with only minor anthropogenic influence. Therefore, for surface water background concentrations are based on model estimations (Van der Weijden and Middelburg, 1989; Zuurdeeg et al., 1992), and for soil and sediment background concentrations are based on 90th percentile values of regression lines describing the relationship between organic matter and clay and concentrations found in relatively unpolluted sites in the Netherlands, the so-called reference-lines (TCB, 1990;1992). It must thus be realised that these “background concentrations” cannot be considered as *natural* background concentrations (see also chapter 5).

For arsenic, chromium, nickel, lead and zinc MPCs and NCs for water, soil and sediment have been derived in Van de Meent et al. (1990). The MPCs for cadmium, copper and mercury have also been derived in Van de Meent et al. (1990) but because of their potential for bioaccumulation, these metals have been reconsidered by Van de Plassche (1994). For the trace metals antimony, barium, beryllium, cobalt, molybdenum, selenium, thallium, tin and vanadium, MPCs and NCs have been derived in Van de Plassche and De Bruijn (1992).

From table 2.1 it can be seen that in many cases the previously derived NCs, but sometimes also MPCs derived from ecotoxicological laboratory data, are below the background concentration in water, soil and sediment. This demonstrates the necessity to take into account the background concentrations when setting risk levels.

Table 2.1 Maximum Permissible Concentrations (MPCs), Negligible Concentrations (NCs) and background concentrations (C*b*) in the Netherlands as published in the framework of the project "Setting Integrated Environmental Quality Objectives" and other RIVM projects since 1990. MPCs and NCs for water are expressed as dissolved concentrations. C*b*s for water are expressed as total concentrations. MPCs, NCs and C*b*s for soil and sediment are expressed as a value in standard soil/sediment (containing 10% organic matter and 25% clay).

metal	NC	MPC	C*b**
antimony			
surface water (µg/l)	0.062	6.2 (e)	0.32 (l)
	0.03	3.0 (m, q)	
sediment (mg/kg)	0.16	16 (f, q)	3.0 (l)
soil (mg/kg)	0.0053	0.53 (f)	3.0 (l)
air (µg/m^3)	0.032	3.2 (m, q)	
arsenic			
surface water (µg/l)	0.086	8.6 (a, q)	-
	0.06	6 (n)	
sediment (mg/kg)	0.56	56 (c, q)	-
	1.5	150 (n)	
soil (mg/kg)	0.071	7.1 (b, q)	29 (k)
	1.5	150 (n)	
air (µg/m^3)	0.005	0.5 (n,q)	
barium			
surface water (µg/l)	1.5	150 (e)	76 (l)
sediment (mg/kg)	1.5	150 (f)	155 (l)
soil (mg/kg)	0.09	9.0 (f)	155 (l)
beryllium			
surface water (µg/l)	0.0016	0.16 (d)	0.02 (l)
sediment (mg/kg)	0.001	0.1 (f)	1.1 (l)
soil (mg/kg)	0.00006	0.006 (f)	1.1 (l)
air (µg/m^3)		0.04 (t)	
cadmium			
surface water (µg/l)	0.0016	0.16 (a)	0.002 (k)
	0.0038	0.38 (g)	
	0.0035	0.35 (j, q)	
sediment (mg/kg)	0.14	14 (c)	0.25 (k)
	0.29	29 (i, q)	
soil (mg/kg)	0.0017	0.17 (a)	0.8 (k)
	0.0027	0.27 (g)	
	0.000035	0.0035 (j, q)	
chromium			
surface water (µg/l)	0.02	2.0 (a)	0.90 (k)
	0.05	5.0 (q)	
	0.07	7.0 (s)	
sediment (mg/kg)	2.7	270 (c)	72 (k)
	9.5	950 (q)	
soil (mg/kg)	0.024	2.4 (b)	100 (k)
	1-2	100-200 (s, q)	
air (µg/m^3)	0.000025	0.0025 (s,q)	
cobalt			
surface water (µg/l)	0.02	2.0 (d)	0.22 (l)
sediment (mg/kg)	0.08	8.0 (f)	9.0 (l)
soil (mg/kg)	0.0008	0.08 (e)	9.0 (l)

Table 2.1 (continued) Maximum Permissible Concentrations (MPCs), Negligible Concentrations (NCs) and background concentrations (C*b*) in the Netherlands as published in the framework of the project "Setting Integrated Environmental Quality Objectives" and other RIVM projects since 1990. MPCs and NCs for water are expressed as dissolved concentrations. C*b*s for water are expressed as total concentrations. MPCs, NCs and C*b*s for soil and sediment are expressed as a value in standard soil/sediment (containing 10% organic matter and 25% clay).

metal	NC	MPC	C*b**
copper			
surface water (µg/l)	0.017	1.7 (a)	0.4 (k)
	0.041	4.1 (g, q)	
	0.064	6.4 (j)	
sediment (mg/kg)	0.6	60 (c)	13 (k)
	1.42	142 (i, q)	
soil (mg/kg)	0.035	3.5 (a)	36 (k)
	0.062	6.2 (g)	
	0.0055	0.55 (j, q)	
lead			
surface water (µg/l)	0.02	2.0 (a)	0.1 (k)
	0.1	10 (q)	
sediment (mg/kg)	8.6	860 (c)	21 (k)
	43	4300 (q)	
soil (mg/kg)	0.22	22 (a)	85 (k)
mercury			
surface water (µg/l)	0.0001	0.01 (a, o, q)	-
	0.00056	0.056 (g)	
	0.000019	0.0019 (j)	
sediment (mg/kg)	0.011	1.1 (c)	-
	0.0021	0.21 (i)	
	0.01	1.0 (o, q)	
soil (mg/kg)	0.002	0.2 (b,h)	0.3 (k)
	0.000033	0.0033 (j)	
	0.01	1.0 (o, q)	
molybdenum			
surface water (µg/l)	2.9	290 (e)	1.4 (l)
sediment (mg/kg)	2.5	250 (f)	0.5 (l)
soil (mg/kg)	2.5	250 (f)	0.5 (l)
nickel			
surface water (µg/l)	0.014	1.4 (a)	1.0 (k)
	0.009	0.9 (q, r)	
sediment (mg/kg)	0.074	7.4 (c)	29 (k)
	0.072	7.2 (q, r)	
soil (mg/kg)	0.026	2.6 (b, q, r)	35 (k)
air (µg/m^3)	0.0025	0.25 (r,q)	
selenium			
surface water (µg/l)	0.053	5.3 (d)	0.042 (l)
sediment (mg/kg)	0.022	2.2 (f)	0.7 (l)
soil (mg/kg)	0.0011	0.11 (f)	0.7 (l)
thallium			
surface water (µg/l)	0.016	1.6 (e)	0.04 (l)
sediment (mg/kg)	0.016	1.6 (f)	-
soil (mg/kg)	0.0025	0.25 (f)	-
tin			
surface water (µg/l)	0.18	18 (e)	0.002 (l)
sediment (mg/kg)	220	22,000 (f)	19 (l)
soil (mg/kg)	0.35	35 (f)	19 (l)

Table 2.1 (continued) Maximum Permissible Concentrations (MPCs), Negligible Concentrations (NCs) and background concentrations (C*b*) in the Netherlands as published in the framework of the project "Setting Integrated Environmental Quality Objectives" and other RIVM projects since 1990. MPCs and NCs for water are expressed as dissolved concentrations. C*b*s for water are expressed as total concentrations. MPCs, NCs and C*b*s for soil and sediment are expressed as a value in standard soil/sediment (containing 10% organic matter and 25% clay).

metal	NC	MPC	C*b**
vanadium			
surface water (µg/l)	0.035	3.5 (e)	0.96 (l)
sediment (mg/kg)	0.14	14 (f)	42 (l)
soil (mg/kg)	0.011	1.1 (f)	42 (l)
air (µg/m^3)		1.0 (u)	
zinc			
surface water (µg/l)	0.016	1.6 (a)	1.0 (k)
	0.06	6.0 (p, q)	
sediment (mg/kg)	1.2	120 (c)	68 (k)
	4.5	450 (p, q)	
soil (mg/kg)	0.007	0.7 (b)	140 (k)
	0.3-0.7	30-70** (p)	

Notes:

*: background concentrations based on model estimations (water) or upperbound of reference lines (sediment and soil), see text and chapter 5 for explanation,

**: added concentration,

-: no data available,

(a): MPC based on direct effects using statistical extrapolation method (Van de Meent et al., 1990),

(b): MPC based on direct effects using modified EPA-method (Van de Meent et al., 1990),

(c): MPC based on aquatic effects applying equilibrium partitioning (Van de Meent et al., 1990),

(d): MPC based on direct effects using statistical extrapolation method (Van de Plassche and De Bruijn, 1992),

(e): MPC based on direct effects using modified EPA-method (Van de Plassche and De Bruijn, 1992),

(f): MPC based on aquatic effects applying equilibrium partitioning (Van de Plassche and De Bruijn, 1992),

(g): MPC based on direct effects using statistical extrapolation method (Van de Plassche, 1994),

(h): MPC based on direct effects using modified EPA-method (Van de Plassche, 1994),

(i): MPC based on aquatic effects applying equilibrium partitioning (Van de Plassche, 1994),

(j): MPC based on indirect effects applying secondary poisoning methodology (Van de Plassche, 1994),

(k): background concentration the same as reported in Van de Meent et al. (1990),

(l): background the same as reported in Van de Plassche and De Bruijn (1992),

(m): Slooff et al. (1992a),

(n): Slooff et al. (1990a),

(o): Slooff et al. (1995),

(p): Cleven et al. (1993),

(q): Janus et al. (1994),

(r): Slooff et al. (1992b),

(s): Slooff et al. (1990b),

(t): Janssen et al. (1995),

(u): Janssen et al. (1997).

CHAPTER 3 METHODOLOGY

In order to avoid misunderstanding of frequently used terms in this report, some definitions are given in section 3.1. As was shown in fig. 1.1 the derivation of MPCs and NCs starts with the collection and evaluation of data from the literature. The sources from which the data have been taken and the applied evaluation criteria are described in section 3.2. On the basis of the evaluated literature a selection of NOECs is made that is used in the extrapolation. The selection criteria are described in section 3.3.

The existing extrapolation methods used for the derivation of the Maximum Permissible Concentration (MPC) are the refined effect assessment or statistical extrapolation method and the preliminary effect assessment or modified EPA-method. These methods are described in section 3.4.1 and 3.4.2, respectively.

As was outlined in the introduction (1.2.2) for metals and other naturally occurring substances, the Maximum Permissible Addition (MPA) is defined as the concentration that may be added on top of the background concentration. The MPC is regarded as the sum of the MPA and the background or Cb. In formula: MPC = MPA + Cb. The existing statistical extrapolation methods are elaborated into "The Added Risk Approach" to be used for all substances naturally occurring or anthropogenic, with which the MPA can be calculated. This is described in section 3.5.1 and 3.5.2 for the statistical extrapolation method and the modified EPA-method, respectively.

The harmonisation methods are described in 3.6. The equilibrium partition method is used to harmonise MPCs for soil with MPCs for water and is described in section 3.6.1. Besides this, the equilibrium partitioning method is used to derive MPCs for soil and sediment if for soil and/or sediment no experimental data are available. Section 3.6.2 describes the methodology to derive the CritCONC(air). The Critical Air Concentration or CritCONC(air) is defined as the concentration in air that leads to a concentration in soil equal to the MPC in soil. The CritCONC(air) for metals can be compared with MPCs in air for humans if available. In this way the MPC(soil) can be harmonised with the MPC(air).

3.1 Definitions of frequently used terms

-*Total concentration of a metal:* In case of aqueous systems the total concentration is the total amount of metal present, including the fraction sorbed to particles and dissolved organic matter (C(total) = C(sorbed)+C(dissolved)). In case of terrestrial or sediment systems, it is the concentration of a metal that is measured after complete destruction of the mineral matrix. This total concentration is equal to the sum of the concentration that is part of the structure of the minerals (fixed), the concentration adsorbed or precipitated onto the surface of minerals and onto organic matter exchange sites (bound) and the concentration in the interstitial water (soluble) (C(total)=C(fixed)+C(bound)+C(soluble); Bockting et al., 1992).

-*Background concentration or Cb:* The concentration that is present in rural sites due to natural causes only. In the Netherlands it is impossible to find locations at which real background concentrations can be measured. For surface water background concentrations are based on model estimations (Van der Weijden and Middelburg, 1989; Zuurdeeg et al., 1992). For soil and sediment background concentrations are based on 90th percentile values of regression lines describing the relationship between organic matter and clay and concentrations found in relative unpolluted sites in the Netherlands, the so-called reference-lines (TCB, 1990;1992). Therefore, it must be realised that the background concentrations derived represent the upperbound of concentrations found in relative unpolluted soils and cannot be considered as natural background concentrations (see also chapter 5).

-*Bioavailable fraction of the background concentration or φCb:* The fraction that is available for uptake by a specific organism. The bioavailability is however species and soil/sediment dependent. For instance for worms in a certain soil the bioavailability may be high (in this case the concentration in the pore water determines uptake), while for arthropods in the same soil the bioavailability may be low (uptake by food is the dominant uptake route for these organisms). On the other hand, depending on soil characteristics, bioavailability for one organism varies when exposed in different soils due to varying soil characteristics.

-*Unavailable fraction or (1- φ)Cb:* The fraction that is not available for uptake by a specific organism (Struijs et al., 1997).

-*Maximum Permissible Concentration or MPC:* Concentration above which the risk for the ecosystem is considered unacceptable (VROM, 1989b). The MPC is the sum of the background concentration C*b* and the so-called Maximum Permissible Addition (MPA), i.e., MPC = MPA + C*b*.

-*Maximum Permissible Addition:* The maximum concentration allowed to be put on top of the background concentration. The MPA is based on the fraction of species which are allowed to be affected due to the (bioavailable) concentration of the substance considered.

-*Negligible Concentration or NC:* Concentration below which the risk for the ecosystem is considered negligible (VROM, 1989b). The NC is the sum of the background concentration C*b* and the so-called Negligible Addition (NA), i.e., NC = NA + C*b*.

-*Negligible Addition:* Anthropogenic concentration below which the risk for the ecosystem is considered negligible. The NA in contrast to the MPA, is not based on a fraction of species protected and is derived by dividing the MPA by a factor 100. This factor is applied to take into account combination toxicity and uncertainties in risk assessment (VROM, 1989b).

-*Potentially Affected Fraction or PAF:* Fraction of all species that is exposed to concentrations higher than the No Observed Effect Concentration (NOEC) (Struijs et al., 1997) (see section 3.4 for a more detailed explanation).

-*PAF_b:* Fraction of all species that is potentially affected by the background concentration (Struijs et al., 1997) (see section 3.5 for a more detailed explanation).

-*PAF_a:* Fraction of all species that is potentially affected by the anthropogenic concentration (Struijs et al., 1997) (see section 3.5 for a more detailed explanation).

-*PAF_{max}:* The maximum fraction of all species that is potentially affected. (Struijs et al., 1997) (see section 3.5 for a more detailed explanation).

-*Reference lines:* In case of soil, for all metals so-called reference lines were derived by correlating measured ambient background concentrations (total concentrations in the soil-matrix) at a series of remote rural sites in the Netherlands to the percentage clay and the organic matter content of these soils (Edelman, 1984; De Bruijn and Denneman, 1992).

-*Standard soil:* In the Netherlands a hypothetical soil, defined to contain 25% lutum or clay and 10% organic matter, is indicated a standard soil. The standard soil is used to extrapolate toxicity and exposure data.

3.2 Literature search and evaluation

3.2.1 Sources for toxicity data

For some of the metals considered the data on toxicity have been updated for this report. This concerns the metals As, Cd, Cr and Cu. For all the other metals reference is made to other reports published in the framework of "Setting Integrated Environmental Quality Objectives" and other RIVM-projects. Table 3.1 gives an overview of the reports where the original data and the data used in the extrapolations can be found. For the metals for which an update of data is made the evaluation criteria are published in the Quality Assurance documents of the Centre for Substances and Risk Assessment (CSR, 1996). For all the other metals the evaluation criteria are described in the report where the data have been published.

Table 3.1 References for original data on toxicity and data used in extrapolations for the metals considered in this report.

metal	publication of original data	data used for extrapolation
antimony	Van de Plassche et al., 1992	Van de Plassche et al., 1992
arsenic	Appendix I, II, III and IV of this report	Appendix V and VI of this report
barium	Van de Plassche et al., 1992	Van de Plassche et al., 1992
beryllium	Van de Plassche et al., 1992	Van de Plassche et al., 1992
cadmium	Appendix I, II, III and IV of this report	Appendix V and VI of this report
chromium	Appendix I, II, III and IV of this report	Appendix V and VI of this report
cobalt	Van de Plassche et al., 1992	Van de Plassche et al., 1992
copper	Appendix I, II, III and IV of this report	Appendix V and VI of this report
lead	Janus et al., 1997	Appendix V and VI of this report
mercury	Slooff et al., 1995	Appendix V and VI of this report
molybdenum	Van de Plassche et al., 1992	Van de Plassche et al., 1992
nickel	Van de Meent et al., 1990	Appendix V and VI of this report
selenium	Van de Plassche et al., 1992	Van de Plassche et al., 1992
thallium	Van de Plassche et al., 1992	Van de Plassche et al., 1992
tin	Van de Plassche et al., 1992	Van de Plassche et al., 1992
vanadium	Van de Plassche et al., 1992	Van de Plassche et al., 1992
zinc	Janus, 1993: Janus et al., 1996	Appendix V and VI of this report

3.2.2 Re-evaluation of toxicity studies

As this report concerns an update of formerly derived MPCs and NCs not all the toxicity studies have been re-evaluated. The methodology used to evaluate toxicity studies is constantly in development and therefore the methodology used for the different metals may be slightly different. For an extensive description of the criteria used for these studies, it is referred to the reports from which data have been taken (see 3.2.1). With the exception of three aspects these differences are considered negligible. The aspects that are taken into consideration are:

- In this report the *added* risk approach is applied and ideally the data used should be based on the concentrations added to the test media in the laboratory. Especially for ecotoxicological data which result in values close to the background concentration, it is critical to know if the result is including or excluding the background of the test medium. Therefore for *all* the metals, references of ecotoxicological data with a value less than ten times the background concentration (as assumed in the present report, see chapter 5) have been re-evaluated,
- In ecotoxicological studies with essential elements it can theoretically occur that the effects observed are caused by element limitation instead of other toxic effects. To prevent this, special attention is paid to studies resulting in extreme low NOEC or L(E)C50 values. Studies resulting in extremely low NOEC or L(E)C50 values have been re-evaluated paying extra attention to the following criteria:
  -Only studies in which there is a concentration-effect relationship are used. This criteria is applied to be sure that NOECs are based on effects due to toxic effects instead of limitation,
  -The NOEC should be derived after a sufficiently long exposure period and in the toxic concentration band. This criteria is considered especially for studies in which the test-organisms are cultured in media containing low levels of trace metals. According to Van Tilborg and Van Assche (1995) species cultured in conditions with a lower concentration of zinc than those in which they occur naturally may be more sensitive in the experimental situation. This might be reflected in an improved performance relative to the control group if the exposure-time is too short or at low test concentrations (Janus et al., 1996),
- Species that are not common for the Dutch situation may be adapted to very specific conditions not representative for the Dutch situation. Special attention is paid to the representativeness of the tested species for the Dutch situation. On the basis of existing data-sheets on species occurring in the Netherlands and the information on the occurrence of the species supplied in the original manuscripts the decision is made to include or exclude the species in the data.

One aspect that is considered very important for the result of the toxicity test is the influence of metal speciation. Physico-chemical characteristics like for instance the pH and hardness of the test medium used in the test will influence the bioavailability of metals due to differences in speciation. These differences in bioavailability will result in a different uptake and hence in differences in sensitivity of species exposed under different characteristics of the test medium. With respect to the abiotic factors influencing the toxicity of metals in fresh water, hardness is usually considered as one of the main factors or as the main factor: the toxicity of metals is generally assumed to be inversely related to hardness. In some countries, for example the United States and Canada, the relevance of this factor is reflected in hardness-related Water Quality Criteria, derived for a number of metals[1]. On the basis of the evaluations of the aquatic toxicity of metals in the underlying report and in the RIVM Integrated Criteria Documents (see chapter 9 for results of this evaluation) the decision is made not to correct the results of the toxicity tests for hardness when deriving MPCs.

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[1] In the United States, hardness-related Water Quality Criteria were set for Cd, Cr(III), Cu, Pb, Ni, and Zn, but not for other metals (EPA, 1991, cited in BKH, 1995). In Canada, hardness-related WQCs were set for Cd, Cu, Ni and Pb (CCME, 1994, cited in BKH, 1995).

Salinity is another factor influencing speciation and differences in sensitivity (expressed as external concentrations) may be expected between fresh water and marine species (Jonkers and Everts, 1992). Some studies in which comparisons have been made between fresh water and marine species (Scholten et al., 1991; Van de Plassche et al., 1992), did not show any differences in sensitivity. In a literature study performed by Hall and Anderson (1995) it was concluded that the toxicity of some metals increased with decreasing salinity. It must be noted that these studies are all based on small data sets. As long as this conclusion is not based on more data, special attention has to be paid to this subject (TCB, 1994). In the present report sensitivities of freshwater and marine species are compared, statistically, if possible. Only if differences are found, freshwater and marine data are not combined. In all other cases, if no difference is proven or if it is not possible to compare sensitivities, the freshwater and marine data are combined to derive the MPC.

3.3 Selection of data used for extrapolation

In the extrapolation methods used (see 3.4) only one value per species is used as input. If more than one value for a certain species or process is available, one value is selected/calculated for use in the extrapolation. The method used to select one value, is explained in the footnotes of the appendices which present the data used for extrapolation (Appendix IV and V). Especially if another recent RIVM document on a certain metal is available, these selected data are included in the present report. This is the case for lead and zinc. For these metals selected data have been taken from these reports. Because the methodology used to evaluate and select data is constantly in development, the methodology used for the different metals may therefore be slightly different.

When selecting data the following rules are applied (Slooff, 1992):
-Toxicological criteria which may affect the species at the population level are taken into account. In general these are survival, growth and reproduction and are commonly expressed as an L(E)C50 (short-term tests, duration four days or less) or NOEC (long-term tests, duration more than four days, with the exception of micro-organisms and algae for which a NOEC may be derived from experiments during less than four days),
-If for one species several toxicity data based on the same toxicological endpoint are available, these values are averaged by calculating the geometric mean,
-If for one species several toxicity data based on different toxicological endpoints are available, the lowest value is selected. The lowest value is determined on the basis of the geometric mean, if more than one value for the same parameter is available (see above),
-In some cases data for effects of different life-stages are available. If from these data it becomes evident that a distinct life-stage is more sensitive, this result may be used in the extrapolation.

For soil toxicity data on terrestrial species as well as for microbial and enzymatic processes may be available. The latter are in principle summed parameters expressing the performance of a process. The process in question may be performed by more than one species and under toxic stress, the functioning of the process may be taken over by less sensitive species. From the foregoing it may be clear that effects on species and effects on processes are quite different. According to Van Beelen and Doelman (1996) the results of ecotoxicological tests with microbial processes can not be used together with single species tests in a single extrapolation, because of the difference between them. Therefore these data are not combined and data are selected to be able to derive to different values.

For the data on microbial processes and enzymatic activity more than one value per process is included in the extrapolation method. It is reasoned that NOECs for the same process but using a different soil as substrate are NOECs based on different populations of bacteria and/or microbes. Therefore these NOECs are treated separately. Only if values are derived from a test using the same soil, one value is selected/calculated.

3.4 Existing extrapolation methods

The existing extrapolation methods used for the MPC are the refined effect assessment or statistical extrapolation method and the preliminary effect assessment or modified EPA-method. The first one is applied if chronic toxicity data (NOECs) for species of at least four different taxonomic groups are available. The second one if less chronic data or only acute data are available. The first and second method are described in section 3.4.1 and 3.4.2 respectively.

3.4.1 Refined effect assessment: statistical extrapolation

The aim of environmental quality objectives is that the MPC is set at a level that protects all species in an ecosystem. However, in order to be able to use extrapolation methods like the one of Aldenberg and Slob (1993), a 95% protection level is chosen as a sort of cut-off value (VROM, 1989b). The concentration corresponding with a 95% protection level which is the same as a Potentially Affected Fraction of all species of 5% or PAF = 0.05, is called the MPC and can be derived using statistical extrapolation methods.

Statistical extrapolation methods are based on the assumption that the sensitivities of species in an ecosystem, expressed as NOEC or L(E)C50 values, can be described by a statistical frequency distribution. This frequency distribution can be estimated using NOEC or L(E)C50 values of species of different taxonomic groups as input. From the estimated distribution a concentration can be derived which is assumed to be "safe" for an ecosystem. For a detailed overview of the theory and the statistical adjustments since its introduction, it is referred to the original literature (Kooijman, 1987; Van Straalen and Denneman, 1989; Wagner and Løkke, 1991, Aldenberg and Slob, 1993).

The method of Aldenberg and Slob (1993) is used in the project "Setting Integrated Environmental Quality Objectives" if NOEC values for four or more different taxonomic groups are available. This method assumes that the NOEC values used for estimating the distribution fit the log-logistic distribution. The advantage of the log-logistic distribution is that it allows the analytical evaluation of the cumulative distribution PAF(x) by integration:

$$PAF(x) = 1/(1+ \exp((\alpha - x)/\beta)) \quad \textbf{(1)}$$

in which:

PAF(x) = potentially affected fraction of all possible species at concentration x
α = mean value of the log-logistic distribution
β = scale parameter of the log-logistic distribution
x = log(c): logarithm of the concentration

The log-logistic distribution can be characterised by α and β. The α indicates the mean value of the distribution which determines the location of the distribution on the concentration axis (log(NOEC) or log(c)) and β is the scale parameter of the distribution which determines the width or shape of the distribution and is equal to approximately half times σ ($\beta = \sigma \sqrt{3}/\pi$). In fig. 3.1 some examples of the log-logistic frequency distribution and in fig. 3.2 of the cumulative log-logistic distribution are shown.

PAF(x) has a value between 0 and 1 and is the fraction of species that have log(NOEC) values smaller than x. When PAF is equal to 0.05, the corresponding concentration can be calculated with 50% and 95% confidence. In the Netherlands the MPC is set equal to the former value. The concentration, corresponding with a certain fraction of species unprotected can be derived by rewriting equation 1 into:

$$x = \alpha - \beta \ln((1-PAF)/PAF) \quad \textbf{(2)}$$

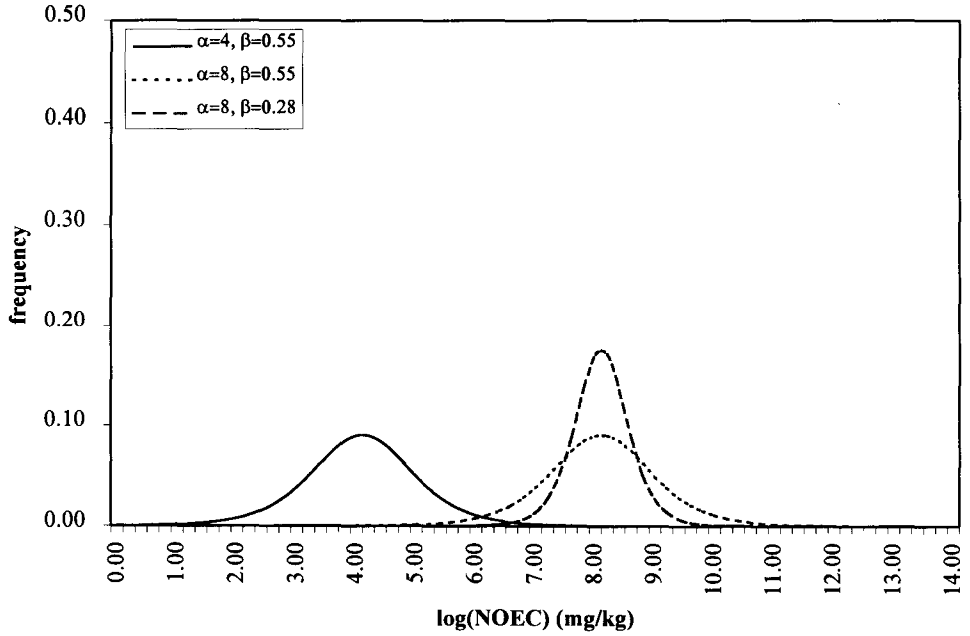

Figure 3.1 Examples of log-logistic frequency distributions with different α and β.

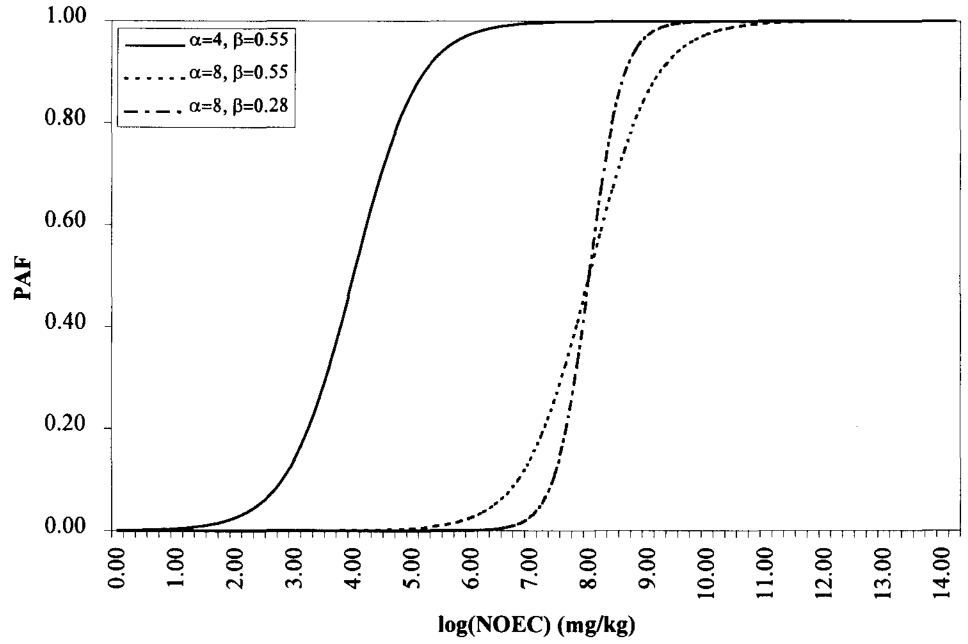

Figure 3.2 Examples of cumulative log-logistic distributions with different α and β (see also equation 1).

As mentioned before the method of Aldenberg and Slob (1993) assumes that the NOEC values used for estimating the distribution fit the log-logistic distribution. For checking this assumption the data available can be tested statistically with the empirical distribution function (EDF): Kolmogorov-Smirnov D^*sqrt(n) test (Aldenberg and Slob, 1993). If the NOEC values are not log-logistically distributed at a significance level of 1% and there are no reasons for leaving out outliers this is mentioned in a note.

The Negligible Concentration (NC), in contrast to the MPC, is not based on a fraction of species protected and is derived by dividing the MPC by a factor 100. This factor is applied to take into account combination toxicity and uncertainties in risk assessment (VROM, 1989b).

3.4.2 Preliminary effect assessment: the modified EPA-method

The preliminary effect assessment method is a modified EPA-method in which fixed assessment factors are applied to toxicity data (Van de Meent et al., 1990; OECD, 1992). The empirically derived assessment factors are not based on any theoretical model, but have been developed in line with experience with chemical effect assessment. The assumption is made that there is a constant and identical difference between acute and chronic toxicity and between single-species (laboratory) and ecosystem sensitivity. Hence the assessment factors may be used to extrapolate from the lowest chronic NOEC to the field situation and from concentrations with acute effects to no-observed effect concentrations (EPA, 1984). For each extrapolation a factor 10 is suggested. The assessment factors and conditions used are shown in table 3.2 for aquatic effect assessment and in table 3.3 for terrestrial effect assessment. The Negligible Concentration (NC) is again derived by dividing the MPC with a factor of 100.

Table 3.2 modified-EPA method for aquatic ecosystems

Available information	Assessment factor
lowest acute L(E)C50-value or QSAR estimate for acute toxicity	1000
lowest acute L(E)C50-value or QSAR estimate for acute toxicity for minimal algae/crustacean/fish	100
lowest NOEC-value or QSAR estimate for chronic toxicity*	10
lowest NOEC-value or QSAR estimate for chronic toxicity for minimal algae/crustacean/fish	10

*this value is subsequently compared to the extrapolated value based on acute L(E)C50 toxicity values. The lowest one is selected.

Table 3.3 Modified-EPA method for terrestrial ecosystems

Available information	Assessment factor
lowest acute L(E)C50-value or QSAR estimate for acute toxicity	1000
lowest acute L(E)C50-value or QSAR estimate for acute toxicity of microbe-mediated processes, earthworms or arthropods and plants	100
lowest NOEC-value or QSAR estimate for chronic toxicity*	10
lowest NOEC-value or QSAR estimate for chronic toxicity for three representatives of minimal microbe-mediated processes, earthworms or arthropods and plants	10

*this value is subsequently compared to the extrapolated value based on acute L(E)C50 toxicity values. The lowest one is selected.

The modified EPA-method is used if less than 4 NOECs from different taxonomic groups are available. This implicitly assumes that in this case the frequency distribution of the species sensitivity is unknown. In other words, the availability of 4 NOECs from different taxonomic groups is regarded as a cut-off value for knowing the distribution function.

3.5 The added risk approach

For metals and other naturally occurring substances, the Maximum Permissible Addition (MPA) is defined as the concentration that may be added on top of the background concentration. The basic starting point for this approach is the calculation of Maximum Permissible Addition (MPA) that is calculated on the basis of the available data from laboratory toxicity tests. This MPA, which is due to anthropogenic activities, is subsequently added to the background concentration of the metal leading to the Maximum Permissible Concentration (MPC). In formula: MPC = MPA + C*b*.

Whether or not the background concentration is bioavailable or may even lead to deleterious effects on the ecosystem is ignored since from an environmental policy point of view these effects can even be regarded as desirable since they may lead to an increase in biodiversity. Although from a policy point of view the effects due to the background concentration may be ignored, a more scientific investigation of the resulting outcome of the approach as published by Struijs et al. (1997) may however be warranted as also discussed by Struijs et al. (1997). Throughout the present report an evaluation will be made for the different MPC values that result when the bioavailable fraction of the background concentration is taken into account.

The existing statistical extrapolation methods are elaborated into "The Added Risk Approach" to be used for all substances naturally occurring or anthropogenic, with which the MPA can be calculated. This is described in section 3.5.1 and 3.5.2 for the statistical extrapolation method and the modified EPA-method, respectively.

3.5.1 Refined effect assessment: statistical extrapolation

The added risk approach as published by Struijs et al. (1997) is followed in the present report, but it must be mentioned that the terminology as proposed by Struijs et al. (1997) has been modified (see section 1.2.2). The following explanation of the added risk approach is the version as used in the present report.

It is assumed by Struijs et al. (1997) that the background concentration or C*b* consists of two fractions: the active or the bioavailable fraction φ exerting an effect and the inactive or the fraction not bioavailable (1- φ) to exert an effect (see fig. 3.3). Besides this it is assumed that the fraction of the background concentration or φC*b* indicated as "active" in fig. 3.3 is the relevant fraction to be compared with the NOEC data from laboratory tests. In this reasoning it is assumed that in the laboratory NOECs pertain to 100% availability.

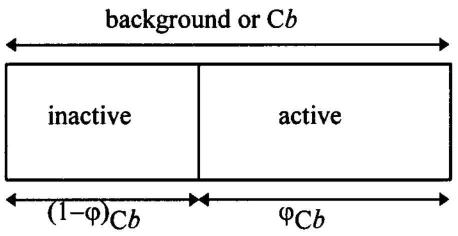

Figure 3.3 The inactive or unavailable (1−φ) and active or bioavailable (φ) fractions of the background concentration C*b*.

In "the added risk approach" a Maximum Permissible Addition or MPA is defined. This MPA is the concentration that is allowed to be added to the background concentration (see fig. 3.4). According to Struijs et al. (1997) the MPA is related with "an acceptable added effect" or PAF_a (expressed as a fraction unprotected). In fig. 3.4 the bar is extended with a maximum permissible (active) addition (MPA) of anthropogenic origin.

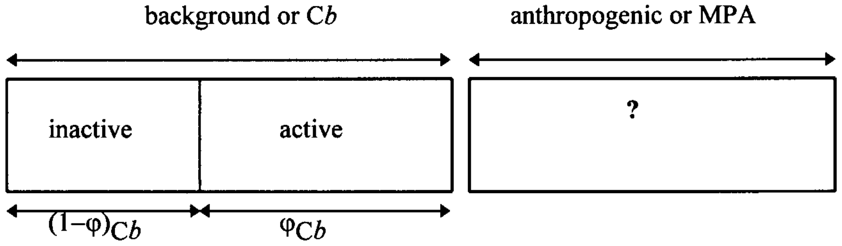

Figure 3.4 The background C*b* and the Maximum Permissible Addition

Depending on the (fraction of the) background concentration that is bioavailable, φ, this method can be worked out in different ways. Figure 3.5 gives an overview of the possibilities.

In case 1 the background is very low compared to the ecotoxicological effects data. This situation is comparable with the situation for xenobiotics which have a zero background and the procedure reduces to the well known "Aldenberg and Slob method" as described in section 3.3.1. This means that MPA equals the concentration corresponding with an PAF of 0.05, i.e. MPC = MPA.

In case 2 there is a significant background concentration compared to the ecotoxicological effects data. In this case it has to be determined whether or not the background is bioavailable, i.e. whether there is an active fraction that is able to exert toxic effects. Two situations can be distinguished (case 2a and case 2b):

In case 2a where there is a background which is not bioavailable ($\varphi = 0$), the maximum permissible addition or MPA equals, as in case 1 the concentration corresponding with an PAF of 0.05. The MPC is set to the sum of the MPA and the background concentration, i.e. MPC = MPA + Cb.

In case 2b the background is (partly) bioavailable ($\varphi > 0$). The standard procedure for calculating the concentration corresponding with an PAF of 0.05 cannot be followed any more since part of the species in the ecosystem may be affected by the bioavailable fraction of the background. The MPA depends on the background concentration or Cb, the fraction bioavailable or φ and the cumulative NOEC distribution curve (characterised by α and β). Again the MPC is set to the sum of the MPA and the background concentration, i.e. MPC = MPA + Cb. It must be noted however that in this case it is not possible to combine the MPC with another background or bioavailability φ than used to calculate the MPC. As indicated above the MPA is dependent on the background concentration and the bioavailable fraction.

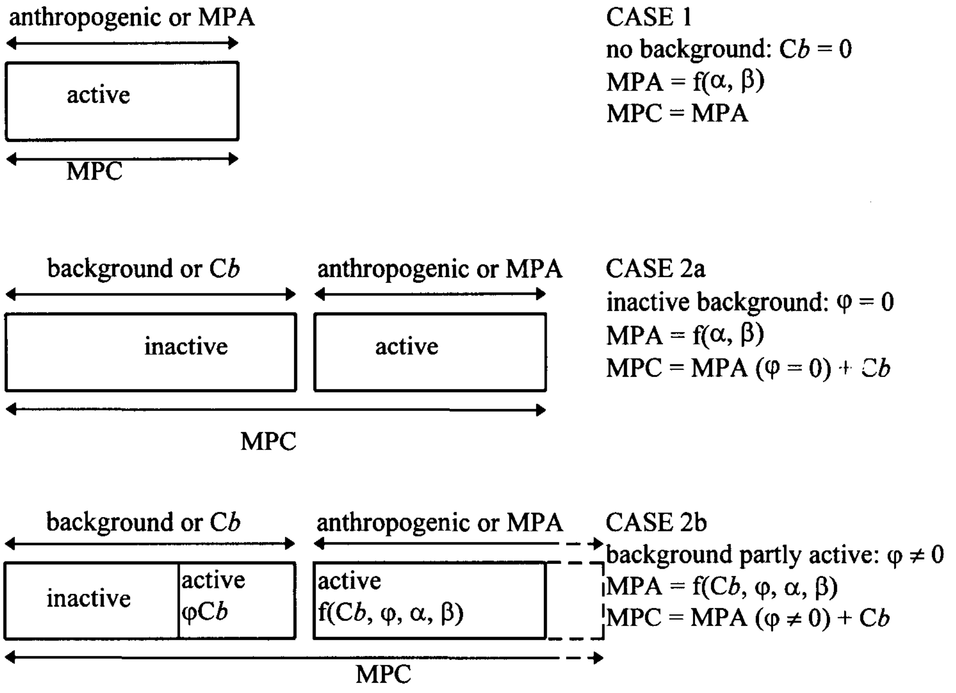

Figure 3.5 Overview of possibilities to derive the MPC when applying the added risk approach.

At this moment not enough information is available to estimate the bioavailable fraction of the background concentration for all the metals considered in this report. For the time being three different approaches will be dealt with and compared with each other in this report: 0%, 50% and 100% availability or $\varphi = 0$, 0.5 and 1. These three possibilities will be worked out in the results and discussed in chapter 9.

To be able to derive the MPCs the following information is required: 1) ecotoxicity data or NOECs for species of different taxonomic groups, 2) the effect induced by the background concentration or the bioavailable fraction of the background concentration (φCb, $\varphi = 0$, 0.5 and 1) and 3) the risk limit chosen by environmental policy makers as tolerable if there is no background concentration (PAF = 0.05, see also 3.4).

For $\varphi = 0$, the MPA is derived by deriving the concentration corresponding with an PAF of 0.05 as described in section 3.4 and the MPC is derived by adding the background concentration. Four steps are necessary to calculate the MPC for $\varphi = 0.5$ and $\varphi = 1$:
-step 1: The background effect or PAF_b has to be derived. This background effect is defined as the fraction of species that is potentially affected by the bioavailable fraction of the background concentration (φCb) and can be derived from the cumulative log-logistic frequency distribution (by inserting φCb as x in equation 1, see also fig. 3.6).

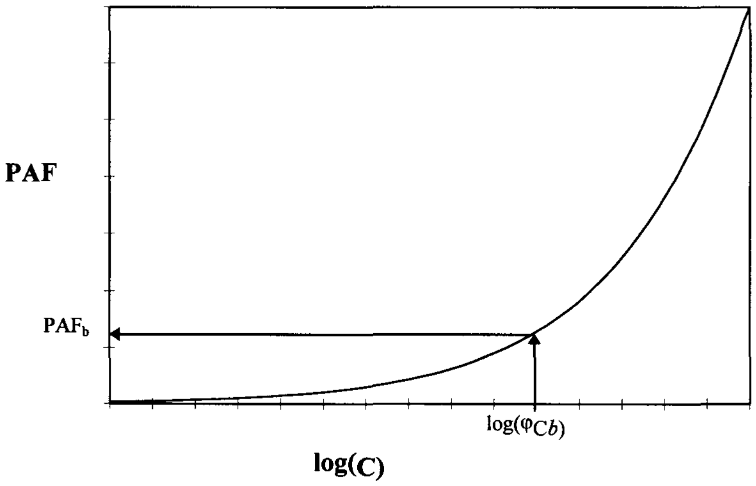

Figure 3.6 Deriving the fraction of species unprotected at the background concentration from the cumulative estimated statistical frequency distribution (see also equation 1).

-step 2: Deriving the additional effect or PAF_a. Additional means that it is allowed to put this effect on top of the background effect, PAF_b. This additional effect is related to the remaining fraction of species, being $1 - PAF_b$. It is proposed to accept an additional effect of 0.05 of these remaining species. Therefore the additional effect is defined as:

$$PAF_a = (1 - PAF_b) \cdot 0.05 \qquad (3)$$

in which:
PAF_a = fraction of potentially affected species on top of the background effect
PAF_b = background effect; fraction of species that is potentially affected by the bioavailable fraction of the background concentration

-step 3: Deriving the maximum permissible effect or PAF_{max} by adding the additional effect on top of the background effect:

$$PAF_{max} = PAF_b + PAF_a = PAF_b + (1 - PAF_b) \cdot 0.05 \qquad \textbf{(4)}$$

-step 4: The concentration corresponding with the PAF_{max} can be derived. As can be seen in fig. 3.7 the PAF_{max} is related to log(φC*b* + MPA) and can be derived from the cumulative log-logistic frequency distribution (by inserting PAF_{max} as PAF(x) in equation 2). The concentration to be added on top of the background concentration or MPA can be derived.

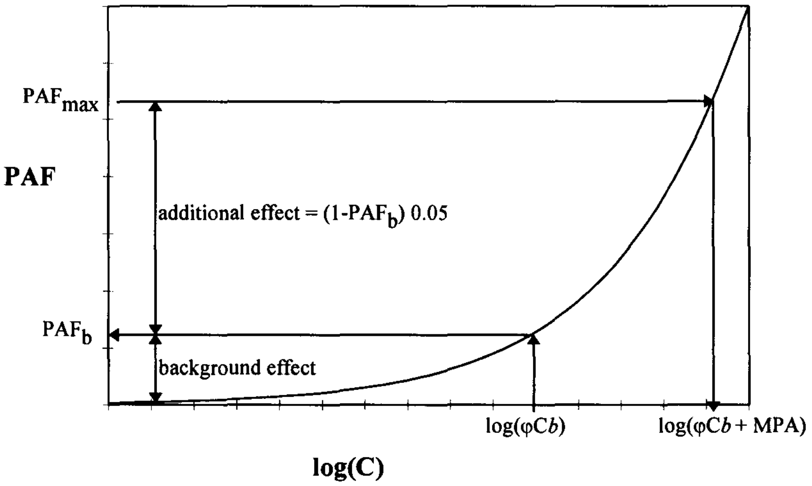

Figure 3.7 Deriving MPA from the cumulative estimated statistical frequency distribution.

As was also outlined in figure 3.5 and its explanation, the absence of any background activity, because either φ or C*b* equals zero, will result in an MPA that is only dependent on α and β (case 1 and case 2a in figure 3.5). With $PAF_b > 0$, in principle there is no real limitation to (φC*b* + C*a*) as, theoretically, PAF_{max} may approximate 1 if there are extremely high background effects.

In all cases the NA is obtained by dividing the MPA by 100:

$$NA = MPA/100 \qquad \textbf{(5)}$$

The NC is obtained by adding the background concentration to the NA from equation 5:

$$NC = NA + Cb \qquad \textbf{(6)}$$

3.5.2 Preliminary effect assessment: the modified EPA-method

If less than four NOECs from different taxonomic groups are available and the frequency distribution of the species sensitivity is unknown, the modified EPA method is used. Since it is not possible to estimate the proportion of species affected, the effect of the bioavailable fraction of the background concentration on the MPC cannot be evaluated as in the case of statistical extrapolation (3.5.1). The MPA is obtained by applying the assessment factors on the toxicity data concentration as outlined in table 3.2 and 3.3 and adding the background concentration, i.e. MPC = MPA + Cb. The same as outlined for statistical extrapolation in formula 5 and 6, the Negligible Concentration (NC) is derived by dividing the MPA with a factor 100 and adding the background concentration: NC = MPA/100 + Cb.

3.6 Harmonisation methods

The equilibrium partitioning method is used to harmonise MPCs for soil with MPCs for water and is described in section 3.6.1. Besides this, the equilibrium partitioning method is used to derive MPCs for soil and sediment if for soil and/or sediment no experimental data are available. Critical Air Concentrations or CritCONC(air)s are calculated and compared with MPCs in air for humans if available. In this way the MPA(soil) is harmonised with the MPC(air). Section 3.6.2 describes the methodology to derive the CritCONC(air).

3.6.1 Equilibrium partitioning

The equilibrium partitioning method or EP-method was originally proposed by Pavlou and Weston (1984) to develop sediment quality criteria. The concept has been described in detail by Shea (1988) and DiToro et al. (1991). Three assumptions are made when applying this method. Firstly, it is assumed that bioavailability, bioaccumulation and toxicity are closely related to the pore water concentrations; Secondly, it is assumed that sensitivities of aquatic organisms are comparable with sensitivities of organisms living in the sediment or soil; Thirdly, it is assumed that an equilibrium exists between the chemical sorbed to the particulate sediment organic carbon and the pore water and that these concentrations are related by a partition coefficient (Kp).

Considering these assumptions, several examples exist in which the response of the sediment organism is related to the concentration in the pore water: for instance for the amphipods *Rhepoxynius abronius*, *Rhepoxynius hudsoni* and *Ampelisca abdita* exposed to cadmium (DiToro et al., 1990). As the amount of metals available in the pore water depends strongly on sediment/soil characteristics, relationships between the accumulation of metals by invertebrates and sediment or soil characteristics can be expected (reviewed by Van Gestel et al., 1995 for soil). Also relationships between toxicity and soil characteristics have been found like for instance for cadmium and earthworms (Van Gestel and Van Dis, 1988), and copper and earthworms (Jäggy and Streit, 1982).

It is realised that the definition of one partition coefficient to be used in the EP-method is by far an oversimplification in view of the strong influence of soil/sediment characteristics on speciation and therefore on the bioavailability of metals. At the moment however, an insufficient scientific basis is present for implementation of models that take into account the speciation of the metal, the (geo)chemistry of water, soil and sediment and thus the real bioavailable fraction (see also chapter 9).

With the EP-method a concentration in the soil or sediment is calculated from the concentration in the water using the following formula:

$$C(\text{soil/sediment}_{EP}) = C(\text{water}) * Kp \tag{7}$$

in which:

$C(soil/sediment_{EP})$ = concentration in soil or sediment in mg/kg using the equilibrium partitioning method
$C(water)$ = concentration in water in mg/l
Kp = partition coefficient in l/kg

The frequency distribution of benthic species is unknown, since no ecotoxicological data on those organisms are available. When applying the EP-method it is thus not possible to estimate the proportion of species affected, and the effect of the bioavailable fraction of the background concentration cannot be evaluated as proposed for statistical extrapolation (3.5.1).

It is proposed to obtain the MPA for soil or sediment by using the MPA for water as a starting-point and adding the background concentration for soil/sediment. The same as outlined for statistical extrapolation in formula 5 and 6, the Negligible Concentration (NC) is derived by dividing the MPA with factor 100 and adding the background concentration: NC = MPA/100 + C*b*.

3.6.2 Calculating critical air concentrations

The Critical air Concentration (CritCONC(air)) is the concentration in the air that corresponds with the MPA(soil) and can be calculated from the MPA(soil) using the Steady-State soil/air Concentration Ratios ($SSCR_{soil/air}$) for heavy metals. The $SSCR_{soil/air}$ for the different metals is derived using the SimpleBox model; version 1.1 (Van de Meent, 1993). The Critical air Concentration CritCONC(air) can be compared with the MPC(air)s that are based on human toxicological data and further to harmonise these MPAs for soil with the MPC(air).

In the calculations it is assumed that the main emission route is through the air (the primary compartment) and that natural soil is the compartment of focus (secondary compartment). This secondary compartment is only loaded indirectly via the primary compartment, the air (so the emission from soil to air is assumed zero).

The SimpleBox model is a model that is often referred to as a Mackay-type: it is a multimedia fate model in which the environmental compartments are represented by homogeneous boxes. For an extensive description of the model reference is made to Van de Meent (1993) and Van de Meent and De Bruijn (1995). From this $SSCR_{soil/air}$ it is possible to calculate Critical Air Concentrations (CritCONC(air)) using equation 8:

$$\mathrm{CritCONC(air)} = \mathrm{MPC(soil)}/\mathrm{SSCR}_{soil/air} \qquad \mathbf{(8)}$$

where:

CritCONC(air) = Critical CONCentration in air in g/m^3
MPC(soil) = Maximum Permissible Concentration in soil in g/kg (dry weight)
$SSCR_{soil/air}$ = Steady State soil/air Concentration Ratio in m^3/kg (dry weight)

The SimpleBox model is originally developed for organic substances. The model is therefore not directly applicable for calculation of CritCONC(air)s for heavy metals. In order to make estimates for CritCONC(air) for heavy metals, parameter settings are adapted for log K*ow*, vapour pressure, scavenging ratio, fraction aerosol bound metal and degradation rates. The adapted parameter settings are explained in the results (section 7.7).

For the metals for which MPCs for air are available (antimony, arsenic, beryllium, chromium, lead, nickel and vanadium) a comparison can be made between this MPC(air) and the CritCONC(air). The MPCs for air are derived without taking background concentrations into account. Therefore, the MPCs for air are compared with the CritCONC(air) calculated using the MPA for soil.

3.7 Summary of methodology used in this report for water, soil and sediment

In general, for each compartment the MPA for metals is based on laboratory toxicity data and applying extrapolation methods. The following steps can be discerned:

1. Laboratory toxicity data are selected from the data set and are based on concentrations excluding the background,
2. If NOECs for species of more than four taxonomic groups are available, the MPA is calculated using statistical extrapolation,
3. If less NOECs or only acute data are available, the modified EPA-method is used to derive the MPA,
4. The MPC is calculated as MPC = MPA+C*b,*
5. The NC is calculated as NC = MPA/100 + C*b*.

Considering fresh surface water, marine surface water and groundwater the following remarks can be made:

-Sensitivities of fresh and marine species are statistically compared. If no differences in sensitivity are found and if it is not possible to compare the sensitivities, the MPA for fresh surface water, the MPA(fresh) presented in section 6.1, and the MPA for marine surface water, the MPA(marine) presented in section 6.2, are based on the combined data set. The MPA(freshwater species), based on data for freshwater species only, and the MPA(marine species), based on data for marine species only, are however included in the text of section 6.1.

