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Preconsultation report: Proposed EQS for Water Framework Directive Annex VIII substances: chromium(VI) and chromium(III) (dissolved)

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The UK Technical Advisory Group (UKTAG) supporting the implementation of the Water Framework Directive (2000/60/EC) is a partnership of UK environmental and conservation agencies. It also includes partners from the Republic of Ireland. This report is the result of research commissioned and funded on behalf of UKTAG by the Scotland & Northern Ireland Forum for Environmental Research (SNIFFER) and the Environment Agency's Science Programme.

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Steve Killeen Head of Science

Use of this report

The development of UK-wide classification methods and environmental standards that aim to meet the requirements of the Water Framework Directive (WFD) is being sponsored by the UK Technical Advisory Group (UKTAG) for WFD on behalf of its members and partners.

This technical document has been developed through a collaborative project, managed and facilitated by the Scotland & Northern Ireland Forum for Environmental Research (SNIFFER), the Environment Agency and the Scottish Environment Protection Agency (SEPA) and has involved members and partners of UKTAG. It provides background information to support the ongoing development of the standards and classification methods.

Whilst this document is considered to represent the best available scientific information and expert opinion available at the stage of completion of the report, it does not necessarily represent the final or policy positions of UKTAG or any of its partner agencies.

Executive Summary

This document is a **preconsultation report** and was presented as background information during the UK Technical Advisory Group (UKTAG) Stakeholder Review on Specific Pollutants from June to August 2007. The actual standards proposed during the consultation were given in the UKTAG document 'Proposals for Environmental Quality Standards for Annex VIII Substances (SR1 - 2007, June 2007)'. Therefore, this overriding UKTAG document should also be referred to when considering the information given here

The UK Technical Advisory Group (UKTAG) has commissioned a programme of work to derive Environmental Quality Standards (EQSs) for substances falling under Annex VIII of the Water Framework Directive (WFD). This report proposes predicted no-effect concentrations (PNECs) for chromium using the methodology described in Annex V of the Directive. There are existing EQSs for chromium, but the method used to derive these is not considered to comply with the requirements of Annex V and so is unsuitable for deriving Annex VIII EQSs.

The PNECs described in this report are based on a technical assessment of the available ecotoxicity data for chromium, along with any data that relate impacts under field conditions to exposure concentrations. An EU Risk Assessment Report (RAR) has been compiled for chromium. Toxicity data taken from the EU RAR were not subjected to additional quality assessment. This is because they had already been assessed by the authors of the risk assessment and by an international advisory forum of experts from EU Member States.

The recommendations described in this report were submitted to an independent peer review group advising on Annex VIII EQSs. The UK is committed to the use of PNECs derived through the EU risk assessment process as the basis for Water Framework Directive Annex X EQSs. Consequently, this report recommends available RAR PNECs as the corresponding proposed Annex VIII EQSs.

Where possible, PNECs have been derived for freshwater and saltwater environments, and for long-term/continuous exposure and short-term/transient exposure. If they were to be adopted as EQSs, the long-term PNEC would normally be expressed as an annual average concentration and the short-term PNEC as a 95th percentile concentration.

The feasibility of implementing these PNECs as EQSs has not been considered at this stage. However, this would be an essential step before a regulatory EQS can be recommended.

Properties and fate in water

Chromium occurs naturally but also enters the environment through emissions from the metallurgy and metal-finishing industries and from its use as a chemical intermediate.

In surface waters, chromium exists in two oxidation states, 3+ (III) and 6+ (VI), but the more thermodynamically stable state is Cr(VI). Almost all the Cr(VI) in the environment arises from human activities. Conversion from Cr(VI) into Cr(III) can be slow, depending on the prevailing conditions that can stabilise Cr(III).

Chromium readily sorbs to sediments, though the high water solubility of Cr(VI) limits the extent to which this occurs. Chromium(III) is less toxic than Cr(VI) and its low solubility in water limits its bioavailability. PNECs for Cr(VI) and Cr(III) are considered separately.

Availability of data
Substantial short-term (st) and long-term (lt) ecotoxicological datasets are available that describe the effects of Cr(III) and Cr(VI) compounds for a wide variety of organisms (freshwater and marine fish, invertebrates, algae, plants, amphibians). Saltwater data are available only for Cr(VI) compounds from studies with algae, crustaceans, fish and echinoderms. There are few reliable ecotoxicological data for saltwater organisms exposed to Cr(III).

Derivation of PNECs
The EU RAR adopted a total risk approach as almost all hexavalent chromium [Cr(VI)] in the environment is of anthropogenic origin and natural background levels of Cr(VI) are, therefore, negligible.

Because of the low solubility and hence reduced bioavailability of Cr(III) species, there would seem to be little requirement for thresholds for Cr(III). However, if such standards were needed, the added risk approach could be recommended to take account of spatial differences in natural chromium background levels if the background concentrations were significantly lower than those of the derived PNEC. Sufficient data are available to permit the derivation of freshwater PNECs for Cr(III), but there are insufficient data to derive saltwater PNECs.

Long-term studies with freshwater invertebrates do not show any clear dependence of Cr(VI) toxicity on the properties of the water. Although relationships between hardness and toxicity have been described for divalent metal cations, the fact that the chromium species here are oxoanions means that their toxicity may be less influenced by water properties. Detailed relationships between the behaviour of chromium and environmental factors were not developed in the EU RAR and we agree that the data do not warrant normalisation of chromium toxicity for water quality parameters.

Chromium(VI)

<u>Long-term PNEC for freshwaters</u>
There are sufficient long-term data to construct a species sensitivity distribution (SSD) and to estimate a threshold based on the lower 5th percentile from the model fitted to the ranked no observable effect concentration (NOEC) data (the HC5). Indeed, this is the basis of the $PNEC_{freshwater\_lt}$ recommended in the EU RAR. In accordance with the Annex V methodology, an assessment factor of 3 is applied to the HC5 to reflect the substantial taxonomic spread in the available dataset and the

fact that there was considered to be a reasonable fit of the available data to the model. The resulting $PNEC_{freshwater\_lt}$ of 3.4 µg l^{-1} Cr(VI).

The external peer review group considering PNECs for consideration as Annex VIII EQSs took issue with the last assertion and suggested that the data actually reflected two distinct distributions. There was also a lack of consensus about the validity of the SSD approach, even though it is an accepted approach for chemical risk assessment and allowed under the Annex V methodology.
A separate $PNEC_{freshwater\_lt}$ can also be derived using the deterministic (critical data/assessment factor) approach. This value is more stringent, being based on an assessment factor of 10 applied to the lowest reliable NOEC of 4.7 µg l^{-1} for reproduction of the cladoceran *Ceriodaphnia dubia*, i.e. a $PNEC_{freshwater\_lt}$ of 0.47 µg l^{-1} Cr(VI). This is the lowest factor permitted under the Annex V approach for laboratory data, even with a substantial dataset.

The existing EQSs for chromium are banded according to water hardness, with values ranging between 5 and 50 µg l^{-1} as dissolved chromium for the protection of 'sensitive taxa'. The $PNEC_{freshwater\_lt}$ derived from the SSD is comparable with the most stringent value from this range, but the $PNEC_{freshwater\_lt}$ based on a deterministic approach is at least 10 times more stringent.

<u>Short-term PNEC for freshwaters</u>
The lowest valid acute EC50 (20 µg l^{-1}) is for immobilisation of the crustacean *Moina australiensis* after 48-hour exposure. Similar effect concentrations were evident from acute studies with other crustaceans, molluscs and annelids. A small assessment factor is justified because:

- acute effects values of the most sensitive species are close to the lowest chronic effects values (i.e. a low acute to chronic effects ratios);
- a broad range of taxonomic groups is represented by the acute dataset.

This results in a $PNEC_{freshwater\_st}$ of 2 µg l^{-1} Cr(VI).

There is no existing short-term EQS for chromium.

<u>Long-term PNEC for saltwaters</u>
The lowest available NOEC of 4–6 µg l^{-1} in *Mytilus edulis* is unbounded (highest concentration tested) and consequently unsuitable for PNEC derivation. The next lowest value, a 2-week $NOEC_{mortality}$ of 6 µg l^{-1} in *Nereis arenaceodentata*, was regarded as valid for PNEC derivation in the EU RAR. Since reliable long-term data are also available for five other taxa, an assessment factor of 10 can be justified, leading to a $PNEC_{saltwater\_lt}$ of 0.6 µg l^{-1} Cr(VI).

The existing EQS for the protection of marine organisms is 15 µg l^{-1} dissolved chromium, based on a range of acute and chronic data to which no assessment factor was applied. The proposed $PNEC_{saltwater\_lt}$ is lower by a factor of ~30, reflecting both the availability of new data and the assessment factor used.

<u>Short-term PNEC for saltwaters</u>
A 96-hour LC50 of 0.32 mg l^{-1} obtained with *Callinectes sapidus* is the basis for the

derivation of the $PNEC_{saltwater\_st}$. An assessment factor of 10 is considered adequate to extrapolate to the PNEC because good quality data are available for algae, crustaceans and echinoderms. Although acute data for saltwater fish are lacking, chronic data indicate they are unlikely to be the most sensitive group. In addition, the resulting PNEC will be in the range of the lowest NOECs obtained for species with a short life-cycle such as algae and crustaceans. The proposed $PNEC_{saltwater\_st}$ of 32 µg l^{-1} Cr(VI).

There is no existing short-term EQS for chromium.

Chromium(III)
PNECs for Cr(III) were developed in the EU RAR but only for the protection of freshwater organisms, due to a lack of saltwater toxicity data. There are no existing EQSs specifically for Cr(III).

Long-term PNEC for freshwaters
The lowest reliable chronic NOEC values are 0.05 mg l^{-1} for rainbow trout (*Oncorhynchus mykiss*) and 0.047 mg l^{-1} for *Daphnia magna* from studies using soft water. Long-term toxicity data are available for representatives of at least three different taxonomic groups, permitting the use of an assessment factor of 10. Applying this factor to the lowest available NOEC gives a $PNEC_{freshwater\_lt}$ of 4.7 µg l^{-1} Cr(III).

Short-term PNEC for freshwaters
Based on the available toxicity data for Cr(III), algae are the most sensitive organisms. The lowest EC50 of 0.32 mg l^{-1} is reported for *Selenastrum capricornutum* biomass gain over 96 hours. For invertebrates, the lowest L(E)C50 values are in the range of 1–15 mg l^{-1} and, for fish, the lowest acute LC50 is 3.33 mg l^{-1}. Given the availability of data for a number of taxa, an assessment factor of 10 applied to the EC50 of 0.32 mg l^{-1} for *Selenastrum capricornutum* is recommended, resulting in a $PNEC_{freshwater\_st}$ of 32 µg l^{-1} Cr(III).

PNEC for secondary poisoning
There are avian and mammalian toxicity data for Cr(VI) but not Cr(III). Although there is evidence of bioaccumulation of chromium, in fish and possibly other biota, Cr(VI) is reduced to Cr(III). It is not possible to derive a $PNEC_{secpois}$ for Cr(III) as there are no mammalian or avian toxicity data for this form.

PNEC for sediment
There are insufficient sediment toxicity data to derive a sediment PNEC for chromium.

Summary of proposed PNECs

Receiving medium/exposure scenario	Proposed PNEC ($\mu g\ l^{-1}$ dissolved)	Existing EQS ($\mu g\ l^{-1}$ total dissolved chromium)
Chromium(VI)		
Freshwater/long-term	0.47 (det), 3.4 (SSD)	Range from 5–50, depending on hardness
Freshwater/short-term	2	No standard
Saltwater/long-term	0.6	15
Saltwater/short-term	32	No standard
Chromium(III)		
Freshwater/long-term	4.7	-
Freshwater/short-term	32	-
Saltwater/long-term	No proposal	-
Saltwater/short-term	No proposal	-

Analysis
The lowest proposed PNEC derived for chromium is 0.47 $\mu g\ l^{-1}$. Current analytical methodologies provide detection limits as low as 1 $\mu g\ l^{-1}$. Since the data quality requirements are that, at a third of the EQS, total error of measurement should not exceed 50 per cent, they may not offer adequate performance to analyse for the lowest TGD-derived PNECs for water.

Implementation issues
Before PNECs for chromium can be adopted as EQSs, it will be necessary to address the following issues:

Chromium(VI)
1. The proposed PNECs for the protection of freshwater organisms from long-term exposure to Cr(VI) are suitable for adoption as EQSs. However, risks from Cr(VI) are greater than from Cr(III) and should, therefore, take priority.

2. The PNEC derived using the SSD approach is preferred over the PNEC obtained by application of an assessment factor to critical data. While the use of an SSD is a legitimate option within the Annex V methodology, this approach was not unanimously supported by the EQS peer review panel.

3. Analytical sensitivity may not be adequate for assessing compliance with the PNECs for Cr(VI). Further method development may, therefore, be necessary before PNECs can be adopted as EQSs.

4. Existing EQSs are recommended as interim standards while this work is being undertaken.

Chromium(III)
1. Risks from Cr(III) are small so any EQSs may be required only in exceptional circumstances.

2. Because background levels of Cr(III) are low, an added risk approach may be

recommended. However, this would first require an appreciation of background concentrations of Cr(III) at a defined range of scales.

3. Since there is no existing EQS, there can be no interim standard for Cr(III) while this work is being undertaken.

Contents

1. Introduction

The UK Technical Advisory Group (UKTAG) supporting the implementation of the Water Framework Directive (2000/60/EC)[1] is a partnership of UK environmental and conservation agencies. It also includes partners from the Republic of Ireland. UKTAG has commissioned a programme of work to derive Environmental Quality Standards (EQSs) for substances falling under Annex VIII of the Water Framework Directive (WFD). This report proposes predicted no-effect concentrations (PNECs) for chromium using the methodology described in Annex V of the Directive. There are existing EQSs for chromium, but the method used to derive these is not considered to comply with the requirements of Annex V and so is unsuitable for deriving Annex VIII EQSs.

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The recommendations described in this report were submitted to an independent peer review group advising on Annex VIII EQSs. The UK is committed to the use of PNECs derived through the EU risk assessment process as the basis for Water Framework Directive Annex X EQSs. Consequently, this report recommends available RAR PNECs as the corresponding proposed Annex VIII EQSs.

The feasibility of implementing these PNECs as EQSs has not been considered at this stage. However, this would be an essential step before a regulatory EQS can be recommended.

This report provides a data sheet for chromium(III) and chromium(VI).

1.1 Properties and fate in water

Chromium occurs naturally but also enters the environment through emissions from the metallurgy and metal-finishing industries, and from its use as a chemical intermediate.

In surface waters, chromium exists in two oxidation states, 3+ (III) and 6+ (VI), but the more thermodynamically stable state is Cr(VI). Almost all the Cr(VI) in the environment arises from human activities. Conversion from Cr(VI) into Cr(III) can be slow, depending on the prevailing conditions that can stabilise Cr(III). Chromium readily sorbs to sediments, although the high water solubility of Cr(VI) limits the extent to which this occurs. Chromium(III) is less toxic than Cr(VI) and its low solubility in water limits its bioavailability.
PNECs for Cr(VI) and Cr(III) are considered separately.

[1] *Official Journal of the European Communities*, **L327**, 1–72 (22/12/2000). Can be downloaded from http://www.eu.int/comm/environment/water/water-framework/index_en.html

2. Results and observations

2.1 Identity of substance

Table 2.1 gives the chemical name and Chemical Abstracts Service (CAS) number for the species of interest.

Table 2.1 Species covered by this report

Name	CAS Number
Chromium metal	7440-47-3

2.2 PNECs proposed for derivation of quality standards

The EU Risk Assessment Report (RAR) on chromates [56] adopted a total risk approach as almost all hexavalent chromium in the environment is of anthropogenic origin. The natural background levels of Cr(VI) are therefore insignificant and negligible.

The PNECs proposed in this report as a basis for setting EQSs refer to the dissolved fraction of the total (i.e. natural background plus anthropogenic addition) concentration.

Chromium(III) is considered to be less toxic than Cr(VI) and, under natural conditions, hardly bioavailable due to the low solubility of the Cr(III) species. However, since Cr(VI) is converted into Cr(III) under some conditions, the possible effects of Cr(III) may also be taken into consideration.

The bioavailability, and hence toxicity, of chromium(III) or chromium(VI) species may be influenced by water quality parameters such as hardness, pH or salinity. Detailed relationships between chromium properties and environmental factors were, however, not developed in the EU RAR. In addition, the data available are not sufficient to allow for a normalisation of chromium toxicity for water quality parameters.

Tables 2.2 and 2.3 list proposed PNECs for Cr(VI) and Cr(III), respectively, obtained using the methodology described in the Technical Guidance Document (TGD) issued by the European Chemicals Bureau (ECB) on risk assessment of chemical substances [152], and existing EQSs obtained from the literature [184, 185].

Section 2.6 summarises the effects data identified from the literature for chromium. The use of these data to derive the values given in Tables 2.2 and 2.3 is explained in Sections 3 and 4.

Table 2.2 PNEC/EQS proposals referring to Cr(VI) species (dissolved)

PNEC	TDG deterministic approach (AFs)	TGD probabilistic approach (SSDs)	Existing EQS (as total dissolved chromium)
Freshwater short-term	2 µg l^{-1} (see Section 4.1.1)	-	-
Freshwater long-term	0.5 µg l^{-1} (see Section 4.1.1)	3.4 µg l^{-1} (see Section 4.2.1)	$CaCO_3$ / EQS 1 / EQS 2 0-50 mg l^{-1} / 5 µg l^{-1} / 150 µg l^{-1} 50-100 mg l^{-1} / 10 µg l^{-1} / 175 µg l^{-1} 100-150 mg l^{-1} / 20 µg l^{-1} / 200 µg l^{-1} 150-200 mg l^{-1} / 20 µg l^{-1} / 200 µg l^{-1} 200-250 mg l^{-1} / 50 µg l^{-1} / 250 µg l^{-1} >250 mg l^{-1} / 50 µg l^{-1} / 250 µg l^{-1} (all as AA)*
Saltwater short-term	32 µg l^{-1} (see Section 4.1.2)	-	-
Saltwater long-term	0.6 µg l^{-1} (see Section 4.1.2)	Derivation not possible – insufficient data (see Section 4.2.2)	15 µg l^{-1} (AA)
Freshwater sediment ($PNEC_{aqua}$ based on AF method)	Derivation not possible – insufficient data	-	-
Freshwater sediment ($PNEC_{aqua}$ based on SSD method)	Derivation not possible – insufficient data	-	-
Saltwater sediment ($PNEC_{aqua}$ based on AF method)	Derivation not possible – insufficient data	-	-
Freshwater secondary poisoning	5.7 mg/kg food (see Section 4.5)	-	-
Saltwater secondary poisoning	5.7 mg/kg food (see Section 4.5)	-	-

AA = annual average; AF = assessment factor; SSD = species sensitivity distribution
*In addition the EQSs were updated as follows (all as dissolved AA):

$CaCO_3$ (mg l^{-1})	*Freshwater (µg l^{-1})*	*Saltwater (µg l^{-1})*
0–50	2	5
50–100	10	
100–150	10	
150–200	20	
200–250	20	
>250	20	

Table 2.3 PNEC/EQS proposals referring to Cr(III) species (dissolved)

PNEC	TDG deterministic approach (AFs)	TGD probabilistic approach (SSDs)	Existing EQS (as total dissolved chromium)
Freshwater short-term	32 µg l^{-1} (see Section 4.1.1)	-	-
Freshwater long-term	4.7 µg l^{-1} (see Section 4.1.1)	Derivation not possible – insufficient data (see Section 4.2.1)	$CaCO_3$ / EQS 1 / EQS 2 0-50 mg l^{-1} / 5 µg l^{-1} / 150 µg l^{-1} 50-100 mg l^{-1} / 10 µg l^{-1} / 175 µg l^{-1} 100-150 mg l^{-1} / 20 µg l^{-1} / 200 µg l^{-1} 150-200 mg l^{-1} / 20 µg l^{-1} / 200 µg l^{-1} 200-250 mg l^{-1} / 50 µg l^{-1} / 250 µg l^{-1} >250 mg l^{-1} / 50 µg l^{-1} / 250 µg l^{-1} (all as AA)*
Saltwater short-term	Derivation not possible – insufficient data (see Section 4.1.2)	-	
Saltwater long-term	Derivation not possible – insufficient data (see Section 4.1.2)	Derivation not possible – insufficient data (see Section 4.2.2)	15 µg l^{-1} (AA)
Freshwater sediment ($PNEC_{aqua}$ based on AF method)	Derivation not possible – insufficient data (see Section 4.4.1)	-	-
Freshwater sediment ($PNEC_{aqua}$ based on SSD method)	Derivation not possible – insufficient data (see Section 4.4.2)	-	-
Saltwater sediment ($PNEC_{aqua}$ based on AF method)	Derivation not possible – insufficient data (see Section 4.4.1)	-	-
Freshwater secondary poisoning	Derivation not possible – insufficient data (see Section 4.5)	-	-
Saltwater secondary poisoning	Derivation not possible – insufficient data (see Section 4.5)	-	-

AA = annual average
AF = assessment factor
SSD = species sensitivity distribution
*In addition the EQSs were updated as follows (all as dissolved AA):

$CaCO_3$ (mg l^{-1})	*Freshwater (µg l^{-1})*	*Saltwater (µg l^{-1})*
0–50	2	5
50–100	10	
100–150	10	
150–200	20	
200–250	20	
>250	20	

2.3 Hazard classification

Table 2.4 gives the R-phrases (Risk-phrases) and labelling for the species of interest.

Table 2.4 Hazard classification

CAS Number	Chemical name	Classification and R-phrases	Reference
7440-47-3	Chromium metal	This chemical substance is not classified in the Annex I of Directive 67/548/EEC.	[54]
1333-82-0	Chromium trioxide	O; R9–Carc. Cat. 1; R45–Muta. Cat. 2; R46–Repr. Cat. 3; R62–T+; R26–T; R24/25-48/23–C; R35–R42/43–N; R50-53	
7775-11-3	Sodium chromate	Carc. Cat. 2; R45–Muta. Cat. 2; R46–Repr. Cat.2; R60-61–T+; R26–T; R25-48/23–Xn; R21–C; R34–R42/43–N; R50-53	
10588-01-9 7778-50-9	Sodium dichromate Potassium dichromate	O; R8–Carc. Cat. 2; R45–Muta. Cat. 2; R46–Repr. Cat. 2; R60-61–T+; R26–T; R25-48/23–Xn; R21–C; R34–R42/43–N; 50-53	

2.4 Physical and chemical properties

Table 2.5 summarises the physical and chemical properties of the species of interest.

