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MAXIMUM PERMISSIBLE CONCENTRATIONS FOR WATER, SEDIMENT AND SOIL DERIVED FROM TOXICITY DATA FOR NINE TRACE METALS

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PREFACE

This report contains results of research carried out in the framework of the project 'Setting integrated environmental quality objectives'. The results have been discussed in the 'Setting integrated environmental quality objectives advisory group'. Members thereoff are J.H.M. de Bruijn (Ministry of Housing, Physical Planning and the Environment), J.H. Canton (National Institute of Public Health and Environmental Protection), C.A.J. Denneman (Ministry of Housing, Physical Planning and the Environment), J.W. Everts (Ministry of Transport, Public Works and Water Management, Tidal Waters Division), M.P.M. Janssen (Institute for Forestry and Nature Research), P. Leeuwangh (Winand Staring Centre for Integrated Land, Soil and Water Research), E.J. van de Plassche (National Institute of Public Health and Environmental Protection), P.B.M. Stortelder (National Institute of Inland Water Management), J. Struijs (National Institute of Public Health and Environmental Protection), M. Vossen (National Institute of Inland Water Management), and J. van Wensem (Technical Committee on Soil Protection).

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CONTENTS

SAMENVATTING

In dit rapport zijn in het kader van het project Integrale Normstelling (INS) op basis van toxicologische gegevens Maximaal Toelaatbare Risiconivo's (MTR's) afgeleid voor 9 sporenelementen: antimoon, barium, beryllium, cobalt, molybdeen, seleen, thallium, tin en vanadium.
Voor het aquatisch milieu konden voor alle sporenelementen MTR's afgeleid worden. Hiertoe werden zowel toxicologische gegevens voor zoet- als voor zoutwaterorganismen gebruikt. Tevens werd een vergelijking gemaakt tussen de gevoeligheid van aquatische organismen in beide milieus voor deze sporenelementen en een aantal andere metalen. Hieruit kwam naar voren dat er geen verschil was in acute toxiciteit maar dat zoetwaterorganismen gevoeliger waren in chronische testen. Voor deze organismen waren echter veel meer gegevens beschikbaar.
Voor het terrestrisch milieu kon alleen voor cobalt een MTR afgeleid worden. Voor de andere sporenelementen waren geen betrouwbare toxiciteitsdata beschikbaar. Voor sedimentbewoners kon voor geen enkel sporenelement een MTR bepaald worden omdat geen gegevens beschikbaar waren voor benthische organismen blootgesteld via het sediment.
Bij het afleiden van MTR's is tevens rekening gehouden met doorvergiftiging via de routes water → vis → vis-etende vogel of zoogdier en bodem → regenworm → regenworm-etende vogel of zoogdier. Hierbij is gebruik gemaakt van een 'screening-methode' waarbij uitgegaan is van informatie uit reviews. Alleen voor selenium en thallium waren gegevens beschikbaar voor de aquatische route. Hieruit kwam naar voren dat voor beide metalen geen risico was voor doorvergiftiging.

SUMMARY

In this report Maximum Permissible Concentrations (MPC) are derived for 9 trace metals based on ecotoxicological data. The elements are: antimony, barium, beryllium, cobalt, molybdenum, selenium, thallium, tin, and vanadium. The study was carried out in the framework of the project 'Setting integrated environmental quality objectives'.
For the aquatic environment MPC's could be derived for all trace elements. These values were based on toxicity data for freshwater as well as saltwater organisms. Also a comparison was made between the sensitivity of saltwater and freshwater organisms for these trace elements and some other metals. The conclusion could be drawn that in acute tests freshwater and saltwater organisms are equally sensitive but that freshwater organisms are more senisitive in chronic tests. It should be stated however that much more data were available for freshwater organisms.
For the soil only for cobalt a MPC could be derived. For the other trace elements no reliable toxicity data were available. For sediment dwelling organisms no MPC's could be derived because no toxicity data were available for benthic organisms exposed via the sediment.
Secondary poisoning was taken into account for the routes water → fish → fish-eating bird or mammal and soil → earthworm → worm-eating bird or mammal. A 'screening-method' was used in which only information from reviews was used. Only for thallium and selenium data were available for the aquatic route. From these data it could be concluded that there was no risk for secondary poisoning for these metals.

1. INTRODUCTION

In 1989 the project 'Setting integrated environmental quality objectives' started arising from action item A-35 of the National Environmental Policy Plan. [1] Goal of this project is to derive integrated quality objectives for air, water, and soil for a great number of compounds based on the risk philosophy of the Ministry of Housing, Physical Planning and the Environment. [2] The project is carried out by the National Institute of Public Health and Environmental Protection. The first sub-project 'MILBOWA' resulted in the report 'Desire for levels'. [3] In this report a methodology was proposed for deriving these objectives for several compounds like heavy metals, chlorophenols, pesticides and polycyclic aromatics. Based on this report integrated environmental quality objectives for water and soil were proposed by the Minister of the Environment from The Netherlands for several compounds. [4]
The second sub-project was called 'exotic metals'[1]. Goal of this project was to derive integrated quality objectives for water, sediment, and soil for antimony, barium, beryllium, cobalt, molybdenum, selenium, thallium, tin, and vanadium. Air was not taken into account because it was expected that there would be no toxicity data for the exotic metals. For deriving these quality objectives almost the same methods are used as described in 'Desire for levels'. This means that maximum permissible concentrations (MPC) for the three compartments are determined using extrapolation methods based on toxicity data, and that these MPC's for the different compartments are coordinated using the equilibrium partitioning method. Therefore the following had to be done:

1. derivation of MPC's for water, sediment, and soil based on ecotoxicological data. Also secondary poisoning had to be taken into account.
2. derivation of partition coefficients in order to apply the equilibrium partitioning method,
3. gathering information about background levels in soil, groundwater, and surface water,
4. proposing integrated quality objectives.

It was decided by the National Institute of Public Health and Environmental Protection and the Ministry of Housing, Physical Planning, and the Environment to publish separate reports about these four aspects. This report contains the ecotoxicological data and the calculation of MPC's using extrapolation procedures based on these data.

2. METHODOLOGY

2.1 Literature search

Several sources were used for the collection of single species toxicity data:

- on-line search was carried out in TOXLINE, AQUIRE and BIOSIS. 1970 was used as starting point for freshwater and terrestrial organisms. Based on the results of this on-line search it was decided to use reliable reviews for saltwater organisms as a starting point. For barium, beryllium, selenium and vanadium therefore on-line search was carried out using 1989, 1989, 1986, and 1987 as starting points, respectively. For the other metals 1970 was used as starting point.

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[1] These metals are denoted 'exotic metals', because they were only relatively seldom subject of environmental studies. Although selenium and antimony are strictly speaking not metals but metalloids they are denoted trace metal or 'exotic metal' in this report.

literature present at the Advisory Center of Toxicology of the National Institute of Public Health and the Environment,
- retrospective literature search. Next to public literature reviews were used as a basis for this kind of literature search. The reviews used are summed up in appendix 1.

It has to be stated that only studies carried out with anorganic salts of the 'exotic metals' were selected because MPC's had to be derived for the respective elements. E.g. a test carried out with antimonytartrate was not used because it will not dissociate in water in antimony and tartrate.

2.2 Deriving toxicity data from literature

2.2.1 Quality criteria for studies

First of all a study had to meet several requirements with respect to the experimental design. Most of these requirements are stated in test-guidelines like the ones of the OECD. For metals data concerning the medium used, especially pH, are essential with respect to the speciation of metals. Also the chemical species in which the metal is added is important. Attention should also be paid to the addition of chelators like EDTA. A reduction of toxicity for metals can be expected when EDTA is present in the medium. The results of toxicity tests were always expressed as dissolved metal. In case no information was present in literature results were corrected. This means that if e.g. a LC50 was presented as y mg/l $CoCl_2$ the LC50 was calculated as (Molecular Weight Co / Molecular Weight $CoCl_2$ = 0.45 * y) mg/l Co^{2+}.

All results from experiments with soil organisms were converted to a standard soil, which is a soil with a clay and organic matter content of 25 and 10%, respectively. Therefore the so called 'soil type correction factors' were used. For the 'exotic metals' the following 'soil type correction factors' were available (L: clay content; H: organic matter content) [5]:

barium:	30 + 5 * L
beryllium:	0.4 + 0.024 x L
cobalt:	2 + 0.28 x L
tin:	4 + 0.6 x L
vanadium:	12 + 1.2 x L

For the other 'exotic metals' no 'soil type correction factors' could be derived. This means that only the test-result can be presented.

2.2.2 Parameters

For environmental effects assessment principally only those parameters are taken into account that exclusively affect species on the level of population. In general the parameter in acute studies is mortality. In (semi)chronic studies next to mortality other parameters like growth and reproduction are studied. Also other parameters are studied however, e.g. behaviour. Results of such studies were used only if the parameter considered was ecologically relevant, e.g. immobility in tests with daphnids or lying on the bottom of the test-vessel in experiments with fish.

The parameter acidification as a result of the assimilation of added glucose in a test with Pseudomonas was not considered ecologically relevant, so test results were not used for the derivation of MPC values. [6]

2.2.3 Procedures for deriving L(E)C50 values

In principle a distinct concentration-effects relationship had to be present. In most cases however, the raw data were not presented in literature. In general these studies were considered reliable, because acute studies have been carried out already for a long time and have been standardized to a great extent, especially in aquatic ecotoxicology. Only when strong indications were present about the unreliability of a study or when the results were given as a very short summary only, these data were not accepted. If only raw data were available the L(E)C50 was calculated according to the method of Spearman and Karber [7].

2.2.4 Procedures for deriving NOEC values

Several procedures were used for deriving NOEC (No Observed Effect Concentration) values depending on whether statistical methods have been used or not:

- if the NOEC value was based on a statistical method these results were used: the concentration tested had to differ from the control at a significance level of at least $P < 0.05$,
- if no statistical method was applied or could be used in principle the concentration showing less than 10% effect was considered as the NOEC. There had to be a distinct concentration-effects relationship however.
- if there were not enough NOEC values available to apply refined effects assessment or when there was a LOEC (Lowest Observed Effect Concentration) which was lower than the available reliable NOEC value(s) the following procedures were applied:
  1) LOEC >10 to 20% effect: the NOEC = LOEC/2,
  2) LOEC ≥20% effect and a distinct concentration-effects relationship: the EC10 was calculated or extrapolated and regarded as the NOEC,
  3) LOEC ≥20% with no distinct concentration-effects relationship:
     a) LOEC 20 to 50% effect: NOEC = LOEC/3,
     b) LOEC ≥50% effect: NOEC = LOEC/10.

  If other test-results were available within the same taxonomical group with distinct concentration-effects relationships, these were used to verify the above mentioned assessment factors. If for instance an acute-chronic ratio was available within the same taxonomical group this ratio was used instead of one of the factors mentioned above.

In aquatic ecotoxicology several other toxicological criteria are used. These were dealt with in the following way:

- 16% reproductive impairment concentration of Biesinger and Christensen, defined as the minimal reproducable value below which the variability in reproduction could not be detected from controles. [8] A factor of 2 was used to derive a NOEC.
- Toxische Grenzkonzentration (TGK) or Toxic Threshold of Bringmann and Kühn. [9] The NOEC was calculated as TGK/2.
- Maximum Acceptable Toxicant Concentration (MATC): if the MATC was presented as a range of 2 values the lowest value was used as the NOEC. If the MATC was presented as one value the NOEC was calculated as MATC/2.

2.3 Extrapolation methods

In the Netherlands two extrapolation methods are used for deriving environmental quality objectives:

1. preliminary effects assessment: modified EPA method,
2. refined effects assessment: Modification 0 of the method of van Straalen and Denneman as developed by Aldenberg and Slob.

These methods are described in detail in Slooff (1992) and Aldenberg and Slob (1991) [10, 11]. A short description of both methods is given below:

2.3.1 Preliminary effects assessment

In the modified EPA method assessment factors are applied on toxicity data. The size of this factor depends on the number and kind of toxicity data. In tables 1 and 2 the method is summarized for aquatic and terrestrial ecosystems, respectively. The outcome of the method is called an indicative MPC because this method lacks scientific basis. In contrast with the former EPA method, the modified method weights chronic as well as acute toxicity data over the species according to the method described below for Aldenberg & Slob. In addition also acute/chronic ratios are used to derive NOEC values. These ratios are applied only within a taxonomical group.

Table 1. Modified EPA method for aquatic ecosystems

available information	assessment factor
lowest acute L(E)C50-value or QSAR estimate for acute toxicity	1,000
lowest acute L(E)C50-value or QSAR estimate for acute toxicity for minimal algae/crustaceans/fish	100
lowest NOEC-value or QSAR estimate for chronic toxicity	10[a]
lowest NOEC-value or QSAR estimate for chronic toxicity for minimal algae/crustaceans/fish	10

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

Table 2. Modified EPA method for terrestrial ecosystems

available information	assessment factor
lowest acute L(E)C50-value or QSAR estimate for acute toxicity	1,000
lowest acute L(E)C50-value or QSAR estimate for minimal three representatives of microbe-mediated processes, earthworms or arthropods and plants	100
lowest NOEC-value or QSAR estimate for chronic toxicity	10[a]
lowest NOEC-value or QSAR estimate for chronic toxicity for minimal three representatives of microbe-mediated processes, earthworms or arthropods and plants	10

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

2.3.2 Refined effects assessment

Modification 0 calculates a Hazardous Concentration (HC*p*) defined as the concentration at which p% of the species in the community may be adversely affected. The decision on what is an acceptable value for p% is not a matter of science, but a political compromise. Anticipating on political discussions, a protection level for the ecosystem is assumed as follows: ecosystems are supposed to be protected if 95% of the species is protected, which means that in the ecosystem the NOEC is exceeded for 5% of the species. This 95% protection level can be calculated with a 50% and 95% confidence level. In The Netherlands the former value is called the MPC. [2] To indicate the uncertainty in the estimation of the MPC the 95% protection level with both 50 and 95% confidence is calculated. The method uses the lowest NOEC per species as input data and is applied when at least 4 NOEC values for different taxonomic groups are available. NOEC values used as input data for the extrapolation methods are evaluated as follows [3]:

- if for a single species several NOEC values are derived for different effect parameters the lowest is selected,
- if for a single species several NOEC values are derived for the same effect parameter a geometric mean is calculated.

Modification 0 assumes that the NOEC values used for calculation fit the log-logistic distribution. For checking this assumption the data available are tested statistically with the so called empirical distribution function (EDF): Kolmogorov-Smirnov D*sqrt(n) test. The significance level (1, 2, 5, or 10%) is presented at which the test rejects the distribution as being log-logistic. Only if the NOEC values are not log-logistically distributed at a significance level of 1% and there are no reasons for leaving out outliers also the modified EPA method is applied. The lowest value is considered as the MPC. [10]

2.4 Secondary poisoning

Secondary poisoning was taken into account according to the method of Romijn et al. (1991) for the routes water → fish → fish-eating bird or mammal and soil → earthworm → worm-eating bird or mammal. [12, 13] The method calculates a MPC for secondary poisoning using the algorithm $MPC = NOEC_{fish\text{-}eater} / BCF$ or $MPC = NOEC_{worm\text{-}eater} / BCF$ for water and soil, respectively. These MPC's are compared with the MPC based on ecotoxicological data for aquatic or terrestrial organisms. If the latter MPC's are higher secondary poisoning can be a critical pathway.

Because it was expected that secondary poisoning will not occur for these metals it was decided to carry out a global literature search for bioconcentrationfactors for fish and earthworms and for toxicological data on birds and mammals. Only if there was a risk an extensive on-line search would be carried out.

3. RESULTS OF LITERATURE SEARCH FOR TOXICITY DATA

3.1 Effects on aquatic organisms

Results of the effects on freshwater and marine organisms are presented in appendices 2 and 3, respectively. For both organisms three tables have been made: acute data, chronic data, and toxicity data not used for the application of extrapolation methods, e.g. (semi)chronic LC50 values for fish. The difference between acute and (semi)chronic exposure depends on the organism tested. In general an exposure time ≤96 hour was considered as an acute test. For lower organisms however this could be considered as a chronic test, e.g. a 72 hour study

with algae. No difference was made between water column and benthic species exposed via the water phase. With respect to environmental quality objective setting this might be important if the sensitivity of both kind of organisms differed considerably. From an analysis of data compiled in the EPA water quality criteria documents Di Toro et al. (1991) demonstrate that benthic species have a similar sensitivity compared to water column species, for saltwater as well as freshwater organisms. [14]
In general it can be stated, as was expected, that there was little information on ecotoxicological effects of these metals in aquatic systems. Especially chronic data are lacking for most metals. More information was present for effects on freshwater than on marine organisms.
In the paragraphs hereafter the results for the different metals will be discussed shortly. Also some general information is given about the behaviour of the metals in the aquatic environment.

3.1.1 Antimony (Sb)

Of the oxidation states of antimony Sb(III) and Sb(V) are dominant and exist as hydroxo-complexed species under typical environmental conditions. Over the pH range expected in typical natural environments $Sb(OH)_6^-$ is the dominant species for Sb(V); for Sb(III) $Sb(OH)_3^o$ is the dominant species. [15]
Tests were carried out with $K[Sb(OH)_6]$ and Sb_2O_3. For freshwater organisms acute data were available for crustaceans, worms, and fish varying from an EC50 for *Daphnia magna* of 420 mg/l to a LC50 of 1,100 mg/l for *Leuciscus idus melanotus*. For marine organisms only one LC50 was available for *Cyprinodon variegatus* of 6.2-8.3 mg/l. Chronic data were available only for freshwater organisms, with a lowest NOEC value of 23 mg/l for *Microcystis aeruginosa*.
These results differ from the ones presented in the EPA Quality Criteria for Water. [16] From the EPA report 'Ambient water quality criteria for antimony' the following can be concluded [17]:

- an EC50 for chlorophyll a and reduction of cell numbers for *Selenastrum capricornutum* at 0.61 and 0.63 mg/l, respectively was derived in a test with Sb_2O_3. This result was only presented in a table however and the original reference could not be obtained.
  Contrary to the test result above Bringmann and Kühn determined a NOEC of >492 mg/l for another green algae *Scenedesmus quadricauda* in a cell multiplication test. [18]
- for *Daphnia magna* an EC50 and chronic value of 19 and 5.4 mg/l, respectively was derived in a test with $SbCl_3$. For Pimephales promelas a LC50 and chronic value of 22 and 1.6 mg/l was derived in a test with the same compound. Here also, however the original references could not be traced.
  In an article by LeBlanc (1984b) a EC50 of >530 mg/l with a hardness of 173 mg/l $CaCO_3$ is presented. [19] For *Daphnia magna* one EC50 value of 420 mg/l with a hardness of 245 mg/l $CaCO_3$ was available. From these data it can be concluded that toxicity of antimony is affected by hardness.
  For effects of antimony on *Pimephales promelas* one other article was obtained. In a 30 day post-hatch test according to EPA procedures no effects were detected on hatching, survival, length, and weight of the larvae at the highest test concentration of 7.5 µg/l. [20]
  The LC50 of 1,100 mg/l for *Leuciscus idus melanotus* from appendix 2 is from a test with a water hardness of 255 mg/l $CaCO_3$. It is well known that *Pimephales promelas* is more sensitive than *Leuciscus idus melanotus*, but it is difficult to compare both results.

From this it can be concluded that the information presented in appendix 2 might underestimate the toxicity of antimony to freshwater organisms. The original data are lacking however.

3.1.2 Barium (Ba)

For barium no toxicity data were available for marine organisms. All tests with freshwater organisms were carried out with Ba(II) added as $BaCl_2$, which is the dominant species in aqueous environments containing Cl^-, SO_4^{2-}, NO_3^-, and CO_3^{2-} ions at pH ≤9.3. [15] In waters with high sulfate concentrations the amount of free Ba(II) is controlled by $BaSO_4$ which has a solubility in water of 2 mg/l at 20 °C. [21]
Acute data were available for crustaceans, fish and plants. L(E)C50 values varied from 15 mg/l for *Daphnia magna* to 570 mg/l for *Leuciscus idus melanotus*. For *Daphnia magna* the 48 h EC50 value was a factor 13 higher than the LC50 value. An explanation for these differences could be adsorption of barium on glass of the test vessels. [22] Chronic data were available for algae and crustaceans, i.e. NOEC values of 2.9 and 17 mg/l for *Daphnia magna* and *Scenedesmus*, respectively.

3.1.3 Beryllium (Be)

Also for beryllium no toxicity data were available for marine organisms. All freshwater tests were carried out with Be(II) added as $Be(NO_3)_2$ or $BeSO_4$. Concentrations of dissolved beryllium in water will be low due to the very low solubility of $Be(OH)_2$. [15]
Acute data were available for crustaceans, worms, fish, and amphibians, L(E)C50 values varying from 0.16 to 32 mg/l for *Lebistes reticulatus* and *Ambystoma opacum*, respectively. Acute toxicity of fish appeared to be related to water hardness, with beryllium being more toxic in soft water. In an acute test with Lebistes reticulatus LC50 values decreased from 19 to 0.16 mg/l for water with a hardness of 400 and 22 mg/l $CaCO_3$, respectively. [23] The same results were obtained in a test with larvae of the salamander *Ambystoma opacum*. [24] No information about this phenomenom was present for other taxonomical groups.
Chronic data were available for several lower organisms and fish with NOEC values varying from 0.68 to 260 µg/l for *Pseudomonas putida* and *Chilomonas paramaecium*, respectively. It should be stated that all tests were carried out in water with a hardness of ≤50 mg/l $CaCO_3$. In a summary of the ambient water quality criteria for beryllium, as presented in Environmental Health Criterium 106, it is stated that in a chronic test no effects on reproduction of *Daphnia magna* occurred at 3.8 µg/l (hardness 220 mg/l $CaCO_3$). [25] The original reference could however not be obtained.

3.1.4 Cobalt (Co)

Co is an essential element for mammals (vitamin B_{12} contains Co^{3+}) and micro-organisms (Co plays a role in biological N-fixation). Co also appears to be essential for (blue-green) algae. [26] Some toxicity tests with algae are therefore carried out with Co added to the medium, e.g. Bold's basal medium contains 40 µg/l $Co(NO_3)_2$. [27] Most important cobalt compounds are $CoCl_2$, $Co(NO_3)_2$, and $CoSO_4$ which are very soluble in water. [28]
Toxicity data were available for fresh as well as saltwater organisms. Acute data for freshwater organisms varied from 1.1 mg/l for *Daphnia magna* to 140 mg/l for *Tubifex tubifex*. Acute data for saltwater organisms varied from 4.5 mg/l for *Nitocra spinipes* to 170 mg/l for *Artemia salina*. The test with *Nitocra spinipes* was carried out with test water with a salinity of 7 $^{o}/_{oo}$, which means that the test was actually carried out under estuarine conditions.
For freshwater organisms NOEC values were available for algae, crustaceans, and fish. The value for *Daphnia magna* of 5 µg/l was more than a factor 10 lower compared to the other NOEC values. In the article of Biesinger no explanation is given for this low value. [8]
Also the two NOEC values for saltwater organisms varied considerably: 114 and 0.45 mg/l for

Carcinus maenas and *Homarus vulgaris*, respectively, both being crustaceans. Also in this case no explanation can be given for these differences. From these data it can be concluded that the sensitivity of marine and freshwater organisms for cobalt is comparable for acute exposure. With respect to chronic exposure the data were too scarce to draw conclusions.