- For groundwater the MPA is based on the same ecotoxicological data as the MPA for surface water. Although it can be doubted that the sensitivity of surface water species and groundwater species is comparable (GZR, 1995), this approach is taken as long as no data on sensitivity of groundwater species for metals are available. The results are presented in section 6.3.

-When applying statistical extrapolation it is possible to include the bioavailable fraction of the background concentration. In principle, this must be done for each metal discussed in the present report. For water, however, no or only few information is present on the bioavailability of the background concentrations. In chapter 6, for the metals for which statistical extrapolation is applied, MPAs and MPCs are derived assuming that background concentrations are 0%, 50% and 100% bioavailable. This means that values of $\varphi = 0$, 0.5 and 1 are assumed.

-As was indicated in section 3.5.1 the MPA for $\varphi = 0$ is only dependent on α and β, and therefore only on the underlying data of the statistical distribution. In this case the background has no influence on the outcome. The MPA(fresh), the MPA(marine) and the MPA(groundw) are the same (as the same data are used as input) for $\varphi = 0$ (case 2a in figure 3.5). If there is a significant background concentration and $\varphi \neq 0$ (case 2b in figure 3.5), the MPA is also dependent on the background concentration. Therefore MPAs $\varphi = 0.5$ and 1 are calculated if there is information on the background concentration in the corresponding watertype.

- In case the modified EPA method is used only results for $\varphi = 0$ are presented, as it is not possible to include the percentage bioavailable of the background concentration. This has as a consequence that the MPA(fresh), the MPA(marine) and the MPA(grw) are the same.

Considering the soil the following remarks can be made:

- Soil data are recalculated into data for a standard soil containing 10% organic matter and 25% clay, the so-called standard soil.

-MPAs, MPCs, NAs and NCs are expressed as a value in standard soil containing 10% organic matter and 25% clay.

-The same as for water, no or only few information is present on the bioavailability of the background concentrations in soil. In chapter 7, for the metals for which statistical extrapolation is applied, MPAs and MPCs are derived assuming that background concentrations are 0%, 50% and 100% bioavailable. This means that values of $\varphi = 0$, 0.5 and 1 are assumed.

-If possible for species as well for processes an MPA is derived.

-If less than 4 NOECs for different taxonomic groups are available the modified EPA method is used. Only results for $\varphi = 0$ are presented in section 7.1, as it is not possible to include the percentage bioavailable.

-If no toxicity data on the sensitivities of terrestrial species and processes are available, the MPC for soil is derived using equilibrium partitioning. The MPC(soil$_{EP}$)s are presented in section 7.2. Only results for $\varphi = 0$ are presented in section 7.1, as it is not possible to include the percentage bioavailable.

Considering the sediment the following remarks can be made:

-For sediment no or only few data are available. Therefore MPAs for sediment are derived using equilibrium partitioning (MPC(sed$_{EP}$)). As was indicated in chapter 3.6.1, use of the EP-method follows that the frequency distribution of the species sensitivity is unknown. Therefore, it is not possible to estimate the proportion of species affected and the effect of the bioavailable fraction of the background cannot be included. The MPA(sed$_{EP}$) which is based on the MPA(fresh) for $\varphi = 0$, is presented in section 8.1.

-As for soil the MPAs, MPCs, NAs and NCs for sediment are derived the so-called standard sediment.

CHAPTER 4 PARTITION COEFFICIENTS

Partition coefficients for the distribution of metals between particulate matter and water ($Kp_{(pm/w)}$) are used to calculate the dissolved background concentrations from the total background concentrations in surface water. Partition coefficients for partitioning of metals between soil and water ($Kp_{(soil/w)}$) and between sediment and water ($Kp_{(sed/w)}$) are used to apply the equilibrium partitioning method.

4.1 Particulate matter

For the metals arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, and zinc experimental partition coefficients for particulate matter in fresh surface water ($Kp_{(pm/w)}$) have been reported by Stortelder et al. (1989), Venema (1994) and Koelmans and Radovanovic (1997) (table 4.1). The $\log Kp_{(pm/w)}$s of Stortelder et al. (1989) are derived on the basis of measurements of these metals in water samples of four Dutch locations from 1983 to 1986. The $\log Kp_{(pm/w)}$s of Venema (1994) are derived from measurements in particulate matter and water of seven different Dutch locations from 1988 to 1992 and the $\log Kp_{(pm/w)}$s of Koelmans and Radovanovic (1997) are derived from measurements in particulate matter and water of three different Dutch locations from 1992 to 1994. According to Venema (1994) the proposed values of Stortelder et al. (1989), on the basis of measurements in water, did not have to be adjusted because no significant differences were found.

For the metals arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc partition coefficients for particulate matter in marine surface water ($\log Kp_{(pm/w)}$) are derived by Yland and Smedes (1996). Besides this, Yland (1996) also derived values for partitioning between particulate matter and marine surface water, in which the concentration of the particulate matter is corrected for the background concentration. All these values are comparable with the values in fresh surface water. Because the $\log Kp_{(pm/w)}$s of Stortelder et al. (1989) have been used for deriving risk limits in earlier reports (Van de Meent et al., 1990) and are still in use at several Dutch institutes, these values will also be used in the present report for fresh and marine surface water (underlined in table 4.1).

For the metals antimony, barium, beryllium, cobalt, molybdenum, selenium, thallium, tin and vanadium Bockting et al. (1992) derived $\log Kp_{(pm/w)}$s in the same way as described in Stortelder et al. (1989). The values for antimony and vanadium are also based on measurements in Dutch surface waters (four locations from 1983-1986). For barium, beryllium, cobalt, molybdenum, selenium and tin no values have been proposed on the basis of measurements in Dutch surface waters. The $\log Kp_{(pm/w)}$s in table 4.1 are the values proposed by Bockting et al. (1992) and are based on measurements in North American rivers (Popp and Laquer, 1980; Li et al., 1984).

Table 4.1 Partition coefficients for metals between particulate matter and water ($\log Kp_{(pm/w)}$), between soil and water ($\log Kp_{(soil/w)}$, experimental (exp) and field-based (field)), and between sediment and water ($\log Kp_{(sed/w)}$, estimated (est) and based on monitoring data (mon)). All log-values are based on the Kp in l/kg. The values for soil and sediment are expressed as a value in standard soil/sediment (containing 10% organic matter and 25% of clay). Values used in this report are underlined.

Metal	$\log Kp_{(pm/w)}$						$\log Kp_{(soil/w)}$			$\log Kp_{(sed/w)}$		
	1989(a)	1992(b)	1994(c)	1996(d)	1996(e)	1996(f)	exp(g)	field(h)	field(i)	est(j)	mon(k)	mon(l)
antimony		3.57					1.93			3.41		
arsenic	4.00		4.08		3.85	3.45	2.28		3.61	3.82*	4.07	3.99
barium		3.13					1.78			3.00		
beryllium		2.93					1.58			2.78		
cadmium	5.11		5.18	5.35	4.23	4.14	2.30	2.85	1.58	4.93*	4.90	4.31
chromium	5.46		5.24		5.70	5.12	2.04		3.94	5.28*	5.15	5.67
cobalt		3.59					1.60			3.60		
copper	4.70		4.58	4.02	4.28	3.86	2.99	2.38	2.72	4.53*	4.22	4.34
lead	5.81		5.93	5.95	5.65	5.46	3.28	4.03	4.25	5.63*	5.18	5.66
mercury	5.23				4.66	4.55	2.23			5.05*	4.56	4.65
molybdenum		3.05					2.94			2.93		
nickel	3.90		4.15	4.01	4.18	3.44	2.08	3.13	3.16	3.72*	3.99	4.26
selenium		2.77					1.30			2.62		
thallium		3.18					2.20			3.00		
tin		5.57					3.28			6.09		
vanadium		3.74					2.49			3.59		
zinc	5.04		5.03	4.73	5.04	4.80	2.20	3.07	3.22	4.86*	4.82	5.08

Notes:

*: No value proposed by Bockting et al. (1992), value estimated according to Bockting et al. (1992) using data of Stortelder et al. (1989),

(a): Values derived from measurements of metals in water samples of 4 locations in the Netherlands from 1983-1986 (Stortelder et al., 1989),

(b): Values derived by Bockting et al. (1992) using measurements of metals in fresh surface water samples of 4 locations in the Netherlands from 1983-1986 and data from Popp and Laquer (1980) and Li et al. (1984), in North American rivers,

(c): Values derived from measurements of metals in particulate matter and fresh surface water of 7 locations in the Netherlands from 1988-1992 (Venema, 1994),

(d): Values derived from measurements of metals in particulate matter and fresh surface water of 3 locations in the Netherlands from 1992-1994 (Koelmans and Radovanovic, 1997),

(e): Values calculated from measurements of metal concentrations in particulate matter and marine surface water at different locations in the North Sea and Wadden Sea during 1995 (Yland, and Smedes 1996),

(f): Values calculated from measurements of metal concentrations in marine surface water and particulate matter (same values as e) corrected for background concentrations, at different locations in the North Sea and Wadden Sea during 1995 (Yland, 1996),

(g): Values based on literature study using batch experiments (Bockting et al., 1992),

(h): Field-based Kps from sites with background levels derived by Van den Hoop (1995b),

(i): Field-based Kps from polluted sites derived by Janssen et al. (1996),

(j): Estimated values on the basis of partition coefficients between particulate matter and water (Stortelder et al., 1989),

(k): Values based on monitoring data in freshwater and sediment at 3 different locations in the Netherlands during different time-intervals (Venema, 1996),

(l): Values based on monitoring data in marine surface water and sediment at different locations in the North Sea and Wadden Sea during 1995 (Yland, 1996).

4.2 Soil

In the equilibrium partitioning method Kps are used to predict the concentration in sediment or soil from the concentration in water. It is assumed that the relation between metal content of the solid phase and aqueous concentrations is approximately linear for the range of concentrations considered (see also section 3.6). This may hold for partitioning of metals controlled by adsorption processes but not for partitioning of metals controlled by precipitation processes.

According to Bockting et al. (1992) the Kps used for the equilibrium partitioning method should be based on experiments where adsorption processes control the aqueous concentrations. The metal concentrations should be at equilibrium or in a steady state situation and the Kp should be based on the fraction of the metal content that can actually exchange with the aqueous phase and not on the total metal content. Because of these conditions Kps resulting from batch experiments are preferred.

All the experimental $\log Kp_{(soil/w)}$s listed in table 4.1 are derived from Bockting et al. (1992) and are based on a literature study. Most values reported by Bockting et al. (1992) are based on batch experiments with 11 American soils carried out by Buchter et al. (1989). For the methods used and criteria applied reference is made to Bockting et al. (1992).

Van den Hoop (1995b) determined field-based $\log Kp_{(soil/w)}$s for Dutch soils (also in table 4.1). Sites were selected on the following criteria: - concentrations should be near the background concentration, - soil samples should vary with respect to organic carbon content, clay content, pH and carbonate content. The variability of the field $Kp_{(soil/w)}$s as determined by Van den Hoop (1995b) was in the same order of magnitude as the mean value (the standard deviation in Kp is approximately equal to its mean value), due to variations in soil and pore water composition. Janssen et al. (1996) determined field-based $\log Kp_{(soil/w)}$s for Dutch polluted soils (also in table 4.1), in a comparable way as described by Van den Hoop (1995b).

The partition coefficients reported by Van den Hoop (1995b) and Janssen et al. (1996) are based on total metal contents in the solid phase and pore water. The Kps to be used for the equilibrium partitioning method should be based on the part of the metals that can actually exchange and is assumed to be in equilibrium with the water phase (However, part of the metals in the solid phase are fixed and bound (see section 3.1)). Subsequently, it can be assumed that one or maybe both of these fractions are not involved in the exchange with the water phase.

In the batch experiments reported by Buchter et al. (1989) the metal is added to a solid/solute suspension. The $\log Kp_{(soil/w)}$ is derived from the amount sorbed (calculated as the difference between the initial and final concentration in the solute phase) and the concentration in the solute phase. Hence, the fraction bound and fixed metals is not considered in these experiments. Subsequently, results from these experiments are better suited for application of the equilibrium partitioning method compared to field based Kps.

The field-based partition coefficients from Van den Hoop (1995b) and Janssen et al. (1996) are in the same order of magnitude as the $Kp_{(soil/w)}$ reported by Bockting et al. (1992).

However, based on the considerations given above it is decided to use the values proposed by Bockting et al. (1992) in the present report (underlined in table 4.1).

4.3 Sediment

As for soil, partition coefficients for sediment and water ($Kp_{(sed/w)}$) to be used in the EP-method should preferably be based on batch experiments. However, only few data on the adsorption of metals on sediments are available (Bockting et al., 1992). The $Kp_{(sed/w)}$s for antimony, barium, beryllium, cobalt, molybdenum, selenium, thallium, tin and vanadium in table 4.1 are the values proposed by Bockting et al. (1992). If no experimental data on $Kp_{(sed/w)}$ were available the $Kp_{(sed/w)}$ is based on the $Kp_{(pm/w)}$ divided by 1.5 as proposed by Stortelder et al. (1989), Bockting et al. (1992) and Van de Meent et al. (1990).

For the metals arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc no $Kp_{(sed/w)}$ is proposed by Bockting et al. (1992). For these metals the same methodology as proposed for the other metals by Bockting et al. (1992) is performed to obtain the $Kp_{(sed/w)}$ using the $Kp_{(pm/w)}$ of Stortelder et al. (1989). It should be noted that these values are the same as the ones derived in Van de Meent et al. (1990).

Besides these estimated values, also $Kp_{(sed/w)}$ based on monitoring data for the freshwater and the marine environment have been derived (Venema, 1996; Yland, 1996). These monitoring based values are comparable with the estimated values. Because the $Kp_{(sed/w)}$s of Stortelder et al. (1989) have been used for deriving risk limits in earlier reports (Van de Meent et al., 1990) and are still in use at several Dutch institutes, these values will also be used in this report (underlined in table 4.1).

CHAPTER 5 BACKGROUND CONCENTRATIONS IN WATER, SOIL AND SEDIMENT

The background concentrations (C*b*) to be used for deriving MPCs and NCs are presented in table 5.1 for surface water (fresh and marine), groundwater, soil and sediment. For the metals antimony, barium, beryllium, cobalt, molybdenum, selenium, tin, thallium and vanadium the background concentrations as described by De Bruijn and Denneman (1992) are used. These background concentrations are the same as used for deriving Environmental Quality Objectives for these metals in 1992 (Van de Plassche and De Bruijn, 1992; see also table 2.1). For arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc the background concentrations are based on a study by Van Den Hoop (1995a). For a complete overview of the literature evaluated and the methodology used when reviewing this literature it is referred to these reports.

5.1 Water

According to Van der Weijden and Middelburg (1989) and Zuurdeeg et al. (1992) it is impossible to derive background concentrations for fresh surface water (C*b*(fresh)) by analysing water samples in the Netherlands. No sampling sites can be found without or with only minor anthropogenic influence. Two different models have been proposed by Van der Weijden and Middelburg (1989) and by Zuurdeeg et al. (1992), respectively, to derive background concentrations for surface water. Although the values derived using the model presented by Zuurdeeg et al. (1992) are thought to be influenced by anthropogenic sources, these values are advised to be used as background concentrations in the Netherlands (De Bruijn and Denneman, 1992). Instead of using the 90th percentile values it is advised to use the geometric mean for the metals antimony, barium, beryllium, cobalt, molybdenum, selenium, thallium and vanadium. For tin this would result in an extremely low value and it is advised to use the 90th-percentile for this metal.

For arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc the background concentrations are presented by Van den Hoop (1995a) using the same methodology as described by De Bruijn and Denneman (1992). Because all the presented background concentrations for freshwater are expressed as total concentrations and MPCs and NCs are based on dissolved concentrations the C*b* is converted using the following formula (Van de Plassche, 1994):

$$Cb(\text{dissolved}) = Cb(\text{total})/\{1+(Kp_{(pm/w)} * S * 10^{-6})\} \qquad \textbf{(9)}$$

in which:

Cb(dissolved) = dissolved background concentration in μg/l

Cb(total) = total background concentration in μg/l

$Kp_{(pm/w)}$ = partition coefficient for partition between water and particulate matter in l/kg

S = concentration particulate matter = 30 mg/l

Table 5.1 Background concentrations in the Netherlands: For freshwater, C*b*(fresh), concentrations are based on model estimations; total and dissolved concentrations are given; for marine surface water, C*b*(marine), and groundwater, C*b*(grw), only dissolved concentrations are given; For soil and sediment the reference line is given which is used to calculate the background concentrations in soil/sediment (L= % clay; H= % organic matter): C*b*(soil/sed), values are expressed as a concentration in standard soil (soil containing 10% organic matter and 25%).

metal	C*b*(fresh)		C*b*(marine)	C*b*(grw)	Reference line	C*b*(soil/sed)
	total	dissolved	dissolved	dissolved		total
	(µg/l)	(µg/l)	(µg/l)	(µg/l)		(mg/kg)
antimony	0.32 (b)	0.29 (c)		0.09 (b)	3.0 (d)	3.0 (b)
arsenic	1.0 (a)	0.77 (c)		7.0 (a)	15 + 0.4 (L + H) (a)	29(a)
barium	76 (b)	73 (c)		197 (b)	30 + 5L (d)	155(b)
beryllium	0.02 (b)	0.02 (c)		0.05 (b)	0.3 + 0.033L (d)	1.1 (b)
cadmium	0.41 (a)	0.08 (c)	0.025 (a)	0.06 (a)	0.4 + 0.007 (L + 3H) (a)	0.8 (a)
chromium	1.6 (a)	0.17 (c)		2.4 (a)	50 + 2L (a)	100 (a)
cobalt	0.22 (b)	0.20 (c)		0.63 (b)	2 + 0.28 L (d)	9.0 (b)
copper	1.1 (a)	0.44 (c)	0.25 (a)	1.3 (a)	15 + 0.6 (L + H) (a)	36 (a)
lead	3.1 (a)	0.15 (c)	0.02 (a)	1.6 (a)	50 + L + H (a)	85 (a)
mercury	0.06 (a)	0.01 (c)	0.0025 (a)	-	0.2 + 0.0017 (2L + H) (a)	0.3 (a)
molybdenum	1.4 (b)	1.4 (c)		0.69 (b)	0.5 (d)	0.5 (b)
nickel	4.1 (a)	3.3 (c)		2.1 (a)	10 + L (a)	35 (a)
selenium	0.04 (b)	0.04 (b)		0.02 (b)	0.7 (d)	0.7 (b)
thallium	0.04 (b)	0.04 (c)		<2 (b)	-	1.0 (b)*
tin	0.002 (b)	0.0002 (c)		<2 (b)	4+ 0.6L (d)	19 (b)
vanadium	0.96 (b)	0.82 (c)		1.2 (b)	12 + 1.2L (d)	42 (b)
zinc	12 (a)	2.8 (c)	0.35 (a)	24 (a)	50 + 1.5 (2L + H) (a)	140 (a)

Notes:

(a): Van den Hoop (1995a),
(b): Van de Plassche and De Bruijn (1992),
(c): Calculated using equation 9,
(d): De Bruijn and Denneman (1992),
*: adjusted on the basis of the advise of the Technical Soil Protection Committee (TCB, 1994).

For marine surface water only for the metals cadmium, copper, lead, mercury and zinc measurements are available. The values presented in table 5.1 are based on the dissolved fraction of metals in the North Sea as presented by Van Eck et al. (1985) and are proposed by Van den Hoop (1995a) to be used as the background concentrations for the marine environment (C*b*(marine)) at this moment. These values are derived from measurements performed in the early eighties and are probably anthropogenically influenced. It is stressed by Van den Hoop (1995a) that new measurements are necessary to derive more reliable estimations of background concentrations for the Dutch marine environment.

The background concentrations for ground water (C*b*(grw)) are based on measurements from the "Dutch national groundwater monitoring programme". The results of the measurements for the metals antimony, barium, cobalt, molybdenum, selenium and vanadium have been published by Van Duijvenbooden and Prins (1991). The metals beryllium, tin and thallium are not monitored in the "Dutch national groundwater monitoring programme" but have been investigated by Stuyfzand (1991; 1992). It is advised by De Bruijn and Denneman (1992) to use the 90th percentile values of these measurements as the background concentrations for groundwater. The values advised by Van den Hoop (1995a) for arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc are based on measurements published by Van Drecht et al. (1995) and have been derived in the same way as described in De Bruijn and Denneman (1992).

5.2 Soil

The background concentrations for soil (C*b*(soil)) as presented in table 5.1 are all based on measurements in soil samples from a large number of relatively unpolluted natural areas in the Netherlands (Edelman, 1984; IWACO, 1992; Aalbers et al., 1992; De Wilde et al., 1992). On the basis of these results De Bruijn and Denneman (1992) derived "reference lines" for the metals barium, beryllium, cobalt, antimony, tin and vanadium in the same way as described by the Technical Soil Protection Committee (TCB, 1990; 1992). These "reference lines" are derived by correlating the total concentrations in the soil-matrix to the percentage lutum (%L) and the organic matter content (%H) of these soils and moving the regression lines along the y-axis in a way that 90 percent of the measurements is placed under the regression line. From this regression line, the so called "reference line", the background concentration for a standard soil is calculated (soil containing 10% organic matter (H=10%) and 25% clay (L=25%). This means that the background concentrations for soil, used in this report, are, just as for fresh surface water, estimations and are assumed to represent background concentrations.

For molybdenum and selenium no reference line could be derived. The values proposed by De Bruijn and Denneman (1992) are based on the few data available. For thallium no data at all for soil in the Netherlands were available. The value proposed is based on indicated values by Stuyfzand (1991) and Zuurdeeg et al. (1992). This value has been changed on the basis of an advice given by the Technical Soil Protection Committee (TCB, 1994).

For arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc the background concentrations in soil are reported by Van den Hoop (1995a). These values have been derived in the same way as described in Denneman and De Bruijn (1992).

5.3 Sediment

Because only few data on background concentrations for sediment (C*b*(sed)) in the Dutch situation are available Van den Hoop (1995a) advised to use the concentrations derived from the "Edelman regression lines" or reference lines (see also 5.2) for sediment as an approximation.

CHAPTER 6 MPAs AND MPCs FOR WATER

In this chapter MPAs and MPCs for water for are derived using the added risk approach as described in chapter 3. MPAs and MPCs for fresh surface water (MPA(fresh) and MPC(fresh)) are derived in section 6.1. As was already mentioned in the methodology (see section 3.7) the data for freshwater species and marine species are combined to derive the MPA(fresh), unless differences in sensitivity between freshwater- and marine species are proven. In table 6.1 the MPAs and MPCs are presented together with the background concentration (C*b*). In the accompanied text also the MPA for freshwater species and marine species separately are mentioned.

If enough toxicity data are available to apply statistical extrapolation, the ecotoxicological data used and the estimated species sensitivity distribution are presented in figures in section 6.1. In these figures the x-axis presents the sensitivity in categories (width 0.5 log(NOEC)) and the y-axis the number of data within a category. The experimental data are scaled on the same y-axis as the estimated curve by dividing the amount of data in a certain category by the total number of data (fresh and marine) available.

The MPA(marine) and MPC(marine) for marine surface water and the MPA(grw) and MPC(grw) for groundwater is derived only for those metals for which a background concentration in the marine surface water or groundwater is available (see table 5.1). Results are presented in sections 6.2 and 6.3 and are summarised in table 6.2 and 6.3 respectively together with the background concentration (C*b*).

For some metals the potential to accumulate in aquatic food chains has been studied in relation with the derivation of MPCs (Van de Plassche, 1994). Besides this the effect of several metals has been studied in the field (Emans et al., 1993). For the methodologies used it is referred to the respective studies. In section 6.4 and 6.5 the results from these studies are summarised and compared with the MPAs and MPCs from section 6.1 and 6.2.

In section 6.6 the MPAs and MPCs from 6.1 to 6.3 are summarised and these values are presented together with the C*b*. Besides this, these "new" values are compared with the "old" values derived by Van de Meent et al. (1990) and Van de Plassche and De Bruijn (1992).

The toxicity data used in the extrapolations for arsenic, barium, beryllium, cobalt, molybdenum, selenium, thallium, tin and vanadium can be found in Van de Plassche et al. (1992). For arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc the toxicity data used for extrapolations can be found in Appendix V. For lead and zinc the selected data from Janus et al. (1997) and Janus (1993; adapted Janus et al. 1996) respectively have been used, with a correction for the background concentration in the test medium when necessary.

6.1 MPAs and MPCs for fresh surface water

Antimony

For antimony no update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). All MPAs are calculated using the modified EPA-method, based on acute toxicity data and applying a factor 1000. This results in an MPA for freshwater species of 420 μg/l and an MPA for marine species of 6.2 μg/l. The MPA(fresh) is derived by combining the data sets for freshwater and marine species resulting in a value of 6.2 μg/l. The background concentration is 0.29 μg/l (table 5.1) resulting in an MPC(fresh) of 6.5 μg/l.

Arsenic

The same as for mercury, arsenic can occur in a methylated form (D'Itri, 1990). However not enough information is available from the results of the toxicity tests to discriminate between different forms. For arsenic an update of ecotoxicological data is made. For freshwater 15 NOECs for species of 6 taxonomic groups are available and a log-logistic frequency distribution is estimated. For the marine environment 2 NOECs for a macrophytic algae and a crustacean are available. These NOECs fall within the distribution range of the freshwater data (fig. 6.1).

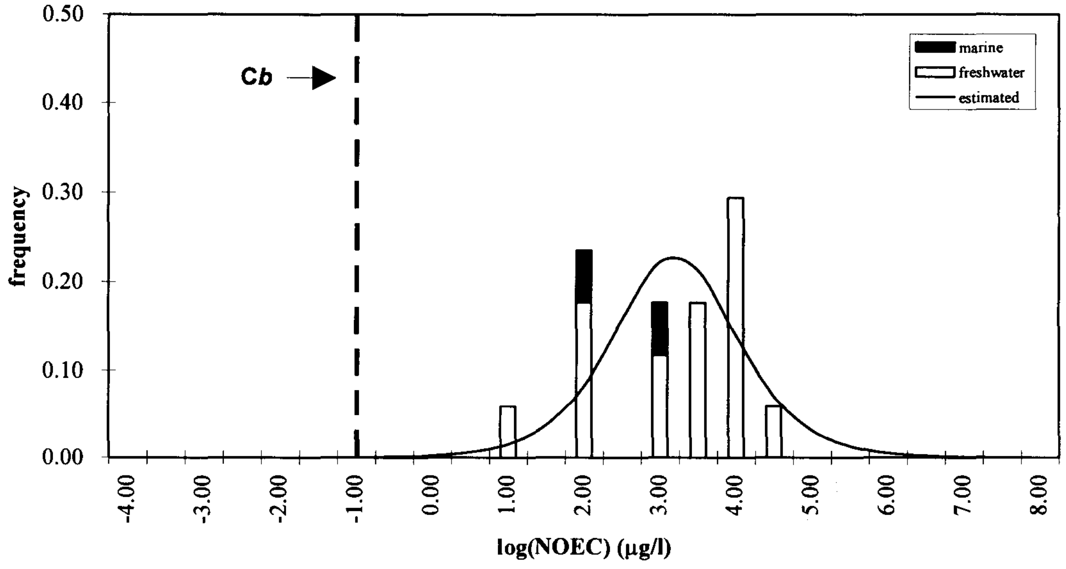

Figure 6.1 Arsenic: Estimated species sensitivity distribution using the combined data set (α=2.9, β=0.54, n=17) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

The MPA for freshwater species is derived using statistical extrapolation and is 25 μg/l, 26 μg/l and 26 μg/l for φ = 0, 0.5 and 1 respectively. The MPA for marine species of 9.5 μg/l is derived using the modified EPA-method by applying a factor 10 on the lowest NOEC of 95 μg/l. The MPA(fresh) is derived using statistical extrapolation and is 24 μg/l, 24 μg/l and 25 μg/l for φ = 0, 0.5 and 1 respectively. The background concentration is 0.77 μg/l (table 5.1) resulting in an MPC(fresh) of 25 μg/l.

Barium

For barium only data for the sensitivity of freshwater species are available. No update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). An MPA(fresh) of 150 μg/l is derived using the modified EPA-method by applying a factor 100 on an LC50 for *Daphnia magna*. The background concentration is 73 μg/l (table 5.1) resulting in an MPC(fresh) of 220 μg/l.

beryllium

For beryllium no update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). For beryllium data for freshwater species are available for more than four taxonomic groups. For marine species no data are available (fig. 6.2). The MPA(fresh) is 0.16 μg/l, 0.18 μg/l and 0.19 μg/l for φ = 0, 0.5 and 1 respectively and is derived using statistical extrapolation. The background concentration is 0.02 μg/l (table 5.1) resulting in an MPC(fresh) of 0.18 μg/l.

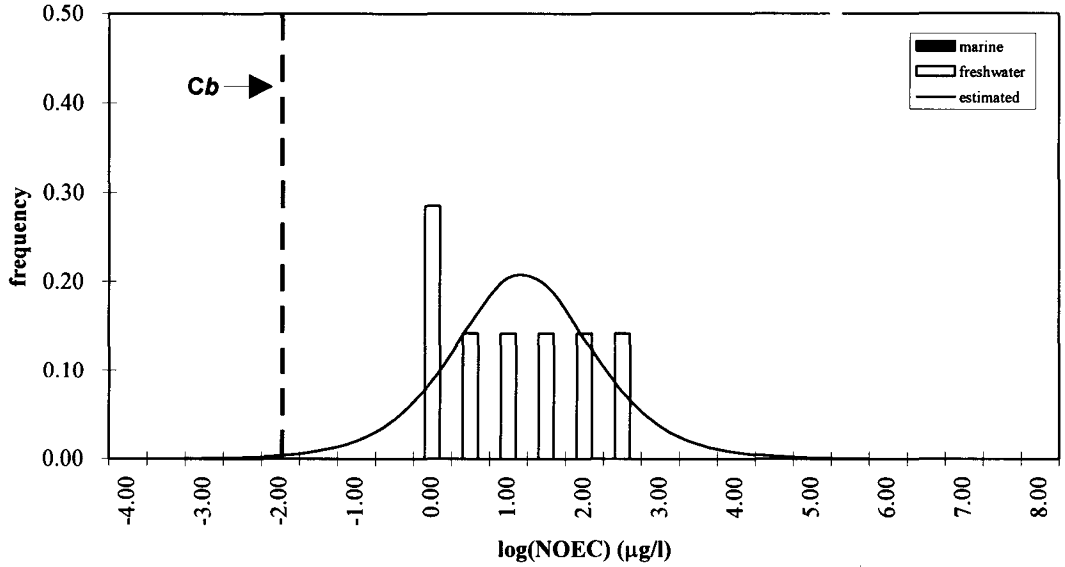

Figure 6.2 Beryllium: Estimated species sensitivity distribution (α=0.94, β=0.59, n=7) and frequency of experimental NOECs for freshwater species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

Cadmium

For cadmium an update of ecotoxicological data is made. The data for marine species show a large variation. This was also noticed by Vranken et al. (1985) who showed that the susceptibility of marine species varies widely, even within a taxonomic group. No significant differences between the freshwater and the marine data sets are found (fig. 6.3). The data sets for marine species and the combined data set are not log-logistic or normally distributed. The MPA for freshwater species and the MPA for marine species are derived using statistical extrapolation. The MPA for freshwater species is 0.42 µg/l, 0.43 µg/l and 0.44 µg/l for $\varphi = 0$, 0.5 and 1 respectively. The MPA for marine species is 0.34 µg/l, 0.43 µg/l and 0.48 µg/l for $\varphi = 0$, 0.5 and 1 respectively. Because no differences in sensitivity are found between freshwater and marine species, the MPA(fresh) is derived using statistical extrapolation, combining the data sets, being 0.34 µg/l, 0.40 µg/l and 0.42 µg/l for $\varphi = 0$, 0.5 and 1 respectively. The background concentration is 0.08 µg/l (table 5.1) resulting in an MPC(fresh) of 0.42 µg/l.

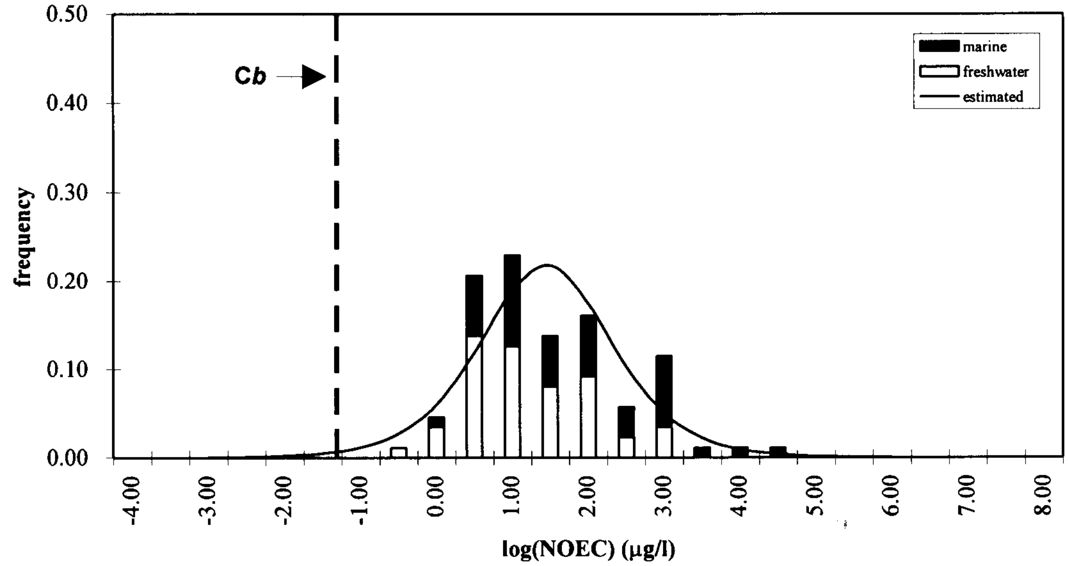

Figure 6.3 Cadmium: Estimated species sensitivity distribution using the combined data set (α=1.2, β=0.56, n=87) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

Chromium

Chromium occurs in several oxidation states, two of which can be stable in the environment: Cr(III) and Cr(VI). The distribution between Cr(III) and Cr(VI) depends on the condition of the water for instance pH, redox potential and total chromium concentration (Schmidt, 1984). Cr(VI) compounds are generally more soluble in water than Cr(III) and do not usually form complexes with inorganic and organic ligands (Nieboer and Jusys, 1988), so that Cr(VI) is relatively mobile. Although Cr(III) is hardly soluble, it can nevertheless form readily soluble complexes, which remain stable over a broad pH range (Bartlett and Kimble, 1977). Cr(III) and Cr(VI) can be interconverted depending on environmental conditions. However in surface water, especially marine surface water, either Cr(III) or Cr(VI) can be stable.

For chromium an update of ecotoxicological data is made. Experimental data for freshwater are available for chromium(III). For chromium(VI) freshwater and marine data are available. According to Nriagu and Nieboer (1988) Cr(VI) is more toxic than Cr(III) for most organisms, Cr(III) even being an essential trace element for mammals. On the basis of the data presented in fig. 6.4 and 6.5 it can be concluded that there is less variation in the NOECs for chromium(III) than for chromium(VI) but no differences in sensitivity of the combined sets (freshwater and marine species) between Cr(III) and Cr(VI) were proven. This comparison is however based on a smaller amount of data for Cr(III) (n=7) than for Cr(VI) (n=55). Therefore, MPAs are derived for both Cr(III) and Cr(VI) and toxicity data are not combined.

The background concentration of 0.17 μg/l is expressed as total Cr, without discrimination between Cr(III) and Cr(VI). Slooff et al. (1990b) state that insight into the occurrence of Cr(III) and Cr(VI) species in surface water is in fact limited. The scarce data available show that 40-80% and 20-60% in river water is present as Cr(VI) and Cr(III), respectively. For sea water these values are 25-40% and 20-60%, respectively. At the moment better data are not available. Therefore, it is assumed that the background concentration consists of 100% Cr(III) or Cr(VI) first. Subsequently, the most critical MPA will be selected as the MPA(fresh) for chromium.

-Chromium(III)

For freshwater species the MPA is derived using statistical extrapolation resulting in an MPA for freshwater species of 34 μg/l for $\varphi = 0$, 0.5 and 1. For marine no data are available. The MPA(fresh) is therefore the same as the MPA for freshwater species: 34 μg/l for $\varphi = 0$, 0.5 and 1.

-Chromium(VI)

One protozoan species is very sensitive compared to other species for Cr(VI). The distribution of all freshwater species is log-logistic (fig. 6.5). Statistical extrapolation is used to derive an MPA for freshwater species of 6.4 μg/l, 6.6 μg/l and 6.7 μg/l for $\varphi = 0$, 0.5 and 1 respectively. For the marine environment only data for three taxonomic groups are available and the modified EPA-method is used. This results in an MPA for marine species of 2.5 μg/l. An MPA(fresh) is derived combining the data for freshwater species and marine species and using statistical extrapolation. The values are 8.5 μg/l, 8.6 μg/l and 8.7 μg/l for $\varphi = 0$, 0.5 and 1 respectively.

As the MPA(fresh) for Cr(VI) is lower than the one for Cr(III) the values for Cr(VI) are presented in table 6.1. The background concentration is 0.17 μg/l resulting in an MPC(fresh) of 8.7 μg/l.

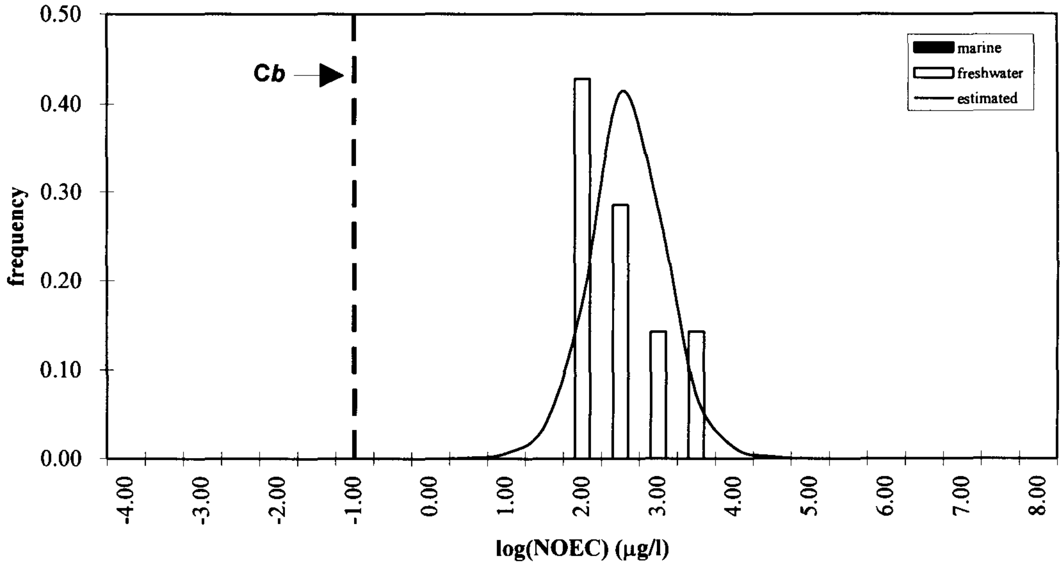

Figure 6.4 Chromium(III): Estimated species sensitivity distribution using the combined data set (α=2.3, β=0.28, n=7) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

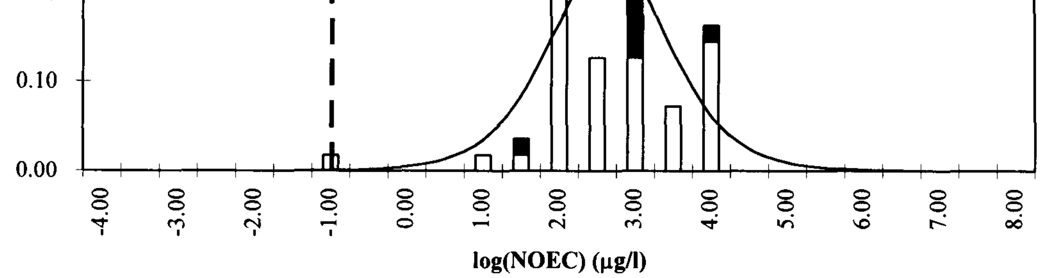

Figure 6.5 Chromium(VI): Estimated species sensitivity distribution using the combined data set (α=2.4, β=0.50, n=55) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

Cobalt

For cobalt no update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). For freshwater species more than four chronic data are available but for marine species only three chronic data are available, one for fish and two for crustacean (fig. 6.6). The MPA for freshwater species is derived applying statistical extrapolation and is 2.6 µg/l, 2.9 µg/l and 3.0 µg/l for φ = 0, 0.5 and 1 respectively. The MPA for marine species of 3.0 µg/l is derived using the modified EPA-method by applying a factor 100 on the lowest L(E)C50 of 300 µg/l.

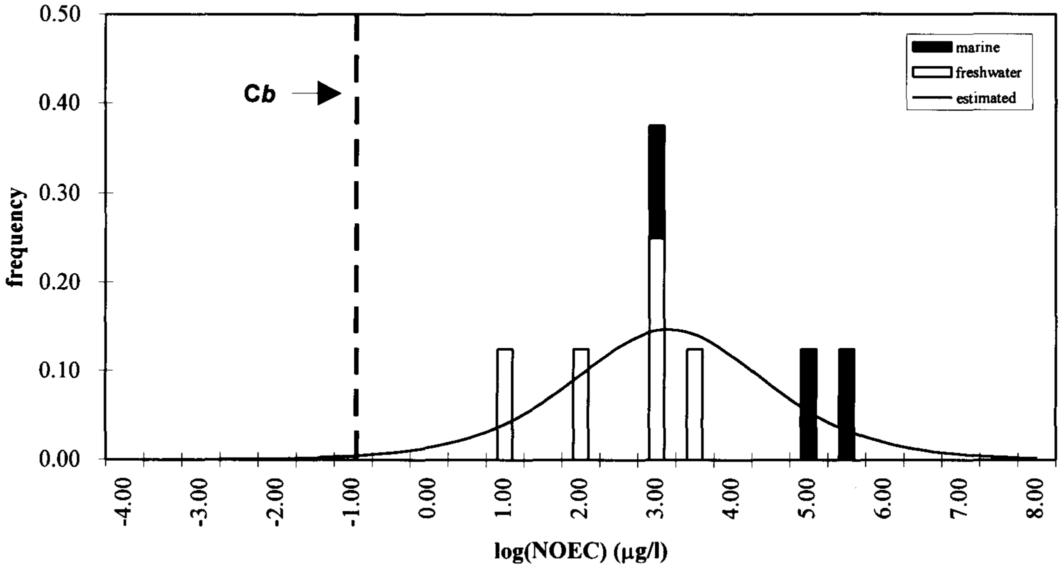

Figure 6.6 Cobalt: Estimated species sensitivity distribution using the combined data set (α=2.9, β=0.84, n=8) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

The MPA(fresh) for cobalt is derived combining the data for freshwater species and marine species and applying statistical extrapolation. The values are 2.6 µg/l, 3.6 µg/l and 4.1 µg/l for φ = 0, 0.5 and 1 respectively. The background concentration is 0.20 µg/l (table 5.1) resulting in an MPC(fresh) of 2.8 µg/l.

Copper

For copper an update of ecotoxicological data is made. The freshwater and marine data sets are not significantly different. Both the data of the freshwater species and the combined sets are log-logistically distributed, while the marine data are not log-logistically nor normally distributed. The MPA for freshwater species and the MPA for marine species are derived using statistical extrapolation. The MPA for freshwater species is 1.2 μg/l, 1.2 μg/l and 1.1 μg/l for φ = 0, 0.5 and 1 respectively. The MPA for marine species is 0.98 μg/l, 1.0 μg/l and 1.0 μg/l for φ = 0, 0.5 and 1 respectively. Because no differences in sensitivity are found the MPA(fresh) is derived using statistical extrapolation, combining the data sets. An MPA(fresh) of 1.1 μg/l for φ = 0, 0.5 and 1 is derived. The background concentration is 0.44 μg/l (table 5.1) resulting in an MPC(fresh) of 1.5 μg/l.

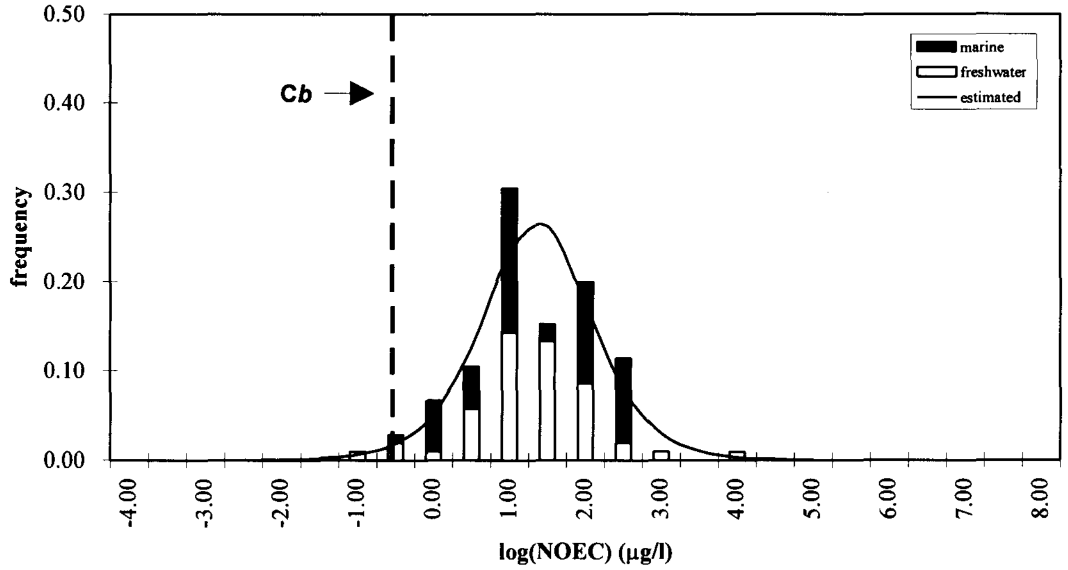

Figure 6.7 Copper: Estimated species sensitivity distribution using the combined data set (α=1.3, β=0.41, n=89) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

Lead

For lead the selected data from Janus et al. (1997) are taken, where information on the ecotoxicity tests and selection of data used for extrapolation can be found. The same as for mercury, lead can occur in a methylated form (D'Itri, 1990). However not enough information is available from the results of the toxicity tests to discriminate between different forms. The MPA for freshwater species and the MPA for marine species are derived using statistical extrapolation. The MPA for freshwater species is 12 μg/l for φ = 0, 0.5 and 1. The MPA for marine species is 6.5 μg/l for φ = 0, 0.5 and 1. Because no differences in sensitivities between freshwater species and marine species are found the MPA(fresh) is derived using statistical extrapolation, combining the data sets. The MPA(fresh) is 11 μg/l for φ = 0, 0.5 and 1. The background concentration is 0.15 μg/l (table 5.1) resulting in an MPC(fresh) of 11 μg/l.

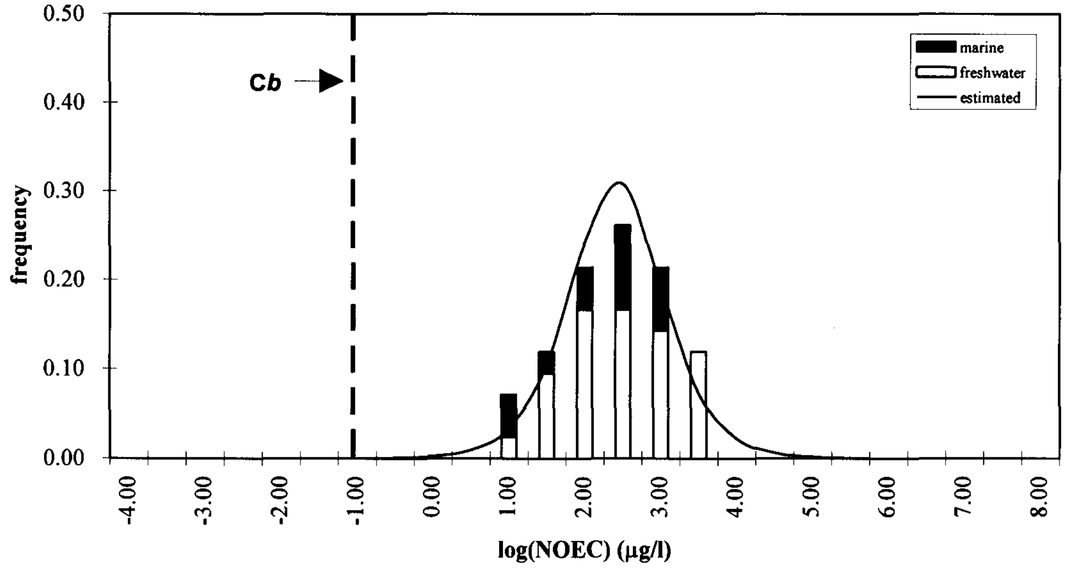

Figure 6.8 Lead: Estimated species sensitivity distribution using the combined data set (α=2.2, β=0.39, n=42) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

Mercury

In natural water systems inorganic mercury is continuously methylated into its organic form, methyl-mercury. This transformation is carried out by micro-organisms in the water column and in anoxic sediment (Korthals and Winfrey, 1987). According to Pieters et al. (1993) approximately 1-10% of mercury occurs as methyl-mercury in fresh surface water. Besides uptake of methyl-mercury itself from the water column, transformation of inorganic mercury into methyl-mercury is possible in the intestinal and mucous layers of fish (Rudd et al., 1980a; Jernelöv, 1972).

For mercury the data from Slooff et al. (1995) are taken, where information on the ecotoxicity tests and selection of data used for extrapolation can be found. No significant difference is found between the toxicity of inorganic and organic mercury, when comparing the freshwater and the combined data sets. However, this comparison is based on a smaller data set for methyl-mercury (n=11, NOEC range from 0.03 µg/l-19 µg/l) than for inorganic mercury (n=38, NOEC range from 0.1 µg/l- 780 µg/l) and when the NOECs of both forms are compared (see figures 6.9 and 6.10 and Table 5.6.1 to 5.6.4 in Appendix V), the NOECs for methyl-mercury are lower. Separate MPAs for inorganic and organic mercury are derived below and included in the table. Also, as for chromium, the background concentration is given as mercury without discrimination between inorganic mercury and methyl-mercury.

-Inorganic mercury

The MPA for freshwater species and the MPA for marine species are derived applying statistical extrapolation. The MPA for freshwater species is 0.42 µg/l, 0.43 µg/l and 0.43 µg/l for φ = 0, 0.5 and 1 respectively. The MPA for marine species is 0.20 µg/l for φ = 0, 0.5 and 1. Because no differences in sensitivity between freshwater species and marine species are found the MPA(fresh) is derived using statistical extrapolation, combining the data sets. The MPA(fresh) is 0.23 µg/l, 0.24 µg/l and 0.24 µg/l for φ = 0, 0.5 and 1 respectively. The background concentration is 0.01 µg/l (table 5.1) resulting in an MPC(fresh) of 0.24 µg/l.

-Methyl-mercury

The MPA for freshwater species is derived using statistical extrapolation and is 0.01 µg/l for φ = 0, 0.5 and 1. For marine organisms only one NOEC of 0.3 µg/l is available. This NOEC falls within the range of the freshwater NOEC values (fig. 6.10). An MPA for marine species of 0.03 µg/l, is based on this NOEC using the modified EPA-method by applying a factor 10. The MPA(fresh) is derived combining the data for freshwater species and marine species and using statistical extrapolation. The value is 0.01 µg/l for φ = 0, 0.5 and 1. The background concentration is 0.01 µg/l (table 5.1) resulting in an MPC(fresh) of 0.02 µg/l.