Table 2.5 Physical and chemical properties of chromium

Property	Value	Reference
Molecular formula	Cr	
Relative molecular weight	51.996	[105]
Melting point (°C)	1,903 ± 10	[105]
Boiling point (°C)	2,642	[105]
Vapour pressure	The metal is an involatile solid at normal temperatures	
Water solubility (mg l^{-1})	Insoluble	[79]
Soil–water partition coefficient (log Kp)	1.91×10^5 l kg^{-1}	[43]

2.5 Environmental fate and partitioning

Table 2.6 summarises the information obtained from the literature on the environmental fate and partitioning of chromium.

Table 2.6 Environmental fate and partitioning of chromium

Property	Value	Reference
Abiotic fate	The processes that control the environmental chemistry of chromium include: • the form it enters the environment; • redox transformation; • precipitation/dissolution; • adsorption/desorption reactions.	[79]
	Most of the chromium present in water will ultimately be deposited in sediments. In the aquatic phase, chromium occurs in the soluble state or adsorbed onto suspended particulate matter.	[13]
	Soluble Cr(VI) may persist in some bodies of water for a long time, but will eventually be reduced to Cr(III) by organic matter or other reducing agents in water.	[159]
	The residence times of total chromium in lake water range from 4.6 to 18 years.	[139]
	The kinetics of oxidation of Cr(III) to Cr(VI) are slow and, under certain conditions, will not be significant in natural waters.	[13]
	Chromium compounds do not volatilise from water.	[13, 79]
Speciation	Chromium occurs in each of the oxidation states from –2 to +6, with only the 0 (elemental), +2, +3 and +6 states common in nature. Chromium(II) is unstable in most compounds as it is easily oxidised by air to the trivalent form.	[13, 79]
	The thermodynamically stable state of chromium in water is Cr(VI). However, the slowness with which this equilibrium is attained and the influence of other substances and biological processes in water can lead to the presence of significant concentrations of the reduced for Cr(III) in most natural waters.	[51]
	There are three principal processes that control the concentration of Cr(III) in water: • the oxidation of dissolved organic matter leading to the reduction of Cr(VI) to Cr(III); • microbial reduction of Cr(VI), which could still occur in samples filtered to 0.4 µm, as it is accepted that a pore size of 0.2 µm is required to remove bacteria; • the stabilisation of the reduced species by organic ligands in most natural waters.	[84, 170]
	The presence of oxidisable organic matter and the stabilising role of complexing organic ligands are proposed as the main controlling influences of redox speciation in filtered samples.	[63]

Property	Value	Reference
	Commonly occurring reductants such as ferrous iron and organic material can transform Cr(VI) to Cr(III), but manganese oxides are the only inorganic oxidants found in the environment that cause rapid oxidation of Cr(III) to Cr(VI).	[13]
Hydrolytic stability	Not applicable	
Photostability	Only potentially significant for chromium associated with organic ligands	[84]
Distribution in water/sediment systems	Most of the chromium released into water will ultimately be deposited in the sediment, with a very small percentage present in the aqueous phase in both soluble and insoluble forms. Most of the soluble chromium is present as Cr(VI) or as soluble Cr(III) complexes.	[13, 79]
	The adsorption of Cr(III) and Cr(VI) is complicated by redox changes that can occur. Chromium(VI) is the thermodynamically stable species under highly oxidising conditions, whereas Cr(III) predominates under reducing conditions.	[79]
	The adsorption of Cr(III) on suspended solids and sediment increases as pH increases, in contrast to Cr(VI), the adsorption of which decreases with increasing pH.	[13, 79]
Fate in soil	In most soils, chromium will be present predominantly in the Cr(III) state. Chromium(III) in soil is mostly present as insoluble carbonates and oxides, and will not be mobile in soil. The fate of chromium in soil is greatly dependent upon the speciation of chromium, which is a function of redox potential and the pH of the soil.	[79]
Biotransformation	Factors affecting the microbial reduction of Cr(VI) to Cr(III) include biomass concentration, initial Cr(VI) concentration, temperature, pH, carbon source, redox potential, and the presence of both oxyanions and metal cations.	[13]
	Although high levels of Cr(VI) are toxic to most microbes, several resistant bacterial species have been identified.	[13]
Partition coefficients	Sediment–water partition coefficient: Kp = 1.91 x 10^5 l kg^{-1}.	[43]
Bioaccumulation BCF	Cr(VI) rainbow trout (*Oncorhynchus mykiss*) = 1.0	[13]
	Chromium is not expected to biomagnify in the aquatic food chain.	[13]
	BCFs for Cr(III) in saltwater organisms range 86–153. Cr(III) oyster = 116	[159]
	Cr(III) soft-shell clam = 153	[158]

Property	Value	Reference
	Cr(III) blue mussel = 86	[158]
	Cr(VI) range 125–236 for bivalve molluscs and polychaetes	[158]
	Total Cr benthic organisms range = 86–192	[160]
	Total Cr molluscs = 440	[13]
	Total Cr benthic algae = 1,600	[112]
	Total Cr phytoplankton = 2,300	[112]
	Total Cr zooplankton = 1,900	[112]

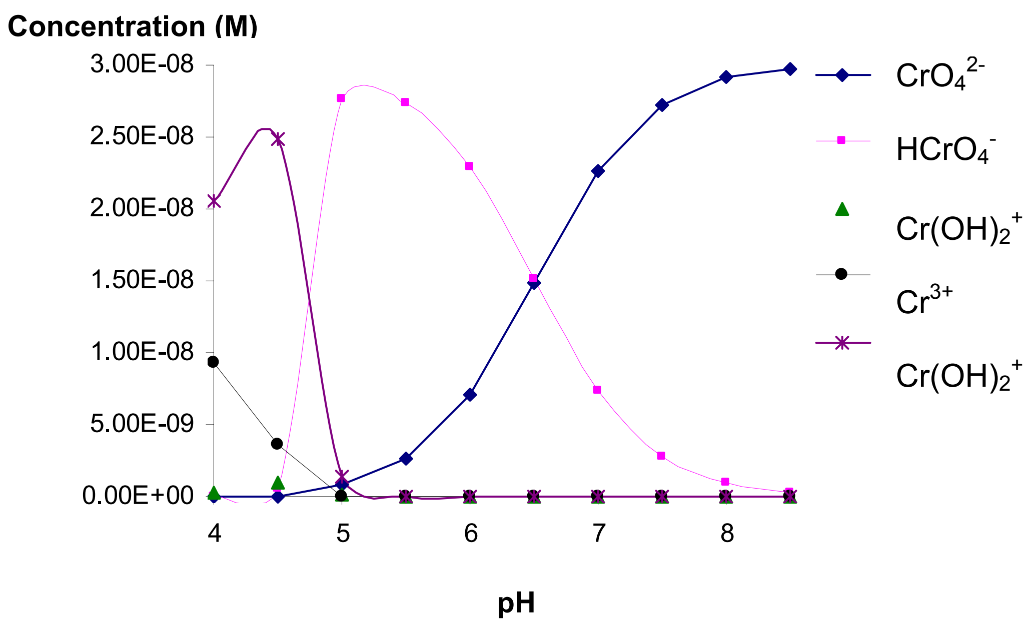
The concentrations of chromium in rivers and freshwaters are usually between 1 and 10 µg l^{-1} (although levels in lakes in Scandinavia tend to be lower than this). In oceans, the chromium concentrations are typically reported to be in the range 0.1–5 µg l^{-1} and generally <1 µg l^{-1}. Naturally occurring chromium is almost always present in the trivalent state [56].

Almost all the hexavalent chromium in the environment arises from human activities. It is derived from the industrial oxidation of mined chromium deposits and possibly from the combustion of fossil fuels, wood, paper, etc. In this oxidation state, chromium is relatively stable in air and pure water, but there is a large body of evidence indicating that Cr(VI) can be reduced to Cr(III) under anaerobic conditions by both biotic and abiotic processes. These include reaction with iron (II), sulfides, organic matter and anaerobic micro-organisms. The reduction is generally favoured by increasing concentration of the reductant and lower pH. Thus, the reduction of Cr(VI) would be expected to occur most rapidly in acidic soils with high iron, sulfide or organic carbon contents. Under such conditions, reduction of Cr(VI) to Cr(III) may be complete within a few hours.

Under aerobic conditions and at higher pH (around 7–8 and above), Cr(VI) appears to be more stable to reduction than at lower pH under anaerobic conditions. Chromium(VI) in surface water appears to be relatively stable under these conditions. The same is also likely to be the case in aerobic sediments and soils, but here Cr(VI) is considered to be relatively mobile. Consequently, it would be expected to migrate to the anaerobic layers where reduction to Cr(III) could occur. Therefore, under aerobic conditions, the rate of reduction of Cr(VI) to Cr(III) may be limited by the rate of transport of the chromium ion to suitable environments for reduction to occur. Under less favourable conditions [e.g. alkaline conditions (pH ~>8) and/or neutral conditions, where low concentrations of reductants for Cr(VI) exist], the rate of reduction of Cr(VI) to Cr(III) is assumed to be slow, with a half-life of around 1 year. Such conditions are found in seawater, where a pH of around 8 is typical. The relationship between chromium speciation and pH is illustrated in Figure 2.1.

There is an environmental cycle for chromium from rocks and soils to water, biota, air, and back to the soil. However, a substantial amount (estimated at 6.7 x 10^6 kg per year) is diverted from this cycle by discharge into streams, and by runoff and dumping into the sea. The ultimate repository is ocean sediment.

Figure 2.1 Relationship between chromium speciation and pH. NB These species are for pe = 12.7 (i.e. oxygenated water) and for total chromium concentration of $3e^{-8}$ M



2.5.1 Bioaccumulation

The estimation methods given in the Technical Guidance Document [152] for determining bioconcentration or bioaccumulation factors for fish, earthworms and uptake in the food chain are not applicable to chromium compounds. The following is a brief synopsis of the conclusions of the EU RAR [56].

The uptake and accumulation of chromium by fish appears to be lower than for other aquatic organisms. Bioconcentration factors (BCFs) of around 1 l kg^{-1} have been determined for Cr(VI) using rainbow trout over 22–30 days exposure, with a value of 2.8 l kg^{-1} being reported in trout muscle for a longer exposure of 180 days [158, 180, 181].

Bioconcentration factor values of 18–90 for rainbow trout exposed for 2 years in a lake polluted with chromates from cooling towers were reported by Janus and Krajnc [182] (as quoted in Braunschweiler [183]).

For the EU RAR [56], a reliable value for the BCF in fish was needed. The available data indicated that the BCF for Cr(VI) in fish is relatively low at around 1 l kg^{-1}. Once in the organism, reduction of Cr(VI) to Cr(III) appears to occur, resulting in an accumulation of total chromium in the organisms to a factor of approximately 100 times the original concentration in water. Uptake of Cr(III) directly from water is likely to be very low due to the limited water solubility and strong adsorption to sediment under most conditions found in the environment.

Thus, the following BCFs were used in the RAR:

To estimate the concentration of Cr(VI) in fish:

$$\frac{[Cr(VI)]_{fish}\ mg/kg}{[Cr(VI)]_{water}\ mg\ l^{-1}} = BCF_{Cr(VI)} = 1\ l\ kg^{-1}$$

To estimate the concentration of Cr(III) in fish resulting from uptake and subsequent reduction of Cr(VI):

$$\frac{[Cr(III)]_{fish}\ mg/kg}{[Cr(VI)]_{water}\ mg/kg} = BCF_{Cr(VI)-Cr(III)} = 100\ l\ kg^{-1}$$

The uptake of chromium by other organisms appears to be higher than seen for fish, although few if any of the experiments distinguish between Cr(VI) and Cr(III). Similar to the situation for fish, it is possible that once taken up by the organism, Cr(VI) is reduced to Cr(III) in the tissues, resulting in a build-up of Cr(III) and hence an overestimate for the true BCF for Cr(VI). BCFs of up to around 9,100 l kg^{-1} (on a mussel dry weight basis) for Cr(VI) and 2,800 l kg^{-1} (on a mussel dry weight basis) for Cr(III) have been determined in mussels. In algae, BCFs of around 500 l kg^{-1} (on a cell dry weight basis) for Cr(VI) and 12,000–130,000 l kg^{-1} (on a cell dry weight basis) for Cr(III) have been determined. Transfer of chromium via the alga⇒bivalve and sediment⇒bivalve food chains appears to be relatively low.

2.6 Effects data and assessment

Data collation followed a tiered approach.

Critical data on freshwater and marine organisms were collected from the existing UK EQS documents [184, 185] as well as from the EU RAR on chromium [56].

Further data published after derivation of the current UK EQS and the EU RAR were obtained from:

- the US Environmental Protection Agency (US EPA) ECOTOX database;[2]
- Hazardous Substances Data Bank (HSDB®) database of the US National Library of Medicine[79];
- the US EPA Integrated Risk Information System (IRIS);[3]
- Web of Science®.[4]

The EU RAR covers the substances listed in Table 2.7.

[2] http://www.epa.gov/ecotox/
[3] http://www.epa.gov/iris/index.html
[4] http://scientific.thomson.com/products/wos/

Table 2.7 Chromium compounds covered by the EU RAR

CAS Number	Chemical name
1333-82-0	Chromium trioxide
7775-11-3	Sodium chromate
10588-01-9	Sodium dichromate
7789-09-5	Ammonium dichromate
7778-50-9	Potassium dichromate

Data published after the EU RAR and UK EQS were sought for the 13 chemicals listed in Table 2.8.

Table 2.8 Chemicals for which further data were sought

CAS Number	Chemical Name
7440-47-3	Chromium
1333-82-0	Chromium trioxide
13907-47-6	Chromate
7775-11-3	Sodium chromate
10588-01-9	Sodium dichromate
7789-00-6	Potassium chromate
7778-50-9	Potassium dichromate
10049-05-5	Chromous chloride
10025-73-7	Chromic chloride
13548-38-4	Nitric acid, Chromium(III) salt
12680-48-7	Sodium chromate
10101-53-8	Chromium(III) sulfate
7738-94-5	Chromic acid

Toxicity data and other information on the inherent properties of chromium taken from the EU RAR were not subjected to additional quality assessment as these data had already been assessed by the authors of the RAR and by the 'Technical Meeting on Existing Substances', an international advisory forum of experts from EU Member States, industry, and 'green' non-governmental organisations (NGOs). This body was set up to discuss and advise on the risk assessments for existing substances conducted in accordance with Commission Regulation (EC) No. 1488/94.

Validity criteria used in the EU RAR for the evaluation of studies are listed in Table 2.9. Only studies rated 'I', 'II' or 'IIIb' have been used for PNEC derivation.

Data relevant for PNEC derivation, but originating from sources other than the RAR were quality assessed in accordance with the so-called Klimisch Criteria (KC) [87]. The KC has four categories (Table 2.10). Only studies/data assigned to categories 1 or 2 were used for the assessment (see also Annex 1).

Table 2.9 Validity criteria for aquatic toxicity tests used in the EU RAR

Validity marking	Validity criteria
I	The method is, or is very similar to, the current recommended test guidelines. The test is well reported and most important experimental details are given.
II	The method used in essentially similar or compatible with the current recommended test guidelines. The test is well reported but there may be some aspects of the test for which information is not given.
IIIa	Insufficient data reported to make a judgement on the validity.
IIIb	Some part of the method deviates significantly from what would normally be expected in the current recommended test guidelines, making the significance of the result difficult to interpret. Examples may be tests carried out at very high or low temperatures, results where effects were seen but the statistical significance is uncertain, or inappropriate concentrations tested.
IV	Result is clearly invalid or not relevant.

Table 2.10 Klimisch Criteria

Code	Category	Description
1	Reliable without restrictions	Refers to studies/data carried out or generated according to internationally accepted testing-guidelines (preferably GLP*) or in which the test parameters documented are based on a specific (national) testing guideline (preferably GLP), or in which all parameters described are closely related/comparable to a guideline method.
2	Reliable with restrictions	Studies or data (mostly not performed according to GLP) in which the test parameters documented do not comply totally with the specific testing guideline, but are sufficient to accept the data or in which investigations are described that cannot be subsumed under a testing guideline, but which are nevertheless well-documented and scientifically acceptable.
3	Not reliable	Studies/data in which there are interferences between the measuring system and the test substance, or in which organisms/test systems were used that are not relevant in relation to exposure, or which were carried out or generated according to a method which is not acceptable, the documentation of which is not sufficient for an assessment and which is not convincing for an expert assessment.
4	Not assignable	Studies or data which do not give sufficient experimental details and which are only listed in short abstracts or secondary literature.

* OECD Principles of Good Laboratory Practice (GLP). See:
http://www.oecd.org/department/0,2688,en_2649_34381_1_1_1_1_1,00.html

All relevant studies with regard to the aquatic toxicity of Cr(VI) compounds are listed in:

- Table 2.11: long-term toxicity data of freshwater species;
- Table 2.12: short-term toxicity data of freshwater species;
- Table 2.16: long-term data of saltwater species;
- Table 2.17: short-term toxicity data of saltwater species.

Studies conducted with Cr(III) compounds and evaluated and considered relevant and reliable in the EU RAR are listed in:

- Table 2.13: studies with fish;
- Table 2.14: invertebrates;
- Table 2.15: algae.

2.6.1 Toxicity to freshwater organisms

Short-term and long-term ecotoxicological data on the effects of trivalent and hexavalent chromium compounds are available for a wide variety of:

- organisms – freshwater and marine fish, invertebrates, algae, plants, amphibians;
- life stages – juveniles, adults, fry, larvae, tadpoles, eggs, etc.;
- endpoints – LC50s, EC50s, no observed effect concentrations (NOECs), lowest observed effect concentrations (LOECs) based on mortality, reproduction, hatching, etc.;
- test conditions.

The results are expressed as the concentrations of Cr(III) or Cr(VI) for ease of comparison between the trivalent or hexavalent compounds. In general, the majority of ecotoxicological information is available for potassium dichromate because it is a reference toxicant.

All relevant studies with regard to the aquatic toxicity of Cr(VI) compounds are listed in Tables 2.11 (long-term toxicity data of freshwater species), 2.12 (acute data of freshwater species). Studies conducted with Cr(III) compounds are listed in Tables 2.14 (studies with fish), 2.15 (invertebrates) and 2.16 (algae).

Diagrammatic representations of the available freshwater data (cumulative distribution functions) for Cr(VI) are presented in Figures 2.2 and 2.3 and, for Cr(III), in Figures 2.4 and 2.5. These diagrams include all data regardless of quality and provide an overview of the spread of the available data. These diagrams are not species sensitivity distributions and have not been used to set the chromium PNECs.

Figure 2.2 Cumulative distribution function of freshwater long-term data (mg l^{-1}) for Cr(VI)

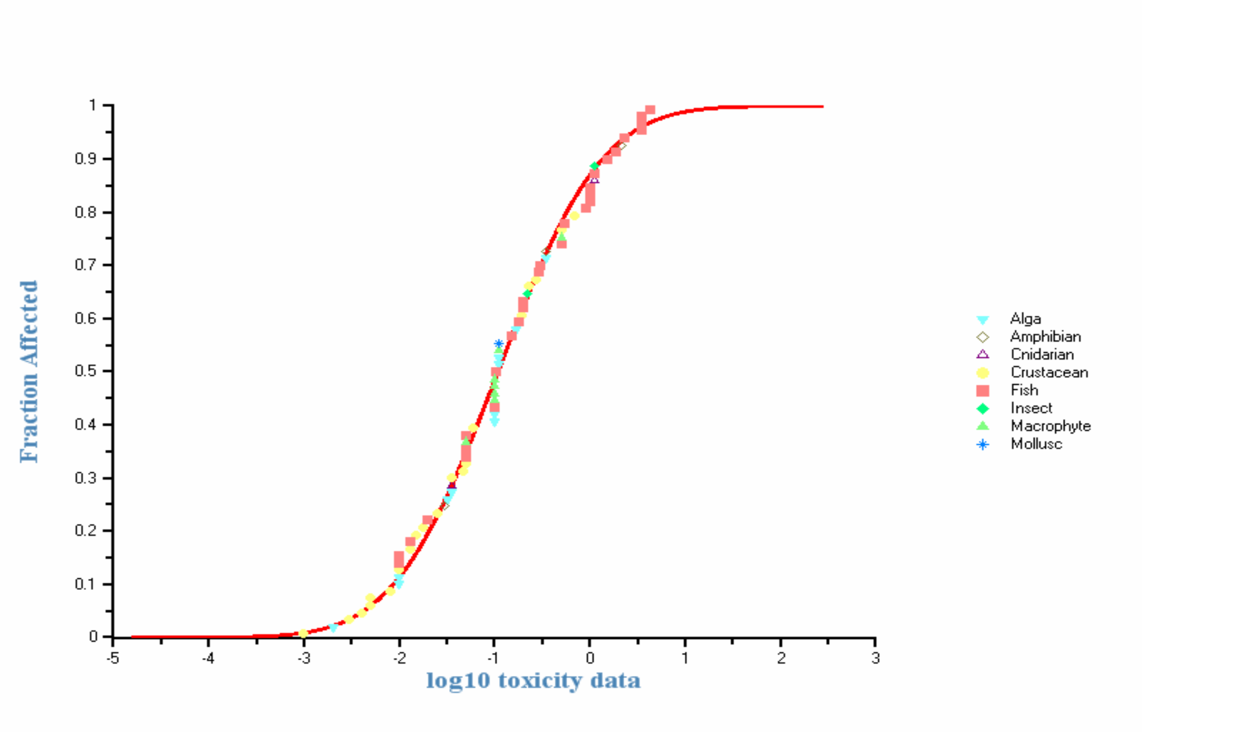


Figure 2.3 Cumulative distribution function of freshwater short-term data (mg l^{-1}) for Cr(VI)