3.1.5 Molybdenum (Mo)

From the 5 oxidation states possible Mo(IV) and Mo(VI) predominate, while in most natural water Mo occurs as the molybdate anion MoO_4^{2-}. [26] Molybdenum is an essential element for mammals. Also for algae molybdenum is essential. [29] In the OECD standard medium e.g. 9.79 µg/l molybdenum is added as $(NH_4)_6Mo_7O_{24}.4H_2O$. [30]
Acute data were available for freshwater and marine organisms, while chronic data were available only for one freshwater algae *Scenedesmus* (NOEC = 27 mg/l). All tests except one were carried out with Na_2MoO_4. For freshwater organisms L(E)C50 values varied from 29 to 2,700 mg/l for *Tubifex tubifex* and *Crangonyx pseudogracilis*, respectively. For marine organisms data were available for crustaceans and fish, L(E)C50 values varying from 250 to 2,600 mg/l for *Allorchestes compressa* and *Cyprinodon variegatus*, respectively. The sensitivity of salt and freshwater organisms for molybdenum seems comparable, although data were very scarce.

3.1.6 Selenium (Se)

Selenium is found in nature in the -2, 0, +4, and +6 oxidation states. In aerobic water the selenious acid species selenite (SeO_3^{2-}) and selenate (SeO_4^{2-}) dominate under intermediate to slightly oxidizing conditions. Under moderately reducing conditions many heavy metals are precipitated as the selenides. [15]
Selenium is an essential element for mammals, including human beings. It is found as selenocysteine in the enzyme glutathione peroxidase. [28] Selenium has also been shown to be essential for fish. A dietary level of 0.07 mg/kg dry feed with a waterborne level of 0.4 ± 0.2 µg/l was sufficient to prevent selenium deficiency symptoms in a study with *Oncorhynchus mykiss*. [31] Lindström (1983) has determined that selenium is also essential for the dinoflagellate *Peridinium cinctum* and possibly for the diatom *Stephanodiscus hautzschi* and eight species of green algae. [32] Essential concentrations were c. 0.5 µg/l.
Many studies have been carried out about selenium deficiency in daphnids. Winner (1984) describes antennal damage for *Daphnia pulex* caused by selenium deficiency. [33] According to Balk et al. (1989) however these effects were due to chronic toxicity of copper being present in the medium. [34] In a test with *Daphnia magna* stimulation of reproduction and improvement of the condition of the animals could be obtained not only by the addition of 1 µg/l selenium added as SeO_2 to ISO medium, but also by other trace elements. Balk et al. (1989) conclude that the attribution of the observed deficiencies exclusively to a lack of selenium remains disputable. In damaged antennae of daphnids Elendt showed that at the ultrastructural level the effects were consistent with the biochemical function of selenium in the enzym glutathione peroxidase, i.e. preventing cellular components from peroxidating. [35] Elendt and Bias (1990) conclude that at least in part, the occurrence of deficiency symptoms in tests with *Daphnia magna* could be attributed to selenium deprivation. [36] They obtained the best results in culturing daphnids with a medium with a complex trace element composition, containing 25, 5, 1, and 0.3 µg/l molybdenum, cobalt, selenium, and vanadium, respectively.
Selenium influences the toxicity of other metals. A selenium enriched diet reduced the toxicity of cadmium to *Daphnia magna*. [37] Antagonism between cadmium and selenium was also shown in the freshwater mollusc *Lymnaea stagnalis*, acting in both directions. [38] Addition of

5 µg/l selenium reduced chronic toxicity of copper at a concentration of 10 µg/l for *Dapnia pulex*. [33] The interaction of selenium and mercury in fish is more complex. The addition of 3 mg/l selenium in a test with *Semotilus atromaculatus* favored the accumulation of mercury at relatively low concentrations of 0.01 to 0.07 mg/l, added as $HgCl_2$. At higher concentrations of 0.1 to 0.16 mg/l the opposite was determined. [39] In a test with *Esox lucius* reduced mercury and methyl-mercury uptake was observed at low selenium concentrations of 1 and 1-10 µg/l, respectively. No effect was observed at higher concentrations of 100 µg/l selenium. [40]
Many acute as well as chronic toxicity data were available for freshwater and marine organisms. Most tests were carried out with selenite or selenate. Sometimes SeO_2 was used. Acute data for freshwater organisms were available for crustaceans, insects, fish, worms, and plants. L(E)C50 values varied between 0.071 and 120 mg/l for *Daphnia pulex* and *Oncorhynchus kisutch*, respectively. For marine organisms data were available for cumaceans, crustaceans, molluscs, and fish. LC50 values varied between 0.26 and 33 mg/l for *Argopecten irradians* and *Scylla serrata*, respectively. For freshwater organisms daphnids were more sensitive to selenium than other organisms.
For freshwater chronic data were available for bacteria, blue algae, green algae, protozoa, crustaceans, insects, and fish. NOEC values varied between 0.9 and 5,600 µg/l for *Entosiphon sulcatum* and *Pseudomonas putida*, respectively. For marine organisms chronic data were available for algae, crustaceans, and fish. NOEC values varied between 0.01 and 79 mg/l for *Platymonas subcordiformis* and *Pavlova lutheri*, respectively. From these data the conclusion can be drawn that selenium is more toxic in fresh than in saltwater.
From the data available it appeared that selenite is more toxic than selenate, i.e. a factor 1.4-3.7, 4.2, and 8.6 in acute tests with *Daphnia magna*, *Oncorhynchus kisutch*, and *Oncorhynchus tshawytscha*, respectively. In a test with *Chironomus riparius* contradictory results were obtained: in soft water selenate was more toxic, i.e. a factor 1.4, and in hard water selenite, i.e. a factor 2.0. As the differences in sensitivity between organisms is considerably higher than the difference in toxicity between selenite and selenate it seems reasonable to make no distinction between the two selenium species.

3.1.7 Thallium (Tl)

Thallium can occur in the +1 and +3 oxidation states of which Tl^+ is the predominant species in most natural waters. Tl-organic reactions may be important in natural waters, but information is scarce. [15]
All tests were carried out with Tl(I) as $TlNO_3$ or Tl_2SO_4. Only one acute LC50 of 21 mg/l for *Cyprinodon variegatus* was available for saltwater organisms. For freshwater organisms acute data were available for algae, crustaceans, and fish, varying from 0.11 to 140 mg/l for *Daphnia magna* and *Leuciscus idus melanotus*, respectively. The latter value of 140 mg/l was considerably higher than all other toxicity data. One chronic study was found, resulting in a NOEC of 30 µg/l for growth for *Pimephales promelas*.
In the EPA report "Ambient water quality criteria for thallium" other data are presented [41]:

- freshwater organisms: EC50 values for *Selenastrum capricornutum* of 110 and 100 µg/l for chlorophyll a and inhibition of cell numbers, respectively,
- saltwater organisms: LC50 of 2.13 mg/l for *Mysidopsis bahia* and a NOEC of 4.3 mg/l for *Cyprinodon variegatus* in an embryo-larval test.

From this information it appears that fish in freshwater are more sensitive to thallium than saltwater fish. The test conditions for the saltwater tests were however unknown because the original references could not be obtained.

3.1.8 Tin (Sn)

Almost no information is available on the speciation of anorganic tin in the aquatic environment. Tin can have two oxidation states, the stannous Sn^{2+} and stannic Sn^{4+} compounds. [42]
Acute toxicity data were available for freshwater for algae and crustaceans and for saltwater organisms for algae only. All tests were carried out with $SnCl_2$ or $SnCl_4$. For freshwater organisms L(E)C50 values varied from 5.5 to 50 mg/l for *Ankistrodesmus falcatus* and *Crangonyx pseudogracilis*, respectively. For saltwater the two EC50 values were 0.29 and 0.32 mg/l. Only for freshwater organisms chronic data were available, i.e. for algae, crustaceans, and fish. NOEC values varied from 0.09 to 7.8 mg/l for *Ankistrodesmus falcatus* and *Cyprinus carpio*, respectively. The data are too scarce to draw conclusions about differences in sensitivity between marine and freshwater organisms, although acute data for saltwater algae were much lower than for freshwater algae.

3.1.9 Vanadium (V)

Vanadium can have different oxidation states of which the pentavalent state is dominant and stable over a wide range of pH in aqueous solutions. Occurring species are vanadiumpentoxide V_2O_5, sodium vanadate $NaVO_3$, and ammonium vanadate NH_4VO_3. The formation of isopoly and heteropoly compounds by forming V-O-V-O linkages is most characteristic of V(V) in aqueous solutions. [43]
Vanadium is considered essential for some animals, e.g. rats and chickens. Vanadium is propably also essential for the green alga *Scenedesmus obliguus* at levels of 1-10 µg/l. [43] In a mineral medium for daphnids as described by Keating (1985), 0.5 µg/l vanadium as NH_4VO_3 must be added. [44]
For saltwater organisms only one acute LC50 was available for *Limanda limanda* of 28 mg/l. Chronic data were available for algae only, NOEC values varying from 0.05 to 0.3 mg/l for *Dunaliella marina* and *Prorocentrum micans*, respectively. For freshwater organisms acute and chronic data were available for oligochaeta, daphnids, and fish, the lowest LC50 and NOEC being 3.5 and 0.041 mg/l for *Daphnia magna* and *Jordanella floridae*, respectively. The data are too scarce to draw conclusions about the difference in sensitivity between freshwater and marine organisms.
Knudtson studied the toxicity of different vanadium species to two freshwater fish *Carassius auratus* and *Lebistes reticulatus*. [45] It appeared that toxicity decreased in the order $V_2O_5 \rightarrow VOSO_4 \rightarrow NH_4VO_3 \rightarrow NaVO_3$.

3.2 Effects on soil and benthic organisms

No toxicity data were available of effects on benthic organisms exposed via sediment to which the respective metals were added. Toxicity data for soil organisms are presented in appendix 4. Almost no reliable toxicity data were available. Only for cobalt a study with *Eisenia foetida* resulted in a NOEC value which could be used as input for the EPA method. All other experiments were aimed at studying sum parameters like nitrification and respiration. In most experiments only one or two test concentrations were used. Only in the study of Lighthart et al. (1983) 4 concentrations were used but no distinct concentration-effects relationship could be distinguished for any of the metals studied. [46] In many cases hormesis occurred, shown in appendix 4 as stimulation.

3.3 Secondary poisoning

For the terrestrial route no data on BCF's for earthworms could be obtained. In case of the aquatic route only for selenium and thallium data on bioconcentration in fish were available. This means that only for these metals an initial risk assessment could be carried out for secondary poisoning for the route water → fish → fish-eating bird or mammal.
In an article on selenium levels in fish from the San Joaquin Valley by Nakamoto et al. BCF's for *Pimephales promelas* of 4,400; 29, and 10.5 are presented for test concentrations of 0.083 ng/l, 50.6 µg/l, and 0.3 mg/l, respectively. The high BCF value of 4,400 is probably not due to bioaccumulation but to the fact that selenium is an essential element for fish. This is supported by the other almost equal values for different test concentrations. [47] Lemly (1982) determined BCF's in several tissues for *Lepomis macrochirus* and *Micropterus salmoides*. BCF values ranged from 40 for brain to 1825 in spleen. [48] Hunn et al. (1987) determined whole body BCF values of 31-71 for 7.8-21 µg/l for *Oncorhynchus mykiss*. [49] Finally, Hodson et al. (1980) determined BCF's in several tissues for *Oncorhynchus mykiss* ranging from 3 in peritoneal fat to 240 in liver. [50] Based on these data a MPC for secondary poisoning was calculated using a BCF of 500. Toxicity data were available for mammals only. The lowest NOEC available was one for growth for *Rattus norvegicus* of 4.8 mg/kg bw for 6 weeks exposure to Na_2SeO_3. [51] This value was converted to mg/kg food using a BW/DFI (body weight / daily food intake) factor of 20 resulting in 88 mg/kg food. [12] Using the EPA method as presented by Romijn et al. (1991) a $NOEC_{fish\text{-}eater}$ of 8.8 mg/kg food is calculated.
For thallium all data originate from reviews of Zitko (1975) and the EPA (1980). [41, 52] BCF's for *Salmo salar* of 130, 170, and 480 are presented for muscle, liver, and gills, respectively. [52] For *Mya arenaria* and *Mytilus edulis* BCF's were available of 18 and 12, respectively both for edible portion. [41] Based on these data a MPC for secondary poisoning was calculated using a BCF of 250. The lowest NOEC available was from a 105 days experiment with *Rattus norvegicus* resulting in a value of 15 mg/kg bw for mortality and growth. [41] The converted value using a BW/DFI factor of 20 was 300 mg/kg food. Using the EPA method as presented by Romijn et al. (1991) a $NOEC_{fish\text{-}eater}$ of 30 mg/kg food is calculated.
It has to be stated that for selenium as well as thallium no toxicity data were obtained for birds.

4. COMPARISON OF TOXICITY FOR FRESHWATER AND SALTWATER ORGANISMS

In The Netherlands a discussion is still ongoing whether special environmental quality objectives are necessary for saltwater ecosystems like the Northsea and Waddensea. [53] One of the underlying motives could be that saltwater organisms are more sensitive to environmental pollutants than freshwater organisms. Therefore a study was carried out by Scholten et al. (1991), in which MPC's were determined based on toxicity data for saltwater organisms. [54] For 17 compounds MPC's for saltwater organisms were compared with MPC's for freshwater organisms, both calculated with the modified EPA method. MPC's for freshwater organisms were taken from Van De Meent et al. (1990) [3] For the metals cadmium, zinc, nickel, lead, mercury, chromium, copper, and arsenic the MPC's for marine organisms were always higher than the MPC's for freshwater organisms, i.e. a factor 1.7 to 140. Based on these results it was concluded that the sensitivity of marine and freshwater organisms do not differ significantly. It was proposed however to compare toxicity data on the level of taxonomical groups.
In order to make such a comparison for the metals studied the following method was used

here:

- taxonomic groups for which toxicity data for salt as well as freshwater organisms were present were determined,
- a geometric mean L(E)C50 or NOEC was calculated per taxonomic group. If for one species more data were available the geometric mean was calculated. From NOEC's values based on different parameters the lowest (geometric mean) value was used.
- after log transformation both values were compared.

For the comparison of chronic toxicity also data for arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc were used. For marine organisms toxicity data were taken from Scholten et al. (1991), and for freshwater organisms from Emans et al. (submitted), Van De Meent et al. (1991), and Hesse et al. (1990). [3, 54, 55, 56].

In appendix 5 acute and chronic toxicity data used are presented, respectively. Acute data sets were available for 6 metals for algae (1), crustaceans (3), and fish (4). Chronic data sets were available for 9 metals for algae (3), crustaceans (9), molluscs (2), and fish (4). This means that only for four taxonomic groups a comparison could be made. In figure 1 and 2 LC50 and NOEC values for fresh and saltwater organisms are graphically presented.

From figure 1 it can be concluded that there is no difference in sensitivity between salt and freshwater organisms in acute tests. This is in agreement with results obtained for organic compounds. Nendza and Klein (1990) derived QSAR's for 26 organic chemicals with toxicity data obtained from 9 freshwater and 3 saltwater species testing, i.e. bacteria, algae, protozoans, crustaceans, and fish. They concluded from multivariate analysis that the susceptibility of species is discriminated for classes of organisms regardless of freshwater or estuarine environment. [57] From figure 2 it can be concluded that freshwater organisms are more sensitive than marine organisms in chronic tests. This might be explained by a decreased bioavailability of metals in saltwater caused by complexation with chlorides or carbonates. [53] However, this does occur also in acute tests.

The following remarks should be made with respect to these results:

- the comparison is based on toxicity data for only 4 taxonomical groups. Also there is a great difference in sensitivity within taxonomic groups, especially within the algae, crustaceans, and molluscs. For these organisms it is better to compare data on a lower taxonomical level. This was not possible however due to a lack of data, especially for marine organisms.
- for freshwater organisms more data were available than for saltwater organisms, acute as well as chronic. A statistical analysis of the data was therefore not carried out.

It can be concluded that for metals marine organisms are at least not more sensitive than freshwater organisms. This means that it is acceptable to combine both data sets to calculate a MPC. It should be stated that, based on the information presented above, this might lead to an underestimation of the MPC for freshwater organisms when the MPC is based on chronic toxicity data.

Figure 1. Comparison of sensitivity of freshwater and saltwater organisms based on results from acute tests (log L(E)C50 in mg/l)

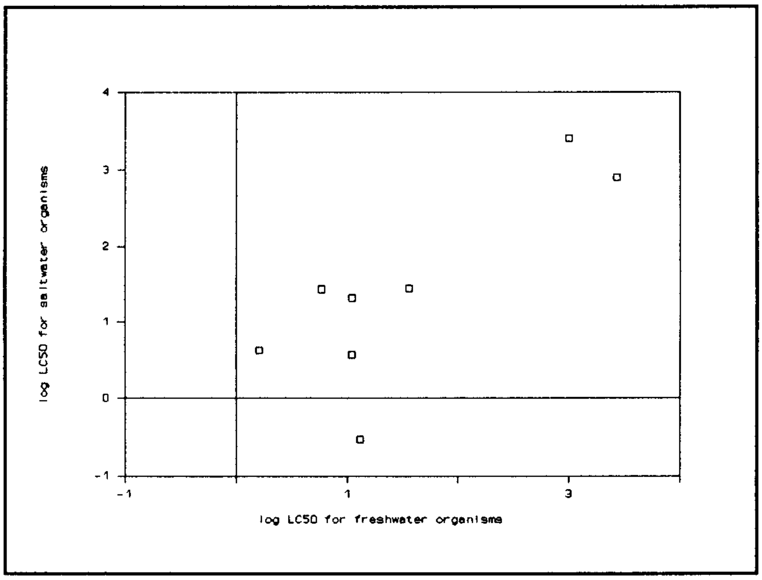
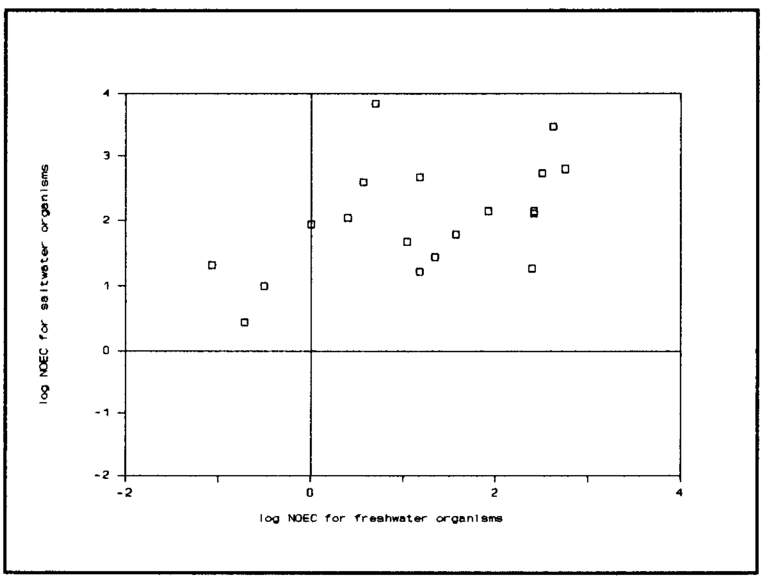


Figure 2. Comparison of sensitivity of freshwater and saltwater organisms based on results from chronic tests (log NOEC in µg/l)



5. CALCULATION OF MAXIMUM PERMISSIBLE CONCENTRATIONS

5.1 Aquatic organisms

In appendix 6 toxicity data used as input data for the extrapolation methods are presented. In table 3 MPC's are given based on toxicity data for freshwater and saltwater organisms only, and on the combined data set. For saltwater organisms no MPC's could be calculated for barium and beryllium because no toxicity data were available. For the other metals, except for selenium, the modified EPA method had to be applied. For freshwater organisms only for beryllium, cobalt, and selenium enough toxicity data were available to use Modification 0. Combining both data sets did not lead to more cases for which Modification 0 could be applied. In order to compare the MPC calculated with the toxicity data for freshwater and saltwater organisms a survey of acute and chronic toxicity data is presented in table 4 and 5, respectively. The data are presented as if they are used as input data for the extrapolation methods. This means that acute as well as chronic toxicity data are weighted over the species as decribed in paragraphs 2.2.1 and 2.2.2.

Table 3. Maximum permissible concentrations (µg/l) based on toxicity data for fresh and saltwater organisms separately, and on the combined data set. The lowest chronic NOEC for each metal is also presented.

metal	$MPC_{freshwater}$ (µg/l)	$MPC_{saltwater}$ (µg/l)	$MPC_{combined}$ (µg/l)	lowest NOEC (µg/l)
antimony	420[1]	6.2[1]	6.2[1]	23,000
barium	150[1,2]	-	150[1]	2,900
beryllium	0.16[3] (57[4])	-	0.16[3] (57[4])	0.68
cobalt	2.6[5] (320[4])	3.0[1,6]	2.0[5] (240[4])	5.0
molybdenum	290[1,7]	250[1]	290[1]	27,000
selenium	2.8[3] (7.4[4])	16[3] (10[4])	5.3[3] (3.8[4])	0.9
thallium	3.0[1]	0.16[1]	1.6[1]	30
tin	18[1]	0.29[1]	18[1]	180
vanadium	3.5[1]	10[1]	3.5[1]	41

1 indicative MPC based on modified EPA method

2 a factor 100 was applied although no acute data were available for algae. In a 96 h study with *Scenedesmus* a NOEC value for growth of 17 mg/l was derived. Therefore it can be concluded that the acute EC50 for algae will be higher than the LC50 value for *Daphnia magna*, which was used as input datum for the modified EPA method.

3 toxicity data come from a log-logistic distribution with a significance of $P < 0.05$

4 ratio between $MPC_{50\%\ confidence}$ and $MPC_{95\%\ confidence}$ calculated with Modification 0

5 toxicity data come from a log-logistic distribution with a significance of $P < 0.025$

6 a factor 100 was applied although no acute data were available for fish. In a study with adult *Blennius pholis* no mortality was observed in 15 days at 45 mg/l. Therefore it can be concluded that the acute LC50 for fish will be higher than the lowest EC50 value available for algae. The NOEC value of 45 mg/l was not used as input data for Modification 0 because the test cannot be considered as a chronic test.

7 a factor 100 was applied although no acute data were available for algae. A chronic NOEC value of 27 mg/l for *Scenedesmus* was however available. Therefore it can be concluded that the acute EC50 for algae will be higher than the lowest EC50 value available, i.e. 29 mg/l for *Tubifex tubifex*.

Table 4. Survey of acute fresh and saltwater toxicity data: L(E)C50 in mg/l (F = freshwater organisms; S = saltwater organisms)

taxonomic group	F/S	Sb	Ba	Be	Co	Mo	Se	Tl	Sn	V
fish	F	1,100	570	1.9 3.9 6.1	4.8	1,000	1.8 2.1 6.5 10 11 13 16 16 28 30 110	0.86 140		11 120
	S	6.2				2,600	1.6 4.4 7.4	21		28
crustaceans	F	420	15 200	1.2 1.8	1.3 2.0 4.0 16 39	2,700	0.53 0.60 1.8	0.42	42 50	3.5 12
	S				4.5 170	250 1,100 1,900	1.2 1.5 4.6 4.8 33			
green algae	F							3.0	7.0 23	
	S				0.3 24			0.16	0.29 0.32	
protozoa	F				28					
oligochaetae	F									31
amphibians	F			10 12						
molluscs	S					1,900	0.26 1.9 2.9			
worms	F	680		10	140	29	7.7			
cumaceans	S						6.1			
plants	F		26				2.4			
insects	F				57		3.1 11.9			

Table 5. Survey of chronic fresh and saltwater toxicity data: NOEC in mg/l (F = freshwater organisms; S = saltwater organisms)

taxonomic group	F/S	Sb	Ba	Be	Co	Mo	Se	thallium	tin	vanadium
fish	F			0.08	1.1		0.015	0.03	7.8	0.041
	S				45		0.47			1.0
crustaceans	F		2.9		0.005		0.03 0.05 0.16 0.2		0.18	1.0
	S				0.45 110		0.14			
green algae	F		17	0.001	0.058 0.5	27	0.005 0.05 0.2 0.26 1.3		0.26	
	S						0.01 0.079 0.1 0.25 0.79 0.79 0.79 2.5 7.9 10			0.1 0.2 0.3
blue algae	F	23		0.015	0.5		0.079 1.0 4.7 5.0			
protozoa	F	120		0.002 0.0085 0.26			0.0009 0.031 0.059			
insects	F						0.3			
bacteria	F			0.00068			5.6			

The results for the different metals will be discussed shortly hereafter:

- antimony: all MPC's were calculated using the modified EPA method, based on acute toxicity data applying a factor 1000. The $MPC_{saltwater}$ is c. 70 times lower than the $MPC_{freshwater}$ due to the low LC50 for marine fish. Both MPC's are more than a factor 55 lower than the lowest NOEC available but the MPC's are based on toxicity data for crustaceans and fish, while only NOEC values were available for lower organisms.