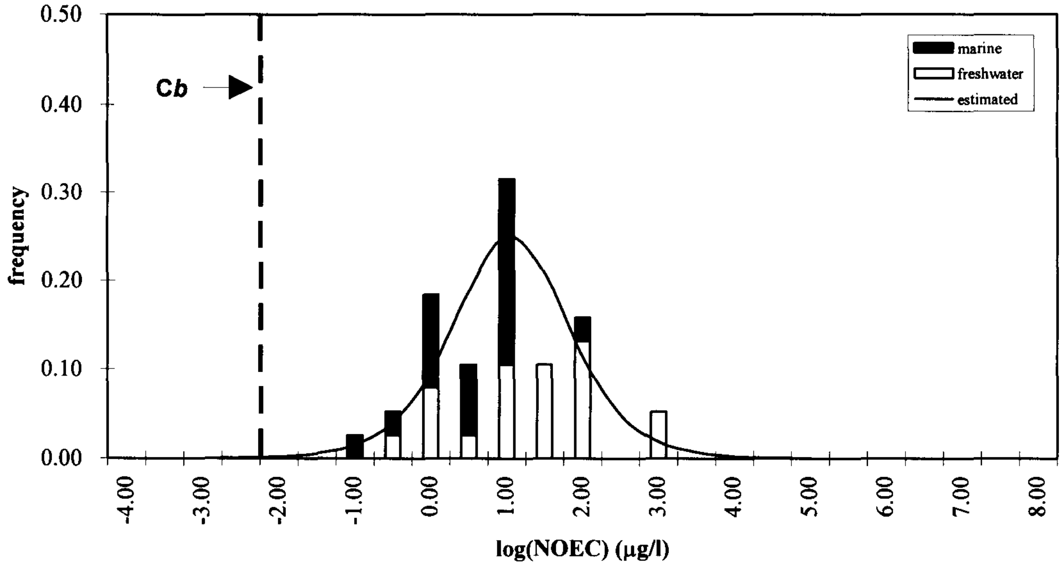

Figure 6.9 Inorganic mercury: Estimated species sensitivity distribution using the combined data set (α=0.80, β=0.49, n=38) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

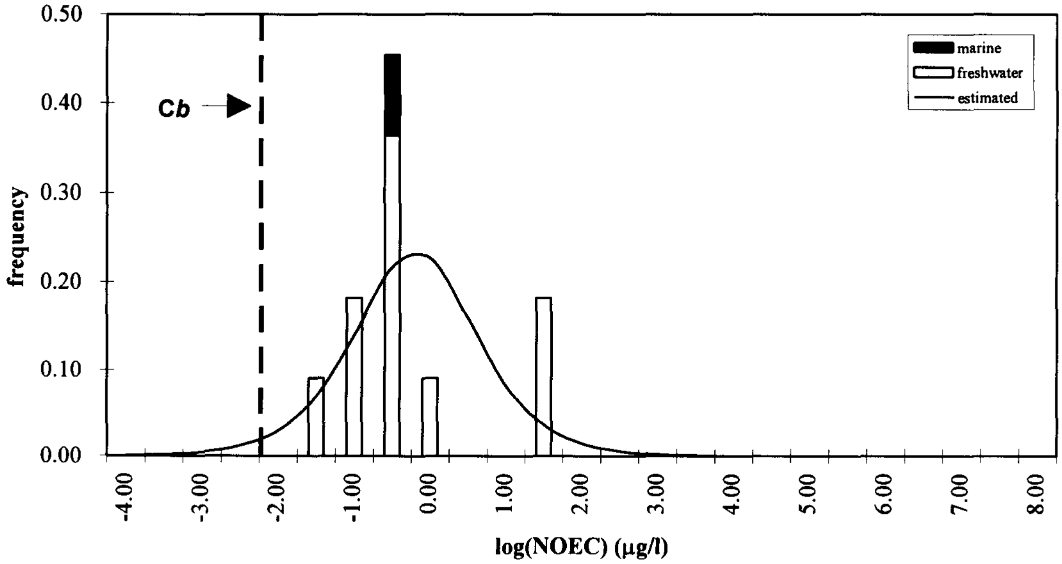

Figure 6.10 Methyl-mercury: Estimated species sensitivity distribution using the combined data set (α=-0.45, β=0.52, n=11) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

Molybdenum

For molybdenum no update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). An MPA for freshwater species, an MPA for marine species and an MPA(fresh) of 290 μg/l, 250 μg/l and 290 μg/l respectively are derived using the modified EPA-method. A factor 1000 on the lowest L(E)C50s available is used to derive the MPA for marine species. For the MPA for freshwater species and the MPA(fresh) a factor 100 is applied although no acute data are available for algae. A chronic NOEC value of 27 mg/l for *Scenedesmus* is however available. Considering this value it can be expected that the acute EC50 for algae will be higher than the lowest EC50 available (29 mg/l for *Tubifex tubifex*). The background concentration is 1.4 μg/l (table 5.1) resulting in an MPC(fresh) of 290 μg/l.

Nickel

For nickel no update of ecotoxicological data is made. The data are taken from Van de Meent et al. (1990). Information on the ecotoxicity tests can be found in the mentioned report. On the basis of these data a selection of data used for extrapolation has been made, the necessary information is given in the footnotes of table 5.7.1 of Appendix V. For freshwater species data for more than four taxonomic groups are available. The MPA for freshwater species of 1.7 μg/l, 5.0 μg/l and 6.5 μg/l for φ = 0, 0.5 and 1 respectively is based on statistical extrapolation. As no marine data are available the MPA(fresh) is the same as the MPA for freshwater species: 1.8 μg/l, 5.2 μg/l and 6.7 μg/l for φ = 0, 0.5 and 1 respectively. The background concentration is 3.3 μg/l (table 5.1) resulting in an MPC(fresh) of 5.1 μg/l.

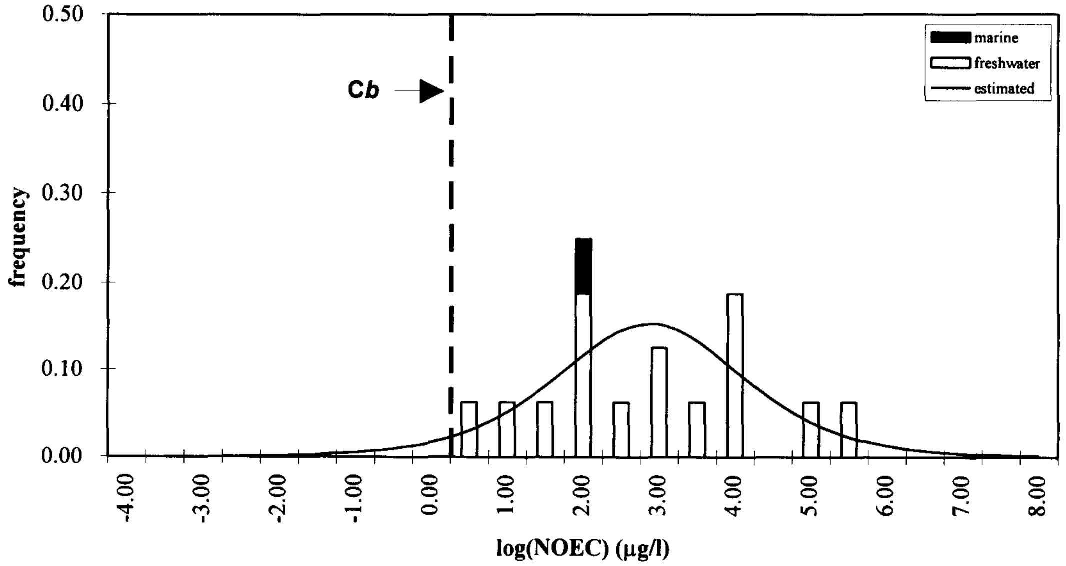

Figure 6.11 Nickel: Estimated species sensitivity distribution using freshwater data (α=2.7, β=0.83, n=15) and frequency of experimental NOECs for freshwater species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

Selenium

For selenium no update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). For freshwater species 19 (7 taxonomic groups) and for marine species 12 chronic NOECs (3 taxonomic groups, algae, crustacean and fish) are available. No significant differences between the sensitivities of freshwater and marine species were found. An MPA for freshwater species of 3.2 μg/l, 3.3 μg/l and 3.3 μg/l for $\varphi = 0$, 0.5 and 1 respectively is derived using statistical extrapolation. The MPA for marine species of 9.4 μg/l is derived by applying a factor 10 on the lowest NOEC. The MPA(fresh) is derived combining the data for freshwater species and marine species and statistical extrapolation. The value is 5.3 μg/l, 5.4 μg/l and 5.5 μg/l for $\varphi = 0$, 0.5 and 1 respectively. The background concentration is 0.04 μg/l (table 5.1) resulting in an MPC(fresh) of 5.3 μg/l.

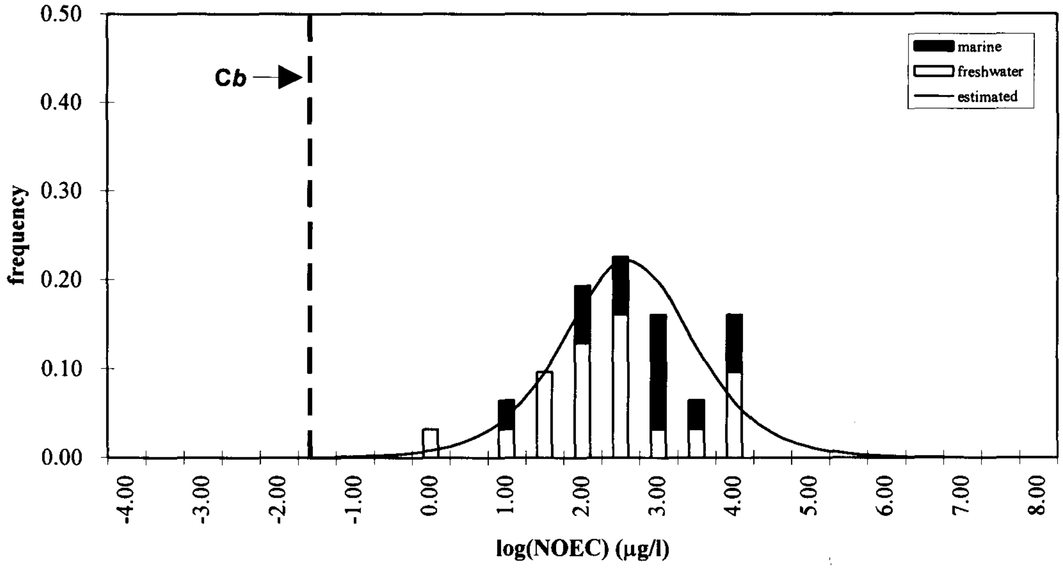

Figure 6.12 Selenium: Estimated species sensitivity distribution using the combined data set (α=2.4, β=0.55, n=31) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

Thallium

For thallium no update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). The MPA for freshwater species of 3.0 μg/l is derived by applying the modified EPA-method and is based on an NOEC value for fish. The MPA for marine species and MPA(fresh) are based on the same EC50 value for *Ditylium brightwelli* of 0.16 mg/l and are derived applying the modified EPA-method. The MPA for marine species is derived by applying a factor 1000 resulting in a value of 0.16 μg/l. In case of the MPA(fresh) a factor 100 instead of a factor 1000 is applied because acute data for algae, crustaceans and fish are available resulting in a value of 1.6 μg/l. The background concentration is 0.04 μg/l (table 5.1) resulting in an MPC(fresh) of 1.6 μg/l.

Tin

For tin no update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). The same as for mercury, tin can occur in a methylated form (D'Itri, 1990). However not enough information is available from the results of the toxicity tests to discriminate between different forms. In Van de Plassche et al. (1992) an MPA for freshwater species, MPA for marine species and MPA(fresh) of 18 µg/l, 0.29 µg/l and 18 µg/l respectively are derived using the modified EPA-method. The background concentration is 0.0002 µg/l (table 5.1) resulting in an MPC(fresh) of 18 µg/l.

Vanadium

For vanadium no update of ecotoxicological data is made. Information on the ecotoxicity tests and selection of data used for extrapolation can be found in Van de Plassche et al. (1992). As outlined in the introduction the resulting value will be indicated as the MPA instead of as the MPC in Van de Plassche et al. (1992). In Van de Plassche et al. (1992) an MPA for freshwater species, MPA for marine species and MPA(fresh) of 3.5 µg/l, 10 µg/l and 3.5 µg/l respectively are derived using the modified EPA-method. The background concentration is 0.82 µg/l (table 5.1) resulting in an MPC(fresh) of 4.3 µg/l.

Zinc

For zinc the selected data from Janus (1993) (adapted Janus et al., 1996) are taken, where information on the ecotoxicity tests and selection of data used for extrapolation can be found. In the footnotes of Table 5.8.1 and 5.8.2 in Appendix V it is indicated whether values have been corrected for the background concentration in the test medium. The data for freshwater species and the combined dataset are log-logistically distributed. The data for marine species are log-normally distributed, but not log-logistically. The freshwater and marine data are not significantly different.

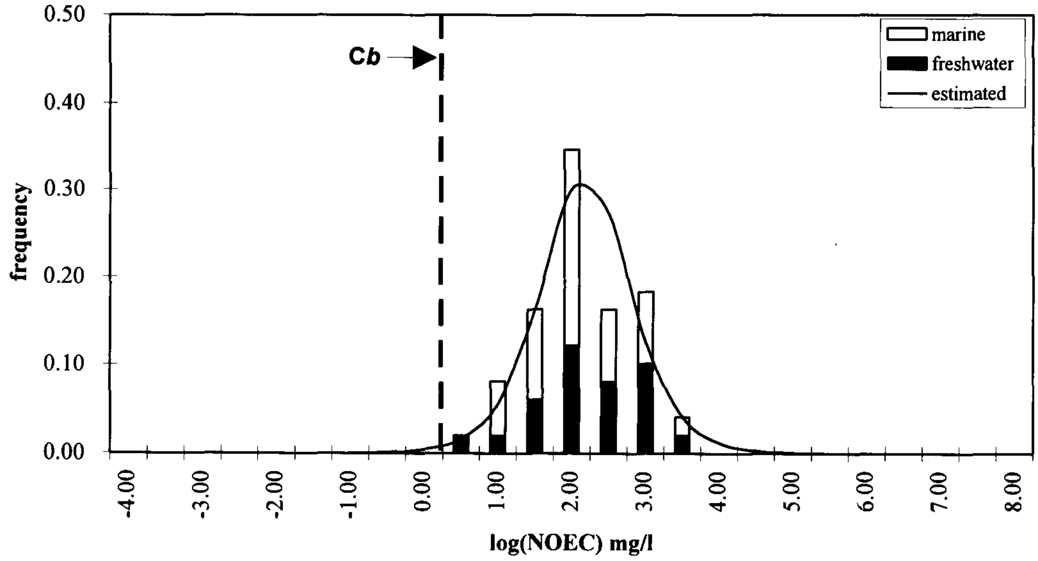

Figure 6.13 Zinc: Estimated species sensitivity distribution using the combined data set (α=1.9, β=0.38, n=49) and frequency of experimental NOECs for freshwater and marine species (frequency of experimental data within a category obtained by dividing the number of data in a category by the total number of data). The vertical line indicates the level of the background concentration.

The MPA for freshwater species and MPA for marine species are derived using statistical extrapolation. The MPA for freshwater species is 5.4 μg/l for $\varphi = 0$, 0.5 and 1. The MPA for marine species is 7.0 μg/l, 6.5 μg/l and 6.2 μg/l for $\varphi = 0$, 0.5 and 1 respectively. The MPA(fresh) is derived combining the data for freshwater species and marine species and using statistical extrapolation. The value is 6.6 μg/l, 6.2 μg/l and 6.0 μg/l for $\varphi = 0$, 0.5 and 1 respectively. The background concentration is 2.8 μg/l (table 5.1) resulting in an MPC(fresh) of 9.4 μg/l.

Table 6.1 MPA values for fresh surface water (MPA(fresh)) if possible for different percentages availability of the background concentration (0, 50 and 100% or $\varphi = 0$, 0.5 and 1), MPC values for freshwater (MPC(fresh)), background concentration (C*b* from table 5.1) and lowest NOEC value of the data set. All values are dissolved concentrations in μg/l.

availability	0% ($\varphi = 0$)		50% ($\varphi = 0.5$)	100% ($\varphi = 1$)			lowest
Metal	MPA(fresh)		MPA(fresh)	MPA(fresh)	C*b*	MPC(fresh)	NOEC
antimony	6.2	(e)			0.29	6.5	23,000
arsenic	24	(a)	24	25	0.77	25	10
barium	150	(d)			73	220	2900
beryllium	0.16	(a)	0.18	0.19	0.02	0.18	0.68
cadmium	0.34	(b)	0.40	0.42	0.08	0.42	0.11
chromium*	8.5	(a)	8.6	8.7	0.17	8.7	0.058
cobalt	2.6	(a)	3.6	4.1	0.20	2.8	5.0
copper	1.1	(a)	1.1	1.1	0.44	1.5	0.06
lead	11	(a)	11	11	0.15	11	9.0
inorganic mercury	0.23	(a)	0.24	0.24	0.01	0.24	0.07
methyl-mercury	0.01	(a)	0.01	0.01	0.01	0.02	0.03
molybdenum	290	(d)			1.4	290	27,000
nickel	1.8	(a)	5.2	6.7	3.3	5.1	2.5
selenium	5.3	(a)	5.4	5.5	0.04	5.3	0.9
thallium	1.6	(d)			0.04	1.6	30
tin	18	(c)			0.0002	18	180
vanadium	3.5	(e)			0.82	4.3	0.82
zinc	6.6	(a)	6.2	6.0	2.8	9.4	3.0

Notes:

(a): MPA based on statistical extrapolation, toxicity data follow a log-logistic distribution,

(b): MPA based on statistical extrapolation, toxicity data do not follow a log-logistic distribution,

(c): MPA based on modified EPA-method, applying a factor 10 on the lowest NOEC,

(d): MPA based on modified EPA-method, applying a factor 100 on the lowest L(E)C50,

(e): MPA based on modified EPA-method, applying a factor 1000 on the lowest L(E)C50,

*: Based on results for chromium(VI).

6.2 MPAs and MPCs for marine surface water

Table 6.2 gives the MPA(marine) and MPC(marine) for the metals, for which a background concentration in marine surface water is available, using the methodology as described in section 3.7. As was indicated in chapter 3 (see figure 3.5), for $\varphi = 0$, the MPA is only dependent on α and β of the species sensitivity distribution and the MPA(marine)s for $\varphi = 0$ are therefore the same as the ones for freshwater in table 6.1. Because for the MPA(marine) the same toxicity data are used as for the MPC(fresh) it is referred to chapter 6.1 for a description of the method and data used for each metal. The MPA for $\varphi > 0$ however, is not only dependent on α and β of the species sensitivity distribution, but also on the background concentration and the bioavailability of the background concentration, φ. The MPA(marine)s for $\varphi = 0.5$ and 1 may therefore be different from the ones in table 6.1.

For cadmium, copper, lead, mercury and zinc the MPA(marine) is (almost) equal to the MPA(fresh) presented in Table 6.1. The background concentration in freshwater is higher than in saltwater: a factor 1.8 to 8. Because the background concentration for freshwater as well as saltwater is low compared to the MPA this doesn't have much influence on the height of the MPA for both compartments.

Table 6.2 MPA values for marine surface water (MPA(marine)) if possible for different percentages availability of the background concentration (0, 50 and 100% or $\varphi = 0$, 0.5 and 1), MPC values for marine surface (MPC(marine)), background concentration (C_b from table 5.1) and lowest NOEC value of the data set. All values are dissolved concentrations in µg/l.

availability	0% ($\varphi = 0$)	50% ($\varphi = 0.5$)	100% ($\varphi = 1$)			lowest
Metal	MPA(marine)	MPA(marine)	MPA(marine)	C_b	MPC(marine)	NOEC
cadmium	0.34 (b)	0.39	0.41	0.025	0.37	0.11
copper	1.1 (a)	1.1	1.1	0.25	1.4	0.06
lead	11 (a)	11	11	0.02	11	9.0
inorganic mercury	0.23 (a)	0.24	0.24	0.0025	0.23	0.07
methyl-mercury	0.01 (a)	0.01	0.01	0.0025	0.013	0.03
zinc	6.6 (a)	6.5	6.4	0.35	7.0	3.0

(a): MPA based on statistical extrapolation, toxicity data follow a log-logistic distribution,
(b): MPA based on statistical extrapolation, toxicity data do not follow a log-logistic distribution.

6.3 MPAs and MPCs for groundwater

Table 6.3 gives the MPA(grw) for the metals for which a background concentration in groundwater is available, using the methodology as described in section 3.7. As was indicated in chapter 3 (see figure 3.5), for $\varphi = 0$, the MPA is only dependent on α and β of the species sensitivity distribution and the MPA(marine)s for $\varphi = 0$ are therefore the same as the ones for freshwater and marine water in table 6.1 and table 6.2 respectively. Because for the MPA(grw) the same toxicity data are used as for the MPC(fresh) it is referred to chapter 6.1 for a description of the method and data used for each metal. The MPA for $\varphi > 0$ however, is not only dependent on α and β of the species sensitivity distribution, but also on the background concentration and the bioavailability of the background concentration, φ. The MPA(grw)s for $\varphi = 0.5$ and 1 may therefore be different from the ones in table 6.1.

For mercury no MPA(grw) is derived because no background concentration in groundwater is available.

Table 6.3 MPA values for groundwater (MPA(grw)) if possible for different percentages availability of the background concentration (0, 50 and 100% or φ = 0, 0.5 and 1), MPC values for groundwater (MPC(grw)), background concentration (C*b* from table 5.1) and lowest NOEC value of the data set. All values are dissolved concentrations in µg/l.

availability	0% ($\varphi = 0$)	50% ($\varphi = 0.5$)	100% ($\varphi = 1$)			lowest
Metal	MPA(grw)	MPA(grw)	MPA(grw)	C*b*	MPC(grw)	NOEC
antimony	6.2 (e)			0.09	6.3	23,000
arsenic	24 (a)	23	28	7.0	31	10
barium	150 (d)			197	350	2900
beryllium	0.16 (a)	0.17	0.21	0.05	0.21	0.68
cadmium	0.34 (b)	0.45	0.47	0.06	0.40	0.11
chromium*	8.5 (a)	9.2	10	2.4	11	0.058
cobalt	2.6 (a)	4.4	5.2	0.63	3.2	5.0
copper	1.1 (a)	1.1	1.1	1.3	2.4	0.06
lead	11 (a)	10	10	1.6	13	9.0
molybdenum	290 (d)			0.69	290	27,000
nickel	1.8 (a)	4.5	5.6	2.1	3.9	2.5
selenium	5.3 (a)	5.4	5.4	0.02	5.3	0.9
thallium	1.6 (d)			<2 (f)	3.6	30
tin	18 (c)			<2 (f)	20	180
vanadium	3.5 (e)			1.2	4.7	0.82
zinc	6.6 (a)	5.6	5.8	24	31	3.0

Notes:

(a): MPA based on statistical extrapolation, toxicity data follow a log-logistic distribution,
(b): MPA based on statistical extrapolation, toxicity data do not follow a log-logistic distribution,
(c): MPA based on modified EPA-method, applying a factor 10 on the lowest NOEC,
(d): MPA based on modified EPA-method, applying a factor 100 on the lowest L(E)C50,
(e): MPA based on modified EPA-method, applying a factor 1000 on the lowest L(E)C50,
(f): A value of 2 µg/l is assumed in the calculations,
*: Based on results for Cr(VI).

6.4 Secondary poisoning; aquatic food chain

Some of the metals considered may have a bioaccumulation potential. Subsequently, the uptake of accumulated metals by higher members of the food chain may lead to secondary poisoning. The metals for which secondary poisoning is expected have already been considered by Van de Plassche (1994). For water the metals cadmium, copper and methyl-mercury have been considered. The methodology used is based on a study performed by Romijn et al. (1991a), who analysed the aquatic food-chain, water → fish or mussel → fish or mussel eating bird or mammal, to derive an MPC(indirect effects). The effect of the background concentration is not included in this MPC. As outlined in the introduction this value will be indicated as the MPA instead of as the MPC in Van de Plassche (1994). The comparison of the MPAs derived in the mentioned report is therefore made with MPAs for $\varphi = 0$ only from the present report.

The method in Van de Plassche (1994) can be summarised as follows (for an extensive description it is referred to Van de Plassche (1994) and Romijn et al. (1991a)): data available for direct and indirect exposure are treated separately. A comparison is made between the MPA(direct) derived on the basis of direct effects on aquatic organisms and the MPA(indirect) based on indirect effects for birds and mammals. The MPA for birds and mammals is expressed as a concentration of the substance in the food, which is divided by the Bioconcentration Factor (BCF) for the compound considered for fish or mussel. This results in an MPA(indirect effects) expressed as a concentration in water. Van de Plassche (1994) applied extra correction factors in order to extrapolate the results from toxicity studies with birds and/or mammals to field conditions.

In the following text the results for cadmium, copper and mercury as presented in Van de Plassche (1994) are compared with the results from the present report:

cadmium: for cadmium Van de Plassche (1994) derived an MPA of 0.35 μg/l based on indirect effects. This MPA(indirect effects) is based on toxicity for birds and laboratory based BCF values for fish and is slightly below the one based on direct effects of 0.38 μg/l (Van de Plassche, 1994). The data set for cadmium has been updated in the present report leading to an MPA(fresh) and MPA(marine) of 0.34 for $\varphi = 0$ (table 6.1, table 6.2).

copper: for copper an MPA of 6.4 μg/l is derived by Van de Plassche (1994) based on indirect effects, which is higher than the value for direct effects of 4.1 μg/l derived in the same report. This MPA for indirect effects is based on the toxicity for mammals and laboratory based BCF values for fish and is also higher than the MPA(fresh) and the MPA(marine) of 1.1 μg/l for $\varphi = 0$ (table 6.1 and table 6.2) derived in this report, using an updated data set.

methyl-mercury: for methyl-mercury Van de Plassche (1994) derived an MPA of 0.0019 μg/l based on indirect effects. This MPA for indirect effects is however based on a limited data set of NOECs for birds and mammals and laboratory based BCFs for fish. This value is considerably lower than the MPA for direct effects of 0.056 μg/l derived in the same report. In the present report the data of Slooff et al. (1995) are used, which is an updated data set, leading to an MPA(fresh) and MPA(marine) of 0.01 for $\varphi = 0$ (table 6.1 and table 6.2).

In conclusion: on the basis of a comparison of the MPAs based on indirect effects and the MPAs based on direct effects as derived in this report, for methyl-mercury the MPA for direct effects is much higher. However this MPA is based on a limited set of NOECs and laboratory based BCFs, the latter being much higher than field BCFs reported by Hendriks (1995) and Hendriks et al. (submitted). Because of the uncertainties in the BCFs, no adjustment of the MPA for methyl-mercury as derived in this report on the basis of indirect exposure is made.

6.5 Comparison of MPAs with multi-species studies

It was recommended by the OECD (1989) and the Health Council of the Netherlands (GZR, 1989), that a validation had to be carried out by comparing NOECs derived from multiple species experiments with the MPCs. Such a comparison has been performed for organic compounds and metals (Emans et al., 1993). In Table 6.4 the results of this comparison for the metals considered in the present report are given together with the MPA(fresh) derived in section 6.1 for freshwater and MPA(marine) derived in section 6.2.

Emans et al. (1993) categorised MS-NOECs into unreliable, less reliable and unreliable depending on the quality of the multi-species study. Only reliable and less-reliable MS-NOECs from Emans et al. (1993) are included in Table 6.4. (for an extensive description of the methodology it is referred to Emans et al. (1993)).

Table 6.4 Comparison of MPAs (fresh) from table 6.1 for $\varphi = 0, 0.5$ and MPAs (marine) from table 6.2 for $\varphi = 0$ with multiple species NOECs (reliable and less reliable) derived by Emans et al. (1993). n is the number of experiments from which an MS-NOEC is derived by Emans et al. (1993).

Metal	MS-NOEC (μg/l)	n	MPA(fresh, $\varphi = 0$) = MPA(marine, $\varphi = 0$) (μg/l)	C*b*(fresh) (μg/l)	C*b*(marine) (μg/l)
cadmium	0.7-1.0	2	0.34	0.08	0.025
copper	0.3-4.0	4	1.1	0.44	0.25
selenium	8.3-10	1	5.3	0.04	-

The MS-NOECs for cadmium are based on one taxonomic group (Borgmann et al., 1989) and ten taxonomic groups (Gächter, 1976) respectively. For copper the MS-NOECs are based on three (Clements et al., 1989), two (Leland et al., 1989), eight (Leland and Carter, 1984; Leland et al., 1989; Leland and Kent, 1981) and eight taxonomic groups (Hedtke, 1984) respectively. The two studies for selenium are both based on two taxonomic groups (Rudd et al., 1980b).

Most MS-NOECs are in line with the MPAs derived in the present report. For zinc only unreliable MS-NOECs were available: 1.7 μg/l from Marshall et al. (1983) and 4.3 μg/l from Patrick (1978). Although these values are somewhat lower than the MPA(fresh) and MPA(marine) (6.6 for $\varphi = 0$), the MPCs as derived in the present report are not adjusted due to the unreliability of the MS-NOEC.

6.6 Summary of MPAs and MPCs and comparison with 'old' values

In table 6.5 the MPAs (if possible for different percentages availability of the background concentration), MPCs and C*b*s from 6.1 to 6.3 are summarised. As explained in the introduction (section 1.2) the MPCs for $\varphi = 0$ are recommended to be used for setting Environmental Quality Objectives. Besides the values derived in the present report also the old MPCs derived in Van de Meent et al. (1990) and Van de Plassche and De Bruijn (1992) (old MPC) are presented in table 6.5.

Comparing the MPAs for different fractions bioavailable φ, it becomes evident that the choice of φ is not of much influence for the MPA. For most of the metals considered almost no or only small differences in MPAs were found. Only for cobalt, copper and nickel somewhat larger differences were found. Since the old MPCs are derived without taking into account background concentrations, all the new MPC values are higher.

Table 6.5 Summary of MPA and MPC values from table 6.1 to 6.3, if possible for different percentages availability of the background (0, 50 and 100% or $\varphi = 0, 0.5$ and 1). The values recommended to be used for setting Environmental Quality Objectives are underlined. The underlined MPA values are used for calculating the MPCs. Besides this the background concentrations (C*b*) and "old" MPCs are included. All values are dissolved concentrations in µg/l.

	MPA(fresh)				MPC(fresh)	MPA(marine)				MPC(marine)	MPA(grw)				MPC(grw)	old
	$\varphi = 0$	$\varphi = 0.5$	$\varphi = 1$	C*b*		$\varphi = 0$	$\varphi = 0.5$	$\varphi = 1$	C*b*		$\varphi = 0$	$\varphi = 0.5$	$\varphi = 1$	C*b*		MPC
antimony	6.2 (e)			0.29	6.5						6.2 (e)			0.09	6.3	6.2 (h)
arsenic	24 (a)	24	25	0.77	25						24 (a)	23	28	7.0	31	8.6 (g)
barium	150 (d)			73	220						150 (d)			197	350	150 (h)
beryllium	0.16 (a)	0.18	0.19	0.02	0.18						0.16 (a)	0.17	0.21	0.05	0.21	0.16 (h)
cadmium	0.34 (b)	0.40	0.42	0.08	0.42	0.34 (b)	0.39	0.41	0.025	0.37	0.34 (b)	0.45	0.47	0.06	0.40	0.16 (g)
chromium*	8.5 (a)	8.6	8.7	0.17	8.7						8.5 (a)	9.2	10	2.4	11	2.0 (g)
cobalt	2.6 (a)	3.6	4.1	0.20	2.8						2.6 (a)	4.4	5.2	0.63	3.2	2.0 (h)
copper	1.1 (a)	1.1	1.1	0.44	1.5	1.1 (a)	1.1	1.1	0.25	1.4	1.1 (a)	1.1	1.1	1.3	2.4	1.7 (g)
lead	11 (a)	11	11	0.15	11	11 (a)	11	11	0.02	11	11 (a)	10	10	1.6	13	2.0 (g)
inorganic mercury	0.23 (a)	0.24	0.24	0.01	0.24	0.23 (a)	0.24	0.24	0.0025	0.23						
methyl-mercury	0.01 (a)	0.01	0.01	0.01	0.02	0.01 (a)	0.01	0.01	0.0025	0.013						0.01 (g)
molybdenum	290 (d)			1.4	290						290 (d)			0.69	290	290 (h)
nickel	1.8 (a)	5.2	6.7	3.3	5.1						1.8 (a)	4.5	5.6	2.1	3.9	1.4 (g)
selenium	5.3 (a)	5.4	5.5	0.04	5.3						5.3 (a)	5.4	5.4	0.02	5.3	5.3 (h)
thallium	1.6 (d)			0.04	1.6						1.6 (d)			<2 (f)	3.6	1.6 (h)
tin	18 (c)			0.0002	18						18 (c)			<2 (f)	20	18 (h)
vanadium	3.5 (e)			0.82	4.3						3.5 (e)			1.2	4.7	3.5 (h)
zinc	6.6 (a)	6.2	6.0	2.8	9.4	6.6 (a)	6.5	6.4	0.35	7.0	6.6 (a)	5.6	5.8	24	31	1.6 (g)

Notes:

(a): MPA based on statistical extrapolation, toxicity data follow a log-logistic distribution,

(b): MPA based on statistical extrapolation, toxicity data do not follow a log-logistic distribution,

(c): MPA based on modified EPA-method, applying a factor 10 on the lowest NOEC,

(d): MPA based on modified EPA-method, applying a factor 100 on the lowest L(E)C50,

(e): MPA based on modified EPA-method, applying a factor 1000 on the lowest L(E)C50,

(f): a value of 2 µg/l is assumed in the calculations,

(g): Van de Meent et al. (1990),

(h): Van de Plassche and De Bruijn (1992),

*: Based on results for Cr(VI).

CHAPTER 7 MPAs AND MPCs FOR SOIL

In this chapter MPAs and MPCs for soil are derived using the methodology as described in section 3.7. In section 7.1 MPAs for terrestrial species (MPA(species)) and MPAs for microbial and enzymatic processes (MPC(processes)) are derived using experimental data. The lowest of these two is selected as the MPA(soil) and is presented together with the background concentration, C*b* and the MPC in table 7.1.

If enough data are available to apply the statistical extrapolation the data and the estimated sensitivity curves are presented in a figure. In these figures the x-axis presents the sensitivity in categories (width 0.25 log(NOEC)) and on the y-axis the number of data within a category. The experimental data are scaled on the same y-axis as the estimated curve by dividing the amount of data in a certain category by the total number of data available.

If no experimental data are available an MPA($soil_{EP}$) is derived using equilibrium partitioning in section 7.2. The MPA($soil_{EP}$) is presented together with the background concentration, C*b* and the MPC($soil_{EP}$) in table 7.2. For the metals for which an MPA(soil) is derived using experimental data in 7.1, these MPAs are harmonised in section 7.3.

As for the aquatic compartment secondary poisoning of mercury, copper and cadmium via terrestrial food-chains has been studied by Van de Plassche (1994). In section 7.4 the results from this study are summarised and compared with the MPAs derived in sections 7.1/7.2. For the methodology used it is referred to Van de Plassche (1994). For some metals effects encountered in the field have been studied. In section 7.5 the results of these studies are summarised.

Section 7.6 summarises the MPAs and MPCs from table 7.1 and 7.2. Besides this the new values are compared with the "old" MPCs derived by Van de Meent et al. (1990) and Van de Plassche and De Bruijn (1992). Critical air concentrations are presented in section 7.7.

The data used in the extrapolations for arsenic, barium, beryllium, cobalt, molybdenum, selenium, thallium, tin and vanadium can be found in Van de Plassche et al., (1992). For arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc the data used for the extrapolations can be found in Appendix VI. For lead and zinc the selected data from Janus et al. (1997) and Janus (1993; adapted Janus et al. 1996) respectively have been used, with a correction for the background concentration in the test medium when necessary.

7.1 MPAs and MPCs for soil using experimental data

Arsenic

For terrestrial species only three NOECs for two taxonomic groups are available (2 for plants and one for a worm). The MPA(species) of 4.5 mg/kg is derived applying a factor 10 on the lowest NOEC of 45 mg/kg. Enough experimental data to estimate a sensitivity distribution are available for microbial and enzymatic processes (fig. 7.1). The MPA(processes) of 25 mg/kg, 17 mg/kg and 14 mg/kg for φ = 0, 0.5 and 1, respectively, is obtained using statistical extrapolation. The lowest of these two is selected to be the MPA(soil): 4.5 mg/kg based on the MPA(species), the background concentration is 29 mg/kg (table 5.1) resulting in an MPC(soil) of 34 mg/kg.

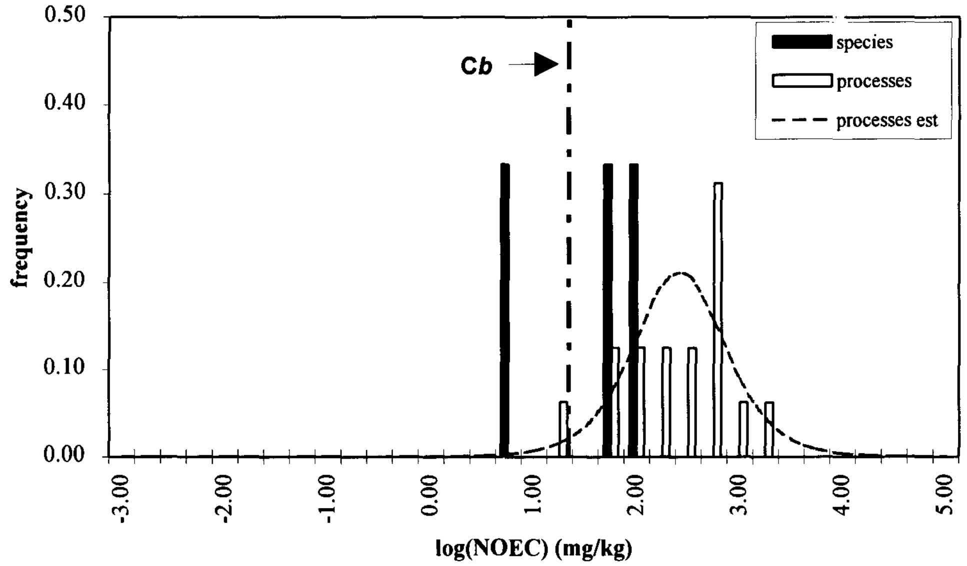

Figure 7.1 Arsenic: Estimated sensitivity distribution for terrestrial processes (α=2.2, β=0.28, n=20) and number of data within a category. Frequency of experimental data within a category is obtained by dividing the amount of data in a category by the total number of data. The vertical line indicates the level of the background concentration.

Cadmium

For cadmium enough experimental NOECs are available for species as well as processes to estimate sensitivity distributions (fig. 7.2). The MPAs for species is 0.76 mg/kg, 0.73 mg/kg and 0.73 mg/kg for φ = 0, 0.5 and 1, respectively, and for microbe-mediated processes 11 mg/kg, for φ = 0, 0.5 and 1. The lowest of these two is selected to be the MPA(soil): is 0.76 mg/kg, 0.73 mg/kg and 0.73 mg/kg for φ = 0, 0.5 and 1, respectively, based on the MPA(species). The background concentration is 0.8 mg/kg (table 5.1) resulting in an MPC(soil) of 1.6 mg/kg.

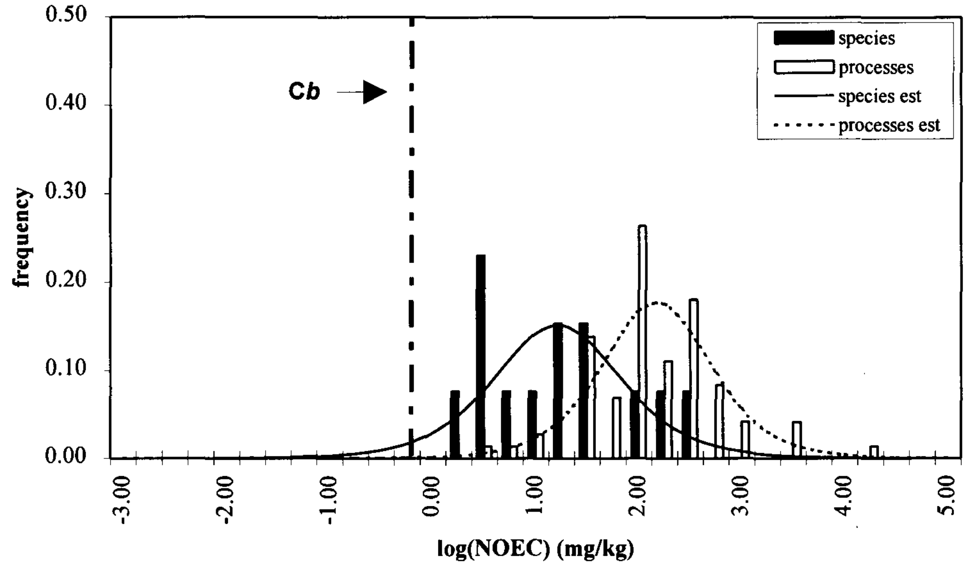

Figure 7.2 Cadmium: Estimated sensitivity distributions for terrestrial species (α=1.1, β=0.41, n=13), processes (α=2.0, β=0.35, n=72) and number of data within a category. Frequency of experimental data within a category is obtained by dividing the amount of data in a category by the total number of data. The vertical line indicates the level of the background concentration.

Chromium

In the soil Cr(III) is the most common stable form. The Cr(VI) present is for the most part directly reduced to Cr(III). Only in oxygen rich soils, containing no organic matter and in which manganese oxide is present as an oxidant, Cr(III) is oxidized to Cr(VI) (Slooff et al., 1990b).

Most toxicity tests in soil are for Cr(III), the most stable form. A statistical comparison between the data for Cr(III) and Cr(VI) cannot be made because of the limited data set for chromium(VI). The NOECs for chromium(VI) are within the range of the toxicity data for chromium(III) (see Appendix VI). MPAs are derived for both Cr(III) and Cr(VI). It must be remarked however that the background concentration is expressed as total Cr, without discrimination between Cr(III) and Cr(VI).

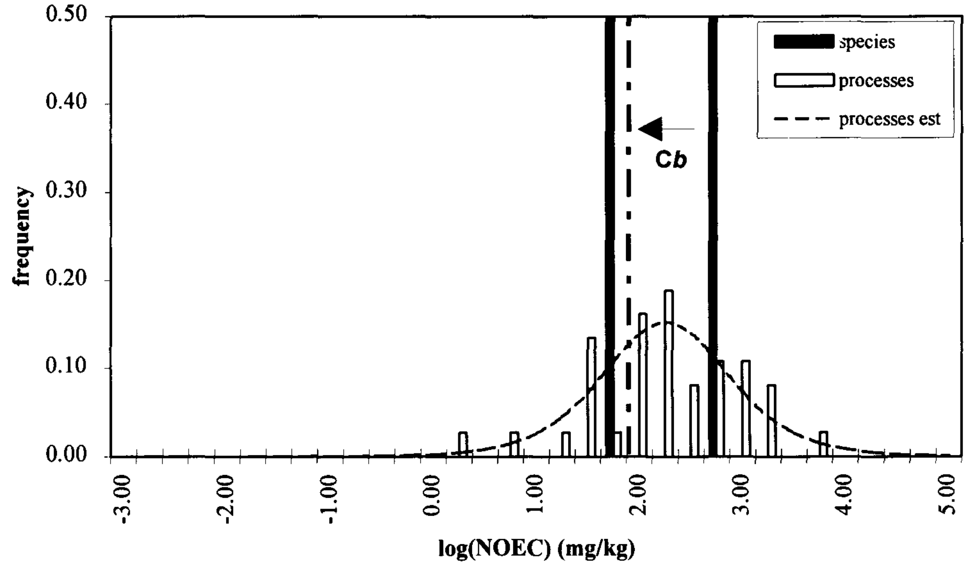

Figure 7.3 Chromium(III): Estimated sensitivity distribution for terrestrial processes (α=2.1, β=0.41, n=37) and number of data within a category. Frequency of experimental data within a category is obtained by dividing the amount of data in a category by the total number of data. The vertical line indicates the level of the background concentration.

-Chromium(III)

NOECs are available for plants and earthworms, the lowest value of 38 mg/kg for an earthworm resulting in an MPA(species) of 3.8 mg/kg using the modified EPA-method (applying a factor 10). For microbe-mediated processes an MPA of 8.6, 9.5 and 9.8 mg/kg for φ = 0, 0.5 and 1, respectively, is derived using statistical extrapolation.

-Chromium(VI)

For chromium(VI) experimental data for processes only are available. The lowest value of these NOECs, 680 mg/kg, is used to derive an MPA(processes) by applying a factor 10, resulting in a value of 68 mg/kg.

The lowest of the values is selected to be the MPA(soil): 3.8 mg/kg based on the MPA(species) for Cr(III). The background concentration is 100 mg/kg (table 5.1) resulting in an MPC(soil) of 100 mg/kg.

Cobalt

The MPA(soil) for cobalt is based on a NOEC of 240 mg/kg for earthworms. After applying a factor 10 the MPA(soil) is 24 mg/kg (Van de Plassche et al., 1992). The background concentration is 9 mg/kg (table 5.1) resulting in an MPC(soil) of 33 mg/kg.

Copper

For copper enough experimental data are available to estimate sensitivity distributions for both species and processes (fig. 7.4). For species an MPA of 24, 21 and 20 mg/kg is derived (for φ = 0, 0.5 and 1 respectively). The data for microbe-mediated processes are not log-logistically or normally distributed, but the deviation is not substantial. An MPA(processes) of 3.5, 4.1 and 5.0 mg/kg (for φ = 0, 0.5 and 1 respectively) is derived. The lowest of these two is selected to be the MPA(soil): 3.5, 4.1 and 5.0 mg/kg (for φ = 0, 0.5 and 1 respectively) based on the MPA(processes). The background concentration is 36 mg/kg (table 5.1) resulting in an MPC(soil) of 40 mg/kg.

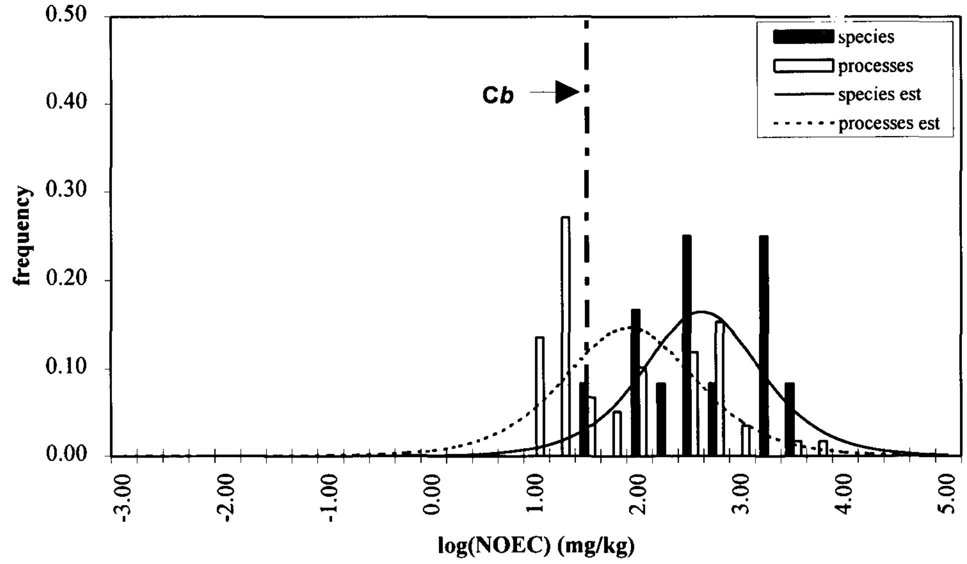

Figure 7.4 Copper: Estimated sensitivity distributions for terrestrial species (α=2.5, β=0.37, n=12), processes (α=1.8, β=0.44, n=56) and number of data within a category. Frequency of experimental data within a category is obtained by dividing the amount of data in a category by the total number of data. The vertical line indicates the level of the background concentration.

Lead

The distribution of the available experimental NOECs for lead (species as well as processes) is shown in fig. 7.5. MPAs are derived using statistical extrapolation. The MPA(species) is 64, 45 and 38 mg/kg (for $\varphi = 0$, 0.5 and 1 respectively). The MPA(processes) is 55, 42 and 38 mg/kg (for $\varphi = 0$, 0.5 and 1 respectively). The lowest of these two is selected to be the MPA(soil): 55, 42 and 38 mg/kg (for $\varphi = 0$, 0.5 and 1 respectively) based on the MPA(processes). The background concentration is 85 mg/kg (table 5.1) resulting in an MPC(soil) of 140 mg/kg.

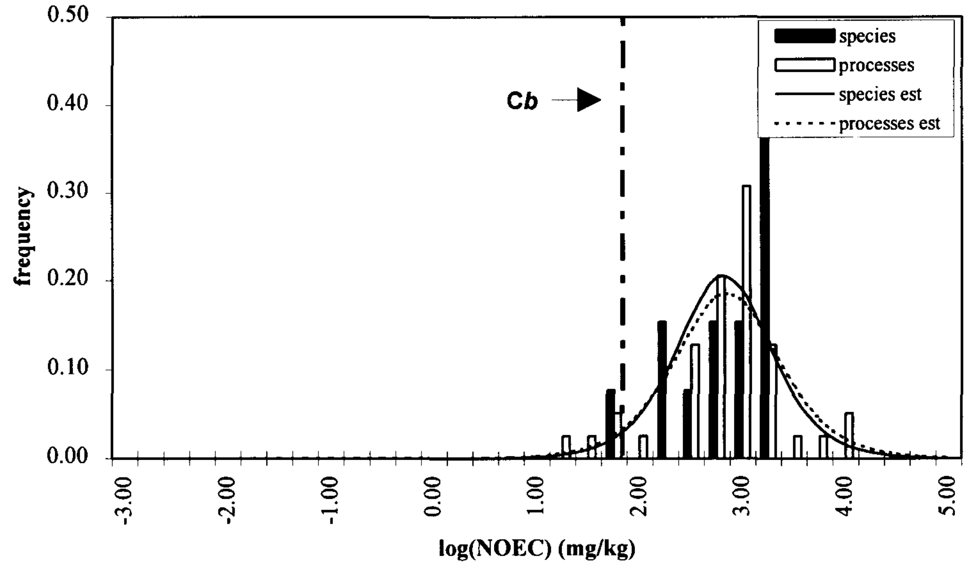

Figure 7.5 Lead: Estimated sensitivity distributions for terrestrial species (α=2.7, β=0.30, n=13), processes (α=2.7, β=0.33, n=39) and number of data within a category. Frequency of experimental data within a category is obtained by dividing the amount of data in a category by the total number of data. The vertical line indicates the level of the background concentration.

Mercury:

Slooff et al. (1995) state that although methylation of inorganic mercury primarily occurs in sediments, it may also occur in soils. However, hardly any data are available for soils. Based on the scarce data available Slooff et al. (1995) assume that mercury in soil mainly occurs as inorganic mercury. However, as methyl-mercury in soil organisms has been demonstrated an MPA for organic (methyl-mercury) as well as inorganic mercury is derived.

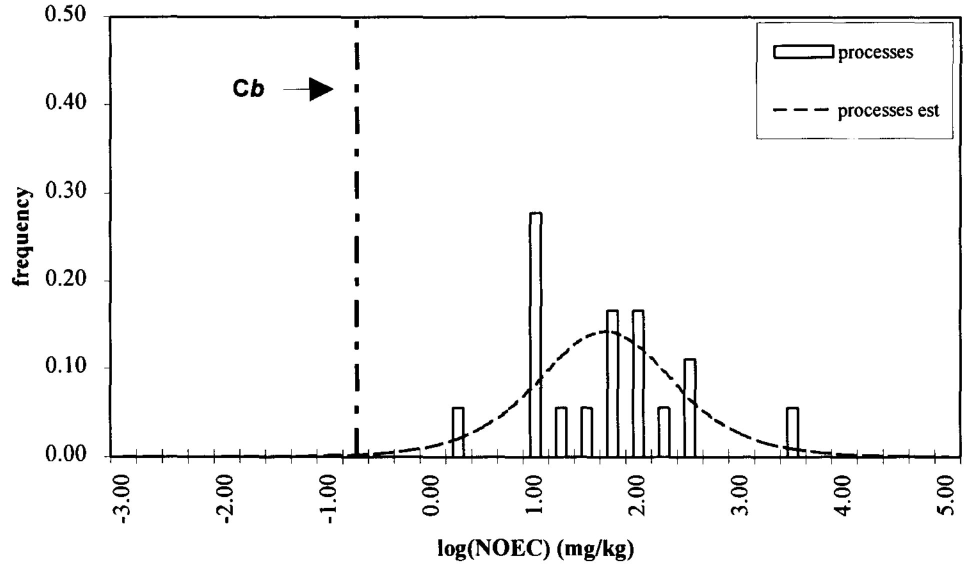

Figure 7.6 inorganic-mercury: Estimated sensitivity distribution for processes (α=1.6, β=0.43, n=18) and number of data within a category. Frequency of experimental data within a category is obtained by dividing the amount of data in a category by the total number of data. The vertical line indicates the level of the background concentration.

- Inorganic mercury. For inorganic mercury enough data on processes are available to apply statistical extrapolation. No data on species are available. The MPA(processes) is 1.9 mg/kg for φ = 0, 0.5 and 1. The background concentration is 0.3 mg/kg (table 5.1) resulting in an MPC(soil) of 2.2 mg/kg.

- methyl-mercury. Only one NOEC for methyl-mercury is available. The MPA(species) of 0.37 mg/kg for methyl-mercury is based on this NOEC of 3.7 mg/kg divided by a factor 10. The background concentration is 0.3 mg/kg (table 5.1) resulting in an MPC(soil) of 0.67 mg/kg.

Nickel

The MPA(species) is 6.5 mg/kg using the EPA-method, and is based on the only NOEC of 65 mg/kg that was available for earthworms (applying a factor 10). Two NOECs for microbe-mediated processes are available. Using the modified EPA-method the MPC(processes) is 2.6 mg/kg, calculated from the lowest NOEC of 26 mg/kg and applying a factor 10. The lowest of these two is selected to be the MPA(soil): 2.6 mg/kg based on the MPA(processes). The background concentration is 35 mg/kg (table 5.1) resulting in an MPC(soil) of 38 mg/kg.

Zinc

The distribution of the available experimental NOECs (species as well as processes) is shown in fig. 7.7. The MPA(species) is 132, 71 and 37 mg/kg (for φ = 0, 0.^{5} and 1 respectively) and the MPA(processes) is 16, 14 and 16 mg/kg (for φ = 0, 0.5 and 1 respectively). The lowest of these two is selected to be the MPA(soil): 16, 14 and 16 mg/kg (for φ = 0, 0.5 and 1 respectively) based on the MPA(processes). The background concentration is 140 mg/kg (table 5.1) resulting in an MPC(soil) of 160 mg/kg.