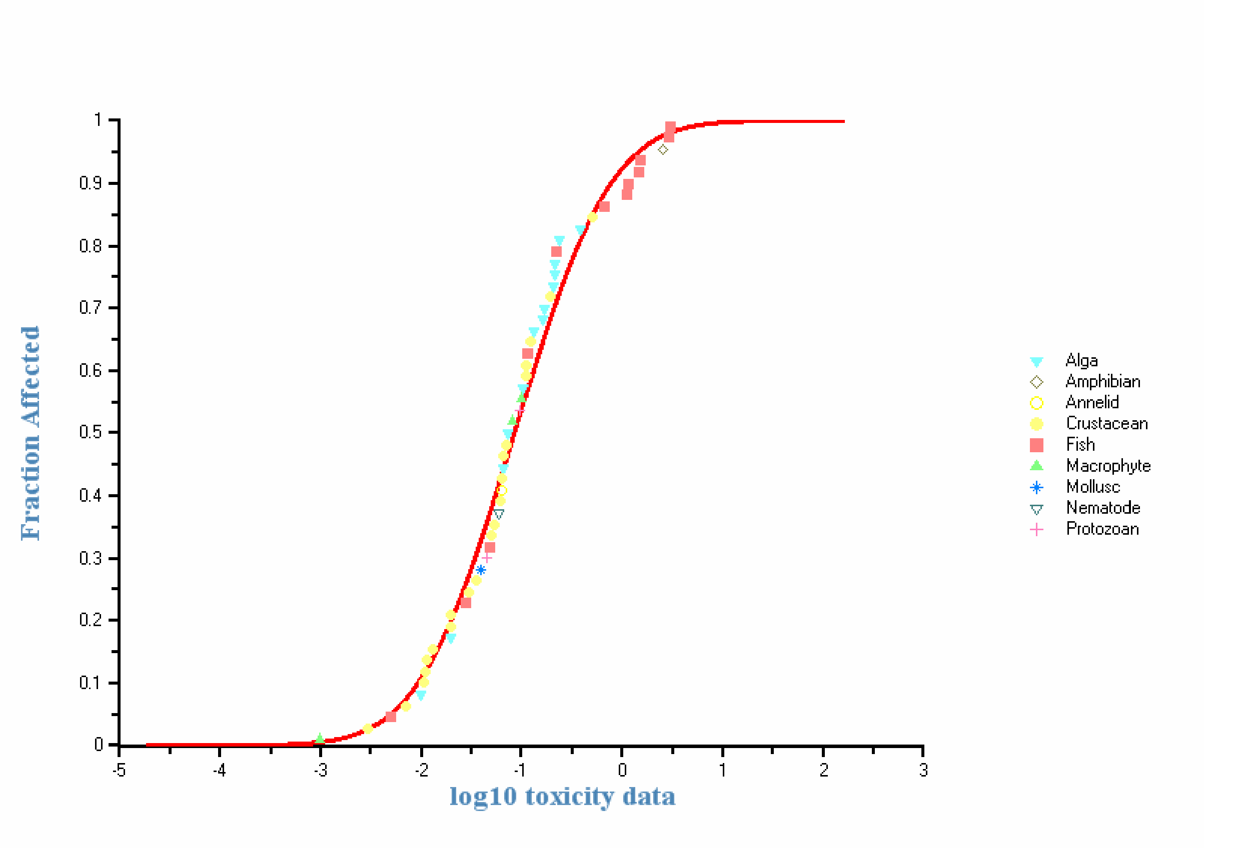


Figure 2.4 Cumulative distribution function of freshwater long-term data (mg l^{-1}) for Cr(III)

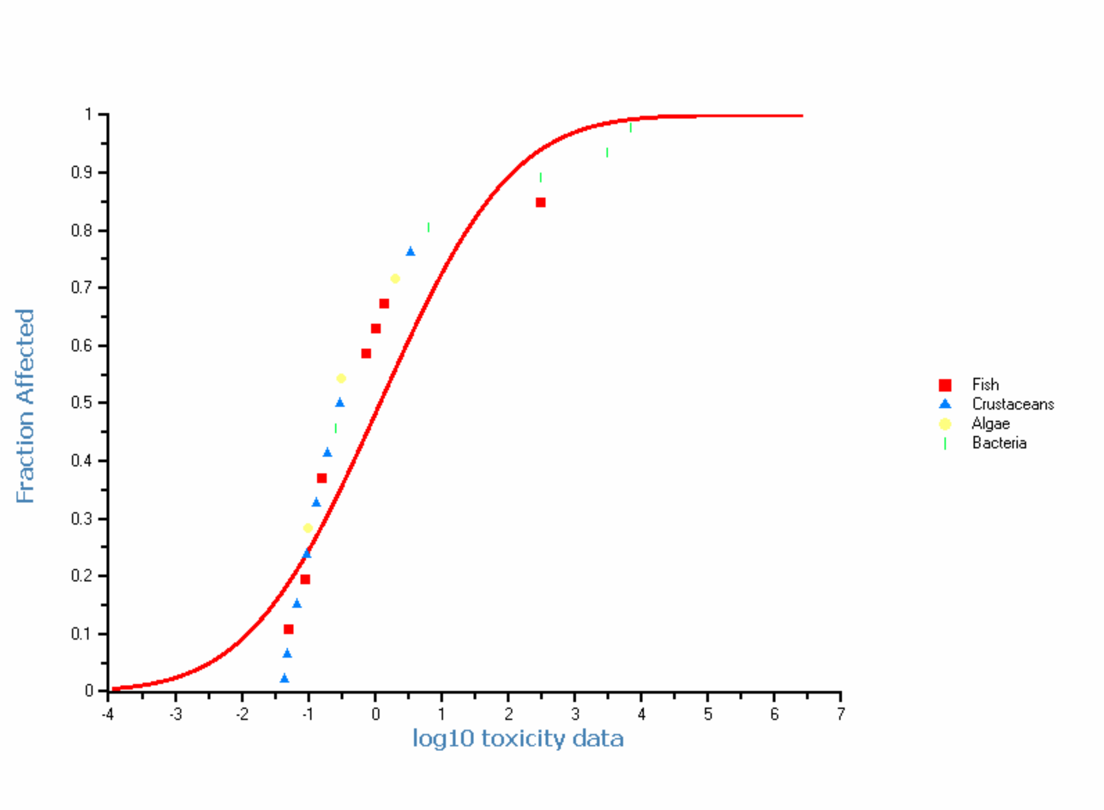


Figure 2.5 Cumulative distribution function of freshwater short-term data (mg l^{-1}) for Cr(III)

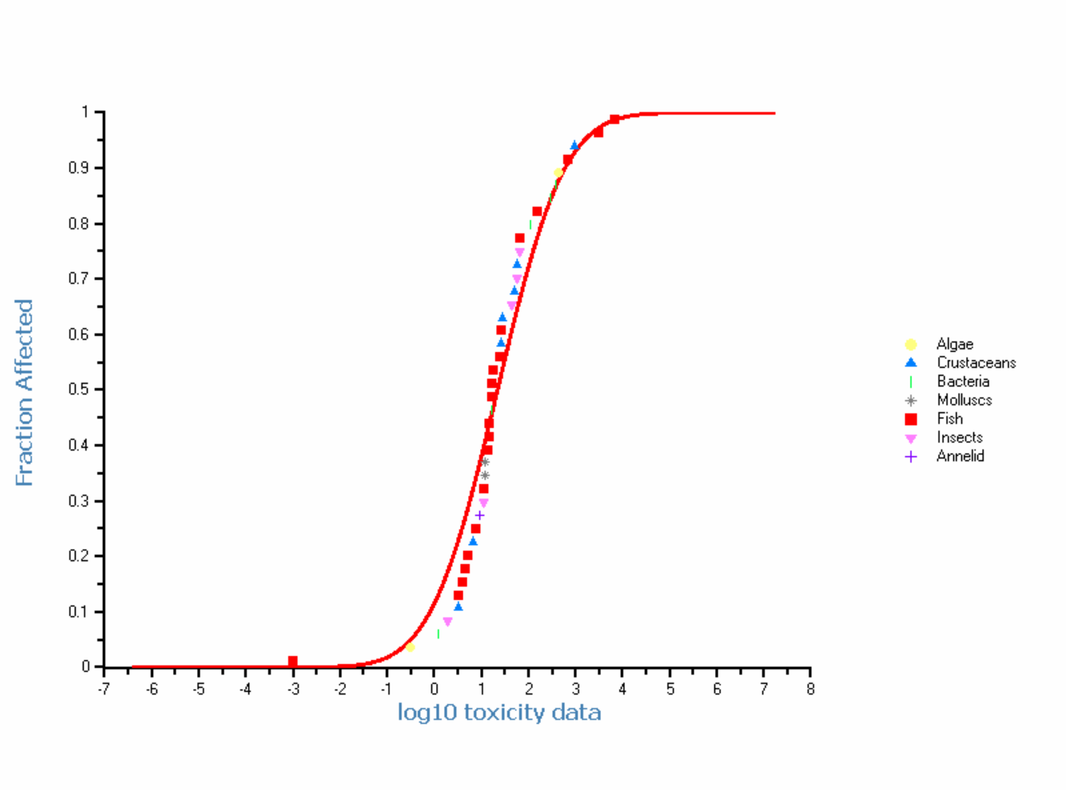


Table 2.11 Most sensitive long-term aquatic toxicity data for freshwater organisms exposed to Cr(VI)

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Exposure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Algae											
Cr^{6+} (Na_2CrO_4)	*Chlorella pyrenoidosa*	Green alga	Algae	NOEC	Biomass	96 hours	0.100	s	n		[104] EU RAR (II)
Cr^{6+} (Na_2CrO_4)	*Chlorella* sp. (wild)	Green alga	Algae	NOEC	Biomass	96 hours	0.100	s	n		[104] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Chlorella* sp.	Green alga	Algae	NOEC	Nitrogen content	44 hours	0.035	s	stock solution only	25°C	[61] KC 3
Cr (K_2CrO_4)	*Glaucocystis nostochinearum*	Green alga	Algae	NOEC	Carotenoids/ protein content/ nitrase reduction	7 days	0.010	s	n	25°C	[129] KC 3
Cr^{6+} ($K_2Cr_2O_7$)	*Microcystis aeruginosa*	Blue-green alga	Algae	NOEC	Growth rate log phase	96 hours	0.350	s	n	23°C	[142] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Microcystis aeruginosa*	Blue-green alga	Algae	NOEC	Biomass	8 days	0.002	s	n	pH 7	[26] EU RAR (IIIb)
Cr^{6+} ($K_2Cr_2O_7$)	*Microcystis aeruginosa*	Blue-green alga	Algae	EC50	Chlorophyll	7 days	0.211			pH 8.1–8.3	[73] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Scenedesmus pannonicus*	Green alga	Algae	NOEC	Biomass log phase	96 hours	0.110	s	n	23°C	[142] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Scenedesmus subspicatus*	Green alga	Algae	EC10	Biomass log phase	72 hours	0.032	s	n	pH 8; 24°C	[91] EU RAR (I)
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	EC10	Growth rate log phase	72 hours	0.11	batch	n	pH 8; 25°C; hardness 24 mg l^{-1} $CaCO_3$	[114] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	EC10	Growth rate log phase	72 hours	0.01	batch	n	pH 8.1; 24–26°C	[37, 38] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	NOEC	Biomass	72 hours	0.100			pH 7.3–10.1; 24°C	[39] ECOTOX database KC 4

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Exposure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Higher plants											
Cr	*Hydrilla verticillata*	Hydrilla	Macrophytes		Biomass	21 days	0.050	s	n	pH 6.5; 25°C	[141] ECOTOX database KC 4
Cr^{6+} ($K_2Cr_2O_7$)	*Lemna minor*	Duckweed	Macrophytes	NOEC	Growth	7 days	0.11	s	n	25°C	[142] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Lemna minor*	Duckweed	Macrophytes	LOEC	Growth inhibition	14 days	0.100	ss	stock solution only	Tests carried out in nutrient solution	[143] KC 3
Cr (Na_2CrO_4)	*Lemna gibba*	Duckweed	Macrophytes	NOEC	Growth biomass	8 days	0.100	s		pH 6.9–7.7; 17°C (air)	[147] EU RAR (IIIb)
Cr^{6+} ($K_2Cr_2O_7$)	*Lemna gibba*	Duckweed	Macrophytes	NOEC	Growth inhibition	14 days	0. 100	ss	stock solution only	Tests carried out in nutrient solution	[143] KC 3
Cr (Na_2CrO_4)	*Spirodela polyrhiza*	Large duckweed	Macrophytes	NOEC	Growth	8 days	0.100	s		pH 6.9–7.7; 17°C (air)	[147] EU RAR (IIIb)
Cr (Na_2CrO_4)	*Spirodela punctata*	Duckweed	Macrophytes	NOEC	Growth	8 days	0.500			pH 6.9–7.7; 17°C (air)	[147] EU RAR (IIIb)
Invertebrates											
Cr^{6+} ($K_2Cr_2O_7$)	*Asellus aquaticus*	Isopod	Crustaceans	LC50	Mortality	10 days	0.51	f	y	pH 7.6–8.4; 12°C	[186] KC 3
Cr^{6+} ($K_2Cr_2O_7$)	*Ceriodaphnia dubia*	Water flea	Crustaceans	NOEC	Reproduction	7 days	0.0047		y	Geometric mean of 18 ring tests	[46] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Ceriodaphnia dubia*	Water flea	Crustaceans	NOEC	Survival	7 days	0.0084		y	Geometric mean of 18 ring tests	[46] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Ceriodaphnia dubia*	Water flea	Crustaceans	IC50	Reproduction	7 days	0.013	ss	y		[46] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia carinata*	Water flea	Crustaceans	NOEC	Reproduction	14 days	0.050	ss	n	pH 7.9; 20°C; hardness 250 mg l^{-1} $CaCO_3$	[75] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	NOEC	Mortality/ reproduction	21 days	0.018	ss	y	pH 8; 25°C; hardness 16 mg l^{-1} $CaCO_3$	[93] EU RAR (I)
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	NOEC	Mortality/ reproduction	21 days	0.035	ss	n	19°C	[142] EU RAR (II)

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Exposure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	NOEC	Growth	21 days	0.060	ss	y	pH 8.1; hardness 225 mg l^{-1} $CaCO_3$	[166] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	NOEC	Reproduction	14 days	0.025	ss	n	pH 7.9; 20°C; hardness 250 mg l^{-1} $CaCO_3$	[75] EU RAR (II)
Total Cr ($Na_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	NOEC	Reproduction/ growth	21 days	0.0125	ss	n	20°C; ASTM hard water	[49] KC 2
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	NOEC	Survival/ growth/ reproduction	63 days	0.0035	ss	stock solution only	pH 7.7; 20°C; hardness 200 mg l^{-1} $CaCO_3$	[66] KC 2
Cr^{6+}	*Daphnia magna*	Water flea	Crustaceans	NOEC	Survival	14 days	0.015	s	n	pH 8; 23°C; hardness 240 mg l^{-1} $CaCO_3$	[52] EU RAR (IIIb)
Cr ($Na_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	NOEC	Reproduction	14 days	0.0005	s	n	pH 8; 23°C; hardness 240 mg l^{-1} $CaCO_3$	[52] EU RAR (II)
Cr^{6+} ($NaCrO_4$)	*Daphnia magna*	Water flea	Crustaceans	NOEC	Survival/ reproduction	28 days	<0.010	ss	y	pH 8–8.5; 21°C	[153] EU RAR (IV)
Cr^{6+} ($Na_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	MATC	Reproduction	14 days	0.0025	f	y	pH 7.3–7.4; 25°C; hardness 45 mg l^{-1} $CaCO_3$	[108] ECOTOX database KC 4
Cr	*Daphnia magna*	Water flea	Crustaceans	LC100	Mortality	21 days	0.005	s	n	pH 7.6–7.8; 21°C; hardness 63.3–66.5 mg l^{-1} $CaCO_3$	[110] ECOTOX database KC 4
Cr^{6+} Cr	*Daphnia magna*	Water flea	Crustaceans	LC50	Mortality	7 days	0.0113	f	n	pH 7.2–7.4; 25°C; hardness 45 mg l^{-1} $CaCO_3$	[109] [185]
Cr^{6+} ($K_2Cr_2O_7$)	*Moina macrocopa*	Water flea	Crustaceans	LT50	Mortality	9.43 days	0.020	s	n	pH 6.5–7; 24–27°C	[176] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Gammarus fossarum*	Amphipod	Crustaceans	LC50	Mortality	10 days	0.19	f	y	pH 7.6–8.4; 12°C	[186] KC 3
Cr^{6+} ($K_2Cr_2O_7$)	*Mesocyclops pehpeiensis*	Copepod	Crustaceans	EC50	Larval development	9 days	0.268	ss	n	25°C	[175] KC 2

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Exposure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Cr^{6+} ($K_2Cr_2O_7$)	*Niphargus rhenorhodanensis*	Amphipod	Crustaceans	LC50	Mortality	10 days	0.23	f	y	pH 7.6–8.4; 12°C	[186] KC 3
Cr^{6+} ($K_2Cr_2O_7$)	*Culex pipiens*	Mosquito	Insects	NOEC	Survival/ growth 1st instar	25 days	1.1	ss	n	27°C	[142] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Heptagenia sulphurea*	Mayfly	Insects	LC50	Mortality	10 days	0.22	f	y	pH 7.6–8.4; 12°C	[186] KC 3
Cr^{6+} ($K_2Cr_2O_7$)	*Hydra littoralis*		Coelenterates	Threshold	Reproduction	11 days	0.035	ss		pH 8.15	[45] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Hydra oligactis*		Coelenterates	NOEC	Growth rate	21 days	1.100	ss	n	18°C	[142] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Lymnaea stagnalis*	Snail	Molluscs	NOEC	Reproduction budless	40 days	0.110	ss	n	20°C	[142] EU RAR (II)
Vertebrates (fish and amphibians)											
Cr^{6+} ($Na_2Cr_2O_7$)	*Catostomus commersoni*	White sucker	Fish	NOEC	Growth eggs/fry	60 days	0.29	f	y	pH 6.9–7.2; 17°C; hardness 38.5 mg l^{-1} $CaCO_3$	[137] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Cyprinus carpio*	Carp	Fish	LC100	Mortality adult	42 days	1.00	f	y	pH 7.8; 15.5°C; hardness 206.9 mg l^{-1} $CaCO_3$	[118] KC 4
Cr^{6+} ($Na_2Cr_2O_7$)	*Esox lucius*	Northern pike	Fish	NOEC	Mortality Eggs/fry	20 days	0.538	f	y	pH 6.7–7; 17°C; hardness 37.8 mg l^{-1} $CaCO_3$	[137] EU RAR (IIIb)
Cr^{6+} ($Na_2Cr_2O_7$)	*Ictalurus punctatus*	Channel catfish	Fish	NOEC	Growth eggs/fry	30 days	0.15	f	y	pH 7.9–8.1; 22°C; hardness 36.2 mg l^{-1} $CaCO_3$	[137] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Ictalurus punctatus*	Channel catfish	Fish	LC50	Mortality 4 weeks	30 days	1.5	s	y	pH 7–7.4; 23–26°C; hardness[4] 88–108 mEq l^{-1}	[64]
Cr^{6+} ($K_2Cr_2O_7$)	*Nuria danrica*	Channelfish	Fish	LC50	Mortality adult	20 days	0.304	s	n	pH 6.1–6.3; hardness 4–5 mg l^{-1} $CaCO_3$	[2] ECOTOX database, [185] KC 4

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Exposure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Cr^{6+} ($Na_2Cr_2O_7$)	*Oncorhynchus mykiss*	Rainbow trout	Fish	NOEC	Growth eggs/fry	60 days	0.051	f	y	pH 6.7–7; 10°C; hardness 33.4 mg l^{-1} $CaCO_3$	[137] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Oncorhynchus mykiss*	Rainbow trout	Fish	NOEC	Growth Alevin-juvenile	8 months	0.10	f	y	pH 7.8; 7–15°C; hardness 42 mg l^{-1} $CaCO_3$	[17] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Oncorhynchus mykiss*	Rainbow trout	Fish	NOEC LOEC	Growth fry	110 days	0.013 0.020	f	y	pH 7.6–8.2; 13–19°C; hardness 70 mg l^{-1} $CaCO_3$	[117] ECOTOX database KC 4
Cr^{6+} ($Na_2Cr_2O_4$)	*Oncorhynchus mykiss*	Rainbow trout	Fish	NOEC	Mortality eyed eggs	244 days	0.020	f	y	pH 6.5–7.8; 12°C; hardness 80 mg l^{-1} $CaCO_3$	[164, 165] EU RAR (IIIb)
Cr^{6+} (CrO_3)	*Oncorhynchus mykiss*	Rainbow trout	Fish	LC50	Mortality embryo-larval	28 days	0.180	ss	y	pH 7.2–7.8; 12–13°C; hardness 104 mg l^{-1} $CaCO_3$	[19, 20] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Oncorhynchus mykiss*	Rainbow trout	Fish		Biochemical alterations in liver – adults	180 days	0.200	f	y	pH 7.4; 15°C; hardness 320 mg l^{-1} $CaCO_3$	[12] KC 4
Cr^{6+} ($Na_2Cr_2O_7$)	*Oncorhynchus tshawytscha*	Chinook salmon	Fish	NOEC LOEC	Growth egg	7 months	0.010 0.016	f	y	pH 7.6–8.2; 3.5–13.5°C; hardness 70 mg l^{-1} $CaCO_3$	[117] ECOTOX database KC 4
Cr^{6+} ($K_2Cr_2O_7$)	*Oryzias latipes*	Medaka	Fish	NOEC	Mortality Embryo/ larvae	40 days	3.5	ss	n	23°C	[142] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	NOEC	Growth larvae	30 days	0.050	f	y	pH 7.8; 25°C; hardness 220 mg l^{-1} $CaCO_3$	[27] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	NOEC	Growth larvae	7 days	1.10			Median of results of ring test	[47] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	LOEC	Growth larvae	28 days	1.86	f	y	pH 8.17; 25°C	[15] KC 4
Cr^{6+} ($K_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	NOEC	Survival 4-week juvenile	412 days	1.0	f	y	pH 7.5–8.2; 13–27°C; hardness 209 mg l^{-1} $CaCO_3$	[123] EU RAR (II)

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Exposure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Cr^{6+} ($Na_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	MATC	Mortality/ Reproduction 30 days/0.15 g	32 days	2.27	f	y	pH 7.4; 25°C; hardness 43.9 mg l^{-1} $CaCO_3$	[146] [185] KC 4
Cr^{6+} ($Na_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	LC50	Mortality juvenile	30 days	4.36	f	y	pH 7.8; 25°C; hardness 220 mg l^{-1} $CaCO_3$	[27] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	LC50	Mortality 3–14 days	30 days	0.900	s	y	pH 7–7.4; 23–26°C; hardness[4] 88–108 mEq l^{-1}	[64] KC 2
Cr^{6+} ($K_2Cr_2O_7$)	*Poecilia reticulata*	Guppy	Fish	NOEC	Mortality 3–4 weeks	28 days	3.5	ss	n	23°C	[142] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Salmo salar*	Atlantic salmon	Fish	MATC	Mortality eyed egg swim-up fry	113 days	0.010	ss	n	pH 6.3; 3–10°C; hardness 11 mg l^{-1} $CaCO_3$	[68] [185] KC 4
Cr^{6+} ($K_2Cr_2O_7$)	*Salmo trutta*	Brown trout	Fish	NR	Reduction body weight >1 year	266 days	1.01	f	y	pH 7.8; 15.5°C; hardness 207 mg l^{-1} $CaCO_3$	[118] [185] KC 4
Cr^{6+} ($Na_2Cr_2O_7$)	*Salvelinus fontinalis*	Brook trout	Fish	NOEC	Growth	8 months	0.01	f	y	pH 7–8; 7–15°C; hardness 45 mg l^{-1} $CaCO_3$	[17] EU RAR (II) KC 2
Cr^{6+} ($Na_2Cr_2O_7$)	*Salvelinus namaycush*	Lake trout	Fish	NOEC	Growth eggs/fry	60 days	0.105	f	y	pH 6.8–7.1; 10°C; hardness 34 mg l^{-1} $CaCO_3$	[137] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Wallago attu*	Wallago	Fish	NOEC	Mortality	35 days	0.500	s	n		[3] KC 4
Cr^{6+} ($K_2Cr_2O_7$)	*Xenopus laevis*	Clawed toad	Amphibians	NOEC	Mortality tadpole <2 days	100 days	0.350	ss	n	20°C	[142] EU RAR (II)

[1] Exposure: s = static; ss = semi-static; f = flow-through. [2] Toxicant analysis: y = measured; n = not measured. [3] Descriptions of the Validity Criteria used in the EU RAR and shown here in parenthesis and Klimisch Criteria (KC) used to quality assess other data are given in Tables 2.9 and 2.10, respectively. [4] Where 100 mg l^{-1} Ca = 4.99 mEq l^{-1}.