If the information about the toxicity of antimony presented in paragraph 3.1.1 is taken into account the $MPC_{combined}$ will be 6.1 µg/l based on the EC50 for *Selenastrum capricornutum*. This value is in agreement with the $MPC_{combined}$ presented in table 3. The toxicity data for algae however were contradictionary.

- barium: the MPC was calculated using the modified EPA method based on an acute LC50 for *Daphnia magna* applying a factor 100. The MPC is a factor 20 lower than the lowest NOECbeing also a value for *Daphnia magna*. Taken into account that the MPC is an indicative MPC the value presented in table 5 seems a reasonable one.

- beryllium: the MPC is a factor 4.3 lower than the lowest NOEC available. As all data presented in table 4 and 5 show that beryllium is very toxic the MPC presented in table 3 seems a reasonable one.

- cobalt: the MPC*saltwater* was calculated using the modified EPA method based on an EC50 for algae applying a factor 100. The $MPC_{combined}$ is a factor 2.5 lower than the lowest NOEC available, being one for *Daphnia magna*. This NOEC value might be too low taken into account that the EC50 values for crustaceans range from 1.3 to 39 mg/l, at least a factor 260 higher. As stated in 3.1.4. there are however no reasons to reject this value. The lowest NOEC for marine organisms is a factor 90 higher than the $MPC_{combined}$. Considering these remarks it might be concluded that the MPC presented in table 3 is on the low side.

From the information presented in 3.1.4 it can be concluded that waterborne concentrations for cobalt should not be lower than 5-40 µg/l because otherwise deficiency might occur for algae and daphnids. The $MPC_{combined}$ is 2.5 to 20 times lower than these concentrations. It should be stated however that no extensive literature search was carried out to determine at which concentrations deficiency symptoms begin to occur. On the other hand this conclusion underlines the remark that the $MPC_{combined}$ might be too low.

- molybdenum: all MPC's were calculated using the modified EPA method based on acute toxicity data applying a factor 100 and 1000 for freshwater and saltwater organisms, respectively. The $MPC_{freshwater}$ is almost equal to the one for saltwater organisms. The $MPC_{combined}$ is a factor 93 lower than the only NOEC available, being one for green algae.

From the information presented in 3.1.5 it can be concluded that waterborne concentrations for molybdenum should not be lower than 10 µg/l because otherwise deficiency might occur for algae. The $MPC_{combined}$ is a factor 29 higher.

- selenium: all MPC's were calculated with Modification 0 based on 19 and 12 chronic toxicity data for freshwater and saltwater organisms, respectively. The $MPC_{freshwater}$ is a factor 5.7 lower than the one for marine organisms. It should be stated that the $MPC_{saltwater}$ is almost based only on NOEC values for algae. The $MPC_{combined}$ lies between the other MPC's.

The $MPC_{combined}$ is factor 5.9 higher than the lowest NOEC available, being 0.9 µg/l for *Entosiphon sulcatum*. This is caused by the fact that a 95% protection level is calculated and that this NOEC value is very low compared to the other chronic toxicity data. The second lowest NOEC, being 5.0 µg/l for *Ankistrodesmus falcatus*, is much higher, although also somewhat lower than the MPC. The $MPC_{combined}$ is 1.9 times lower than the lowest NOEC for saltwater organisms.

From the information presented in 3.1.6 it can be concluded that waterborne concentrations for selenium should not be lower than 1 µg/l because otherwise deficiency might occur for daphnids. The $MPC_{combined}$ is a factor 5.3 higher.

The canadian government has tried to develop water quality guidelines for antimony, beryllium, selenium, and thallium. Only for selenium sufficient data were available for establishing a guideline of 1 µg/l total selenium. [58] This value is lower than the MPC's calculated in table 3. The EPA has tried to derive water quality guidelines for antimony, barium, beryllium, selenium, and thallium. Also here only for selenium a guideline was established being 5 µg/l as a 4 day average. [59] This value is almost equal to the $MPC_{combined}$ presented in table 3 although it should be stated that the EPA value is a 4 day average criterion.
The $MPC_{combined}$ is also in good agreement with a study of Hermanutz et al. (1992) in which effects on the survival, growth, and reproduction of *Lepomis macrochirus* and the early life stage of their progeny were the endpoints in a 356 study in replicated outdoor experimental streams at concentrations of 10 and 30 µg/l. Exposures of adults at both concentrations for 40 weeks before spawning resulted in reduced embryo and larval survival and produced larvae with a high incidence of edema, lordosis, and internal hemorrhaging. [59]
Based on these condsiderations it can be concluded that the $MPC_{combined}$ presented in table 3 seems a reasonable one.
- <u>thallium</u>: all MPC's are calculated using the modified EPA method. The $MPC_{freshwater}$ is based on a NOEC value for fish. Both the $MPC_{saltwater}$ and the $MPC_{combined}$ are based on the same EC50 value for *Ditylum brightwelli* of 0.16 mg/l. In case of the $MPC_{combined}$ a factor of 100 in stead of 1000 is applied because acute toxicity data were available for algae, crustaceans, and fish due to the combining of the data for fresh- and saltwater organisms. The $MPC_{combined}$ is c. a factor 20 lower than the only NOEC available, being one for freshwater fish. Based on the acute data available it can be concluded that algae and crustaceans might be slightly more sensitive for thallium. Based on these remarks it can be concluded that the $MPC_{combined}$ presented in table 3 seems a reasonable one.
- <u>tin</u>: all MPC's were calculated using the modified EPA method. For the $MPC_{freshwater}$ chronic toxicity data were available for algae, crustaceans, and fish, so a factor 10 was applied to the lowest NOEC value, being 180 µg/l for *Daphnia magna*. For saltwater organisms only acute data were available for algae so a factor 1000 was applied to the lowest EC50. Based on the toxicity data presented in table 4 and 5 it can be concluded that the $MPC_{combined}$ presented in table 3 seems a reasonable one.
- <u>vanadium</u>: all MPC's were calculated using the modified EPA method. The $MPC_{freshwater}$ is obtained by applying a factor 1000 on an EC50 value for *Daphnia magna*. The $MPC_{saltwater}$ is calculated using a NOEC value for algae. Both MPC's are in the same order of magnitude. The $MPC_{combined}$ is a factor 12 lower than the lowest NOEC.
From the information presented in 3.1.9 it can be concluded that waterborne concentrations for vanadium should not be lower than 0.5-10 µg/l because otherwise deficiency might occur for algae and daphnids. The $MPC_{combined}$ lies between these two values. It should be stated however that no extensive literature search was carried out to determine at which concentrations deficiency symptoms begin to occur. Based on these considerations it can be concluded that the $MPC_{combined}$ might be on the low side.

From the information presented above it can be concluded that for antimony, thallium, and tin the MPC is lower for marine than for freshwater organisms. Based on these data however no conclusions can be drawn about the combining of toxicity data on marine and freshwater organisms in order to calculate MPC's. About the $MPC_{combined}$ presented in table 3 it can be concluded all values seem reasonable.

5.2 Soil and benthic organisms

For sediment no MPC's could be calculated because no toxicity data were available for benthic organisms exposed via sediment. For soil only for cobalt a MPC could be calculated. Based on a NOEC of 240 mg/kg for earthworms a MPC of 24 mg/kg can be derived using the EPA method. MPC's for soil and sediment can be calculated using MPC's for aquatic organisms by application of the equilibrium partitioning method. [3] Results thereoff will be published in a separate report.

5.3 Secondary poisoning

For selenium the preliminary MPC for secondary poisoning is 8.8 : 500 = 17.6 µg/l for the aquatic environment. This value is higher than the MPC's from table 3, i.e. a factor 1.1-6.3. For thallium the preliminary MPC for secondary poisoning is 30 : 250 = 120 µg/l, being a factor 75-750 higher than the MPC's presented in table 3. Therefore it can be concluded that there will probably no risk for secondary poisoning via the route water → fish → fish-eating mammal for both metals. It has to be stated however that only reviews were consulted and no toxicity data were obtained for birds. Next to this the preliminary MPC for secondary poisoning for selenium doesn't differ much from the MPC's based on aquatic toxicological data. A more thorough literature search on secondary poisoning will however certainly be hampered by a lack of reliable data.

6. CONCLUSIONS

The derivation of MPC's for soil and sediment for the trace metals studied was hampered by the lack of reliable toxicity data. For benthic organisms no data were found at all. For soil organisms only for cobalt a MPC could be derived because for all other metals no reliable toxicity data were available. For the aquatic environment enough data were present to derive MPC's, although most data were from acute tests. Modification 0, the extrapolation method used in refined effects assessment, could be applied for beryllium, cobalt, and selenium. Only for selenium a large data set was present.
Due to this scarcity of data it was difficult to compare the sensitivity of marine and freshwater organisms on a taxonomical level. Therefore also chronic data for other metals were used. It can be concluded that it is possible to combine the data sets of salt and freshwater organisms for the derivation of MPC's. It has to be stated however that no extensive literature search was carried out for the other metals mentioned above.
Several metals studied were essential elements. Although no extensive literature search was carried out, an attempt was made to relate the calculated MPC's for the aquatic environment to concentration levels neccessary for aquatic organisms. These levels were for cobalt, molybdenum, selenium, and vanadium in the same range as the MPC's. These concentration levels should, as is the case with the MPC's, also be related to background levels in the aquatic environment. This falls however outside the scope of this report, but will be dealt with in a final report in which proposals are made for integrated environmental quality objectives.
A screening method was applied to calculate MPC's for secondary poisoning for an aquatic and terrestrial route. Only for selenium and thallium data were available for the route water → fish → fish-eating mammal. For both metals secondary poisoning could not be considered as a critical route, although for selenium the MPC's didn't differ much.

7. REFERENCES

1. National Environmental Policy Plan: To choose or to lose (1989). Second Chamber, session 1988-1989, 21137, no. 1-2. The Hague.

2. Premises for risk management: Risk limits in the context of environmental policy (1989). Second Chamber, session 1988-1989, 21137, no. 1-2. The Hague.

3. 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 standard for water and soil". RIVM report No. 670101 002.

4. Notitie Milieukwaliteitsdoelstellingen bodem en water. Ministerie van Volksgezondheid, Ruimtelijke Ordening en Milieubeheer. Tweede Kamer, vergaderjaar 1990-1991, 21 990, No. 1. (in Dutch)

5. J.H.M. de Bruijn en C.A.J. Denneman (in press). Achtergrondgehalten van negen sporenmetalen in oppervlaktewater, grondwater en grond van Nederland. (in Dutch)

6. Bringmann, G., und Kühn, R. (1959). Vergleichende wasser-toxikologische Untersuchungen an Bakterien, Algen und Kleinkrebsen. Gesundheits-Ingenieur **80**, (4), 115-120.

7. Hamilton, M.A., Russo, R.C., and Thurston, R.V. (1977). Trimmed Spearman-Karber method of estimating median lethal concentrations in toxicity bioassays. Environ. Sci. Technol. **11**, 714-719 (correction: 1978, **12**, 417).

8. Biesinger, K.E., and Christensen, G.M. (1972). Effects of various metals on survival, growth, reproduction, and metabolism of *Daphnia magna*. J. Fish. Res. Board Canada **26**, (12), 1691-1700.

9. Bringmann, G. und Kühn, R. (1977). Grenzwerte der Schadwirkung wassergefährdender Stoffe gegen Bakterien (*Pseudomonas putida*) und Grünalgen (*Scenedesmus quadricauda*) im Zellvermehrungstest. Z. f. Wasser- und Abwasserforschung **10**, (5), 161-166.

10. Slooff, W. (1992). RIVM guidance document. Ecotoxicological effects assessment: deriving Maximum Tolerable Concentrations (MTC) from single-species toxicity data. RIVM report No. 719102 018.

11. Aldenberg T., and Slob, W. (1991). Confidence limits for hazardous concentrations based on logistically distributed NOEC toxicity data. RIVM report No. 719102 002.

12. Romijn, C.A.F.M., Luttik, R., V.D. Meent, D., Slooff, W., and Canton, J.H. (1991). Presentation and analysis of a general algorithm for risk-assessment on secondary poisoning. RIVM report No. 679102 002.

13. Romijn, C.A.F.M., Luttik, R., Slooff, W., and Canton, J.H. (1991). Presentation of a general algorithm for effect-assessment on secondary poisoning. II terrestrial food chains. RIVM report No. 679102 007.

14. Di Toro, D.M., Zarba, C.S., Hansen, D.J., Berry, W.J., Schartz, R.C., Cowan, C.E., Pavlou, S.P., Allen, H.E., Thomas, N.A., and Paquin, P.R. (1991). Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. Annual Review of Environ. Toxicol. Chem. 1068-1112.

15. Bodek, I., Lyman, W.J., Rechl, W.F., Rosenblatt, D.H. (eds) (1988). Environmental inorganic chemistry: Properties, processes and estimation methods. SETAC Special Publication Series, Pergamon Press, New York.

16. EPA (1986). Quality criteria for water 1986. EPA 440/5-86-001.

17. EPA (1980). Ambient water quality criteria for antimony. EPA 440/5-80-020.

18. Bringmann, G., und Kühn, R. (1978). Grenzwerte der Schadwirkung wassergefährdender Stoffe gegen Blaualgen (*Microcystus aeruginosa*) und Grünalgen (*Scenedesmus quadricauda*) im Zellvermehrungshemmtest. Vom Wasser **50**, 45-60.

19. LeBlanc, G.A. (1984b). Acute toxicity of priority pollutants to water flea (*Daphnia magna*). Bull. Environ. Contam. Toxicol. **24**, 684-691.

20. LeBlanc, G.A., and Dean, W. (1984). Antimony and thallium toxicity to embryos and larvae of fathead minnows (*Pimephales promelas*). Bull. Environ. Contam. Toxicol. **32**, 565-569.

21. IPCS (1990). Environmental Health Criteria 107, barium. WHO, Genève.

22. De Boer, J.L.M. (1992). Personal communication. From the National Institute of Public Health and Environmental Protection, Bilthoven.

23. Slonim, C.B., and Slonim, A.R. (1973). Effect of water hardness on the tolerance of the guppy to beryllium sulfate. Bull. Environ. Contam. Toxicol. **10**, (5), 295-301.

24. Slonim, A.R., and Ray, E. (1975). Acute toxicity of beryllium sulfate to salamander larvae (*Ambystoma spp*). Bull. Environ. Contam. Toxicol. **13**, (3), 307-312.

25. IPCS (1990). Environmental Health Criterium 106, beryllium. WHO, Genève.

26. Allowey, B.J. (eds) (1990). Heavy metals in soils. John Wiley & Sons Inc., New York.

27. Coleman, R.D., Coleman, R.L., and Rice, E.L. (1971). Zinc and cobalt bioconcentration and toxicity in selected algal species. Botanical Gazette **132**, (2), 102-109.

28. Seiler, H., Sigel, H., and Sigel, A. (eds) (1988). Handbook on toxicity of inorganic compounds. Marcel Dekker Inc., New York.

29. Jarrell, W.M., Page, A.L., and Elseewi, A.A. (1980). Molybdenum in the environment. Residue Reviews, Volume 74. Springer Verlag New-York Inc.

30. OECD Guideline for testing of chemicals. No. 201: Alga, growth inhibition test. Adopted June 1984.

31. Hilton, J.W., Hodson, P.V., and Slinger, S.J. (1980). The requirement and toxicity of selenium in rainbow trout (*Salmo gairdneri*). J. Nutrit. **110**, 2527-2535.

32. Lindström, K. (1983). Selenium as a growth factor for plankton algae in laboratory experiments and in some Swedish lakes. Hydrobiologia **101**, 35-48.

33. Winner, R.W. (1984). Selenium effects on antennal integrity and chronic copper toxicity in *Daphnia pulex* (deGeer). Bull. Environ. Contam. Toxicol. **33**, 605-611.

34. Balk, F., Blok, J., Klijnstra, J.W., and Span, A.S.W. (1989). The contribution of humic compounds, EDTA and trace elements to the reproduction of *Daphnia magna*. External report of Akzo Research Laboraties Arnhem, No. CRL E89004.

35. Elendt, B.P. (1990). Selenium deficiency in Crustacea. An ultrastructural approach to antennal damage in *Daphnia magna Straus*. Protoplasma **154**, 25-33.

36. Elendt, B.P., and Bias, W.R. (1990). Trace nutrient deficiency in *Daphnia magna* cultured in standard medium for toxicity testing. Effects of the optimization of culture conditions on life history parameters of *D. magna*. Water Res. **24**, (9), 1157-1167.

37. Winner, R.W., and Whitford, T.C. (1987). The interactive effects of a cadmium stress, a selenium deficiency and water temperature on the survival and reproduction of *Daphnia magna Straus*. Aquat. Toxicol. **10**, 217-224.

38. Van Puymbroeck, S.L.C., Stips, W.J.J., and Vanderborght, O.L.J. (1982). The antagonism between selenium and cadmium in a freshwater mollusc. Arch. Environm. Contam. Toxicol. **11**, 103-106.

39. Kim, J.H., Birks, E., and Heisinger, J.F. (1977). Protective action of selenium against mercury in northern creek chubs. Bull. Environ. Contam. Toxicol. **17**, (2), 132-136.

40. Klaverkamp, J.F., Hodgins, D.A., and Lutz, A. (1983). Selenite toxicity and mercury-selenium interactions in juvenile fish. Arch. Environ. Contam. Toxicol. **12**, 405-413.

41. US-EPA (1980). Ambient water quality criteria for thallium. EPA 440/5-80-074.

42. Friberg, L., Nordberg, G.F., and Vouk, V.B. (eds) (1986). Handbook of the toxicology of metals, vol. I and II. Elsevier Science Publishers B.V., Amsterdam.

43. IPCS (1988). Environmental health criteria 81, vanadium. WHO, Genève.

44. Keating, K.I. (1985). A system of defined (sensu stricto) media for daphnid (*Cladocera*) culture. Water Res. **19**, (1), 73-78.

45. Knudtson, B.K. (1979). Acute toxicity of vanadium to two species of freshwater fish. Bull. Environ. Contam. Toxicol. **23**, 95-99.

46. Lighthart, B., Baham, J., and Volk, V.V. (1983). Microbial respiration and chemical speciation in metal-amended soils. J. Environm. Qual. **12**, (4), 543-548.

47. Nakamoto, R.J., and Hassler, T. (1992). Selenium and other trace elements in bluegills from agricultural return flows in the San Joaquin Valley, California. Arch. Environ. Contam. Toxicol. **22**, 88-98.

48. Lemly, A.D. (1982). Response of juvenile centrarchids to sublethal concentrations of waterborne selenium. I. Uptake, tissue distribution, and retention. Aquat. Toxicol. **2**, 235-252.

49. Hunn, J.B., Hamilton, S.J., and Buckler, D.R. (1987). Toxicity of sodium selenite to rainbow trout fry. Wat. Res. **21**, 233-238.

50. Hodson, P.V., Spry, D.J., and Blunt, B.R. (1980). Effects on rainbow trout (*Salmo gairdneri*) of a chronic exposure to waterborne selenium. Can. J. Fish Aquat. Sci. **37**, 233-240.

51. IPCS (1990). Environmental health criteria 58, selenium. WHO, Genève.

52. Zitko, V. (1975). Toxicity and pollution potential of thallium. Sci. Total. Environ. **4**, 185-192.

53. Jonkers, D.A., and Everts, J.W. (1992). Seaworthy. Derivation of micropollutant risk levels for the North Sea and Wadden Sea. Directorate-General for the Environment and Directorate-General for Public Works and Water Management. Publikatiereeks gebiedsgericht beleid No. 1992/3.

54. Scholten, M.C.T., Schobben, H.P.M., Kaag, N.H.B.M., Bowmer, C.T., en Stronkhorst, J. (1991). De berekening van maximaal toelaatbare risico-niveaus voor stoffen in zoute wateren. Instituut voor Milieuwetenschappen TNO (IMW), TNO-rapport nr. 91/268. (in Dutch)

55. Emans, H.J.B., Okkerman, P.C., Van De Plassche, E.J., Sparenburg, P.M., and Canton, J.H. (submitted). Validation of some extrapolation methods used for effects assessment.

56. Hesse, J.M., Janus, J.A., Krajnc, E.I., and Kroese, E.D. (1990). Integrated criteria document arsenicum: effects. RIVM report. Appendix to report No. 710401 004.

57. Nendza, M., and Klein, W. (1990). Comparative QSAR study on freshwater and estuarine toxicity. Aquatic Toxicology **17**, 63-74.

58. Task force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers (1987). Canadian water quality guidelines.

59. Hermanutz, R.O., Allen, K.N., Roush, T.H., and Hedtke, S.F. (1992). Effects of elevated selenium concentrations on bluegills (*Lepomis macrochirus*) in outdoor experimental streams. Environ. Toxicol. Chem. **11**, 217-224.

Appendix 1. Reviews used for literature search

All or more than one metal:

Cardwell, R.D., Foreman, D.G., Payne, T.R., and Wilbur, D.J. (1976) Acute toxicity of selected toxicants to six species of fish. US-EPA 600/3-76-008, PB68-01-0748.

EPA (1986). Quality criteria for water 1986. EPA 440/5-86-001.

Friberg, L., Nordberg, G.F., and Vouk, V.B. (eds) (1986). Handbook on the toxicology of metals, vol. I and II. Elsevier Science Publishers B.V., Amsterdam.

Holland, G.A., Lasater, J.E., Neumann, E.D., and Eldridge, W.E. (1964). Toxic effects of organic and inorganic pollutants on young salmon and trout. Research Bulletin No. 5. State of Washington Department of Fisheries.

Mance, G. (1987). Pollution threat of heavy metals in aquatic environments. Elsevier Applied Science, London and New York.

Mulder, D.E., Cardinaals, J.M., Mak, J.K., and Van Knippenberg, J.A.J. (1986). Review of literature data on antimony and some anorganic antimony compounds. NOTOX Toxicological Research & Consultancy, 's Hertogenbosch, and DHV Consulting Engineers B.V., Amersfoort.

Seiler, H., Sigel, H., and Sigel, A. (eds) (1988). Handbook on toxicity of inorganic compounds. Marcel Dekker Inc., New York.

Skidmore, J.F., and Firth, I.C. (1983). Acute sensitivity of selected australian freshwater animals to copper and zinc. Australian Water Resources Council, Technical Paper No. 81. Australian Government Publishing Service, Canberra.

Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environment Ministers (1987). Canadian water quality guidelines.

Reviews about an individual metal:

Antimony:
EPA (1980). Ambient water quality criteria for antimony. US-EPA 440/5-80-020.

Barium:
IPCS (1990). Environmental health criteria 107, barium. WHO, Genève.

Beryllium:
IPCS (1990). Environmental health criteria 106, beryllium. WHO, Genève.

Selenium:
IPCS (1987). Environmental health criteria 58, selenium. WHO, Genève.

Thallium:
EPA (1980). Ambient water quality criteria for thallium. US-EPA 440/5-80-074.