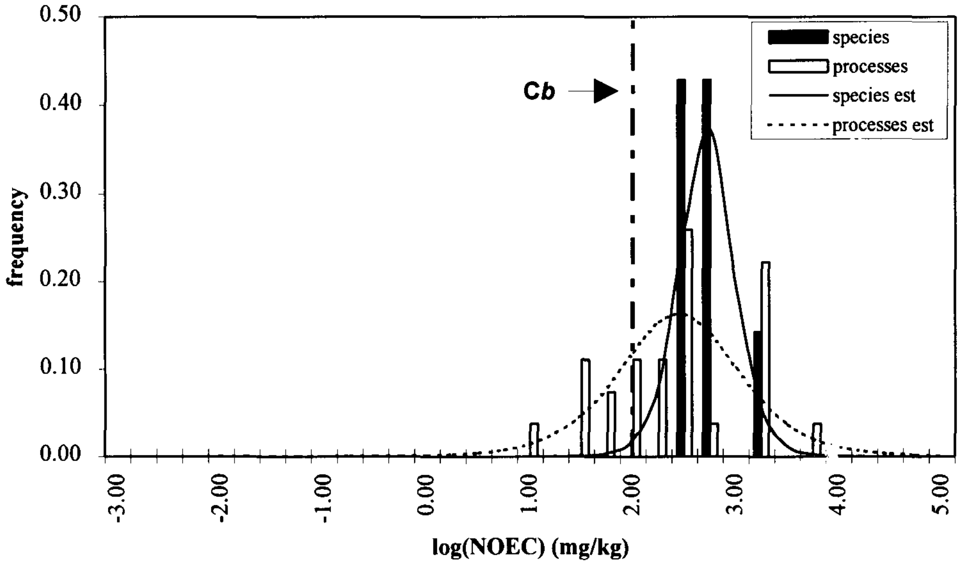

Figure 7.7 Zinc: Estimated sensitivity distributions for terrestrial species (α=2.6, β=0.16, n=7), processes (α=2.3, β=0.38, n=25) and number of data within a category. Frequency of experimental data within a category is obtained by dividing the amount of data in a category by the total number of data. The striped vertical line indicates the level of the background concentration.

Table 7.1 MPA and MPC values for soil (MPA(soil) and MPC(soil)) using experimental data for different percentages availability of the background (0, 50 and 100% or φ = 0, 0.5 and 1), background concentration (C*b* from table 5.1) and lowest NOEC value of the dataset. Values are in mg/kg standard soil (soil containing 10% organic matter and 25 % clay).

availability	0% (φ = 0)		50% (φ = 0.5)	100% (φ = 1)			lowest
Metal	MPA(soil)		MPA(soil)	MPA(soil)	C*b*	MPC(soil)	NOEC
arsenic	4.5	(c)			29	34	17
cadmium	0.76	(a)	0.73	0.73	0.8	1.6	1.1
chromium*	3.8	(c)			100	100	1.5
cobalt	24	(c)			9.0	33	240
copper	3.5	(a)	4.1	5.0	36	40	6.7
lead	55	(a)	42	38	85	140	17
inorganic mercury	1.9	(b)	1.9	1.9	0.3	2.2	1.4
methyl-mercury	0.37	(c)			0.3	0.67	3.7
nickel	2.6	(c)			35	38	26
zinc	16	(a)	14	16	140	160	9.0

Notes:

(a): MPA based on statistical extrapolation, toxicity data follow a log-logistic distribution,
(b): MPA based on statistical extrapolation, toxicity data do not follow a log-logistic distribution,
(c): MPA based on modified EPA-method, applying a factor 10 on the lowest NOEC,
(d): MPA based on modified EPA-method, applying a factor 100 on the lowest L(E)C50,
(e): MPA based on modified EPA method, applying a factor 1000 on the lowest L(E)C50,
*: Based on results for Cr(III).

7.2 MPAs and MPCs for soil using equilibrium partitioning

If no experimental data are available an MPA(soil$_{EP}$) is derived using equilibrium partitioning. The MPA(soil$_{EP}$) is based on the sensitivities of species in the water compartment. The MPA for water used in this method is the MPA(fresh) presented in section 6.1 based on toxicity data for freshwater species and marine species and $\varphi = 0$ (see also section 3.7).

Antimony

An MPA(soil$_{EP}$) of 0.53 mg/kg is derived using an MPA(fresh) of 6.2 µg/l and a partition coefficient (log $Kp_{(soil/w)}$) of 1.93 l/kg (table 4.1). The background concentration is 3.0 mg/kg (table 5.1) resulting in an MPC(soil$_{EP}$) of 3.5 mg/kg.

Barium

An MPA(soil$_{EP}$) of 9.0 mg/kg is derived using an MPA(fresh) of 150 µg/l and a partition coefficient (log $Kp_{(soil/w)}$) of 1.78 l/kg (table 4.1). The background concentration is 155 mg/kg (table 5.1) resulting in an MPC(soil$_{EP}$) of 165 mg/kg.

Beryllium

An MPA(soil$_{EP}$) of 0.0061 mg/kg is derived using an MPA(fresh) of 0.16 µg/l and a partition coefficient (log $Kp_{(soil/w)}$) of 1.58 l/kg (table 4.1). The background concentration is 1.1 mg/kg (table 5.1) resulting in an MPC(soil$_{EP}$) of 1.1 mg/kg.

Molybdenum

An MPA(soil$_{EP}$) of 253 mg/kg is derived using an MPA(fresh) of 290 µg/l and a partition coefficient (log $Kp_{(soil/w)}$) of 2.94 l/kg (table 4.1),. The background concentration is 0.5 mg/kg (table 5.1) resulting in an MPC(soil$_{EP}$) of 254 mg/kg.

Selenium

An MPA(soil$_{EP}$) of 0.11 mg/kg is derived using an MPA(fresh) of 5.3 µg/l, and a partition coefficient (log $Kp_{(soil/w)}$) of 1.30 l/kg (table 4.1). The background concentration is 0.70 mg/kg (table 5.1) resulting in an MPC(soil$_{EP}$) of 0.81 mg/kg.

Thallium

An MPA(soil$_{EP}$) of 0.25 mg/kg is derived using an MPA(fresh) of 1.6 µg/l and a partition coefficient (log $Kp_{(soil/w)}$) of 2.20 l/kg (table 4.1). The background concentration is 1.0 mg/kg (table 5.1) resulting in an MPC(soil$_{EP}$) of 1.3 mg/kg.

Tin

An MPA(soil$_{EP}$) of 34 mg/kg is derived using an MPA(fresh) of 18 µg/l and a partition coefficient (log $Kp_{(soil/w)}$) of 3.28 l/kg (table 4.1). The background concentration is 19 mg/kg (table 5.1) resulting in an MPC(soil$_{EP}$) of 53 mg/kg.

Vanadium

An MPA(soil$_{EP}$) of 1.1 mg/kg is derived using an MPA(fresh) of 3.5 μg/l and a partition coefficient (log $Kp_{(soil/w)}$) of 2.49 l/kg (table 4.1). The background concentration is 42 mg/kg (table 5.1) resulting in an MPC(soil$_{EP}$) of 43 mg/kg.

Table 7.2 MPA and MPC values for soil using equilibrium partitioning (MPA(soil$_{EP}$) and MPC(soil$_{EP}$)) for those metals for which no experimental data for soil are available, partition coefficient (log $Kp_{(soil/w)}$), MPA(fresh) used in the calculation and background concentration (C*b* from table 5.1) for soil.

Metal	MPA(fresh) (μg/l)	log$Kp_{(soil/w)}$ (l/kg)	MPA(soil$_{EP}$) (mg/kg)	C*b* (mg/kg)	MPC(soil$_{EP}$) (mg/kg)
antimony	6.2	1.93	0.53	3.0	3.5
barium	150	1.78	9.0	155	165
beryllium	0.16	1.58	0.0061	1.1	1.1
molybdenum	290	2.94	253	0.5	254
selenium	5.3	1.30	0.11	0.70	0.81
thallium	1.6	2.20	0.25	1.0	1.3
tin	18	3.28	34	19	53
vanadium	3.5	2.49	1.1	42	43

7.3 Harmonisation

The MPAs for soil based on experimental data have to be harmonised with the MPAs for water. In order to do so the equilibrium partitioning method is used (see section 3.5.1). Only the MPA(soil) for $\varphi = 0$ can be harmonised, as it is not possible to integrate the background concentration in the equilibrium partitioning method. The MPA for water used in this method is the MPA(fresh) derived in section 6.1 based on toxicity data for freshwater species and marine species and $\varphi = 0$. For chromium the MPA(fresh) for Cr(III) is used instead of the value for Cr(VI) from table 6.5, because the MPA(soil) that has to be harmonised is based on the results for Cr(III).

Table 7.3 Harmonisation of the MPA(soil) based on experimental data from table 7.1 with MPA(fresh) (for $\varphi = 0$, from table 6.5). Partition coefficient (log$Kp_{(soil/w)}$ from table 4.1), MPA for soil applying equilibrium partitioning (MPA(soil$_{EP}$)) and background concentration for soil (C*b* from table 5.1).

Metal	MPA(fresh) (μg/l)	log$Kp_{(soil/w)}$ (l/kg)	MPA(soil$_{EP}$) (mg/kg)	C*b* (mg/kg)	MPA(soil) (mg/kg)
arsenic	24	2.28	4.6	29	4.5
cadmium	0.34	2.30	0.068	0.8	0.76
chromium*	34	2.04	3.7	100	3.8
cobalt	2.6	1.60	0.10	9.0	24
copper	1.1	2.99	1.1	36	3.5
lead	11	3.28	21	85	55
inorganic mercury	0.23	2.23	0.39	0.3	1.9
methyl-mercury	0.01	2.23	0.0017	0.3	0.37
nickel	1.8	2.08	0.22	35	2.6
zinc	6.6	2.20	1.0	140	16

Notes:

*: Based on the results for Cr(III).

For arsenic, chromium, copper, inorganic mercury, nickel and lead the MPA(soil$_{EP}$) and the MPA(soil) are not much different: the difference is less than a factor 10. For cadmium, cobalt, methyl-mercury and zinc the difference is larger. Following Van de Plassche and De Bruijn (1992) and Van de Plassche (1994) the MPA(soil) is however, not adjusted on the basis of harmonisation for these metals. The reason is the uncertainty of the partition coefficient between soil and pore water $Kp_{(soil/w)}$ for metals. As was also found by Van den Hoop (1995b) the variation in the $Kp_{(soil/w)}$ for metals is very large and highly dependent on soil characteristics. For the field-based $Kp_{(soil/w)}$s the standard deviation was equal to the reported mean values. If for instance for lead an MPA(soil$_{EP}$) is calculated using an $\log Kp_{(soil/w)}$ of 4.25 this would result in an MPA(soil$_{EP}$) of 196.

7.4 Secondary poisoning: terrestrial food chain

As for the water compartment (see section 6.4) also for the soil compartment secondary poisoning can be taken into account. The metals for which secondary poisoning is expected have already been studied by Van de Plassche (1994): cadmium, copper and methyl-mercury. The methodology used is based on a study performed by Romijn et al. (1991b). They proposed to analyse the terrestrial food-chain, soil → earthworm → worm eating bird or mammal, to derive an MPA(indirect effects). The effect of the background concentration is not included. As outlined in the introduction this value will be indicated as the MPA instead of as the MPC in Van de Plassche (1994). The comparison with the values derived in this report is therefore made for the MPAs for $\varphi = 0$ only.

The method can be summarised as follows: data available for direct exposure and indirect exposure are treated separately. A comparison is made between the MPA(direct) based on data for direct effects and the MPA(indirect) based on the basis of indirect effects for birds and mammals. The MPA derived for birds and mammals is expressed as a concentration of the substance in the food, which is divided by the Bioconcentration Factor for the compound considered (BCF) for earthworms. This results in an MPA(indirect effects) expressed as a concentration in the soil. Van de Plassche (1994) applied extra correction factors in order to extrapolate the results from toxicity studies with birds and mammals to field conditions.

In the following text the results for cadmium, copper and mercury as presented by Van de Plassche (1994) are summarised:

cadmium: for cadmium Van de Plassche (1994) derived an MPA of 0.0035 mg/kg based on indirect effects. This value is however based on only a limited set of NOECs for birds and a limited set of laboratory based BCFs for worms. This MPA is much lower than the one based on direct effects of 0.27 mg/kg. In the present report the ecotoxicological data set for cadmium has been updated leading to an MPC of 0.76 mg/kg (table 7.1).

copper: for copper Van de Plassche (1994) derived an MPA of 0.55 mg/kg for indirect effects. This MPA for indirect effects is based on the toxicity for mammals and laboratory based BCF values for worms and is lower than the MPA based on direct effects of 6.2 mg/kg. In the present report the ecotoxicological data set for copper has been updated leading to an MPA of 3.5 mg/kg (table 7.1).

mercury: Van de Plassche (1994) derived an MPA for indirect effects of 0.0033 mg/kg for methyl-mercury. This value is however based on a limited data set of NOECs for birds and mammals and a limited set of laboratory based BCFs. This MPA is much lower than the one based on direct effects of 0.2 mg/kg. In the present report an MPA of 0.37 mg/kg is derived based on data from Slooff et al. (1995).

In conclusion: on the basis of a comparison of the MPAs based on indirect effects and the MPAs based on direct effects as derived in this report, for cadmium, copper and methyl-mercury the MPAs for direct effects are higher than the MPAs based on indirect effects. However, the MPAs for indirect effects are based on limited sets of NOECs and on BCFs that are higher than field BCFs as reported by Hendriks et al. (1995). Because of the uncertainties in the NOECs and BCFs, no adjustment of the MPAs derived in this report are made.

7.5 Validation of MPCs for soil

At the moment a project is executed by different institutes in the Netherlands, entitled "Validation Toxicity Data and Risk levels for Soils". Two questions are dealt with in this project. In the first place attention is paid to the question: do species in the field and in the laboratory react in the same way if exposed to a comparable level of metal contamination? In the second place attention is paid to the question: how representative are the risk levels derived using laboratory toxicity data? Or: are the expected effects at a certain risk levels comparable with effects encountered in the field at a comparable concentration (Notenboom and Van Beelen, 1992; Notenboom and Posthuma, 1994; Notenboom and Posthuma, 1995; Van Beelen and Notenboom, 1996).

To study the first question (do species in the field and in the laboratory react in the same way if exposed to a comparable level of metal contamination?) laboratory bioassays with several organisms (bacteria, plants, arthropods, oligochaetes) have been performed in metal contaminated soils originating from the neighbourhood of a zinc smelter works at Budel. The results from these bioassays are compared with results from experiments performed with the same species in standardised soils spiked with metals (Notenboom and Posthuma, 1994). Besides this mesocosm study, experiments are performed with laboratory species and results are compared with laboratory experiments using the same species (Notenboom and Posthuma, 1995; Van Beelen and Notenboom, 1996).

For bacteria tests have been performed by studying the acetate mineralisation rate, survival of the bacteria *Pseudomonas putida* and mineralisation rate of glutamine acid. The plants considered are *Avena sativa, Latuca sativa* and *Lycopersicum esculentum.* Experiments for plants have been performed according to the OECD guideline 208 for terrestrial plants (OECD, 1984b). Other species tested are the oligochaete species *Eisenia andrei,* the enchytraeid species *Enchytraeus crypticus* and *Enchytraeus albidus*, the nematod species *Plectus acuminatus* and the arthropod species *Folsomia candida* (Notenboom and Posthuma, 1994).

Important factors determining differences between effects in laboratory and field are probably related to the interaction between metals in combination, deviation in biological activity, or both. In the context of the project it would be better to compare effects on the basis of internal concentrations (Posthuma et al., 1994). Although the water soluble part of zinc could not fully explain differences between tested soils with *Folsomia candida*, it is recommended by Smit and Van Gestel (1996) to include pore water analysis in future research to improve interpretation and application of laboratory toxicity tests.

To study the second question (how representative are the risk levels derived using laboratory toxicity data?), an onset has been made by studying the species composition and abundance of nematods along a gradient of contaminated soil. It seems that it is difficult to establish a direct relationship between toxic metal concentration and composition and abundance of nematods, caused by the variation in natural factors. On the basis of a literature study Posthuma (1997) compared community effects in a metal polluted gradient with a hazardous concentration for 5% of the species based on laboratory toxicity tests. He concluded that there was a close similarity between the hazardous concentration for 5% of the species and the EC5 of loss of species diversity in a soil invertebrate community. A full report of the different research results will be provided in the near future.

7.6 Summary of MPAs and MPCs and comparison with 'old' MPCs

In table 7.4 the MPAs (if possible for different percentages availability of the background concentration), MPCs and C*bs* from table 7.1 and 7.2 are summarised. As explained in the introduction (section 1.2) the MPCs for $\varphi = 0$ are recommended to be used for setting Environmental Quality Objectives. Besides the values derived in the present report, also the 'old' MPCs derived in Van de Meent et al. (1990) and Van de Plassche and De Bruijn (1992) are presented in table 7.5.

Comparing the MPAs for different fractions bioavailable φ, it becomes evident that the choice of φ is not of much influence for the MPA. For most of the metals considered almost no or only small differences in MPAs were found. Only for lead somewhat larger differences were found. Since the old MPCs are derived without taking into account background concentrations, all the new MPC values are higher.

Table 7.4 Summary of MPA and MPC values for soil derived in the present report (MPA(soil)) for different percentages availability of the background (0, 50 and 100% or $\varphi = 0, 0.5$ and 1) if possible. The values to be used for setting Integrated Environmental Quality Objectives are underlined. Besides this background concentrations (*Cb*) and old MPCs are presented. Values are in mg/kg standard soil (soil containing 10% organic matter and 25 % clay).

	MPA(soil)				MPC(soil)	old MPC
metal	$\varphi = 0$	$\varphi = 0.5$	$\varphi = 1$	C*b*		
antimony	0.53(f)			3.0	3.5	0.53 (h)
arsenic	4.5 (c)			29	34	7.1 (g)
barium	9.0 (f)			155	165	9.0 (h)
beryllium	0.0061 (f)			1.1	1.1	0.006 (h)
cadmium	0.76 (a)	0.73	0.73	0.8	1.6	0.17 (g)
chromium*	3.8 (c)			100	100	2.4 (g)
cobalt	24 (c)			9.0	33	24 (h)
copper	3.5 (a)	4.1	5.0	36	40	3.5 (g)
lead	55 (a)	42	38	85	140	22 (g)
inorganic mercury	1.9 (a)	1.9	1.9	0.3	2.2	
methyl-mercury	0.37 (c)			0.3	0.67	0.2 (g)
molybdenum	253 (f)			0.5	254	250 (h)
nickel	2.6 (c)			35	38	2.6 (h)
selenium	0.11 (f)			0.7	0.81	0.11 (h)
thallium	0.25 (f)			1.0	1.3	0.25 (h)
tin	34 (f)			19	53	35 (h)
vanadium	1.1 (f)			42	43	1.1 (h)
zinc	16 (a)	14	16	140	160	0.7 (g)

Notes:

(a): MPA based on statistical extrapolation, toxicity data follow a log-logistic distribution,
(b): MPA based on statistical extrapolation, toxicity data do not follow a log-logistic distribution,
(c): MPA based on modified EPA-method, applying a factor 10 on the lowest NOEC,
(d): MPA based on modified EPA-method, applying a factor 100 on the lowest L(E)C50,
(e): MPA based on modified EPA-method, applying a factor 1000 on the lowest L(E)C50,
(f): MPA based on equilibrium partitioning,
(g): Van de Meent et al., (1990),
(h): Van de Plassche and De Bruijn (1992),
*: Based on results for Cr(III).

7.7 Critical air concentrations

The Critical air Concentration (CritCONC(air)) is the concentration in the air that corresponds with the MPA(soil) and can be calculated from the MPC(soil) using the Steady-State soil/air Concentration Ratios ($SSCR_{soil/air}$) for heavy metals. The $SSCR_{soil/air}$ for the different metals is derived using the SimpleBox model; version 1.1 (Van de Meent, 1993). The Critical air Concentration CritCONC(air) can be compared with the MPC(air)s that are based on human toxicological data and further to harmonise these MPCs for soil with the MPC(air). In the calculations it is assumed that the main emission route is through the air (the primary compartment) and that natural soil is the compartment of focus (secondary compartment). This secondary compartment is only loaded indirectly via the primary compartment, the air. Besides this it is assumed that in air there is no background concentration.

The SimpleBox model is originally developed for organic substances. The model is therefore not directly applicable for calculation of Critical Air Concentrations for heavy metals. In order to make estimates for CritCONC(air) for heavy metals, parameter settings are adapted for log*Kow*, vapour pressure, scavenging ratio, fraction aerosol bound metal and degradation rates. The adapted parameter settings used for all metals except mercury, are explained below. As the behaviour of mercury is different from all other metals, other values are used for mercury.

LogKow

For metals log*Kow* values are not meaningful because metals bind specifically to carbohydrates rather than to lipids, except for mercury. The conclusion is that metals will accumulate in animals, but not in the same way as organic substances. Although log*Kow* is not a meaningful parameter for metals it is not possible to avoid the log*Kow* as an input parameter or to set the value at 0, because SimpleBox then chooses the adopted default value. Therefore, a relatively high log*Kow* value of 10 is used for the model calculations, the height of this factor is arbitrary. Changing the selected log*Kow* value into an even higher value would not result in a different output of the model in this case.

Vapour pressure

The vapour pressure for heavy metals is set to $1*10^{-30}$ Pa, because metals absorbed on soil particles or dissolved in water will not evaporate. An exception is made for mercury (see below). The outcome was not influenced by changes in the vapour pressure, as long as the vapour pressure was very low. The log*Kow* and vapour pressure are used by the SimpleBox model to calculate the water solubility, which is a low value in the order of 10^{-10} $g.l^{-1}$. Determining experimental water solubilities for metals is complicated due to differences in speciation. From the set vapour pressure and the calculated water solubility, SimpleBox calculates a Henry law constant of approximately $2*10^{-22}$ $Pa.m^3.mol^{-1}$.

Scavenging ratio

In the SimpleBox model a default value for the scavenging ratio (relation between rain water concentration and air concentration) of $2*10^5$ is set. According to Van Jaarsveld (*pers. Comm.*) this value is between $1*10^5$ and $2*10^5$ for most metals. If however, the scavenging ratios are determined using measured values for air and rainwater concentration, using year average concentrations from 1987 to 1993 (jaaroverzicht luchtkwaliteit, 1987-93 (Aben et al., 1993), the ratio varies between $0.5*10^5$ and $4*10^5$. The reason for the discrepancies with the expected values, are the difficulties in measuring metal concentrations in air and rainwater. Calculation of the long-term lead scavenging ratio showed an average value of approximately $1*10^5$. Since lead presents the most reliable scavenging ratio based on measured concentrations (Van Jaarsveld *pers. comm.)*, this ratio is applied for all metals except for mercury. For mercury the scavenging ratio proposed in the criteria document mercury (Slooff *et al.*, 1995) is used, which is based on scarce measured environmental concentrations. This ratio is equal to the default value in SimpleBox.

Fraction aerosol bound

All metals, except mercury, are bound to aerosols for the major part. The fraction aerosol bound arsenic was reported to be >90% (Slooff *et al.*, 1990a) and 99% for zinc (Cleven *et al.*, 1992). A fraction of aerosol bound metals of 0.95 is used for the calculations. This fraction is confirmed by Van Jaarsveld (*pers comm.*). For mercury a fraction of 0.05 (Slooff *et al.*, 1995) is used. Changing the fraction aerosol for all metals had almost no effect on the calculated Critical Air Concentrations. Apparently, the influence of the fraction aerosol bound metal is low.

Degradation rates

The degradation rates in all compartments are set to an extreme low value i.e. $1.0*10^{-30}$ d^{-1}, since metals are not degradable.

Mercury

The behaviour of mercury is different from all other metals. Mercury is present in the atmosphere mainly as metallic mercury (Hg^0) for more than 75%. Metallic mercury is volatile and has a relatively high air-water partition coefficient. In the water phase mercury is present as ionic mercury. This causes the phenomena that the boundary between air and water presents a transition of an extreme high to an extreme low air-water partition coefficient. SimpleBox is not suitable to model this situation. SimpleBox calculates an air-water partition coefficient for all metals. However to make calculations possible for mercury an air-water partition coefficient is set to a value of $1.3*10^{-5}$ This value is in agreement with (Slooff *et al.*, 1995; Peijnenburg *pers comm.*). Another difference with other metals is that mercury has an organic and an inorganic form. The organic form, methyl mercury, is methylated or demethylated by chemical and biological processes. Data on the rate of this compound is scarce. However, the importance of methyl mercury is considered to be low since the total fraction methyl mercury on the total mercury load is very low.

Table 7.5 Steady-State soil/air Concentration Ratios (SSCR(soil/air)) and Critical Air Concentrations (CritCONC(air)), MPA values for standard soil (soil containing 10% organic matter and 25 % clay) derived in the present report (MPA(soil)) and MPC for air if available (MPC(air)).

	SSCR(soil/air) m^3/kg	MPC(soil) mg/kg	CritCONC(air) $\mu g/m^3$	MPC(air) $\mu g/m^3$
antimony	8480	3.5	0.41	3.2 (a)
arsenic	19000	34	1.80	0.50 (b)
barium	6000	165	28	
beryllium	3790	1.1	0.29	0.04 (c)
cadmium	21300	1.6	0.075	
chromium	10900	100	9.2	0.0025 (d)
cobalt	3960	33	8.3	
copper	97300	40	0.41	
lead	190000	140	0.74	0.50 (e)
inorganic mercury	24500	2.2	0.09	
methyl-mercury	24500	0.67	0.03	
molybdenum	86700	254	2.9	
nickel	12000	38	3.2	0.25 (f)
selenium	1990	0.81	0.41	
thallium	15800	1.3	0.08	
tin	190000	53	0.28	
vanadium	30800	43	1.4	1.0 (g)
zinc	15800	160	10	

Notes:

(a): Slooff et al. (1992a)
(b): Slooff et al. (1990a),
(c): Janssen et al. (1995),
(d): Slooff et al. (1990b),
(e): Janus et al. (1997),
(f): Slooff et al. (1992b),
(g): Janssen et al. (1997).

The Steady-State soil/air Concentration Ratios and Critical Air Concentrations for all metals are listed in table 7.6. The MPC(air) included in this table is based on the human toxicological effects for humans exposed through the air, and is derived without taking background concentrations into account.

It should be stressed that the calculated Critical Air Concentrations are to be used as indicative values only, because of the uncertainties in using SimpleBox for non organic substances. Especially mercury is a compound that has a behaviour that is different from organics, but also different from all other metals.

For 7 metals for which MPAs are proposed for the compartment air it was possible to compare the CritConc(air) with an MPC(air) based on human toxicity: antimony, arsenic, beryllium, chromium, lead, nickel and vanadium. If the MPC(air) is higher than the CritCONC(air) this means that the concentration at steady state in the secondary compartments (soil) will also be higher than the MPA(soil). The analysis indicates that maintaining the concentration at the MPC(air) level for antimony will result in a concentration in soil that is almost more than a factor 10 higher than the MPA(soil). A factor 10 difference is expected to be non significant since the variation in partition coefficients and MPCs are considered high.

It should be mentioned that the MPC(soil) for chromium is based on total chromium concentrations, in which both Cr(III) and Cr(VI) are present, whereas the MPC(air) is based strictly on Cr(VI). Therefore, it is not possible to directly compare the calculated Critical Air Concentration with the MPC(air). The differentiation between total chromium and Cr(VI) is necessary because Cr(VI) is considered to be a strong genotoxic carcinogen when inhalated. Estimates of the Cr(VI) fraction in air range from 0.01-30%. There is however, no satisfactory methodology for determining reliable Cr(VI) levels. Therefore, the practical use of the mentioned Cr(VI) fractions is considered very limited.

CHAPTER 8 MPAs AND MPCs FOR SEDIMENT

In this chapter MPAs and MPCs for sediment are derived using the methodology as described in section 3.7. In section 8.1 the MPAs and MPCs are derived using equilibrium partitioning and are presented in table 8.1. In section 8.2 the MPAs from 8.1 are compared with data from sediment toxicity tests. The proposed MPAs and MPCs are compared with the "old" MPCs derived by Van de Meent et al. (1990) and Van de Plassche and De Bruijn (1992).

8.1 MPAs and MPCs for sediment

MPAs for sediment are derived using equilibrium partitioning (MPA(sed)) using the MPA(fresh) from chapter 6 and the partition coefficients ($Kp_{(sed/w)}$) from chapter 4. The MPA(sed) is presented together with the MPA(fresh), the log $Kp_{(sed/w)}$, the background concentration (C*b*) and the MPC(sed) in table 8.1. As it is not possible to estimate the effect of the bioavailable fraction of the background, no different values for $\varphi = 0$, 0.5 and 1 are derived. As already explained in section 3.6 the MPA for water used to derive the MPA(sed) should be based on toxicity data for aquatic organisms, i.e. without taking the background concentration in water into account. These MPA values have been derived in section 6.5 and are the MPA(fresh) values for $\varphi = 0$.

Table 8.1 MPA and MPC values for standard sediment (=sediment containing 10% organic matter and 25% clay) using equilibrium partitioning (MPA(sed) and MPC(sed)), MPA(fresh) (for $\varphi = 0$ from table 6.5) and partition coefficient log $Kp_{(sed/w)}$ (from table 4.1) used in the calculations, and background concentration in sediment (C*b* from table 5.1).

Metal	MPA(fresh) (µg/l)	log $Kp_{(sed/w)}$ (l/kg)	MPA(sed) (mg/kg)	C*b* (mg/kg)	MPC(sed) mg/kg
antimony	6.2	3.41	16	3.0	16
arsenic	24	3.82	160	29	160
barium	150	3.00	150	155	150
beryllium	0.16	2.78	0.096	1.1	0.096
cadmium	0.34	4.93	29	0.8	29
chromium*	8.5	5.28	1620	100	1620
cobalt	2.6	3.60	10	9.0	10
copper	1.1	4.53	37	36	37
lead	11	5.63	4700	85	4700
inorganic mercury	0.23	5.05	26	0.3	26
methyl-mercury	0.01	5.05	1.1	0.3	1.1
molybdenum	290	2.93	250	0.5	250
nickel	1.8	3.72	9.4	35	9.4
selenium	5.3	2.62	2.2	0.7	2.2
thallium	1.6	3.00	1.6	1.0	1.6
tin	18	6.09	22000	19	22,000
vanadium	3.5	3.59	14	42	14
zinc	6.6	4.86	480	140	480

Notes:

*: Based on results for Cr(VI).

The MPA for water based on toxicity data is derived combining the data sets for fresh and marine species leading to one MPC for both environments. This means that the same MPC(sed) is derived for freshwater as well as marine sediments.

8.2 Comparison of MPCs for sediment with tests in water-sediment systems

The MPCs for sediment in table 8.1 are all derived on the basis of sensitivities of aquatic species and applying the equilibrium partitioning method. More and more tests are being performed in sediment-water systems and the knowledge of this specific habitat is still developing. Behaviour of metals in sediment-water systems is very complex, and influenced by many variables like for instance Acid Volatile Sulphide (AVS). Attempts to design standard test procedures for sediment-water systems are complicated and still in development. The data that are available are difficult to interpret and not comparable with each other due to the enormous variation in test circumstances.

For the metals for which the data-set has been updated also tests performed in sediment-water systems were evaluated. The results are presented in Appendix VII. Only for cadmium, chromium and copper reliable tests were found. Below these results are compared with the MPCs derived for sediment in section 8.1. Especially the tests with benthic species are relevant when evaluating MPCs for sediment.

For *cadmium* the most sensitive benthic species is the marine crustacean *Rhepoxynius abronius* with a mean NOEC in standardised sediment (10% humus and 25% lutum) of 7.1 mg/kg. The habitat of this animal is a sandy sediment containing little organic matter and clay (> 90% sand). Therefore adsorption of cadmium will be low in this sediment and most of the cadmium added in the test will be dissolved in the porewater and overlying water. The situation in this test can be considered as a worst-case situation that may exist in the marine sediments. The MPA derived in the present report with the equilibrium partition method without adding the background concentration is 29 mg/kg (see table 8.1). This value is comparable to the NOEC for the *R. abronius*.

For *copper* one NOEC of 30 mg/kg for a marine mollusc is available. This value is almost equal to the MPA derived with the equilibrium partition method without adding the background concentration of 37 mg/kg.

For *chromium* no toxicity data for benthic species were found, only tests with fish are available. The comparison of these data with the MPC derived with the equilibrium partitioning method is therefore not considered relevant.

As already stated above tests in sediment-water systems are difficult to interpret and compare. With respect to metals the following remarks can be made:
- in all tests the metal is added to the medium. The amount already present, or the background concentration in the medium is unknown,
- the equilibrium time before the test organism is introduced in the medium and the duration of the test may influence the outcome due to a less bioavailable fraction with increasing exposure time.

8.3 Summary of MPAs and MPCs derived in this report and comparison with 'old' MPCs

Table 8.2 presents the MPAs and MPCs for sediment. Besides this the new values are compared with the "old" MPCs derived by Van de Meent et al. (1990) and Van de Plassche and De Bruijn (1992). Since the old MPCs are derived without taking into account background concentrations, all the new MPC values are higher. Because the 'old' MPCs are derived without taking into account the background concentrations, these 'old' MPCs should be compared with the 'new' MPAs. From this comparison of the 'old' MPC with the new MPA it becomes clear that for most of the metals for which data have been updated, the MPA is much higher than the 'old' MPC.

Table 8.2 Summary of MPA and MPC values for sediment recommended to be used for setting Integrated Environmental Quality Objectives, background concentrations (C*b* from table 5.1) and 'old' MPC. Values are in mg/kg standard sediment (sediment containing 10% organic matter and 25 % clay).

metal	MPA(sed) mg/kg	C*b* mg/kg	MPC(sed) mg/kg	old MPC(sed) mg/kg
antimony	16	3.0	19	16 (b)
arsenic	160	29	190	56 (a)
barium	150	155	300	150 (b)
beryllium	0.096	1.1	1.2	0.1 (b)
cadmium	29	0.8	30	14 (a)
chromium*	1620	100	1720	2.4 (a)
cobalt	10	9.0	19	8.0 (b)
copper	37	36	73	60 (a)
lead	4700	85	4800	860 (a)
inorganic mercury	26	0.3	26	
methyl-mercury	1.1	0.3	1.4	1.1 (a)
molybdenum	250	0.5	250	250 (b)
nickel	9.4	35	44	7.4 (b)
selenium	2.2	0.7	2.9	2.2 (b)
thallium	1.6	1.0	2.6	1.6 (b)
tin	22,000	19	22,000	22,000 (b)
vanadium	14	42	56	14 (b)
zinc	480	140	620	120 (a)

Notes:

(a): Van de Meent et al., (1990),

(b): Van de Plassche and De Bruijn (1992),

*: Based on results for Cr(VI).

CHAPTER 9 DISCUSSION

In this chapter the results of the preceding chapters are discussed. The derivation of MPAs starts with an evaluation of the ecotoxicological literature from which the data used for extrapolation are selected. The way the literature is evaluated and the data are selected is discussed in section 9.1. Since it is the aim of the present report to update the MPCs and NCs for metals, using a comparable methodology as earlier done for other classes of compounds, no or only minor adaptations for data evaluation of the methodology are made in this report.

The added risk approach is discussed in section 9.2. Attention is paid to statistical extrapolation in general (9.2.1) and to some important aspects of the added risk approach: background concentrations (9.2.2), the assumptions on bioavailability (9.2.3) and the MPCs when assuming different levels of bioavailability of the background concentration (9.2.4). The equilibrium partitioning method is discussed in section 9.3. Attention is paid to the method in general (9.3.1), to the partition coefficients that are used (9.3.2) and to the influence of acid volatile sulphide (9.3.3). Some aspects of essential metals are discussed in section 9.4.

In section 9.5 the final MPCs and NCs that are recommended for setting environmental quality objectives are presented for water, soil and sediment (9.5.1, 9.5.2 and 9.5.3, respectively). In section 9.6 the MPCs and NCs derived in this report are compared with available information on measured concentrations in the Netherlands for fresh surface water and particulate matter (9.6.1) and soil (9.6.2).

9.1 Evaluation of literature and selection of data

The evaluation of the literature and selection of the data is crucial since this step decides which data are selected to get insight in the species sensitivities and have a major influence on the resulting MPC. Each test that is evaluated from the literature resulting in a NOEC or L(E)C50 will be included in the data table only when the test is considered reliable. The criteria that are used to judge whether a test is considered reliable or not are described in a Quality Assurance Document (CSR, 1996). The criteria partly concern the test conditions that are included in the tables (see appendices I to IV). These conditions have in common that they all may influence the sensitivity of the species tested. In the following some of these test conditions are discussed.

For example, the temperature used in the experiment is of importance. An increase in temperature generally leads to increased metabolism of the organism and an increase in uptake of the toxicant. This increase in uptake may be compensated by a comparable increase in elimination and hence resulting in no net change of the internal concentration. If this is however not the case and uptake and elimination are not increased in a comparable way, this results in a change of the internal concentration (Bengtsson and Rundgren, 1992; Janssen and Bergema, 1991). The consequences for toxicity remain however unclear. Besides that changes in uptake and elimination may result in a higher or lower internal concentration, the level at which effects occur may also change.

In this report MPCs for water are based on the combined data sets for freshwater and marine species. It must be noted however that because of the complexation of metals with chlorides or carbonates, differences in uptake and therefore differences in sensitivity may be expected between fresh water and marine species (Jonkers and Everts, 1992; Hall and Anderson 1995). For all the metals considered in this report, for which it was possible to statistically test differences in sensitivity, no differences were found. Some studies in which comparisons have been made between fresh water and marine species (Scholten et al., 1991; Van de Plassche et al., 1992), did not show any differences in sensitivity either. In a literature study performed by Hall and Anderson (1995), however it was concluded that the toxicity of some metals increased with decreasing salinity. All these studies are however based on small data sets. As long as this latter conclusion is not based on more data, special attention has to be paid to this subject (TCB, 1994). Further research should be carried out prior to include salinity dependent MPCs.

Methylation of metals is a process that can take place in the environment as well in tissue of a species. In general the toxic properties of these compounds differ drastically from those of the inorganic forms. In the present report, only for mercury a distinction is made between the inorganic form and the organic methylated form, methyl-mercury, since only for this metal sufficient data are available to make comparisons. Also for other metals methylation occurs, like for instance tin, arsenic, and lead (Clarkson, 1986; D'Itri, 1990). For tin Janus and Rikken (1996) compared the toxicity of methyl-tin compounds with anorganic tin compounds: for algae no differences were found between methyl-tin and inorganic tin (EC50 values), but for species only very limited information was available and it was not possible to make comparisons[1] . In conclusion: not enough information is available to make comparisons and/or to derive separate MPCs for metals and their methylated forms.

The oxidation state of the metal-ion may be influenced by physico-chemical characteristics of the medium. Differences in sensitivity of an organism for different oxidation states of the same metal, may be the result of a difference in bioavailability, but also the presence or absence of a binding-site in that organism for the particular oxidation state can be of influence. In this report only for chromium a distinction is made between different oxidation states (Cr(III) and (CrVI)) as only for this metal enough data are available to make comparisons. It can be argued however that this may be relevant also for other metals such as Cu(Cu^+ and Cu^{2+}), Se(Se^+ and Se^{2+}) and Sn(Sn^{2+} and Sn^{4+}) but insufficient information is available either for different forms to make comparisons or to derive separate MPCs. For copper some information on effects in soil tests using different oxidation states is available. For instance, Juma and Tabatabai ((1977) cited in Appendix IV) performed phosphatase activity tests with Cu(I)Cl and Cu(II)SO_4, but no differences in sensitivity of the process studied were found.

Physico-chemical characteristics like the pH and hardness of the water will affect the sensitivity by influencing the bioavailability of metals due to differences in speciation. Differences in sensitivity of species with varying pH and hardness are therefore based on differences in uptake kinetics and/or mode of action (Witters et al., 1996). With respect to the

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[1] Janus and Rikken (1996) also made comparisons of the toxicity of inorganic tin and butyl-tin and phenyl-tin compounds. For the toxicity of butyl-tin and phenyl-tin compounds reference is made to Crommentuijn et al. (1997), where MPCs and NCs for pesticides are derived.

abiotic factors influencing the toxicity of metals in fresh water, hardness is usually considered as one of the main factors or as the main factor: the toxicity of metals is generally assumed to be inversely related to this factor. In some countries, for example the United States and Canada, the relevance of this factor is reflected in hardness-related Water Quality Criteria (cited in BKH, 1995). In the following some remarks are made on the relationship between hardness and aquatic toxicity of metals, based on the evaluations of the aquatic toxicity of metals in the underlying report and in the RIVM Integrated Criteria Document for zinc (Janus, 1993; Janus et al., 1996).

The (assumed) inverse relationship between hardness and toxicity is based mainly on the results from acute toxicity tests, conducted with relatively high metal concentrations. Based on the results of the acute tests, the inverse relationship between hardness and toxicity is considered to be unequivocal, although the following comments should be taken into account:
- most tests used fish as the test organism; data for species from other taxonomic groups, of which some may have different uptake mechanisms than fish, are scarce,
- in natural waters, hardness is qualitatively related to a number of other abiotic factors including alkalinity, ionic strength and pH. In most tests on the effects of hardness on metal toxicity, hard waters were diluted with distilled or otherwise de-ionised water to reduce hardness, resulting in a simultaneous reduction in the other factors. These factors can influence the toxicity of metals in two ways: by influencing the chemical speciation of the metal in water (and hence affecting the bioavailability) and by influencing the uptake/binding of available metal by biological tissues. Based on data on chemical speciation, it is expected that the toxicity of metals will be highest in soft, acid waters, i.e. under environmental conditions that favour the presence of the simple (hydrated) metal ion. In this respect, hardness is the (best) indicator for water conditions influencing metal toxicity. Because water hardness is determined by the calcium and magnesium ions which are divalent, hardness will specifically affect the uptake/binding of other divalent metal ions by biological tissues.

Based on the above it can be assumed that the chronic toxicity of metals, similarly as acute toxicity, will be affected by water hardness (and related factors). However, based on the results of chronic toxicity tests, conducted with relatively low metal concentrations, it is concluded that the relationship between hardness and chronic toxicity of metals appears to be much less consistent than between hardness and acute toxicity and that the influence can be relatively small, especially in the range of hardness between around 50 and 200 mg/l (as $CaCO_3$). Besides this also examples of tests exist in which no effect or even an increase of toxicity with increasing hardness (which means a decrease of the NOEC with increasing hardness) was found. In appendix VIII some examples of comparative studies on the effect of hardness on chronic metal toxicity are given.

In conclusion, it can be stated that the hardness related values of the US-EPA (EPA, 1991, cited in BKH, 1995) were generally derived from acute tests by applying acute-chronic ratios, thereby assuming that the mode of action of the metal inducing acute lethality is similar to chronic effects. This assumption in the US-EPA approach is questionable. As for acute toxicity, the effect of hardness on chronic toxicity can be species dependent (especially between species of different taxonomic groups), because of differences in uptake mechanisms. These conclusions are based on the results of comparative tests and on a rough comparison of the total data sets for the different metals, especially those for cadmium, chromium(VI), copper and zinc, and as far as known, a profound evaluation of the influence of water hardness on chronic metal toxicity has not been performed. Further indepth research is needed to validate these assumptions.

Because of the uncertainties in the approach to derive hardness related EQOs, and in order to allow a "generic" assessment of toxicity, the chronic tests used in the underlying report to derive EQOs were not selected specifically on the basis of water hardness (or other related factors). The same approach was followed in preceding RIVM evaluations of metals, for example in the reports of the project 'Setting Integrated Environmental Quality Objectives' (Van de Meent et al., 1990; Van de Plassche et al., 1992, Van de Plassche, 1994) and the Integrated Criteria Documents for zinc (Janus, 1993; Janus et al., 1996) and lead (Janus et al., 1997).

All the test conditions mentioned in the current section may influence species sensitivities and therefore the variability in species sensitivity and hence the value of the MPC. The same as for water hardness, the question may rise if it is necessary to assume a standard value (which is considered relevant for the Dutch situation) for these conditions and recalculate the outcomes of the toxicity tests to this standard value. For instance for soil it is well known that organic matter- and clay content and pH main factors influencing bioavailability. To be able to do so, however, it is necessary to be able to quantify the effect of a certain condition on the toxicity. Foe organic matter- and clay content the toxicity data are recalculated to the so-called standard soil containing 10% organic matter and 25% clay. For this aim the so-called reference lines are used although it is realised that the scientific evidence for using this method to correct toxicity data is limited. For pH however these relationships are not, or only poorly defined.

Besides this some consideration must be given to the question how relevant the correction for a certain condition is in relation to the variability in species sensitivity. Maybe the decrease in variability disappears in the available variability of species sensitivity. To answer this question it is first important to evaluate the quantitative effect of each correction on the variability of species sensitivity. Such a analysis would thus be recommended prior to adjusting MPCs for different factors.

When applying the added risk approach the results from toxicity tests should, ideally, be based not only on the **added** concentration (on top of the background), but also on the fraction of this added concentration that is **bioavailable**. Considering the first aspect, the added concentration, especially for ecotoxicological data that result in values close to the background concentration, it is critical to know whether the result includes or excludes the background concentration of the metal in the test medium. Especially NOEC values close to the background concentration will change significantly when the background concentration is excluded. Therefore for *all* the metals, references of ecotoxicological data with a value less than ten times the background concentration (so when the NOEC < 10* Cb, Cb as assumed in the present report, see chapter 5) have been re-evaluated.

This re-evaluation resulted in an adaptation of some, mostly terrestrial but also some aquatic NOEC values. The NOECs that have been changed are indicated in Appendix I to IV with an π. This is for instance the case with the NOEC values for *Daphnia magna, Gammarus fasciatus* and *Hyalella azteca* exposed to cadmium, in table 1.2 of Appendix I, the NOEC values for *Lumbricus rubellus, Onychiurus armatus* and *Platynothrus peltifer* exposed to copper, in table 3.4 of Appendix III, and respiration studies with cadmium, in table 4.4 of Appendix IV. If data have been taken from other RIVM-reports, corrected values are indicated in Appendix V and VI. This is for instance the case for zinc and the fish species *Salmo gairdneri,* for which the values included in the geometric mean have been corrected from 320 (minus 30 as background) to 290 μg/l, from 140 (minus 11 as background) to 130 μg/l and from 36 (minus 11 as background) to 25 μg/l.

Considering the second aspect, the bioavailable fraction, it must be remarked that in the literature used for the present report, this information is seldom reported: only very few studies report the results as what is considered the bioavailable concentration. Hence it must be assumed that the amount added to the test medium will be completely bioavailable. It must also be realised that at the moment "the bioavailable fraction" is still a subject of much discussion, not only on which fraction that should be considered as the bioavailable fraction but also on how to determine the bioavailable fraction.

Besides the evaluation of studies to correct for background concentrations, also attention is paid to the representativeness of the test species for the Dutch situation. Some studies with non standardised species resulting in extreme low values, have been evaluated in more detail. Especially when it was evident that the species' habitat was extremely different from the Dutch situation the test was excluded from the data set. This was for instance the case for *Polypedilum nubifer* which is a species that is widely distributed from equatorial Africa to south east Asia and Japan and/or northern Australia and was cultured at a temperature of 24° C (Hatakeyama, 1987).

9.2 The added risk approach

As indicated in the introduction (section 1.2.2) in the present report the so-called "added risk approach" is adopted to calculate risk limits for the different environmental compartments. The basic starting point for this approach is the calculation of a maximum permissible addition (MPA) on the basis of the available data from laboratory studies and the MPC is regarded as the sum of the MPA and the background concentration (C_b). In formula: MPC = MPA + C_b. The MPA is calculated by applying either statistical extrapolation or assessment factors, depending on the amount and type of data. Especially when applying statistical extrapolation, assumptions are made on the relevance of the data used for the ecosystem. These assumptions are discussed in section 9.2.1.

The most important virtue of the added risk approach is that it takes into account the background concentration, for essential as well as non-essential metals (see section 9.5 for a discussion on essential metals). One single value for the background concentration, considered to be valid for the Dutch situation, is assumed in this report. This assumption on background concentrations is discussed in section 9.2.2. When applying statistical extrapolation it is possible to incorporate the level of bioavailability as proposed by Struijs et al (1997). Bioavailability of metals is discussed in section 9.2.3. As was also indicated in the introduction, from a policy point of view the effects due to the background concentration may be ignored or can even be considered desirable, since they may lead to an increase in ecosystem differentiation. Therefore the assumption is made that the background concentration is not available and the MPCs for an availability of 0% are proposed to be used for Setting Integrated Environmental Quality Objectives. A more scientific investigation of the resulting outcome of the approach as published by Struijs et al. (1997), assuming different availabilities of the background concentration, may however be warranted. The resulting MPCs when assuming different levels were first discussed by Struijs et al. (1997). For the metals considered in this report this item is discussed in 9.2.4.

9.2.1 Statistical extrapolation

The method of Aldenberg and Slob (1993) is used as the statistical extrapolation method in the project "Setting Integrated Environmental Quality Objectives" and assumes that the NOEC values used for estimating the distribution fit the log-logistic distribution. The advantage of the log-logistic distribution is that it allows the analytical evaluation of the cumulative distribution PAF(x) by integration.

Statistical extrapolation methods are based on different statistical and biological assumptions (Van Straalen and Denneman, 1989; Wagner and Løkke, 1991). From a statistical point of view it is assumed that the sensitivities of species in an ecosystem can be described by a log-logistic frequency distribution. This frequency distribution can be estimated using NOEC values of species of different taxonomic groups as input.

Biological assumptions are:
-By protecting the species composition, the functioning of ecosystems is protected, so also higher levels of biological organisation are protected,
-The laboratory derived NOECs used to estimate the distribution are a random sample from the distribution,
-The endpoints used are appropriate for evaluating safety,
-Species sensitivity as determined in the laboratory is comparable with species sensitivity in the field.

It can be debated whether these assumptions are valid and still a lot of work has to be done to validate them (Forbes and Forbes, 1993; Smith and Cairns, 1993). Nevertheless statistical extrapolation is chosen as a method to be used in the project "Setting Integrated Environmental Quality Objectives" and this choice is supported by the Technical Soil Protection Committee (TCB, 1991; TCB, 1994) and the Dutch Health Council (GZR, 1989; GZR, 1995) although they both indicate that there is a need for a better support of the assumptions made and they have placed some critical comments on the use of it. Nevertheless these assumptions cannot be underpinned more solid at this moment and the comments made should be seen as directions in which more research is necessary.

9.2.2 Background concentrations

As discussed above and presented in the methodology when using the added risk approach it is required that the background concentration is known. The background concentrations assumed in this report are based on the literature studies of Van den Hoop (1995a) and De Bruijn and Denneman (1992). As was also indicated in chapter 5 it is almost impossible to find locations in the Netherlands which are not influenced by anthropogenic sources. Therefore the background concentrations assumed in this report are based on model estimations or on measurements in relatively pristine areas and cannot be considered as natural background concentrations.

It was argued by the Technical Soil Protection Committee (TCB, 1996) that background concentrations for soil to be used in the added risk approach, should be based on the 50th percentiles of the reference lines instead of the 90th percentiles. According to the TCB (1996) these values give a better approximation of the background concentration than the 90th percentiles. The resulting background concentrations and the consequences for the MPCs, assuming availabilities of 0%, 50% and 100% are presented in Appendix IX. From this comparison it is clear that although for some metals the background concentration based on the 50th percentile is a factor 2-3 lower, like for instance for cadmium and lead, the result for the MPA based on different bioavailable fractions, is only little.

9.2.3 Bioavailability of metals in water, soil and sediment

Important starting-points of the "added risk approach" as applied in this report are that the concentrations in the laboratory experiments are completely available and background concentrations are unavailable. Besides this, if the species sensitivity distribution is known, it is possible to incorporate availability of background concentrations as proposed by Struijs et al. (1997). Subsequently, the value of the bioavailable fraction may have to be determined for water, sediment and soil. In principle, this must be done for each metal discussed in the present report. The metal concentration in the environment, related to anthropogenic sources, is considered to be fully bioavailable.

For water no information is present on the bioavailability of the background concentrations as these values are determined using model calculations (see 9.3.2). On the other hand, it is well-known that the bioavailability of metals is influenced by physico-chemical characteristics like pH, alkalinity and hardness and probably differs for each metal due to differences in speciation. This will also lead to differences in bioavailability between the freshwater and the marine environment. For metals like Cd, Cu, Cr, Zn and Pb data on the influence of physico-chemicals characteristics of the type of water on bioavailability are present, but these are not (yet) suitable to be incorporated in deriving EQOs (Parametrix, 1995). For some of the other metals almost no information is available. At the moment not enough information in the literature was found to estimate φ for the metals considered in soil as well. According to Van Gestel (1992) the bioavailability of metals in soil may depend on soil pH, organic matter content, Cation Exchange Capacity (CEC) and clay content.

For sediment the same factors determine bioavailability as mentioned for soil. In addition binding to sulphides, characterised by the Acid Volatile Sulphide (AVS) content may influence bioavailability as well (see also 9.3.3). Since for deriving MPAs for sediment the equilibrium partition theory is used, which does not include the sulphide bond fraction of the metal in sediment, the fraction of the background concentration bioavailable is not yet incorporated in the MPAs for sediment.