NOEC = no observed effect concentration; LOEC = lowest observed effect concentration; MATC = maximum allowable toxicant concentration

ECx = concentration effective against X% of the organisms tested; LCx = concentration lethal to X% of the organisms tested

IC50 = concentration at which the population effect of the organisms tested is inhibited by 50%

LT50 = exposure time at which the test concentration is lethal to 50% of the organisms tested

NR = not reported

Table 2.12 Most sensitive short-term aquatic toxicity data for freshwater organisms exposed to Cr(VI)

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})[1]	Exposure[2]	Toxicant analysis[3]	Comments	Reference/ Source[4]
Algae and microbes											
Cr^{6+} ($K_2Cr_2O_7$)	*Anacystis aeruginosa*	Blue-green alga	Algae	EC50	Growth	96 hours	0.389	s	n	pH 7.8; 23°C	[4] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Chlorella vulgaris*	Green alga	Algae	EC50	Abundance	72 hours 96 hours	0.120 0.160	ss	n	20°C	[57] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Drepanomonas revoluta*		Protozoans	LC50	Mortality	24 hours	0.046	s	n	pH 7.3; 20°C	[97] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Euglena gracilis*	Flagellate	Algae	IC50	Cellular proliferation	96 hours	0.166	s	y	24°C	[134] KC 2
Cr^{6+} ($K_2Cr_2O_7$)	*Nitzschia linearis*	Diatom	Algae	EC50	Biomass	5 days	0.208	s	n	Soft water	[122] EU RAR (IIIa)
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	EC50	Population change	72 hours	<u>0.0657</u>	ss		24°C	[128] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	EC50	Population growth	72 hours	<u>0.0743</u>	ss	n	24°C	[16] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	EC50	Growth rate log phase	72 hours	<u>0.233</u>	batch	n	pH 8.1; 24–26°C	[37, 38] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	EC50	Growth	72 hours	**0.104**			**Geometric mean**	
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	EC50	Population growth	96 hours	0.170	s	n	24°C	[76] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum capricornutum*	Green alga	Algae	EC50	Biomass	96 hours	0.217		y	pH 5.6–8.9	[187] EU RAR (II)
Cr^{6+} (Cr)	*Selenastrum capricornutum*	Green alga	Algae	NOEC	Carbon uptake	4 hours	0.020	s	n		[126] [185]
Cr^{6+} ($K_2Cr_2O_7$)	*Selenastrum subspicatus*	Green alga	Algae	EC50	Biomass log phase	72 hours	0.130	s	n	pH 8; 24°C	[91] EU RAR (I)

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})[1]	Exposure[2]	Toxicant analysis[3]	Comments	Reference/ Source[4]
Cr^{6+} ($K_2Cr_2O_7$)	*Spirulina platensis*	Blue-green alga	Algae		Photosynthesis	6 hours	0.010	s	n	27°C	[14] KC 3
Higher plants											
Cr^{6+} (K_2CrO_4)	*Hydrilla verticillata*	Hydrilla	Macrophytes	NOEC LOEC	Peroxidase activity	5 days	0.001 0.010			pH 6; 25°C	[31] KC 3
Cr^{6+} ($K_2Cr_2O_7$)	*Lemna minor*	Duckweed	Macrophytes	EC50	Growth	7–10 days	0.080	s	n	pH 8; 25°C; hardness 249.6 mg l^{-1} $CaCO_3$	[188] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Nelumbo lutea*	Yellow lotus	Macrophytes	LOEC? *P*<0.05	Growth	96 hours	0.100			pH 8.2	[59] ECOTOX database
Invertebrates											
Cr	*Anodonta imbecillis*	Mussel	Molluscs	LC50	Mortality	96 hours	0.039	s	n	23°C; hardness 39 mg l^{-1} $CaCO_3$	[189] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Caenorhabditis elegans*	Round worm	Nematodes	LC50	Mortality	96 hours	0.060	s	n	20°C	[190] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Ceriodaphnia dubia*	Water flea	Crustaceans	EC50	Immobilisation	24 hours	0.053	s	n	pH 7.9; 20°C; hardness 250 mg l^{-1} $CaCO_3$	[75] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Ceriodaphnia reticula*	Water flea	Crustaceans	EC50	Immobilisation	48 hours	0.195	s	n	pH 8; 23°C; hardness 240 mg l^{-1} $CaCO_3$	[52] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Ceriodaphnia* sp.	Water flea	Crustaceans	EC50	Immobilisation	48 hours	0.030	s	y	Hardness 40–48 mg $CaCO_3$ l^{-1}	[191] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	EC50	Immobilisation	24 hours	0.003	s	n	pH 8; 20°C	[192] EU RAR (IIIa)
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	EC50	Immobilisation	48 hours	<u>0.035</u>	s	y	pH 8.3; 20°C; hardness 240 mg l^{-1} $CaCO_3$	[148] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	EC50	Immobilisation	48 hours	<u>0.112</u>	s	n	pH 8; 23°C; hardness 240 mg l^{-1} $CaCO_3$	[52] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	LC50	Mortality	48 hours	<u>0.105</u>	s	y	pH 7.8; hardness 170 mg l^{-1} $CaCO_3$	[193] KC 2

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})[1]	Exposure[2]	Toxicant analysis[3]	Comments	Reference/ Source[4]
Cr^{6+} ($Na_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	LC50	Mortality	48 hours	0.011	s	n	23°C	[194] ECOTOX database
Cr^{6+} ($Na_2Cr_2O_7$)	*Daphnia magna*	Water flea	Crustaceans	LC50	Mortality/ immobilisation	48 hours	**0.046**			**Geometric mean**	
Cr^{6+} ($NaCrO_4$)	*Daphnia magna*	Water flea	Crustaceans	LC50	Mortality	96 hours	0.050	s	y	pH 8–8.5; 21°C	[153] EU RAR (II)
Cr^{6+} (K_2CrO_4)	*Daphnia magna*	Water flea	Crustaceans	EC50	Immobilisation	96 hours	0.007	s	y	pH 7.2–8; 20°C; hardness 45.4–54.6 mg l^{-1} $CaCO_3$	[33] EU RAR (IIIa)
Cr^{6+} ($K_2Cr_2O_7$)	*Daphnia pulex*	Water flea	Crustaceans	EC50	Immobilisation	48 hours	0.063	s	y	hardness 40–48 mg l^{-1} $CaCO_3$	[191] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Daphnia pulex*	Water flea	Crustaceans	EC50	Immobilisation	48 hours	0.122	s	n	pH 8; 23°C; hardness 240 mg l^{-1} $CaCO_3$	[52] EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_7$)	*Daphnia pulex*	Water flea	Crustaceans	EC50	Immobilisation	48 hours	**0.0877**			**Geometric mean**	
Cr^{6+} ($K_2Cr_2O_7$)	*Gammarus fasciatus*	Amphipod	Crustaceans	LC50	Mortality	96 hours	0.110	s	n	pH 6.5–8.5; 20°C; hardness 130 mg l^{-1} $CaCO_3$	[195] EU RAR (IIIb)
Cr^{6+} ($K_2Cr_2O_7$)	*Gammarus pseudolimnaeus*	Amphipod	Crustaceans	LC50	Mortality	96 hours	0.067	f	y	hardness 48 mg l^{-1} $CaCO_3$	[33] EU RAR (IIIa)
Cr^{6+}	*Gammarus pulex*	Amphipod	Crustaceans	LC50	Mortality	96 hours	0.070 0.110	s		pH 7.5–8; 13°C; hardness 88–99 mg l^{-1} $CaCO_3$ hardness 236–268 mg l^{-1} $CaCO_3$	[196] [185]
Cr^{6+} ($K_2Cr_2O_7$)	*Mesocyclops pehpeiensis*	Copepod	Crustaceans	LC50	Mortality	48 hours	0.510	s	n	25°C	[175] KC 2
Cr^{6+} ($K_2Cr_2O_7$)	*Moina australiensis*	Water flea	Crustaceans	EC50	Immobilisation	48 hours	0.020	s	y	pH 7.8; 23°C; hardness 36 mg l^{-1} $CaCO_3$	[194] KC 2
Cr^{6+} ($K_2Cr_2O_7$)	*Streptocephalus proboscideus*	Fairy shrimp	Crustaceans	LC50	Mortality	24 hours	0.061	s		pH 6.4–6.6; 30°C; hardness 8–10 mg l^{-1} $CaCO_3$	[198] ECOTOX database

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})[1]	Exposure[2]	Toxicant analysis[3]	Comments	Reference/ Source[4]
Cr^{6+} ($K_2Cr_2O_7$)	*Tubifex tubifex*	Bloodworm	Annelids	LC50	Mortality	48 hours	0.063	ss		pH 6.3; 20°C; hardness 0.1 mg l^{-1} $CaCO_3$	[199] ECOTOX database
Fish											
Cr^{6+} (CrO_3)	*Carassius auratus*	Goldfish	Fish	LC50	Mortality embryo-larval	7 days	0.660	ss	y	pH 7.4; 22°C; hardness 195 mg l^{-1} $CaCO_3$	[19] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Lepomis macrochirus*	Bluegill	Fish	LC50	Mortality	96 hours	0.113	s	n	Soft water	[32] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Lepomis macrochirus*	Bluegill	Fish	LC50	Mortality	96 hours	0.135	s	n	Hard water	[32] ECOTOX database
Cr^{6+} (CrO_3)	*Micropterus salmoides*	Largemouth bass	Fish	LC50	Mortality embryo-larval	8 days	1.17	ss	y	pH 7.2–7.8; 19–22°C; hardness 93–105 mg l^{-1} $CaCO_3$	[20] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Odonthestes bonariensis*	Silverside	Fish	LC50	Mortality	96 hours	1.46	ss	y	pH 7.4; 22°C; hardness 215 mg l^{-1} $CaCO_3$	[34] KC 2
Cr^{6+} ($Na_2Cr_2O_4$)	*Oncorhynchus mykiss*	Rainbow trout	Fish	LC50	Mortality 10–30 g	72 hours	0.220		n	pH 6.9; 12°C; hardness 1.5 mg l^{-1} $CaCO_3$	[77] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Oncorhynchus mykiss*	Rainbow trout	Fish	LOEC	Avoidance yearling	30 min	0.028	f	y	pH 7.2; 14.5°C; hardness 100 mg l^{-1} $CaCO_3$	[10] [185]
Cr^{6+} ($K_2Cr_2O_7$)	*Oncorhynchus mykiss*	Rainbow trout	Fish	-	Reduction in fertilisation	40 min	0.005	s	y	10°C	[18] KC 2
Cr^{6+} ($Na_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	NOEC	Growth larvae	7 days	2.94–3.19	ss f	n	hardness 44–49 mg l^{-1} $CaCO_3$	[113] ECOTOX database
Cr^{6+} Cr	*Pimephales promelas*	Fathead minnow	Fish	NOEC	Growth <24 hours	7 days	3.0	ss	n	pH 8.1–8.3; hardness 175 mg l^{-1} $CaCO_3$	[124] [185]
Cr^{6+} ($K_2Cr_2O_7$)	*Pimephales promelas*	Fathead minnow	Fish	NOEC	Growth (dry wt) larvae	7 days	1.5	ss	n	pH 8–8.5; 25°C; hardness 94–184 mg l^{-1} $CaCO_3$	[125] ECOTOX database

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})[1]	Exposure[2]	Toxicant analysis[3]	Comments	Reference/ Source[4]
Cr	*Bufo melanostictus*	Common Indian toad	Amphibians	LC50	Mortality tadpole	96 hours	2.52	s	n	pH 8.2; 28°C	[200] ECOTOX database

[1] Data used for calculation of a geometric mean are underlined; geometric means are highlighted in bold.
[2] Exposure: s = static; ss = semi-static; f = flow-through.
[3] Toxicant analysis: y = measured; n = not measured.
[4] Descriptions of the Validity Criteria used in the EU RAR and shown here in parenthesis and Klimisch Criteria (KC) used to quality assess other data are given in Tables 2.9 and 2.10, respectively.
NOEC = no observed effect concentration
LOEC = lowest observed effect concentration
EC50 = concentration effective against 50% of the organisms tested
LC50 = concentration lethal to 50% of the organisms tested
IC50 = concentration at which the population effect of the organisms tested is inhibited by 50%

Table 2.13 Most sensitive aquatic toxicity data for fish exposed to Cr(III) (as taken from the EU RAR)**

Species	Method	Chemical tested	Hardness (mg/l)	Endpoint (mg Cr/l)	Reference
FISH - freshwater - short-term (48-96h) studies					
Anguilla rosttrata (American eel)	S; M	-	55	LC_{50} = 13.9	Rehwoldt et al, 1973
Brachydanio rerio (zebra fish)	N	Dichromium trioxide	-	96h-NOEC >6,840	IUCLID, 1999
	M	Dichromium trioxide	-	96h-NOEC >0.001*	
Brachydanio rerio (zebra fish)	SS	Chromium hydroxide sulphate	-	96h-NOEC >3,130	IUCLID, 1999
Carassius auratus (goldfish)	S; N	Chromium potassium sulphate	20	96h-LC_{50} = 4.1	Pickering and Henderson, 1966
Fundulus diaphanus (banded killifish)	S; M	-	55	LC_{50} = 16.9	Rehwoldt et al, 1972
Cyrprinus carpio (common carp)	S; M	-	55	LC_{50} = 14.3	Rehwoldt et al, 1972
Lepomis gibbosus (pumpkinseed)	S; M	-	55	LC_{50} = 17.0	Rehwoldt et al, 1972
Lepomis macrochirus (bluegill)	S; U	Chromium potassium sulphate	20	96h-LC_{50} = 7.46	Pickering and Henderson, 1966
Leuciscus idus (ide)	N	Dichromium trioxide	-	48h-NOEC >684	IUCLID, 1999
Leuciscus idus (ide)		Chromium hydroxide sulphate	-	96h-LC_{50} = 157 (effects may have been due to pH changes)	IUCLID, 1999
Marone americana (white perch)	S; M	-	55	LC_{50} = 14.4	Rehwoldt et al, 1972
Marone saxatillis (striped bass)	S; M	-	55	LC_{50} = 17.7	Rehwoldt et al, 1972
Oncorhynchus mykiss (rainbow trout)	FT; M	Chromic nitrate		LC_{50} = 24.1	Hale, 1977
Oncorhynchus mykiss (rainbow trout)	S; N	Chromic chloride	44	LC_{50} = 11.2	Bills et al, 1977; Markin, 1982.
Oncorhynchus mykiss (rainbow trout)	FT; M	Chromic nitrate	26	LC_{50} = 4.4	Stevens and Chapman, 1984
Pimephales promelas (fathead minnow)	S; U	Chromium potassium sulphate	20	96h-LC_{50} = 5.07	Pickering and Henderson, 1966
			360	96h-LC_{50} = 67.4	
Pimephales promelas (fathead minnow)	FT; M	Chromium potassium sulphate	203	LC_{50} = 27-29	Pickering (unpublished)
Poecillia reticulata (guppy)	S; N	Chromium potassium sulphate	20	96h-LC_{50} = 3.33	Pickering and Henderson, 1966

Table 2.13 (continued) Most sensitive aquatic toxicity data for fish exposed to Cr(III) (as taken from the EU RAR)**

Species	Method	Chemical tested	Hardness (mg/l)	Endpoint (mg Cr/l)	Reference
FISH - saltwater - short-term (48-96h) studies					
Fundulus heterociltus (mummichog)	S; U	Chromic chloride		LC_{50} = 31.5	Dorfman, 1977
FISH - freshwater - long-term studies					
Brachydanio rerio (zebra fish)	early life stage	Chromium hydroxide sulphate	-	30d-NOEC >313	IUCLID, 1999
Oncorhynchus mykiss (rainbow trout)	early life stage	Chromic nitrate	26	NOEC = 0.050 LOEC =0.157 MATC = 0.089	Stevens and Chapman, 1984
Pimephales promelas (fathead minnow)	life-cycle	Chromium potassium sulphate	203	NOEC = 0.75 LOEC = 1.4 MATC = 1.03	Pickering (unpublished)

Note: *effective solubility limit in the test medium
S = static test system
FT = flow-through test system
SS = semi-static test system
N = nominal concentrations
M = measured concentrations

** For details of references, see EU RAR [56].

Table 2.14 Most sensitive aquatic toxicity data for invertebrates exposed to Cr(III) (as taken from the EU RAR)**

Species	Method	Chemical tested	Hardness (mg/l)	Endpoint (mg Cr/l)	Reference
INVERTEBRATES - freshwater - short-term (48-96h) studies					
Crustaceans					
Asellus aquaticus (sowbug)	-	Chromic chloride	-	48h-EC_{50} = 937 96h-EC_{50} = 442	DOSE, 1993
Crangonyx pseudogracilis (amphipod)	-	Chromic chloride		48h-EC_{50} = 388 96h-EC_{50} = 291	DOSE, 1993
Daphnia magna (water flea)	-	Chromic chloride	-	24h-EC_{50} = 111	DOSE, 1993
Daphnia magna (water flea)	S; N	Chromic chloride	-	EC_{50} = 1.2	Anderson, 1948
Daphnia magna (water flea)	S; M	Chromic nitrate	52	EC_{50} = 16.8	Chapman et al
			92	EC_{50} = 27.4	(unpublished)
			110	EC_{50} = 26.3	
			195	EC_{50} = 51.4	
			215	EC_{50} = 58.7	
Gammarus sp. (amphipod)	S; M	-	50	EC_{50} = 3.2	Rehwoldt et al, 1973
Orconectes limosus (crayfish)	S; M	Chromic chloride	-	EC_{50} = 6.6	Boutet and Cheismemartin, 1973
Insects					
Caddis fly (unidentified)	S; M	-	50	EC_{50} = 58	Rehwoldt et al, 1973
Chironomus sp. (midge)	S; M	-	50	EC_{50} = 11.0	Rehwoldt et al, 1973
Damselfly (unidentified)	S; M	-	50	EC_{50} = 43.1	Rehwoldt et al, 1973
Ephemarella subvaris (mayfly)	S; N	Chromic chloride	44	EC_{50} = 2.0	Warnick and Bell, 1969
Hydropsyche bettoni (caddis fly)	S; M	Chromic chloride	44	EC_{50} = 64.0	Warnick and Bell, 1969
Molluscs					
Amnicola sp. (snail; embryo)	S; M	-	50	EC_{50} = 12.4	Rehwoldt et al, 1973
Amnicola sp. (snail; adult)	S; M	-	50	EC_{50} = 12.4	Rehwoldt et al, 1973
Annelids					
Neis sp. (worm)	S; M	-	50	EC_{50} = 9.3	Rehwoldt et al, 1973
INVERTEBRATES - saltwater - short-term (48-96h) studies					
Crassostrea virginica (eastern oyster)	S; U	Chromic chloride		EC_{50} = 10.3	Calabrese et al, 1973
Ophtyotrocha diadema (polychaete worm)	S	Chromic chloride	32‰	48h-EC_{50} = 100	Parker, 1984

Table 2.14 (continued) Most sensitive aquatic toxicity data for invertebrates exposed to Cr(III) (as taken from the EU RAR)**

Species	Method	Chemical tested	Hardness (mg/l)	Endpoint (mg Cr/l)	Reference
INVERTEBRATES - freshwater - long-term studies					
Daphnia magna (water flea)	life-cycle	Chromic nitrate	52	NOEC = 0.047 LOEC = 0.093 MATC = 0.066	Chapman et al (unpublished)
			100	NOEC = 0.129 LOEC = 0.291 MATC = 0.193	
			206	NOEC <0.044*	
Daphnia magna (water flea)	21-day repro.	Chromic chloride		NOEC = 3.4	Kühn et al, 1989; DOSE, 1993
INVERTEBRATES - saltwater - long-term studies					
Neanthes arenaceodentata (ragworm)	mulit-gen.	Chromic chloride		NOEC >50.4	Oshida et al, 1976 and 1981

Note: * effects were thought to be due to ingestion of precipitated chromium in particulate matter
S = static test system
FT = flow-through test system
N = nominal concentrations
M = measured concentrations

** For details of references, see EU RAR [56].

Table 2.15 Most sensitive aquatic toxicity data for algae exposed to Cr(III) (as taken from the EU RAR)*

Species	Chemical tested	Method/comment	Endpoint (mg Cr/l)	Reference
ALGAE				
Chlorella pyrenoidosa	Chromium potassium sulphate	Biomass Cell no.	5d-NOEC >2 5d-NOEC 0.1	Meisch and Schmitt-Beckmann, 1979
Selenastrum capricornutum	Chromic chloride	Biomass	96h-EC_{50} = 0.32	Greene et al, 1988
Scenedesmus subspicatus	Chromium hydroxide sulphate	Oxygen production inhibition	24h-NOEC > 0.313	IUCLID, 1999
BACTERIA				
Activated sludge	Chromium hydroxide sulphate	ISO 8192 - Inhibition of oxygen consumption	3h-NOEC >3,130	IUCLID, 1999
Azobacter vinelandii (soil bacterium)	Chromic chloride	Growth inhibition over 4 days	LOEC/NOEC ~ 0.26	Ueda et al, 1988
Fusarium oxysporum (soil fungus)	Chromic chloride	Growth inhibition over 27 hours	NOEC > 6.5	Ueda et al, 1988
Pseudomonas fluorescens	Dichromium trioxide		24h-NOEC >6,840	IUCLID, 1999
Pseudomonas fluorescens	Chromium hydroxide sulphate		24h-NOEC >313	IUCLID, 1999

Note: see Appendix VII for data on toxicity of chromium (III) to soil processes.