Vanadium:
IPCS (1988). Environmental health criteria 81, vanadium. WHO, Genève.

Appendix 2. Toxicity data for freshwater organisms

A = analysis of test compound:
y = yes
n = no

Test type:
S = static
SS = semi-static
CF = continuous flow
IF = intermittent flow

Test water
rw = reconstituted water
nw = natural water
tw = tap water
am = artificial medium

Exposure time:
min = minutes
h = hours
d = days
w = weeks
m = months

Criterion:
LC = lethal concentration
EC = effect concentration
NOEC = no observed effect concentration

Acute toxicity of antimony to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Daphnia magna S.	n	S	Sb_2O_3	nw	7.2-7.8	235-260	48 h	EC50	420	Khangarot & Ray, 1989a
worms										
Tubifex tubifex	n	S	Sb_2O_3	nw	7.6	245	96 h	EC50[a]	680	Khangarot, 1991
fish										
Leuciscus idus melanotus	n	S	$K[Sb(OH)_6]$	tw	7-8	255	48 h	LC50	1,100	Juhnke & Lüdemann, 1978

[a] immobility

Acute toxicity of barium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Daphnia, < 24 h	n	S	$BaCl_2$	nw	7.5	67	48 h	EC50	200	Bringmann & Kühn, 1959
Daphnia magna, 12 + 12 h	n	S	$BaCl_2$	nw	7.4-8.2	44-53	48 h	LC50	15	Biesinger et al., 1972
fish										
Leuciscus idus melanotus	n	S	$BaCl_2$	tw	7-8	255	48 h	LC50	570	Juhnke & Lüdemann, 1978
plants										
Lemna minor	n	S	Ba^{2+}	rw	7.5	-	96 h	EC50[a]	26	Wang, 1986

[a] growth

Acute toxicity of beryllium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Daphnia magna S.	n	S	$BeSO_4$	nw	7.2-7.8	235-260	48 h	EC50	2.80	Khangarot & Ray, 1989a
Daphnia magna, < 24 h	n	S	$Be(NO_3)_2$	tw	7.6-7.7	272	24 h	EC50	1.20	Bringmann & Kühn, 1977b
worms										
Tubifex tubifex	n	S	$BeSO_4$	nw	7.6	245	96 h	EC50	10	Khangarot, 1991
fish										
Ictalurus punctatus	y	CF	$BeSO_4$		8.0	140	96 h	LC50	6.1	Cardwell et al, 1976
Lebistes reticulatus, 3 m	n	S	$BeSO_4$	rw	5.1-7.0	400	96 h	LC50	19	Slonim & Slonim, 1973
Lebistes reticulatus, 3 m	n	S	$BeSO_4$	rw	5.9-7.3	275	96 h	LC50	13	Slonim & Slonim, 1973
Lebistes reticulatus, 3 m	n	S	$BeSO_4$	rw	6.0-6.7	150	96 h	LC50	5.80	Slonim & Slonim, 1973
Lebistes reticulatus, 3 m	n	S	$BeSO_4$	rw	6.4-6.5	22	96 h	LC50	0.16	Slonim & Slonim, 1973
Leuciscus idus melanotus	n	S	$Be(NO_3)_2$	tw	7-8	255	48 h	LC50	5.90-7.70[1]	Juhnke & Lüdemann, 1978
Leuciscus idus melanotus	n	S	$Be(NO_3)_2$	tw	7-8	255	48 h	LC50	0.54[1]	Juhnke & Lüdemann, 1978
amphibians										
Ambystoma opacum, larvae	n	S	$BeSO_4$	nw	-	400	96 h	LC50	32	Slonim & Ray, 1975
Ambystoma opacum, larvae	n	S	$BeSO_4$	nw	-	20-25	96 h	LC50	3.20	Slonim & Ray, 1975
Ambystoma maculatum, larvae	n	S	$BeSO_4$	nw	-	400	96 h	LC50	22	Slonim & Ray, 1975
Ambystoma maculatum, larvae	n	S	$BeSO_4$	nw	-	20-25	96 h	LC50	6	Slonim & Ray, 1975

[1] different values were obtained for two laboratoria

Acute toxicity of cobalt to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
protozoans										
Philodina acuticornis	n	S	$CoCl_2$	am	7.4-7.9	25	24 h	EC50[a]	28	Buikema et al., 1974
crustaceans										
Crangonyx pseudogracilis	n	S	$CoCl_2$	tw	6.7-6.8	45-55	96 h	EC50	39	Martin & Holdich, 1986
Cyclops abyssorum, < 24 h	n	S	$CoCl_2$	nw	7.2	31	48 h	EC50	16	Baudouin & Scoppa, 1974
Daphnia magna, < 24 h	n	S	$CoCl_2$	nw	7.5	204	48 h	EC50	5.0	Bringmann & Kühn, 1959
Daphnia hyalina, < 24 h	n	S	$CoCl_2$	nw	7.2	31	48 h	EC50	1.30	Baudouin & Scoppa, 1974
Daphnia magna, 12 + 12 h	n	S	$CoCl_2$	nw	7.4-8.2	44-53	48 h	EC50	1.10	Biesinger, 1972
Daphnia magna S.	n	S	$CoCl_2$	nw	7.2-7.8	235-260	48 h	EC50	1.50	Khangarot & Ray, 1989a
Eudiaptomus padanus, < 24 h	n	S	$CoCl_2$	nw	7.2	31	48 h	EC50	4.0	Baudouin & Scoppa, 1974
insects										
Chironomus tentans	n	S	$CoCl_2$	nw	6.1-6.6	18-35	48 h	EC50[a]	57	Khangarot & Ray, 1989b
worms										
Tubifex tubifex	n	S	$CoCl_2$	nw	7.6	245	96 h	EC50[a]	140	Khangarot, 1991
fish										
Oryzias latipes, 8 d fry	n	S	$CoCl_2$	tw	6.9	11	24 h	LC50	4.80	Hiraoka et al., 1985

[a] immobility

Acute toxicity of molybdenum to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Crangonyx pseudogracilis	n	S	Na_2MoO_4	tw	6.7-6.8	45-55	96 h	LC50	2,700	Martin & Holdich, 1986
worms										
Tubifex tubifex	n	S	Na_2MoO_4	nw	7.6	245	96 h	EC50[a]	29	Khangarot, 1991
fish										
Oncorhynchus mykiss, 50 mm	n	S	Na_2MoO_4	tw	6.9-7.2	14-32	96 h	LC50	1,300	McConnell, 1977
Oncorhynchus mykiss, 20 mm	n	S	Na_2MoO_4	tw	6.9-7.2	14-32	96 h	LC50	800	McConnell, 1977

[a] immobility

Acute toxicity of selenium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Ceriodaphnia affinis, < 24 h	y	S	Na_2SeO_3	tw	7.9	101	48 h	EC50	0.60	Owsley & McCauley, 1986
Ceriodaphnia affinis[1]	y	S	Na_2SeO_3	tw	7.9	101	48 h	EC50	0.35	Owsley & McCauley, 1986
Daphnia, < 24 h	n	S	Na_2SeO_3	nw	7.5	204	48 h	EC50	2.50	Bringmann & Kühn, 1959
Daphnia magna, < 24 h	n	S	Na_2SeO_3	tw	7.6-7.7	272	24 h	EC50	9.90	Bringmann & Kühn, 1977b
Daphnia magna, < 24 h	n	S	Na_2SeO_3	tw	7.6-7.7	272	24 h	EC50	3.90	Bringmann & Kühn, 1982
Daphnia magna, < 24 h	n	S	Na_2SeO_3	rw	8.2-8.4	130	48 h	EC50	1.10	Dunbar et al., 1983
Daphnia magna, < 24 h	n	S	Na_2SeO_4	rw	8.2-8.4	130	48 h	EC50	5.30	Dunbar et al., 1983
Daphnia magna, egg	n	SS	Na_2SeO_4	-	8.4	-	72 h	EC50	1.40	Johnston, 1987
Daphnia magna, 6-18 h	n	SS	Na_2SeO_4	-	8.4	-	48 h	EC50	0.55	Johnston, 1987
Daphnia magna, 2 d	y	CF	Na_2SeO_3/O_4	nw	7.3	329	96 h	EC50	0.43[2]	Halter et al., 1980
Daphnia magna, adult	n	S	Na_2SeO_3	-	-	-	48 h	EC50	0.25	Nassos et al. 1980
Daphnia magna, < 24 h	n	S	Na_2SeO_3	rw	7.8	46	48 h	EC50	0.70	Ingersoll et al., 1990
Daphnia magna, < 24 h	n	S	Na_2SeO_4	rw	7.8	46	48 h	EC50	2.60	Ingersoll et al., 1990
Daphnia magna, < 24 h	n	S	Na_2SeO_3	rw	8.2	136	48 h	EC50	3.0	Ingersoll et al., 1990
Daphnia magna, < 24 h	n	S	Na_2SeO_4	rw	8.2	136	48 h	EC50	4.1	Ingersoll et al., 1990
Daphnia magna, < 24 h	n	S	Na_2SeO_3/O_4[3]	rw	7.8	46	48 h	EC50	1.80	Ingersoll et al., 1990
Daphnia magna, < 24 h	n	S	Na_2SeO_3/O_4[3]	rw	8.2	136	48 h	EC50	2.6	Ingersoll et al., 1990
Daphnia pulex, adult	n	S	Na_2SeO_3	rw	7.4	-	96 h	EC50	0.071	Schultz et al., 1980
Daphnia pulex, 12-36 h	n	S	Na_2SeO_3	rw	7.4	46	48 h	EC50	3.90	Reading & Buikema, 1983
insects										
Chironomus riparius, < 24 h	n	S	Na_2SeO_3	rw	7.8	46	48 h	LC50	15	Ingersoll et al., 1990
Chironomus riparius, < 24 h	n	S	Na_2SeO_4	rw	7.8	46	48 h	LC50	11	Ingersoll et al., 1990
Chironomus riparius, < 24 h	n	S	Na_2SeO_3/O_4[3]	rw	7.8	46	48 h	LC50	14	Ingersoll et al., 1990
Chironomus riparius, < 24 h	n	S	Na_2SeO_3	rw	8.2	136	48 h	LC50	8.0	Ingersoll et al., 1990
Chironomus riparius, < 24 h	n	S	Na_2SeO_4	rw	8.2	136	48 h	LC50	16.2	Ingersoll et al., 1990
Chironomus riparius, < 24 h	n	S	Na_2SeO_3/O_4[3]	rw	8.2	136	48 h	LC50	9.3	Ingersoll et al., 1990

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
insects										
Culex fatigans, larvae	n	S	Na_2SeO_3	-	-	-	48 h	LC50	3.1	Nassos et al., 1980
worms										
Tubifex tubifex	n	S	$NaHSeO_3$	nw	7.6	245	96 h	EC50[a]	7.7	Khangarot, 1991
fish										
Catostomus commersoni, adult	y	CF	Na_2SeO_3	nw	6.4	18	96 h	LC50	31	Duncan et al., 1983
Catostomus commersoni, juvenile	y	IF	Na_2SeO_3	nw	6.4	10	96 h	LC50	29	Klaverkamp et al., 1983
Esox lucius, juvenile	y	IF	Na_2SeO_3	nw	6.4	10	72 h	LC50	11	Klaverkamp et al., 1983
Ictalurus punctatus, juvenile	y	IF	SeO_2	-	7.9	140	96 h	LC50	13	Cardwell et al., 1976
Jordanella floridae, juvenile	y	IF	SeO_2	-	7.9	152	96 h	LC50	6.50[2]	Cardwell et al., 1976
Leuciscus idus melanotus	n	S	Na_2SeO_3	tw	7-8	255	48 h	LC50	110	Juhnke & Lüdemann, 1978
Oncorhynchus kisutch, 8-12 wks	n	S	Na_2SeO_3	nw	7.8	211	96 h	LC50	7.8	Hamilton & Buhl, 1990
Oncorhynchus kisutch, 8-12 wks	n	S	Na_2SeO_4	nw	7.8	211	96 h	LC50	33	Hamilton & Buhl, 1990
Oncorhynchus tshawytscha, 8-12 wks	n	S	Na_2SeO_3	nw	7.8	211	96 h	LC50	14	Hamilton & Buhl, 1990
Oncorhynchus tshawytscha, 8-12 wks	n	S	Na_2SeO_4	nw	7.8	211	96 h	LC50	120	Hamilton & Buhl, 1990
Oncorhynchus tshawytscha, 0.46 g	n	S	Na_2SeO_3	rw	7.6	42	96 h	LC50	13	Hamilton & Buhl, 1990
Oryzias latipes, 8 d fry	n	S	Na_2SeO_3	tw	6.9	11	24 h	LC50	16[2]	Hiraoka et al., 1985
Pimephales promelas, 1 d fry	y	IF	SeO_2	-	7.8	151	96 h	LC50	2.1	Cardwell et al., 1976
Oncorhynchus mykiss, adults	-	-	Na_2SeO_3	nw	7.2	40	96 h	LC50	1.8	Hunn et al., 1987
Savelinus fontinalis, adult	y	IF	SeO_2	-	7.8	148	96 h	LC50	10	Cardwell et al., 1976
plants										
Lemna minor	n	S	Se^{4+}	rw	7.5	-	96 h	EC50[b]	2.4	Wang, 1986

[a] immobility
[b] growth

[1] F1-animals of which the parents were exposed to 18-360 mg Se/l during 18-19 days
[2] EC50 and LC50 calculated according to Spearman & Karber
[3] 6:1 selenate:selenite mixture

Acute toxicity of thallium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
green algae										
Chlamydomonas reinhardii	n	S	-[1]	-	7.0	-	15 min	EC50[a]	3.0	Overnell, 1975
crustaceans										
Daphnia magna, < 24 h	n	S	$TlNO_3$	tw	7.6-7.7	272	24 h	EC50	1.60	Bringmann & Kühn, 1977b
Daphnia magna, < 24 h	n	S	$TlNO_3$	tw	7.6-7.7	272	24 h	EC50	0.11	Bringmann & Kühn, 1982
fish										
Leuciscus idus melanotus	n	S	$TlNO_3$	tw	7-7	255	48 h	LC50	140	Juhnke & Lüdemann, 1978
Pimephales promelas	n	S	Tl_2SO_4	nw	6.7-7.1	28-40	96 h	LC50	0.86	LeBlanc & Dean, 1984

[a] photosynthesis

[1] compound added unknown, but EC50 based on Tl^+

Acute toxicity of tin to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
green algae										
Scenedesmus quadricauda	n	S	$SnCl_4$	nw	-	-	4 h	EC50[a]	23	Wong, 1980
Ankistrodesmus falcatus	n	S	$SnCl_2$	nw	-	-	4 h	EC50[a]	8.8	Wong, 1980
Ankistrodesmus falcatus	n	S	$SnCl_4$	nw	-	-	4 h	EC50[a]	5.5	Wong, 1980
crustaceans										
Daphnia magna, 12 + 12 h	n	S	$SnCl_2$	nw	7.2-7.8	44-53	48 h	EC50	42	Biesinger, 1972
Crangonyx pseudogracilis	n	S	$SnCl_2$	tw	6.7-6.8	45-55	96 h	LC50	50	Martin & Holdich, 1986

[a] primairy production measured as uptake of ^{14}C-carbonate

Acute toxicity of vanadium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
oligochaetae										
Pristina leidyi	y	S	Na_3VO_4	tw	7.9	105	48 h	LC50	31[1]	Smith et al., 1991
crustaceans										
Crangonyx pseudogracilis, adult	n	S	$NaVO_3$	tw	6.7-6.8	45-55	96 h	EC50	12	Martin & Holdich, 1986
Daphnia magna, < 24 h	y	S	$NaVO_3$	rw	8.2-8.9	136	48 h	EC50	3.5	Beusen & Neven, 1987
fish										
Jordanella floridae, adult	n	S	V_2O_5	nw	8.2	275	96 h	LC50	11	Holdway & Sprague, 1979
Oncorhynchus mykiss, eyed eggs	y	S	V_2O_5	rw	7.3-8.4	-	96 h	LC50	120	Giles & Klaverkamp, 1982

[1] based on measured concentrations

Chronic toxicity of antimony to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
blue algae										
Microcystis aeruginosa	n	S	$K[Sb(OH)_6]$	am	7.0	28.7	8 d	NOEC[b]	23[1]	Bringmann & Kühn, 1978a
protozoans										
Entosiphon sulcatum S.	n	S	$K[Sb(OH)_6]$	am	6.9	35.3	72 h	NOEC[b]	120[1]	Bringmann & Kühn, 1978b

[a] survival
[b] growth
[c] reproduction

[1] NOEC calculated as TGK:2 (TGK: Toxische Grenzkonzentration or toxicity treshold)

Chronic toxicity of barium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
green algae										
Scenedesmus	n	S	$BaCl_2$	am	-	-	96 h	NOEC[b]	17[1]	Bringmann & Kühn, 1959
crustaceans										
Daphnia magna, 12 + 12 h	n	SS	$BaCl_2$	nw	7.4-8.2	44-53	21 d	NOEC[c]	2.9[2]	Biesinger, 1972

[a] survival
[b] growth
[c] reproduction

[1] NOEC calculated as TGK:2 (TGK: Toxische Grenzkonzentration or toxicity treshold)
[2] NOEC calculated as EC16:2

Chronic toxicity of beryllium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result µg/l	Reference
bacteria										
Pseudomonas putida	n	S	$Be(NO_3)_2$	am	7	42.5	16 h	NOEC[b]	0.68[1]	Bringmann & Kühn, 1977a
blue algae										
Microcystis aeruginosa	n	S	$Be(NO_3)_2$	am	7.0	28.7	8 d	NOEC[b]	15[1]	Bringmann & Kühn, 1976
green algae										
Scenedesmus quadricauda	n	S	$Be(NO_3)_2$	am	7.0	28.7	8 d	NOEC[b]	1.0[1]	Bringmann & Kühn, 1977a
protozoans										
Chilomonas paramaecium E.	n	S	$Be(NO_3)_2$	am	6.9	42.3	48 h	NOEC[b]	260[1]	Bringmann & Kühn, 1980b
Entosiphon sulcatum S.	n	S	$Be(NO_3)_2$	am	6.9	35.3	72 h	NOEC[b]	2[1]	Bringmann & Kühn, 1978b
Uronema parduczi C.	n	S	$Be(NO_3)_2$	am	6.9	35.3	20 h	NOEC[b]	8.5[1]	Bringmann & Kühn, 1980a
fish										
Cyprinus carpio, eggs	y	SS	$Be(NO_3)_2$	nw	-	-	3 d	NOEC[c]	80[2]	Hildebrand & Cushman, 1978

[a] survival
[b] growth
[c] reproduction

[1] NOEC calculated as TGK:2 (TGK: Toxische Grenzkonzentration or toxicity treshold)
[2] based on measured concentrations

Chronic toxicity of cobalt to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result µg/l	Reference
blue algae										
Spirulina platensis	n	S	$CoCl_2$	am	-	-	7 d	NOEC[b]	500	Sharma et al., 1987
green algae										
Chlorella pyrenoidosa	n	-	$CoSO_4$	am	-	20	6 d	NOEC[b]	49[1]	Wong, 1980
Chlorella pyrenoidosa	n	-	$CoSO_4$	am	-	400	6 d	NOEC[b]	69[1]	Wong, 1980
Scenedesmus	n	S	$CoCl_2$	am	-	-	96 h	NOEC[b]	500[2]	Bringmann & Kühn, 1959
crustaceans										
Daphnia magna, 12 + 12 h	n	SS	$CoCl_2$	nw	7.4-8.2	44-53	21 d	NOEC[c]	5[3]	Biesinger, 1972
fish										
Cyprinus carpio, eggs	n	S	$CoCl_2$	-	7.5	360	-	NOEC[c]	1,100[4]	Kapur & Yadav, 1982

[a] survival
[b] growth
[c] reproduction

[1] NOEC calculated as EC50:10
[2] NOEC calculated as TGK:2 (TGK: Toxische Grenzkonzentration or toxicity treshold)
[3] NOEC calculated as EC16:2
[4] NOEC obtained by extrapolation of concentration-effects relationship

Chronic toxicity of molybdenum to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
green algae										
Scenedesmus	n	S	molybdate[1]	am	-	-	96 h	NOEC[b]	27[2]	Bringmann & Kühn, 1959

[a] survival
[b] growth
[c] reproduction

[1] Mo added as ammoniummolybdate: $(NH_4)_6Mo_7O_4.4H_2O)$
[2] NOEC calculated as TGK:2 (TGK: Toxische Grenzkonzentration or toxicity treshold)

Chronic toxicity of selenium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result µg/l	Reference
bacteria										
Pseudomonas putida	n	S	Na_2SeO_3	am	7	42.5	16 h	NOEC[b]	5,600[1]	Bringmann & Kühn, 1977a
blue algae										
Anabaena flos-aquae	n	S	Na_2SeO_3	-	-	-	10 d	NOEC[b]	1,000	Kiffney & Knight, 1990
Anabaena flos-aquae	n	S	Na_2SeO_4	-	-	-	10 d	NOEC[b]	1,000	Kiffney & Knight, 1990
Microcoleus vaginatus	n	S	Na_2SeO_4	am	7.3	-	14 d	NOEC[b]	5,000	Vocke et al., 1980
Microcystis aeruginosa	n	S	Na_2SeO_3	am	7.0	28.7	8 d	NOEC[b]	4,700[1]	Bringmann & Kühn, 1976
Phormidium luridum	n	S	Na_2SeO_3	am	-	-	8 d	NOEC[b,d]	79	Sielicki & Burnham, 1973
green algae										
Ankistrodesmus falcatus	n	S	Na_2SeO_4	am	7.3	-	14 d	NOEC[b]	5	Vocke et al., 1980
Scenedesmus	n	S	Na_2SeO_3	am	-	-	4 d	NOEC[b]	1,300[1]	Bringmann & Kühn, 1959
Scenedesmus obliquus	n	S	Na_2SeO_4	am	7.3	-	14 d	NOEC[b]	50	Vocke et al., 1980
Scenedesmus quadricauda	n	S	Na_2SeO_3	am	7.0	28.7	8 d	NOEC[b]	260[1]	Bringmann & Kühn, 1977a
Selenastrum capricornutum	n	S	Na_2SeO_4	am	7.3	-	14 d	NOEC[b]	200	Vocke et al., 1980
protozoa										
Chilomonas paramaecium E.	n	S	Na_2SeO_3	am	6.9	42.3	48 h	NOEC[b]	31[1]	Bringmann & Kühn, 1980b
Entosiphon sulcatum S.	n	S	Na_2SeO_3	am	6.9	35.3	72 h	NOEC[b]	0.9[1]	Bringmann & Kühn, 1978b
Uronema parduczi C.	n	S	Na_2SeO_3	am	6.9	35.3	20 h	NOEC[b]	59.0[1]	Bringmann & Kühn, 1980a
crustaceans										
Ceriodaphnia affinis	n	SS	Na_2SeO_3	rw	7.9	101	8 d	NOEC[c]	200[2]	Owsley & McCauley, 1986
Ceriodaphnia affinis	n	SS	Na_2SeO_3	rw	7.9	101	8 d	NOEC[c]	50[3]	Owsley & McCauley, 1986
Ceriodaphnia affinis	n	SS	Na_2SeO_3	rw	7.9	101	8 d	NOEC[c]	100[4]	Owsley & McCauley, 1986
Daphnia magna, < 24 h	n	SS	Na_2SeO_4	rw	8.2-8.4	130	32 d	NOEC[c]	1,500	Dunbar et al., 1983
Daphnia magna, < 24 h	n	SS	Na_2SeO_4	rw	8.2-8.4	130	32 d	NOEC[b]	1,000	Dunbar et al., 1983
Daphnia magna, 6-18 h	n	SS	Na_2SeO_4	am	8.4	-	15 d	NOEC[c]	25	Johnston, 1987
Daphnia magna, 6-18	n	SS	Na_2SeO_4	am	8.4	-	15 d	NOEC[b]	50	Johnston, 1987
Daphnia magna, 2 d	y	CF	Na_2SeO_3/O_4	nw	7.3	329	21 d	NOEC[a]	280	Halter et al., 1980
Daphnia magna, < 24 h	y	CF	Na_2SeO_3/O_4	rw	7.9	138	21 d	NOEC[b]	85[5]	Ingersoll et al., 1990