Bioavailability is not only dependent on environmental factors as mentioned above, but also on species dependent factors like the route of exposure. In soil organisms different uptake routes are possible; uptake trough the skin, through the gut wall from ingested soil, by drinking from the pore water, via special organs as for instance the ventral tubulus in springtails or a combination of the routes mentioned. To give an estimate of the bioavailability of a metal it is necessary to get insight into the environmental factors influencing bioavailability but also knowledge on species specific bioavailability is indispensable.

9.2.4 MPCs assuming different levels of bioavailability

As is also emphasised by Allen (1997) and Cook and Hendershot (1996) environmental quality objectives should be based on the bioavailable part of the metal, as only the bioavailable part imposes a risk. In the method developed by Struijs et al. (1997) the fraction of species that is unprotected due to the bioavailable part of the background concentration is theoretically taken into account in deriving the MPA. The fraction of species affected is expressed as the potentially affected fraction of all possible species (PAF) due to a bioavailable concentration of the substance considered. If the background of a substance is (partly) bioavailable, the related background effect expressed as PAF_b is taken into account in deriving the MPA.

The MPA is derived using ecotoxicity data, the bioavailable background concentration and the risk limit chosen by environmental policy makers as permissible if there are no background phenomena. An important assumption in the added risk approach is that background concentrations of naturally occurring chemicals may have an effect, which is quantified in terms of the fraction of species that is potentially affected.

Other assumptions that are made in the added risk approach is that it is possible to distinguish between a bioavailable and an unavailable fraction of the background concentration (only one level of bioavailability is assumed, see 9.2.3), that NOECs in the laboratory pertain to 100% availability and that the unavailable fraction does not cause an effect. The major drawback of this method is that at this moment the bioavailable fraction of the background concentrations is not known and may in practice vary considerably from site to site. To be able to analyse the influence of varying bioavailability of the background concentration on the MPA, default values have been chosen for the calculations in the present report. The values chosen are 0%, 50% and 100% availability of the background concentration or $\varphi = 0$, 0.5 and 1.

If there is no background, as for xenobiotics, or if Cb is relatively low compared to the toxicity or if the bioavailability of the background concentration is assumed 0 % ($\varphi = 0$), the method reduces to the well known Aldenberg-Slob method (Aldenberg and Slob, 1993) and the MPC becomes equal to the concentration corresponding with a PAF of 0.05. If the availability of the background is higher than 0, the MPA is dependent on the total background concentration, the bioavailable fraction and the cumulative NOEC distribution curve. In this case the level of the MPA will change if the background concentration changes.

It must be noted, that the assumption of only one bioavailable fraction is by far an oversimplification of the reality. The bioavailability of a metal is metal and organism specific and is greatly influenced by environmental factors. In the current project “Risk Assessment of Heavy Metals” methods for calculating and measuring potentially and actually bioavailable metal concentrations in soils will be developed and validated, to enable a better estimate of the risks imposed by the presence of heavy metals in the field for the future.

When comparing the MPAs for different bioavailable fractions φ (see tables 6.5, 7.5 and table X.1 in Appendix X), it becomes evident that the choice of φ has only a minor influence on the MPA. For most of the metals considered almost no or only small differences in MPAs were found. Only for cobalt, copper and nickel somewhat larger differences were found considering MPAs for water, and for copper and lead considering terrestrial MPAs. Reasons for the minor influence of φ on the MPA are the level of the background concentration (in relation with the sensitivity distribution) and the width of the sensitivity distribution. If the background concentration is low compared to the sensitivity distribution it can be expected that the fraction of species affected by the bioavailable background concentration PAF_b is low and the MPA will not change or only little. A more extensive evaluation is presented in Appendix IX.

In conclusion, the bioavailable fraction of the background concentration of the metals may be important in deriving MPCs. However the present study shows that for the considered metals, different degrees in bioavailability do, in general not affect the MPCs.

9.3 Equilibrium partitioning

9.3.1 Method

The equilibrium partitioning method is used for different aims: for deriving MPAs for the soil compartment if insufficient data on terrestrial species or processes are available; for deriving MPAs for the sediment compartment since no data on the sensitivity of sediment organisms are available and for harmonising the soil risk limits with the water risk limits. Using the equilibrium partitioning method implies that uncertainties in the equilibrium partitioning concept as well as in the partition coefficients and the MPA(water) used in the calculation have to be taken into account.

Three assumptions are made when applying this method. Firstly, it is assumed that bioavailability, bioaccumulation and toxicity are closely related to the pore water concentrations; Secondly, it is assumed that the sensitivities of aquatic organisms are comparable with the sensitivities of organisms living in the sediment or soil; Thirdly, it is assumed that an equilibrium exists between the chemical sorbed to the particulate sediment organic carbon and the pore water and that these concentrations are related by a partition coefficient (Kp).

With regard to the assumptions made, several examples exist which show that the response of the sediment organism is related to the concentration in the pore water (DiToro et al., 1990). As the amount of metals present in the pore water and available for organisms depends strongly on sediment/soil characteristics, relationships between the accumulation of metals by invertebrates and sediment or soil characteristics can be expected (reviewed by Van Gestel et al., 1995 for soil). The assumption whether sensitivities of water and sediment species are comparable is difficult to judge. Concerning the third assumption it must be reminded that equilibrium of the metal between the sediment or soil and the pore water is also influenced by sediment and soil characteristics like pH, CEC and clay and organic matter content (see also 9.2.3). Therefore, large variation exists in the Kps for different sediments or soil as was found e.g. by Van den Hoop (1995b) for soil.

As was indicated in section 8.2 more and more tests are performed in sediment/water systems and the knowledge of this specific habitat is still developing. Behaviour of metals in sediment/water systems is very complex, and affected by many variables like Acid Volatile Sulphide (AVS) (see also 9.3.3). Attempts to design standard test procedures for sediment/water systems are complicated and still in development (Hill et al., 1993). The data that are available are difficult to interpret and compare with each other due to the enormous variation in test circumstances.

At the moment no evaluation procedure is thus available to include the results of the sediment/water tests in a (statistical) extrapolation method (CSR, 1996). One must, however, not conclude that these tests are of no value for deriving MPCs. One way to include the results of the sediment/water tests in the procedure is by comparing the results of the sediment/water tests with the MPCs that were derived applying equilibrium partitioning as was done in section 8.3.

9.3.2 Partition coefficients

Kps to be used in the equilibrium partitioning method should, according to Bockting et al. (1992), be based on experiments where adsorption processes control the aqueous concentrations. The metal concentrations should be at equilibrium or in a steady state situation and the Kps should be based on the fraction of the metal content that can actually exchange with the aqueous phase and not on the total metal content. Because of these conditions, Kps resulting from batch experiments are preferred (Bockting et al., 1992).

The log $Kp_{(soil/w)}$s used in this report are derived from Bockting et al. (1992) and are based on batch experiments with 11 American soils carried out by Buchter et al. (1989). Van den Hoop (1995b) determined field-based $Kp_{(soil/w)}$s for Dutch soils (also in table 4.1). The variability of these field $Kp_{(soil/w)}$s was enormous, and was as large as the average values, due to variations in soil and pore water composition. As the Kps to be used for the equilibrium partitioning method should be based on the fraction of the metals that can actually exchange between soil and water, it is decided to use the values proposed by Bockting et al. (1992) in the present report.

As for soil, partition coefficients for partitioning between water and sediment ($Kp_{(sed/w)}$) should preferably be based on batch experiments. However, only few data on the adsorption of metals on sediments are available (Bockting et al., 1992). Therefore, the $Kp_{(sed/w)}$s are based on the partition coefficients for partitioning between water and particulate matter ($Kp_{(pm/w)}$), for which more data are available. The $Kp_{(sed/w)}$s are derived by dividing corresponding $Kp_{(pm/w)}$s by 1.5, as proposed by Stortelder et al. (1989), Bockting et al. (1992) and Van de Meent et al. (1990) if no experimental data for sediments are available.

It can be concluded from table 4.1 that sediment/water partition coefficients ($Kp_{(sed/w)}$) are higher than the soil/water partition coefficients ($Kp_{(soil/w)}$). To investigate if these higher values are caused by including background concentrations, Yland (1996) also derived values for partitioning between particulate matter and marine surface water, in which the concentration of the particulate matter is corrected for the background concentration. All these values are found to be comparable with the values in fresh surface water.

A comparison of estimated values for sediment with $Kp_{(sed/w)}$s based on monitoring data did not show any differences, neither for freshwater (Venema, 1996) nor for marine surface water (Yland, 1996). Because the $Kp_{(sed/w)}$s of Stortelder et al. (1989) have been used for deriving risk limits in earlier reports (Van de Meent et al., 1990) and the validity of these data are confirmed by the recent monitoring data, these values are also used in the present report for fresh surface water and marine surface water (underlined in table 4.1).

9.3.3 Acid Volatile Sulphide

Under aerobic conditions the dissolved and precipitated part of metals is reasonably exchangeable. Under anaerobic conditions, however, the formation of poorly soluble metal-sulphide complexes may lead to the precipitation of the metals. Comparisons of availability of metals for sediment species in sediments with different amounts of AVS showed that the biological availability of the metals is dramatically decreased by this process (DiToro et al., 1990; Carlson et al., 1991; Ankley et al., 1991).

It has been suggested that metal bioavailability in sediments can be predicted by comparing the concentration of simultaneously extractable metals (SEM) with the concentration of acid volatile sulphide (AVS) (Casas and Crecelius, 1994; DiToro et al., 1990; 1991). The SEM/AVS methodology measures the concentration of metal that associates with sulphide and is therefore not bioavailable. At a SEM/AVS ratio less than 1, the concentration of the metals in the interstitial water will be extremely low, and the metals are not available for organisms by uptake from water (Hamelink et al., 1994). Numerous examples show that the toxicity of metals in sediment is related to the interstitial water concentrations, the latter being influenced by AVS (Berry et al., 1996; Hansen et al., 1996a; DeWitt et al., 1996; Sibley et al., 1996: Liber et al., 1996; Hansen et al., 1996b).

As anaerobic conditions are very common in the subsurface layers of sediment, more knowledge and data on AVS contents of sediments are required to develop an adapted equilibrium partition method, which takes into account AVS content and the resulting implications for bioavailability of the metals. Recently, a preliminary study was performed in which spatial and seasonal variations of AVS in the Netherlands were determined (Van den Hoop et al, 1995). Levels of AVS in fifteen marine and six freshwater sediments were analysed. AVS levels varied between non detectable(<0.1 mmol per kilogram dry sediment) and approximately 50 mmol per kilogram dry sediment. Approximately half of the locations had values between 10 and 50 mmol per kilogram dry sediment. The SEM/AVS ratio was found to be smaller than one in nineteen cases. This would imply that in these cases the metals are not available for uptake.

When the MPCs, NCs and background concentrations are expressed on a molar basis, they can be compared with the AVS levels in the sediments. When it is further assumed that levels which are higher than approximately 10 mmol/kg are possibly bioavailable in the Dutch sediments the following may result. Chromium (which, however, will not form a sulphide precipitate due to its anionic speciation), lead, tin, and zinc have MPCs that are higher than approximately 10 mmol/kg (table 9.1), and will thus possibly be bioavailable for a great extent in the Dutch sediments. With regard to NCs, no metals have values that are higher than approximately 10 mmol/kg (table 9.1), and all metals considered will thus possibly be not bioavailable for a great extent in the Dutch sediments. The actual bioavailability, however, will be dependent not only on the AVS content, but also on the presence of other metals and other environmental conditions.

Table 9.1 Maximum Permissible Concentrations (MPCs), Negligible Concentrations (NCs) and background concentrations (C*b*s) for sediments, expressed on a molar basis. These values may be compared with Acid Volatile Sulphide contents in Dutch marine and freshwater sediments that varied between non detectable (<0.1 mmol/kg dry weight) and 50 mmol/kg dry weight (Van den Hoop et al, 1995).

	MPC (mmol/kg)	NC (mmol/kg)	Cb (mmol/kg)
antimony (Sb)	0.16	0.03	0.02
arsenic (As)*	2.54	0.41	0.39
barium (Ba)	2.18	1.14	1.13
beryllium (Be)	0.13	0.12	0.12
cadmium (Cd)	0.27	0.01	0.01
chromium (Cr)*	33.1	2.23	1.92
cobalt (Co)	0.32	0.15	0.15
copper (Cu)	1.15	0.57	0.57
lead (Pb)	23.2	0.64	0.41
mercury (Hg)	0.13	0.003	0.001
molybdenum (Mo)	2.61	0.03	0.01
nickel (Ni)	0.75	0.60	0.60
selenium (Se)	0.04	0.01	0.01
thallium (Tl)	0.01	0.005	0.005
tin (Sn)	185	2.01	0.16
vanadium (V)	1.10	0.82	0.82
zinc (Zn)	9.48	2.22	2.14

Notes:

*: Arsenic, selenium and chromium are present in anionic form, and therefore not relevant for sulphide precipitation.

Further, seasonal variations in AVS concentration were observed by Van den Hoop et al. (1995), which in case of constant SEM levels, will lead to changing SEM/AVS ratios through the year. As long as not enough knowledge is available to incorporate AVS in the setting of environmental quality objective it is advised to incorporate AVS data in estimations of actual risks, for instance in making priorities for sediment clean-up activities.

9.4 Essential metals

According to Hopkin (1993) the use of statistical extrapolation methods for essential metals may lead to MPCs set at a level that may result in effects due to element limitation instead of toxic effects of the element. The same comment was made by Van Tilborg and Van Assche (1995) in a reaction on the "Integrated Criteria Document Zinc" (ICDZ; Cleven et al., 1992). As an alternative approach they describe a "Deficiency Toxicity" (DT) model, to be used for deriving MPCs for essential elements. This model is quantitatively elaborated for zinc in the form of a deficiency curve, a toxicity curve and "Optimal Concentration band for Essential Elements" (OCEE) curves for the water types "ocean", "North Sea" and "surface water". Besides their comment on statistical extrapolation methods, Van Tilborg and Van Assche (1995) commented on the use of some of the selected studies and NOECs thereof, used for deriving an MPC for zinc in the ICDZ (Cleven et al., 1992).

Janus et al. (1996) argue that there is no reason to adopt a different approach for essential metals from that used to derive MPC values for other substances, provided that allowance is made for background levels. The basic point of departure of the DT model is that in case of essential metals such as zinc, adverse effects occur below a certain concentration, is accepted. However, the further elaboration of the model, including its quantification for zinc, cannot be subscribed for two reasons.

In the first place, Janus et al. (1996) argue that the elaboration of the DT model implies a pursuit of optimum conditions for all species. However, environmental policy is not concerned with an optimisation of the environment for all species, but with the protection of the biodiversity of natural ecosystems. As naturally occurring deficiencies play an important role in maintaining the biodiversity, this should not be regarded as a negative phenomenon. It is therefore not desirable to aim for optimum conditions as recommended by Van Tilborg and Van Assche (1995).

In the second place, the lower and upper bounds of the OCEE curves for the various water types distinguished are underpinned by poor arguments. The lower bound is based partly on the zinc levels prescribed in the OECD guidelines for algae (OECD, 1984a) and daphnids (OECD, 1984b). According to Janus et al. (1996) it is however debatable whether the zinc levels mentioned in these guidelines can be viewed as deficiency levels. The OCEE upper bound is based on a rejection of a number of low NOEC-values and subsequently rejection of the lowest NOEC as the MPC.

With the exception of some NOEC values, the criticism of Van Tilborg and Van Assche (1995) is largely rejected by Janus et al. (1996). Therefore it is decided in this report that there is no reason to re-evaluate all previously derived NOEC values for other essential metals. The NOEC values which have been revised on the basis of Van Tilborg and Van Assche (1995) in Janus et al. (1996) are incorporated in this report. Besides this, special attention is given to the criteria applied in selecting studies to be used for deriving MPCs for essential metals (see chapter 3.2) and studies resulting in NOECs lower than ten times the background have been evaluated in more detail (see 3.2 and 9.1).

It may be assumed that the current background concentrations will supply a sufficient level of essential elements for many existing species. These means that including background concentrations in risk assessment has as a consequence that the risk limits derived do not result in effects due to deficiency. The added risk approach therefore implicitly takes into account the essentiality of metals. It must be noted however that only very little information on deficiency levels of species is available and more research in this area is needed.

9.5 Data availability and final MPC and NC values

9.5.1 MPC and NC values for water

For 12 (including methyl-kwik) of the 18 metals considered enough data are available to apply statistical extrapolation: arsenic, beryllium, cadmium, chromium(VI), cobalt, copper, lead, inorganic mercury, methyl-mercury, nickel, selenium, and zinc. For these metals the number of data used in the extrapolation is considerable. The number of NOECs used for extrapolation are 17, 7, 101, 66, 8, 105, 43, 38, 11, 16, 31 and 50, respectively. The MPAs for these metals are therefore considered reliable. For the other metals (antimony, barium, molybdenum, tin, thallium and vanadium) not enough data are available to apply the added risk approach and the modified EPA method is used to derive MPAs.

The proposed MPAs, MPCs, NAs and NCs for water to be used for setting integrated environmental quality objectives are presented in table 9.2, together with the background concentrations. For fresh surface water, marine surface water and groundwater the same data are used to derive the MPA. Therefore the MPAs for fresh surface water, marine surface water and groundwater are the same, and only one value is presented: the MPA(water) to be used as the MPA(fresh), the MPA(marine) and the MPA(grw). Only when a background concentration for the different water-types is available this will result in a different MPC.

In Van de Meent et al. (1990) the MPC is derived on the basis of ecotoxicological only, without taking background concentrations into account. Therefore the MPAs from the present report have to be compared with the MPCs from Van de Meent et al. (1990). The MPAs for water for arsenic, cadmium, cobalt, lead, nickel and zinc are higher than the MPCs derived by Van de Meent et al. (1990). The MPAs and for chromium, and copper are lower than the MPCs derived by Van de Meent et al. (1990). These changes are the result of the use of an extended data set.

9.5.2 MPC and NC values for soil

Data availability for terrestrial species and microbial processes is much lower than for aquatic species. Only for arsenic, cadmium, copper, lead, inorganic-mercury and zinc the proposed MPA is based on statistical extrapolation and can be considered reliable. The number of NOECs used for extrapolation are 23(processes), 13(species), 56(processes), 51(processes), 43(processes) and 25(processes), respectively. For chromium(III), cobalt and nickel the proposed MPA is based on the modified EPA method. For the other metals the proposed MPA is based on the equilibrium partitioning method.

The proposed MPAs, MPCs, NAs and NCs for soil to be used for setting integrated environmental quality objectives are presented in table 9.3, together with the background concentrations. The same as for water, in Van de Meent et al. (1990) the MPC for soil is derived on the basis of the ecotoxicological, without taking background concentrations into account. Therefore the new MPAs are compared with the MPCs from Van de Meent et al. (1990).The MPAs for soil are higher than the MPCs derived by Van de Meent et al. (1990) for arsenic, lead and zinc and lower for cadmium, chromium, copper and mercury. These changes are the result of the use of an extended data set.

The MPCs derived are expressed as a value for standard soil containing 10% organic matter and 25% clay. In general, soil consists of different layers, with varying physical chemical characteristics. It was questioned by the Technical Soil Protection Committee if the MPC for standard soil will protect species living in the upper layer of soils that contains more than 30% of organic matter. According to Faber (1995) species living in an organic soil are more sensitive for cadmium than species living in a mineral soil and it was stressed that attention has to be paid to these differences in sensitivity while analysing data.

As was also indicated in footnote 2 of section 1.1, besides the Environmental Quality Objectives derived in the project Setting Integrated Quality Objectives, in the Netherlands also an intervention value for soil clean-up is used (Kreule et al., 1995). The intervention value for soil clean-up is based on the integration of a separately derived human toxicological serious soil contamination concentration or HUM-TOX SCC as well as an ecotoxicological serious soil contamination concentration or ECOTOX SCC. The HUM-TOX SCC and ECOTOX SCC values proposed for metals are summarised in table 9.4. As these values are proposed for soil as well as for sediment, only one value for each is given. As the MPCs are all based on ecotoxicological data a comparison with the ECOTOX SCC is made. For all metals, except for antimony and Cr(VI) the ECOTOX SCC is lower than the HUM-TOX SCC. All MPAs for soil are lower than the ECOTOX SCC. All MPAs for soil are lower than the HUM-TOX SCC, except for Cr(VI) where the two values are comparable. The MPAs for sediment based on equilibrium partition are in some cases higher or equal to the HUM-TOX SCC: antimony, cadmium, chromium and lead. The differences may be due to the fact that for deriving the MPAs data have been updated, while the HUM-TOX SCCs are based on a data set from some time ago. This comparison shows that MPAs and HUM-TOX SCCs have to be harmonised, but this is considered out of the scope of this report.

Table 9.4 Human toxicological serious soil contamination concentration (HUM-TOX SCC), ecotoxicological serious soil contamination concentration (ECOTOX SCC) and MPCs for soil and sediment (MPC(soil) and MPC(sed) respectively). All values are in mg/kg standard soil (soil containing 10% organic matter and 25 % clay).

	HUM-TOX SCC	ECOTOX SCC	MPA(soil)	MPA(sed$_{EP}$)
antimony	15.7 (c)	2890 (c)	0.53	16
arsenic	678 (a)	40 (b)	4.5	133
barium	4260 (a)	650	9.0	150
beryllium	233 (c)	29 (c)	0.0061	0.1
cadmium	34.9 (a)	12	0.76	29
chromium(VI)	0.315 (a)	230	3.8	266
cobalt	452 (a)	120	24	8.0
copper	31300 (a)	190	3.5	19
lead	301 (a)	290	55	4700
mercury	197 (a)	10	0.37	1.1
molybdenum	-	-	253	247
nickel	6580 (a)	210	2.6	8.9
selenium	-	-	0.11	2.2
thallium	-	-	0.25	1.6
tin	646000 (a)	-	34	22000
vanadium	-	-	1.1	14
zinc	56500 (a)	720	16	543

Notes:

-: No value proposed,

(a): Van den Berg (1995),

(b): Denneman and Van Gestel (1990),

(c): Van den Berg et al. (1994).

9.5.3 MPC and NC values for sediment

MPAs for sediment are based on the equilibrium partitioning method using the MPAs for water. Although some data on sediment species are available, no methodology is available at the moment to incorporate these data in a comparable way as for aquatic and terrestrial data. Therefore the sediment data available are incorporated in an evaluative way, by comparing these data with the MPAs derived using equilibrium partitioning.

The proposed MPAs, MPCs, NAs and NCs for sediment to be used for setting integrated environmental quality objectives are presented in table 9.3, together with the background concentrations. In Van de Meent et al. (1990) the MPC is derived on the basis of the ecotoxicological, without taking background concentrations into account. Therefore the new MPAs are compared with the MPCs from Van de Meent et al. (1990). For sediment the 'new' MPAs are higher than the old ones for arsenic, cadmium, chromium, lead, nickel and zinc. For copper the new MPC is lower than the 'old' one. These changes are the result of the use of an extended data set on toxicity, and other partition coefficients.

table 9.2 Maximum Permissible Addition (MPA), Negligible Addition (NA), background concentration (B*c*) in freshwater (fresh), saltwater (marine) and groundwater (grw), Maximum Permissible Concentration (MPC) and Negligible Concentration (NC) for metals. Values are given as dissolved concentrations in µg/l.

Metal	MPA(fresh)	NA(fresh)	B*c*(fresh)	MPC(fresh)	NC(fresh)	B*c*(marine)	MPC(marine)	NC(marine)	B*c*(grw)	MPC(grw)	NC(grw)
antimony(Sb)	6.2 (b)	0.062	0.29	6.5	0.35				0.09	6.3	0.15
arsenic (As)	24 (a)	0.24	0.77	25	1.0				7.0	31	7.2
barium (Ba)	150 (b)	1.5	73	220	75				197	350	190
beryllium (Be)	0.16 (a)	0.0016	0.02	0.18	0.022				0.05	0.21	0.052
cadmium (Cd)	0.34 (a)	0.0034	0.08	0.42	0.083	0.025	0.37	0.028	0.06	0.40	0.063
chromium (Cr)	8.5 (a)	0.085	0.17	8.7	0.26				2.4	11	2.5
cobalt (Co)	2.6 (a)	0.026	0.20	2.8	0.23				0.63	3.2	0.66
copper (Cu)	1.1 (a)	0.011	0.44	1.5	0.45	0.25	1.4	0.26	1.3	2.4	1.3
lead (Pb)	11 (a)	0.11	0.15	11	0.26	0.02	11	0.13	1.6	13	1.7
mercury (Hg)	0.23 (a)	0.0023	0.01	0.24	0.012	0.0025	0.23	0.0048			
methyl-mercury	0.01 (a)	0.0001	0.01	0.02	0.01	0.0025	0.013	0.0026			
molybdenum (Mo)	290 (b)	2.9	1.4	290	4.3				0.69	290	3.6
nickel (Ni)	1.8 (a)	0.018	3.3	5.1	3.3				2.1	3.9	2.1
selenium (Se)	5.3 (a)	0.053	0.04	5.3	0.093				0.02	5.3	0.073
thallium (Tl)	1.6 (b)	0.016	0.04	1.6	0.056				<2	3.6	2.0
tin (Sn)	18 (b)	0.18	0.0002	18	0.18				<2	20	2.2
vanadium (V)	3.5 (b)	0.035	0.82	4.3	0.86				1.2	4.7	1.2
zinc (Zn)	6.6 (a)	0.066	2.8	9.4	2.9	0.35	7.0	0.42	24	31	24

(a): MPA based on statistical extrapolation
(b): MPA based on modified EPA-method

table 9.3 Maximum Permissible Addition (MPA), Negligible Addition (NA), background concentration (B*c*) in soil and sediment (sed), Maximum Permissible Concentration (MPC) and Negligible Concentration (NC) for metals. Values are given as concentrations in mg/kg standard soil/sediment (soil/sediment containing 10% organic matter and 25% clay.

Metal	MPA(soil)		NA(soil)	B*c*(soil)	MPC(soil)	NC(soil)	MPA(sed) (c)	NA(sed)	B*c*(sed)	MPC(sed)	NC(sed)
antimony (Sb)	0.53	(c)	0.0053	3.0	3.5	3.0	16	0.16	3.0	19	3.2
arsenic (As)	4.5	(c)	0.045	29	34	29	160	1.6	29	190	31
barium (Ba)	9.0	(c)	0.09	155	165	155	150	1.5	155	300	157
beryllium (Be)	0.0061	(c)	0.000061	1.1	1.1	1.1	0.096	0.00096	1.1	1.2	1.1
cadmium (Cd)	0.76	(a)	0.0076	0.8	1.6	0.81	29	0.29	0.8	30	1.1
chromium (Cr)	3.8	(b)	0.038	100	100	100	1620	16	100	1720	116
cobalt (Co)	24	(b)	0.24	9.0	33	9.2	10	0.10	9.0	19	9.1
copper (Cu)	3.5	(a)	0.035	36	40	36	37	0.37	36	73	36
lead (Pb)	55	(a)	0.55	85	140	86	4700	47	85	4800	132
mercury (Hg)	1.9	(a)	0.019	0.3	2.2	0.32	26	0.26	0.3	26	0.56
methyl-mercury	0.37	(b)	0.0037	0.3	0.67	0.30	1.1	0.011	0.3	1.4	0.31
molybdenum (Mo)	253	(c)	2.5	0.5	254	3.0	250	2.5	0.5	250	3.0
nickel (Ni)	2.6	(b)	0.026	35	38	35	9.4	0.094	35	44	35
selenium (Se)	0.11	(c)	0.0011	0.7	0.81	0.70	2.2	0.022	0.7	2.9	0.72
thallium (Tl)	0.25	(c)	0.0025	1.0	1.3	1.0	1.6	0.016	1.0	2.6	1.0
tin (Sn)	34	(c)	0.34	19	53	19	22000	220	19	22000	239
vanadium (V)	1.1	(c)	0.011	42	43	42	14	0.14	42	56	42
zinc (Zn)	16	(a)	0.16	140	160	140	480	4.8	140	620	145

Notes:

(a): MPA based on statistical extrapolation

(b): MPA based on modified EPA-method

(c): MPA based on equilibrium partition

9.6 Comparison of MPCs with measured concentrations

9.6.1 Fresh surface water and particulate matter

Concentrations of the metals arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc in fresh surface water, particulate matter and sediment are measured by the National Institute of Inland Water Management on different locations in the Netherlands. The concentrations are compared with the MPCs from this report by the National Institute of Inland Water Management as described by Geenen (1995). Comparisons are made on the basis of measurements during 1995.

A comparison is made between the 90th percentile of the measured total concentrations in fresh surface water and particulate matter at a certain location with the MPC. The results are presented in table 9.5 and are expressed as the number of locations for which the total concentration is lower than the MPC (- in table 9.5) and the number of locations for which the total concentration is higher than the MPC (+ in table 9.5).

All the measured concentrations are expressed as total concentrations, while the MPC are expressed as dissolved concentrations. MPCs are recalculated into total concentrations using equation 9. The MPC for particulate matter is calculated by multiplying the MPC for sediment with a factor 1.5.

Table 9.5 Comparison of MPC(water) (expressed as total concentration) for fresh surface water and particulate matter MPC(pm) with 90th percentile of measured concentrations in corresponding media in the Netherlands using the methodology presented by Geenen (1995) (number of locations for which the total concentration is lower than the MPC: -; number of locations for which the total concentration is higher than the MPC: +.

metal	MPC(water) total µg/l	-	+	MPC(pm) mg/kg	-	+
arsenic	25	11	0	285	3	0
cadmium	0.42	32	1	45	21	4
chromium	8.7	33	0	2580	25	0
copper	1.5	5	28	110	11	14
lead	11	33	0	7200	25	0
inorganic mercury	0.24	33	0	39	25	0
methyl-mercury	0.02	30	3	2.1	22	3
nickel	5.1	11	14	66	11	14
zinc	9.4	15	17	930	19	6

From table 9.5 it can be concluded that especially for copper and zinc the measured concentrations in water and suspended matter are higher than the MPC. For mercury comparisons for inorganic mercury as well as for methyl-mercury are made, although the measured concentrations are based on total mercury.

9.6.2 Soil

Concentrations of the metals arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc in soil have been measured by several institutes in the Netherlands and are presented by Van Drecht et al. (1996). In table 9.6 a comparison is made between the mean concentrations, the minimum and the maximum concentrations measured. The values presented are based on all data without distinction between soil-type and/or soil-use. Concentrations in soils considering its use and type are also presented by Van Drecht et al. (1996).

Table 9.6 Comparison of MPC(soil) with measured concentrations in soil in the Netherlands. All values are in mg/kg standard soil containing 10% organic matter and 25% clay.

metal	(MPA)(soil)	C*b*(soil)	MPC(soil)	measured concentrations		
				mean	minimum	maximum
arsenic	4.5	29	34	11	0.38	110
cadmium	0.76	0.8	1.6	0.4	0.01	4.5
chromium	3.8	100	100	52.8	8.0	119
copper	3.5	36	40	18.2	0.8	179
lead	55	85	140	33	0.5	460
inorganic mercury	1.9	0.3	2.2	0.15	0.01	8.5
methyl-mercury	0.37	0.3	0.67	0.15	0.01	8.5
nickel	2.6	35	38	16	0.5	61
zinc	16	140	160	64	2.9	515

From table 9.6 it can be concluded that there is a large variation in measured concentrations. For mercury comparisons for inorganic mercury as well as for methyl-mercury are made, although the measured concentrations are based on total mercury. For all the metals considered the mean measured concentration is below the MPC for soil.

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APPENDIX I TOXICITY OF ARSENIC, CADMIUM, CHROMIUM AND COPPER TO FRESHWATER SPECIES

LEGEND

Species	Species or species groups categorised in taxonomic groups: Bacteria, Cyanophyta, Algae, Algae (macrophytic), Protozoa, Planaria, Porifera, Macrophyta, Rotifera, Mollusca, Annelida, Crustacea, Insecta, Pisces, Amphibia. When available the lifestage and/or length or weight of the organism is mentioned; egg-larval study (ELS), life cycle (LC) or partial life cycle (PLC) can be reported if available,
A	Nominal concentration (N) or Analysed concentration (Y), π: result corrected for background concentration,
Test type	Static (S), Renewal (R), Intermittent flow (IF) or Continuous Flow-through (F). In the notes additional information is given on the frequency of renewal,
Testcompound	If the complete formulation of the salt is not mentioned, (..) is added,
Test water	artificial media (am), natural water (nw), Dutch standard water (dsw), reconstituted water (rw), dechlorinated natural water (dnw); dechlorinated tap water (dtw), tap water (tap); brackish water (bw); reconstituted natural water (rnw),
pH and hardness	sometimes given as range or estimate if no exact data are presented in the study,
Exposure time	given in hours (h); days (d); weeks (w); months (m) or number of generations (gen); sometimes given as a range or estimate if no exact data are presented in the study,
Criterion	NOEC values. Notes indicate the effect parameter or the extrapolation factor used to calculate the NOEC.
Result	Expressed as concentration of the ion in μg/l.

Notes:

a	mortality or immobility
a1	deflagellation
a2	encysted cells
b	growth
b1	population growth rate
b2	cell number
b3	multiplication rate
b4	spawning frequency
b5	length
b6	weight
b7	biomass
b8	number of internodes
b9	shell growth
b10	final yield of population
c	teratogenic effects
c1	abnormalities embryo
c2	abnormalities young
d	photosynthesis
d1	chlorophyll content
d2	oxygen consumption, resp. rate
e	reproduction
e1	sporophyte production
e2	meiospore release
e3	number of eggs
e4	number of young
e5	hatchability
e6	emergence
e7	settlement rate larvae
f	filtration or feeding rate
g	effect parameter not reported
v	extrapolated from graph
w	EC 11 - 19%: NOEC = EC/2
x	NOEC calculated as MATC/2
y	EC 20 - 49%: NOEC = EC/3
z	EC 50 - 90%: NOEC = EC/10

1. renewal every working day
2. renewal every second or third day
3. renewal every 12 hours
4. renewal every four days
5. renewal every week
6. 2% nutrient medium
7. 20% nutrient medium
8. nominal concentration was confirmed by analysis
9. more food levels tested. The test included was carried out using the food level conform EC protocol
10. Acid tolerable species
11. added Cu + present Cu in solution
12. Copper was dissolved in 3 ml concentrated O_3 and made up to volume with distilled water.

Table 1.1 Chronic toxicity of arsenic to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Bacteria										
Pseudomonas putida	N	S	Na_2HAsO_4	nw	-	-	16 h	NOEC[b]	9700	Bringmann & Kühn, 1977
Cyanophyta										
Microcystis aeruginosa	N	S	Na_2HAsO_4	nw	-	-	8 d	NOEC[b]	11000	Bringmann & Kühn, 1978
Algae										
Ankistrodesmus falcatus	N	S	Na_2HAsO_4	am	7	-	14 d	NOEC[b]	10	Vocke *et al.*, 1980
Asterionella formosa	Y	F	AsO_4	am	8.2	-	24 d	NOEC[b]	86	Conway, 1978
Scenedesmus quadricauda	N	S	Na_2HAsO_4	nw	-	-	7 d	NOEC[b]	4700	Bringmann & Kühn, 1977
Selenastrum capricornutum	N	S	Na_2HAsO_4	nw	7	-	14 d	NOEC[b]	10000	Vocke *et al.*, 1980
Protozoa										
Entosiphon sulcatum	N	S	Na_2HAsO_4	nw	-	-	72 h	NOEC[b]	4800	Bringmann & Kühn, 1981
Crustacea										
Ceriodaphnia dubia, 24 h	Y	R	Na_8AsO_4	nw	8.2	100	7 d	NOEC[a,b,x]	570	BKH, 1995
Daphnia magna, < 24 h	Y	R	As_2O_5	nw	8.1	225	21 d	NOEC[b5,y]	1100	BKH, 1995
							21 d	NOEC[a,b,y]	3300	
Daphnia magna	Y	F	As_2O_5	nw	8.1	225	17 d	NOEC[b10]	2200	BKH, 1995
Daphnia magna	Y	S	$NaAsO_4$	nw	7.7	45	21 d	NOEC[e,w]	260	Biesinger & Christensen, 1972
							21 d	NOEC[b,w]	498	
Daphnia magna, < 24 h	Y	R	$NaAsO_2$	am	7.2-8.1	48	28 d	NOEC[b,e]	630	Lima *et al.*, 1984
Gammarus pseudolimnaeus	Y	F	As_2O_3	nw	7	42-45	14 d	NOEC[a]	88	Spehar *et al.*, 1980

Table 1.1 (cont.) Chronic toxicity of arsenic to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Pisces										
Channa punctatus, fingerling	N	S	As_2O_3	tap	7.2	124	31 d	NOEC^{b5,b6,w}	2100	BKH, 1995
Jordanella floridae	Y	F	$NaAsO_2$	am	7.2-8.1	48	31 d	NOEC^{a,b}	2100	Lima *et al.*, 1984
Oncorhynchus kisutch	N	F	As_2O_3	nw	8.2	69	6 m	NOEC^{e8}	76	Nichols *et al.*, 1984
Oncorhynchus mykiss, fingerling	Y	F	Na_2HAsO_4	nw	7.9	377	11 w	NOEC^{a,b6}	8400	BKH, 1995
Pimephales promelas, 30 d, 0.15 g	Y	F	Na_8AsO_4	nw	7.4	44	32 d	NOEC^{a,e,x}	1700	BKH, 1995
Pimephales promelas, egg/fry	Y	F	$NaAsO_2$	am	7.2-8.1	48	29 d	NOEC^{a,b,e5}	2100	Lima *et al.*, 1984

Table 1.2 Chronic toxicity of cadmium to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg CaCO$_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Bacteria										
Pseudomonas putida	-	-	-	-	-	-	16 h	NOEC^{b}	80	Bringmann & Kühn, 1980
Salmonella typhimurium	N	S	-	-	-	-	8 h	NOEC^{b,y}	220	Canton & Slooff, 1982
Cyanophyta										
Anabaena flos-aquae	N	S	CdCl$_2$	am	-	-	10 d	NOEC^{b2,w,v}	50	BKH, 1995
Microcystis aeruginosa	-	-	-	-	-	-	8 d	NOEC^{b}	70	Bringmann & Kühn, 1978
Algae										
Chlamydomonas reinhardtii	N	S	CdCl$_2$	am	7.1-7.2	-	72 h	NOEC^{b2,v}	38	BKH, 1995
Chlamydomonas reinhardtii	Y	F	CdCl$_2$	am	6.2	-	10 d	NOEC^{b2,v}	70	BKH, 1995
Chlorella fusca	N	S	Cd(NO$_3$)$_2$	am	-	-	10 d	NOEC^{b3,y,v}	83	BKH, 1995
Chlorella pyrenoidosa	Y	F	CdCl$_2$	am (+EDTA)	-	-	17 gen	NOEC^{b2,y}	36	BKH, 1995
Chlorella pyrenoidosa	-	-	-	-	-	-	48 h	NOEC^{b}	3100	Slooff *et al.*, 1983
Chlorella vulgaris	N	S	CdCl$_2$	am	6.9	-	96 h	NOEC^{b2,y}	33	BKH, 1995
Chlorella vulgaris	-	-	-	-	-	-	96 h	NOEC^{a,y}	500	Canton & Slooff, 1982
Scenedesmus pannonicus	-	-	-	-	-	-	48 h	NOEC^{b}	900	Slooff *et al.*, 1983
Scenedesmus quadricauda	-	-	-	-	-	-	7 d	NOEC^{b}	31	Bringmann & Kühn, 1980
Scenedesmus subspicatus	N	S	CdCl$_2$	am	7.1-7.2	-	72 h	NOEC^{b2,v}	11	BKH, 1995
Selenastrum capricornutum	N	S	Cd(NO$_3$)$_2$	am	7.8	-	48 h	NOEC^{b2}	2	BKH, 1995
							96 h	NOEC^{b2}	4	
Selenastrum capricornutum	N	S	Cd..	am	-	-	5 d	NOEC^{b2,y}	10	BKH, 1995
Selenastrum capricornutum	-	-	-	-	-	-	96 h	NOEC^{b}	700	Slooff *et al.*, 1983

Table 1.2 (cont.) Chronic toxicity of cadmium to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result µg/l	Reference
Algae, macrophytic										
Chara vulgaris	Y	S	$CdSO_4$	am	-	-	14 d	NOEC[b8]	1.1	BKH, 1995
Macrophyta										
Eichornia crassipes	N	R[5]	$Cd(NO_3)_2$	am	4.75	-	27 d	NOEC[b6,y]	33	BKH, 1995
Lemna trisculca	N[8]	R[5]	Cd..	am	7.8	50	14 d	NOEC[b3,w]	9	BKH, 1995
(frond-fragment)							14 d	NOEC[b10,w]	9	
Lemna polyrriza	N	S	$CdSO_4$	am	-	-	14 d	NOEC[b2]	20	BKH, 1995
Limnanthemium cristatum, rooted leaves	N	S	$CdCl_2$	am	-	-	7 d	NOEC[d1]	5	BKH, 1995
Salvinia minima, 200 mg monoculture	N	S	Cd..	am[6]	6.4	-	30 d	NOEC[b6,z]	1	BKH, 1995
400 mg monoculture	N	S	Cd..	am[6]	6.4	-	30 d	NOEC[b6,y]	3.3	
200 mg monoculture	N	S	Cd..	am[7]	6.4	-	30 d	NOEC[b6,y]	3.3	
Spirodela punctata, 200 mg monoculture	N	S	Cd..	am[6]	6.4	-	30 d	NOEC[b6]	10	
400 mg monoculture	N	S	Cd..	am[6]	6.4	-	30 d	NOEC[b6]	10	
200 mg monoculture	N	S	Cd..	am[7]	6.4	-	30 d	NOEC[b6,y]	3.3	
Protozoa										
Entosiphon sulcatum	-	-	-	-	-	-	72 h	NOEC[b]	11	Bringmann & Kühn, 1980
Tetrahymena pyriformis	N	S	$CdCl_2$	am	7.1-7.2	-	96 h	NOEC[b2,v]	670	BKH, 1995
Rotatoria										
Brachionus calyciflorus, 0.25 mm	Y	S	Cd..	am	-	-	48 h	NOEC[e]	40	BKH, 1995
Mollusca										
Aplexa hypnorum	-	-	-	-	-	45	26 d	NOEC[a,e]	2.5	Holcombe *et al.*, 1984
Dreissena polymorpha	Y	R[1]	$CdCl_2$	nw	7.9	150	10 w	NOEC[f,y]	3	BKH, 1995

Table 1.2 (cont.) Chronic toxicity of cadmium to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite- rion	Result µg/l	Reference
Annelida										
Aelosoma headleyi	-	R	-	-	-	180	20 d	NOEC[b1]	54	Niederlehner *et al.*, 1984
Aelosoma headleyi	-	R	-	-	-	60	20 d	NOEC[b1]	17	
Crustacea										
Ceriodaphnia dubia, neonate	N	R[2]	$CdSO_4$	am	-	90	7 d	NOEC[e3]	1.0	Winner, 1988
							7 d	NOEC[e3,y]	0.33	
							7 d	NOEC[e4,y]	0.33	
							7 d	NOEC[e4,z]	0.1	
Ceriodaphnia dubia, 24 h	Y	R	$Cd(NO_3)_2$	nw	8.2	100	7 d	NOEC[a,e,x]	1.1	BKH, 1995
Daphnia magna, < 24 h	N	R[2]	$CdCl_2$	dsw	8.4	150	25 d	NOEC[b5]	0.5	Bodar *et al.*, 1988
							25 d	NOEC[e4]	5.0	
							25 d	NOEC[b7]	1.0	
Daphnia magna, adult	N	R	Cd..	rw	8.2	180	28 d	NOEC[a,b,e4]	0.5	Dillon & Suedel, 1986
Daphnia magna, ≤ 24 h	N[8]	R[2]	$CdCl_2$	am	8.0	250	21 d	NOEC[e]	0.6	BKH, 1995
Daphnia magna, adult	Y,π	R[2]	$Cd(NO_3)_2$	dtw	8.2-8.8	130	21 d	NOEC[a]	7.6	Borgman *et al.*, 1989
							21 d	NOEC[e4,w]	0.55	
Daphnia magna, neonate	N	R[2]	$CdSO_4$	am	-	90	7 d	NOEC[b5]	1.0	Winner, 1988
							7 d	NOEC[e3,e4]	2.0	
Daphnia magna, < 24 h	N	R[2]	$CdCl_2$	nw	8.0	240	14 d	NOEC[e]	2.5	BKH, 1995
Daphnia magna, ≤ 24 h	N	R[2]	$CdCl_2$	nw[9]	8.1	225	21 d	NOEC[b5,v]	1.2	BKH, 1995
							21 d	NOEC[b1,e4,w]	1.2	
Daphnia magna, ≤ 24 h	N	R[2]	$CdCl_2$	nw[9]	8.1	225	21 d	NOEC[b5,v]	4.1	BKH, 1995
							21 d	NOEC[e4,w]	3.5	
							21 d	NOEC[b1,w]	2	
Daphnia magna	-	R	-	-	-	-	20 d	NOEC[a,y]	0.12	Canton and Slooff, 1982
							20 d	NOEC[e]	0.5	

Table 1.2 (cont.) Chronic toxicity of cadmium to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite- rion	Result µg/l	Reference
Crustacea (cont.)										
Daphnia magna, 0-24 h	N	IF	$CdCl_2$	nw	8.4	200	21 d	NOEC^{b10,y}	0.11	BKH, 1995
Daphnia magna, 0-24 h	N	R^1	$CdCl_2$	nw	8.1	224	21 d	NOEC^{e4,y}	0.33	BKH, 1995
							21 d	NOEC^{a,b1}	1	
Daphnia magna, 0-24 h	N	R^1	$CdCl_2$	nw	8.4	200	21 d	NOEC^{b5}	0.16	BKH, 1995
							21 d	NOEC^{b1,e4}	3.2	
							21 d	NOEC^{a}	10	
Daphnia pulex, < 24 h	N	R^2	$CdCl_2$	rw	-	-	21 d	NOEC^{a,v}	0.3	BKH, 1995
							21 d	NOEC^{e4,v}	0.03	
Daphnia pulex	Y	R^2	$CdSO_4$	rw	8.3-9.0	58	6 w	NOEC^{a,e}	3.8	BKH, 1995
Daphnia pulex	Y	R^2	$CdSO_4$	rw	8.3-9.0	115	6 w	NOEC^{e}	7.5	BKH, 1995
							6 w	NOEC^{a}	13	
Daphnia pulex	Y	R^2	$CdSO_4$	rw	8.3-9.0	230	6 w	NOEC^{e}	7.5	BKH, 1995
							6 w	NOEC^{a}	13	
Gammarus fasciatus, 0-1 w	Y,π	R^5	$Cd(NO_3)_2$	dtw	8.2-8.8	130	6 w	NOEC^{a}	1.2	Borgman *et al.*, 1989
Hyalella azteca, 0-1 w	Y,π	R^5	$Cd(NO_3)_2$	dtw	8.2-8.8	130	6 w	NOEC^{a}	0.29	Borgman *et al.*, 1989
Moina macrocopa, 24 h neonate	N	R^1	$CdCl_2$	tap	6.5	-	11 d	NOEC^{a}	5	BKH, 1995
							11 d	NOEC^{e}	1	
Insecta										
Chironomus riparius, 1 h, first instar	N	R^1	Cd..	dtw	7.6	98	17 d	NOEC^{b}	15	BKH, 1995
Chironomus riparius, first instar	Y	R^5	$CdCl_2$	nw	-	-	4-8 w	NOEC^{a,e4,b6}	2	BKH, 1995
Pisces										
Catostomus commersoni, larva	N	R	$CdCl_2$	dtw	7.8-8.2		7 d	NOEC^{b,v}	20	BKH, 1995
Catostomus commersoni, ELS	-	-	-	-	-	45	6 w	NOEC^{a}	4.2	Eaton *et al.*, 1978
Esox lucius, ELS		-	-	-	-	45	5 w	NOEC^{a}	4.2	Eaton *et al.*, 1978
Ictalurus punctatus, ELS	-	-	-	-	-	35-38	9 w	NOEC^{a,b5}	20	Sauter *et al.*, 1976
Ictalurus punctatus, ELS	-	-	-	-	-	142-223	9 w	NOEC^{b5,b6}	12	Sauter *et al.*, 1976
Jordanella floridae	-	-	-	-	-	44	14 w	NOEC^{e}	4.1	Spehar, 1976
Jordanella floridae	-	-	-	-	-	45	30 d	NOEC^{a}	3	McKim, 1977

Table 1.2 (cont.) Chronic toxicity of cadmium to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Pisces(cont.)										
Lepomis macrochirus, adult	Y	F	$CdCl_2$	tap	7.6	363	5 m	NOEC[a]	3900	BKH, 1995
							5 m	NOEC[b5,b6]	1100	
Lepomis macrochirus	-	-	-	-	-	200	11 m	NOEC[a,b]	31	Eaton, 1974
Micropterus dolomieui, ELS	-	-	-	-	-	45	5 w	NOEC[a]	4.3	Eaton *et al.*, 1978
Notropis cornutis, young	N	R	$CdCl_2$	dtw	7.8-8.2	-	7 d	NOEC[b,w]	10	BKH, 1995
Oncorhynchus kisutch, ELS	-	-	-	-	-	45	27/47 d	NOEC[a]	1.3	Eaton *et al.*, 1978
Oncorhynchus mykiss, 50 mm	Y	F	Cd..	dtw	6.9	50	14 w	NOEC[a]	1.3	BKH, 1995
Oncorhynchus mykiss, 50 mm	Y	F	Cd..	dtw	6.9	200	14 w	NOEC[a]	2.6	BKH, 1995
Oncorhynchus mykiss, 50 mm	Y	F	Cd..	dtw	6.9	400	14 w	NOEC[a]	2.6	BKH, 1995
Oncorhynchus trutta, ELS	-	-	-	-	-	45	9 w	NOEC[a]	3.8	Eaton *et al.*, 1978
Pimephales promelas, 30 d, 0.15 g	Y	F	$Cd(NO_3)_2$	nw	7.4	44	32 d	NOEC[b,x]	5	BKH, 1995
Pimephales promelas, ELS	Y	F	$CdCl_2$	rw	7.7	102	8 d	NOEC[a]	12	BKH, 1995
Pimephales promelas, ELS	Y	R[3]	$CdCl_2$	rw	7.7	101.6	8 d	NOEC[a]	12	BKH, 1995
Pimephales promelas	-	-	-	-	-	200	11 m	NOEC[e]	37	Pickering & Gast, 1972
Salvelinus fontinalis	-	-	-	-	-	44	3 gen	NOEC[a,b]	1.7	Benoit *et al.*, 1976
Salvelinus fontinalis, ELS	-	-	-	-	-	45	9-18 w	NOEC[b]	1.1	Eaton *et al.*, 1978
Salvelinus fontinalis, ELS	-	-	-	-	-	33-51	9 w	NOEC[a,b5,b6]	3	Sauter *et al.*, 1976
Salvelinus fontinalis, ELS	-	-	-	-	-	164-213	9 w	NOEC[a,b5,b6]	7	Sauter *et al.*, 1976
Salvelinus namaycush, ELS	-	-	-	-	-	45	41/64 d	NOEC[a]	4.4	Eaton *et al.*, 1978
Stizostedion vitreum, ELS	-	-	-	-	-	32-39	4 w	NOEC[a]	9	Sauter *et al.*, 1976
Amphibia										
Xenopus laevis, ELS	-	-	-	-	-	hard	14 w	NOEC[c1,c2,y]	3	Canton & Slooff, 1982

Table 1.3 Chronic toxicity of chromium(VI) to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Bacteria										
Escherichia coli	N	S	K_2CrO_4	am	-	-	24 h	NOEC[a,w,v]	130	BKH, 1995
Escherichia coli	N	S	$K_2Cr_2O_7$	am	-	-	24 h	NOEC[a,v]	2500	BKH, 1995
Pseudomonas putida	N	S	$Na_2Cr_2O_7$	am	7	77	16 h	NOEC[b]	380	Bringmann & Kühn, 1980
Cyanophyta										
Microcystis aeruginosa	N	S	$Na_2Cr_2O_7$	am	7	60	8 d	NOEC[b]	1.9	Bringmann & Kühn, 1978
Microcystis aeruginosa	Y	S	$K_2Cr_2O_7$	am	7.8	36	8 d	NOEC[b]	200	Adema *et al.*, 1981
							8 d	NOEC[b]	200	
Microcystis aeruginosa	N	S	$K_2Cr_2O_7$	am	7.8	36	96 h	NOEC[b]	350	Slooff & Canton, 1983
Microcystis aeruginosa	Y	S	$K_2Cr_2O_7$	am	7.8	24	96 h	NOEC[b]	110	Hanstveit *et al.*, 1985
					8.8	24	96 h	NOEC[b]	110	
Nostoc muscorum	N	S	$K_2Cr_2O_7$	am	-	-	15 d	NOEC[b2,y]	3300	BKH, 1995
Algae										
Chlorella pyrenoidosa	N	S	K_2CrO_4	am	6.8	-	-	NOEC[b2]	250	BKH, 1995
							-	NOEC[d1,y]	33	
Chlorella pyrenoidosa	Y	S	$K_2Cr_2O_7$	am	7.7	54	96 h	NOEC[b]	64	Adema *et al.*, 1981
Euglena gracilis	Y	S	$K_2Cr_2O_7$	am	7.7	54	96 h	NOEC[b]	35	Adema *et al.*, 1981
Gomphonema parvulum	Y	S	$K_2Cr_2O_7$	am	7.8	24	96 h	NOEC[b]	35	Hanstveit *et al.*, 1985
Scenedesmus pannonicus	Y	S	$K_2Cr_2O_7$	am	7.7	54	14 d	NOEC[b]	110	Adema *et al.*, 1981
Scenedesmus pannonicus	N	S	$K_2Cr_2O_7$	am	7.8	36	96 h	NOEC[b]	110	Slooff & Canton, 1983
Scenedesmus quadricauda	N	S	$Na_2Cr_2O_7$	am	7	77	7 d	NOEC[b]	580	Bringmann & Kühn, 1980
Scenedesmus subspicatus	N	S	$K_2Cr_2O_7$	am	8.5	-	72 h	NOEC[b2]	230	BKH, 1995
Scenedesmus subspicatus	N	S	$K_2Cr_2O_7$	am	8.6	54	72 h	NOEC[b]	32	BKH, 1995