The toxicity data included in the tables have been largely taken from existing reviews.

* For details of references, see EU RAR [56].

2.6.2 Toxicity to saltwater organisms

Chromium(VI)

Long-term aquatic toxicity data of saltwater organisms are presented in Table 2.16. Aquatic invertebrates such as the blue mussel (*Mytilus edulis*, 12-week $NOEC_{growth}$ 4–6 µg l^{-1}) or the polychaete worm *Nereis arenaceodentata* (2-week $NOEC_{mortality}$ 6 µg l^{-1}) and the yellow rock crab (*Cancer anthonyi*, 12-week $LOEC_{mortality, hatching}$ 10 µg l^{-1}) appear to be the most sensitive organisms. Some algae species may be equally sensitive, whereas the available (sub-chronic) studies with fish indicate a lower sensitivity of this group.

Short-term toxicity data of marine biota are presented in Table 2.17. Data on the effects of hexavalent chromium compounds are available for saltwater algae, crustaceans, fish and echinoderms.

Diagrammatic representations of the available saltwater data (cumulative distribution functions) for Cr(VI) are presented in Figures 2.6 and 2.7. These diagrams include all data regardless of quality and provide an overview of the spread of the available data. These diagrams are not species sensitivity distributions and have not been used to set the chromium PNECs.

Figure 2.6 Cumulative distribution function of saltwater long-term data (mg l^{-1}) for Cr(VI)

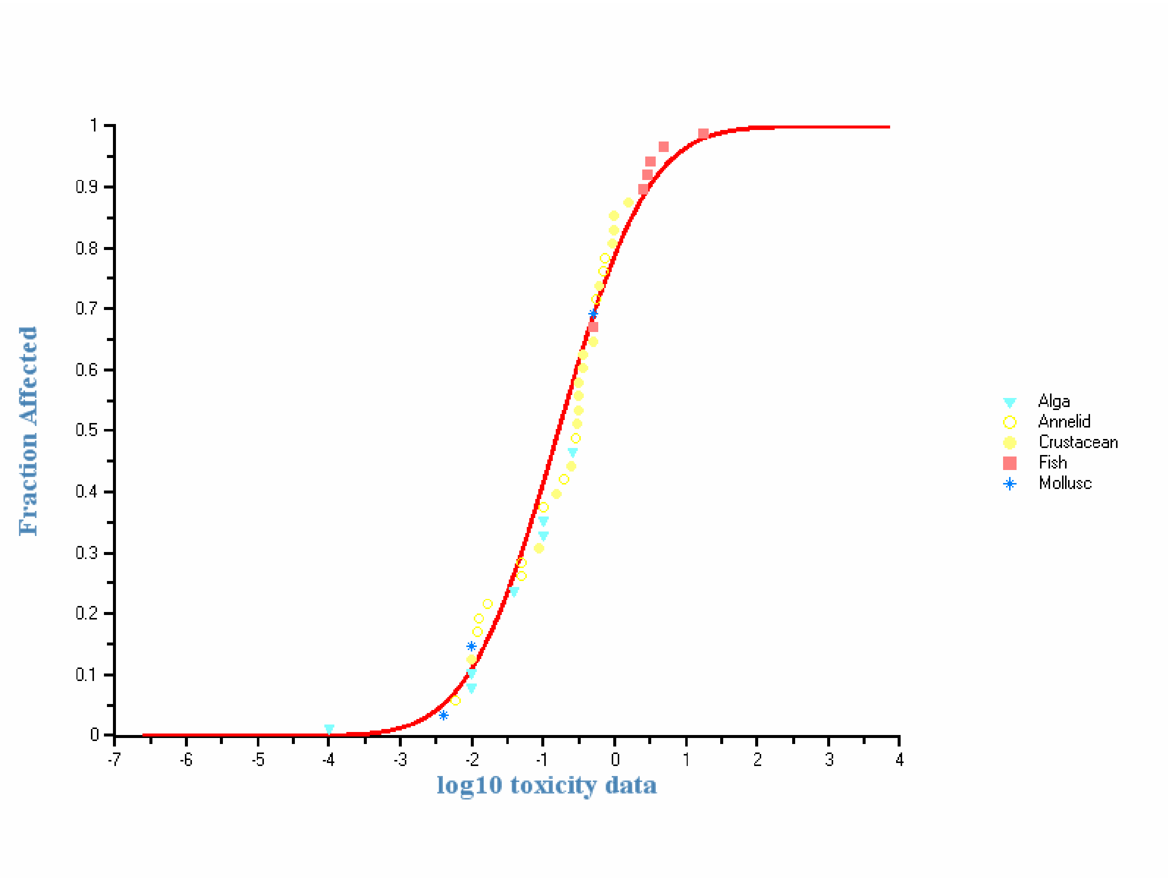
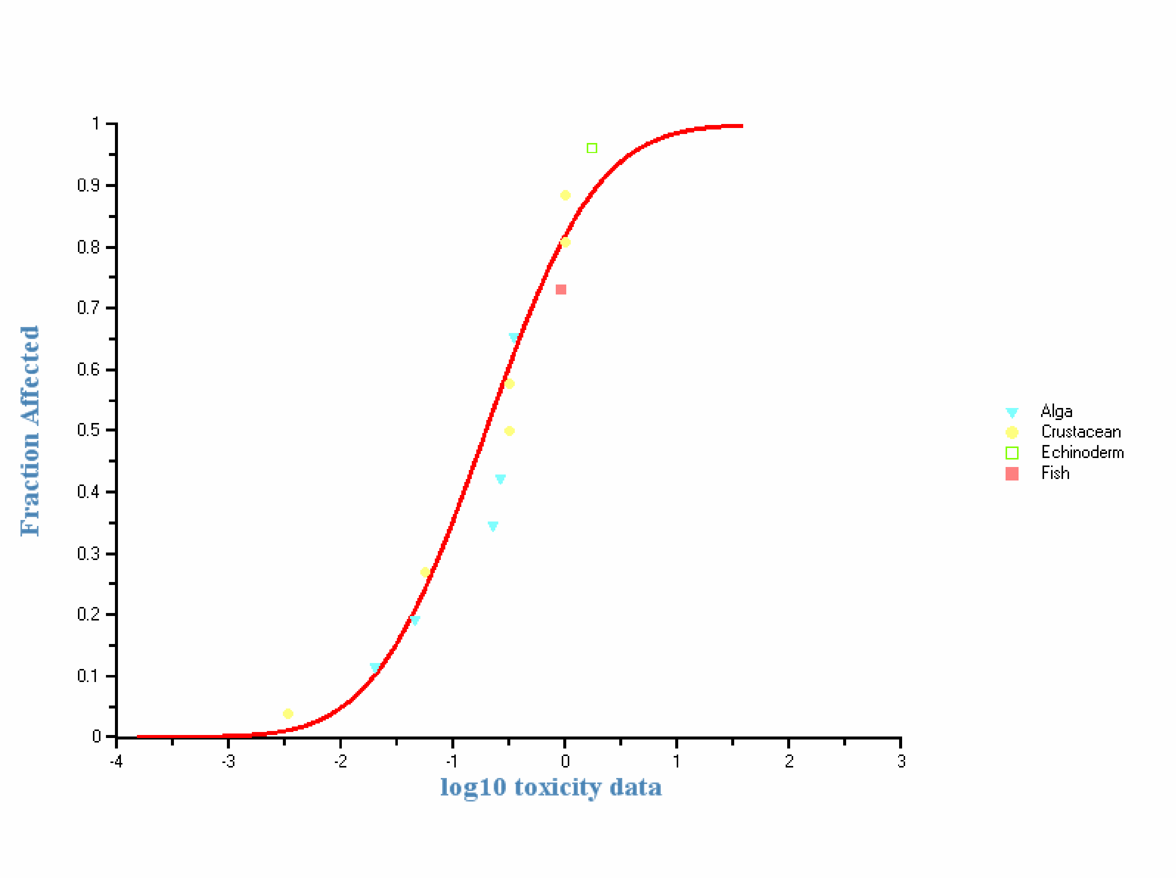


Figure 2.7 Cumulative distribution function of saltwater short-term data (mg l^{-1}) for Cr(VI)



Chromium(III)

There is only one multi-generation NOEC of >50 mg l^{-1} for the polychaete worm *Neanthes arenaceodentata* and some acute studies for other marine invertebrates and fish available (see Tables 2.13–2.15). This database is deemed insufficient to derive PNECs for saltwater bodies.

Table 2.16 Most sensitive long-term aquatic toxicity data for saltwater organisms exposed to Cr(VI)

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Expo-sure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Algae											
Cr^{6+} (K_2CrO_4)	*Champia parvula*	Red seaweed	Algae	NOEC	Reproduction	48 hours	0.0001 –0.010	s	n	pH 7.7–8.2; 22°C; salinity 27–31 ppt	[85] KC 4
Cr	*Glenodinium halli*	Dinoflagellate			Population decreasing	8–14 days	0.010	f	n	28°C; salinity 28 ppt	[174] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Gracilaria tenuistipitata*	Red algae	Algae	NOEC	Population growth	96 hours	0.040	s	n	pH 8; 25°C; salinity 6 ppt	[72] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Gracilaria tenuistipitata*	Red algae	Algae	NOEC	Population growth	96 hours	0.260	s	n	pH 8; 25°C; salinity 17 ppt	[72] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Skeletonema costatum*	Diatom	Algae	MATC	Biomass	96 hours	0.100	ss	n	Salinity 30 ppt	[106] ECOTOX database
Cr^{6+} ($Na_2Cr_2O_7$)	*Thalassiosira pseudonana*	Diatom	Algae	NOEC	Growth inhibition	15 days	0.100	s	n	20°C; salinity 4–32.5 ppt	[60] EU RAR (IIIb)
Cr	*Thalassiosira pseudonana*	Diatom	Algae	LOEC	Population growth	48 hours	0.010	s	n	28°C; salinity 14 ppt	[174] ECOTOX database
Invertebrates											
Cr^{6+} (CrO_3)	*Capitella capitata*	Polychaete worm	Annelids	LC50	Mortality adult	28 days	0.280	s	n	pH 7.8	[133] EU RAR (II)
Cr^{6+} (CrO_3)	*Ctenodrilus serratus*	Polychaete worm	Annelids	LOEC	Reproduction adult	21 days	0.050	s	n	pH 7.8 (~25% reduction)	[132] EU RAR (II)
Cr^{6+} (K_2CrO_4)	*Dinophilus gyrociliatus*	Polychaete	Annelids	NOEC	Reproduction	7 days	0.100	s	y	pH 7.7–8.2; 20°C; salinity 25 ppt	[85] [185]
Cr^{6+} (CrO_3)	*Neanthes arenaceodentata*	Polychaete worm	Annelids	LC50	Mortality adult	28 days	0.55		n	pH 7.8	[133] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Nereis arenaceodentata*	Polychaete worm	Annelids	ET50	Reproduction	123 days	0.050	ss	n	pH 7.5–8.3; 20°C; salinity 34 ppt	[121] ECOTOX database

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Exposure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Cr^{6+} ($K_2Cr_2O_7$)	*Nereis arenaceodentata*	Polychaete worm	Annelids	LC50	Mortality	59 days	0.200	ss	n	pH 7.5–8.3; 20°C; salinity 34 ppt	[121] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Nereis arenaceodentata*	Polychaete worm	Annelids	NOEC	Reproduction F_1 gen.	2 generation life-cycle	0.017	ss	y	pH 7.8–8.4; 20.8°C; salinity 33.6 ppt	[119] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Nereis arenaceodentata*	Polychaete worm	Annelids	NOEC	Reproduction Reduction in no. of progeny 2nd generation	2 generation life-cycle	0.0125	ss	y	pH 7.9; 20°C; salinity 33.6 ppt	[120] EU RAR (II)
Cr^{6+} (CrO_3)	*Nereis arenaceodentata*	Polychaete worm	Annelids	NOEC	Mortality	14 days	0.006	s	y	pH 7.8–8; 20°C; salinity 35.5 ppt	[103] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Nereis arenaceodentata*	Polychaete worm	Annelids	LOEC	Reproduction	350 days	<0.012	ss	y	pH 7.8–8; 20°C; salinity 33.5 ppt	[103] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Nereis diversicolor*	Polychaete worm	Annelids	LC50	Mortality	16 days	0.700	s	n	10°C; salinity 10 ppt	[28] [185]
Cr^{6+} ($K_2Cr_2O_7$)	*Acartia tonsa*	Copepod	Crustaceans	NOEC	Development	5 days	1.0	ss	n	Salinity 18 ppt	[8] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Allorchestes compressa*	Amphipod	Crustaceans	LOEC	Mortality	28 days	0.250	f	y	pH 8; 19°C; salinity 31 ppt	[5] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Americamysis bahia*	Opossum shrimp	Crustaceans	NOEC	Reproduction	7 days	0.320	ss	n	25°C; salinity 25 ppt	[65] ECOTOX database
Cr^{6+} (K_2CrO_4)	*Americamysis bahia*	Opossum shrimp	Crustaceans	NOEC	Growth	7 days	0.600	ss	y	pH 7.7–8.2; 26°C; salinity 27–31 ppt	[85] ECOTOX database
Cr^{6+} ($NaCrO_4$)	*Callinectes sapidus*	Blue crab	Crustaceans	EC50	Development	40 days	0.93		n	25°C; salinity 30 ppt	[23] EU RAR (IIIb)
Cr^{6+} ($K_2Cr_2O_7$)	*Cancer anthonyi*	Yellow rock crab	Crustaceans	LOEC	Mortality/ hatching success	7 days	0.01	ss	y	pH 7.8; 20°C; salinity 34 ppt	[95] EU RAR (II)

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Expo-sure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Cr^{6+} ($K_2Cr_2O_7$)	*Mysidopsis bahia*	Mysid shrimp	Crustaceans	NOEC	Reproduction brood size	38 days	0.088	f	y	pH 7.8–8.2; 20–25°C; salinity 30 ppt	[94] EU RAR (II)
Cr^{6+} ($NaCrO_4$)	*Neomysis integer*	Shrimp	Crustaceans	NOEC	Mortality	14 days	0.156	ss	n	pH 8.4; 20°C; salinity 3.3 ppt	[163] EU RAR (IIIb)
Cr^{6+} ($NaCrO_4$)	*Palaemon elegans*	Rockpool prawn	Crustaceans	NOEC	Mortality	38 days	1.56	ss	n	pH 8.4; 17–20°C; salinity 33 ppt	[163] EU RAR (II)
Cr^{6+} ($NaCrO_4$)	*Palaemonetes pugio*	Daggerblade grass shrimp	Crustaceans	LOEC	Histopatho-logical changes	28 days	0.500	ss	n	20°C; salinity 10 ppt	[131] [185]
Cr^{6+} ($NaCrO_4$)	*Palaemonetes varians*	Atlantic shrimp	Crustaceans	LOEC	Survival and larval development	30 days	0.312	ss	n	pH 8.4; 20°C; salinity 3.3 ppt	[163] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Portunus pelagicus*	Crab	Crustaceans	MATC	Growth	6 weeks	0.300	ss	n	26°C; salinity 33 ppt	[107] KC 3
Cr^{6+} ($NaCrO_4$)	*Praunus flexuosus*	Mysid	Crustaceans	NOEC	Mortality	23 days	1.0	ss	n	pH 8.4; 20°C; salinity 23 ppt	[163]) EU RAR (II)
Cr^{6+} ($Na_2Cr_2O_4$)	*Rhithropanopeus harrisii*	Mud crab	Crustaceans	NOEC	Survival to 1st crab stage	19 days	0.360	ss	n	25°C; salinity 20 ppt	[23] EU RAR (II)
Cr^{6+} ($NaCrO_4$)	*Rhithropanopeus harrisii*	Mud crab	Crustaceans	NOEC	Survival Hatch – 1st crab	19 days	0.36	ss	n	25°C; salinity 20 ppt	[23] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Tisbe battagliai*	Copepod	Crustaceans	NOEC	Reproduction	8 days	0.320	ss	y	pH 7.7–8.1; 20.5°C; salinity 35 ppt	[80] ECOTOX database
Cr	*Crassostrea gigas*	Pacific oyster	Molluscs		Growth inhibition	14 days	0.010	s	n		[171] [185]
Cr^{6+} ($Na_2Cr_2O_7$)	*Mytilus edulis*	Mussel	Molluscs	NOEC (unbounded)	Growth	12 weeks	0.004–0.006	f	y	Salinity 29–32 ppt	[179] KC 3
Cr^{6+} ($K_2Cr_2O_7$)	*Monodonta turbinate*	Snail	Molluscs	LT50	Mortality	16.8 days	0.500		n		[99] ECOTOX database
Cr^{6+} (NaCrO4)	*Monhystera disjuncta*	Nematode	Nematodes	LOEC	Reproduction	96 hours	0.750	s	n	17°C; salinity 30 ppt	[168] ECOTOX database

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration	Conc. (mg l^{-1})	Expo-sure[1]	Toxicant analysis[2]	Comments	Reference/ Source[3]
Vertebrates (fish)											
Cr^{6+} ($K_2Cr_2O_7$)	*Citharichthys stigmaeus*	Speckled sanddab	Fish	LC50	Mortality 5 g	21 days	5.0	f	y	pH 7.8–8.4; 12–12.3°C; salinity 33.5 ppt	[103] EU RAR (II)
Cr^{6+} ($K_2Cr_2O_7$)	*Cyprinodon variegates*	Sheepshead minnow	Fish	NOEC	Growth larvae <24 hours	7 days	3.2	ss	n	25°C; salinity 20–30 ppt	[102] ECOTOX database
Cr^{6+} (K_2CrO_4)	*Cyprinodon variegates*	Sheepshead minnow	Fish	NOEC	Growth larvae <24 hours	7 days	2.5	ss	y	pH 7.7–8.2; 25°C; salinity 27–31 ppt	[85] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Dicentrarchus labrax*	Sea bass	Fish		Biochemical changes	15 days	2.84–14	ss	n	15°C	[135] ECOTOX database
Cr^{6+} (K_2CrO_4)	*Oncorhynchus kisutch*	Coho salmon	Fish	NOEC	Mortality 106 mm	11 days	17.8	s	n	pH 7.8; 7.2°C	[78] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Pleuronectes platessa*	Plaice	Fish		Histopatho-logical changes spleen macrophage	27 days	0.500	ss	n	15°C; salinity 30 ppt	[88] [185]

1 Exposure: s = static; ss = semi-static; f = flow-through.
2 Toxicant analysis: y = measured; n = not measured.
3 Descriptions of the Validity Criteria used in the EU RAR and shown here in parenthesis and Klimisch Criteria (KC) used to quality assess other data are given in Tables 2.9 and 2.10, respectively.
NOEC = no observed effect concentration; LOEC = lowest observed effect concentration; MATC = maximum allowable toxicant concentration
LC50 = concentration lethal to 50% of the organisms tested; EC50 = concentration effective against 50% of the organisms tested
ET50 = exposure time at which the test concentration is effective against 50% of the organisms tested
LT50 = exposure time at which the test concentration is lethal to 50% of the organisms tested
ppt = parts per trillion

Table 2.17 Most sensitive short-term aquatic toxicity data for saltwater organisms exposed to Cr(VI)

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration (hours)	Conc. (mg l^{-1})	Expo-sure[1]	Toxicant analysis[2]	Comments	Reference/ source[3]
Algae											
Cr^{6+} (K_2CrO_4)	*Cryptophycophyta*			EC50	Population growth	72	0.230		n	16°C	[151] ECOTOX database
Cr	*Gymnodinium splendens*	Dinoflagellate		?	Population decreasing >65%	48	0.020–0.500	s	n	28°C; salinity 28 ppt	[174] ECOTOX database
Cr^{6+} (K_2CrO_4)	*Nitzschia* sp.	Diatom	Algae	EC50	Population growth	72	0.260		n	16°C	[151] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Skeletonema costatum*	Diatom	Algae	EC10	Photosynthesis	20	0.046	s	n	pH 8; 15°C; salinity 20‰	[201] EU RAR (IIIb)
Cr	*Thalassiosira pseudonana*	Diatom	Algae	EC50	Population growth	48	0.350	s	n	28°C; salinity 14 ppt	[174] ECOTOX database
Invertebrates											
Cr^{6+} ($K_2Cr_2O_7$)	*Ampelisca araucana*	Amphipod	Crustaceans	LC50	Mortality	48	56.9		n	13°C	[145] ECOTOX database KC 4
Cr^{6+} ($K_2Cr_2O_7$)	*Artemia franciscana*	Brine shrimp	Crustaceans	NOEC	Mortality	24	1.0	s	n	25°C; salinity 35 ppt	[71] KC 2
Cr^{6+} ($NaCrO_4$)	*Callinectes sapidus*	Blue crab	Crustaceans	LC50	Mortality	96	0.320	ss	n	25°C; salinity 30 ppt	[23] EU RAR (IIIb)
Cr^{6+} ($K_2Cr_2O_7$)	*Paracentrotus lividus*	Sea urchin	Echinoderms	NOEC	Embryo development	48	1.7 (0.78–3.85)	s	n	18°C; salinity 36‰; geometric mean (*n* = 11)	[101] KC 2
Cr^{6+} ($K_2Cr_2O_7$)	*Penaeus chinensis*	Fleshy prawn	Crustaceans	LC50	Mortality	96	0.0034		n		[36]) ECOTOX database

Test substance	Scientific name	Common name	Taxonomic group	Endpoint	Effect	Test duration (hours)	Conc. (mg l^{-1})	Expo-sure[1]	Toxicant analysis[2]	Comments	Reference/ source[3]
Cr	*Penaeus indicus*	Indian prawn	Crustaceans	LC50	Mortality	48	1.010		n		[67] ECOTOX database
Cr^{6+} ($K_2Cr_2O_7$)	*Portunus pelagicus*	Crab	Crustaceans	MATC	Moult inhibition Z1–Z2	72	0.320	ss	n	26°C; salinity 33 ppt	[107] KC 3
Fish											
Cr^{3+} ($CrCl_3$)	*Cynoglossus joyneri*	Red tongue sole	Fish	LC50	Mortality larvae	72	0.900	s	n		[44] ECOTOX database

[1] Exposure: s = static; ss = semi-static.
[2] Toxicant analysis: n = not measured.
[3] Descriptions of the Validity Criteria used in the EU RAR and shown here in parenthesis and Klimisch Criteria (KC) used to quality assess other data are given in Tables 2.9 and 2.10, respectively.
NOEC = no observed effect concentration
MATC = maximum allowable toxicant concentration
ECx = concentration effective against X% of the organisms tested
LC50 = concentration lethal to 50% of the organisms tested

2.6.3 Toxicity to sediment-dwelling organisms

No experimental data with sediment-dwelling freshwater or saltwater organisms are available to derive a PNEC for sediment.