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result µg/l	Reference
crustaceans										
Daphnia magna, < 24 h	y	CF	Na_2SeO_3/O_4	rw	7.9	138	21 d	NOEC[c]	160[5]	Ingersoll et al., 1990
Daphnia pulex, 12-36 h	n	SS	Na_2SeO_3	rw	7.2	42	28 d	NOEC[c]	200	Reading & Buikema, 1983
Hyalella azteca, adult	y	CF	Na_2SeO_3/O_4	nw	7.3	329	21 d	NOEC[a]	30	Halter et. al., 1980
insects										
Chironomus riparius, < 24 h	y	CF	Na_2SeO_3/O_4	rw	7.9	138	30 d	NOEC[c]	300[5]	Ingersoll et. al., 1990
fish										
Oncorhynchus mykiss, eyed eggs	y	CF	Na_2SeO_3	rw	7.9	135	44 w	NOEC[a]	15[5]	Hodson et al., 1980
Oncorhynchus mykiss, eggs	y	CF	Na_2SeO_3	rw	7.2	40	90 d	NOEC[a,b]	21[5]	Hunn et. al., 1987

[a] survival
[b] growth
[c] reproduction
[d] photosynthesis

[1] NOEC calculated as TGK:2 (TGK: Toxische Grenzkonzentration or toxicity treshold)
[2] total number of young in the first three broods of the P-generation
[3] total number of young in the first three broods of the F1-generation
[4] total number of young in the first three broods of the F2 and F3-generations
[5] based on measured concentrations

Chronic toxicity of thallium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result µg/l	Reference
fish										
Pimephales promelas, larvae	n	CF	Tl_2SO_4	nw	6.7-7.1	28-40	30 d post-hatch	NOEC[a] NOEC[b] NOEC[c]	160 30 100	LeBlanc & Dean, 1984

a survival
b growth
c reproduction

Chronic toxicity of tin to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
green algae										
Ankistrodesmus falcatus	n	S	$SnCl_2$	am	8	-	8 d	NOEC[b]	0.75[1]	Wong, 1980
Ankistrodesmus falcatus	n	S	$SnCl_4$	am	8	-	8 d	NOEC[b]	0.09[1]	Wong, 1980
crustaceans										
Daphnia magna, 12 + 12 h	n	SS	$SnCl_2$	nw	7.4-8.2	44-53	21 d	NOEC[c]	0.18[2]	Biesinger, 1972
fish										
Cyprinus carpio, eggs	n	S	$SnCl_2$	-	7.5	360	-	NOEC[c]	7.80[3]	Kapur & Yadav, 1982

[a] survival
[b] growth
[c] reproduction

[1] NOEC calculated as LOEC/10
[2] NOEC calculated as EC16:2
[3] NOEC obtained by extrapolation of concentration-effects relationship

Chronic toxicity of vanadium to freshwater organisms

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result µg/l	Reference
crustaceans										
Daphnia magna, < 24 h	n	SS	$NaVO_3$	rw	8.2-8.9	136	23 d	NOEC[a]	1,600	Beusen & Neven, 1987
Daphnia magna, < 24 h	n	SS	$NaVO_3$	rw	8.2-8.9	136	23 d	NOEC[c]	1,900	Beusen & Neven, 1987
Daphnia magna, 10 d	n	CF	$NaVO_3$	nw	8.1	197	97 d	NOEC[a]	1,000	Van der Hoeven, 1990
fish										
Jordanella floridae, eggs[1]	n	CF	V_2O_5	rw	8.2	347	34 d	NOEC[b]	41	Holdway & Sprague, 1979

[a] survival
[b] growth
[c] reproduction

[1] F1 eggs from P-generation which was exposed for 96 days to similar concentrations of V_2O_5

Toxicity of beryllium to freshwater organisms, data not used for extrapolation

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
fish										
Pimephales promelas	y	CF	$BeSO_4$		8.0	140	14 d	LC50	4.0	Cardwell et al, 1976
Carassius auratus	y	CF	$BeSO_4$		7.6	147	10 d	LC50	6.5	Cardwell et al, 1976

Toxicity of cobalt to freshwater organisms, data not used for extrapolation

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
green algae										
Euglena virdis	n	-	$Co(NO_3)_2$	am	-	-	21 d	EC50[a]	1.3[1,2]	Coleman et al., 1971

[a] growth

[1] EC50 derived from data presented by the author
[2] effect possibly underestimated because growth was measured as dry weight

Toxicity of selenium to freshwater organisms, data not used for extrapolation

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Daphnia magna, adult	n	SS	Na_2SeO_4	am	8.4	-	6 d	EC50	0.42[1]	Johnston, 1987
Daphnia magna, adult	n	SS	Na_2SeO_3	am	8.4	-	7 d	EC50	0.32[1]	Johnston, 1987
fish										
Carassius auratus, adult	y	IF	SeO_2	-	7.6	148	14 d	LC50	6.3	Cardwell et al., 1976
Lepomis macrochirus, juvenile	y	IF	SeO_2	-	7.9	140	14 d	LC50	13	Cardwell et al., 1976
Perca flavescens, juvenile	y	IF	Na_2SeO_3	nw	6.4	10	10 d	LC50	4.8[2]	Klaverkamp et al., 1983
Pimephales promelas, juvenile	n	SS	Na_2SeO_3	nw	7.3	329	17 d	LC50	0.60	Halter et al., 1980
Pimephales promelas, juvenile	y	IF	SeO_2	-	7.8	151	9 d	LC50	2.10	Cardwell et al., 1976
Oncorhynchus mykiss, juvenile	y	CF	Na_2SeO_3	rw	7.9	135	9 d	LC50	6.40	Hodson et al., 1980

[1] calculated acoording to Spearman and Karber
[2] based on measured concentrations

Toxicity of vanadium to freshwater organisms, data not used for extrapolation

Organism	A	Test type	Test compound	Test water	pH	Hardness mg $CaCO_3$/l	Exp. time	Criterion	Result mg/l	Reference
fish										
Brachydanio rerio, juv/adult	y	SS	$NaVO_3$	nw	7.7-8.5	136	7 d	LC50	2.30	Beusen & Neven, 1987
Carassius auratus, 3-5 cm	n	S	V_2O_5	rw	6.0-6.5	35	6 d	LC50	8.10	Knudtson, 1979
Carassius auratus, 3-5 cm	n	S	$VOSO_4$	rw	6.0-6.5	35	6 d	LC50	3.00	Knudtson, 1979
Carassius auratus, 3-5 cm	n	S	NH_4VO_3	rw	6.0-6.5	35	6 d	LC50	3.80	Knudtson, 1979
Carassius auratus, 3-5 cm	n	S	$NaVO_3$	rw	6.0-6.5	35	6 d	LC50	2.50	Knudtson, 1979
Jordanella floridae, 1 week	n	CF	V_2O_5	rw	8.2	347	96 d	LC50	1.10	Holdway & Sprague, 1979
Jordanella floridae, eggs[1]	n	CF	V_2O_5	rw	8.2	347	34 d	LC50	0.69	Holdway & Sprague, 1979
Lebistes reticulatus, 1.5-2.5 cm	n	S	V_2O_5	rw	6.0-6.5	35	6 d	LC50	1.10	Knudtson, 1979
Lebistes reticulatus, 1.5-2.5 cm	n	S	$VOSO_4$	rw	6.0-6.5	35	6 d	LC50	0.37	Knudtson, 1979
Lebistes reticulatus, 1.5-2.5 cm	n	S	NH_4VO_3	rw	6.0-6.5	35	6 d	LC50	1.50	Knudtson, 1979
Lebistes reticulatus, 1.5-2.5 cm	n	S	$NaVO_3$	rw	6.0-6.5	35	6 d	LC50	0.49	Knudtson, 1979
Poecilia reticulata, juv/adult	y	SS	$NaVO_3$	rw	7.7-8.5	136	7 d	LC50	3.30	Beusen & Neven, 1987
Oncorhynchus mykiss, juvenile	y	CF	V_2O_5	rw	5.5-8.8	30	7 d	LC50	2.4-3.0[2]	Stendahl & Sprague, 1982
Oncorhynchus mykiss, juvenile	y	CF	V_2O_5	rw	5.5-8.8	100	7 d	LC50	3.4-5.1[2]	Stendahl & Sprague, 1982
Oncorhynchus mykiss, juvenile	y	CF	V_2O_5	rw	5.5-8.8	356	7 d	LC50	2.5-6.0[2]	Stendahl & Sprague, 1982
Oncorhynchus mykiss, juvenile	y	CF	V_2O_5	rw	7.7	100	13-20 d	LC50	2.50[2]	Stendahl & Sprague, 1982

[1] F1 eggs from P-generation which was exposed for 96 days to similar concentrations of V_2O_5
[2] based on measured concentrations

REFERENCES

1. Literature used

Baudouin, M.F., and Scoppa, P. (1974). Acute toxicity of various metals to freshwater zooplankton. Bull. Environ. Contam. Toxicol. **12**, (6), 745-751.

Beusen, J.M., and Neven, B. (1987). Toxicity of vanadium to different freshwater organisms. Bull. Environ. Contam. Toxicol. **39**, 194-201.

Biesinger, K.E., and Christensen, G.M. (1972). Effects of various metals on survival, growth, reproduction, and metabolism of Daphnia magna. J. Fish Res. Board Can. **29**, (12), 1691-1700.

Bringmann, G., and Kühn, R. (1959). Vergleichende wasser-toxikologische Untersuchungen an Bakterien, Algen und Kleinkrebsen. Gesundheits-Ingenieur **80**, (4), 115-120.

Bringmann, G., and Kühn, R. (1976). Vergleichende Befunde der Schadwirkung wassergefährdender Stoffe gegen Bakterien (Pseudomonas putida) und Blaualgen (Microcystis aeruginosa). GWF-Wasser/Abwasser **117**, (9), 410-413.

Bringmann, G., and Kühn, R. (1977a). Grenzwerte der Schadwirkung wassergefährdender Stoffe gegen Bakterien (Pseudomonas putida) und Grünalgen (Scenedesmus quidricauda) im Zellvermehrungstest. Z. f. Wasser- und Abwasser-Forschung **10**, (3/4), 87-98.

Bringmann, G., and Kühn, R. (1977b). Befunde der Schadwirkung wassergefährdender Stoffe gegen Daphnia magna. Z. f. Wasser- und Abwasser-Forschung **10**, (5), 161-166.

Bringmann, G., and Kühn, R. (1978a). Grenzwerte der Schadwirkung wassergefährdender Stoffe gegen Blaualgen (Microcystis aeruginosa) und Grünalgen (Scenedesmus quidricauda) im Zellvermehrungstest. Vom Wasser **50**, 45-60.

Bringmann, G. (1978b). Bestimmung der biologischen Schadwirkung wassergefährdender Stoffe gegen Protozoen (I. Bakterienfressende Flagellaten; Modellorganismus: Entosiphon sulcatum Stein). Z. f. Wasser- und Abwasser-Forschung **11**, (6), 210-215.

Bringmann, G., and Kühn, R. (1980a). Bestimmung der biologischen Schadwirkung wassergefährdender Stoffe gegen Protozoen (II. Bakterienfressende Ciliaten). Z. f. Wasser- und Abwasser-Forschung **13**, (1), 26-31.

Bringmann, G., and Kühn, R. (1980b). Bestimmung der biologischen Schadwirkung wassergefährdender Stoffe gegen Protozoen (III. Saprozoische Flagellaten). Z. f. Wasser- und Abwasser-Forschung **13**, (5), 170-173.

Bringmann, G., and Kühn, R. (1982). Ergebnisse der Schadwirkung wassergefährdender Stoffe gegen Daphnia magna in einem weiterentwickelten standardisierten Testverfahren. Z. f. Wasser- und Abwasser-Forschung **15**, (1), 1-6.

Buikema, A.L., Cairns, J., and Sullivan, G.W. (1974). Evaluation of Philodina acuticornis (Rotifera) as a bioassay organism for heavy metals. Water Resources Bulletin **10**, (4), 648-661.

Cardwell, R.D., Foreman, D.G., Payne, T.R., and Wilbur, D.J. (1976). Acute toxicity of selenium dioxide to freshwater fishes. Arch. Environ. Contam. Toxicol. **4**, 129-144.

Coleman, R.D., Coleman, R.L., and Rice, E.L. (1971). Zinc and cobalt bioconcentration and toxicity in selected algal species. Bot. Gaz. **132**, (2), 102-109.

Dunbar, A.M., Lazorchak, J.M., and Waller, W.T. (1983). Acute and chronic toxicity of sodium selenate to Daphnia magna Strauss. Environ. Toxicol. and Chem. **2**, 239-244.

Duncan, D.A., and Klaverkamp, J.F. (1983). Tolerance and resistance to cadmium in white suckers (Catostomus commersoni) previously exposed to cadmium, mercury, zinc or selenium. Can. J. Fish Aquat. Sci. **40**, (2), 128-138.

Giles, M.A., and Klaverkamp, J.F. (1982). The acute toxicity of vanadium and copper to eyed eggs of rainbow trout (Salmo gairdneri). Water Res. **16**, 885-889.

Halter, M.T., Adams,W.J., and Johnson, H.E. (1980). Selenium toxicity to Daphnia magna, Hyalella azteca and the fathead minnow in hard water. Bull. Environ. Contam. Toxicol. **24**, 102-107.

Hamilton, M.A., Russo, R.C., and Thurston, R.V. (1977). Trimmed Spearman-Karber method for estimating median lethal concentrations in toxicity bioassays. Environ. Sci. Technol. **11**, (7), 714-719 (correction: (1978). **12**, (4), 417).

Hamilton, S.J., and Buhl, K.J. (1990). Acute toxicity of boron, molybdenum and selenium to fry of chinook salmon and coho salmon. Arch. Environ. Contam. Toxicol. **19**, 366-373.

Hildebrand, S.G., and Cushman, R.M. (1978). Toxicity of gallium and beryllium to developing carp eggs (Cyprinus carpio) utilizing copper as a reference. Toxicology Letters **2**, 91-95.

Hiraoka, Y., Ishizawa, S., Kamada, T., and Okuda, H. (1985). Acute toxicity of 14 different kinds of metals affecting medaka fry. Hiroshima Journal of Medical Sciences **34**, (3), 327-330.

Hodson, P.V., Spry, D.J., and Blunt, B.R. (1980). Effects on rainbow trout (Salmo gairdneri) of a chronic exposure to waterborne selenium. Can. J. Fish Aquat. Sci. **3**, (2), 233-240.

Holdway, D.A., and Sprague, J.B. (1979). Chronic toxicity of vanadium to flagfish. Water Res. **13**, 905-910.

Hunn, J.B., Hamilton, S.J., and Bucker, D.R. (1987). Toxicity of sodium selenite to rainbow trout fry. Water Res. **21**, (2), 233-238.

Ingersoll, C.G., Dwyer, F.J., and May, T.W. (1990). Toxicity of inorganic and organic selenium to Daphnia magna (Cladocera) and Chironomus riparius (Diptera). Environ. Toxicol. Chem. **9**, 1171-1181.

Johnston, P.A. (1987). Acute toxicity of inorganic selenium to Daphnia magna (Strauss) and the effect of sub-acute exposure upon growth and reproduction. Aquat. Toxicol. **10**, 335-352.

Juhnke, I., and Lüdemann, D. (1978). Ergebnisse der Untersuchung von 200 chemischen Verbindungen auf akute Fischtoxizität mit dem Goldorfentest. Z. f. Wasser- und Abwasser-Forschung **11**, (5), 161-164.

Kapur, K., and Yadav, N.A. (1982). The effects of certain heavy metal salts on the development of eggs in common carp, Cyprinus carpio, var. communis. Acta Hydrochim. Hydrobiol. **10**, (5), 517-522.

Khangarot, B.S., and Ray, P.K. (1989a). Investigation of correlation between physicochemical properties of metals and their toxicity to the water flea Daphnia magna Straus. Ecotoxicol. Environ. Saf. **18**, 109-120.

Khangarot, B.S., and Ray, P.K. (1989b). Sensitivity of midge larvae of Chironomus tentans Fabricius (diptera Chironomidae) to heavy metals. Bull. environ. contam. toxicol. **42**, 325-330.

Khangarot, B.S. (1991). Toxicity of metals to a freshwater tubificid worm, Tubifex tubifex (Muller). Bull. Environ. Contam. Toxicol. **46**, 906-912.

Kiffney, P., and Knight, A. (1990). The toxicity and bioaccumulation of selenate, selenite and seleno-methionine in the cyanobacterium Anabaena flos-aquae. Arch. Environ. Contam. Toxicol. **19**, 488-494.

Klaverkamp, J.F., Hodgins, D.A., and Lutz, A. (1983). Selenite toxicity and mercury-selenium interactions in juvenile fish. Arch. Environ. Contam. Toxicol. **12**, (4), 405-413.

Knudtson, B.K. (1979). Acute toxicity of vanadium to two species of freshwater fish. Bull. Environ. Contam. Toxicol. **23**, 9-99.

LeBlanc, G.A. (1984). Interspecies relationships in acute toxicity of chemicals to aquatic organisms. Environ. Toxicol. Chem. **3**, 47-60.

LeBlanc, G.A., and Dean, J.W. (1984). Antimony and thallium toxicity to embryos and larvae of fathead minnow (Pimephales promelas). Bull. Environ. Contam. Toxicol. **32**, 565-569.

Martin, T.R., and Holdich, D.M. (1986). The acute lethal toxicity of heavy metals to peracarid crustaceans (with particular reference to fresh-water asellids and gammarids). Water Res. **20**, (9), 1137-1147.

McConnell, R.P. (1977). Toxicity of molybdenum to rainbow trout under laboratory conditions. In Molybdenum in the environment. Volume 2: The geochemistry, cycling and industrial uses of molybdenum). Proceedings of an international symposium on Molybdenum in the environment held in Denver, Colorado (Chappell, W.P. and Kellogg-Petersen, Eds.), pp. 725-730. Marcel Dekker, New York.

Nassos, P.A., Coats, J.R., Metcalf, R.L., Brown, D.D., and Hansen, L.G. (1980). Model ecosystem, toxicity and uptake evaluation of Se-selenite. Bull. Environ. Contam. Toxicol. **24**, 752-758.

Overnell, J. (1975). The effect of some heavy metal ions on photosynthesis in a freshwater alga. Pestic. Biochem. Physiol. **5**, 19-26.

Owsley, J.A., and McCauley, D.E. (1986). Effect of extended sublethal exposure to sodium selenite to Ceriodaphnia affinis. Bull. Environ. Contam. Toxicol. **36**, 876-880.

Reading, J.T., and Buikema, Jr., A.L. (1983). Chronic effects of selenite-selenium on Daphnia pulex. Arch. Environ. Contam. Toxicol. **12**, 399-404.

Schultz, T.W., Freeman, S.R., and Dumont, J.N. (1980). Uptake, depuration and distribution of selenium in Daphnia and its effects on survival and ultrastructure. Arch. Environ. Contam. Toxicol. **9**, (1), 23-40.

Sielicki, M., and Burnham, J.C. (1973). The effect of selenite on the physiological and morphological properties of the blue-green alga Phormidium luridum var. Olivacea. J. Phycol. **9**, 509-514.

Sharma, R.M., Panigrahi, S., and Azeez, P.A. (1987). Effect of cobalt on the primary productivity of Spirulina platensis. Bull. Environ. Contam. Toxicol. **39**, (4), 716-720.

Slonim, C.B., and Slonim, A.R. (1973). Effect of water hardness on the tolerance of the guppy to beryllium sulfate. Bull. Environ. Contam. Toxicol. **10**, (5), 295-301.

Slonim, A.R., and Ray, E.E. (1975). Acute toxicity of beryllium sulfate to Salamander larvae (Ambystoma spp). Bull. Environ. Contam. Toxicol. **13**, (3), 307-312.

Smith, D.P., Kennedy, J.H., and Dickson, K.L. (1991). An evaluation of a naidid oligochaete as a toxicity test organism. Environ. Toxicol. Chem. **10**, 1459-1465.

Stendahl, D.H., and Sprague, J.B. (1982). Effects of water hardness and pH on vanadium lethality to rainbow trout. Water Res. **16**, 1479-1488.

Van Der Hoeven, N. (1990). Effect of 3,4-dichloroaniline and metavanadate on Daphnia populations. Ecotox. Environ. Saf. **20**, 53-70.

Vocke, R.W., Sears, K.L., O'Toole, J.J., and Wildman, R.B. (1980). Growth responses of selected freshwater algae to trace elements and scrubber ash slurry generated by coal-fired power plants. Water Res. , **14**, 141-150.

Wang, W. (1986). Toxicity tests of aquatic pollutants using common duckweed. Environ. Pollut. (Ser. B) **11**, 1-14.

Wong, M.H. (1980). Toxic effects of cobalt and zinc to Chlorella pyredoinosa in soft and hard water. Microbios **28**, 19-25.

2. Literature not used

Ahluwalia, A.S., and Kaur, M. (1988). Effect of some heavy metal compounds on growth and differentiation in a blue-green and a green alga. Microbios **53**, 37-45.

Bell, M.V., Kelly, K.F., and Sargent, J.R. (1980). The uptake of orthovanadate into various organs of the common eel, Anguilla anguilla, maintained in fresh water. Sci. Total Environ. **16**, 99-108.

Bennett, W.M. (1988). Assessment of selenium toxicity in algae using turbidostat culture. Water Res. **22**, (7), 939-942.

Boyum, K.W., and Brooks, A.S. (1988). The effect of selenium in water and food on Daphnia populations. Arch. Environ. Contam. Toxicol. **17**, 555-560.

Bringmann, G., and Kühn, R. (1981). Vergleich der Wirkung von Schadstoffen auf flagellate sowie ciliate bzw. auf holozoische bakterienfressende sowie saprozoische Protozoen. GWF-Wasser/Abwasser **122**, 308-313.

Brown, T.A., and Smith, D.G. (1979). Effects of inorganic selenium compounds on growth, cell size, and ultrastructure of Cryptococcus albidus. Microbios Letters **10**, 55-61.

Carter, J.W., and Cameron, I.L. (1973). Toxicity bioassay of heavy metals in water using Tetrahymena pyriformis. Water Res. **7**, 951-961.

Colmano, G. (1973). Molybdenum toxicity: abnormal cellular division of teratogenic appearance in Euglena gracilis. Bull. Environ. Contam. Toxicol. **9**, (6), 361-364.

El Nawawy, A.S., Hamdi, Y., El-Sayed, and Shalan, S.N. (1973). Growth of the blue-green alga Tolypothrix tenuis as affected by cobalt and molybdenum. Zbl. Bakt. Abt. H. **128**, 452-456.

Ewell, W.S., Gorsuch, J.W., Kringle, R.O., Robillard, K.A., and Spiegel, R.C. (1986). Simultaneous evaluation of the acute effects of chemicals on seven aquatic species. Environ. Toxicol. Chem. **5**, 831-840.

Gissel-Nielsen, M., and Gissel-Nielsen, G. (1978). Sensitivity of trout to chronic and acute exposure to selenium. Agric. Environ., **4**, 85-91.

Hilton, J.W., Hodson, P.V., and Slinger, S.J. (1980). The requirement and toxicity of selenium in rainbow trout (Salmo gairdneri). J. Nutr. **110**, 2527-2535.