Table 1.3 (cont.) Chronic toxicity of chromium(VI) to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Algae(cont.)										
Selenastrum capricornutum	N	S	$K_2Cr_2O_7$	am	8.1	-	72 h	NOEC^{b2}	180	BKH, 1995
Selenastrum capricornutum	N	S	$K_2Cr_2O_7$	am	-	24	96 h	NOEC^{b}	110	BKH, 1995
Selenastrum capricornutum	Y	S	$K_2Cr_2O_7$	am	7.7	54	96 h	NOEC^{b}	200	Adema *et al.*, 1981
Selenastrum capricornutum	Y	S	Cr^{6+}..	rnw	5.6-8.9	-	96 h	NOEC^{b6}	70	BKH, 1995
Macrophyta										
Lemna gibba	Y	S	Na_2CrO_4	am	7.3	-	8 d	NOEC^{b}	100	Staves & Knaus, 1985
Lemna minor	Y	S	$K_2Cr_2O_7$	nw	8	255	7 d	NOEC^{b}	11	Adema & De Zwart, 1984
Lemna minor	N	S	$K_2Cr_2O_7$	nw	-	255	7 d	NOEC^{b}	110	Slooff & Canton, 1983
Spirodela polyrhiza	Y	S	Na_2CrO_4	am	7.3	-	8 d	NOEC^{b}	100	Staves & Knaus, 1985
Spirodela punctata	Y	S	Na_2CrO_4	am	7.3	-	8 d	NOEC^{b}	100	Staves & Knaus, 1985
Protozoa										
Chilomonas paramecium	N	S	$Na_2Cr_2O_7$	am	6.9	106	48 h	NOEC^{b}	0.058	Bringmann & Kühn, 1981
Colpidium campylum	N	S	$K_2Cr_2O_7$	am	6.5	103	48 h	NOEC^{b}	3200	Sudo & Aiba, 1973
Entosiphon sulcatum	N	S	$Na_2Cr_2O_7$	am	6.9	77	72 h	NOEC^{b}	9600	Bringmann & Kühn, 1981
Opercularia spec.	N	S	$K_2Cr_2O_7$	am	6.5	103	48 h	NOEC^{b}	6400	Sudo & Aiba, 1973
Uronema parduczi	N	s	$Na_2Cr_2O_7$	am	6.9	107	20 h	NOEC^{b}	1000	Bringmann & Kühn, 1981
Vorticella microstoma	N	S	$K_2Cr_2O_7$	am	6.5	103	48 h	NOEC^{b}	100	Sudo & Aiba, 1973
Coelenterata										
Hydra oligactis, 24 h, juvenile	N	R	$K_2Cr_2O_7$	am	8.2	208	21 d	NOEC^{b}	1100	Slooff & Canton, 1983
Rotatoria										
Brachionus calyciflorus, 0.25 mm	Y	S	Cr^{6+}..	am	-	-	48 h	NOEC^{e}	2000	BKH, 1995

Table 1.3 (cont.) Chronic toxicity of chromium(VI) to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Mollusca										
Lymnaea stagnalis, 5 m, adult	N	R	$K_2Cr_2O_7$	am	8.2	208	6 w	NOEC^{e}	110	Slooff & Canton, 1983
							6 w	NOEC^{a}	3500	
Crustacea										
Ceriodaphnia dubia, 24 h	Y	R	$Na_2Cr_2O_7$	nw	8.2	100	7 d	NOEC^{a,e,x}	32	BKH, 1995
Ceriodaphnia dubia, 24 h	Y	R	$K_2Cr_2O_7$	am			7 d	NOEC^{a}	9	De Graeve *et al.*, 1992
							7 d	NOEC^{e}	5.7	
Ceriodaphnia dubia, 24 h	Y	S	K_2CrO_4	am	8	157	7 d	NOEC^{a}	95	Patterson *et al.*, 1992
							7 d	NOEC^{e}	65	
						182	7 d	NOEC^{a}	250	
							7 d	NOEC^{e}	110	
						182	7 d	NOEC^{a}	340	
							7 d	NOEC^{e}	120	
Daphnia magna, ≤ 24 h	N^{8}	R^{2}	$K_2Cr_2O_7$	am	8	250	21 d	NOEC^{e}	18	BKH, 1995
Daphnia magna, ≤ 24 h	N	R^{2}	$K_2Cr_2O_2$	nw^{9}	8.1	225	21 d	NOEC^{b5,w}	135	Enserink *et al.*, 1993
							21 d	NOEC^{e4,w}	270	
							21 d	NOEC^{b1,w}	270	
Daphnia magna, ≤ 24 h	Y	F	$K_2Cr_2O_7$	nw	8.1	225	21 d	NOEC^{b5}	60	BKH, 1995
Daphnia magna, ≤ 24 h	Y	F	$K_2Cr_2O_7$	nw	8.1	225	21 d	NOEC^{a,e}	350	BKH, 1995
Daphnia magna, 24 h	Y	R	$K_2Cr_2O_7$	am	8.2	200	21 d	NOEC^{a,e}	35	Adema *et al.*, 1981
Daphnia magna, < 24 h	N,π	R	Na_2CrO_4	nw	8.3	-	28 d	NOEC^{e,v}	2.9	Trabalka & Gehrs, 1977
Moina macrocopa, 24 h	N	R	$K_2Cr_2O_7$	am	6.7	-	14 d	NOEC^{e}	20	Wong, 1993
Insecta										
Culex pipiens, 24 h larva	N	R	$K_2Cr_2O_7$	am	8.2	208	25 d	NOEC^{a,e5}	1100	Slooff & Canton, 1983

Table 1.3 (cont.) Chronic toxicity of chromium(VI) to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Pisces										
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	60000	BKH, 1995
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	60000	BKH, 1995
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	60000	BKH, 1995
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	60000	BKH, 1995
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	30000	BKH, 1995
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	60000	BKH, 1995
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	7500	BKH, 1995
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	7500	BKH, 1995
Brachydanio rerio, ELS	N	R^1	$K_2Cr_2O_7$	rw	7.5	100	≤16d	$NOEC^a$	30000	BKH, 1995
Brachydanio rerio, eggs	N	R	$K_2Cr_2O_7$	am	8.2	200	5 w	$NOEC^b$	4700	Canton *et al.*, 1984
Brachydanio rerio, eggs	N	R	$K_2Cr_2O_7$	am	8.2	200	5 w	$NOEC^a$	7000	Canton *et al.*, 1984
Catostomus commersoni, eggs	Y	F	Na_2CrO_4	nw	7	32-46	9 w	$NOEC^{b5,b6}$	290	Sauter *et al.*, 1976
Gasterosteus aculeatus, 5 h eggs	Y	R	$K_2Cr_2O_7$	am	8.2	200	5 w	$NOEC^b$	6700	Van den Dikkenberg *et al.*, 1989
							5 w	$NOEC^a$	12000	
Ictalurus punctatus, 2 w	Y	S	$K_2Cr_2O_7$	dtw	7.9-8.1	88-108	30 d	$NOEC^{a,z}$	1500	BKH, 1995
Ictalurus punctatus, 3 d eggs	Y	F	$Na_2Cr_2O_7$	nw	7.2	36	9 w	$NOEC^{a,b5,b6}$	305	Sauter *et al.*, 1976
Lepomis macrochirus, eggs	Y	F	$Na_2Cr_2O_7$	nw	6.9	33-45	9 w	$NOEC^{b6}$	520	Sauter *et al.*, 1976
Jordanella floridae, 24 h eggs	Y	R	$K_2Cr_2O_7$	am	8.2	200	28 d	$NOEC^b$	1100	Adema *et al.*, 1981
								$NOEC^a$	3500	
Oncorhynchus mykiss, eggs	Y	F	Na_2CrO_4	tap	7.8	80	7 m	$NOEC^{a,b}$	200	Van der Putte *et al.*, 1982
eggs	Y	F	Na_2CrO_4	tap	6.5	80	7 m	$NOEC^a$	20	
9 w, juvenile	Y	F	Na_2CrO_4	tap	7.8	80	7 m	$NOEC^a$	200	
9 w, juvenile	Y	F	Na_2CrO_4	tap	6.5	80	7 m	$NOEC^a$	200	
14 m, juv/adult	Y	F	Na_2CrO_4	tap	6.5	80	12 w	$NOEC^a$	200	
Oncorhynchus mykiss, juvenile	Y	F	$Na_2Cr_2O_7$	nw	7.5	45	8 m	$NOEC^a$	100	Benoit, 1976
Oncorhynchus mykiss, eggs	Y	F	$Na_2Cr_2O_7$	nw	6.8	33	13 w	$NOEC^b$	51	Sauter *et al.*, 1976
							13 w	$NOEC^a$	380	

Table 1.3 (cont.) Chronic toxicity of chromium(VI) to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result μg/l	Reference
Pisces(cont.)										
Oncorhynchus salar, eggs	Y	R	$Na_2Cr_2O_7$	nw	6.3	11	16 w	NOEC[a]	10	Grande & Anderson, 1983
Oryzias latipes, 24 h eggs	N	R	$K_2Cr_2O_7$	am	8.2	200	6 w	NOEC[a]	3500	Slooff & Canton, 1983
							6 w	NOEC[e5]	35000	
Oryzias latipes, 24 h eggs	Y	R	$K_2Cr_2O_7$	am	8.2	200	28 d	NOEC[a,b]	3500	Adema *et al.*, 1981
Pimephales promelas, 1 m, juvenile	Y	F	$K_2Cr_2O_7$	nw	7.8	209	14 m	NOEC[a]	1000	Pickering, 1980
Pimephales promelas, 24 h larve	Y	S	$Na_2Cr_2O_7$	am	8.2	-	28 d	NOEC[b]	1200	Barron & Adelman, 1984
Pimephales promelas, 3-14 d	Y	S	$K_2Cr_2O_7$	dtw	7.9-8.1	88-108	30 d	NOEC[a,z]	900	BKH, 1995
Pimephales promelas, 30 d, 0.15 g	Y	F	$Na_2Cr_2O_7$	nw	7.4	43.9	32 d	NOEC[a,b,x]	1100	BKH, 1995
Poecilia reticulata, 24 d, juvenile	Y	R	$K_2Cr_2O_7$	am	8.2	200	28 d	NOEC[b]	3500	Adema *et al.*, 1981
							28 d	NOEC[a]	6300	
Poecilia reticulata, 24 d, juvenile	N	R	$K_2Cr_2O_7$	am	8.2	200	28 d	NOEC[a,b]	3500	Slooff & Canton, 1983
Salmo gairdneri	Y	F	$Na_2Cr_2O_7$	nw	6.9	33	9 w	NOEC[a]	380	Sauter *et al.*, 1976
								NOEC[b5]	190	
								NOEC[b6]	51	
Salvelinus fontinalis, eyed eggs	Y	F	$Na_2Cr_2O_7$	nw	7-8	45	8 m	NOEC[a,b]	100	Benoit, 1976
alevins LC							22 m	NOEC[a,b,e]	350	
Salvelinus namaycush, 24 h, eggs	Y	F	$Na_2Cr_2O_7$	nw	6.9	34	9 w	NOEC[b6]	110	Sauter *et al.*, 1976
							4 w	NOEC[a]	2900	
Amphibia										
Xenopus laevis, 48 h, eggs	N	R	$K_2Cr_2O_7$	am	8.2	208	14 w	NOEC[a]	350	Slooff & Canton, 1983
							14 w	NOEC[b]	1100	

Table 1.4 Chronic toxicity of chromium(III) to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Bacteria										
Escherichia coli	N	S	$Cr_2(SO_4)_3$	am	-	-	24 h	NOEC^{a,w,v}	1300	BKH, 1995
Algae										
Chlorella pyrenoidosa	-	-	Cr-glycine	nw	-	-	96 h	NOEC^{b}	100	Meisch & Schmitt-Beckmann, 1979
Chlorella spec.	-	-	Cr-glycine	nw	-	-	96 h	NOEC^{b}	100	Meisch & Schmitt-Beckmann, 1979
Selenastrum capricornutum	Y	S	Cr^{3+}..	mw	5.6-8.9	-	96 h	NOEC^{b6}	170	Greene *et al.*, 1988
Crustacea										
Daphnia magna, ≤ 24 h	N^{8}	R^{2}	$CrCl_3$	am	8	250	21 d	NOEC^{b2,e}	700	BKH, 1995
Pisces										
Oncorhynchus kisutch	-	-	-	-	-	-	12 w	NOEC^{a,b}	200	Mance *et al.*, 1984
Oncorhynchus mykiss, 1 h, eggs	Y	F	$Cr(NO_3)$	-	7.3	20-30	±9 w	NOEC^{a,b,e5}	48	Stevens & Chapman, 1984
eyed eggs							6-8 w	NOEC^{a,b,e5}	160	

Table 1.5 Chronic toxicity of copper to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Bacteria										
Nitrosomonas europaea	N	S	Cu..	am	8.5	-	5 d	NOEC[b2,z]	10	BKH, 1995
Algae										
Chlamydomonas reinhardtii	Y	S	$CuSO_4$	rw	8.0	76	72 h	NOEC[a1]	5	BKH, 1995
							72 h	NOEC[a2]	19	
Chlamydomonas reinhardtii	Y	S	Cu..	nw	8.0-8.3	133	72 h	NOEC[b2,v]	8.5	BKH, 1995
	Y	S	Cu..	nw	8.0-8.3	95	72 h	NOEC[b2,v,x]	19	
Chlamydomonas reinhardtii	N[11]	S	$CuSO_4$	am	7.1-7.2	-	72 h	NOEC[b2,v]	13	BKH, 1995
Chlamydomonas reinhardtii	Y	S	Cu..	nw	8.0-8.3	95	72 h	NOEC[a1,v,x]	12	BKH, 1995
	Y	S	Cu..	nw	8.0-8.3	133	72 h	NOEC[a1,v,x]	14	
Chlamydomonas reinhardtii	Y	F	$CuSO_4$	am	6.2	-	10 d	NOEC[b2]	22	BKH, 1995
Chlamydomonas reinhardtii	N[11]	F	$CuSO_4$	am	6.2	-	10 d	NOEC[b2,v]	22	BKH, 1995
Chlorella pyrenoidosa	N	S	$CuCl_2$	am (+EDTA)	6.8	-	-	NOEC[b2]	100	BKH, 1995
								NOEC[d,w]	50	
								NOEC[d1,y]	33	
Chlorella fusca	N	S	$CuCl_2$	am	-	-	10 d	NOEC[b3,y,v]	5.3	BKH, 1995
Chlorella vulgaris	Y	S	$CuCl_2$	nw	-	85	96 h	NOEC[b2,v]	50	BKH, 1995
Chlorella saccarophila[10]	N	S	Cu..	am (no EDTA)	3	-	10 d	NOEC[b2,y,v]	330	BKH, 1995
Melosira spec.	N	S	$CuSO_4$	nw	-	115	9 d	NOEC[b]	10	Horne & Goldman, 1974
Oocystus spec.	N	S	$CuSO_4$	nw	-	115	9 d	NOEC[b]	10	Horne & Goldman, 1974
Scenedesmus quadricauda	N	S	$CuSO_4$	am	8	-	72 h	NOEC[d,y]	33	BKH, 1995
Scenedesmus quadricauda	N	S	$CuSO_4$	am	4.5	-	15 d	NOEC[b2]	50	BKH, 1995
Scenedesmus quadricauda	N	S	$CuSO_4$	am	6.5	-	15 d	NOEC[b2]	50	BKH, 1995
Scenedesmus subspicatus	N[11]	S	$CuSO_4$	am	7.1-7.2	-	72 h	NOEC[b2,v]	64	BKH, 1995

Table 1.5 (cont.) Chronic toxicity of copper to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Algae(cont.)										
Selenastrum capricornutum	N	S	Cu^{2+}	dsw	-	-	72 h	$NOEC^{b2}$	64	Van de Meent *et al.*, 1993
Selenastrum capricornutum	Y	S	$CuCl_2$	nw	-	85	96 h	$NOEC^{b2,v}$	15	BKH, 1995
Selenastrum capricornutum	N	S	$CuSO_4$	am	7.5-8.5	-	72 h	$NOEC^{b2}$	19	BKH, 1995
							72 h	$NOEC^{b2}$	24	
							5 d	$NOEC^{b2}$	21	
Selenastrum capricornutum	N	S	$CuSO_4$	am (+ EDTA)	7-7.5	4.1	96 h	$NOEC^{b2}$	57	BKH, 1995
Protozoa										
Tetrahymena pyriformis	N	S	$CuSO_4$	am	7.1-7.2	-	96 h	$NOEC^{b2,v}$	3800	BKH, 1995
Rotatoria										
Brachionus calyciflorus, 0.25 mm	Y	S	Cu..	am	-	-	48 h	$NOEC^{e}$	20	BKH, 1995
Mollusca										
Campeloma decisum, 11-27 mm, PLC	Y	F	$CuSO_4$	nw	7.7	45	6 w	$NOEC^{a}$	8	Arthur & Leonard, 1970
Dreissena polymorpha	Y	R^1	$CuCl_2$	nw	7.9	150	11 w	$NOEC^{f,y}$	17	BKH, 1995
Physa integra, 4-7 mm, PLC	Y	F	$CuSO_4$	nw	7.7	45	6 w	$NOEC^{a,b,e}$	8	Arthur & Leonard, 1970
Crustacea										
Ceriodaphnia dubia, < 4 h, LC	Y	R	$CuCl_2$	nw	7.2	32	7 d	$NOEC^{a,e}$	12	Carlson *et al.*, 1986
Ceriodaphnia dubia, 2-8 h	Y	R^2	Cu..	nw	8.15	94	7 d	$NOEC^{e}$	6.3	BKH, 1995
Ceriodaphnia dubia, 2-8 h	Y	R^2	Cu..	nw	8.31	179	7 d	$NOEC^{e,y}$	6.4	BKH, 1995
Ceriodaphnia dubia (24h)	Y	R	$Cu(NO_3)_2$	nw	8.2	100	7 d	$NOEC^{a,e,x}$	23	BKH, 1995
Ceriodaphnia dubia, < 12 h	Y	R^2	Cu..	nw	8.0-8.3	75	7 d	$NOEC^{e4,v,x}$	27	BKH, 1995
Ceriodaphnia dubia, < 12 h	Y	R^2	Cu..	nw	8.0-8.3	13	7 d	$NOEC^{e4,v,x}$	40	

Table 1.5 (cont.) Chronic toxicity of copper to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Crustacea (cont.)										
Daphnia ambigua, ≤ 24 h, LC	N	R	$CuSO_4$	nw	8.8	145	6 w	NOEC[b]	20	Winner & Farrell, 1976
Daphnia ambigua, ≤ 24 h, LC	N	R	$CuSO_4$	nw	8.8	145	6 w	NOEC[a]	40	Winner & Farrell, 1976
Daphnia magna, ≤ 24 h	N	R[2]	$CuCl_2$	nw	-	85	14 d	NOEC[e4]	10	BKH, 1995
Daphnia magna, ≤ 24 h	-	-	-	nw	-	45	21 d	NOEC[e]	11	Biesinger & Christensen, 1972
Daphnia magna, neonates, LC	Y	R	$CuCl_2$	nw	8.1	225	14 d	NOEC[e]	5	Van Leeuwen *et al.*, 1988
Daphnia magna, neonates, LC							21 d	NOEC[b]	13	
Daphnia magna, LC							21 d	NOEC[a]	37	
Daphnia pulex, < 24 h	N	R[2]	$CuCl_2$	rw	-	-	21 d	NOEC[a,v]	0.03	BKH, 1995
							21 d	NOEC[e4,v]	0.3	
Daphnia pulex, < 24 h	Y	R[2]	$CuSO_4$	rw	>8	230	6 w	NOEC[a]	11	BKH, 1995
Daphnia pulex, < 24 h	Y	R[2]	$CuSO_4$	nw[6]	>8	104	6 w	NOEC[a]	35	
Daphnia pulex, < 24 h, LC	Y	R	$CuSO_4$	am	8.5	106	10 w	NOEC[a]	5	Ingersoll & Winner, 1982
							10 w	NOEC[e]	10	
Gammarus pseudolimnaeus, LC	Y	F	$CuSO_4$	nw	7.7	45	15 w	NOEC[b1]	5	Arthur & Leonard, 1970
Gammarus pulex, mixed size classes	Y	F	$CuSO_4$	dtw	7.5	410	14 w	NOEC[b1,d]	11	BKH, 1995
Gammarus pulex, 2nd/3rd molt	Y	R[1]	$CuSO_4$	am	6.8-7.2	151	10 d	NOEC[a,z]	3.3	BKH, 1995
Insecta										
Chironomus riparius, 2nd instar	Y	R[1]	$CuSO_4$	am	6.8-7.2	151	10 d	NOEC[a,z]	20	BKH, 1995
Chironomus tentans, 4th instar, PLC	Y	F	$CuCl_2$	nw	7.4	36	21 d	NOEC[a]	34	Nebeker *et al.*, 1984
Clistoronia magnifica 5th instar PLC	Y	F	$CuCl_2$	nw	7.3	26	8 m	NOEC[e]	8	
							8 m	NOEC[e]	13	

Table 1.5 (cont.) Chronic toxicity of copper to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Crite-rion	Result µg/l	Reference
Pisces										
Brachydanio rerio, blastula stage	N	R[1]	$CuSO_4$	rw	7.5-7.7	100	16 d	NOEC[e5,v]	0.063	Dave & Xiu, 1991
							16 d	NOEC[a,v]	0.5	
Catostomus commersoni, eyed egg, ELS	Y	F	$CuSO_4$	nw	7.6	45	6 w	NOEC[a,b]	13	McKim *et al.*, 1978
Corogonus artedi, eyed egg, ELS	Y	F	$CuSO_4$	nw	7.6	45	9 w	NOEC[a,b]	43	
Cyprinus carpio, 7-9 cm, PLC	-	R	$CuSO_4$	tap	7	11	13 w	NOEC[a]	50	Muramoto, 1982
Esox lucius, green egg, ELS	Y	F	$CuSO_4$	nw	7.6	45	6 w	NOEC[a,b]	35	McKim *et al.*, 1978
Ictalurus punctatus, ELS	Y,π	F	$CuSO_4$	nw	7.5	38	9 w	NOEC[a]	15	Sauter *et al.*, 1976
							9 w	NOEC[b5]	9	
Ictalurus punctatus, ELS	Y,π	F	$CuSO_4$	nw	7.5	186	9 w	NOEC[a,b5,b6]	10	
Lepomis macrochirus, juvenile, PLC	Y	F	$CuSO_4$	nw	7.5	45	22 m	NOEC[a]	40	Benoit, 1976
							22 m	NOEC[b,e]	77	
Lepomis macrochirus, larva, PLC	Y	F	$CuSO_4$	nw	7.	45	13 w	NOEC[a]	21	
							13 w	NOEC[b]	40	
Micropterus dolomieui, eyed egg, ELS	Y	F	$CuSO_4$	nw	7.6	45	5 w	NOEC[a,b]	37	McKim *et al.*, 1978
Noemacheilus barbatulus, PLC	Y	F	$CuSO_4$	bw	8.3	249	9 w	NOEC[a]	120	Solbe & Cooper, 1976
Oncorhynchus mykiss, eyed egg, ELS	Y	F	$CuSO_4$	nw	7.6	45	7 w	NOEC[a,e]	11	McKim *et al.*, 1978
Oncorhynchus mykiss, ELS	Y	F	$CuCl_2$	nw	7.4	120	11 w	NOEC[b]	16	Seim *et al.*, 1984
							11 w	NOEC[a,e]	31	
Oncorhynchus trutta, green egg, ELS	Y	F	$CuSO_4$	nw	7.6	45	18 w	NOEC[a,b]	22	McKim *et al.*, 1978
early eyed egg							14 w	NOEC[a,b]	46	
late eyed egg							10 w	NOEC[a,b]	100	

Table 1.5 (cont.) Chronic toxicity of copper to freshwater species

Species	A	Test type	Test compound	Test water	pH	Hardness mg CaCO$_3$/l	Exp. time	Crite- rion	Result µg/l	Reference
Pisces(cont.)										
Pimephales promelas, fry, LC	Y	F	CuSO$_4$	nw	7	30	11 m	NOEC^{a,b,e}	11	Mount & Stephan, 1969
Pimephales promelas, ELS							4 m	NOEC^{a}	8	
							4 m	NOEC^{b}	11	
Pimephales promelas, fry, LC	Y	F	CuSO$_4$	nw	7.9	198	11 m	NOEC^{a,e}	15	Mount, 1968
							11 m	NOEC^{b}	33	
Pimephales promelas, 30 d 0.15 g	Y	F	Cu(NO$_3$)$_2$	nw	7.4	43.9	32 d	NOEC^{a,b,x}	3.1	BKH, 1995
Pimephales promelas, 1 h post-hatch	Y	R^1	Cu..	nw	-	48	7 d	NOEC^{b6}	9.9	BKH, 1995
Pimephales promelas, 2 d post-hatch	Y	IF	CuSO$_4$	nw	8.17	-	28 d	NOEC^{a}	61	BKH, 1995
							28 d	NOEC^{b5,w}	31	
							28 d	NOEC^{b6,y}	20	
Pimephales promelas, 2 d post-hatch	Y	IF	CuSO$_4$	nw	8.17	-	28 d	NOEC^{a,e5}	340	BKH, 1995
							28 d	NOEC^{c}	200	
Pimephales promelas, 5-10 h eggs	Y	IF	CuSO$_4$	nw	8.17	-	8 d	NOEC^{a}	61	BKH, 1995
Salvelinus fontinalis, yearlings, LC	Y	F	CuSO$_4$	nw	7.5	45	22 m	NOEC^{a,b}	9	McKim & Benoit, 1971
							22 m	NOEC^{e}	17	
Salvelinus fontinalis, alevins, PLC							11 m	NOEC^{b}	9	
Salvelinus fontinalis, eyed egg	Y	F	CuSO$_4$	nw	7.6	45	11 w	NOEC^{a,b}	22	McKim *et al.*, 1978
Salvelinus fontinalis, egg	Y,π	F	CuSO$_4$	nw	6.8	38	9 w	NOEC^{b5}	1.0	Sauter *et al.*, 1976
							9w	NOEC^{b6}	0.67	
							9 w	NOEC^{a}	10	
Salvelinus fontinalis, egg	Y,π	F	CuSO$_4$	nw	6.9	187	9 w	NOEC^{b5}	2.0	
							9 w	NOEC^{b6}	2.0	
							9 w	NOEC^{a}	19	
Salvelinus namaycush, eyed egg	Y	F	CuSO$_4$	nw	7.6	45	13 w	NOEC^{a,b}	22	McKim *et al.*, 1978
Stizostedion vitreum, egg	Y,π	F	CuSO$_4$	nw	7	35	4 w	NOEC^{a,b}	10	Sauter *et al.*, 1976
							4 w	NOEC^{e5}	18	

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APPENDIX II TOXICITY OF ARSENIC, CADMIUM, CHROMIUM AND COPPER TO MARINE SPECIES

LEGEND

Species	Species or species groups categorised in taxonomic groups: Bacteria, Cyanophyta, Algae, Algae (macrophytic), Protozoa, Planaria, Porifera, Macrophyta, Rotifera, Mollusca, Annelida, Crustacea, Insecta, Pisces, Amphibia. When available the lifestage and/or length or weight of the organism is mentioned; egg-larval study (ELS),life cycle (LC) or partial life cycle (PLC) can be reported if available,
A	Nominal concentration (N) or Analysed concentration (Y),
Test type	Static (S), Renewal (R), Intermittent flow (IF) or Continuous Flow-through (F). In the notes additional information is given on the frequency of renewal,
Testcompound	If the complete formulation of the salt is not mentioned, (..) is added,
Test water	artificial media (am), natural water (nw), Dutch standard water (dsw), reconstituted water (rw), dechlorinated natural water (dnw); dechlorinated tap water (dtw), tap water (tap); brackish water (bw); reconstituted natural water (rnw),
pH and salinity	sometimes given as range or estimate if no exact data are presented in the study,
Exposure time	given in hours (h); days (d); weeks (w); months (m) or number of generations (gen); sometimes given as a range or estimate if no exact data are presented in the study,
Criterion	NOEC values. Notes indicate the effect parameter or the extrapolation factor used to calculate the NOEC,
Result	Expressed as concentration of the ion in µg/l.

Notes:

a	mortality or immobility
a1	deflagellation
a2	encysted cells

b	growth
b1	population growth rate
b2	cell number
b3	multiplication rate
b4	spawning frequency
b5	length
b6	weight
b7	biomass
b8	number of internodes
b9	shell
b10	final yield of population

c	teratogenic effects
c1	abnormalities embryo
c2	abnormalities young

d	photosynthesis
d1	chlorophyll content
d2	oxygen consumption, resp. rate

e	reproduction
e1	sporophyte production
e2	meiospore release
e3	number of eggs
e4	number of young
e5	hatchability
e6	emergence
e7	settlement rate larvae

f	filtration or feeding rate
g	effect parameter not reported

v	extrapolated from graph
w	EC 11 - 19%: NOEC = EC/2
x	NOEC calculated as MATC/2
y	EC 20 - 49%: NOEC = EC/3
z	EC 50 - 90%: NOEC = EC/10

1. renewal every working day
2. renewal every second or third day
3. renewal every 12 hours
4. renewal every four days
5. renewal every week
6. 2% nutrient medium
7. 20% nutrient medium
8. nominal concentration was confirmed by analysis
9. more food levels tested. The test included was carried out using the food level conform EC protocol
10. Acid tolerable species
11. added Cu + present Cu in solution
12. Copper was dissolved in 3 ml concentrated HNO_3 and made up to volume with distilled water.

Table 2.1. Chronic toxicity of arsenic to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Algae, macrophytic										
Champia parvula	-	R	As(III)...	am	-	-	14 d	NOEC[b]	113	Thursby & Steele, 1984
Champia parvula	-	R	As(III)...	am	-	-	14 d	NOEC[e]	95	
Crustacea										
Mysidopsis bahia, 24 h	Y	F	$NaAsO_2$	nw	-	30	5 w	NOEC[a]	630	BKH, 1995
								NOEC[e]	630	

Table 2.2. Chronic toxicity of cadmium to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Cyanophyta										
Anabaena variabilis	N	S	CdCl$_2$	am	-	-	7d	NOEC^{d1,z}	39	BKH, 1995
Algae										
Asterionella glacialis	N	R	CdSO$_4$	nw	8.2	36	4-5w	NOEC^{e}	1.1	BKH, 1995
Bacteriastrum delicatulum	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	11	BKH, 1995
Bacteriastrum hyalinum	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	11	BKH, 1995
Biddulphia mobiliensis	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	3.4	BKH, 1995
Chlorella vulgaris	N	S	CdCl$_2$	am	-	-	7 d	NOEC^{d1,z}	39	BKH, 1995
Dicrateria zhanjiangenis	N	S	CdCl$_2$	nw	-	-	6 d	NOEC^{b2}	110	BKH, 1995
Ditylum brightwellii	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	34	BKH, 1995
Dunaliella sp.	N	S	CdCl$_2$	nw	-	-	6 d	NOEC^{b2}	1100	BKH, 1995
Emiliania huxleyi	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	1.1	BKH, 1995
Gymnodinium spec.	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	11	BKH, 1995
Heterocapsa triquetra	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	3.4	BKH, 1995
Hymenomonas carterae	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	1.1	BKH, 1995
Lithodesmium undulatum	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	3.4	BKH, 1995
Peridinium spec.	N	R	CdSO$_4$	nw	8.2	36	4-5w	NOEC^{e,w}	0.56	BKH, 1995
Prorocentrum micans	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	1.1	BKH, 1995
Rhizosolenia setigera	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	11	BKH, 1995
Skeletonema costatum	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	34	BKH, 1995
Synechococcus bacillaris	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	3.4	BKH, 1995
Streptotheca tamesis	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	11	BKH, 1995
Thoracosphaera heimii	N	R	CdSO$_4$	mw	8.2	36	4-5w	NOEC^{e}	3.4	BKH, 1995

Table 2.2 (cont.) Chronic toxicity of cadmium to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Nematoda										
Monhystera microphthalma, 0.35 mm	N	S	$CdCl_2$	am	7-7.5	20	13 d	NOEC^{a,w}	500	BKH, 1995
Monhystera disjuncta, 0.35 mm	N	S	$CdCl_2$	am	7-7.5	30	11 d	NOEC^{a}	5000	BKH, 1995
Pellioditis marina, 0.42 mm	N	S	$CdCl_2$	am	7-7.5	30	8 d	NOEC^{a}	25000	BKH, 1995
Mollusca										
Crassostrea virginica	-	-	-	-	-	20-22	9 m	NOEC^{e}	5	Zaroogian & Morrison, 1981
Mytilus edulis	-	-	-	-	-	-	17 d	NOEC^{b}	110	Poulsen *et al.*,1982
Annelida										
Capitella capitata	-	-	-	-	-	-	25-40 d	NOEC^{e}	320	Reish, 1978
Ctenodrilus serratus	-	-	-	-	-	-	28-31 d	NOEC^{e}	1000	Reish, 1978
Ctenodrilus serratus	-	-	-	-	-	-	21 d	NOEC^{e}	1000	Reish & Carr, 1978
Nereis arenaceodentata	-	-	-	-	-	-	4 m	NOEC^{e}	560	Reish, 1978
Ophryotrocha diadema	-	-	-	-	-	-	28 d	NOEC^{e}	500	Reish, 1978
Ophryotrocha diadema	-	-	-	-	-	-	28 d	NOEC^{e}	500	Reish & Carr, 1978
Ophryotrocha labronica	-	-	-	-	-	-	30 d	NOEC^{b,e}	200	Roed, 1980
Crustacea										
Allorchestes compressa,	Y	F	$CdCl_2$	nw	8	31	28 d	NOEC^{b6,z}	2.1	BKH, 1995
first instar juveniles							28 d	NOEC^{a,w}	11	
Artemia salina, encysted embryos	N	S	$CdCl_2$	am	-	24.7	48 h	NOEC^{e5,z}	1.1	BKH, 1995
Callianassa australiensis	-	-	-	-	-	-	14 d	NOEC^{a}	320	Ahsanullah *et al.*,1981
Cancer anthonyi, embryo	N	S	$CdCl_2$	nw	7.8	34	7 d	NOEC^{a,w}	5	BKH, 1995
							7 d	NOEC^{e5}	10	

Table 2.2 (cont.) Chronic toxicity of cadmium to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Crustacea (cont.)										
Mysidopsis bahia	-	-	-	-	-	-	7 w	NOEC[e]	5.1	Gentile *et al.*,1982
Mysidopsis bahia, < 24 h	Y	F	Cd..	nw	-	13	28 d	NOEC[a]	2.5	BKH, 1995
						13	28 d	NOEC[e4]	2.5	
						21	28 d	NOEC[a,w]	0.6	
						21	28 d	NOEC[e4]	6.1	
						29	28 d	NOEC[a,y]	0.6	
						29	28 d	NOEC[e4,w]	0.9	
Mysidopsis bahia, 24-48 h, juvenile	N[8]	IF	$CdCl_2$	nw	-	30	5 w	NOEC[b9,w]	2	BKH, 1995
							5 w	NOEC[a]	4	
							5 w	NOEC[e4]	8	
Mysidopsis bahia, 8 d	N	R[1]	$CdCl_2$	nw	7.5-8.2	25	7 d	NOEC[a]	5	BKH, 1995
							7 d	NOEC[b6]	5	
							7 d	NOEC[e]	5	
Mysidopsis bahia, 8 d	N	R[1]	$CdCl_2$	nw	7.5-8.2	25	7 d	NOEC[a]	25	BKH, 1995
							7 d	NOEC[b6]	5	
							7 d	NOEC[e]	15	
Mysidopsis bahia, 8 d	N	R[1]	$CdCl_2$	nw	7.5-8.2	25	7 d	NOEC[a]	15	BKH, 1995
							7 d	NOEC[b6]	5	
							7 d	NOEC[e]	15	
Mysidopsis bahia, 24 h	Y	F	$CdCl_2$	nw	-	30	7 w	NOEC[a]	5.1	BKH, 1995
							7 w	NOEC[e4]	10	
Mysidopsis bigelowi	-	-	-	-	-	-	7 w	NOEC[e]	5.1	Gentile *et al.*,1982
Pisces										
Clupea harengus, ELS	-	-	-	-	-	16-32	15 d	NOEC[e]	100	Von Westernhage *et al.*,1974
Mugil cephalus, fry	N	R	$CdCl_2$	nw	-	37.3	8 w	NOEC[a]	20	BKH, 1995
Mugil cephalus, juvenile	N	R	$CdCl_2$	nw	-	37.3	8 w	NOEC[a]	100	BKH, 1995
Pleuronectes flesus, ELS	-	-	-	-	-	25-42	21 d	NOEC[e]	1000	Von Westernhage & Dethlefsen, 1975

Table 2.3 Chronic toxicity of chromium(VI) to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Algae										
Skeletonema costatum	N	S	$K_2Cr_2O_7$	am	8.2	30	96 h	NOEC[b7]	300	BKH, 1995
	N	S	$K_2Cr_2O_7$	am	8.2	30	96 h	NOEC[b2]	600	
	N	S	$K_2Cr_2O_7$	am	8.2	30	96 h	NOEC[b7]	800	
	N	S	$K_2Cr_2O_7$	am	8.2	30	96 h	NOEC[b2]	1400	
Skeletonema costatum	N	S	$K_2Cr_2O_7$	am	8.3	30	5 d	NOEC[b]	350	Cowgill *et al.*,1989
Skeletonema costatum	N	S	$K_2Cr_2O_7$	enw	-	20	72 h	NOEC[b]	60	Kusk & Nyholm, 1992
Annelida										
Capitella capitata, larva	N	S	$K_2Cr_2O_7$	-	-	35	5 m	NOEC[a,e]	50	Reish, 1975
Dinophilis gyrociliatus, 24-48 h juvenile	Y	S	$K_2Cr_2O_7$	nw	7.8	25	7 d	NOEC[a]	1000	BKH, 1995
							7 d	NOEC[e]	100	
Dinophilis gyrociliatus	Y	S	$K_2Cr_2O_7$	nw	7.8	25	7 d	NOEC[a]	1000	BKH, 1995
							7 d	NOEC[e,y]	33	
Neanthes arenaceodentata, juvenile	Y	R	$K_2Cr_2O_7$	-	7.9	33.5	10 m	NOEC[e]	25	Mears *et al.*,1976
							10 m	NOEC[a]	50	
Ophryotrocha diadema, adult	N	S	CrO_3	-	-	-	21 d	NOEC[a,e]	500	Reish & Carr, 1978

Table 2.3 (cont.) Chronic toxicity of chromium(VI) to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Crustacea										
Callinectes sapidus,larva	Y	R	Na_2CrO_4	-		30	6 w	NOEC[a,e8]	770	Bookhout *et al.*,1984
Mysidopsis bahia, 24 h	Y	F	$K_2Cr_2O_7$	nw	8	30	5 w	NOEC[e4]	88	BKH, 1995
Mysidopsis bahia, 7 d	N	R[1]	$K_2Cr_2O_7$	am	-	25	7 d	NOEC[e4]	320	BKH, 1995
Mysidopsis bahia, 7 d	N	R[1]	$K_2Cr_2O_7$	am	-	25	7 d	NOEC[e4]	420	BKH, 1995
							7 d	NOEC[a]	1200	
Mysidopsis bahia, 7 d	N	R[1]	$K_2Cr_2O_7$	am	-	25	7 d	NOEC[e4]	420	BKH, 1995
							7 d	NOEC[a]	1200	
Mysidopsis bahia, < 9 d	Y	R[1]	$K_2Cr_2O_7$	nw	7.8	30	7 d	NOEC[a]	1600	BKH, 1995
							7 d	NOEC[b6]	650	
							7 d	NOEC[e]	1600	
Mysidopsis bahia, < 9 d	Y	R[1]	$K_2Cr_2O_7$	nw	7.8	30	7 d	NOEC[a]	650	BKH, 1995
							7 d	NOEC[b6]	1600	
							7 d	NOEC[e]	1600	
Palaemon elegans, larva	N	R	Na_2CrO_4	am	8.3	33	5 w	NOEC[e5]	520	Van der Meer *et al.*,1988
							5 w	NOEC[a]	1600	
Palaemonetes varians, adult	N	R	Na_2CrO_4	am	8.3	23	28 d	NOEC[a]	5200	Van der Meer *et al.*,1988
larva	N	R	Na_2CrO_4	am	8.3	23	23 d	NOEC[a]	5200	
larva	N	R	Na_2CrO_4	am	8.3	33	30 d	NOEC[a]	5200	
Praunus flexuosus, adult	N	R	Na_2CrO_4	am	8.3	23	23 d	NOEC[a]	1000	
Rhithropanopeus harrisii, larva	Y	R	Na_2CrO_4	-	-	20	21 d	NOEC[a]	360	Bookhout *et al.*,1984
Tisbe battagliai, juvenile	N	R	$K_2Cr_2O_7$	nw	7.9	35	8 d	NOEC[a]	320	Hutchinson *et al.*,1994
adult	N	R	$K_2Cr_2O_7$	nw	7.9	35	8 d	NOEC[e]	320	

Table 2.4 Chronic toxicity of copper to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Cyanophyta										
Anabaena variabilis	N	S	$CuSO_4$	am	-	-	7 d	NOEC^{d1,z}	5.0	BKH, 1995
Algae										
Asterionella glacialis	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	64	BKH, 1995
Bacteriastrum delicatulum	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	130	BKH, 1995
Bacteriastrum hyalinum	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	6.4	BKH, 1995
Biddulphia moluliensis	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	250	BKH, 1995
Chaetoceros sp.	N	S	$CuSO_4$	am	-	-	7 d	NOEC^{b2}	2.5	BKH, 1995
Chlorella vulgaris	N	S	$CuSO_4$	am	-	-	7 d	NOEC^{d1,y}	17	BKH, 1995
Cyclococcolithina leptopora	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	0.64	BKH, 1995
Ditylum brightwellii	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	250	BKH, 1995
Emiliania huxleyi	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	6.4	BKH, 1995
Emiliania huxleyi	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	64	BKH, 1995
Emiliania huxleyi	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	190	BKH, 1995
Emiliania huxleyi	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	250	BKH, 1995
Gephyrocapsa oceanica	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	64	BKH, 1995
Gymnodinium spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	190	BKH, 1995
Hemiaulus sinensis	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	130	BKH, 1995
Hymenomonas carterae	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	64	BKH, 1995
Hymenomonas carterae	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	190	BKH, 1995
Laminaria saccharina, gametophytes	N	R^{4}	$CuSO_4$	am	-	-	21 d	NOEC^{e2}	10	BKH, 1995
Lithodesmium undulatum	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	250	BKH, 1995
Macrocystis pyrifera, motile zoöspore	Y	R^{4}	Cu..	am	7.8-8.3	35-37	19 d	NOEC^{e1,z}	1	BKH, 1995
Peridinium spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	6.4	BKH, 1995
Peridinium spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	6.4	BKH, 1995
Prorocentrum spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	0.64	BKH, 1995
Prorocentrum spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	64	BKH, 1995
Prorocentrum spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC^{e}	64	BKH, 1995
Rhizosolenia stolterfothii	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	64	BKH, 1995
Rhizosolenia setigera	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC^{e}	130	BKH, 1995

Table 2.4 (cont.) Chronic toxicity of copper to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Algae(cont.)										
Skeletonema costatum	N	S	$CuSO_4$	am	-	30	12 d	NOEC[b2,y]	170	BKH, 1995
Skeletonema costatum	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC[e]	250	BKH, 1995
Skeletonema costatum	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	640	BKH, 1995
Streptotheca tamesis	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	64	BKH, 1995
Streptotheca tamesis	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC[e]	64	BKH, 1995
Synechococcus spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	0.64	BKH, 1995
Synechococcus bacillaris	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	0.64	BKH, 1995
Synechococcus spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	6.4	BKH, 1995
Synechococcus spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	6.4	BKH, 1995
Synechococcus spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	6.4	BKH, 1995
Synechococcus spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	64	BKH, 1995
Synechococcus spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	64	BKH, 1995
Synechococcus spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	64	BKH, 1995
Thoracosphaera heimii	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC[e]	0.64	BKH, 1995
Thoracosphaera spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	6.4	BKH, 1995
Thoracosphaera heimii	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	6.4	BKH, 1995
Thoracosphaera spec.	N	R	$CuSO_4$	mw	8.2	33	4-5w	NOEC[e]	64	BKH, 1995
Umbilicosphaera hulburtiania	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC[e]	6.4	BKH, 1995
Umbilicosphaera sibogae	N	R	$CuSO_4$	mw	8.2	37	4-5w	NOEC[e]	130	BKH, 1995
Coelentherata										
Campanularia flexuosa	N	R	-	am	-	-	14 d	NOEC[g]	10	Stebbing, 1976
Hydra littoralis	N	S	-	am	-	-	14 d	NOEC[g]	2.5	Stebbing & Pomroy, 1978
Eirene viridula	N	R	-	-	-	-	13 w	NOEC[g]	10	Karbe, 1972
Mollusca										
Busicon canaliculatum	N	R	-	nw	-	-	8 w	NOEC[a]	100	Betzer & Yevich, 1975
Crassostrea virginica, larva	N	R	-	nw	-	-	14 d	NOEC[g]	10	Calabrese *et al.*, 1977
Mercenaria mercenaria, larva	N	R	-	nw	-	-	7 d	NOEC[g]	5	Calabrese *et al.*, 1977

Table 2.4 (cont.) Chronic toxicity of copper to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Mollusca(cont.)										
Mytilus edulis, 0.15 mm larva	N	R[2]	$CuSO_4$	nw	-	32	10 d	NOEC[a]	1	BKH, 1995
							10 d	NOEC[b5]	0.5	
Mytilus edulis, adult	Y	F	$CuSO_4$	nw	-	32	30 d	NOEC[b4]	1.3	BKH, 1995
Mytilus edulis	N	R[2]	$CuCl_2$	nw	-	32	15 d	NOEC[b9,w]	10	BKH, 1995
							15 d	NOEC[a]	100	
Mytilus edulis, ca. 15 mm	Y,β	R[1]	$CuCl_2$	nw	-	-	20 d	NOEC[b9,w]	5.6	Redapath, 1985
Pecten maximus, larva	N	R[2]	$CuCl_2$	nw	-	32	15 d	NOEC[a,y]	6.7	BKH, 1995
							15 d	NOEC[b9,y]	6.7	
Saccostrea commercialis, eyed larva	N	R[1]	$CuCl_2$	nw	7-8.5	30	5 d	NOEC[e7,z]	10	BKH, 1995
Annelida										
Ctenodrilus serratus	-	-	-	-	-	-	21-31 d	NOEC[e]	50	Reish & Carr,1978
Neanthes arenaceodentata, 3-4 w larva	Y	F	$CuCl_2$	nw	-	29	28 d	NOEC[a,z]	3.9	BKH, 1995
Neanthes arenaceodentata, 3-4 w larva	Y	F	$CuCl_2$	nw	-	29	28 d	NOEC[a,z]	8	BKH, 1995
Nereis diversicolor	N	R	-	nw	-	-	6 w	NOEC[a]	100	Bryan & Hummerstone,1971
Ophryotrocha diadema	-	-	-	-	-	-	28 d	NOEC[e]	100	Reish & Carr,1978
Crustacea										
Allorchestes compressa, first instar juvenile	N	F	$CuSO_4$	nw	8	31	28 d	NOEC[a]	24	BKH, 1995,
							28 d	NOEC[b6]	5.2	
							28 d	NOEC[b7]	3.7	
Artemia salina, cysts	N	S	$CuSO_4$	am	-	-	72 h	NOEC[e5,y]	0.2	BKH, 1995
Callianassa australiensis	-	-	-	-	-	-	14 d	NOEC[a]	60	BKH, 1995
Cancer anthonyi, embryo	N	R[1]	$CuCl_2$	nw	7.8	34	7 d	NOEC[a]	100	BKH, 1995
							7 d	NOEC[e5,y]	3.3	
Mysidopsis bahia, 24 h	Y	F	$CuCl_2$	nw	-	30	5 w	NOEC[a]	77	BKH, 1995
							5 w	NOEC[e4]	38	
Pandalus danae, larva	Y	F	-	nw	-	-	6 w	NOEC[g]	10	Young *et al.*,1979

Table 2.4 (cont.) Chronic toxicity of copper to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result µg/l	Reference
Pisces										
Atherinops affinis,	Y	S	$CuCl_2$	nw	7.1-7.7	33	12 d	NOEC[c1]	120	BKH, 1995
early blastula embryos, stage 8-9							12 d	NOEC[e5]	120	
							12 d	NOEC[c2]	63	
Atherinops affinis,	Y	S	$CuCl_2$	nw	7.1-7.7	33	12 d	NOEC[c1]	120	BKH, 1995
early blastula embryos, stage 8-9							12 d	NOEC[e5]	120	
							12 d	NOEC[c2]	68	
Atherinops affinis,	Y	S	$CuCl_2$	nw	7.1-7.7	33	12 d	NOEC[c1]	55	BKH, 1995
early blastula embryos, stage 8-9							12 d	NOEC[e5]	55	
							12 d	NOEC[c2]	55	

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APPENDIX III TOXICITY OF ARSENIC, CADMIUM, CHROMIUM AND COPPER TO TERRESTRIAL SPECIES

LEGEND

Species	Species or species groups categorized in the taxonomic groups: Bacteria, Fungi, Macrophyta, Mollusca, Nematoda, Oligochaeta, Isopoda, Collembola, Acari, Microbial processes, Enzyme activity,
A	Analyzed or nominal: measured concentration corrected for background (π), added concentration (δ), total concentration including the background concentration (ϕ),
Soil type	artificial soil (art. soil),
% O.m.	% organic matter (if presented in % organic carbon a factor of 1.7 was used to calculate % OM),
Exp. time	given in hours (h), days (d), weeks (w), months (m),
Criterion	LC: lethal concentration; EC: effect concentration; NOEC: no observed effect concentration,
stand. soil	results from test soil recalculated to NOEC in standard soil (10 % O.m. and 25% clay). No upper or lower limits are applied for the percentages of O.m. and clay, except for tests performed in food, manure of spar-mor, containing >90% O.m. In that situation 30% O.m. was used in the calcution to standard soil,
Result	Expressed as concentration of the ion in µg/l.