2.6.4 Endocrine-disrupting effects

No data could be located on the effects of chromium compounds on the endocrine system.

3. Derivation of quality standards for chromium

3.1 Use of the Added Risk Approach

The EU RAR on chromates adopted a total risk approach since almost all hexavalent chromium in the environment is of anthropogenic origin. The natural background levels of Cr(VI) are, therefore, insignificant and negligible.

Since Cr(VI) is converted into Cr(III) under some conditions in the environment, the possible effects of Cr(III) must also be taken into consideration. However, it appears that the Cr(III) species to which Cr(VI) may be reduced are much less soluble, and hence less bioavailable to pelagic organisms, than the soluble salts of Cr(III) used in toxicity tests. When the more insoluble forms of Cr(III) (e.g. chromium hydroxide sulfate and dichromium trioxide) have been tested, they have generally shown no effects on aquatic organisms at concentrations up to their effective water solubility.

Because of the low solubility and hence bioavailability of Cr(III) species occurring in the environment, it may be that there is no need for EQSs referring to Cr(III). However, if the necessity of such standards should be acknowledged, consideration could be given to applying the added risk approach for Cr(III) species to take account of spatial differences in natural chromium background levels.

3.2 Consideration of factors determining chromium bioavailability and toxicity in the water column

The EU RAR [56] states that the acute toxicity of Cr(VI) is dependent on a number of factors, including pH, water hardness, salinity and temperature. In general, Cr(VI) toxicity is increased with:

- decreased pH (i.e. 8.0 to 6.0);
- increased temperature (i.e. 15 to 25°C);
- decreased water hardness (>100 to <100 mg l^{-1} as $CaCO_3$) or salinity (<2%).

The values in parenthesis are general values for fish and aquatic invertebrates and will vary according to individual species' optimum environmental requirements. However, there are also studies that show little change in toxicity with changes in water properties.

Available long-term studies with freshwater invertebrates do not appear to show any clear dependence of Cr(VI) toxicity on the properties of the water. There are indications that toxicity may be higher in lower hardness waters, but there are few, if any, studies which allow the comparison to be made for the same species at different levels of hardness, or other properties. Although relationships between hardness and toxicity have been described for divalent metal cations, the fact that the chromium species here are oxoanions means that their toxicity may be less influenced by water properties.

With regard to Cr(III), the EU RAR concludes that the available data appears to show that Cr(III) is less toxic than Cr(VI) in waters of medium hardness (>50 mg l^{-1} $CaCO_3$). In lower hardness waters, the acute toxicity would increase; however, there were also indications that NOEC values would decrease with decreasing hardness.

Detailed relationships between chromium properties and environmental factors were not developed in the EU RAR and the data available from the RAR and from the supplementary sources consulted (see Section 2.6) are not sufficient to allow for a normalisation of Cr(VI) acute toxicity for water quality parameters such as hardness, pH, etc., by, for example, (multiple) regression analysis. It was therefore only possible to derive PNECs without consideration of water quality parameters.

4. Calculation of PNECs as a basis for the derivation of quality standards

4.1 Derivation of PNECs by the TGD deterministic approach (AF method)

4.1.1 PNECs for freshwaters

PNEC referring to the annual average concentration
Chromium(VI)
According to the standard assessment factor approach, the PNEC is derived from the lowest high quality long-term NOEC available. A particularly low NOEC of 0.5 µg l^{-1} was reported for water flea (*Daphnia magna*) reproduction [52]. However, based on the available data the EU RAR regarded this value as an outlier. According to the EU RAR, the lowest reliable value was a NOEC of 4.7 µg l^{-1} for reproduction of the cladoceran *Ceriodaphnia dubia* [46] (Table 2.11).

There is a large amount of good quality long-term effect data on a wide range of aquatic organisms available including algae, insects, molluscs and fish (Table 2.11). An assessment factor of 10 is therefore used, giving a PNEC of 0.47 µg l^{-1}.

$PNEC_{freshwater\_lt}$ = 4.7 µg l^{-1}/(AF 10) = 0.47 µg l^{-1} Cr(VI) (dissolved)

Chromium(III)
Since Cr(VI) is converted into Cr(III) under some conditions in the environment, the possible effects of Cr(III) should also be considered. Aquatic toxicity data referring to Cr(III) were evaluated in the EU RAR (summarised in Tables 2.13–2.15).

From the available data, Cr(III) appears to be less toxic than Cr(VI) in waters of medium hardness (>50 mg l^{-1} $CaCO_3$). In lower hardness waters, the acute toxicity increases; there are also indications that NOEC values decrease with decreasing hardness. From the freshwater data reported in Tables 2.13–2.15, the lowest good quality long-term NOEC values are 0.05 mg l^{-1} for rainbow trout (*Oncorhynchus mykiss*) [149], 0.047 mg l^{-1} for invertebrates (*Daphnia magna*) [35] and >2 mg l^{-1} for algae (*Chlorella pyrenoidosa*) [104]. In addition, an EC50 of 0.32 mg l^{-1} is reported for *Selenastrum capricornutum* [187]. The fish and invertebrate values relate to hardness levels of 26 and 52 mg l^{-1}, respectively.

As long-term toxicity data for representatives of at least three different taxonomic groups are available, the appropriate assessment factor is 10. Applying this assessment factor to the lowest available NOEC gives a tentative PNEC for Cr(III) of 4.7 µg l^{-1} for soft water.

$PNEC_{freshwater\_lt}$ = 47µg l^{-1}/(AF 10) = 4.7 µg l^{-1} Cr(III) (dissolved)

PNEC accounting for transient concentration peaks

Chromium(VI)

Short-term ecotoxicological data on the effects of hexavalent chromium compounds are available for a wide variety of freshwater organisms (algae, plants, crustaceans, fish, amphibians, annelids and nematodes) (see Table 2.12).

The lowest reported value for algae was an effect on photosynthesis of *Spirullina platensis* after a 6-hour exposure to 0.01 mg l^{-1} [14]. However, this value was based on nominal concentrations. It is also very difficult to establish the extent of the effect. Consequently, the relevance of the study is questioned. A particularly sensitive 5-day NOEC of 0.001 mg l^{-1} was also reported for peroxidase activity in the plant *Hydrilla verticillata* [31]. However, the relevance of this effect is not known. The NOEC for growth of the plants in this test was 0.1 mg l^{-1}. In addition, there was no mention of chemical analysis in this study and so these data are used in a supporting capacity only.

The more detailed dataset for freshwater invertebrate species shows that the most sensitive group is cladocerans, such as *Moina australiensis* (48-hour EC50 20 µg l^{-1}), *Ceriodaphnia* sp. (48-hour EC50 30 µg l^{-1}) and *Daphnia magna* (48-hour geometric mean EC50 46 µg l^{-1}). A low effect value for *Daphnia magna* (24-hour EC50 value of 3 µg l^{-1}) was reported by Wernersson and Dave [192]. However, this value is not considered reliable because in a ring test involving 129 EC50 determinations from 46 laboratories, the mean 24-hour EC50 value was determined as 530 µg l^{-1} Cr(VI) [56]. A 96-hour EC50 of 7 µg l^{-1} for the same species [33] was also regarded as unreliable in the RAR.

Invertebrates of other taxonomic groups such as molluscs (*Anodonta imbecillis*, 96-hour LC50 39 µg l^{-1}), nematodes (*Caenorhabditis elegans*, 96-hour LC50 60 µg l^{-1}) and annelids (*Tubifex tubifex*, 48-hour LC50 63 µg l^{-1}) also appear to be very sensitive to Cr(VI).

There was also a particularly sensitive value reported for reproduction in rainbow trout. A 40-minute exposure to a concentration of 5 µg l^{-1} resulted in a significant reduction in fertilisation in trout sperm and eggs [18]. However, the sperm underwent significant preparation/dilution in the test, so the relevance to the field may be in question. In addition, there was no mention of replication in this study. Consequently, these data have been used in a supporting capacity only.

The PNEC accounting for effects following short-term exposure to Cr(VI) is calculated on the basis of the general guidance given in the TGD [152] on the effects assessment for intermittent releases (Section 3.3.2 of Part II) and the lowest valid EC50 of 20 µg l^{-1} for immobilisation of the crustacean *Moina australiensis* [197]. As the acute effects values of these most sensitive species are nearly in the range of the lowest chronic effects values (i.e. very low acute to chronic effects ratios) and a broad range of taxonomic groups is covered by the acute database, the use of a reduced assessment factor of 10 (instead of 100) is suggested in order to extrapolate from the 50 per cent acute effect level to the short-term no effect level.

$PNEC_{freshwater\_st}$ = 20 µg l^{-1}/AF (10) = 2 µg l^{-1} Cr(VI) (dissolved)

Chromium(III)
Based on the available toxicity data for Cr(III), it appears that algae are the most sensitive organisms. The lowest EC50 of 0.32 mg l^{-1} Cr(III) is reported for *Selenastrum capricornutum* biomass gain over 96 hours. For invertebrates, the lowest L(E)C50 values are in the range of 1–15 mg l^{-1} (crustaceans, insects, molluscs and annelids) and, for fish, the lowest LC50 of 3.33 mg l^{-1} reported refers to the guppy.

The PNEC accounting for effects following short-term exposure to Cr(III) is calculated on the basis of the general guidance given in the TGD [152] on the effects assessment for intermittent releases (Section 3.3.2 of Part II) and the lowest valid EC50 of 0.32 mg l^{-1} for biomass gain of the alga *Selenastrum capricornutum*. A reduced assessment factor of 10 may suffice to extrapolate from the 50 per cent acute effect level to the short-term no effect level.

$PNEC_{freshwater\_st}$ = 320 µg l^{-1}/AF (10) = 32 µg l^{-1} Cr(III) (dissolved)

From the available acute toxicity of *Daphnia magna*, it appears that Cr(III) is less toxic for this species in hard water than in soft water.

4.1.2 PNECs for saltwaters

Freshwaters and saltwaters differ in various abiotic physico-chemical factors including natural background concentrations of essential and other elements. For metals/metalloids, it was decided not to combine the freshwater and saltwater effects databases, but to derive PNECs for freshwaters and saltwaters on the basis of their respective effects data.

PNEC referring to the annual average concentration
Chromium(VI)
A PNEC referring to the pelagic community in saltwater was not derived in the EU RAR on chromates [56].

Long-term aquatic toxicity data of saltwater organisms are presented in Table 2.16. Aquatic invertebrates such as the blue mussel (*Mytilus edulis*, 12-week $NOEC_{growth}$ 4–6 µg l^{-1}) or the polychaete worm *Nereis arenaceodentata* (2-week $NOEC_{mortality}$ 6 µg l^{-1}) and the yellow rock crab (*Cancer anthonyi*, 12-week $LOEC_{mortality, hatching}$ 10 µg l^{-1}) appear to be the most sensitive organisms. An algal NOEC of 0.1 µg l^{-1} is also available [85]. However, there were very few details available to assess the quality of this study. Studies with fish indicate lower sensitivity than invertebrates.

The lowest available NOEC of 4–6 µg l^{-1} in *Mytilus edulis* was unbounded (highest concentration tested). Consequently, it was not suitable for PNEC derivation. The next lowest value, a 2-week $NOEC_{mortality}$ of 6 µg l^{-1} in *Nereis arenaceodentata*, was regarded as valid for PNEC derivation by the EU RAR.

According to the provisions of the TGD on marine effects assessment, an assessment factor of 10 is appropriate to derive the PNEC on the basis of the lowest NOEC (additional good quality long-term data for fish, crustaceans and algae were available as well as for more than two additional marine taxonomic groups):

$PNEC_{saltwater\_lt}$ = 6 µg l^{-1}/(AF 10) = 0.6 µg l^{-1} Cr(VI) (dissolved)

Chromium(III)
There was only one multi-generation NOEC of >50 mg l^{-1} for the polychaete worm *Neanthes arenaceodentata* and some acute studies for other marine invertebrates and fish available for Cr(III) (see Tables 2.13–2.15). This database is deemed insufficient to derive a PNEC referring to the annual average concentration of Cr(III) in saltwater bodies.

The results of the available short-term studies with marine fish and invertebrates appear to cover the same range as the respective studies of their freshwater relatives. Therefore, the PNEC derived for Cr(III) in freshwater may be used as an indicative value for marine water bodies until sufficient long-term studies with marine organisms are available.

PNEC accounting for transient concentration peaks
Chromium(VI)
Short-term ecotoxicological data on the effects of hexavalent chromium compounds are available for saltwater algae, crustaceans, fish and echinoderms (see Table 2.17).

Unfortunately, problems with the validation of data occurred. With regard to the alga data, the report by Wilson and Freeburg [174] is an internal US EPA report that was not available to quality assess. In addition, two other publications [44, 151] are in Chinese (with English abstracts) and could not be quality assessed. The same problem (Chinese language paper) prevented the quality assessment of the study by Chen and Chen [36], who reported a 48-hour LC50 of 0.0034 mg l^{-1} for the prawn *Penaeus chinensis*. However, in the light of the results obtained for other prawn and crab species where significantly higher Cr(VI) concentrations were required to cause toxic effects, the value of this LC50 appears questionable. The lowest quality assessed toxicity data that meet the minimum requirements used in the EU RAR are the 96-hour LC50 of 0.32 mg l^{-1} reported for the crab *Callinectes sapidus* [23] and the 20-hour EC10 of 46 µg l^{-1} reported for effects on photosynthesis of the diatom *Skeletonema costatum* [201]. However, the alga EC10 is for a non-standard test duration and endpoint.

The LC50 of 0.32 mg l^{-1} obtained with *Callinectes sapidus* could be used as the basis for the derivation of the $PNEC_{saltwater\_st}$. The TGD [152] does not provide specific guidance for assessment of acute effects of intermittent releases to marine water bodies. However, the PNEC may be derived on the basis of the general guidance given in the TGD on the effects assessment for intermittent releases (Section 3.3.2 of Part II). A reduced assessment factor of 10 (instead of 100) is considered sufficient to extrapolate from the 50 per cent acute effect level to the short-term no effect level because good quality data are available for algae, crustacean and echinoderms. Short-term saltwater fish data are lacking. However, long-term data indicate that fish are unlikely to be the most sensitive group. In addition, the resulting PNEC will also be in the range of the lowest NOECs obtained for species with a short life cycle, such as algae and crustaceans of the genus *Ceriodaphnia*.

$PNEC_{saltwater\_st}$ = 320 µg l^{-1}/AF (10) = 32 µg l^{-1} Cr(VI) (dissolved)

Chromium(III)
For Cr(III), the minimum data set of three short-term toxicity data with an alga, crustacean and fish species is not available. Data on marine algae and crustacean

species are lacking, but short-term data for a mussel and annelid species are available instead (Tables 2.13–2.15). Overall, the available dataset comprises only five saltwater L(E)C50s for one marine fish, one mollusc and one annelid species and, therefore, is considered too small for the calculation of a reliable PNEC.

The results of the available short-term studies with marine fish and invertebrates appear to cover the same range as the respective studies of their freshwater relatives. Therefore, the PNEC derived for Cr(III) in freshwater may be used as an indicative value for marine water bodies until sufficient long-term studies with marine organisms are available.

4.2 Derivation of PNECs by the TGD probabilistic approach (SSD method)

4.2.1 Annual average PNEC for freshwaters

Chromium(VI)
Twenty-six long-term NOECs (or geometric mean NOECs) were selected in the EU RAR [56] as input data for the derivation of a $PNEC_{freshwater}$ by means of statistical extrapolation (Table 4.1). Searches for additional relevant studies from other sources such as the existing EQS [184], the US EPA ECOTOX database and Web of Science did not result in additional relevant long-term NOEC data (see Table 2.11). Therefore, the same approach as used in EU RAR is adopted here.

Table 4.1 Data used for establishing an SSD on the basis of long-term NOECs of freshwater species

	Species	**NOEC (mg l^{-1} Cr)**	**Notes**
Blue-green algae	*Microcystis aeruginosa*	0.35	
Algae	*Chlorella pyrenoidosa*	0.1	
	Chlorella sp. (wild)	0.1	
	Scenedesmus pannonicus	0.11	
	Selenastrum capricornutum	0.033	Geometric mean of EC10 (g)
Macrophytes	*Lemna gibba*	0.1	
	Lemna minor	0.11	
	Spirodela polyrhiza	0.1	
	Spirodela punctata	0.5	
Crustaceans	*Ceriodaphnia dubia*	0.0047	Reproduction value
	Daphnia carinata	0.05	
	Daphnia magna	0.019	Geometric mean of reproduction values
Coelenterates	*Hydra littoralis*	0.035	
	Hydra oligactis	1.1	
Insect	*Culex pipiens*	1.1	Survival/growth NOEC
Mollusc	*Lymnaea stagnalis*	0.11	Reproduction value

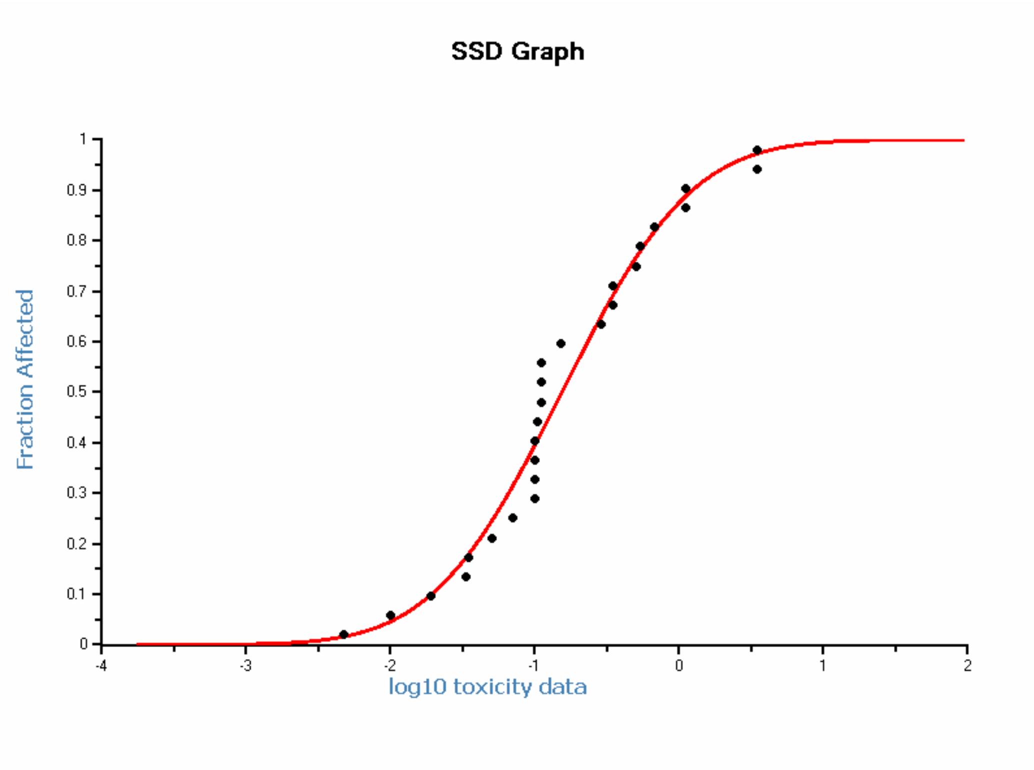
	Species	NOEC (mg l^{-1} Cr)	Notes
Fish	*Catastomus commersoni*	0.29	Longer growth value
	Esox lucius	0.538	
	Ictalurus punctatus	0.15	30-day growth NOEC
	Oncorhynchus mykiss	0.07	Geometric mean of growth NOECs
	Oryzias latipes	3.5	Survival NOEC
	Pimephales promelas	0.68	Geometric mean of growth NOECs
	Poecilia reticulata	3.5	Growth/mortality NOEC
	Salvelinus fontinalis	0.01	Growth NOEC
	Salvelinus namaycush	0.105	Growth NOEC
Amphibian	*Xenopus laevis*	0.35	Mortality NOEC

Based on the 26 NOECs presented in Table 4.1 and the program ETX 2.0 [55], the median (i.e. 50 per cent confidence) 5th percentile cut-off value of 10.3 µg l^{-1} Cr(VI) is calculated with a lower 95 per cent confidence interval (CI) of 3.8 µg l^{-1} and an upper 95 per cent CI of 21 µg l^{-1}. The 5th percentile cut-off value is the same as calculated in the EU RAR for an assumed log-normal distribution using the method described by Wagner and Løkke [169].[5]

Using the Anderson–Darling Goodness-of-Fit test for normality and the Cramer van Mises test, normal distributions of the log-transformed data are accepted up to the highest significance levels of 10 per cent, thus, accepting the assumption of normally distributed input data. The Kolmogorov–Smirnov test accepted the null-hypothesis as well, but only to a significance level of $P = 0.05$. It could be suggested that the distribution (Figure 4.1) is bimodal given the poor fit around the midpoint. However, if the data were split and two distributions generated there would be insufficient data available to fulfil the TGD criteria for the generation of a species sensitivity distribution (SSD). Therefore, in line with the EU RAR, only one distribution has been generated using all the available long-term data.