Hodson, P.V., and Hilton, J.W. (1983). The nutritional requirements and toxicity to fish of dietary and waterborne selenium. Ecol. Bul. **35**, 335-340.

Hutchinson, T.C. (1973). Comparative studies of the toxicity of heavy metals to phytoplankton and their synergistic interactions. Water Pollut. Res. Can. **8**, 68-90.

Jonas, R.B., Gilmour, C.C., Stoner, D.L., Weir, M.M., and Tuttle, J.H. (1984). Comparison of methods to measure acute metal and organometal toxicity to natural aquatic microbial communities. Appl. Environ. Microbiol. **47**, (5), 1005-1011.

Karlander, P.K., and Krauss, R.W. (1972). Absorption and toxicity of beryllium and lithium in Chlorella vanielii Shihira and Krauss. Chesapeake Science **13**, (4), 245-253.

Khangarot, B.S., Ray, P.K., and Chandra, H. (1987). Daphnia magna as a model to assess heavy metal toxicity: comparative assessment with mouse system. Acta Hydrochim. Hydrobiol. **15**, (4), 427-432.

Kumar, D., Jha, M., and Kumar, H.D. (1985). Heavy-metal toxicity in the cyanobacterium Nostoc linckia. Aquatic Botany **22**, 101-105.

Kumar, H.D., and Prakash, G. (1971). Toxicity of selenium to the blue-green algae, Anacystis nidulans and Anabaena variabilis. Ann. Bot. **35**, 697-705.

LeBlanc, G.A. (1980). Acute toxicity of priority pollutants to water flea (Daphnia magna). Bull. Environ. Contam. Toxicol. **24**, 684-691.

LeBlanc, G.A. (1984a). Acute toxicity of priority pollutants to water flea (Daphnia magna). Bull. Environ. Contam. Toxicol. **24**, 684-691.

Lemly, A.D. (1982). Response of juvenile centrarchids to sublethal concentrations of waterborne selenium. I. Uptake, tissue distribution and retention. Aquat. Toxicol. **2**, 235-252.

Meisch, H., and Bielig, H. (1975). Effect of vanadium on growth, chlorophyll formation and iron metabolism in unicellular green algae. Arch. Microbiol. **105**, 77-82.

Moede, A., Greene, R.W., and Spencer, D.F. (1980). Effects of selenium on the growth and phosphorus uptake of Scenedesmus dimorphus and Anabaena cylindrica. Environ. Exper. Botany, **20**, 207-212

Nehring, D. (1962). Untersuchungen über die toxikologische Wirkung von Thallium-Ionen auf Fische und Fischnährtiere. Z. Fish. **11**, 557-561.

Norberg-King, T.J. (1989). An evaluation of the fathead minnow seven-day subchronic test for estimating chronic toxicity. Environ. Toxicol. Chem. **8**, (11), 1075-1089.

Puymbroeck, S., van, and Blokken, M. (1982). Cadmium en selenium: interakties in aquatische organismen. Biologisch jaarboek **50**, 28-35.

Pyron, M., and Beitinger, T.L. (1989). Effect of selenium on reproductive behaviour and fry of fathead minnows. Bull. Environ. Contam. Toxicol. **42**, 609-613.

Rai, L.C., and Dubey, S.K. (1989). Impact of chromium and tin on a nitrogen-fixing cyanobacterium Anabaena doliolum: interaction with bivalent cations. Ecotoxicol. Environ. Saf. **17**, (1), 94-104.

Reading, J.T., and Buikema, Jr., A.L. (1980). Effects of sublethal concentrations of selenium on metabolism and filtering rate of Daphnia pulex. Bull. Environ. Contam. Toxicol. **24**, 929-935.

Ruthven, J.A., and Cairns, J.C. jr. (1973). Response of fresh-water protozoan artificial communities to metals. J. Protozool. **20**, (1), 127-135.

Sato, T., Ose, Y., and Sakai, T. (1980). Toxicological effect of selenium on fish. Environ. Pollut. (Ser. A) **21**, 217-224.

Singh, S. (1989). Cobalt-induced inhibition of growth in cyanobacteria Anabaena doliolum and Anacystis nidulans: interaction with sulphur containing amino acids. Indian Journal of Exp. Biol. **27**, 1092-1093.

Stanley, R.A. (1974). Toxicity of heavy metals and salts to Eurasian watermilfoil (Myriophyllum spicatum L.). Arch. Environ. Contam. Toxicol. **2**, (4), 331-341.

Vareille-Morel, C., and Debord, J. (1990). Sensibilité du Mollusque prosobranche Potamopyrgus jenkisi Smith à l'action de chlorures métalliques ($ZnCl_2$, $BaCl_2$, $CuCl_2$) et d'un molluscicide de synthèse, la N-trityl-morpholine. Ann. Rech. Vét. **21**, 111-118.

Whitton, B.A., and Shehata, H.A. (1982). Influence of cobalt, nickel, copper and cadmium on the blue-green alga Anacystis nidulans. Environ. Pollut. (Ser. A) **27**, 275-281.

Wong, P.T.S., Chau, Y.K., Kramar, O., and Bengert, G.A. (1982). Structure-toxicity relationship of tin compounds on algae. Can. J. Fish Aquat. Sci. **39**, 483-488.

Yumnam, D.D., and Reddy, P.M. (1989). Influence of trace elements on akinete differentiation and germination in a blue-green alga (cyanobacterium), Nodularia spumigena. Arch. Hydrobiol. Suppl. **82**, (3), 371-379.

Zencirci, N. (1980). Contribution a l'étude de l'accumulation et de la toxicité de l'étain et du plomb chez des crustaces gammarides. Hydrobiologia **69**, (1-2), 179-186.

Zitko, V. (1975). Toxicity and pollution potential of thallium. Sci. Total Environ. **4**, 185-192.

Zitko, V., Carson, W.V., and Carson, W.G. (1975). Thallium: occurence in the environment and toxicity to fish. Bull. Environ. Contam. Toxicol. **13**, (1), 23-30.

Appendix 3. Toxicity data for marine organisms

A = analysis of test compound:
y = yes
n = no

Test type:
S = static
SS = semi-static
CF = continuous flow
IF = intermittent flow

Test water
rw = reconstituted water
nw = natural water
tw = tap water
am = artificial medium

Exposure time:
min = minutes
h = hours
d = days
w = weeks
m = months

Criterion:
LC = lethal concentration
EC = effect concentration
NOEC = no observed effect concentration

Acute toxicity of antimony to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
fish										
Cyprinodon variegatus	n	-	-	nw	-	10-31	96 h	LC50	6.2-8.3	Heitmuller, 1981

Acute toxicity of cobalt to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
algae										
Nitzschia closterium	n	S	$CoSO_4$	am	6.7-6.9	24-37	96 h	EC50[a]	24	Rosko, 1975
Ditylum brightwelli	n	S	$CoCl_2$	am	8.0	18.8[1]	5 d	EC50[a]	0.3	Canterford, 1980
crustaceans										
Artemia salina	n	S	$Co(NO_3)_3$	nw	-	-	48 h	LC50	170	Kissa, 1984
Nitocra spinipes	n	S	$CoCl_2$	nw	8.0	7	96 h	LC50	4.5	Bengtsson, 1978
Artemia salina	n	S	$Co(NO_3)_3$	nw	-	-	48 h	EC50[b]	10	Kissa, 1984

[a] growth
[b] reproduction

Acute toxicity of molybdenum to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Penaeus duorarum	y	S	$NaMoO_4.2H_2O$	am	-	25	96 h	LC50	1,900	Knothe, 1988
Mysidopsis bahia	y	S	$NaMoO_4.2H_2O$	nw	-	27	96 h	LC50	1,100	Knothe, 1988
Allorchestes compressa	y	CF	$(NH_4)_6Mo_7O_{24}$ $4H_2O$	nw	5.0-5.4	34.8	96 h	LC50	250	Ahsannulah, 1982
molluscs										
Mytilus edulis, larvae	y	S	$(NH_4)_6Mo_7O_{24}.$ $4H_2O$	nw	8.4	26	48 h	EC50[a]	150	Morgan, 1986
Crassostrea virginica	y	SS	$NaMoO_4.2H_2O$	am	-	20	96 h	EC50[b]	1,900	Knothe, 1988
fish										
Cyprinodon variegatus	y	S	$NaMoO_4.2H_2O$	am	-	25	96 h	LC50	2,600	Knothe, 1988

[a] reproduction
[b] growth

Acute toxicity of selenium to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
cumaceans										
Cyclaspis usitata	y	CF	$NaSeO_3.5H_2O$	nw	8.1	35.4	96 h	LC50	6.1	Ahsanullah, 1980
crustaceans										
Allorchestes compressa	y	CF	$NaSeO_3.5H_2O$	nw	7.5	34.8	96 h	LC50	4.8	Ahsanullah, 1980
Scylla serrata	n	SS	SeO_2	am	7-7.2	-	96 h	LC50	33	Krishnaja, 1987
Mysidopsis bahia	y	IF	H_2SeO_3	nw	-	30	96 h	LC50	1.5	Ward, 1981
Penaeus aztecus	n	S	$NaSeO_3.5H_2O$	nw	-	30	96 h	LC50	1.2	Ward, 1981
Callinectus sapidus	n	S	$NaSeO_3.5H_2O$	nw	-	30	96 h	LC50	4.6	Ward, 1981
molluscs										
Argopecten irradians	n	SS	SeO_2	nw	6.9-7.5	25	96 h	LC50	0.26	Nelson, 1988
Spisula solidissima	n	SS	SeO_2	nw	6.9-7.5	25	96 h	LC50	1.9	Nelson, 1988
Notacallista sp.	y	CF	$NaSeO_3.5H_2O$	nw	8.0	35.6	96 h	LC50	2.9	Ahsanullah, 1980
fish										
Morone saxatilis	n	S	Na_2SeO_3	am	7.9	1	96 h	LC50	1.6	Palawski, 1985
Cyprinodon variegatus	y	IF	$NaSeO_3.5H_2O$	nw	-	30	96 h	LC50	7.4	Ward, 1981
Lagodon rhomboides	n	S	$NaSeO_3.5H_2O$	nw	-	30	96 h	LC50	4.4	Ward, 1981

Acute toxicity of thallium to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
algae										
Ditylum brightwelli	n	S	TlCl	am	8.0	18.8	5 d	EC50[a]	0.16	Canterford, 1980
fish										
Cyprinodon variegatus	n	-	Tl	nw	-	10-31	96 h	LC50	21	Heitmuller, 1981

[a] growth

Acute toxicity of tin to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
algae										
Skeletonema costatum	y	S	$SnCl_2$	am	8.1	30	72 h	EC50[a]	0.29	Walsh, 1985/1987
Thalassiosira pseudonana	y	S	$SnCl_2$	am	8.1	30	72 h	EC50[a]	0.32	Walsh, 1985/1987

[a] growth

Acute toxicity of vanadium to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
fish										
Limanda limanda	y	CF	NH_4VO_3	nw	7.7	34.6	96 h	LC50	28	Taylor, 1985

Chronic toxicity of cobalt to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Carcinus maenas, adult	n	S	$CoCl_2$	nw	7.4-7.8	-	10 d	NOEC[a]	110	Amiard, 1976
Homarus vulgaris, 3 stage larvae	n	S	$CoCl_2$	nw	7.4-7.8	-	9 d	NOEC[a]	0.45	Amiard, 1976
fish										
Blennius pholis, adult	n	S	$CoCl_2$	nw	7.4-7.8	-	15 d	NOEC[a]	45	Amiard, 1976

[a] survival
[b] growth
[c] reproduction

Chronic toxicity of selenium to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
algae										
Agemenellum quadruplicatum	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,1}$	0.079	Wong, 1991
Agemenellum quadruplicatum	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,2}$	0.79	Wong, 1991
Agemenellum quadruplicatum	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,2}$	0.79	Wong, 1991
Amphidinium carterae	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,1}$	0.79	Wong, 1991
Amphidinium carterae	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,2}$	0.079	Wong, 1991
Amphidinium carterae	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,1}$	0.79	Wong, 1991
Amphidinium carterae	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,2}$	0.79	Wong, 1991
Chaetoceros vixvisibilis	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,1}$	7.9	Wong, 1991
Chaetoceros vixvisibilis	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,2}$	0.79	Wong, 1991
Chaetoceros vixvisibilis	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,1}$	0.79	Wong, 1991
Chaetoceros vixvisibilis	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,2}$	0.79	Wong, 1991
Chlorella sp.	n	S	Na_2SeO_3	am	-	32	14 d	$NOEC^{b}$	10	Wheeler, 1982
Dunaliella primolecta	n	S	Na_2SeO_4	am	-	32	14 d	$NOEC^{b}$	0.1	Wheeler, 1982
Dunaliella tertiolecta	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,1}$	0.79	Wong, 1991
Dunaliella tertiolecta	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,2}$	0.79	Wong, 1991
Dunaliella tertiolecta	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,2}$	7.9	Wong, 1991
Isochrysis galbana	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,1}$	0.79	Wong, 1991
Isochrysis galbana	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,2}$	0.79	Wong, 1991
Isochrysis galbana	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,1}$	7.9	Wong, 1991
Isochrysis galbana	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,2}$	7.9	Wong, 1991
Nannochloropsis oculata	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,1}$	7.9	Wong, 1991
Nannochloropsis oculata	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,2}$	7.9	Wong, 1991
Pavlova lutheri	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,1}$	0.79	Wong, 1991
Pavlova lutheri	n	S	Na_2SeO_3	am	-	-	60 d	$NOEC^{b,2}$	0.079	Wong, 1991
Pavlova lutheri	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,1}$	79	Wong, 1991
Pavlova lutheri	n	S	Na_2SeO_4	am	-	-	60 d	$NOEC^{b,2}$	7.9	Wong, 1991
Platymonas subcordiformis	n	S	Na_2SeO_4	am	-	32	14 d	$NOEC^{b}$	0.01	Wheeler, 1982

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
crustaceans										
Mysidopsis bahia	y	IF	H_2O_3Se	nw	-	26	-	NOEC[a,c]	0.14[3]	Ward, 1981
fish										
Cyprinodon variegatus	y	IF	$Na_2SeO_3 \cdot 5H_2O$	nw	-	27	-	NOEC[c]	0.47[3]	Ward, 1981

[a] survival
[b] growth
[c] reproduction

[1] exponential growth rate
[2] maximum yield
[3] calculated from MATC of an ELS test

Chronic toxicity of vanadium to marine organisms

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
algae										
mDunaliella marina	n	S	$NaVO_3$	nw	-	38	15 d	NOEC[a]	0.1	Miramand, 1978
Asterionella japonica	n	S	$NaVO_3$	nw	-	38	15 d	NOEC[a]	0.2[1]	Miramand, 1978
Prorocentrum micans	n	S	$NaVO_3$	nw	-	38	15 d	NOEC[a]	0.3[1]	Miramand, 1978

[a] survival
[b] growth
[c] reproduction

[1] calculated as EC50:10

Toxicity of thallium to marine organisms, data not used for extrapolation

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
algae										
Dunaliella tertiolecta	n	SS	TL^+	am	7.0	-	15 min	NOEC[a,1]	2.0[2]	Overnell, 1975
Phaeodactylum tricornutum	n	SS	TL^+	am	7.0	-	15 min	NOEC[a,1]	20[2]	Overnell, 1975

[a] growth

[1] rate of oxygen evolution
[2] determined from concentration-effects relationship

Toxicity of vanadium to marine organisms, data not used for extrapolation

Organism	A	Test type	Test compound	Test water	pH	Salinity in ‰	Exp. time	Criterion	Result mg/l	Reference
molluscs										
Mytilus galloprovincialis	n	SS	$NaVO_3$	nw	-	38	9 d	LC50	65	Miramand, 1978
crustaceans										
Carcinus maenas	n	SS	$NaVO_3$	nw	-	38	9 d	LC50	35	Miramand, 1978
annelids										
Nereis diversicolor	n	SS	$NaVO_3$	nw	-	38	9 d	LC50	10	Miramand, 1978

[a] survival

References

1. Literature used

Amiard, J.C. (1976). Etude expérimentale de la toxicité aigue de sels de cobalt, d'antimoine, de strontium et d'argent chez quelques crustacés et leurs larves et chez quelques téléostéens. Rev. Intern. Océanogr. Méd. Tome **43**, 79-95.

Ahsanullah, M., Palmer, D.H. (1980). Acute toxicity of selenium to three species of marine invertebrates, with notes on a continuous-flow test system. Aust. J. Mar. Freshwater Res. **31**, 795-802.

Bengtsson, B.E. (1978). Use of a harpacticoid copepod in toxicity tests. Marine Pollution Bulletin **9**, 238-241.

Bogaert, T., Samoiloff, M.R., Persoone, G. (1984). Determination of the toxicity of four heavy metal compounds and three carcinogens using two marine nematode species, Monhystera microphthalma and Diplolaimelloides bruciei. In: Ecotoxicological testing for the marine environment, Persoone, G. (ed.), State University of Ghent, Belgium, ISBN 90-9000814-4.

Canterford, G.S., Canterford, D.R. (1980). Toxicity of heavy metals to the marine diatom Ditylum brightwellii (west) grunow: correlation between toxicity and metal speciation. J. Mar. Biol. Ass. U.K. **60**, 227-242.

Heitmuller, P.T., Hollister, T.A., Parrish, P.R. (1981). Acute toxicity of 54 industrial chemicals to sheepshead minnows (Cyprinodon variegatus). Bull. Environ. Contam. Toxicol. **27**, 596-604.

Kissa, E., Moraitou-Apostolopoulou, M., Kiortsis, V. (1984). Effects of four heavy metals on survival and hatching rate of Artemia salina (L.). Arch. Hydrobiol. **102**, (2), 255-264.

Knothe, D.W., Van Riper, G.G. (1988). Acute toxicity of sodium molybdate dihydrate (molyhibit 100) to selected saltwater organisms. Bull. Environ. Contam. Toxicol. **40**, 785-790.

Krishnaja, A.P., Rege, M.S., Joshi, A.G. (1987). Toxic effects of certain heavy metals (Hg, Cd, Pb, As and Se) on the intertidal crab Scylla serrata. Mar. Environm. Res. **21**, (2), 109-119.

Miramand, P., Unsal, M. (1978). Toxicite aigue du vanadium vis-a-vis de quelques especes benthiques et phytoplanctoniques marines. Chemosphere **10**, 827-832.

Morgan, J.D., Mitchell, D.G., Chapman, P.M. (1986). Individual and combined toxicity of manganese and molybdenum to mussel, Mytilus edulis, larvae. Bull. Environ. Contam. Toxicol. **37**, 303-307.

Müller, D. (1962). Über jahres - und lunarperiodische Erscheinungen bei einigen Brunalgen. Bot. Mar. **4**, 140-155.

Nelson, D.A., Miller, J.E., Calabrese, A. (1988). Effect of heavy metals on bay scallops, surf clams, and blue mussels in acute and long-term exposures. Arch. Environ. Contam. Toxicol. **17**, 595-600.

Overnell, J. (1975). The effect of heavy metals on photosynthesis and loss of cell potassium in two species of marine algae, Dunaliella tertiolecta and Phaeodactylum tricornutum. Marine Biology **29**, 99-103.

Palawski, D., Hunn, J.B., Dwyer, F.J. (1985). Sensitivity of young striped bass to organic and inorganic contaminants in fresh and saline waters. Trans. Am. Fish Soc. **114**, 748-753.

Rosko, J.J., Rachlin, J.W. (1975). The effect of copper, zinc, cobalt and manganese on the growth of the marine diatom Nitzschia closterium. Bull. of the Torrey Bot. Club **102**, (3), 100-106.

Taylor, D., Maddock, B.G., Mance, G. (1985). The acute toxicity of nine 'grey list' metals (arsenic, boron, chromium, copper, lead, nickel, tin, vanadium, and zinc) to two marine species: dab (Limanda limanda) and grey mullet (Chelon labrosus). Aquat. Toxicol. **7**, 135-144.

EPA (1975). Methods for acute toxicity tests with fish, macroinvertebrates, and amphibians. Ecological Research series, EPA-660/3-75-009.

EPA, (1978). Bioassay procedures for the ocean disposal permit program. EPA 600/9-78-010.

Walsh, G.E., McLaughlin, L.L., Lores, E.M., Louie, M.K., Deans, C.H. (1985). Effects of organotins on growth and survival of two marine diatoms, Skeletonema costatum and Thalassiosira pseudonana. Chemosphere **14**, (3/4), 383-392.

Walsh, G.E., Deans, C.H., McLaughlin, L.L. (1987). Comparison of the EC50s of algal toxicity tests calculated by four methods. Environ. Toxicol. Chem. **6**, 767-770.

Ward, G.S., Hollister, T.A., Heitmuller, P.T., Parrish, P.R. (1981). Acute and chronic toxicity of selenium to estuarine organisms. Northeast Gulf Science **4**, (2), 73-78.

Wheeler, A.E., Zingaro, R.A., Irgolic, K. (1982). The effect of selenate, selenite, and sulfate on the growth of six unicellular marine algae. J. Exp. Mar. Biol. Ecol. **57**, 181-194.

Wong, D., Oliviera, L. (1991). Effects of selenite and selenate on the growth and motility of seven species of marine microalgae. Can. J. Fish Aquat. Sci. **48**, 1193-1200.

Zitko, V., Carson, W.V., Carson, W.G. (1975). Thallium: Occurence in the environment and toxicity to fish. Bull. Environ. Contam. Tox. **13**, (1), 23-31.

2. Literature not used

Abbott, O.J., (1977). The toxicity of ammonium molybdate to marine invertebrates. Marine Pollution Bulletin **8/9**, 204-205.

Amiard, J.-C. (1976). Les variations de la phototaxie des larves de crustacés sous l'action de divers polluants métalliques: mise au point d'un test de toxicité subléthale. Marine biology **34**, 239-245.

Brown, A.C. (1982). Pollution and the sandy-beach whelk Bullia. Trans. Roy. Soc. S. Afr. **44 (4)**, 555-562.

Cantelmo, F.R., Tagatz, M.E., Ranga Rao, K. (1979). Effect of barite on meiofauna in a flowthrough experimental system. Mar. Environ. Res. **2**, 301.

Dawson, G.W., Jennings, A.L., Drozdowski, D., Rider, E. (1975/1977). The acute toxicity of 47 industrial chemicals to fresh and saltwater fishes. Journal of Hazardous Materials **1**, 303-318.

Farnsworth, C.G. (1970). Study of molybdenum in public water supply. Water Sewage Works **117**, (12), 418-421.

Johnson, C.H., Epel, D. (1983). Heavy metal chelators prolong motility and viability of sea urchin sperm by inhibiting spontaneous acrosome reactions. The Journal of Experimental Zoology **226**, 431-440.

Kinoshita, S., Saiga, H. (1979). The role of proteoglycan in the development of sea urchins. Experimental Cell Research **123**, 229-236.

Lallier, M.R. (1968). Recherches sur la toxicite des ions thalleux sur l'oeuf de l'oursin Paracentrotus lividus. C.R. Acad. Sc. Paris **267**, 962-964.

Martin, M., Osborn, K.E., Billig, P., Glickstein, N. (1981). Toxicities of ten metals to Crassostrea gigas and Mytilus edulis embryos and Cancer magister larvae. Marine Pollution Bulletin **12 (9)**, 305-308.

Micallef, S., Tyler, P.A. (1990). Effect of mercury and selenium on the gill function of Mytilus edulis. Marine Pollution Bulletin **21**, (6), 288-292.

Mitchell, D.G., Morgan, J.D., Vigers, G.A., Chapman, P.M. (1985). Acute toxicity of mine tailings to four marine species. Marine Pollution Bulletin **16**, (11), 450-455.

Pesando, D., Aubert, M. (1975). Effets des pollutions chimiques vis-a-vis de télémediateurs intervenant dans l'écologie microbiologique et planctonique en milieu marin 3^e partie. Rev. Intern. Océanogr. Méd. Tomes **39/40**, 109-116.