Notes:

a	mortality or immobility
a1	inhibition
b	growth
b1	shoot growth
b2	root growth
c	reproduction: number young
d	reproduction: cocoon production
e	maturation
f	emergence
g	sperm production
h	reproductive behaviour

w	EC 11 - 19%: NOEC = EC/2
x	EC 20 - 49%: NOEC = EC/3
y	EC 50 - 90%: NOEC = EC/10
z	extrapolated from graph
*	value was estimated by the evaluators,

q	demineralized water, HCL and HNO_3 (1/1/4 v/v) extractable fraction
r	water extractable fraction
s	0.1 M $CaCl_2$ extractable fraction
t	Test compound added in aqueous solution
u	added as powder
≈	actual value not reported; the experiment was performed with peat. Therefore the clay percentage is assumed to be 0%
#	mean concentration, derived from range >320 <560 mg/kg

1. L-methionine was added as carbon source
2. horse dung was applied in a hole in the middle of the soil
3. horse dung was mixed homogeneously through the soil
4. without feeding
5. with feeding

Table 3.1 Chronic toxicity of arsenic to terrestrial species

Species	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Macrophyta												
Glycine max	δ	As_2O_3	clay	-	3.2*	35*	-	6 w	NOEC[b]	75	72	Denneman & Van Gestel, 1990
Gossypium hirsutum	δ	As_2O_3	clay	-	3.2*	35*	-	6 w	NOEC[b]	149	140	
	δ	As_2O_3	sandy loam	-	3*	18*	-	6 w	NOEC[b]	18	22	
Oligochaeta												
Eisenia fetida, 5 weeks	δ^t	$KAsO_3$	peat +	7.5	42.8	$1^{\approx}$	19-22	8 w	NOEC[a]	50	45	BKH, 1995

Table 3.2 Chronic toxicity of cadmium to terrestrial species

Species	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Macrophyta												
Grain species	δ	Cd-	marine loam	5.6	1.6	7.8	-	5 m	NOEC^{b*}	12.5	20	Denneman & van Gestel, 1990
	δ	acetate	marine loam	5.4	2.4	26	-	5 m	NOEC^{b*}	6.25	7.9	
	δ	Cd-	loam	5.2	3.2	37.7	-	5 m	NOEC^{b*}	50	55	
	δ	acetate	sand	5.0	3.4	2.6	-	5 m	NOEC^{b*}	6.25	10	
	δ	Cd-	sand	5.4	6.8	3.3	-	5 m	NOEC^{b*}	50	71	
	δ	acetate	sand	4.6	19.4	2.6	-	5 m	NOEC^{b*}	6.25	6.1	
Raphanus sativa	ϕ	$CdCl_2$	loamy sand	5.4	3*	18*	25	6 w	NOEC^{b1}	10.7	14	Denneman & van Gestel, 1990
Spinacia oleracea	δ	$Cd(NO_3)_2$	sand	5.8	2.2	5*	-	-	EC10^{b}	0.9	1.5	
Spinacia oleracea	δ	$Cd(NO_3)_2$	sand	5.4	5.1	5*	-	-	EC10^{b}	1.5	2.2	
Spinacia oleracea	δ	$Cd(NO_3)_2$	sandy loam	5.8	1.7	18*	-	-	EC10^{b}	0.8	1.1	
Spinacia oleracea	δ	$Cd(NO_3)_2$	sandy loam	7.1	2.1	18*	-	-	EC10^{b}	1.8	2.5	
Spinacia oleracea	δ	$Cd(NO_3)_2$	clay	5.8	3	50*	-	-	EC10^{b}	2.4	2.3	
Spinacia oleracea	δ	$Cd(NO_3)_2$	clay	7.2	2.8	50*	-	-	EC10^{b}	3.5	3.4	
Mollusca												
Helix aspersa	δ	$CdCl_2$	food	-	86*	0*	-	30 d	NOEC^{h}	10	7.8	Denneman & Van Gestel, 1990
Oligochaeta												
Dendrobaena rubida	π	$Cd(NO_3)_2$	-	6.5	9.7	5*	14	3 m	NOEC^{d}	101	130	Denneman & Van Gestel, 1990
Eisenia andrei	π^{t}	$CdCl_2$	art.soil	6.0	10	20	20	3 w	NOEC^{d,w}	5.0	5.3	Van Gestel *et al.*, 1992
								3 w	NOEC^{c}	10	11	
Eisenia andrei, juvenile	δ	$CdCl_2$	art.soil^{2}	6.7	10	20	23	12 w	NOEC^{b}	32	34	Van Gestel *et al.*, 1991
Eisenia andrei, juvenile	δ	$CdCl_2$	art.soil^{3}	6.5	10	20	23	12 w	NOEC^{b}	18	19	
Eisenia fetida	δ	$Cd(NO_3)_2$	soil + manure	-	50*	5*	-	8 w	NOEC^{d}	25	13	Denneman & Van Gestel, 1990
								8 w	NOEC^{b}	50	26	
Eisenia fetida, adult	ϕ	$Cd(NO_3)_2$	art.soil	6.3	10	20	20	8 w	NOEC^{d}	39.2	41	Spurgeon *et al.*, 1994
Lumbricus rubellus	π	$CdCl_2$	sandy clay	7.3	3.4	17	-	12 w	NOEC^{d}	10	14	Denneman & Van Gestel, 1990
Lumbricus terrestris	-	-	art.soil	-	8	10	10	14 d	NOEC^{g}	200	250	Vonk *et al.*, 1994

Table 3.2 (cont.) Chronic toxicity of cadmium to terrestrial species

Species	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Isopoda												
Porcellio scaber	π	$Cd(NO_3)_2$ $CdSO_4$	leaf litter	6.4-6.8	30	0	-	8 w	NOEC[b]	6	4.6	Van Wensem et al., 1992
Porcellio scaber	δ	$Cd(NO_3)_2$	food	-	30	0	20	10 w	NOEC[b]	2.25	1.7	Denneman & Van Gestel, 1990
								10 w	NOEC[c,f]	10	7.8	
Collembola												
Folsomia candida, adult	π[q]	$CdCl_2$	art.soil OECD 207	6.0	10	20	20	7 w	NOEC[a]	325	350	Crommentuijn et al., 1993
								26 d	NOEC[b]	147	160	
								26 d	NOEC[c]	34	36	
Folsomia candida	-	-	art.soil	5.25	8	10	-	6 w	NOEC[c/d]	71	89	Vonk et al., 1994
Orchesella cincta	π	$CdSO_4$	food	-	30	0	20	9 w	NOEC[b]	3.7	2.9	Van Straalen et al., 1989
								9 w	NOEC[a,c]	55	43	
Acari												
Platynothrus peltifer	π	$CdSO_4$	food	-	30	0	20	12 w	NOEC[c]	1.6	1.2	Van Straalen et al., 1989
								12 w	NOEC[a]	115	89	

Table 3.3 Chronic toxicity of chromium(III) to terrestrial species

Species	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Result stand. soil (mg/kg d.w.)	Reference
Macrophyta												
Grain species	δ	Cr III -acetate	marine loam	5.6	1.6	7.8	-	5 m	NOEC^{b*}	631	960	Denneman & Van Gestel, 1990
	δ		marine loam	5.4	2.4	26	-	5 m	NOEC^{b*}	200	200	
	δ		loam	5.2	3.2	37.7	-	5 m	NOEC^{b*}	200	160	
	δ		sand	5	3.4	2.6	-	5 m	NOEC^{b*}	400	720	
	δ		sand	5.4	6.8	3.3	-	5 m	NOEC^{b*}	200	350	
Oligochaeta												
Eisenia andrei	π^t	$Cr(NO_3)_3$	art.soil OECD	6.7-6.9	10	20	20	3 w	NOEC^c	34	38	Van Gestel *et al.*, 1992
									NOEC^b	280	310	
									NOEC^d	280	310	

Table 3.4 Chronic toxicity of copper to terrestrial species

Species	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Macrophyta												
Avena sativa, seeds	δ	$CuSO_4$	sandy loam	5.5	2.2	12.4	24	2 w	NOEC^{f,z}	1000	1500	BKH, 1995
Cucumis sativus, seeds	δ	$CuSO_4$	sandy loam	5.5	2.2	12.4	24	2 w	NOEC^{f,z}	1000	1500	
Glycine max, seeds	δ	$CuSO_4$	sandy loam	5.5	2.2	12.4	24	2 w	NOEC^{f,z}	1000	1500	
Grain species	δ	Cu-acetate	marine loam	5.6	1.6	7.8	-	5 m	NOEC^{b*}	200	350	Denneman & Van Gestel, 1990
	δ	Cu-acetate	marine loam	5.4	2.4	26	-	5 m	NOEC^{b*}	200	220	
	δ	Cu-acetate	loam	5.2	3.2	37.7	-	5 m	NOEC^{b*}	200	180	
	δ	Cu-acetate	sand	5	3.4	2.6	-	5 m	NOEC^{b*}	200	390	
	δ	Cu-acetate	sand	5.4	6.8	3.3	-	5 m	NOEC^{b*}	200	340	
Nematoda												
Caenorhabditis elegans	δ^t	$CuCl_2$	sandy loam	6.2	1.7	16	20	24 h	NOEC^{a,z}	210	300	BKH, 1995
	δ^t	$CuCl_2$	sandy loam	6.1	3.0	16	20	24 h	NOEC^{a,z}	210	290	
	δ^t	$CuCl_2$	loam	5.1	3.4	20	20	24 h	NOEC^{a,z}	890	1100	
	δ^t	$CuCl_2$	clayloam	6.2	2.2	39	20	24 h	NOEC^{a,4,z}	890	810	
	δ^t	$CuCl_2$	clayloam	6.2	2.2	39	20	24 h	NOEC^{a,5,z}	210	190	
Oligochaeta												
Allolobophora caliginosa	δ	$CuSO_4$	sand + 1% grass	-	2*	5*	-	14 d	NOEC^{d}	50	94	Denneman & Van Gestel, 1990
								14 d	NOEC^{b}	100	190	
								14 d	NOEC^{a}	500	940	
Dendrobaena rubida	π	$Cu(NO_3)_2$	sand+dung	6.5	9.7	5	14	13 w	NOEC^{d}	122	180	Denneman & Van Gestel, 1990
Eisenia andrei, juvenile	δ	$CuCl_2$	art.soil^3	6.7	10	20	20	12 w	NOEC^{b,e}	56	61	BKH, 1995
Eisenia andrei	δ^t	$CuCl_2$	art.OECD soil	6.3-7.1	10	20	20	3 w	NOEC^{d}	60	65	BKH, 1995
Eisenia fetida	ϕ^t	$Cu(NO_3)_2$	art.soil OECD207	6.3	10	20	20	8 w	NOEC^{a}	210	230	Spurgeon *et al.*, 1994
									NOEC^{d}	32	35	
Eisenia fetida	δ	Cu-acetate	soil+dung	-	50*	5*	-	8 w	NOEC^{b,d}	500	380	Denneman & Van Gestel, 1990
Eisenia fetida								6w	NOEC^{b,d}	1000	750	Denneman & Van Gestel, 1990

Table 3.4 (cont.) Chronic toxicity of copper to terrestrial species

Species	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Oligochaeta(cont.)												
Lumbricus rubellus	π	$Cu(Cl)_2$	sandy clay	7.3	3.4	17	-	12 w	NOEC^d	30	40	Denneman & Van Gestel, 1990
Lumbricus rubellus	π	$Cu(Cl)_2$	sandy clay	7.3	3.4	17	18	12 w	NOEC^d	13	17	
								12 w	NOEC^b	373	490	
Collembola												
Onychiurus armatus	π	$Cu(NO_3)_2$	food	-	95*	0*	20	17 w	NOEC^b	2608	2800	Denneman & Van Gestel, 1990
Acari												
Platynothrus peltifer	π	$Cu(NO_3)_2$	food	-	95*	0*	18	10 w	NOEC^c	168	180	Denneman & Van Gestel, 1990

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APPENDIX IV TOXICITY OF ARSENIC, CADMIUM, CHROMIUM AND COPPER TO TERRESTRIAL PROCESSES

LEGEND

Species	Process
A	Analyzed or nominal: measured concentration corrected for background (β), added concentration (δ), total concentration including the background concentration (φ),
Soil type	artificial soil (art. soil),
% O.m.	% organic matter (if presented in % organic carbon a factor of 1.7 was used to calculate % OM),
Exp. time	given in hours (h), days (d), weeks (w), months (m),
Criterion	EC: effect concentration; NOEC: no observed effect concentration,
stand. soil	results from test soil recalculated to NOEC in standard soil (10 % O.m. and 25% clay). No upper or lower limits are applied for the percentages of O.m. and clay, except for tests performed in food, manure of spar-mor, containing >90% O.m. In that situation 30% O.m. was used in the calcution to standard soil.
Result	Expressed as concentration of the ion in µg/l.

Notes:

a1	inhibition

w	EC 11 - 19%: NOEC = EC/2
x	EC 20 - 49%: NOEC = EC/3
y	EC 50 - 90%: NOEC = EC/10
z	extrapolated from graph
*	value was estimated by the evaluators

q	demineralized water, HCL and HNO_3 (1/1/4 v/v) extractable fraction
r	water extractable fraction
s	0.1 M $CaCl_2$ extractable fraction
t	Test compound added in aqueous solution
u	added as powder
≈	actual value not reported; the experiment was performed with peat. Therefore the clay percentage is assumed to be 0%

1.	L-methionine was added as carbon source

Table 4.1 Toxicity of arsenic to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
N-mineralization	δ	$NaAsO_2$	-	5.8	4.4	23	37	1.5h	NOEC	375	420	Denneman & Van Gestel, 1990
N-mineralization	δ	Na_2HAsO_4	-	5.8	4.4	23	37	1.5h	NOEC	375	420	
N-mineralization	δ	$NaAsO_2$	-	6.6	5.0	45	37	1.5h	NOEC	375	310	
N-mineralization	δ	Na_2HAsO_4	-	6.6	5.0	45	37	1.5h	NOEC	375	310	
N-mineralization	δ	$NaAsO_2$	-	7.8	6.4	30	37	1.5h	NOEC	375	370	
N-mineralization	δ	Na_2HAsO_4	-	7.8	6.4	30	37	1.5h	NOEC	375	370	
N-mineralization	δ	$NaAsO_2$	-	7.4	9.3	34	37	1.5h	NOEC	375	340	
N-mineralization	δ	Na_2HAsO_4	-	7.4	9.3	34	37	1.5h	NOEC	375	340	
Phosphatase (acid)	δ	$NaAsO_2$	Webster	5.8	4.4	23	37	1.5h	NOEC	190	210	BKH, 1995
Phosphatase (acid)	δ	Na_2HAsO_4	Webster	5.8	4.4	23	37	1.5h	EC33^{al,x}	190	71	
Phosphatase (acid)	δ	$NaAsO_2$	Harps	7.8	6.4	30	37	1.5h	NOEC	1900	1900	
Phosphatase (acid)	δ	Na_2HAsO_4	Harps	7.8	6.4	30	37	1.5h	EC39^{al,x}	1900	620	
Phosphatase (acid)	δ	$NaAsO_2$	Okoboji	7.4	9.3	34	37	1.5h	EC16^{al,x}	1900	850	
Phosphatase (acid)	δ	Na_2HAsO_4	Okoboji	7.4	9.3	34	37	1.5h	EC62^{al,y}	1900	170	
Phosphatase (alkaline)	δ	$NaAsO_2$	Harps	7.8	6.4	30	37	1.5h	EC35^{al,x}	1900	620	
Phosphatase (alkaline)	δ	Na_2HAsO_4	Harps	7.8	6.4	30	37	1.5h	EC75^{al,y}	1900	190	
Phosphatase (alkaline)	δ	$NaAsO_2$	Okoboji	7.4	9.3	34	37	1.5h	NOEC	190	170	
Phosphatase (alkaline)	δ	Na_2HAsO_4	Okoboji	7.4	9.3	34	37	1.5h	EC32^{al,x}	190	57	
Phosphatase	δ	$NaAsO_2$	spar-mor	4.3	93	<1	22	3 h	EC20^{x}	749	140	Denneman & Van Gestel, 1990
Phosphatase	δ	As_2O_3	spar-mor	4.3	93	<1	22	3 h	EC23^{x}	1498	280	
Phosphatase	δ	$NaAsO_2$	mull	6.3	13	29	22	3 h	NOEC	749	680	
Phosphatase	δ	As_2O_3	mull	6.3	13	29	22	3 h	NOEC	1498	1400	
Urease	δ	$NaAsO_2$	Weller	5.1	2.6	17	37	2 h	EC98^{al,y}	375	48	Tabatabai, 1977
Urease	δ	$NaAsO_2$	Nicollet	6.1	5.6	30	37	2 h	NOEC	375	370	
Urease	δ	$NaAsO_2$	Webster	5.8	4.4	23	37	2 h	EC27^{al,x}	375	140	
Urease	δ	$NaAsO_2$	Harps	7.8	6.4	30	37	2 h	NOEC	38	37	
Urease	δ	$NaAsO_2$	Luton	6.8	7.4	42	37	2 h	EC44^{al,x}	375	100	
Urease	δ	$NaAsO_2$	Okoboji	7.4	9.3	34	37	2 h	EC14^{al,w}	38	17	

Table 4.2 Toxicity of cadmium to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Nitrification	δ	$NaAsO_2$	Webster	5.8	4.4	23	37	1.5h	EC98^{al,y}	375	42	Liang & Tabatabai, 1978
Nitrification	δ	Na_2HAsO_4	Webster	5.8	4.4	23	37	1.5h	EC71^{al,y}	375	42	
Nitrification	δ	$NaAsO_2$	Harps	7.8	6.4	30	37	1.5h	EC88^{al,y}	375	37	
Nitrification	δ	Na_2HAsO_4	Harps	7.8	6.4	30	37	1.5h	EC27^{al,x}	375	120	
Nitrification	δ	$NaAsO_2$	Okoboji	7.4	9.3	34	37	1.5h	EC64^{al,y}	375	34	
Nitrification	δ	Na_2HAsO_4	Okoboji	7.4	9.3	34	37	1.5h	EC14^{al,w}	375	170	
Arginine-ammonification	δ	$CdCl_2$	gley	5.5	3.6	5	26	9 w	EC82^y	200	31	BKH, 1995
Arginine-ammonification	δ	$CdCl_2$	cambisol	5.7	2.2	4	26	9 w	EC37^x	200	110	BKH, 1995
ATP-content	δ	$CdCl_2$	cambisol	6.6	1.2	9	15	9 w	NOEC	50	80	BKH, 1995
Cellulose respiration	δ^t	$CdCl_2$	gley	5.8	0.8	2.2	28	8 w	NOEC	112	200	BKH, 1995
Fe(III)reduction	δ	-	gleysol	5.1	3.8	4	-	5 d	NOEC	40	62	Denneman & Van Gestel, 1990
Glucose respiration	δ^t	$CdCl_2$	gley	5.8	0.8	2.2	28	14 d	NOEC	112	200	BKH, 1995
Nitrification	δ	$CdSO_4$		5.8	4.4	23	30	14 d	EC94^y	562	69	Denneman & Van Gestel, 1990
Nitrification	δ	$CdSO_4$		7.8	6.4	30	30	14 d	EC70^y	562	60	
Nittrification	δ	$CdSO_4$		7.4	9.3	34	30	14 d	EC74^y	562	54	
Nitrification	δ	$CdCl_2$	cambisol	6.6	1.2	9	15	9 w	EC11^w	50	40	BKH, 1995
N-mineralization	δ	$CdSO_4$		5.8	4.4	23	30	20 d	EC17^w	562	340	Denneman & Van Gestel, 1990
N-mineralization	δ	$CdSO_4$		6.6	5.0	45	30	20 d	EC27^x	562	180	
N-mineralization	δ	$CdSO_4$		7.8	6.4	30	30	20 d	EC39^x	562	200	
N-mineralization	δ	$CdSO_4$		7.4	9.3	34	30	20 d	EC18^y	562	270	
N-mineralization	δ β^r	$CdCl_2$	river sand	8.5	0.12	0.2	28	8 w	NOEC	337 6.2	650	BKH, 1995
N-mineralization	δ β^r	$CdCl_2$	gley soil	5.8	0.22	2.2	28	8 w	NOEC	1124 88.6	2100	BKH, 1995
N-mineralization	δ β^r	$CdCl_2$	gray lowland soil	6.2	0.87	19.0	28	8 w	NOEC	337 1.9	480	BKH, 1995
N-mineralization	δ β^r	$CdCl_2$	light colored andosol	6.4	5.4	27.6	28	8 w	NOEC	337 4.8	370	BKH, 1995
N-mineralization	δ β^r	$CdCl_2$	humic andosol	5.7	12.2	28.7	28	8 w	NOEC	337 4.3	310	BKH, 1995

Table 4.2 (cont.) Toxicity of cadmium to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Respiration	δ	$CdCl_2$	sandy loam	5.1	5.7	9	20	28 d	EC10	30	41	Denneman & Van Gestel, 1990
								10 m	NOEC*^{al}	150	200	
Respiration	δ	$CdCl_2$	sand	7.7	1.6	2	20	10 m	EC10	13	23	
								16 m	EC9	150	270	
Respiration	δ	$CdCl_2$	silty loam	7.4	2.4	19	20	10 m	EC10	27	37	
								21 m	NOEC*^{al}	150	200	
Respiration	δ	$CdCl_2$	sandy peat	4.3	12.8	5	20	10 m	EC10	52	59	
								19 m	NOEC*^{al}	400	450	
Respiration	δ	$CdCl_2$	clay	6.8	3.2	60	20	19 m	NOEC*^{al}	150	130	
Respiration	δ	$CdSO_4$	sandy loam	4.9	2.1	5	30	8 w	EC11^{w}	100	83	Denneman & Van Gestel, 1990
Respiration	δ	$CdCl_2$	river sand	8.5	0.12	0.2	28	8 w	NOEC	33.7	65	BKH, 1995
	β^r									0.96		
Respiration	δ	$CdCl_2$	gley soil	5.8	0.22	2.2	28	8 w	NOEC	33.7	63	BKH, 1995
	β^r									0.71		
Respiration	δ	$CdCl_2$	gray lowland soil	6.2	0.87	19.0	28	8 w	NOEC	112	160	BKH, 1995
	β^r									0.78		
Respiration	δ	$CdCl_2$	light colored andosol	6.4	5.4	27.6	28	8 w	NOEC	112	120	BKH, 1995
	β^r									0.52		
Respiration	δ	$CdCl_2$	humic andosol	5.7	12.2	28.7	28	8 w	NOEC	337	310	BKH, 1995
	β^r									4.3		
Arylsulphatase	δ^u	$CdCl_2$	sand	7.7	1.6	2	20	6w	EC10	819	1500	Haanstra & Doelman, 1991
								18 m	EC10	3.4	6.1	
Arylsulphatase	δ^u	$CdCl_2$	sandy loam	5.1	5.7	9	20	18 m	EC10	3.4	4.7	
Arylsulphatase	δ^u	$CdCl_2$	silty loam	7.4	2.4	19	20	6w	EC10	143	200	
								18 m	EC10	6.7	9.2	
Arylsulphatase	δ^u	$CdCl_2$	clay	6.8	3.2	60	20	6w	EC10	4440	4000	
								18 m	EC10	28	25	
Arylsulphatase	δ^u	$CdCl_2$	sandy peat	4.3	12.8	5	20	6 w	EC10	2660	3000	

Table 4.2 (cont.) Toxicity of cadmium to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Dehydrogenase	δ^{t}	$CdCl_2$	sandy luvisol	6	1.5	7	20	9 w	EC38^{x}	100	54	BKH, 1995
Dehydrogenase	δ	$CdCl_2$	cambisol	6.6	1.2	9	15	9 w	EC33^{x}	50	27	BKH, 1995
Dehydrogenase	δ	$CdCl_2$	gley-podsol	5.4	1.8	5	26	9 w	EC13^{w}	200	170	BKH, 1995
Dehydrogenase	δ	$CdCl_2$	gley	5.5	3.6	5	26	9 w	EC54^{y}	200	31	
Dehydrogenase	δ	$CdCl_2$	cambisol	5.8	1.0	8	26	9 w	EC28^{x}	200	110	
Dehydrogenase	δ	$CdCl_2$	cambisol	5.9	4.3	12	26	9 w	EC30^{x}	200	91	
Dehydrogenase	δ	$CdCl_2$	cambisol	7.9	2.0	13	26	9 w	EC26^{x}	200	98	
Dehydrogenase	δ	$CdCl_2$	cambisol	7.0	7.6	29	26	9 w	EC24^{x}	200	69	BKH, 1995
Dehydrogenase	δ	$CdCl_2$	cambisol	5.7	2.2	4	26	9 w	EC71^{y}	200	33	BKH, 1995
Dehydrogenase	δ	$CdCl_2$	pelosol	8.5	2.1	30	26	9 w	EC63^{y}	200	24	
Dehydrogenase	δ	$CdCl_2$	paracambisol	7.5	1.4	16	26	9 w	EC57^{y}	200	29	
Dehydrogenase	δ	$CdCl_2$	paracambisol	7.0	4.0	23	26	9 w	EC19^{w}	200	120	
Dehydrogenase	δ	$CdCl_2$	rendzina	8.0	2.4	28	26	9 w	EC26^{x}	200	81	
Dehydrogenase	δ	$CdCl_2$	rendzina	8.0	5.7	38	26	9 w	EC22^{x}	200	67	
Dehydrogenase	δ	$CdCl_2$	pararendzina	8.2	1.2	17	26	9 w	EC37^{x}	200	96	
Dehydrogenase	δ	$CdCl_2$	pararendzina	8.2	6.2	16	26	9 w	EC36^{x}	200	81	
Phosphatase	δ	$CdCl_2$	spar-mor	4.3	93	<1	22	3 h	EC7	1124	380	Denneman & Van Gestel, 1990
			mull	6.3	13	29	22	3 h	EC6	1124	1000	
Phosphatase (acid)	δ	$CdSO_4$	Webster	5.8	4.4	23	37	1.5h	EC14^{al,w}	280	170	Juma & Tabatabai, 1977
Phosphatase (acid)	δ	$CdSO_4$	Harps	7.8	6.4	30	37	1.5h	EC51^{al,y}	2800	300	
Phosphatase (acid)	δ	$CdSO_4$	Okoboji	7.4	9.3	34	37	1.5h	EC48^{al,x}	2800	270	
Phosphatase (alkaline)	δ	$CdSO_4$	Harps	7.8	6.4	30	37	1.5h	EC78^{al,y}	2800	300	
Phosphatse (alkaline)	δ	$CdSO_4$	Okoboji	7.4	9.3	34	37	1.5h	EC27^{al,x}	280	90	
Phosphatase	δ	$CdCl_2$	sand	7.7	1.6	2	20	6 w	EC10	9.0	16	Doelman & Haanstra, 1989
								18 m	EC10	16	29	
Phosphatase	δ	$CdCl_2$	sandy loam	5.1	5.7	9	20	18 m	EC10	8070	11000	
Phosphatase	δ	$CdCl_2$	silty loam	7.4	2.4	19	20	6 w	EC10	1405	1900	
								18 m	EC10	13	18	
Phosphatase	δ	$CdCl_2$	clay	6.8	3.2	60	20	6 w	EC10	140	130	
								18 m	EC10	830	750	

Table 4.2 (cont.) Toxicity of cadmium to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Urease	δ^u	$CdCl_2$	sand	7.7	1.6	2	20	6w	EC10	150	270	Doelman and Haanstra, 1986
								18 m	EC10	40	71	
Urease	δ^u	$CdCl_2$	silty loam	7.4	2.4	19	20	6w	EC10	360	490	
								18 m	EC10	280	380	
Urease	δ^u	$CdCl_2$	clay	6.8	3.2	60	20	6w	EC10	950	860	
								18 m	EC10	3.0	2.7	
Urease	δ^u	$CdCl_2$	sandy peat	4.4	12.8	5	20	6w	EC10	1980	2200	
Urease	δ	$CdSO_4$	Weller	5.1	2.6	17	37	2 h	EC67^{al,y}	560	77	BKH, 1995
Urease	δ	$CdSO_4$	Nicollet	6.1	5.6	30	37	2 h	EC51^{al,y}	560	60	
Urease	δ	$CdSO_4$	Webster	5.8	4.4	23	37	2 h	EC50^{al,y}	560	67	
Urease	δ	$CdSO_4$	Harps	7.8	6.4	30	37	2 h	EC19^{al,w}	56	30	
Urease	δ	$CdSO_4$	Luton	6.8	7.4	42	37	2 h	EC58^{al,y}	560	52	
Urease	δ	$CdSO_4$	Okoboji	7.4	9.3	34	37	2 h	EC13^{al,w}	56	26	

Table 4.3 Toxicity of chromium(VI) to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Phosphatase	δ	Na_2CrO_4	spar-mor	4.3	93	<1	22	3 h	$EC8^{a1}$	520	1000	Denneman & Van Gestel, 1990
									$EC10^{a1}$	1040	2000	
Phosphatase	δ	Na_2CrO_4	mull	6.3	13	29	22	3 h	$EC2^{a1}$	520	480	
									$EC3^{a1}$	1040	960	

Table 4.4 Toxicity of chromium(III) to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Arylsulphatase	δ[u]	$CrCl_3$	sand	7.7	1.6	2	20	18 m	EC10	2.1	3.9	Haanstra and Doelman, 1991
Arylsulphatase	δ[u]	$CrCl_3$	sandy loam	5.1	5.7	9	20	6w	EC10	46	68	
								18 m	EC10	1.0	1.5	
Arylsulphatase	δ[u]	$CrCl_3$	silty loam	7.4	2.4	19	20	18 m	EC10	83	94	
Arylsulphatase	δ[u]	$CrCl_3$	clay	6.8	3.2	60	20	6w	EC10	43	25	
								18 m	EC10	276	160	
Arylsulphatase	δ[u]	$CrCl_3$	sandy peat	3.0	12.8	5	20	6w	EC10	3338	5600	
								18 m	EC10	2730	4600	
Nitrification	δ	$Cr_2(SO_4)_3$	-	7.2	2*	17*	30	21 d	NOEC*[al]	100	120	Denneman & Van Gestel, 1990
Nitrification	δ	$CrCl_3$	Webster	5.8	4.4	23	37	2 h	EC96[al,y]	260	27	Denneman & Van Gestel, 1990
Nitrification	δ	$CrCl_3$	Harps	7.8	6.4	30	37	2 h	EC87[al,y]	260	24	
Nitrification	δ	$CrCl_3$	Okoboji	7.4	9.3	34	37	2 h	EC59[al,y]	260	22	
N-mineralisation	δ	$CrCl_3$	-	5.8	4.4	23	30	20 d	EC20[al,x]	260	90	Denneman & Van Gestel, 1990
N-mineralisation	δ	$CrCl_3$	-	6.6	5	45	30	20 d	EC15[al,w]	260	93	
N-mineralisation	δ	$CrCl_3$	-	7.8	6.4	30	30	20 d	EC13[al,w]	260	120	
N-mineralisation	δ	$CrCl_3$	-	7.4	9.3	34	30	20 d	EC24[al,x]	260	73	
Phosphatase (acid)	δ	$CrCl_3$	Webster	5.8	4.4	23	37	1.5h	NOEC	130	140	Juma & Tabatabai, 1977
Phosphatase (acid)	δ	$CrCl_3$	Harps	7.8	6.4	30	37	1.5h	EC25[al,x]	1300	390	
Phosphatase (acid)	δ	$CrCl_3$	Okoboji	7.4	9.3	34	37	1.5h	EC27[al,x]	1300	370	
Phosphatase (alkaline)	δ	$CrCl_3$	Okoboji	7.4	9.3	34	37	1.5h	EC14[al,w]	130	55	
Phosphatase (alkaline)	δ	$CrCl_3$	Harps	7.8	6.4	30	37	1.5h	EC27[al,x]	1300	390	
Phosphatase	δ[u]	$CrCl_3$	sand	7.7	1.6	2	20	6 w	EC10	1092	2000	Doelman and Haanstra, 1989
								18 m	EC10	723	1300	
Phosphatase	δ[u]	$CrCl_3$	sandy loam	6	5.7	9	20	6 w	EC10	2782	4100	
								18 m	EC10	858	1300	
Phosphatase	δ[u]	$CrCl_3$	silty loam	7.4	2.4	19	20	6 w	EC10	728	830	
								18 m	EC10	280	320	
Phosphatase	δ[u]	$CrCl_3$	clay	7.5	3.2	60	20	6 w	EC10	52	31	
								18 m	EC10	2153	1300	
Phosphatase	δ[u]	$CrCl_3$	sandy peat	4.4	12.8	5	20	6 w	EC10	380	630	

Table 4.4 (cont.) Toxicity of chromium(III) to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Respiration	δ	$CrCl_3$	sandy loam	5.1	5.7	9	20	8 w	EC10	5	7.4	Denneman & Van Gestel, 1990
								10 m	NOEC*	148	220	
								10 w	EC10	7	10	
								43 w	EC10	6	8.8	
Respiration	δ	$CrCl_3$	silty loam	7.4	2.6	19	20	21 m	EC10	86	100	
								21 m	NOEC*	182	210	
Respiration	δ	$CrCl_3$	sandy peat	4.3	12.8	5	20	19 m	EC10	71	120	
Respiration	δ	$CrCl_3$	clay	6.8	3.2	60	20	19 m	NOEC*	400	240	
Urease	δ^{u}	$CrCl_3$	sand	7.7	1.6	2	20	6w	EC10	1880	3500	Doelman and Haanstra, 1986
								18 m	EC10	390	720	
Urease	δ^{u}	$CrCl_3$	silty loam	7.4	2.4	19	20	6w	EC10	2050	2300	
								18 m	EC10	890	1000	
Urease	δ^{u}	$CrCl_3$	clay	7.5	3.2	60	20	6w	EC10		160	
								18 m	EC10	350	210	
Urease	δ^{u}	$CrCl_3$	sandy peat	4.4	12.8	5	20	6 w	EC10	360	600	
Urease	δ	$CrCl_3$	Weller	5.1	2.6	17	37	2 h	EC50^{a1,y}	260	31	Denneman & Van Gestel, 1990
Urease	δ	$CrCl_3$	Nicollet	6.1	5.6	30	37	2 h	EC22^{a1,x}	260	79	
Urease	δ	$CrCl_3$	Webster	5.8	4.4	23	37	2 h	EC25^{a1,x}	260	90	
Urease	δ	$CrCl_3$	Harps	7.8	6.4	30	37	2 h	NOEC	26	24	
Urease	δ	$CrCl_3$	Luton	6.8	7.4	30	37	2 h	EC17^{a1,w}	260	120	
Urease	δ	$CrCl_3$	Okoboji	7.4	9.3	34	37	2 h	EC19^{a1,w}	26	11	

Table 4.5 Toxicity of copper to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Ammonification	δ	$CuCl_2$	-	5.8	2.6	23	-	20 d	NOEC	300	360	Van de Meent et al., 1990
Ethylene production	δ	$CuSO_4$	crownhill[1]	6.07	5.4	59	30	7 d	NOEC	10	6.7	BKH, 1995
	δ	$CuSO_4$	santa lucia[1]	6.31	4.4	48	30	7 d	NOEC	10	7.8	
	δ	$CuSO_4$	sheephead[1]	6.87	3.9	26	30	7 d	NOEC	10	11	
	δ	$CuSO_4$	tollhouse[1]	6.82	3.6	21	30	7 d	NOEC	10	12	
	δ	$CuSO_4$	fallbrook[1]	6.60	2.8	26	30	7 d	NOEC	10	11	
	δ	$CuSO_4$	cibo[1]	7.42	2.8	54	30	7 d	NOEC	10	7.3	
	δ	$CuSO_4$	kitchen creek[1]	7.36	2.6	23	30	7 d	NOEC	10	12	
	δ	$CuSO_4$	altamont[1]	7.45	2.0	46	30	7 d	NOEC	10	8.2	
	δ	$CuSO_4$	garey[1]	5.91	1.9	21	30	7 d	NOEC	10	13	
	δ	$CuSO_4$	kimberly[1]	7.61	1.9	26	30	7 d	NOEC	10	11	
	δ	$CuSO_4$	pico[1]	8.55	1.5	26	30	7 d	NOEC	10	11	
	δ	$CuSO_4$	ramona[1]	6.31	1.3	26	30	7 d	NOEC	10	11	
	δ	$CuSO_4$	oildale[1]	7.70	1.2	23	30	7 d	NOEC	10	12	
	δ	$CuSO_4$	hanford[1]	7.15	0.8	18	30	7 d	NOEC	10	14	
	δ	$CuSO_4$	oceano[1]	7.03	0.8	16	30	7 d	NOEC	10	14	
	δ	$CuSO_4$	domino[1]	8.55	0.7	29	30	7 d	NOEC	10	11	
	δ	$CuSO_4$	redding[1]	8.56	0.6	64	30	7 d	NOEC	10	6.7	
	δ	$CuSO_4$	milham[1]	8.24	0.6	34	30	7 d	NOEC	10	10	
	δ	$CuSO_4$	hesperia[1]	7.22	0.5	18	30	7 d	NOEC	10	14	
Nitrification	δ[t]	$CuCl_2$	peat	4.4	72	0[≈]	25	19 w	NOEC	500	310	BKH, 1995
Nitrification	δ	$CuCl_2$	Webster	5.8	4.4	23	37	10 d	EC60[y]	318	36	Denneman & Van Gestel, 1990
Nitrification	δ	$CuCl_2$	Harps	7.8	6.4	30	37	10 d	EC31[x]	318	100	
Nitrification	δ	$CuCl$	Okoboji	7.4	9.3	34	37	10 d	EC43[x]	318	90	
N-mineralisation	δ	$CuSO_4$	-	6.6	5	45	30	20 d	NOEC[a1]	318	250	Denneman & Van Gestel, 1990
	δ	$CuSO_4$	-	7.8	6.4	30	30	20 d	EC7[a1]	318	310	

Table 4.5 (cont.) Toxicity of copper to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Respiration	δ	CuCl$_2$	silty loam	7.4	2.4	19	20	21 m	NOEC^{al*}	400	520	Denneman & Van Gestel, 1990
Respiration	ϕ	CuSO$_4$	sandy loam	4.9	3.6	5.2	30	8 w	NOEC	12.1	21	BKH, 1995
Respiration	δ	CuCl$_2$	sandy loam	5.1	5.7	9	20	8 w	EC10	4.0	6.0	Denneman & Van Gestel, 1990
								10 m	NOEC^{al*}	6.5	9.8	
Respiration	δ	CuCl$_2$	sandy peat	4.3	12.8	5	20	10 m	EC10	77	110	
								19 m	NOEC^{al*}	400	560	
Respiration	δ	CuCl$_2$	sand	7.7	1.6	2	20	16 m	NOEC^{al*}	150	310	
								10 m	EC10	22	46	
Arylsulphatase	δ^{u}	CuCl$_2$	sand	7.7	1.6	2	20	6 w	EC10	330	690	Haanstra & Doelman, 1991
								18 m	EC10	6.4	13	
Arylsulphatase	δ^{u}	CuCl$_2$	sandy loam	5.1	5.7	9	20	6 w	EC10	813	1200	
								18 m	EC10	347	520	
Arylsulphatase	δ^{u}	CuCl$_2$	silty loam	7.4	2.4	19	20	6 w	EC10	100	130	
								18 m	EC10	286	370	
Arylsulphatase	δ^{u}	CuCl$_2$	clay	6.8	3.2	60	20	6 w	EC10	619	420	
								18m	EC10	2667	1800	
Arylsulphatase	δ^{u}	CuCl$_2$	sandy peat	4.3	12.8	5	20	6 w	EC10	8570	12000	
								18 m	EC10	3321	4700	
Phosphatase (acid)	δ	CuCl	Webster	5.8	4.4	23	37	1.5h	EC18^{al,w}	159	91	Juma & Tabatabai, 1977
Phosphatase (acid)	δ	CuSO$_4$	Webster	5.8	4.4	23	37	1.5h	EC11^{al,w}	159	91	
Phosphatase (acid)	δ	CuC	Harps	7.8	6.4	30	37	1.5h	EC28^{al,x}	1590	520	
Phosphatase (acid)	δ	CuSO$_4$	Harps	7.8	6.4	30	37	1.5h	EC26^{al,x}	1590	520	
Phosphatase (acid)	δ	CuCl	Okoboji	7.4	9.3	34	37	1.5h	EC43^{al,x}	1590	470	
Phosphatase (acid)	δ	CuSO$_4$	Okoboji	7.4	9.3	34	37	1.5h	EC36^{al,x}	1590	470	
Phosphatase (alkaline)	δ	CuCl	Harps	7.8	6.4	30	37	1.5h	EC30^{al,x}	1590	520	
Phosphatase (alkaline)	δ	CuSO$_4$	Harps	7.8	6.4	30	37	1.5h	EC20^{al,x}	1590	520	
Phosphatase (alkaline)	δ	CuCl	Okoboji	7.4	9.3	34	37	1.5h	NOEC	159	140	
Phosphatase (alkaline)	δ	CuSO$_4$	Okoboji	7.4	9.3	34	37	1.5h	NOEC	159	140	
Phosphatase	δ^{u}	CuCl$_2$	sand	7.7	1.6	2	20	6 w	EC10	3.2	6.7	Doelman & Haanstra, 1989
								8 m	EC10	8.3	17	

Table 4.5 (cont.) Toxicity of copper to microbial processes and enzyme activity

Process	A	Test compound	Soil type	pH	% O.m.	% Clay	Temp °C	Exp. time	Criterion	Result test soil (mg/kg d.w.)	Calc. NOEC stand. soil (mg/kg d.w.)	Reference
Phosphatase	δ[u]	$CuCl_2$	sandy loam	5.1	5.7	9	20	8 m	EC10	438	660	Doelman & Haanstra, 1989
Phosphatase	δ[u]	$CuCl_2$	silty loam	7.4	2.4	19	20	6 w	EC10	1840	2400	
								8 m	EC10	170	220	
Phosphatase	δ[u]	$CuCl_2$	clay	6.8	3.2	60	20	6 w	EC10	290	200	
								8 m	EC10	960	650	
Phosphatase	δ[u]	$CuCl_2$	sandy peat	4.3	12.8	5	20	6 w	EC10	99	140	
								8 m	EC10	58	81	
Urease	δ[u]	$CuCl_2$	sand	7.7	1.6	2	20	6 w	EC10	80	170	Doelman & Haanstra, 1986
								18 m	EC10	20	42	
Urease	δ[u]	$CuCl_2$	sandy loam	5.1	5.7	9	20	6 w	EC10	120	180	
Urease	δ[u]	$CuCl_2$	silty loam	7.4	2.4	19	20	18 m	EC10	340	440	
Urease	δ[u]	$CuCl_2$	clay	6.8	3.2	60	20	6 w	EC10	440	300	
								18 m	EC10	520	350	
Urease	δ[u]	$CuCl_2$	sandy peat	4.3	12.8	5	20	6 w	EC10	60	84	
								18 m	EC10	210	290	
Urease	δ[t]	$CuCl_2$	silty clay loam	6.5	3.7	31	37	5 h	EC16[w]	50	25	BKH, 1995
Urease	δ[t]	$CuCl_2$	clay loam	7.3	2	31	37	5 h	EC13[w]	50	26	
Urease	δ[t]	$CuSO_4$	silty clay loam	6.5	3.7	31	37	5 h	EC14[w]	50	25	
Urease	δ[t]	$CuSO_4$	clay loam	7.3	2	31	37	5 h	EC15[w]	50	26	
Urease	δ	$CuSO_4$	Weller	5.1	2.6	17	37	2 h	EC72[al,y]	320	43	Tabatabai, 1977
Urease	δ	CuCl	Weller	5.1	2.6	17	37	2 h	EC21[al,x]	320	140	
Urease	δ	$CuSO_4$	Nicollet	6.1	5.6	30	37	2 h	EC58[al,y]	320	32	
Urease	δ	CuCl	Nicollet	6.1	5.6	30	37	2 h	EC30[al,x]	320	110	
Urease	δ	$CuSO_4$	Webster	5.8	4.4	23	37	2 h	EC69[al,y]	320	37	
Urease	δ	CuCl	Webster	5.8	4.4	23	37	2 h	EC60[al,y]	320	37	
Urease	δ	$CuSO_4$	Harps	7.8	6.4	30	37	2 h	EC24[al,x]	32	10	
Urease	δ	CuCl	Harps	7.8	6.4	30	37	2 h	EC21[al,x]	32	10	
Urease	δ	$CuSO_4$	Luton	6.8	7.4	42	37	2 h	EC59[al,y]	320	26	
Urease	δ	CuCl	Luton	6.8	7.4	42	37	2 h	EC53[al,y]	320	26	
Urease	δ	$CuSO_4$	Okoboji	7.4	9.3	34	37	2 h	EC17[al,w]	32	14	
Urease	δ	CuCl	Okoboji	7.4	9.3	34	37	2 h	EC14[al,w]	32	14	

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APPENDIX V AQUATIC TOXICITY DATA USED FOR EXTRAPOLATION

Species belonging to taxonomic group:

bac = Bacteriophyta
cya = Cyanophyta
alg = Algae, not further classified
mac = Macrophyta
pro = Protozoa
por = Porifera
coe = Coelenterata
mol = Mollusca
nem = Nematoda
ann = Annelida
cru = Crustacea
ins = Insecta
ech = Echinodermata
pis = Pisces
amp = Amphibia

Table 5.1.1 **Arsenic: freshwater data used for extrapolation**

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
bac	9,700	cru	405[a]
cya	11,000	cru	88
alg	10	pis	2,100
alg	86	pis	2,100
alg	4,700	pis	76
alg	10,000	pis	8,400
pro	4,800	pis	1,900[b]
cru	570		

All data from Appendix I

a: most sensitive parameter(reproduction) for *D. magna,* geometric mean of 630 and 260 µg/l

b: most sensitive parameter(mortality/reproduction) for *P. promelas,* geometric mean of 1700 and 2100 µg/l

Table 5.1.2 **Arsenic: marine data used for extrapolation**

taxonomic group	NOEC (µg/l)
alg	95[a]
cru	630

All data from Appendix II

a: most sensitive parameter(reproduction) for *Champia parvula*

Table 5.2.1 **Cadmium: freshwater data used for extrapolation**

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
bac	80	ann	30[g]
bac	220	cru	0.41[h]
cya	50	cru	0.86[i]
cya	70	cru	1.6[j]
alg	52[a]	cru	1.2
alg	83	cru	0.29
alg	330[b]	cru	1.0[k]
alg	33[c]	ins	2.0[l]
alg	900	pis	4.2[m]
alg	31	pis	4.2
alg	11	pis	15[n]
alg	15[d]	pis	3.0[o]
alg	1.1	pis	180[p]
mac	33	pis	4.3
mac	9.0	pis	10
mac	20	pis	1.3
mac	5.0	pis	2.1[q]
mac	2.2[e]	pis	3.8
mac	6.9[f]	pis	5.0[r]
pro	11	pis	2.5[s]
pro	670	pis	4.4
rot	40	pis	9.0
mol	2.5	amp	3.0
mol	3.0		

All data from Appendix I

a: parameter growth for *C. reinhardtii*, geometric mean of 38 and 70 µg/l

b: parameter growth for *C. pyrenoidosa*, geometric mean of 36 and 3100 µg/l

c: lowest parameter(growth) for *C. vulgaris*

d: parameter growth for *S. capricornutum*, geometric mean of 2, 4, 10 and 700 µg/l

e: parameter growth for *S. minima*, geometric mean of 1, 3.3 and 3.3 µg/l

f: parameter growth for *S. punctata*, geometric mean of 10, 10 and 3.3 µg/l

g: parameter growth for *A. headleyi*, geometric mean of 54 and 17 µg/l

h: parameter(reproduction) for *C. dubia*, geometric mean of 1.0, 0.33, 0.33, 0.1 and 1.1 µg/l

i: lowest parameter(growth) for *D. magna*, geometric mean of 0.5, 1, 0.5, 1, 1.2, 1.2, 4.1, 2, 0.11, 1, 0.16, and 3.2 µg/l

j: lowest parameter(reproduction) for *D.pulex*, geometric mean of 0.03, 3.8, 7.5 and 7.5 µg/l

k: lowest parameter(reproduction) for *M. macrocopa*

l: lowest parameter(mortality/reproduction) for *C. riparius*

m: lowest parameter(mortality) for *C. commersoni*

n: parameter growth for *I. punctatus*, geometric mean of 20 and 12 µg/l

o: lowest parameter(mortality) for *J. floridae*

p: lowest parameter(growth) for *L. macrochirus*, geometric mean of 1100 and 31 µg/l

q: geometric mean of 1.3, 2.6 and 2.6 µg/l, parameter mortality for *O. mykiss*

r: lowest parameter(growth) for *P. promelas*

s: lowest parameter(growth) for *S. fontinalis*, geometric mean of 1.7, 1.1, 3.0 and 7.0 µg/l

Table 5.2.2 **Cadmium: marine data used for extrapolation**

taxonomic group	NOEC in μg/l	taxonomic group	NOEC in μg/l
cya	39	alg	3.4
alg	1.1	nem	500
alg	11	nem	5,000
alg	11	nem	25,000
alg	3.4	mol	5.0
alg	39	mol	110
alg	110	ann	320
alg	34	ann	1,000[a]
alg	1,100	ann	560
alg	1.1	ann	500[b]
alg	11	ann	200
alg	3.4	cru	2.1[c]
alg	1.1	cru	1.1
alg	3.4	cru	320
alg	0.56	cru	5.0[d]
alg	1.1	cru	3.7[e]
alg	11	cru	5.1
alg	34	pis	100
alg	3.4	pis	45[f]
alg	11	pis	1,000

All data from Appendix II

a: geometric mean of 1000 and 1000 μg/l, parameter reproduction for *C. serratus*

b: geometric mean of 500 and 500 μg/l, parameter reproduction for *O. diadema*

c: lowest parameter(growth) for *A. compressa*

d: lowest parameter(mortality) for *C. anthonyi*

e: lowest parameter(mortality) for *M. bahia,* geometric mean of 2.5, 0.6, 0.6, 4, 5, 25, 15 and 5.1 μg/l

f: geometric mean of 20 and 100 μg/l, parameter mortality for *M. cephalus*

Table 5.3.1 Chromium(VI): freshwater data used for extrapolation

taxonomic group	NOEC in μg/l	taxonomic group	NOEC in μg/l
bac	570[a]	coe	1,100
bac	380	rot	2,000
cya	83[b]	mol	110[h]
cya	3,300	cru	44[i]
alg	33[c]	cru	44[j]
alg	35	cru	20
alg	35	ins	1,100
alg	110[d]	pis	4,700[k]
alg	580	pis	290
alg	86[e]	pis	6,700[l]
alg	130[f]	pis	305[m]
mac	100	pis	520
mac	35[g]	pis	1,100[n]
mac	100	pis	100[o]
mac	100	pis	10
pro	0.058	pis	3,500[p]
pro	3,200	pis	1,000[q]
pro	9,600	pis	3,500[r]
pro	6,400	pis	100[s]
pro	1,000	pis	190[t]
pro	100	pis	110[u]
		amp	350[v]

All data from Appendix I

a: geometric mean of 130 and 2500 μg/l, parameter mortality for *E. coli*

b: geometric mean of 1.9, 200, 200, 350, 110 and 110 μg/l, parameter growth for *M. aeruginosa*

c: lowest parameter(photosynthesis) for *C. pyrenoidosa*

d: geometric mean of 110 and 110 μg/l, parameter growth for *S. pannonicus*

e: geometric mean of 230 and 32 μg/l, parameter growth for *S. subspicatus*

f: geometric mean of 180, 110, 200 and 70 μg/l, parameter growth for *S. capricornutum*

g: geometric mean of 11 and 110 μg/l, parameter growth for *L. minor*

h: lowest parameter(reproduction) for *L. stagnalis*

i: lowest parameter(reproduction) for *C. dubia*, geometric mean of 32, 5.7, 65, 110 and 120 μg/l

j: lowest parameter(reproduction) for *D. magna*, geometric mean of 18, 270, 350, 35 and 2.9 μg/l

k: lowest parameter(growth) of the most sensitive life-stage(eggs) for *B. rerio*

l: lowest parameter(growth) for *G. aculeatus*

m: most sensitive life-stage(eggs)/parameter(growth) for *I. punctatus*

n: lowest parameter(growth) for *J. floridae*

o: lowest parameter(growth) of most sensitive life-stage(eggs) for *O. mykiss*, geometric mean of 200 and 51 μg/l

p: lowest parameter(mortality/growth) for *O. latipes*

q: lowest parameter(mortality) for *P. promelas*, geometric mean of 1000, 900 and 1100 μg/l

r: lowest parameter(growth) for *P. reticulata*, geometric mean of 3500 and 3500 μg/l

s: lowest parameter(growth) for *S. gairdneri*, geometric mean of 190 and 51 μg/l

t: lowest parameter(mortality/growth) for *S. fontinalis*, geometric mean of 100 and 350 μg/l

u: lowest parameter(growth) for *S. namaycush*

v: lowest parameter(mortality) for *X. laevis*

Table 5.3.2 Chromium(VI): marine data used for extrapolation

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
alg	402[a]	cru	88[d]
ann	50	cru	520[e]
ann	57[b]	cru	5,200[f]
ann	25[c]	cru	1,000
ann	500	cru	360
cru	770	cru	320

All data from Appendix II

a: geometric mean of 300, 600, 800, 1400, 350 and 60 µg/l, parameter growth for *S. costatum*

b: lowest parameter(reproduction) for *D. gyrociliatus*, geometric mean of 100 and 33 µg/l

c: lowest parameter(reproduction) for *N. arenaceodantata*

d: most sensitive life-stage for *M. bahia*, parameter(reproduction)

e: most sensitive parameter(reproduction) for *P. elegans*

f: geometric mean of 5200, 5200 and 5200 µg/l, parameter mortality for *P. varians*

Table 5.3.3 Chromium(III): freshwater data used for extrapolation

taxonomc group	NOEC in µg/l	taxonomic group	NOEC in µg/l
bac	1,300	cru	700
alg	100	pis	200
alg	100	pis	88[a]
alg	170		

All data from Appendix I

a: geometric mean of 48 and 160 µg/l, parameter mortality/growth/reproduction for *O. mykiss*

Table 5.4.1 Copper: freshwater data used for extrapolation

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
bac	10	cru	5.0
alg	11[a]	cru	3.3[i]
alg	40[b]	ins	20
alg	5.3	ins	34
alg	50	ins	10[j]
alg	330	pis	0.06[k]
alg	10	pis	13
alg	10	pis	43
alg	33[c]	pis	50
alg	64	pis	35
alg	28[d]	pis	9.5[l]
pro	3,800	pis	29[m]
rot	20	pis	37
mol	8.0	pis	120
mol	17	pis	16[n]
mol	8.0	pis	22[o]
cru	15[e]	pis	13[p]
cru	20[f]	pis	3.4[q]
cru	8.2[g]	pis	22
cru	1.7[h]	pis	10[r]

All data from Appendix I

a: lowest parameter(mortality/immobility, deflagellation, encysted cells) for *C. reinhardtii,* geometric mean of 5, 19, 12 and 14 µg/l

b: lowest parameter(photosynthesis) for *C. pyrenoidosa,* geometric mean of 33 and 50 µg/l

c: lowest parameter(photosynthesis) for *S. qaudricauda*

d: geometric mean of 64, 15, 19, 24, 21 and 57 µg/l, parameter growth for *S. capricornutum*

e: geometric mean of 0.25 and 20 µg/l, parameter reproduction

e: lowest parameter(reproduction) for *C. dubia,* geometric mean of 12, 6. 3, 6.4, 23, 27 and 40 µg/l

f: lowest parameter(growth) for *D. ambigua*

g: lowest parameter(reproduction) for *D. magna,* geometric mean of 10, 11 and 5 µg/l

h: lowest parameter(reproduction) for *D. pulex,* geometric mean of 0.3 and 10 µg/l

i: lowest parameter(mortality) for *G. pulex*

j: reproduction for *C. magnifica* geometric mean of 8 and 13 µg/l

k: lowest parameter(reproduction) for *B. rerio*

l: lowest parameter(growth) for for *I. punctatus,* geometric mean of 9 and 10 µg/l

m: lowest parameter(mortality) for *L. macrochirus,* geometric mean of 40 and 21 µg/l

n: lowest parameter(growth) for *O. mykiss*

o: most sensitive life-stage for *O. trutta*

p: most sensitive parameter(growth) for *P. promelas,* geometric mean of 11, 11, 33, 3.1, 9.9, 31 and 20 µg/l,

q: most sensitive parameter(growth) for *S. fontinalis,* geometric mean of 9, 9, 22, 1, 0.67, 2 and 2 µg/l

r: most sensitive parameter(mortality/growth) for *S. vitreum*

Table 5.4.2 Copper: marine data used for extrapolation

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
cya	5.0	alg	6.4[h]
alg	64	alg	6.4
alg	130	alg	130
alg	6.4	coe	10
alg	250	coe	2.5
alg	2.5	coe	10
alg	17	mol	100
alg	0.64	mol	10
alg	250	mol	5.0
alg	66[a]	mol	0.5[i]
alg	64	mol	6.7
alg	190	mol	10
alg	130	ann	50
alg	110[b]	ann	5.6[j]
alg	10	ann	100
alg	250	ann	100
alg	1.0	cru	4.4[k]
alg	6.4[c]	cru	0.2
alg	14[d]	cru	60
alg	64	cru	3.3[l]
alg	130	cru	38[m]
alg	170[e]	cru	10
alg	64[f]	pis	76[n]
alg	8.5[g]		

All data from Appendix II

a: geometric mean of 6.4, 64, 190 and 250 µg/l, parameter reproduction for *E. huxleyi*

b: geometric mean of 64 and 190 µg/l, parameter reproduction for *H. carterae*

c: geometric mean of 6.4 and 6.4 µg/l, parameter reproduction for *Peridinium spec.*

d: geometric mean of 0.64, 64 and 64 µg/l, parameter reproduction for *Prorocentrum spec.*

e: lowest parameter(growth) for *S. costatum*

f: geometric mean of 64 and 64 µg/l, parameter reproduction for *S. tamesis*

g: geometric mean of 0.64, 0.64, 6.4, 6.4, 6.4, 64, 64 and 64 µg/l, parameter reproduction for *Synechococcus spec.*

h: geometric mean of 0.64, 6.4, 6.4 and 64 µg/l parameter reproduction for *Thoracosphaera spec.*

i: lowest parameter(mortality) for most sensitive life-stage(larva) for *M. edulis*

j: geometric mean of 3.9 and 8 µg/l, parameter mortality for *N. arenaceodentata*

k: lowest parameter(growth) for *A. compressa,* geometric mean of 5.2 and 3.7 µg/l

l: most sensitive parameter(reproduction) for *C. anthonyi*

m: most sensitive parameter(reproduction) for *M. bahia*

n: lowest parameter(abnormalities) for *A. affinis,* geometric mean of 120, 63, 120, 68, 55 and 55 µg/l

Table 5.5.1 **Lead: freshwater data used for extrapolation**

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
bac	1,300	pro	70
bac	1,800	mol	12[b]
cya	450	cru	26
alg	500	cru	40[c]
alg	500	pis	120
alg	1,000	pis	120
alg	500	pis	250
alg	500	pis	75
alg	1,300[a]	pis	70
alg	10	pis	120
alg	2,100	pis	41[d]
alg	300	pis	20
pro	220	pis	39[e]
pro	20	pis	48[f]
pro	1,300	pis	240[g]

All data originate from Janus et al., 1997. (Janus, J.A., Annema, J.A., Aben, J.M.M. and Slooff, W. (1997) Evaluatiedocument lood. *RIVM report no.* 601014 003. (Draft, In Dutch)).

a: geometric mean of 1300, 1900, 3000, 500 and 1000 µg/l, parameter growth for *Scenedesmus quadricauda*

b: lowest parameter(survival) for *L. palustris*

c: lowest parameter(reproduction) for *D. magna,* geometric mean of 1.0, 15, 250 and 670 µg/l

d: lowest parameter(abnormalities) for *Salmo gairdneri,* geometric mean of 190, 7.0, 8.0, 28, 250 and 60 µg/l

e: lowest parameter(hatching/abnormalities/growth) for *Salvelinus fontinalis*

f: lowest parameter(survival) for *Salvelinis namaycush*

g: lowest parameter(survival/abnormalities) for *Stizostedion vitreum*

Table 5.5.2 **Lead: marine data used for extrapolation**

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
alg	60	mol	200
alg	9.0	mol	200
pro	150	cru	1,000
coe	300	cru	10
ann	500	cru	17
ann	1,000	cru	50

All data originate from Janus et al., 1997. (Janus, J.A., Annema, J.A., Aben, J.M.M. and Slooff, W. (1997) Evaluatiedocument lood. *RIVM report no.* 601014 003. (Draft, In Dutch)).