[5] ETX 2.0 is based on the publications of Aldenberg and Jaworska [6] and Aldenberg and Luttik [7]. These describe the approaches to set up an SSD and to calculate the 5th percentile based on the assumed log-normal distribution of the input data.

Figure 4.1 SSD of freshwater organisms (input data as presented in Table 4.1)



According to the TGD [152], an assessment factor of 1–5 should be applied to derive the PNEC from the 5th percentile of the SSD. The size of this assessment factor needs to be justified to take account of aspects such as:

- data comprehensiveness and quality;
- fit to the distribution;
- the occurrence of NOEC values below the 5th percentile;
- the results of field tests (if available) and the conventional assessment factor method.

A justified proposal for the size of the assessment factor to be used for the calculation of the PNEC from the 5th percentile is proposed in Section 3.2.1.7.1 of the chromates RAR [56]. The following is an abridged form of that proposal:

- A considerable number of long-term NOEC values are available for calculating a 5th percentile cut-off value for Cr(VI) from a wide range of aquatic taxa including fish, crustaceans, algae, aquatic plants, insects, molluscs, amphibians and coelenterates. These values match the species recommendations set out in the TGD [152].[6] The number of available NOEC values is significantly more than the minimum requirements of at least 10 different species. The tests from which the values come cover a range of chronic endpoints including growth, reproduction and survival, and cover sensitive life stages for longer lived-organisms (e.g. fish) and multiple life cycles

[6] The EU RAR states that a test with a benthic amphipod species is lacking. However, this observation refers to the species requirements agreed at the so-called ‘London workshop’ on the use of statistical extrapolation for the derivation of PNEC values in case of data-rich substances. However, the species requirements were updated in the revised version of the TGD issued in 2003 [152]. As a result, the diversity of the species available for setting up a SSD is now in line with the recommendation of the TGD.

for shorter-lived species (e.g. cladocerans). Multiple data values for the same species and endpoint have been combined as agreed.

- A further consideration for the use of the method is whether the data fit to the expected distribution. All statistical tests applied do not reject the hypothesis that the data come from the expected distribution. Overall, the data set is considered suitable for use in the extrapolation method.
- As regards the application of a possible assessment factor to derive the PNEC value, the following points should be considered:
  - The data set used in the extrapolation covers a wide range of aquatic species and a range of chronic endpoints. It includes the types of organism indicated to be the most sensitive in acute tests and, thus, there do not appear to be any groups of sensitive organisms missing from the data set. The organisms cover a range of trophic levels and feeding strategies including primary producers, herbivores, fish that consume algae and invertebrates, fish that consume other fish, and detritivores.
  - Against these points, there are a relatively large number of results for fish (although they cover different types) and only one each for insects or molluscs. There are also no results from mesocosm or field studies to compare with the derived values. There are two values included in the data set which lie below the HC5–50 per cent value: one for the cladoceran *Ceriodaphnia dubia* and the other for the fish *Salvelinus fontinalis*. In the case of *Ceriodaphnia dubia*, the NOEC for reproduction was 4.7 µg l^{-1}; from the same report, the NOEC for survival was 8.4 µg l^{-1}. These values come from a ring test and are derived from 18 individual results. In the same study, the 50 per cent effect concentration for survival and reproduction over 7 days was 14 µg l^{-1}, indicating a steep dose-response. The NOEC for *Salvelinus fontinalis* is 10 µg l^{-1}, which is virtually the same as the HC5–50 per cent value.

These considerations suggest that a small assessment factor could be applied to the extrapolated value to give a more protective PNEC. The choice of assessment factor to be used with the 5th percentile cut-off value makes little or no difference to the overall result of the assessment. A factor of 3 was accepted during Technical Meeting discussions as a reasonable compromise between those Member States that expressed a view. Hence, the resulting PNEC is as follows:

$PNEC_{freshwater\_lt}$ = 10.3 µg l^{-1}/(AF 3) = 3.4 µg l^{-1} Cr(VI) (dissolved)

Chromium(III)

There are insufficient data available to carry out an SSD calculation for Cr(III).

4.2.2 Annual average PNEC for saltwaters

There are insufficient data available to carry out SSD calculations for Cr(III) or Cr(VI).

4.3 Derivation of existing EQSs

The UK EQS values derived in 1984 [184] (Table 4.2) were for total dissolved chromium and the freshwater standards were banded according to water hardness.

Few data were available at that time, in particular for Cr(III), and a comparison of the toxicities of each oxidation state was not possible. Both Cr(III) and Cr(VI) were found to be more toxic in soft water than in hard water under conditions that produced acute lethal responses, with Cr(III) tending to be the more toxic. Under chronic conditions, particularly in soft water, Cr(VI) was found to be more toxic, with the trivalent form showing little or no adverse effect. Therefore, it was suggested that any standard for the continuous discharge of chromium be solely set on the toxicity of hexavalent chromium. In view of the considerable difference between the proposed EQS values and the prevailing concentrations of total dissolved chromium in UK rivers, it was recommended that the EQS values be adopted as total dissolved chromium concentrations rather than for hexavalent chromium alone.

The EQSs for sensitive freshwater fish were derived to provide protection for salmonid fish populations continuously exposed to concentrations that were generally very low relative to acutely toxic concentrations. The preferred approach was to reduce the lowest (non-lethal) effect dose reported by a suitable margin and to recommend this as an annual mean concentration for the EQS. Typically, the values were derived by taking the lowest concentration having an adverse effect from the available data and halving it. However, the EQS for waters with a hardness between 50 and 100 mg l^{-1} (as $CaCO_3$) was taken from a no adverse effects value reported for a 2-year study. In the case of waters with a hardness between 100 and 200 mg l^{-1} (as $CaCO_3$), no data were available. Therefore, it was recommended that the EQS for such waters should be twice that for softer waters (i.e. 20 µg l^{-1}).

Based on the available literature and the fact that experimental data were very limited, the EQS values proposed for salmonid fish were also adopted for the protection of other aquatic life.

For non-salmonid species, adequate toxicity data were lacking. While the standard for very soft waters was derived using the same general approach as above, the chronic toxicity data for waters of hardness >50 mg l^{-1} (as $CaCO_3$) were insufficient to permit derivation of EQS values. The ratio of the 96-hour LC_{50} values for the fathead minnow in soft and hard water were taken into account to derive the EQS of 250 µg l^{-1} for hard waters (>200 mg l^{-1} as $CaCO_3$), although the report stated that there was no scientific basis for applying acute toxicity ratios in this way [184]. The standards for intermediate hardness were established by linear interpolation.

The data available for the effects of chromium on marine species indicated that the acute toxicity of hexavalent chromium was extremely variable. Fish appeared to be considerably less sensitive than invertebrates, although fish larvae were reported to be susceptible to chromium contamination. The limited information available did not entirely support the view that trivalent chromium was less toxic than the hexavalent form. Because of this and the possibility of transformation between the two species, the EQS was defined as being for total chromium. The standard was based on a chronic lowest adverse effects value of 30 µg l^{-1} for a polychaete worm. This value was halved to give the annual average standard.

The EQSs were subsequently revised [185], although they were never adopted as statutory values.

Table 4.2 EQS values for total dissolved chromium (III + VI) [184]

Use	Annual average concentration ($\mu g\ l^{-1}$ total dissolved chromium)
Freshwater	
Protection of salmonid fish and other aquatic life:	
0–50 mg l^{-1} $CaCO_3$	5
50–100 mg l^{-1} $CaCO_3$	10
100–200 mg l^{-1} $CaCO_3$	20
200–>250 mg l^{-1} $CaCO_3$	50
Protection of non-salmonid fish:	
0–50 mg l^{-1} $CaCO_3$	150
50–100 mg l^{-1} $CaCO_3$	175
100–200 mg l^{-1} $CaCO_3$	200
200–>250 mg l^{-1} $CaCO_3$	250
Saltwater	15

4.4 Derivation of PNECs for sediment

4.4.1 PNEC derivation by the TGD deterministic approach

There are insufficient data available to derive a PNEC from studies on sediment-dwelling organisms.

4.4.2 PNEC derivation by the TGD probabilistic approach

Because no experimental effects data of benthic organisms are available, statistical extrapolation cannot be applied to derive PNECs referring to freshwater or saltwater sediments.

4.5 Derivation of PNECs for secondary poisoning of predators

4.5.1 Mammalian and avian toxicity data

In 2002, the Environment Agency and the Department for Environment, Food and Rural Affairs (Defra) published a report collating data on chromium with regard to soils [48]. This was assumed to contain the most sound and scientifically accurate mammalian data and was, therefore, the primary data source used. The US IRIS [79] was also used. Additional literature searches were performed from 2002 to May 2005 to locate any lower effect data, but none were found. A comprehensive literature search was also performed for all years to search for any relevant avian data.

Avian and mammalian oral toxicity studies with Cr(VI) compounds were also assessed in the EU RAR [56], but no avian studies suitable for the derivation of a $PNEC_{oral}$ and the assessment of secondary poisoning were identified. However, two mammalian studies with a no observed adverse effect level (NOAEL) of 20 mg Cr(VI)/kg body weight (bw) per day were both considered suitable to derive a $PNEC_{oral}$. Study details are presented in Table 4.3.

Table 4.3 Most sensitive mammalian and bird oral toxicity data relevant for the assessment of secondary poisoning

Study and result	Details
Sub-chronic toxicity to mammals	
ATSDR (2000) [13] did not derive any minimal risk levels (MRLs) for oral intermediate exposure to chromium because 'the available data on reproductive and developmental effects are insufficient or too contradictory to establish … intermediate … NOAELs or LOAELs'.	
Chronic toxicity to mammals	
Anderson *et al.* 1997 [9] Cited in Defra and Environment Agency 2002 [48] **Chronic NOAEL = 5 mg Cr(III)/kg bw/day**	Rats received either chromium chloride or chromium tripicolinate in their diet for 6 months at a corresponding maximum dose of 5 mg Cr(III)/kg bw/day. No effects were seen on body weight, organ weights, haematology, clinical biochemistry and histopathology. Hence the NOAEL was set at the highest dose tested.
Ivankovic and Preussmann 1975 [83] Cited in Defra and Environment Agency 2002 [48] and US EPA 2001 [156] **NOAEL = 1,468 mg Cr(III)/kg bw/day**	Rats received Cr_2O_3 in their diet via baked bread for 840 days at a corresponding dose of 1,468 mg Cr(III)/kg bw/day. The NOAEL was based on no toxic effects observed at the dose tested. The US EPA used this value to set a chronic oral reference dose. However the study has a low overall confidence rating, due to lack of protocol detail [i.e. lack of toxicity endpoints studied, effect of vehicle (baked bread) used, etc.].
MacKenzie *et al.* 1958 [96] Cited in Defra and Environment Agency 2002 [48] and US EPA 2001 [157] **Chronic NOAEL = 2.5 mg Cr(VI)/kg bw/day**	Rats received potassium dichromate in their drinking water for 1 year (20 animals per group). The NOAEL was based on no effects seen on appearance, weight gain, food consumption, haematology, liver, kidneys and femurs at the highest dose tested. Although the US EPA used this NOAEL to derive a chronic oral reference dose, it assigned a low overall confidence rating to this figure due to the small group size, small number of endpoints examined and the lack of toxic effects.
Anwar *et al.* 1961 [11] Cited in Defra and Environment Agency 2002 [48] **Chronic NOAEL = 0.30 mg Cr(VI)/kg bw/day**	Female dogs received potassium dichromate in their drinking water for 4 years at corresponding doses of 0.012–0.30 mg Cr(VI)/kg bw/day (two animals per group). The NOAEL was based on no effects seen on appearance, body weight gain, organ weights, urinalysis, haematology and histopathology at any of the doses administered.
EU RAR 2005 [56] **Chronic NOAEL = 20 mg Cr(VI)/kg bw/day**	A NOAEL of 20 mg Cr(VI)/kg bw/day was found for effects on the testes in mouse (oral gavage route). This NOAEL was considered a suitable basis for assessment of secondary poisoning and the derivation of a $PNEC_{oral}$ in the EU RAR.
EU RAR 2005 [56] **Chronic LOAEL = 20 mg Cr(VI)/kg bw/day**	A LOAEL of 20 mg Cr(VI)/kg bw/day for developmental effects in mice (drinking water route) was evaluated in the EU RAR and considered suitable for the assessment of secondary poisoning and the derivation of a $PNEC_{oral}$.

Study and result	Details
Although Cr(VI) is a known human and mammalian carcinogen, and Cr(III) a possible human carcinogen (via the inhalation route), no such classifications can be made for oral exposures. The 2002 Environment Agency/Defra report states that the carcinogenic potential of ingested Cr(VI) cannot be stated due to a lack of high quality data. However, limited studies on Cr(III) have shown it to be non-carcinogenic [48].	
Effects on reproduction of mammals	
Elbetieha and Al-Hamood 1997 [62] Cited in Defra and Environment Agency 2002 [48] **LOEAL = 150 mg Cr(III)/kg bw/day**	Male and female mice received chromium chloride in their drinking water for 12 weeks, at a corresponding dose of 150 mg Cr(III)/kg bw/day. The LOAEL was based on reduced fertility observed at this dose.
Elbetieha and Al-Hamood 1997 [62] Cited in Defra and Environment Agency 2002 [48] **LOEAL = 70 mg Cr(VI)/kg bw/day**	Male and female mice received potassium dichromate in their drinking water for 12 weeks, at corresponding doses of 70–150 mg Cr(VI)/kg bw/day. The LOAEL was based on reduced fertility observed at all doses.
ATSDR (2000) [13] did not derive any MRLs for oral chronic exposure to chromium because 'the available data on reproductive and developmental effects are insufficient or too contradictory to establish…chronic…NOAELs or LOAELs'. The US National Toxicology Program performed a three-part reproductive study on Cr(VI) in both rats and mice, and found that 20 and 60 mg Cr(VI)/kg bw/day, respectively, were not reprotoxic [157].	
Embryotoxicity and teratogenicity	
Kanojia *et al.* 1996 [86] Cited in Defra and Environment Agency 2002 [48] **LOAEL = 40 mg Cr(VI)/kg bw/day**	Female rats received potassium dichromate in their drinking water for 12 weeks at a corresponding maximum dose of 40 mg Cr(VI)/kg bw/day. At this level, unspecified foetal, embryo and maternal toxicity was reported.
Ivankovic and Preussmann 1975 [83] Cited in Defra and Environment Agency 2002 [48] **NOAEL = 1,500 mg Cr(III)/kg bw/day**	Male and female rats received Cr(III) in their diet for 60 days prior to mating and during the female gestational period. The NOAEL was based on no adverse reproductive or developmental effects observed at the dose tested.
Neurotoxicity to mammals	
No data were available on the potential neurotoxic effects of chromium.	
Sub-chronic toxicity to birds	
Krolickzewska *et al.* 2004 [89] **NOAEL = 1,355 µg Cr (via Cr yeast)/kg diet/day**	One-day-old male Hubbard-ISA broiler chicks received chromium (via chromium yeast) in their diets at a maximum level of approximately 1,355 µg/kg diet (including the basal dietary level; 30 birds per group). No adverse toxicity effects were observed apart from increased body weight, weight gain, feed efficiency and HDL cholesterol, decreased total cholesterol, LDL cholesterol, triglycerides and serum glucose. However

Study and result	Details
	these latter effects are thought not to be adverse and are in fact beneficial as they improve the performance of the chicken. Based on the absence of any observed toxic effects at the highest dose used, the NOAEL was set at 1,355 µg/kg diet.
Butkauskas and Sruoga 2004 [30] **LOAEL = 0.142 g Cr(VI)/kg diet**	Two-month-old male Japanese quail (*Coturnix coturnix japonica*) received potassium dichromate in their diets at a level of 0.142 g/kg diet for 3 months as part of a reproduction study. Effects observed were decreased hatchability of F1 embryos when males were mated with untreated females. However, it is unclear whether any other possible effects were investigated. Also only one dose was used; thus, no dose–response relationship was defined.
Burger and Gochfeld 1995 [29] **LOAEL = 50 mg chromium nitrate/kg bw (approx. 11 mg Cr(III)/kg bw)**	One-day-old herring gull chicks (*Larus argentatus*) received a single intraperitoneal administration of 50 mg chromium nitrate/kg bw (approximately 11 mg Cr(III)/kg bw) at 2 days of age. Four to five days post-injection significant differences were observed in body weight (decrease), weight gain (decrease), and various behaviours including begging, righting, balance, thermoregulation, visual cliff and actual cliff (all inhibited). However, no immediate toxicity was observed. From these results it is possible to set a LOAEL, but caution is necessary as no dose–response relationship was established.
Long-term toxicity to birds	
Rao *et al.* 1983 [130] Cited in EU RAR [56] **NOAEL = 40.9 µg Cr(VI)/bird/day**	The toxicity of Cr(VI) (as sodium chromate) was studied in a 1-year feeding study using chickens (*Gallus gallus*). In the study, the chickens were fed parboiled rice containing 0.7 mg Cr/kg rice. The estimated average daily intake of Cr(VI) from the treated rice was 40.9 µg/bird. The control chickens were fed non-spiked rice, and the background daily exposure to total chromium from this rice was around 3.5 µg/bird. No effects were seen over this time period on body weight, organ weights or haematological parameters. No gross or histological changes attributable to the exposure were found in liver, spleen, kidneys, heart, lungs and gonads. Similar results were found in experiments with mice.

LOAEL = lowest observed adverse effect level

4.5.2 PNECs for secondary poisoning of predators

Chromium(VI) has been shown to be taken up by a wide range of organisms from water, sediment and soil. For fish, although uptake does occur, the bioconcentration factors for Cr(VI) are usually very low (~1 l kg^{-1}).

In the EU RAR [56], a $PNEC_{oral}$ for Cr(VI) was derived on the basis of ecologically relevant effects seen in oral studies with mice. The relevant results are a NOAEL of 20 mg Cr(VI)/kg bw/day for effects on the testes in mouse (oral gavage route) and a LOAEL of 20 mg Cr(VI)/kg bw/day for developmental effects in mice (drinking water route). For the purpose of the secondary poisoning assessment, both 20 mg/kg bw/day values are used as effects were seen at this level in one of the studies.

Converting the NOAEL into a concentration in food (the conversion factor from the TGD is 8.3) gives a NOEC in food of 166 mg/kg. As the studies with mice are chronic tests, an assessment factor of 10 was considered appropriate in the EU RAR and a PNEC for secondary poisoning (secpois) of 17 mg Cr(VI)/kg food was derived. However, the size of the assessment factors to be used for derivation of the $PNEC_{oral}$ was modified during the course of the TGD revision. The revised edition [152] recommends that the use of an AF of 30 should be considered. Application of an AF of 30 on the $NOEC_{food}$ would result in a **$PNEC_{oral}$ of 5.7 mg Cr(VI)/kg food**.

As Cr(VI) taken up from water is transformed to Cr(III) in fish, and presumably in crustaceans and other invertebrate species, the $PNEC_{secpois}$ should be based on mammalian and avian toxicity data for Cr(III). However, there is an absence of a suitable mammalian or avian oral toxicity data for Cr(III). Consequently, it is deemed inappropriate to base the $PNEC_{secpois}$ on data for Cr(VI).

5. Analysis and monitoring

In most ambient environmental and occupational samples, chromium may be present in both the trivalent and hexavalent oxidation states. Measurements of low levels of chromium concentrations in water (ng l^{-1}) have been made by specialised methods such as:

- chelation–extraction atomic absorption spectrometry (AAS) [40];
- inductively coupled plasma mass spectrometry (ICP-MS);
- capillary column gas chromatography (HRGC) of chelated chromium with electron capture detection (ECD);
- electrothermal vaporisation inductively coupled plasma mass spectrometry [74, 100, 138].

A method using high performance liquid chromatography (HPLC) interfaced with a direct current plasma emission spectrometer has been used for the determination of Cr(III) and Cr(VI) in water samples [90]. Direct analysis using AAS or ICP-MS usually provides a limit of detection of around 1 µg l^{-1}. An alkaline digestion procedure followed by ultraviolet–visible (UV-vis) spectroscopy has been developed which can quantify Cr(VI) in soil, sediment and sludge [162]. The preferred methods for digestion of environmental samples are discussed by Griepink and Toelg (1989) [70].

A number of reviews provide a detailed description of the available analytical methods for determining chromium in biological samples [58, 81, 82, 154, 159, 173]. The four most frequently used methods are:

- neutron activation analysis (NAA);
- mass spectrometry (MS);
- graphite spark atomic emission spectrometry (AES);
- graphite furnace atomic absorption spectrometry (GFAAS).

Of these four methods, GFAAS has previously been only readily available in laboratories with R&D capability (i.e. that would have had state-of-the-art equipment), although ICP-MS is now becoming the method of choice in commercial laboratories. GFAAS is capable of determining chromium levels in biological samples when an appropriate background correction method is used [69, 127, 155, 167]. Depending on the matrix analysed, limits of detection of less than 0.1 µg/kg can be achieved using this method.

The lowest proposed PNEC derived for freshwaters and saltwaters for either Cr(VI) or Cr(III) is 0.47 µg l^{-1}. To provide adequate precision and accuracy, the data quality requirements are that, at a third of the EQS, total error of measurement should not exceed 50 per cent. From the literature, it can be seen that analytical methodologies provide detection limits as low as 1 µg l^{-1}, which suggests that current analytical methodologies may not offer adequate performance to analyse for the lowest derived PNECs for water.

6. Conclusions

6.1 Availability of data

Substantial short-term and long-term ecotoxicological datasets are available that describe the effects of Cr(III) and Cr(VI) compounds for a wide variety of organisms (freshwater and marine fish, invertebrates, algae, plants and amphibians). Saltwater data are available only for Cr(VI) compounds from studies with algae, crustaceans, fish and echinoderms. There are few reliable ecotoxicological data for saltwater organisms exposed to Cr(III).

6.2 Derivation of PNECs

The EU RAR [56] adopted a total risk approach as almost all hexavalent chromium [Cr(VI)] in the environment is of anthropogenic origin and natural background levels of Cr(VI) are, therefore, negligible.