Prevot, P., Soyer-Gobillard, M.O. (1986). Combined action of cadmium and selenium on two marine dinoflagellates in culture, Prorocentrum micans Ehrbg. and Crypthecodinium cohnii Biecheler. J. Protozool. **33**, (1), 42-47.

Price, N.M., Thompson, P.A., Harrison, P.J. (1987). Selenium: an essential element for growth of the coastal marine diatom Thalassiosira pseudonana (Bacillariophyceae). J. Phycol. **23**, 1-9.

Reish, D.J.,Rossi, S.S., Mearns, A.J., Oshida, P.S., Wilkes, F.G. (1979). Marine and estuarine pollution. J. Water Pollution Control Fed. **51**, (6), 1477-1517.

Reish, D.J., Oshida, P.S., Mearns, A.J., Ginn, T.C. (1991). Effects on saltwater organisms. Res. J. Wat. Poll. Contr. Fed. **63**, (4), 696.

Saboski, E.M. (1977). Effects of mercury and tin on frustular ultrastructure of the marine diatom Nitzschia liebethrutti. Water, Air, and Soil Pollution **8**, 461-466.

Sargent, J.R., Bell, M.V., Kelly, K.F., Johnstone, A., Hawkins, A., Hall, C.D. (1979). Sodium orthovanadate and cardiac activity in teleost fish. Comp. Biochem. Physiol. **66C**, 111-114.

Thomas, W.H., Hollibaugh, J.T., Seibert, D.L.R. (1980). Effects of heavy metals on the morfology of some marine phytoplankton. Phycologia **19**, (3), 202-209.

Tsekos, I., Haritonidis, S., Diannelidis, T. (1972). Protoplasmaresistenz von meeresalgen und meeresanthophyten gegen schwermetallsalze. Protoplasma **75**, 45-65 .

Viso, A-C, Boisson, F., Romeo, M., Gnassia-Barelli, M. (1989). Combined effects of sulphate, selenium (selenate or selenite) and duration of experiment on a coenocytic alga Bryopsis sp.. Marine Environmental Research **28**, 515-519.

Waltz, F. (1979). Uptake and elimination of antimony in the mussel, Mytilus edulis. Veröff. Inst. Meeresforsch. Bremerh. **18**, 203-215.

Watling, H.R. (1981). Effects of metals on the development of oyster embryos. S. Afr. J. Sci **77**, 134-135.

Wong, D., Oliviera, L. (1991). Effects of selenite and selenate toxicity on the ultrastructure and physiology of three species of marine microalgae. Can. J. Fish Aquat. Sci. **48**, 1201-1211.

Wolfenberger, V. (1986). Survival of the hermit crab, Clibanarius vittatus, exposed to selenium and other environmental factors. Bull. Environ. Contam. Tox. **37**, (3), 369-374.

Zitko, V. (1975). Toxicity and pollution potential of thallium. Sci. Total Environ. **4**, 185-192.

Appendix 4. Toxicity data for soil organisms

% om = % organic matter (if presented in % organic carbon a factor of 1.7 was used to calculate % om)

effect/time/parameter:
EC = effect concentration
NOEC = no observed effect concentration
h = hours
d = days
y = years

S.S. = standard soil (10 % om and 25% clay)

Chronic toxicity of cobalt to soil organisms

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
Oligochaeta									
Eisenia foetida	manure + soil		63	5	25	NOEC/24 wk/growth	92	240	Neuhauser et al., 1984
						NOEC/24 wk/repro.	92	240	Neuhauser et al., 1984
	$CoCl_2$								

Toxicity of barium to soil organisms, data not used for extrapolation

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
enzymactivity									
acid phosphatase	clay loam	7.8	6.4	30	37	EC3/1h/inhibition	3,400	2,800	Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC8/1h/inhibition	3,400	2,600	Juma & Tabatabai, 1977
	loam	5.8	4.4	23	37	EC8/1h/inhibition	3,400	3,600	Juma & Tabatabai, 1977
						EC6/1h/inhibition	340	360	Juma & Tabatabai, 1977
	$BaCl_2$								
arylsulfatase		6.2	4.6	29	37	EC24/1h/inhibition	3,400	2,800	Al-Khafaji & Tabatabai, 1979
		7.6	5.5	30	37	EC20/1h/inhibition	3,400	2,900	Al-Khafaji & Tabatabai, 1979
						EC13/1h/inhibition	350	300	Al-Khafaji & Tabatabai, 1979
		6.5	5.0	26	37	EC14/1h/inhibition	3,400	3,300	Al-Khafaji & Tabatabai, 1979
						EC8/1h/inhibition	350	340	Al-Khafaji & Tabatabai, 1979
		7.0	9.0	34	37	EC13/1h/inhibition	3,400	2,600	Al-Khafaji & Tabatabai, 1979
	$BaCl_2$								
alkaline phosphatase	clay loam	7.8	6.4	30	37	EC17/1h/inhibition	3,400	2,800	Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC5/1h/inhibition	3,400	2,600	Juma & Tabatabai, 1977
						EC3/1h/inhibition	340	260	Juma & Tabatabai, 1977
	$BaCl_2$								
urease		5.1	2.6	17	37	EC2/2h/inhibition	690	930	Denneman & v. Gestel, 1990
		6.1	5.6	30	37	EC2/2h/inhibition	690	590	Denneman & v. Gestel, 1990
		5.8	4.4	23	37	EC12/2h/inhibition	690	740	Denneman & v. Gestel, 1990
		7.8	6.4	30	37	EC7/2h/inhibition	690	590	Denneman & v. Gestel, 1990
						EC0/2h/inhibition	69	59	Denneman & v. Gestel, 1990
		6.8	7.4	42	37	EC3/2h/inhibition	690	450	Denneman & v. Gestel, 1990
		7.4	9.3	34	37	EC7/2h/inhibition	690	540	Denneman & v. Gestel, 1990
						EC0/2h/inhibition	69	54	Denneman & v. Gestel, 1990
	$BaCl_2$								

Toxicity of beryllium to soil organisms, data not used for extrapolation

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
microbial processes									
soil respiration	silt loam	6.7	3.1	27	20	EC11/9d/inhibition	0.5	0.48	Lighthart et al., 1983
						EC49/9d/inhibition	450	430	Lighthart et al., 1983
		6.2	64		20	EC3/9d/inhibition	0.5		Lighthart et al., 1983
						EC14/9d/inhibition	450		Lighthart et al., 1983
	clay	7.0	5.5	51	20	EC6/9d/stimulation	0.5	0.31	Lighthart et al., 1983
						EC25/9d/inhibition	450	280	Lighthart et al., 1983
	silt loam	7.2	1.7	21	20	EC18/9d/inhibition	5.9	6.5	Lighthart et al., 1983
						EC43/9d/inhibition	450	500	Lighthart et al., 1983
	sandy loam	8.2	4.7	11	20	EC3/9d/inhibition	0.5	0.75	Lighthart et al., 1983
						EC29/9d/inhibition	450	680	Lighthart et al., 1983
	$BeSO_4$; WHC: 70%; 4 test concentrations: 0.05-50.0 mmol/kg; no distinct concentration-effects relationship								
N- eralisation	sandy cambisol	6.0	2.0	9		EC43/8-9y/inhibition	30	49	Wilke, 1989
						EC48/8-9y/inhibition	80	130	
	$BeSO_4$; field experiment								
nitrification	sandy cambisol	6.0	2.0	9		EC2/8-9y/inhibition	30	49	Wilke, 1989
						EC8/8-9y/stimulation	80	130	
	$BeSO_4$; fieldexperiment								

Toxicity of cobalt to soil organisms, data not used for extrapolation

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
microbial processes									
soil respiration	silt loam	6.7	3.1	27	20	EC25/9d/inhibition	3.0	2.8	Lighthart et al., 1983
						EC43/9d/inhibition	3,000	2,800	Lighthart et al., 1983
	clay	7.0	5.5	51	20	EC3/9d/inhibition	3.0	1.7	Lighthart et al., 1983
						EC46/9d/inhibition	3,000	1,700	Lighthart et al., 1983
	silt loam	7.2	1.7	21	20	EC6/9d/stimulation	3.0	3.4	Lighthart et al., 1983
						EC43/9d/inhibition	3,000	3,400	Lighthart et al., 1983
	sandy loam	8.2	4.7	11	20	EC6/9d/inhibition	3.0	5.3	Lighthart et al., 1983
						EC46/9d/inhibition	3,000	5,300	Lighthart et al., 1983
	$CoSO_4$; WHC: 70%; 4 test concentrations: 0.05-50.0 mmol/kg; no distinct concentration-effects relationship								
N-mineralisation		5.8	4.4	23	30	EC12/20d/inhibition	290	320	Denneman & v. Gestel, 1990
		6.6	5.0	45	30	EC2/20d/inhibition	290	180	Denneman & v. Gestel, 1990
		7.8	6.4	30	30	EC7/20d/inhibition	290	250	Denneman & v. Gestel, 1990
		7.4	9.3	34	30	EC6/20d/inhibition	290	230	Denneman & v. Gestel, 1990
	$CoSO_4$								
nitrification		5.8	4.4	23	30	EC79/10d/inhibition	300	320	Liang & Tabatabai, 1978
		7.8	6.4	30	30	EC22/10d/inhibition	300	260	Liang & Tabatabai, 1978
		7.4	9.3	34	30	EC34/10d/inhibition	300	230	Liang & Tabatabai, 1978
	$CoSO_4$; WHC: c. 60%								
enzymactivity									
acid phosphatase	clay loam	7.8	6.4	30	37	EC8/1h/inhibition	1,500	1,300	Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC5/1h/inhibition	1,500	1,200	Juma & Tabatabai, 1977
	loam	5.8	4.4	23	37	EC1/1h/inhibition	1,500	1,600	Juma & Tabatabai, 1977
						EC0/1h/inhibition	150	160	Juma & Tabatabai, 1977
	$CoSO_4$								
alkaline phosphatase	clay loam	7.8	6.4	30	37	EC16/1h/inhibition	1,500	1,300	Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC6/1h/inhibition	1,500	1,200	Juma & Tabatabai, 1977
						EC5/1h/inhibition	150	120	Juma & Tabatabai, 1977
	$CoSO_4$								
a[illegible]sulfatase		6.2	4.6	29	37	EC10/1h/inhibition	1,500	1,300	Al-Khafaji & Tabatabai, 1979
		7.6	5.5	30	37	EC14/1h/inhibition	1,500	1,300	Al-Khafaji & Tabatabai, 1979
						EC11/1h/inhibition	150	130	Al-Khafaji & Tabatabai, 1979
		6.5	5.0	26	37	EC10/1h/inhibition	1,500	1,500	Al-Khafaji & Tabatabai, 1979
						EC9/1h/inhibition	150	150	Al-Khafaji & Tabatabai, 1979
		7.0	9.0	34	37	EC8/1h/inhibition	1,500	1,200	Al-Khafaji & Tabatabai, 1979
	$CoSO_4$								

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
<u>urease</u>		5.1	2.6	17	37	EC22/2h/inhibition	300	400	Denneman & v. Gestel, 1990
		6.1	5.6	30	37	EC16/2h/inhibition	300	260	Denneman & v. Gestel, 1990
		5.8	4.4	23	37	EC23/2h/inhibition	300	320	Denneman & v. Gestel, 1990
		7.8	6.4	30	37	EC35/2h/inhibition	300	260	Denneman & v. Gestel, 1990
						EC13/2h/inhibition	30	26	Denneman & v. Gestel, 1990
		6.8	7.4	42	37	EC24/2h/inhibition	300	200	Denneman & v. Gestel, 1990
		7.4	9.3	34	37	EC29/2h/inhibition	300	230	Denneman & v. Gestel, 1990
						EC22/2h/inhibition	30	23	Denneman & v. Gestel, 1990
	$CoCl_2$								

Toxicity of molybdenum to soil organisms, data not used for extrapolation

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
microbial processes									
N-mineralisation		5.8	4.4	23	30	EC10/20d/inhibition	480		Denneman & v. Gestel, 1990
		6.6	5.0	45	30	EC22/20d/inhibition	480		Denneman & v. Gestel, 1990
		7.8	6.4	30	30	EC22/20d/inhibition	480		Denneman & v. Gestel, 1990
		7.4	9.3	34	30	EC54/20d/inhibition	480		Denneman & v. Gestel, 1990
	H_2MoO_4								
nitrification		5.8	4.4	23	30	EC74/10d/inhibition	480		Liang & Tabatabai, 1978
		7.8	6.4	30	30	EC39/10d/inhibition	480		Liang & Tabatabai, 1978
		7.4	9.3	34	30	EC48/10d/inhibition	480		Liang & Tabatabai, 1978
	H_2MoO_4; WHC: c. 60%								
enzymactivity									
acid phosphatase	clay loam	7.8	6.4	30	37	EC41/1h/inhibition	2,400		Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC68/1h/inhibition	2,400		Juma & Tabatabai, 1977
	loam	5.8	4.4	23	37	EC93/1h/inhibition	2,400		Juma & Tabatabai, 1977
						EC69/1h/inhibition	240		Juma & Tabatabai, 1977
	H_2MoO_4								
alkaline phosphatase	clay loam	7.8	6.4	30	37	EC25/1h/inhibition	2,400		Juma & Tabatabai, 1977
	silty clay	7.4	9.3	34	37	EC22/1h/inhibition	2,400		Juma & Tabatabai, 1977
	loam					EC12/1h/inhibition	240		Juma & Tabatabai, 1977
	H_2MoO_4								
arylsulfatase		6.2	4.6	29	37	EC63/1h/inhibition	2,400		Al-Khafaji & Tabatabai, 1979
		7.6	5.5	30	37	EC60/1h/inhibition	2,400		Al-Khafaji & Tabatabai, 1979
						EC26/1h/inhibition	240		Al-Khafaji & Tabatabai, 1979
		6.5	5.0	26	37	EC79/1h/inhibition	2,400		Al-Khafaji & Tabatabai, 1979
						EC40/1h/inhibition	240		Al-Khafaji & Tabatabai, 1979
		7.0	9.0	34	37	EC14/1h/inhibition	2,400		Al-Khafaji & Tabatabai, 1979
	H_2MoO_4								
phosphatase	spar-mor	4.3	93	<1	22	EC79/3h/inhibition	960		Denneman & v. Gestel, 1990
	mull	6.3	13	29	22	EC68/3h/inhibition	960		Denneman & v. Gestel, 1990
	Na_2MoO_4								
urease		5.1	2.6	17	37	EC7/2h/inhibition	480		Denneman & v. Gestel, 1990
		6.1	5.6	30	37	EC16/2h/inhibition	480		Denneman & v. Gestel, 1990
		5.8	4.4	23	37	EC14/2h/inhibition	480		Denneman & v. Gestel, 1990
		7.8	6.4	30	37	EC12/2h/inhibition	480		Denneman & v. Gestel, 1990
						EC11/2h/inhibition	50		Denneman & v. Gestel, 1990
		6.8	7.4	42	37	EC4/2h/inhibition	480		Denneman & v. Gestel, 1990
		7.4	9.3	34	37	EC16/2h/inhibition	480		Denneman & v. Gestel, 1990
						EC9/2h/inhibition	50		Denneman & v. Gestel, 1990
	H_2MoO_4								

Toxicity of selenium to soil organisms, data not used for extrapolation

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
Oligochaeta									
Lumbricus terrestris	sandy top s. SeO_3		1.7	9.5		LC50 > 60 d	> 5		Gissel-Nielsen, 1975
microbial processes									
ammonification	moder Ah	3.5	5.4		26	EC23/14d/stimulation	50		Wilke, 1988
						EC61/14d/stimulation	250		Wilke, 1988
	mor Aeh	2.7	3.4		260	EC26/14d/stimulation	50		Wilke, 1988
						EC9/14d/inhibition	250		Wilke, 1988
	Na_2SeO_3; perfusion experiment								
soil respiration	mull Ah	7.9	7.0		26	EC14/14d/inhibition	250		Wilke, 1988
						EC19/14d/inhibition	1,000		Wilke, 1988
	moder Ah	3.5	5.4		26	EC22/14d/inhibition	50		Wilke, 1988
						EC34/14d/inhibition	250		Wilke, 1988
	mor Aeh	2.7	3.4		26	EC13/14d/stimulation	50		Wilke, 1988
						EC9/14d/inhibition	250		Wilke, 1988
	Na_2SeO_3; perfusion experiment								
	silt loam	6.7	3.1	27	20	EC6/9d/inhibition	4.0		Lighthart et al., 1983
						EC64/9d/inhibition	4,000		Lighthart et al., 1983
		6.2	64		20	EC0/9d/inhibition	4.0		Lighthart et al., 1983
						EC14/9d/inhibition	4,000		Lighthart et al., 1983
	clay	7.0	5.5	51	20	EC18/9d/stimulation	4.0		Lighthart et al., 1983
						EC53/9d/inhibition	4,000		Lighthart et al., 1983
	silt loam	7.2	1.7	21	20	EC14/9d/inhibition	4.0		Lighthart et al., 1983
						EC70/9d/inhibition	4,000		Lighthart et al., 1983
	sandy loam	8.2	4.7	11	20	EC21/9d/inhibition	4.0		Lighthart et al., 1983
						EC57/9d/inhibition	4,000		Lighthart et al., 1983
	SeO_2; WHC: 70%; 4 test concentrations: 0.05-50.0 mmol/kg; no distinct concentratie-effects relationship								
N-mineralisation		5.8	4.4	23	30	EC2/20d/inhibition	400		Liang & Tabatabai, 1977a
		6.6	5.0	45	30	EC3/20d/inhibition	400		Liang & Tabatabai, 1977a
		7.8	6.4	30	30	EC9/20d/inhibition	400		Liang & Tabatabai, 1977a
		7.4	9.3	34	30	EC8/20d/inhibition	400		Liang & Tabatabai, 1977a
	H_2SeO_3; WHC: c. 60%								
	sandy cambisol fieldexperiment	6.0	2.0	9	veld	EC0/8-9y	40		Wilke, 1989
nitrification	sandy cambisol fieldexperiment	6.0	2.0	9	veld	EC20/8-9y/stimulation	40		Wilke, 1989
		5.8	4.4	23	30	EC94/10d/inhibition	400		Liang & Tabatabai, 1978
		7.8	6.4	30	30	EC90/10d/inhibition	400		Liang & Tabatabai, 1978
		7.4	9.3	34	30	EC88/10d/inhibition	400		Liang & Tabatabai, 1978
	H_2SeO_3; WHC: c. 60%								

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
	mull Ah	7.9	7.0		26	EC17/14d/stimulation	250		Wilke, 1988
						EC41/14d/stimulation	1,000		Wilke, 1988
	moder Ah	3.5	5.4		26	EC33/14d/stimulation	50		Wilke, 1988
						EC129/14d/stimulation	250		Wilke, 1988
	mor Aeh	2.7	3.4		260	EC10/14d/inhibition	50		Wilke, 1988
						EC0/14d/inhibition	250		Wilke, 1988
	Na_2SeO_3; perfusion experiment								
enzymactivity									
acid phosphatase	clay loam	7.8	6.4	30	37	EC39/1h/inhibition	2,000		Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC34/1h/inhibition	2,000		Juma & Tabatabai, 1977
	loam	5.8	4.4	23	37	EC24/1h/inhibition	2,000		Juma & Tabatabai, 1977
						EC16/1h/inhibition	200		Juma & Tabatabai, 1977
	H_2SeO_3								
alk-'ine phosphatase	clay loam	7.8	6.4	30	37	EC30/1h/inhibition	2,000		Juma & Tabatabai, 1977
	silty clay	7.4	9.3	34	37	EC35/1h/inhibition	2,000		Juma & Tabatabai, 1977
	loam					EC15/1h/inhibition	200		Juma & Tabatabai, 1977
	H_2SeO_3								
	mull Ah	7.9	7.0		26	EC0/14d/inhibition	250		Wilke, 1988
						EC18/14d/inhibition	1,000		Wilke, 1988
	moder Ah	3.5	5.4		26	EC1/14d/stimulation	50		Wilke, 1988
						EC6/14d/inhibition	250		Wilke, 1988
	mor Aeh	2.7	3.4		26	EC1/14d/inhibition	50		Wilke, 1988
						EC12/14d/inhibition	250		Wilke, 1988
	Na_2SeO_3; perfusion experiment								
arylsulfatase		6.2	4.6	29	37	EC32/1h/inhibition	2,000		Al-Khafaji & Tabatabai, 1979
		7.6	5.5	30	37	EC26/1h/inhibition	2,000		Al-Khafaji & Tabatabai, 1979
						EC14/1h/inhibition	200		Al-Khafaji & Tabatabai, 1979
		6.5	5.0	26	37	EC42/1h/inhibition	2,000		Al-Khafaji & Tabatabai, 1979
						EC21/1h/inhibition	200		Al-Khafaji & Tabatabai, 1979
		7.0	9.0	34	37	EC26/1h/inhibition	2,000		Al-Khafaji & Tabatabai, 1979
	H_2SeO_3								
	mull Ah	7.9	7.0		26	EC9/14d/inhibition	250		Wilke, 1988
						EC22/14d/inhibition	1,000		Wilke, 1988
	moder Ah	3.5	5.4		26	EC22/14d/inhibition	50		Wilke, 1988
						EC45/14d/inhibition	250		Wilke, 1988
	mor Aeh	2.7	3.4		26	EC11/14d/inhibition	50		Wilke, 1988
						EC64/14d/inhibition	250		Wilke, 1988
	Na_2SeO_3; perfusion experiment								
dehydrogenase	mull Ah	7.9	7.0		26	EC31/14d/inhibition	250		Wilke, 1988
						EC66/14d/inhibition	1,000		Wilke, 1988
	moder Ah	3.5	5.4		26	EC62/14d/inhibition	50		Wilke, 1988
						EC83/14d/inhibition	250		Wilke, 1988
	Na_2SeO_3; perfusion experiment								

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
urease		5.1	2.6	17	37	EC33/2h/inhibition	400		Liang & Tabatabai, 1977b
		6.1	5.6	30	37	EC24/2h/inhibition	400		Liang & Tabatabai, 1977b
		5.8	4.4	23	37	EC14/2h/inhibition	400		Liang & Tabatabai, 1977b
		7.8	6.4	30	37	EC19/2h/inhibition	400		Liang & Tabatabai, 1977b
						EC5/2h/inhibition	40		Liang & Tabatabai, 1977b
		6.8	7.4	42	37	EC16/2h/inhibition	400		Liang & Tabatabai, 1977b
		7.4	9.3	34	37	EC24/2h/inhibition	400		Liang & Tabatabai, 1977b
						EC9/2h/inhibition	40		Liang & Tabatabai, 1977b