Table 5.6.1 Mercury, inorganic: freshwater data used for extrapolation

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
bac	11[a]	pro	500
bac	1.0	pro	780[b]
cya	2.5	pro	34
alg	100	mol	45[c]
alg	100	cru	18[d]
alg	20	cru	8.5
alg	35	cru	0.7[e]
mac	20	cru	10[f]
pro	8.0	pis	1.0[g]
pro	9.0	pis	0.3[h]

All data originate from Slooff et al., 1995. (Slooff, W., Van Beelen, P., Annema, J A. and Janus, J.A. (1995) Integrated Criteria Document Mercury. *RIVM report no.* 601014 008).

a: geometric mean of 5 and 25 µg/l, parameter growth for *Pseudomonas putida*
b: most sensitive parameter(growth) for *Tetrahymena pyriformis*
c: geometric mean of 20, 40, 100, 20, 60 and 90 µg/l, parameter survival for *Viviparus bengalensis*
d: most sensitive parameter(reproduction) for *Cyclops spec.*
e: most sensitive parameter(reproduction) for *Daphnia magna,* geometric mean of 0.07, 1.7 and 3 µg/l
f: most sensitive parameter(mortality) for *Daphnia similis*
g: most sensitive parameter(mortality) for *Brachydanio rerio*
h: most sensitive parameter(growth) for *Pimephales promelas,* geometric mean of 0.63, 0.31, 0.26 and 0.09 µg/l

Table 5.6.2 Mercury, inorganic: marine data used for extrapolation

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
alg	5.0	mol	1.0[c]
alg	9.0	mol	0.25[d]
alg	9.0	mol	2.0
alg	0.9	mol	4.0
alg	0.9	cru	2.0
pro	2.5	cru	4.9
coe	0.1	cru	0.8[e]
ann	10[a]	cru	6.0
ann	71[b]	pis	10[f]

All data originate from Slooff et al., 1995. (Slooff, W., Van Beelen, P., Annema, J.A. and Janus, J.A. (1995) Integrated Criteria Document Mercury. *RIVM report no.* 601014 008).

a: geometric mean of 10 and 10 µg/l, parameter reproduction for *Ctenodrilus serratus*
b: geometric mean of 50 and 100 µg/l, parameter reproduction for *Ophryotrocha diadema*
c: most sensitive parameter(hatching) for *Crassostrea virginica*
d: most sensitive parameter(reproduction) for *Crepidula fornatica*
e: geometric mean of 0.8 and 0.8 µg/l, parameter reproduction/mortality for *mysidopsis bahia*
f: most sensitive parameter(hatching) for *Fundulus heteroclitus*

Table 5.6.3 **Methyl-mercury: freshwater data used for extrapolation**

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
bac	0.2	pis	0.17
pro	0.2	pis	19[b]
pro	14	pis	0.07[c]
pla	0.03[a]	pis	0.8
cru	0.09	pis	0.15[d]

All data originate from Slooff et al., 1995. (Slooff, W., Van Beelen, P., Annema, J.A. and Janus, J.A. (1995) Integrated Criteria Document Mercury. *RIVM report no.* 601014 008).

a: most sensitive parameter for *Dugesia dorotocephala*

b: geometric mean of 13 and 29 µg/l, parameter mortality for *Oncorhynchus kisutch*

c: most sensitive parameter(mortality) for *Pimephalis promelas*

d: most sensitive parameter(growth) for *Salvelinus fontinalis,* geometric mean of 0.29 and 0.08 µg/l

Table 5.6.4 **Methyl-mercury: marine data used for extrapolation**

taxonomic group	NOEC in µg/l
mol	0.3

Data originate from Slooff et al., 1995 (Slooff, W., Van Beelen, P., Annema, J.A. and Janus, J.A. (1995) Integrated Criteria Document Mercury. *RIVM report no.* 601014 008).

Table 5.7.1 Nickel: freshwater data used for extrapolation

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
bac	100,000	alg	10,000
bac	6,000	alg	1,300[c]
bac	5,000	pro	820[d]
bac	130,000	pro	42[d]
bac	2.5[a]	pro	140[d]
cya	25	cru	90
cya	5[b]	pis	380[e]
		pis	104[f]

All data originate from Van de Meent et al., 1990. (Van de Meent, D., Aldenberg, T., Canton, J.H., Van Gestel, C.A.M. and Slooff, W. (1990) Desire for levels. Background study for the policy document "Setting environmental quality standards for water and soil". *RIVM-report no.* 670101 002).

a: Toxische Grenzkonzentration as reported by Bringmann and Kühn (1977) (see references of Appendix I) is considered the NOEC

b: Toxische Grenzkonzentration as reported by Bringmann and Kühn (1978) (see references of Appendix I) is considered the NOEC

c: Toxische Grenzkonzentration as reported by Bringmann and Kühn (1978) (see references of Appendix I) is considered the NOEC

d: Toxische Grenzkonzentration as reported by Bringmann and Kühn (1981) (see references of Appendix I) is considered the NOEC

e: geometric mean of 380 and 380 µg/l for *Pimephales promelas,* parameter growth/survival

f: geometric mean of 62, 134 and 134 µg/l for *Salmo gairdneri,* parameter growth/survival

Table 5.8.1 Zinc: freshwater data used for extrapolation

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
alg	470[a]	mol	25
alg	200	cru	25[e]
alg	95	cru	37[f]
alg	190	ins	12[g]
alg	1,000	pis	1,300
alg	250[b]	pis	44[h]
alg	15[c]	pis	50
alg	390	pis	120[i]
alg	60	pis	100[j]
alg	1,000	pis	540
por	3.3[d]		

All data originate from Janus, 1993; adapted Janus et al., 1996, corrected for background in this report. (Janus, J.A. (1993) Integrated Criteria Document Zinc: Ecotoxicity. *Appendix to RIVM report no.* 710401 028; Janus, J.A., Van Beelen, P., Vaal, M.A., Senhorst, H.A.J. and Van de Guchte, C. (1996) A further look at Zinc; A response to the Industry addendum to the Integrated Criteria Document Zinc. *RIVM report no.* 601014 012/*RIZA*-96.038).

a: geometric mean of 400 and 560 µg/l, parameter growth for *Chlorella vulgaris*
b: geometric mean of 100, 230 and 700 µg/l, parameter growth for *Scenedesmus quadricauda*
c: geometric mean of 5, 15 and 50 µg/l, parameter growth for *Selenastrum capricornutum*
d: value corrected for background concentration (0.65 µg/l)
e: geometric mean of 25, 8, 25, 25, 50, 25, 25, 50 and 17 µg/l, parameter reproduction for *Ceriodaphnia dubia*
f: most sensitive parameter(growth) for *Daphnia magna*
g: value corrected for background concentration (9.0 µg/l)
h: geometric mean of 26 and 75 mg/l, parameter growth for *Jordanella floridae*
i: most sensitive parameter(deformities) for *Pimephalis promelas*
j: most sensitive parameter(survival) for *Salmo gairdneri,* geometric mean of for background corrected values (320-30), (140-11) and (36-11) µg/l

Table 5.8.2 **Zinc: marine data used for extrapolation**

taxonomic group	NOEC in µg/l	taxonomic group	NOEC in µg/l
alg	100	alg	100
alg	15[a]	coe	300
alg	24[b]	ann	320
alg	500	ann	100[g]
alg	35[c]	ann	100
alg	2,700[d]	ann	100[h]
alg	100	mol	50
alg	15	mol	19
alg	10	mol	50
alg	100	mol	1,000
alg	34[e]	cru	440
alg	140[f]	cru	18
alg	10	cru	120
alg	200	ech	10

All data originate from Janus, 1993; adapted Janus et al., 1996. (Janus, J.A. (1993) Integrated Criteria Document Zinc: Ecotoxicity. *Appendix to RIVM report no.* 710401 028; Janus, J.A., Van Beelen, P., Vaal, M.A., Senhorst, H.A.J. and Van de Guchte, C. (1996) A further look at Zinc; A response to the Industry addendum to the Integrated Criteria Document Zinc. *RIVM report no.* 601014 012/*RIZA*-96.038).

a: geometric mean of 30, 7, 20, 7, 7, 20 and 40 µg/l, parameter growth for *Asterionella japonica*

b: geometric mean of 10 and 60 mg/l, parameter growth for *Chaetoceros compressum*

c: geometric mean of 40, 60, 10 and 60 µg/l, parameter growth for *Nitzschia closterium*

d: geometric mean of 10000, 4000 and 500 µg/l, parameter growth for *Phaeodactylum tricornutum*

e: geometric mean of 25, 50, 100, 20, 60, 7, 7, 30, 200 and 50 µg/l, parameter growth for *Skeletonema costatum*

f: geometric mean of 100 and 200 µg/l, parameter growth for *Thalassiosira pseudonana*

g: geometric mean of 100 and 100 µg/l, parameter reproduction for *Ctenodrilus serratus*

h: geometric mean of 100 and 100 µg/l, parameter reproduction for *Nereis arenaceodentata*

APPENDIX VI TERRESTRIAL TOXICITY DATA USED FOR EXTRAPOLATION

Processes:

bac = Bacteria and Fungi
mac = Macrophyta
iso = Isopoda
col = Collembola
aca = Acari
mol = Mollusca
nem = Nematoda
oli = Oligochaeta

Processes:

N-min = N-mineralisation
phos = phosphatase
ure = urease activity
nitr = nitrification
arg-am = arginine ammonification
ATP = ATP content
cel-resp = cellulose respiration
Fe(III)-red = Fe(III) reduction
glu-resp = glucose respiration
resp = respiration
aryl = arylsulphatase
dehy = dehydrogenase
am = ammonification
eth = ethylene production
glu = glucose mineralisation
cell = cellulose mineralisation
amy = amylase
cellu = cellulase
xyl = xylanase
glut = glutamase

Table 6.1.1 **Arsenic: terrestrial data on species used for extrapolation**

taxonomic group	NOEC in mg/kg standard soil	taxonomic group	NOEC in mg/kg standard soil
mac	72	oli	45
mac	55[a]		

All data from Appendix III

a: geometric mean of 140 and 22 mg/kg, parameter growth for *G. hirsutum*

Table 6.1.2 **Arsenic: terrestrial data on processes used for extrapolation**

process	NOEC in mg/kg standard soil	process	NOEC in mg/kg standard soil
N-min	420[a]	phos	980[k]
N-min	310[b]	ure	48
N-min	370[c]	ure	370
N-min	340[d]	ure	140
phos	120[e]	ure	37
phos	1,100[f]	ure	100
phos	380[g]	ure	17
phos	340[h]	nitr	42[l]
phos	98[i]	nitr	67[m]
phos	200[j]	nitr	76[n]

All data from Appendix IV

a: geometric mean of 420 and 420 mg/kg, process N-mineralisation in soil with pH 5.8

b: geometric mean of 310 and 310 mg/kg, process N-mineralisation in soil with pH 6.6

c: geometric mean of 370 and 370 mg/kg, process N-mineralisation in soil with pH 7.8

d: geometric mean of 340 and 340 mg/kg, process N-mineralisation in soil with pH 7.4

e: geometric mean of 210 and 71 mg/kg, process phosphatase(acid) in Webster soil with pH 5.8

f: geometric mean of 1900 and 620 mg/kg, process phosphatase(acid) in Harps soil with pH 7.8

g: geometric mean of 850 and 170 mg/kg, process phosphatase(acid) in Okoboji soil with pH 7.4

h: geometric mean of 620 and 190 mg/kg, process phosphatase(alkaline) in Harps soil with pH 7.8

i: geometric mean of 170 and 57 mg/kg, process phosphatase(alkaline) in Okoboji soil with pH 7.4

j: geometric mean of 140 and 280 mg/kg, process phosphatase in spar-mor soil with pH 4.3

k: geometric mean of 680 and 1400 mg/kg, process phosphatase in mull soil with pH 6.3

l: geometric mean of 42 and 42 mg/kg, process nitrification in Webster soil with pH 5.8

m: geometric mean of 37 and 122 mg/kg, process nitrification in Harps soil with pH 7.8

n: geometric mean of 34 and 170 mg/kg, process nitrification in Okoboji soil with pH 7.4

Table 6.2.1 Cadmium: terrestrial data on species used for extrapolation

taxonomic group	NOEC in mg/kg standard soil	taxonomic group	NOEC in mg/kg standard soil
mac	18[a]	oli	14
mac	14	oli	250
mac	2.0[b]	iso	2.8[e]
mol	7.8	col	57[f]
oli	130	col	2.9[g]
oli	5.3[c]	aca	1.2[h]
oli	23[d]		

all data from Appendix III

a: geometric mean of 20, 7.9, 55, 10, 71 and 6.1 mg/kg, parameter growth for grain species

b: geometric mean of 1.5, 2.2, 1.1, 2.5, 2.3 and 3.4 mg/kg, parameter growth for *S. oleracea*

c: lowest parameter(reproduction) for *E. andrei*

d: lowest parameter(reproduction) for *E. fetida,* geometric mean of 13 and 42 mg/kg

e: lowest parameter(growth) for *P. scaber,* geometric mean of 4.6 and 1.7 mg/kg

f: lowest parameter(reproduction) for *F. candida,* geometric mean of 36 and 89 mg/kg

g: lowest parameter(growth) for *O. cincta*

h: lowest parameter(reproduction) for *P. peltifer*

Table 6.2.2 Cadmium: terrestrial data on processes used for extrapolation

process	NOEC in mg/kg standard soil	process	NOEC in mg/kg standard soil
arg-am	31	dehy	54
arg-am	110	dehy	27
ATP	80	dehy	170
cel-resp	200	dehy	31
Fe(III)-red	62	dehy	110
glu-resp	200	dehy	91
nitr	69	dehy	98
nitr	60	dehy	69
nitr	54	dehy	33
nitr	40	dehy	24
N-min	340	dehy	29
N-min	180	dehy	120
N-min	200	dehy	81
N-min	270	dehy	67
N-min	650	dehy	96
N-min	2,100	dehy	81
N-min	480	phos	380
N-min	370	phos	1,000
N-min	310	phos	170
resp	200[a]	phos	300
resp	270[b]	phos	270
resp	200[c]	phos	300
resp	450[d]	phos	90
resp	130	phos	29[h]
resp	83	phos	11,000
resp	65	phos	18[i]
resp	63	phos	750[j]
resp	160	ure	71[k]
resp	120	ure	380[l]
resp	310	ure	2.7[m]
aryl	6.1[e]	ure	2200
aryl	4.7	ure	77
aryl	9.2[f]	ure	60
aryl	25[g]	ure	67
aryl	3,000	ure	30
		ure	52
		ure	26

all data from Appendix IV

a: respiration, result from test with sandy loam with pH 5.1 with longest exposure

b: respiration, result from test with sand with pH 7.7 with longest exposure

c: respiration, result from test with silty loam with pH 7.4 with longest exposure

d: respiration, result from test with sandy peat with pH 4.3 with longest exposure

e: arylsulphatase, result from test with sand with pH 7.7 with longest exposure

f: arylsulphatase, result from test with silty loam with pH 7.4 with longest exposure

g: arylsulphatase, result from test with clay with pH 6.8 with longest exposure

h: phosphatase, result from test with sand with pH 7.7 with longest exposure

i: phosphatase, result from test with silty loam with pH 7.4 with longest exposure

j: phosphatase, result from test with clay with pH 6.8 with longest exposure

k: urease, result from test with sand with pH 7.7 with longest exposure

l: urease, result from test with silty loam with pH 7.4 with longest exposure

m: urease, result from test with clay with pH 6.8 with longest exposure

Table 6.3.1 **Chromium(VI): terrestrial data on processes used for extrapolation**

process	NOEC in mg/kg standard soil
mic	1,400[a]
mic	680[b]

All data from Appendix IV

a: geometric mean of 1000 and 2000 mg/kg

b: geometric mean of 480 and 960 mg/kg

Table 6.3.2 **Chromium(III): terrestrial data on species used for extrapolation**

taxonomic group	NOEC in mg/kg standard soil	taxonomic group	NOEC in mg/kg standard soil
mac	380[a]	oli	38[b]

All data from Appendix III

a: geometric mean of 960, 200, 160, 720 and 350 mg/kg for grain species

b: lowest parameter(reproduction) for *E. andrei*

Table 6.3.3 **Chromium(III): terrestrial data on processes used for extrapolation**

process	NOEC in mg/kg standard soil	process	NOEC in mg/kg standard soil
aryl	3.9	phos	1,300[e]
aryl	1.5[a]	phos	320[f]
aryl	94	phos	1300[g]
aryl	160[b]	phos	630
aryl	4,600[c]	resp	220[h]
nitr	120	resp	140[i]
nitr	27	resp	120
nitr	24	resp	240
nitr	22	ure	720[j]
N-min	90	ure	1000[k]
N-min	93	ure	210[l]
N-min	120	ure	600
N-min	73	ure	31
phos	140	ure	79
phos	390	ure	90
phos	370	ure	24
phos	55	ure	120
phos	390	ure	11
phos	1,300[d]		

All data from Appendix IV

a: arylsulphatase, result from test with sandy loam with pH 5.1 with longest exposure

b: arylsulphatase, result from test with clay with pH 6.8 with longest exposure

c: arylsulphatase, result from test with sandy peat with pH 3.0 with longest exposure

d: phosphatase, result form test with sand with pH 7.7 with longest exposure

e: phosphatase, result form test with sandy loam with pH 5.1 with longest exposure

f: phosphatase, result form test with silty loam with pH 7.4 with longest exposure

g: phosphatase, result form test with clay with pH 7.5 with longest exposure

h: respiration, result from test with sandy loam with pH 5.1 with longest exposure

i: respiration, geometric mean of 100 and 210 mg/kg

j: urease, result from test with sand, with pH 7.7 with longest exposure

k: urease, result from test with silty loam, with pH 7.4 with longest exposure

l: urease, result from test with clay, with pH 7.5 with longest exposure

Table 6.4.1 **Copper: terrestrial data on species used for extrapolation**

taxonomic group	NOEC in mg/kg standard soil	taxonomic group	NOEC in mg/kg standard soil
mac	1,500	oli	180
mac	1,500	oli	61[d]
mac	1,500	oli	110[e]
mac	290[a]	oli	26[f]
nem	430[b]	col	2,800
oli	94[c]	aca	180

All data from Appendix III

a: geometric mean of 350, 220, 180, 390 and 340 mg/kg, parameter growth for grain species

b: geometric mean of 300, 290, 1100, 810 and 190 mg/kg, parameter mortality for *C. elegans*

c: lowest parameter(reproduction) for *A. caliginosa*

d: lowest parameter(growth/reproduction) for *E. andrei*

e: lowest parameter(reproduction) for *E. fetida,* geometric mean of 35 and 380 mg/kg

f: lowest parameter(reproduction) for *L. rubellus,* geometric mean of 40 and 17 mg/kg

Table 6.4.2 Copper: terrestrial data on processes used for extrapolation

process	NOEC in mg/kg standard soil	process	NOEC in mg/kg standard soil
am	360	resp	310[c]
eth	6.7	resp	520
eth	7.8	aryl	13[d]
eth	11	aryl	520[e]
eth	12	aryl	370[f]
eth	11	aryl	1,800[g]
eth	7.3	aryl	4,700[h]
eth	12	phos	91[i]
eth	8.2	phos	520[j]
eth	13	phos	470[k]
eth	11	phos	520[l]
eth	11	phos	140[m]
eth	11	phos	17[n]
eth	12	phos	660
eth	14	phos	220[o]
eth	14	phos	650[p]
eth	11	phos	81[q]
eth	6.7	ure	42[r]
eth	10	ure	180
eth	14	ure	440
nitr	310	ure	350[s]
nitr	36	ure	290[t]
nitr	100	ure	25[u]
nitr	90	ure	26[v]
N-min	250	ure	78[w]
N-min	310	ure	60[x]
resp	21	ure	37[y]
resp	9.8[a]	ure	10[z]
resp	560[b]	ure	26[aa]
		ure	14[ab]

All data from Appendix IV

a: respiration, result from test with longest exposure
b: respiration, result from test with longest exposure
c: respiration, result from test with longest exposure
d: arylsulphatase, result from test with longest exposure
e: arylsulphatase, result from test with longest exposure
f: arylsulphatase, result from test with longest exposure
g: arylsulphatase, result from test with longest exposure
h: arylsulphatase, result from test with longest exposure
i: geometric mean of 91 and 91 mg/kg
j: geometric mean of 520 and 520 mg/kg
k: geometric mean of 470 and 470 mg/kg
l: geometric mean of 520 and 520 mg/kg
m: geometric mean of 140 and 140 mg/kg
n: phosphatase, result from test with longest exposure
o: phosphatase, result from test with longest exposure
p: phosphatase, result from test with longest exposure
q: phosphatase, result from test with longest exposure
r: urease, result from test with longest exposure
s: urease, result from test with longest exposure
t: urease, result from test with longest exposure
u: geometric mean of 25 and 25 mg/kg
v: geometric mean of 26 and 26 mg/kg
w: geometric mean of 43 and 140 mg/kg
x: geometric mean of 32 and 110 mg/kg
y: geometric mean of 37 and 37 mg/kg
z: geometric mean of 10 and 10 mg/kg
aa: geometric mean of 26 and 26 mg/kg
ab: geometric mean of 14 and 14 mg/kg

Table 6.5.1 **Lead: terrestrial data on species used for extrapolation**

taxonomic group	NOEC in mg/kg standard soil	taxonomic group	NOEC in mg/kg standard soil
mac	690[a]	oli	1,400[c]
mac	1,500	oli	240[d]
mac	1,500	mol	1,000
mac	120	cru	40
mac	1,500	ins	1,100
mac	120	aca	400
oli	450[b]		

All data originate from Janus et al., 1997. (Janus, J.A., Annema, J.A., Aben, J.M.M. and Slooff, W. (1997) Evaluatiedocument lood. *RIVM report no.* 601014 003. (Draft, In Dutch)).

a: geometric mean of 1,100, 760, 700, 1,200, 1,100, 960 and 180 mg/kg, parameter yield for *Avena sativa*

b: geometric mean of 740, 740 and 170 mg/kg, parameter reproduction for *Dendrobaena rubida*

c: most sensitive parameter(reproduction) for *Eisenia foetida*, geometric mean of 2,000 and 1,000 mg/kg

d: most sensitive parameter(reproduction) for *Lumbricus rubellus*

Table 6.5.2 **Lead: terrestrial data on processes used for extrapolation**

process	NOEC in mg/kg standard soil	process	NOEC in mg/kg standard soil
resp	240	nitr	1,500
resp	200	glu	1,400
resp	1,200	cell	330[a]
resp	2,300	amy	1,000
resp	190	cellu	1,000
resp	15	deh	490
resp	24	deh	6,200
resp	5,200	deh	7,700
resp	1,500	phos	570[b]
resp	1,000	phos	470[c]
resp	500	ure	50[d]
N-min	180	ure	49[e]
N-min	570	ure	900[f]
N-min	440	ure	580[g]
N-min	340	ure	250[h]
N-min	950	ure	320[i]
am	1,500	ure	890[j]
nitr	380	ure	94[k]
nitr	1,000	xyl	1,000
nitr	950		

All data originate from Janus et al., 1997. (Janus, J.A., Annema, J.A., Aben, J.M.M. and Slooff, W. (1997) Evaluatiedocument lood. *RIVM report no.* 601014 003. (Draft, In Dutch)).

a: geometric mean of 160, 180 and 1200 mg/kg
b: geometric mean of 570 and 570 mg/kg
c: geometric mean of 470 and 470 mg/kg
d: geometric mean of 50 and 50 mg/kg
e: geometric mean of 49 and 49 mg/kg
f: geometric mean of 630 and 1,300 mg/kg
g: geometric mean of 1,000 and 340 mg/kg
h: geometric mean of 570 and 110 mg/kg
i: geometric mean of 1,000 and 100 mg/kg
j: geometric mean of 890 and 890 mg/kg
k: geometric mean of 94 and 94 mg/kg

Table 6.6.1 **Mercury, inorganic: terrestrial data on processes used for extrapolation**

process	NOEC in mg/kg standard soil	process	NOEC in mg/kg standard soil
resp	79	resp	40
resp	9.0	resp	248
resp	99	am	6.0
resp	124	am	10
resp	12	nitr	6.0
resp	31	nitr	10
resp	35	amy	79
resp	40	phos	2,406
resp	208	ATP	1.4

All data originate from Slooff et al., 1995. (Slooff, W., Van Beelen, P., Annema, J.A. and Janus, J.A. (1995) Integrated Criteria Document Mercury. *RIVM report no.* 601014 008).

Table 6.6.2 **Methyl-mercury: terrestrial data on species used for extrapolation**

taxonomic group	NOEC in mg/kg standard soil	taxonomic group	NOEC in mg/kg standard soil
oli	3.7		

Data originate from Slooff et al., 1995. (Slooff, W., Van Beelen, P., Annema, J.A. and Janus, J.A. (1995) Integrated Criteria Document Mercury. *RIVM report no.* 601014 008).

Table 6.7.1 Nickel: terrestrial data on species used for extrapolation

taxonomic group	NOEC in mg/kg standard soil	taxonomic group	NOEC in mg/kg standard soil
oli	65		

Data originate from Van de Meent et al., 1990. (Van de Meent, D., Aldenberg, T., Canton, J.H., Van Gestel, C.A.M. and Slooff, W. (1990) Desire for levels. Background study for the policy document "Setting environmental quality standards for water and soil". *RIVM-report no.* 670101 002).

Table 6.7.2 Nickel: terrestrial data on processes used for extrapolation

process	NOEC in mg/kg standard soil	process	NOEC in mg/kg standard soil
resp	520	ure	26

All data originate from Van de Meent et al., 1990. (Van de Meent, D., Aldenberg, T., Canton, J.H., Van Gestel, C.A.M. and Slooff, W. (1990) Desire for levels. Background study for the policy document "Setting environmental quality standards for water and soil". *RIVM-report no.* 670101 002).

Table 6.8.1 **Zinc: terrestrial data on species used for extrapolation**

taxonomic group	NOEC in mg/kg standard soil	taxonomic group	NOEC in mg/kg standard soil
mac	280[a]	oli	1,200[e]
mac	220[b]	mol	380
mac	210[c]	cru	510
mac	420[d]		

All data originate from Janus, 1993, adapted Janus et al., 1996. (Janus, J.A. (1993) Integrated Criteria Document Zinc: Ecotoxicity. *Appendix to RIVM report no.* 710401 028; Janus, J.A., Van Beelen, P., Vaal, M.A., Senhorst, H.A.J. and Van de Guchte, C. (1996) A further look at Zinc; A response to the Industry addendum to the Integrated Criteria Document Zinc. *RIVM report no.* 601014 012/*RIZA*-96.038).

a: geometric mean of 340, 340, 320, 320, 280, 360, 340, 68, 340 and 340 mg/kg, parameter yield for *Medicago sativa*

b: geometric mean of 340, 340, 320, 320, 280, 360, 340, 68, 340, 340, 340 and 14 mg/kg, parameter yield for *Zea mays*

c: geometric mean of 340, 340, 320, 320, 280, 360, 340, 14, 68, 340 and 340 mg/kg, parameter yield for *Latuca sativa*

d: geometric mean of 160, 160, 550, 420, 740, and 1200 mg/kg, parameter yield for *Avena sativa*

e: geometric mean of 1300, 1300, 1300, 320, and 3200 mg/kg, parameter survival/growth/reproduction for *Eisenia fetida*

Table 6.8.2 **Zinc: terrestrial data on processes used for extrapolation**

process	NOEC in mg/kg standard soil	process	NOEC in mg/kg standard soil
resp	89	glut	1,600
resp	130	glut	500
resp	9.0	glut	270
resp	310	glut	1,700
resp	240	amy	1,300
resp	3,800	cellu	1,300
resp	270	phos	180
resp	250	phos	140
N-min	75	ure	30
am	1,300	ure	27
nitr	130	ure	48
nitr	100	ure	47
nitr	180	xyl	1,300
nitr	21		

All data originate from Janus, 1993, adapted Janus et al., 1996. (Janus, J.A. (1993) Integrated Criteria Document Zinc: Ecotoxicity. *Appendix to RIVM report no.* 710401 028; Janus, J.A., Van Beelen, P., Vaal, M.A., Senhorst, H.A.J. and Van de Guchte, C. (1996) A further look at Zinc; A response to the Industry addendum to the Integrated Criteria Document Zinc. *RIVM report no.* 601014 012/*RIZA*-96.038).

APPENDIX VII TOXICITY OF CADMIUM, CHROMIUM AND COPPER TO SPECIES IN SEDIMENT-WATER SYSTEMS

LEGEND

Organism	Crustaceans, Oligochaetes, Molluscs, Fish, Amphibians. Between brackets are presented the lifestage, length or weight of the organism,
A	Nominal concentration (N) or Analyzed concentration (A),
test type	Static (S) or continuous Flow-through (F),
testcompound	if the complete testcompound is not mentioned (..) is added;
Criterion	NOEC and L(E)C50 values. Notes indicate the effect parameter or the extrapolation factor used to calculate the NOEC,
% O.m.	% organic matter in sediment (if presented in % organic carbon a factor of 1.7 was used to calculate % om),
% clay	% clay in sediment ,
temp °C	temperature in °C,
exp. time	Exposure time given in hours (h); days (d) ,
pH, hardness	measured in overlying medium, sometimes given as range or estimate if no exact, data are presented in the study,
criterion	LC: lethal concentration; EC: effect concentration; NOEC: no observed effect concentration
result	given as concentration in the sediment (in mg/kg dry weight) or as concentration in the overlying medium (in mg/l)
NOEC stand.sed	recalculated to NOEC in standard sediment (10% organic matter and 25% clay) and if necessary applying a extrapolation factor for the recalculation from effect concentration to No effect concentration

Notes:

1. Tested for the last 48h of a 10 day period in which cadmium was added to the sediment
2. total cadmium in water
3. nominal concentration was confirmed by analysis
4. Acid-volatile sulfide (AVS) contaminations of the sediment (mmol/g)
5. LC50 calculated from water concentration; concentrations in water and sediment measured.

a mortality or immobility
n hatchability
x EC 50 - 90%: NOEC = EC/10

Table 7.1 Toxicity of Cadmium to freshwater organisms in sediment-water systems: L(E)C50 and NOEC values

Organism	Test compound	A	Test type	pH	% O.m.	% Clay	Temp °C	Hardness mg CaCO$_3$/l	Exp. time	Criterion	Result	NOEC standard sed. (mg/kg d.w.)	Reference
Crustaceans													
Daphnia magna	$CdCl_2$	A^2	S	7.1	5.2	56	19		48h	LC50	252 µg/l		BKH, 1995
Daphnia magna	$CdCl_2$	A^1	S	7.1	5.2	56	19		48h	LC50	69 µg/l		BKH, 1995
Daphnia magna	$CdCl_2$	A^1	S	7.1	5.2	56	19		48h	LC50^x	543 mg/kg 14.2 µg/l	47	BKH, 1995
Hyalella azteca	$CdCl_2$	A^2	S	7.1	5.2	56	19		48h	LC50	74 µg/l		BKH, 1995
Hyalella azteca	$CdCl_2$	A^2	S	7.1	5.2	56	19		48h	LC50	80 µg/l		BKH, 1995
Hyalella azteca	$CdCl_2$	A^2	S	7.1	5.2	56	19		48h	LC50^x	541 mg/kg 44 µg/l	47	BKH, 1995
Oligochaetes													
Lumbricus variegatus	$CdCl_2$	A	F	7.9-8.0	18	38^4	21.5	44.5	10d	NOEC^a	3000 mg/kg	2300	BKH, 1995
Lumbricus variegatus	$CdCl_2$	A	F	7.9-8.0	2.6	6.8^4	21.5	44.5	10d	NOEC^a	800 mg/kg	1300	BKH, 1995
Lumbricus variegatus	$CdCl_2$	A	F	7.9-8.0	3.1	2.8^4	21.5	44.5	10d	NOEC^a	300 mg/kg	490	BKH, 1995
Molluscs													
Helisoma sp.	$CdCl_2$	A	F	7.9-8.0	18	32^4	21.5	44.5	10d	NOEC^a	3000 mg/kg	2300	BKH, 1995
Helisoma sp.	$CdCl_2$	A	F	7.9-8.0	18	7.3^4	21.5	44.5	10d	NOEC^a	2500 mg/kg	2400	BKH, 1995
Helisoma sp.	$CdCl_2$	A	F	7.9-8.0	18	3.2^4	21.5	44.5	10d	NOEC^a	300 mg/kg	290	BKH, 1995
Fish													
Carassius auratus (eggs)	$CdCl_2$	A	S	7.6-7.7	2.26	12	22.3	101.6	7d	NOEC^n	>1008 mg/kg 68.6 µg/l		BKH, 1995
Micropterus salmoidus (eggs)	$CdCl_2$	A	S	7.6-7.7	2.26	12	22.3	101.6	7d	NOEC^n	97.6 mg/kg 6.1 µg/l	140	BKH, 1995
Amphibians													
Rana pipiens (eggs)	$CdCl_2$	A	S	7.6-7.7	2.26	12	22.3	101.6	7d	NOEC^n	>1074 mg/kg 76.5 µg/l		BKH, 1995

Table 7.2 Toxicity of Cadmium to saltwater organisms in sediment-water systems: L(E)C50 and NOEC values

Organism	Test compound	A	Test type	pH	% O.m.	% Clay	Temp °C	Salinity in ‰	Exp. time	Criterion	Result	NOEC standard sed. (mg/kg d.w.)	Reference
Crustaceans													
Rhepoxynius abronius (juv., 1-2 mm length)	Cd..	N^3	F	-	1.5	4	15	25	10d	$LC50^x$	8.2 mg/kg	4.7	BKH, 1995
Rhepoxynius abronius (adult, 3-5 mm length)	Cd..	N^3	F	-	1.5	4	15	25	10d	$LC50^x$	11.5 mg/kg	6.6	BKH, 1995
Rhepoxynius abronius (juv., 1-2 mm length)	Cd..	N^3	F	-	1.5	4	15	25	10d	$NOEC^a$	3 mg/kg	5.1	BKH, 1995
Rhepoxynius abronius (adult, 3-5 mm length)	Cd..	N^3	F	-	1.5	4	15	25	10d	$NOEC^a$	6 mg/kg	10	BKH, 1995

Table 7.3 Toxicity of Copper to saltwater organisms in sediment-water systems: L(E)C50 and NOEC values

Organism	Test compound	A	Test type	pH	% O.m.	% Clay	Temp °C	Salinity in ‰	Exp. time	Criterion	Result	NOEC standard sed. (mg/kg d.w.)	Reference
Molluscs													
Protothaca staminea (16-35 mm)	$Cu(NO_3)_2$	A	F	-	0.15	0	-	-	48d	NOEC[a]	12.4 mg/kg	30	BKH, 1995

Table 7.4 Toxicity of Chromium to freshwater organisms in sediment-water systems: L(E)C50 and NOEC values

Organism	Test compound	A	Test type	pH	% O.m.	% Clay	Temp °C	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result	NOEC standard sed. (mg/kg d.w.)	Reference
Fish													
Pimephales promelas	$K_2Cr_2O_7$	A	S	8.0	0.1-2.4	14-27	25	44-54	96h	LC50	12.3 mg/l[5]		BKH, 1995
(3-14d)										LC50[x]	127.3-169.8 mg/kg	12-22	
Pimephales promelas	$K_2Cr_2O_7$	A	S	8.0	0.1-2.4	14-27	25	44-54	30d	LC50	0.041 mg/l[5]		BKH, 1995
(3-14d)										LC50[x]	0.9-2.4 mg/kg	0.09-0.31	
Ictalurus punctatus	$K_2Cr_2O_7$	A	S	8.0	0.1-2.4	14-27	25	44-54	96h	LC50	1.9 mg/l[5]		BKH, 1995
(2 weeks)										LC50[x]	61.5-77.5 mg/kg	5.9-9.9	
Ictalurus punctatus	$K_2Cr_2O_7$	A	S	8.0	0.1-2.4	14-27	25	44-54	96h	LC50	0.054 mg/l[5]		BKH, 1995
(2 weeks)										LC50[x]	1.3-3.0 mg/kg	0.13-0.38	

References Toxicity to species in sediment-water systems

BKH (1995) Update toxiciteitsgegevens voor vier stoffen in het kader van MILBOWA. Versie maart 1995.

APPENDIX VIII EXAMPLES OF THE INFLUENCE OF HARDNESS ON CHRONIC METAL TOXICITY

In this appendix some examples of the influence of hardness on chronic metal toxicity are presented. To be able to relate the influence of hardness on sensitivity of the species, only comparisons from experiments in which a species is exposed under identical conditions with hardness as the only varying condition, are presented. The selected examples concern cadmium, chromium(VI), copper and zinc. The hardness is expressed as mg $CaCO_3$ /l.

cadmium

- In a study with *Daphnia pulex* (BKH, 1995 cited in Apendix I) exposed to cadmium in water with a hardness of 58, 115 and 230, the NOEC for mortality was 3.8 µg/l, 13 µg/l and 13 µg/l, respectively and the NOEC reproduction 3.8, 7.5 and 7.5 respectively. This means that the NOEC for mortality increased with a factor 3 and the NOEC for reproduction with a factor 2 with increasing hardness from 58 to 230.
- In comparative early-life stage tests in which fish (brook trout *Salvelinus fontinalis* and channel catfish *Ictalurus punctatus*) was exposed to Cd in soft water (hardness of 35) and hard water (hardness of 185) (Sauter et al., 1976 cited in Appendix I), only for brook trout a significant effect of hardness on toxicity was found (NOEC-LOEC in soft and hard water: 1-3 µg/l and 7-12 µg/l, respectively). In the test with catfish no significant effect of hardness on toxicity was found (NOEC for mortality and NOEC for growth 20 µg/l and 12 µg/l respectively). In this study hardness appeared to result in a delay in effects rather than in a decrease in toxicity.

Chromium(VI)

- In a study performed by Patterson et al. (1992, cited in Appendix I), three tests in which *Ceriodaphnia dubia* was exposed to Cr(VI) were performed. The hardness of the water in the three tests was 157, 182 and 182 respectively. The NOEC for mortality was 95 µg/l, 250 µg/l and 340 µg/l respectively and the NOEC for reproduction 65 µg/l, 110 µg/l and 120 µg/l respectively. In conclusion the NOEC for mortality increased with increasing hardness a factor 3 when the first and the second test are compared and a factor 4 when the first and the third test are compared. The NOEC for reproduction increased a factor two with increasing hardness.

Copper

- In a study with *Ceriodaphnia dubia* (BKH, 1995 cited in Appendix I) exposed to copper in water with a hardness of 94 and 179 no effect of hardness on the NOEC for reproduction was found (NOECs of 6.3 µg/l and 6.4 µg/l, respectively).
- In another test, also with *Ceriodaphnia dubia* (BKH, 1995 cited in Appendix I) exposed to copper in water with a hardness of 13 and 75, a decrease (!) of the NOEC for reproduction with increasing hardness was found (NOECs of 40 µg/l and 27 µg/l, respectively).
- In a test with *Daphnia pulex* (BKH, 1995 cited in Appendix I) exposed to copper in water with a hardness of 104 and 230, the NOEC for mortality decreased (!) from 35 µg/l to 10 µg/l, which is a factor three, with increasing hardness.
- In comparative early-life stage tests in which fish (brook trout *Salvelinus fontinalis* and channel catfish *Ictalurus punctatus*) was exposed to Cu in soft water (hardness of 38) and hard water (hardness of 186) (Sauter et al., 1976 cited in Appendix I), no significant or only a small effect of hardness on toxicity was found. For *Salvelinus fontinalis* the NOEC mortality was 10 µg/l and 19 µg/l and the NOEC for growth 0.67-1.0 µg/l and 2.0 µg/l respectively. For *Ictalurus punctatus* the NOEC mortality was 10 µg/l and 15 µg/l respectively and the NOEC for growth 9 µg/l and 10 µg/l respectively. In this study hardness appeared to result in a delay in effects rather than in a decrease Cu in soft water and hard water.

zinc

- In comparative life cycle tests with *Dapnia magna*, diluting the original hard water from 200 mg/l to 100 mg/l did not affect the toxicity of Zn; a further decrease in hardness to 50 mg/l resulted in a 2-fold decrease (!) in toxicity (Chapman et al., cited in EPA, 1987 and Janus, 1993, see references in chapter 10). The somewhat higher toxicity in the hard and medium-hard water can be explained by the relatively high alkalinity in these waters. A high alkalinity results in the formation of insoluble zinc complexes with the carbonates determining the alkalinity, increasing the toxicity to daphnia's by increasing oral exposure. This will also be valid for other metals and other filter-feeding organisms.
- In comparative life cycle tests with *Ceriodapnia dubia* (Belanger and Cherry, 1990 cited in Janus, 1993, see references in chapter 10), no consistent effect of hardness and pH (the two variables tested independently) on the toxicity of Zn was found; the maximum difference between the NOEC values for reproduction including those estimated from the LOEC (see Janus, 1993) was a factor of 6.

APPENDIX IX MPAs FOR SOIL ASSUMING "50th PERCENTILE BACKGROUNDS"

In this appendix the outcome of the MPAs with varying bioavailability of the background concentration and assuming a background concentration based on the 50th percentile of the reference lines (C*b*(50)), is analysed. For molybdenum, nickel, selenium and thallium no reference line is derived (see also section 5.2) and no background concentration based on the 50th percentile of the reference lines for these metals is shown. Only for the metals for which statistical extrapolation is applied, results are shown.

In table IX.1 the MPA(soil) on the basis of the C*b*(50) is shown together with the MPA(soil) on the basis of the background concentration based on the 90th percentile of the reference lines C*b*(90) (between brackets). Although for some metals the background concentration based on the 50th percentile is a factor 2-3 lower, like for instance for cadmium and lead, the result for the MPA assuming different fractions bioavailable is only small.

Table IX.1 MPA values for standard soil (=soil containing 10% organic matter and 25% clay) using the 50th percentile of the reference lines (MPA(soil)) (MPAs using the 90th percentile of the reference lines are shown between brackets), and background concentration based on the 50th percentile of the reference lines (C*b*(50)) and on the 90th percentile of the reference lines (C*b*(90)). All values are in mg/kg.

	MPA(soil)				
	$\varphi = 0$	$\varphi = 0.5$	$\varphi = 1$	C*b*(50)	C*b*(90)
antimony	0.53 (f)			1.5	3.0
arsenic	4.5 (c)			14	29
barium	9.0 (f)			125	155
beryllium	0.0061 (f)			0.89	1.1
cadmium	0.76 (a)	0.74 (0.73)	0.74 (0.73)	0.39	0.8
chromium*	3.8 (c)			50	100
cobalt	24 (c)			7.0	9.0
copper	3.5 (a)	3.7 (4.1)	4.2 (5.0)	21	36
lead	55 (a)	49 (42)	45 (38)	25	85
inorganic mercury	1.9 (a)	1.9 (1.9)	1.9 (1.9)	0.14	0.3
methyl-mercury	0.37 (c)			0.14	0.3
molybdenum	253 (f)			-	0.5
nickel	2.6 (c)			-	35
selenium	0.11 (f)			-	0.7
thallium	0.25 (f)			-	1.0
tin	34 (f)			15	19
vanadium	1.1 (f)			18	42
zinc	16 (a)	14 (14)	14 (16)	81	140

Notes:
-: No reference line available,
(a): MPA based on statistical extrapolation, toxicity data follow a log-logistic distribution,
(b): MPA based on statistical extrapolation, toxicity data do not follow a log-logistic distribution,
(c): MPA based on modified EPA-method, applying a factor 10 on the lowest NOEC,
(d): MPA based on modified EPA-method, applying a factor 100 on the lowest L(E)C50,
(e): MPA based on modified EPA-method, applying a factor 1000 on the lowest L(E)C50,
(f): MPA based on equilibrium partitioning,
(g): Van de Meent et al. (1990),
(h): Van de Plassche and De Bruijn (1992),
*: Based on results for chromium(III).

APPENDIX X EVALUATION OF MPAs ASSUMING DIFFERENT LEVELS OF BIOAVAILABILITY

In this Appendix an evaluation of the influence of the level of the background concentration in relation with the sensitivity distribution and the consequences for the MPA is made. Therefore the *Cb*/MPA(φ = 0)-ratio is calculated for the metals for which statistical extrapolation has been applied. Results are shown in table X.1. For most of the metals considered the background concentration is much lower than the MPA(φ = 0) for aquatic species. This is expressed by a *Cb*/MPA(φ = 0)-ratio smaller than 1. For some of the metals, for which somewhat larger differences between the MPAs with different fractions of bioavailability were found, the background concentration ratio is higher than the MPA(φ = 0), and thus the *Cb*/MPA(φ = 0)-ratio is higher than 1 (Table X.1). This concerns nickel for aquatic MPAs, and cadmium, copper, lead and zinc for the terrestrial MPAs.

Table X.1 Analysis of relationship between MPA(φ = 0) and background concentration (*Cb*) expressed as the *Cb*/MPA(φ = 0)-ratio and width of the species sensitivity distribution, expressed as β.

	aquatic				terrestrial			
	MPA	*Cb*	*Cb*/		MPA	Cb	*Cb*/	
	(φ=0)		MPA	β	(φ = 0)		MPA	β
arsenic	24	0.77	0.03	0.54				
beryllium	0.16	0.02	0.13	0.94				
cadmium	0.34	0.08	0.24	0.56	0.76	0.8	1.1	0.41 (b)
chromium*	8.5	0.17	0.02	0.50				
cobalt	2.6	0.20	0.08	0.84				
copper	1.1	0.44	0.40	0.41	3.5	36	10	0.42 (a)
lead	11	0.15	0.01	0.39	55	85	1.5	0.33 (a)
mercury**	0.01	0.01	1.00	0.52				
nickel	1.8	3.3	1.83	0.83				
selenium	5.3	0.04	0.01	0.55				
zinc	6.6	2.8	0.42	0.38	16	140	8.8	0.38 (a)

Notes:
*: Based on results for chromium(VI),
**: Based on results for methyl-mercury,
(a): Based on data on processes,
(b): Based on data on species.

That not only the relation between the background concentration and the sensitivity distribution is of importance becomes clear from two examples. Although for cobalt the background concentration in water is much smaller than the aquatic MPA(φ=0), also differences in the MPA were found assuming different percentages of availability. For zinc the background concentration in soil is higher than the MPA(φ=0), for terrestrial species and only small differences between MPAs assuming different availabilities were found. In these cases the width of the distribution (expressed as β) is of importance. As was also indicated by Struijs et al. (1997), the MPA will change more with increasing background concentrations for wider distributions (higher β) than for smaller distributions (lower β). As can be seen in Table X.1, the distribution for aquatic species for cobalt is the widest of all metals and for zinc the distribution is one of the smallest observed.

For most of the metals considered the MPA increases with increasing φ. In some cases however, the MPA decreases with increasing φ. This is the case for the MPA(grw) for lead and zinc (table 6.3), the MPA(processes) for arsenic and lead (section 7.1) and for the MPA(species) for cadmium and copper (section 7.1). For zinc the MPA(processes) decreases for φ = 0.5 and decreases for φ =1. This is also a result of the relationship between the background concentration and the position and width of the log-logistic sensitivity distribution.

The β's found in this study using NOECs are comparable with the ones found by Vaal et al. (1997) using L(E)C50s. According to these authors the variation in sensitivities of species for metals is intermediate compared with substances with a narcotic mode of action (having less variation, or smaller β) and substances having a specific mode of action like pesticides (variation higher, or higher β).

Addendum to RIVM report number 601501 001

Crommentuijn, T., Polder, M.D. and Van de Plascche, E.J. (1997) Maximum Permissible Concentrations and Negligible Concentrations for metals. Taking Background Concentrations into account.

•on page 105, Table 8.1, the last column: The values given in this column are the **MPA(sed)** instead of the **MPC(sed).** This means that the background concentrations should be added. The MPC(sed) values in Table 8.2 (third column) are the correct values.

•on page 127, Table 9.5: Although the heading says that the MPC(water) is expressed as the total concentration, the values given in table 9.5 are the dissolved concentrations. The MPC(water) expressed as total concentration is for arsenic 32 µg/l, cadmium 2.1 µg/l, chromium 84 µg/l, copper 3.8 µg/l, lead 220 µg/l, inorganic mercury 1.5 µg/l, methyl-mercury 0.1 µg/l, nickel 6.3 µg/l and zinc 40 µg/l . The comparisons with measured concentrations are performed with the total concentrations, so the results given are correct

•on page 227 in Table 5.8.1, fourth column: The value with note g should be 3 (which is the value corrected for the background concentration) instead of 12. The calculations in the report are performed with the corrected value of 3.