H_2SeO_3; WHC: c. 60%

Toxicity of tin to soil organisms, data not used for extrapolation

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
microbial processes									
soil respiration	silt loam	6.7	3.1	27	20	EC21/9d/inhibition	5.9	5.6	Lighthart et al., 1983
						EC35/9d/inhibition	5,900	5,600	Lighthart et al., 1983
		6.2	64		20	EC3/9d/inhibition	5.9		Lighthart et al., 1983
						EC18/9d/inhibition	5,900		Lighthart et al., 1983
	clay	7.0	5.5	51	20	EC10/9d/stimulation	5.9	3.2	Lighthart et al., 1983
						EC25/9d/inhibition	5,900	3,200	Lighthart et al., 1983
	silt loam	7.2	1.7	21	20	EC18/9d/inhibition	5.9	6.8	Lighthart et al., 1983
						EC57/9d/inhibition	5,900	6,800	Lighthart et al., 1983
	sandy loam	8.2	4.7	11	20	EC11/9d/inhibition	5.9	11	Lighthart et al., 1983
						EC35/9d/inhibition	5,900	11,000	Lighthart et al., 1983
	$SnCl_2$; WHC: 70%; 4 test concentrations: 0.05-50.0 mmol/kg; no distinct concentratie-effects relationship								
N-mineralisation		5.8	4.4	23	30	EC8/20d/inhibition	590	630	Liang & Tabatabai, 1977a
		6.6	5.0	45	30	EC10/20d/inhibition	590	360	Liang & Tabatabai, 1977a
		7.8	6.4	30	30	EC20/20d/inhibition	590	510	Liang & Tabatabai, 1977a
		7.4	9.3	34	30	EC11/20d/inhibition	590	460	Liang & Tabatabai, 1977a
	$SnCl_2$; WHC: c. 60%								
	sandy	6.0	2.0	9		EC0/8-9y/inhibition	120	240	Wilke, 1989
	cambisol					EC8/8-9y/inhibition	470	950	Wilke, 1989
	fieldexperiment								
nitrification	sandy	6.0	2.0	9		EC19/8-9y/stimulation	120	240	Wilke, 1989
	cambisol					EC13/8-9y/stimulation	470	950	Wilke, 1989
	fieldexperiment								
		5.8	4.4	23	30	EC94/10d/inhibition	590	630	Liang & Tabatabai, 1978
		7.8	6.4	30	30	EC25/10d/inhibition	590	510	Liang & Tabatabai, 1978
		7.4	9.3	34	30	EC4/10d/inhibition	590	460	Liang & Tabatabai, 1978
	$SnCl_2$; WHC: c. 60%								
enzymactivity									
acid phosphatase	clay loam	7.8	6.4	30	37	EC15/1h/inhibition	3,000	2,600	Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC21/1h/inhibition	3,000	2,300	Juma & Tabatabai, 1977
	loam	5.8	4.4	23	37	EC41/1h/inhibition	3,000	3,200	Juma & Tabatabai, 1977
						EC12/1h/inhibition	300	320	Juma & Tabatabai, 1977
	$SnCl_2$								
alkaline phosphatase	clay loam	7.8	6.4	30	37	EC25/1h/inhibition	3,000	2,600	Juma & Tabatabai, 1977
	silty clay	7.4	9.3	34	37	EC38/1h/inhibition	3,000	3,200	Juma & Tabatabai, 1977
	loam					EC4/1h/inhibition	300	320	Juma & Tabatabai, 1977
	$SnCl_2$								

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
arylsulfatase		6.2	4.6	29	37	EC60/1h/inhibition	3,000	2,700	Al-Khafaji & Tabatabai, 1979
		7.6	5.5	30	37	EC11/1h/inhibition	3,000	2,600	Al-Khafaji & Tabatabai, 1979
						EC9/1h/inhibition	300	260	Al-Khafaji & Tabatabai, 1979
		6.5	5.0	26	37	EC45/1h/inhibition	3,000	2,900	Al-Khafaji & Tabatabai, 1979
						EC6/1h/inhibition	300	290	Al-Khafaji & Tabatabai, 1979
		7.0	9.0	34	37	EC32/1h/inhibition	3,000	2,300	Al-Khafaji & Tabatabai, 1979
	$SnCl_2$								
urease		5.1	2.6	17	37	EC56/2h/inhibition	590	790	Liang & Tabatabai, 1977b
		6.1	5.6	30	37	EC20/2h/inhibition	590	510	Liang & Tabatabai, 1977b
		5.8	4.4	23	37	EC24/2h/inhibition	590	630	Liang & Tabatabai, 1977b
		7.8	6.4	30	37	EC15/2h/inhibition	590	510	Liang & Tabatabai, 1977b
						EC3/2h/inhibition	59	51	Liang & Tabatabai, 1977b
		6.8	7.4	42	37	EC18/2h/inhibition	590	380	Liang & Tabatabai, 1977b
		7.4	9.3	34	37	EC18/2h/inhibition	590	460	Liang & Tabatabai, 1977b
						EC4/2h/inhibition	59	46	Liang & Tabatabai, 1977b
	$SnCl_2$; WHC: c. 60%								

Toxicity of vanadium to soil organisms, data not used for extrapolation

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
microbial processes									
soil respiration	silt loam	6.7	3.1	27	20	EC6/9d/inhibition	2.6	2.5	Lighthart et al., 1983
						EC18/9d/inhibition	2,600	2,500	Lighthart et al., 1983
		6.2	64		20	EC3/9d/inhibition	2.6		Lighthart et al., 1983
						EC18/9d/stimulation	2,600		Lighthart et al., 1983
	clay	7.0	5.5	51	20	EC6/9d/stimulation	2.6	1.5	Lighthart et al., 1983
						EC18/9d/inhibition	2,600	1,500	Lighthart et al., 1983
	silt loam	7.2	1.7	21	20	EC18/9d/inhibition	2.6	2.9	Lighthart et al., 1983
						EC38/9d/inhibition	2,600	2,900	Lighthart et al., 1983
	sandy loam	8.2	4.7	11	20	EC6/9d/stimulation	2.6	4.3	Lighthart et al., 1983
						EC38/9d/inhibition	2,600	4,300	Lighthart et al., 1983
	$VOSO_4$; WHC: 70%; 4 test concentrations: 0.05-50.0 mmol/kg; no distinct concentration-effects relationship								
N- 'eralisation		5.8	4.4	23	30	EC8/20d/inhibition	260	280	Liang & Tabatabai, 1977a
		6.6	5.0	45	30	EC14/20d/inhibition	260	170	Liang & Tabatabai, 1977a
		7.8	6.4	30	30	EC11/20d/inhibition	260	230	Liang & Tabatabai, 1977a
		7.4	9.3	34	30	EC14/20d/inhibition	260	210	Liang & Tabatabai, 1977a
	WHC: c. 60%								
	sandy cambisol fieldexperiment	6.0	2.0	9		EC7/8-9y/inhibition	400	740	Wilke, 1989
nitrification	sandy cambisol fieldexperiment	6.0	2.0	9		EC9/8-9y/stimulation	100	180	Wilke, 1989
						EC20/8-9y/stimulation	400	740	Wilke, 1989
		5.8	4.4	23	30	EC62/10d/inhibition	260	280	Liang & Tabatabai, 1978
		7.8	6.4	30	30	EC12/10d/inhibition	260	230	Liang & Tabatabai, 1978
		7.4	9.3	34	30	EC38/10d/inhibition	260	270	Liang & Tabatabai, 1978
	WHC: c. 60%								
enzymactivity									
acid phosphatase	clay loam	7.8	6.4	30	37	EC45/1h/inhibition	1,300	1,100	Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC55/1h/inhibition	1,300	1,000	Juma & Tabatabai, 1977
	loam	5.8	4.4	23	37	EC49/1h/inhibition	1,300	1,400	Juma & Tabatabai, 1977
						EC30/1h/inhibition	130	140	Juma & Tabatabai, 1977
alkaline phosphatase	clay loam	7.8	6.4	30	37	EC61/1h/inhibition	1,300	1,100	Juma & Tabatabai, 1977
	silty clay loam	7.4	9.3	34	37	EC60/1h/inhibition	1,300	1,000	Juma & Tabatabai, 1977
						EC21/1h/inhibition	130	100	Juma & Tabatabai, 1977
	$VOSO_4$; WHC: c. 60%								

species/parameter	soil type	pH	% om	% clay	temp °C	effect/time/parameter	result mg/kg	S.S. mg/kg	reference
arylsulfatase		6.2	4.6	29	37	EC87/1h/inhibition	1,300	1,200	Al-Khafaji & Tabatabai, 1979
		7.6	5.5	30	37	EC88/1h/inhibition	1,300	1,100	Al-Khafaji & Tabatabai, 1979
						EC32/1h/inhibition	130	110	Al-Khafaji & Tabatabai, 1979
		6.5	5.0	26	37	EC90/1h/inhibition	1,300	1,300	Al-Khafaji & Tabatabai, 1979
						EC76/1h/inhibition	130	130	Al-Khafaji & Tabatabai, 1979
		7.0	9.0	34	37	EC85/1h/inhibition	1,300	1,000	Al-Khafaji & Tabatabai, 1979
urease		5.1	2.6	17	37	EC39/2h/inhibition	260	340	Liang & Tabatabai, 1977b
		6.1	5.6	30	37	EC17/2h/inhibition	260	230	Liang & Tabatabai, 1977b
		5.8	4.4	23	37	EC18/2h/inhibition	260	280	Liang & Tabatabai, 1977b
		7.8	6.4	30	37	EC17/2h/inhibition	260	230	Liang & Tabatabai, 1977b
						EC3/2h/inhibition	26	23	Liang & Tabatabai, 1977b
		6.8	7.4	42	37	EC18/2h/inhibition	260	180	Liang & Tabatabai, 1977b
		7.4	9.3	34	37	EC28/2h/inhibition	260	210	Liang & Tabatabai, 1977b
						EC13/2h/inhibition	26	21	Liang & Tabatabai, 1977b

REFERENCES

1. Literature used

Al-Khafaji, A.A., and Tabatabai, M.A. (1979). Effects of trace elements on arylsulfatase activity in soils. Soil Science **127**, (3), 129-133.

Denneman, C.A.J., and Van Gestel, C.A.M. (1990). Bodemverontreiniging en bodemecosystemen: voorstel voor C-(toetsings)waarden op basis van ecotoxicologische risico's. RIVM-rapport No. 725201 001.

Denneman, C.A.J., and Van Gestel, C.A.M. (1990). Bijlage bij rapport nr. 725201001 Bodemverontreiniging en bodemecosystemen: voorstel voor C-(toetsings)waarden op basis van ecotoxicologische risico's.

Gissel Nielsen, M., and Gissel-Nielsen, G. (1975). Selenium in soil-animal relationships. Pedobiologia **15**, 65-67.

Juma, N.G. and Tabatabai, M.A. (1977). Effects of trace elements on phosphatase activity in soils. Soil Sci. Am. J. **41**, 343-346.

Liang, C.N. and Tabatabai, M.A. (1977a). Effects of trace elements on nitrogen mineralisation in soils. Environ. Pollut. **12**, (2), 141-147.

Liang, C.N. and Tabatabai, M.A. (1977b). Effects of trace elements on urease activity in soils. Soil Biol. Biochem. **9**, 9-13.

Liang, C.N. and Tabatabai, M.A. (1978). Effects of trace elements on nitrification in soils. J. Environ. Qual. **7**, (2), 291-293.

Lighthart, B., Baham, J., and Volk, V. (1983). Microbial respiration and chemical speciation in metal-amended soils. J. Environmen. Qual. **12**, (4), 543-548.

Neuhauser, E.F., Meyer, J.A., Malecki, M.R., and Thomas, J.M. (1984). Dietary cobalt supplements and the growth and reproduction of the earthworm Eisenia foetida. Soil. Biol. Biochem. **16**, 521-525.

Wilke, B.M. (1988). Effects of sodium selenite on microbial activity of mull, moder and mor soils. Biol. Fertil. Soils **6**, (2), 148-152.

Wilke, B.M. (1989). Long-term- effects of different inorganic pollutants on nitrogen transformations in a sandy cambisol. Biol. Fertil. Soils **7**, (3), 254-258.

2. Literature not used

Abbas, A.S., and Edwards, C. (1990). Effects of metals on Streptomyces coelicolor growth and actinorhodin production. Appl. Eviron. Microbiol. **56**, (3), 675-680.

Abbas, A.S., and Edwards, C. (1989). Effects of metals on a range of Streptomyces species. Appl. Eviron. Microbiol. **55**, (8), 2030-2035.

Cantelmo, F.R., Tagatz, M.E., and Ranga Rao, K. (1979). Effect of barite on meiofauna in a flow-through experimental system. Mar. Environm. Res. **2**, 301-309.

Cheng, A.C., Lu, N.C., Briggs, G.M., and Stokstad, E.L.R. (1979). Effect of particulate materials on population growth of the free-living nematode Caenorhabditis briggsae (40420). Proc. of the Society for Exp. Biol. and Med. **160**, 203-207.

Cooney, J.J., and Wuertz (1989). Toxic effects of tin compounds on microorganisms. J. of Industr.

Microbiol. **4**, 375-402.

Dubey, S.K., and Rai, L.C. (1987). Effect of chromium and tin on survival, growth, carbon fixation, heterocyst differentiation, nitrogenase, nitrate reductase and glutamine synthetase activities of Anabaena doliolum. J. Plant Physiol. **130**, 165-172.

Giesy, J.P., and Hoke, R.A. (1990). Freshwater sediment quality criteria: toxicity bioassessment. In: Sediments: chemistry and toxicity of in-place pollutants. Baudo, R., Giesy, J.P., and Muntar, H. (eds), Lewis Publishers, Inc. Michigan, USA.

Gormley, C.J. and London, S.A. (1973). Effect of beryllium on soil microorganisms. In: Proc. Annu. Conf. Environ. Toxicol., 4th, vol. AD-781031, pp. 401-416.

Janda, J.M. and Fleming, R.W. (1978). Effect of selenate toxicity on soil microflora. J. Environ. Sci. Health **A13**, (9), 697-706.

Jyotishmati, U. and Bahadur, K. (1978). Effect of uranyl and molybdate ions on microbial fixation of nitrogen. Zbl. Bakt. Abt. II, **133**, 157-162.

Kaplan, D.I., Adriano, D.C., Carlson, C.L., and Sajwan, K.S. (1990). Vanadium: toxicity and accumulation by beans. Water Air Soil Pollut. **49**, 81-90.

Munawar, M., and Thomas, R.L. (1989). Sediment toxicity testing in two areas of concern of the Laurentian Great Lakes: Toronto (Ontario) and Toledo (Ohio) harbours. Hydrobiologia **176/177**, 397-409.

Romney, E.M., and Childress (1965). Effects of beryllium in plants and soil. Soil Science **100**, (3), 210-217.

Scherer, P. (1989). Vanadium and molybdenum requirement for the fixation of molecular nitrogen by two Methanosarcina strains. Arch. Microbiol. **151**, 44-48.

Smith, S.J., and Young, L.B. (1984). Mineralization of soil nitrogen in the presence of different metallic and organic solids. Commun. in Soil Sci. Plant Anal. **15**, (2), 125-134.

Tagatz, M.E., and Tobia, M. (1978). Effect of barite ($BaSO_4$) on development of estuarine communities. Estuarine and Coastal Marine Sciences **7**, 401-407.

Tyler, G. (1976). Influence of vanadium on soil phosphatase activity. J. Environ. Qual. **5**, (2), 216-217.

Wallace, A. (1989). Phytotoxicity of cobalt when uniformly mixed in soil versus localized spot placement in soil. Soil Science **147**, (6), 449-450.

Wallace, A., Romney, E.M., Alexander, G.V., and Kinnear, J. (1977). Phytotoxicity and some interactions of the essential trace metals iron, manganese, molybdenum, zinc, copper, and boron. Commun. in Soil Science and Plant Analysis **8**, (9), 741-750.

Appendix 5. Toxicity data used for comparison of sensitivity of salt and freshwater organisms

Acute data

metal	taxonomic group	L(E)C50 values (mg/l)	geometric mean L(E)C50 (mg/l)
freshwater organisms[a]			
cobalt	crustaceans	39; 16; 2.0[1]; 1.3; 4.0	5.8
molybdenum	crustaceans	2,700	
	fish	1,000	
selenium	crustaceans	0.60; 1.9[2]; 3.9	1.6
	fish	30[3]; 11; 13; 6.5; 110; 16[4]; 28[5]; 16; 2.1; 1.8; 10	11
thallium	fish	140; 0.86	11
tin	algae	7.0; 23	13
vanadium	fish	11; 120	36
saltwater organisms[b]			
cobalt	crustaceans	170; 4.5	27
molybdenum	crustaceans	1,900; 1,100; 250	810
	fish	2,600	
selenium	crustaceans	4.8; 33; 1.5; 1.2; 4.6	4.2
	fish	1.6; 7.4; 4.4	3.7
thallium	fish	21	
tin	algae	0.29; 0.32	0.30
vanadium	fish	28	

1 geometric mean of 1.5, 5.0, and 1.1 mg/l
2 geometric mean of 2.5, 1.1, 5.3, 0.55, 0.70, 2.6, 3.0, 4.1, 1.8, and 2.6 mg/l (only 48 h EC50 values are used)
3 geometric mean of 29 and 31 mg/l
4 geometric mean of 7.8 and 33 mg/l
5 geometric mean of 14, 120, and 13 mg/l

a data from appendix 2
b data from appendix 3

Chronic data

metal	taxonomic group	NOEC values (µg/l)	geometric mean NOEC (µg/l)
freshwater organisms[a]			
arsenic	crustaceans	570[1]	
cadmium	algae	3,100; 1,500; 120; 700; 35	420
	crustaceans	0.085	
	molluscs	2.5	
	fish	1.0; 4.2; 4.2; 11; 3.0; 31; 4.3; 1.3; 37; 4.4; 1.0; 3.8; 0.20; 9.0; 3.0	3.7
chromium	crustaceans	1.0	
cobalt	crustaceans	5	
copper	crustaceans	12; 4.0; 5.0; 20; 40; 5.0; 15	11
	fish	13; 43; 50; 35; 12; 100; 21; 37; 120; 21; 8.0; 11; 22; 3.0; 22; 13	22
lead	crustaceans	15	
mercury	crustaceans	32; 1.1; 0.020; 0.020	0.19
	fish	0.31	
nickel	crustaceans	37	
selenium	algae	1,000; 5,000; 4,700; 5; 1,300; 50; 260; 200; 79	320
	crustaceans	50; 200; 30; 160[2]	83
	fish	15	
zinc	algae	1,000; 910; 700; 5.0; 100; 400; 560	260
	crustaceans	25; 2,700	260
	molluscs	250	
saltwater organisms[b]			
arsenic	crustaceans	630	
cadmium	algae	3,000	
	crustaceans	320; 4.5[3]; 5.1; 25	21
	molluscs	110	
	fish	500; 71[4]; 420[5]; 1,000; 580	390
chromium	crustaceans	88	
cobalt	crustaceans	110,000; 450	7,000
copper	crustaceans	60; 38	48
	fish	28	
lead	crustaceans	17	
mercury	crustaceans	2.7; 10; 0.80	2.8
	fish	10	
nickel	crustaceans	61	

metal	taxonomic group	NOEC values (µg/l)	geometric mean NOEC (µg/l)
selenium	algae	79; 250[6]; 790; 790; 2,500[7]; 7,900; 790; 10,000; 100; 10	540
	crustaceans	140	
	fish	470	
zinc	algae	100[8]; 200	140
	crustaceans	440; 18; 120; 300	130
	molluscs	19	

1 geometric mean of 520 and 633 µg/l
2 geometric mean of 50, 85, and 1,000 µg/l
3 geometeric mean of 4.0 and 5.1 µg/l
4 geometric mean of 5.0 and 1,000 µg/l
5 geometric mean of 900 and 200 µg/l
6 geometric mean of 79 and 790 µg/l
7 geometric mean of 7,900 and 790 µg/l
8 geometric mean of 50 and 200 µg/l

a data for arsenic from Hesse et al. (1990); for cadmium, chromium, copper, lead, mercury, and zinc from Emans et al. (submitted); for nickel from Van De Meent, D., et al. (1990); for cobalt and selenium from appendix 2

b data for arsenicum, cadmium, chromium, copper, lead, mercury, nickel, and zinc from Scholten et al. (1991); for cobalt and selenium from appendix 3

Appendix 6. Toxicity data used for extrapolation methods

Freshwater organisms (NOEC and L(E)C50 values in µg/l)

metal	taxonomic group	Modification 0 NOEC	EPA-method L(E)C50	NOEC
antimony	crustaceans		420,000	
barium	crustaceans		15,000	
beryllium	bacteria	0.68		
	blue algae	15		
	green algae	1.0		
	protozoa	2.0		
		8.5		
		260		
	fish	80		
cobalt	blue algae	500		
	green algae	500		
		58[1]		
	crustaceans	5.0		
	fish	1,100		
molybdenum	worms		29,000	
selenium	bacteria	5,600		
	blue algae	1,000		
		5,000		
		4,700		
		79		
	green algae	5.0		
		1,300		
		50		
		260		
		200		
	protozoans	31		
		0.90		
		59		
	crustaceans	50		
		160[2]		
		200		
		30		
	insects	300		
	fish	15		
thallium	fish			30
tin	crustaceans			180
vanadium	crustaceans		3,500	

1 geometric mean of 2 NOEC values for *Chlorella pyrenoidosa* of 69 and 49 µg/l

2 geometric mean of 3 NOEC values for *Daphnia magna* (parameter: growth): 1,000 ; 50 ; and 85 µg/l

Saltwater organisms (NOEC and L(E)C50 values in µg/l)

metal	taxonomic group	Modification 0 NOEC	EPA-method L(E)C50	EPA-method NOEC
antimony	fish		6,200	
cobalt	algae		300	
molybdenum	crustaceans		250,000	
selenium	algae[1]	79		
		250[2]		
		790		
		790[3]		
		2,500[4]		
		7,900		
		790[5]		
		10		
		100		
		10,000		
	crustaceans	140		
	fish	470		
thallium	algae		160	
tin	algae		290	
vanadium	algae			50

1 data for algae were considered as data for more than one taxonomic group because data were available for Cyanophyta, Dinophyta, Bacillariophyta, Chlorophyta, Pyrmnesiophyta, and Eustigmatophyta

2 geometric mean of 2 NOEC values for *Amphidinium carterae* (parameter: yield): 79 and 790 µg/l

3 geometric mean of 2 NOEC values for *Chaetoceros vixvisibilis* (parameter: yield): 790 and 790 µg/l

4 geometric mean of 2 NOEC values for *Isochrysis galbana* (parameter: growth): 7,900 and 790 µg/l

5 geometric mean of 2 NOEC values for *Pavlova lutheri* (parameter: yield): 7,900 and 79 µg/l

Freshwater and saltwater organisms (NOEC and L(E)C50 values in μg/l)

metal	taxonomic group	Modification 0 NOEC	EPA-method L(E)C50	EPA-method NOEC
antimony	fish		6,200	
barium	crustaceans		15,000	
beryllium	bacteria	0.68		
	blue algae	15		
	green algae	1.0		
	protozoa	2.0		
		8.5		
		260		
	fish	80		
cobalt	blue algae	500		
	green algae	500		
		58[1]		
	crustaceans	5.0		
		110,000		
		450		
	fish	1,100		
molybdenum	worms		29,000	
selenium	bacteria	5,600		
	algae	1,000		
		5,000		
		4,700		
		79		
		5.0		
		1,300		
		50		
		260		
		200		
		79		
		250[2]		
		790		
		790[3]		
		2,500[4]		
		7,900		
		790[5]		
		10		
		100		
		10,000		
	protozoans	31		
		0.90		
		59		

metal (μg/l)	taxonomic group	Modification 0 NOEC (μg/l)	EPA-method L(E)C50 (μg/l)	NOEC
selenium	crustaceans	50		
		160[6]		
		200		
		30		
		140		
	insects	300		
	fish	15		
		470		
thallium	fish		160	
tin	algae			180
vanadium	crustaceans		3,500	

1 geometric mean of 2 NOEC values for *Chlorella pyrenoidosa* of 69 and 49 μg/l
2 geometric mean of 2 NOEC values for *Amphidinium carterae* (parameter: yield): 79 and 790 μg/l
3 geometric mean of 2 NOEC values for *Chaetoceros vixvisibilis* (parameter: yield): 790 and 790 μg/l
4 geometric mean of 2 NOEC values for *Isochrysis galbana* (parameter: growth): 7,900 and 790 μg/l
5 geometric mean of 2 NOEC values for *Pavlova lutheri* (parameter: yield): 7,900 and 79 μg/l
6 geometric mean of 3 NOEC values for *Daphnia magna* (parameter: growth): 1,000 ; 50 ; and 85 μg/l