Because of the low solubility and hence reduced availability of Cr(III) species, there would seem to be little requirement for thresholds for Cr(III). However, if such standards were needed, the added risk approach could be recommended to take account of spatial differences in natural chromium background levels if the background concentrations were significantly lower than those of the derived PNEC. Sufficient data are available to permit the derivation of freshwater PNECs for Cr(III), but there are insufficient data to derive saltwater PNECs.

Long-term studies with freshwater invertebrates do not show any clear dependence of Cr(VI) toxicity on the properties of the water. Relationships between hardness and toxicity have been described for divalent metal cations but, because the chromium species here are oxoanions, their toxicity may be less influenced by water properties. Detailed relationships between the behaviour of chromium and environmental factors were not developed in the EU RAR and it is accepted that the data do not warrant normalisation of chromium toxicity for water quality parameters.

PNECs for Cr(III) were developed in the EU RAR but, due to a lack of saltwater toxicity data, only for the protection of freshwater organisms. There are no existing EQSs specifically for Cr(III).

The outcomes of the EU RAR have been subject to extensive peer review and the UK is committed to the use of these data for chemical risk assessment purposes. RAR PNECs have also been adopted for the derivation of the Water Framework Directive Annex X EQSs. Consequently, the available RAR PNECs have been adopted as the corresponding proposed PNECs in this document.

The proposed PNECs are described below and summarised in Table 6.1.

6.2.1 Long-term PNEC for freshwaters

Chromium(VI)
There are sufficient long-term data to construct a species sensitivity distribution and to estimate a threshold based on the lower 5th percentile from the model fitted to the ranked NOEC data (the HC5). Indeed, this is the basis of the $PNEC_{freshwater\_lt}$ recommended in the EU RAR. In accordance with the Annex V methodology, an assessment factor of 3 is applied to the HC5 to reflect the substantial taxonomic spread in the available dataset and the fact that there was considered to be a reasonable fit of the available data to the model. The resulting $PNEC_{freshwater\_lt}$ of 3.4 µg l^{-1} Cr(VI).

The external peer review group considering PNECs for consideration as Annex VIII EQSs took issue with the last assertion and suggested that the data actually reflected two distinct distributions. There was also a lack of consensus about the validity of the SSD approach, even though it is an accepted approach for chemical risk assessment and allowed under the Annex V methodology.

A separate $PNEC_{freshwater\_lt}$ can also be derived using the deterministic (critical data/assessment factor) approach. This value is more stringent, being based on an assessment factor of 10 applied to the lowest reliable NOEC of 4.7 µg l^{-1} for reproduction of the cladoceran *Ceriodaphnia dubia*, i.e. a $PNEC_{freshwater\_lt}$ of 0.47 µg l^{-1} Cr(VI). This is the lowest factor permitted under the Annex V approach for laboratory data, even with a substantial dataset.

The existing EQSs for chromium are banded according to water hardness, with values ranging between 5 and 50 µg l^{-1} as dissolved chromium for the protection of 'sensitive taxa'. The $PNEC_{freshwater\_lt}$ derived from the SSD is comparable with the most stringent value from this range, but the $PNEC_{freshwater\_lt}$ based on a deterministic approach is at least 10 times more stringent.

Chromium(III)
The lowest reliable chronic NOEC values are 0.05 mg l^{-1} for rainbow trout (*Oncorhynchus mykiss*) and 0.047 mg l^{-1} for *Daphnia magna* from studies using soft water. Long-term toxicity data are available for representatives of at least three different taxonomic groups, permitting the use of an assessment factor of 10. Applying this factor to the lowest available NOEC gives a $PNEC_{freshwater\_lt}$ of 4.7 µg l^{-1} Cr(III).

6.2.2 Short-term PNEC for freshwaters

Chromium(VI)
The lowest valid acute EC50 (20 µg l^{-1}) is for immobilisation of the crustacean *Moina australiensis* after 48-hour exposure. Similar effect concentrations were evident from acute studies with other crustaceans, molluscs and annelids. A small assessment factor is justified because:

- acute effects values of the most sensitive species are close to the lowest chronic effects values (i.e. a low acute to chronic effects ratios);
- a broad range of taxonomic groups is represented by the acute dataset.

This results in a $PNEC_{freshwater\_st}$ of 2 µg l^{-1} Cr(VI).

There is no existing short-term EQS for chromium.

Chromium(III)
Based on the available toxicity data for Cr(III), algae are the most sensitive organisms. The lowest EC50 of 0.32 mg l^{-1} is reported for *Selenastrum capricornutum* biomass gain over 96 hours. For invertebrates, the lowest L(E)C50 values are in the range of 1–15 mg l^{-1} and, for fish, the lowest acute LC50 is 3.33 mg l^{-1}. Given the availability of data for a number of taxa, an assessment factor of 10 applied to the EC50 of 0.32 mg l^{-1} for *Selenastrum capricornutum* is recommended, resulting in a $PNEC_{freshwater\_st}$ of 32 µg l^{-1} Cr(III).

6.2.3 Long-term PNEC for saltwaters

Chromium(VI)
The lowest available NOEC of 4–6 µg l^{-1} in *Mytilus edulis* is unbounded (highest concentration tested) and consequently unsuitable for PNEC derivation. The next lowest value, a 2-week $NOEC_{mortality}$ of 6 µg l^{-1} in *Nereis arenaceodentata* was regarded as valid for PNEC derivation in the EU RAR. Since reliable long-term data are also available for five other taxa, an assessment factor of 10 can be justified, leading to a $PNEC_{saltwater\_lt}$ of 0.6 µg l^{-1} Cr(VI).

The existing EQS for the protection of marine organisms is 15 µg l^{-1} dissolved chromium, based on a range of acute and chronic data to which no assessment factor was applied. The proposed $PNEC_{saltwater\_lt}$ is lower by a factor of ~30, reflecting both the availability of new data and the assessment factor used.

6.2.4 Short-term PNEC for saltwaters

Chromium(VI)
A 96-hour LC50 of 0.32 mg l^{-1} obtained with *Callinectes sapidus* is the basis for the derivation of the $PNEC_{saltwater\_st}$. An assessment factor of 10 is considered adequate to extrapolate to the PNEC because good quality data are available for algae, crustaceans and echinoderms. Although acute data for saltwater fish are lacking, chronic data indicate they are unlikely to be the most sensitive group. In addition, the resulting PNEC will be in the range of the lowest NOECs obtained for species with a short life-cycle such as algae and crustaceans. The proposed $PNEC_{saltwater\_st}$ of 32 µg l^{-1} Cr(VI).

There is no existing short-term EQS for chromium.

6.2.5 PNEC for secondary poisoning

There are avian and mammalian toxicity data for Cr(VI)but not Cr(III). Although there is evidence of bioaccumulation of chromium, in fish and possibly other biota, Cr(VI) is reduced to Cr(III). It is not possible to derive a $PNEC_{secpois}$ for Cr(III) as there are no mammalian or avian toxicity data for this form.

6.2.6 PNEC for sediments

There are insufficient sediment toxicity data to derive a sediment PNEC for chromium.

Table 6.1 Summary of proposed PNECs

Receiving medium/exposure scenario	Proposed PNEC ($\mu g\ l^{-1}$ dissolved)	Existing EQS ($\mu g\ l^{-1}$ total dissolved chromium)
Chromium(VI)		
Freshwater/long-term	0.47 (det), 3.4 (SSD)	Range from 5–50, depending on hardness
Freshwater/short-term	2	No standard
Saltwater/long-term	0.6	15
Saltwater/short-term	32	No standard
Chromium(III)		
Freshwater/long-term	4.7	-
Freshwater/short-term	32	-
Saltwater/long-term	No proposal	-
Saltwater/short-term	No proposal	-

6.3 Analysis

The lowest proposed PNEC derived for chromium is 0.47 $\mu g\ l^{-1}$. Current analytical methodologies provide detection limits as low as 1 $\mu g\ l^{-1}$. Since the data quality requirements are that, at a third of the EQS, total error of measurement should not exceed 50 per cent, they may not offer adequate performance to analyse for the lowest TGD-derived PNECs for water.

6.4 Implementation issues

Before PNECs for chromium can be adopted as EQSs, it will be necessary to address the following issues:

Chromium(VI)

1. The proposed PNECs for the protection of freshwater organisms from long-term exposure to Cr(VI) are suitable for adoption as EQSs. However, risks from Cr(VI) are greater than from Cr(III) and should, therefore, take priority.

2. The PNEC derived using the SSD approach is preferred over the PNEC obtained by application of an assessment factor to critical data. Whilst the use of an SSD is a legitimate option within the Annex V methodology, this approach was not unanimously supported by the EQS peer review panel.

3. Analytical sensitivity may not be adequate for assessing compliance with the PNECs for Cr(VI) and so further method development may be necessary before PNECs can be adopted as EQSs.

4. Existing EQSs are recommended as interim standards whilst this work is being undertaken.

Chromium(III)

1. Risks from Cr(III) are small so any EQSs may be required only in exceptional circumstances.

2. Because background levels of Cr(III) are low, an added risk approach may be recommended, but would first require an appreciation of background concentrations of Cr(III) at a defined range of scales.

3. Since there is no existing EQS, there can be no interim standard for Cr(III) whilst this work is being undertaken.

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List of abbreviations

AA	annual average
AAS	atomic absorption spectroscopy
AES	graphite spark atomic emission spectrometry
AF	assessment factor
BCF	bioconcentration factor
BNC	base-neutralising capacity
bw	body weight
CAS	Chemical Abstracts Service
CI	confidence interval
Defra	Department for Environment, Food and Rural Affairs
DO	dissolved oxygen
EC50	concentration effective against 50% of the organisms tested
ECB	European Chemicals Bureau
ECD	electron capture detection
ECx	concentration effective against X% of the organisms tested
ET50	exposure time at which the test concentration is effective against 50% of the organisms tested
EQS	Environmental Quality Standard
GFAAS	graphite furnace atomic absorption spectrometry
GLP	Good Laboratory Practice (OECD)
HRGC	capillary column gas chromatography
HSDB	Hazardous Substances Data Bank
IC50	concentration at which the population effect of the organisms tested is inhibited by 50%
ICP-MS	inductively coupled plasma mass spectrometry
IRIS	Integrated Risk Information System
IUPAC	International Union of Pure and Applied Chemistry
KC	Klimisch Criteria
LC50	concentration lethal to 50% of the organisms tested
LCx	concentration lethal to X% of the organisms tested
LOAEL	lowest observed adverse effect level
LOEC	lowest observed effect concentration
lt	long term

LT50	exposure time at which the test concentration is lethal to 50% of the organisms tested
MAC	maximum allowable concentration
MATC	maximum allowable toxicant concentration
MRL	minimum risk level
NAA	neutron activation analysis
NGO	non-governmental organisation
NOAEL	no observed adverse effect level
NOEC	no observed effect concentration
NR	not reported
OECD	Organisation for Economic Co-operation and Development
PNEC	predicted no-effect concentration
ppt	parts per trillion
RAR	Risk Assessment Report
SEPA	Scottish Environment Protection Agency
secpois	secondary poisoning
SNIFFER	Scotland & Northern Ireland Forum for Environmental Research
SSD	species sensitivity distribution
st	short term
TGD	Technical Guidance Document
UKTAG	UK Technical Advisory Group
US EPA	US Environmental Protection Agency
UV-vis	ultraviolet–visible
WFD	Water Framework Directive

ANNEX 1 Data quality assessment sheets

Identified and ordered by reference number (see References & Bibliography).

Data relevant for PNEC derivation were quality assessed as outlined in Section 2.6.

Reference	2

Information on the test species	
Test species used	*Nuria denricus*
Life stage of the test species used	adult, 5 cm, 500 mg
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Range between 194 and 472 µg l^{-1}
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	WRc EQS and ECOTOX database have different effective concentrations. WRc = 1.7 mg l^{-1}
Study conducted to GLP	Not stated

Reliability of study	Unknown
Relevance of study	**Supporting information**
Klimisch Code	**4**

Reference	3

Information on the test species	
Test species used	*Wallago attu*
Life stage of the test species used	9.9 g
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	MATC reported as 250 µg l^{-1}; NOEC as 500 µg l^{-1}
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Supporting information**
Klimisch Code	**4**

Reference	12

Information on the test species	
Test species used	*Salmo gairdneri* Rich.
Life stage of the test species used	Adult, 150–200 g
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Flow-through
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Supporting information**
Klimisch Code	**4**

Reference	14

Information on the test species	
Test species used	*Spirulina platensis*
Life stage of the test species used	Not stated
Holding conditions prior to test	Not stated
Source of the test organisms	Laboratory culture; origin not stated

Information on the test design	
Methodology used	Not carried out to a standardised methodology.
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	0.01, 0.1 1 and 10 mg l^{-1}
Number of replicates per concentration	3
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Temperature
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	No analysis and very difficult to establish the extent of the effect. The relevance of the study therefore is in question.
Study conducted to GLP	Not stated

Reliability of study	Reliable with restriction
Relevance of study	Questionable relevance
Klimisch Code	3

Reference	15

Information on the test species	
Test species used	*Pimephales promelas*
Life stage of the test species used	Larvae
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Sodium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Flow-through
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	Unknown
Relevance of study	**Supporting information**
Klimisch Code	**4**

Reference	18

Information on the test species	
Test species used	*Oncorhynchus mykiss*
Life stage of the test species used	Gemetes
Holding conditions prior to test	Not stated
Source of the test organisms	Stock brood

Information on the test design	
Methodology used	Not carried out to a standardised methodology.
Form of the test substance	Potassium dichromate
Source of the test substance	Merck
Type and source of the exposure medium	Diluent (not seawater)
Test concentrations used	0.0004–100 mg l^{-1}
Number of replicates per concentration	Not stated (from graphs there appears to be no replication)
Number of organisms per replicate	Not stated (diluted sperm)
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	Effects based on measured concentrations, but no mention of replication. This appears to be a valid study. However, the sperm underwent significant preparation in the test so the relevance to the real world may be in question.
Study conducted to GLP	Not stated

Reliability of study	Reliable
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	31

Information on the test species	
Test species used	*Hydrilla verticillata*
Life stage of the test species used	Not stated
Holding conditions prior to test	Held under constant light at 25°C
Source of the test organisms	Field collected

Information on the test design	
Methodology used	Not carried out to a standardised methodology.
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Hoaglands solution
Test concentrations used	0.001–1 mg l^{-1}
Number of replicates per concentration	3
Number of organisms per replicate	1?
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	Not stated
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	No analysis. The relevance of the effect (peroxidase activity) is in question. Effects on growth only occurred at 1 mg l^{-1}.
Study conducted to GLP	Not stated

Reliability of study	Reliable with restriction
Relevance of study	Questionable relevance
Klimisch Code	3

Reference	**34**

Information on the test species	
Test species used	*Odonthestes bonariensis*
Life stage of the test species used	14 days
Holding conditions prior to test	Dechlorinated tap water, hardness 215 mg l^{-1} $CaCO_3$; pH 7.4; 22 ± 1°C; dissolved oxygen (DO) ≥7 mg l^{-1}
Source of the test organisms	Field fertilization of eggs from Lobos Lagoon (35°17' S, 59° 7' W, Lobos, Buenos Aires

Information on the test design	
Methodology used	Non-standard but well described
Form of the test substance	Potassium dichromate
Source of the test substance	Anedra
Type and source of the exposure medium	Dechlorinated tap water as above
Test concentrations used	Control + five test concentrations
Number of replicates per concentration	3
Number of organisms per replicate	10
Nature of test system (static, semi-static or flow-through, duration, feeding)	Semi-static renewal every 24 hours
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Yes
Water quality criteria satisfied	Yes
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	**39**

Information on the test species	
Test species used	*Selenastrum capricornutum*
Life stage of the test species used	Exponential growth
Holding conditions prior to test	Not stated
Source of the test organisms	Strain ATCC 22662

Information on the test design	
Methodology used	Not stated
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Not stated
Measurement of exposure concentrations	No
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Supporting information**
Klimisch Code	**4** (ECOTOX database document code M)

Reference	**49**

Information on the test species	
Test species used	*Daphnia magna* Straus
Life stage of the test species used	Neonate <24 hours
Holding conditions prior to test	ASTM hard water with organic additive at 20°C in groups of 10 animals per litre of medium
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not carried out to a standardised methodology, but the test procedure was described.
Form of the test substance	Sodium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	ASTM medium with an organic additive
Test concentrations used	control + six toxicant concentrations
Number of replicates per concentration	10
Number of organisms per replicate	One animal per litre of medium, fed *C. vulgaris* (0.322 mg carbon/daphnia/day).
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static renewal every other day
Measurement of exposure concentrations	No
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Yes
Endpoint comment	Stated as total Cr concentration not as Cr^{6+} ion
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	61

Information on the test species	
Test species used	*Chlorella* sp.
Life stage of the test species used	Exponential growth
Holding conditions prior to test	Cultivated on a mechanical shaker (Gerhardt LS 5) with 100 rpm. The shaking was performed to improve gas exchange and reduce pH variation in the stock solutions. Every day the stock solution was diluted with fresh medium in order to keep it in exponential growth.
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Amended ISO 8692
Form of the test substance	Potassium dichromate
Source of the test substance	Riedel-de Haën, Seelze, Germany, (UN No. 2811)
Type and source of the exposure medium	Algal medium
Test concentrations used	0, 0.1035, 0.207, 0.3105 mg l^{-1}
Number of replicates per concentration	Not stated
Number of organisms per replicate	10^3 cells/ml
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No – stock solution only
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	Non-standard endpoint – nitrogen content; study authors suggest refinement of test method required.
Study conducted to GLP	Not stated

Reliability of study	**Unreliable**
Relevance of study	**Relevant**
Klimisch Code	**3**

Reference	64

Information on the test species	
Test species used	*Pimephales promelas* *Ictalurus punctatus*
Life stage of the test species used	*P. promelas*: 3–14 days *I. punctatus*: 4 weeks
Holding conditions prior to test	Dechlorinated tap water; 23–26°C; pH 7.9–8.1; hardness 88–108 mEq l^{-1}; DO 7.9–8.5 mg l^{-1}.
Source of the test organisms	*P. promelas:* established laboratory culture University of North Texas. *I. punctatus*: 2-week-old fish obtained from D & B Fish Farms in Crockett, Texas

Information on the test design	
Methodology used	Non-standard but described
Form of the test substance	Potassium dichromate
Source of the test substance	Fisher Scientific Co. (Fair Lawn, NJ)
Type and source of the exposure medium	Dechlorinated tap water, as for holding conditions
Test concentrations used	Range 0–12 mg l^{-1}
Number of replicates per concentration	2
Number of organisms per replicate	10
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	Yes on first and last days. Minimal difference found and mean used for computing LC50
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Yes
Water quality criteria satisfied	Yes
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	Reliable
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	66

Information on the test species	
Test species used	*Daphnia magna* (Straus)
Life stage of the test species used	<24 hours
Holding conditions prior to test	Same conditions as test without toxicant
Source of the test organisms	Italian Institute of Hydrobiology, Pallanza, Italy

Information on the test design	
Methodology used	Not carried out to a standardised methodology, but the test procedure was described.
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Well water
Test concentrations used	3.5, 7 and 14 µg l^{-1} Cr(VI) at two feeding levels
Number of replicates per concentration	6
Number of organisms per replicate	5
Nature of test system (static, semi-static or flow-through, duration, feeding)	Semi-static (food and medium renewed every other day) Half fed on 1.2 x 10^5 cells/ml of *S. acutus* and rest on 0.24 x 10^5 cells/ml
Measurement of exposure concentrations	Stock solution only
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Yes
Endpoint comment	NOEC survival, growth and fecundity 3.5 µg l^{-1} at both feeding levels 7 µg l^{-1} significant reduction (*P* <0.001) life span, but no effect on growth and no. of neonates. 14 µg l^{-1}: significant reduction (*P* <0.001) survival with extinction of both cohorts within 40 days and had different effects on growth and fecundity depending on feeding regime.
Study conducted to GLP	Not stated

Reliability of study	Reliable
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	68

Information on the test species	
Test species used	*Salmo salar*
Life stage of the test species used	Eyed egg swim-up fry
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Sodium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	WRc EQS 10% mortality; 70% at 0.1 mg l^{-1}
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Relevant**
Klimisch Code	**4**

Reference	71

Information on the test species	
Test species used	*Artemia franciscana*
Life stage of the test species used	Neonate <24 hours
Holding conditions prior to test	Standard seawater was prepared by dissolving the following substances in distilled and deionized water: NaCl, 26.4 g l^{-1}; KCl, 0.84 g l^{-1}; $CaCl_2$, 1.26 g l^{-1}; $MgCl_2$, 2.15 g l^{-1}; $MgSO_4$, 2.72 g l^{-1}; $NaHCO_3$, 0.17 g l^{-1}; and H_3BO_3, 0.03 g l^{-1}.
Source of the test organisms	Hatched from cysts that were bought from Creasel, Belgium.

Information on the test design	
Methodology used	Multiwell plates. Experiment carried out in duplicate.
Form of the test substance	Potassium dichromate
Source of the test substance	Fluka, Germany.
Type and source of the exposure medium	Standard seawater as above
Test concentrations used	Concentration range (1–12 mg l^{-1})
Number of replicates per concentration	3
Number of organisms per replicate	10
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Yes
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	85

Information on the test species	
Test species used	*Champia parvula*
Life stage of the test species used	Not stated
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Chromium(VI)
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	Not stated
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	Very few details available with which to quality assess the study
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Relevant**
Klimisch Code	**4 (unknown)**

Reference	92

Information on the test species	
Test species used	*Daphnia magna*
Life stage of the test species used	<24 hours
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Chromium chloride
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Semi-static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	EU RAR reports NOEC as 3.4 mg l^{-1}, WRc EQS and ECOTOX database as 0.7 mg l^{-1}
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Relevant**
Klimisch Code	**4** (ECOTOX database document code C)

Reference	101

Information on the test species	
Test species used	*Paracentrotus lividus* (Lamark)
Life stage of the test species used	Embryo
Holding conditions prior to test	Filtered natural seawater salinity 36 ‰; 18 ± 1°C
Source of the test organisms	Adults collected from Tyrrenian Sea (Bay of Naples), gametes were harvested and embryos reared for toxicity testing

Information on the test design	
Methodology used	Standard embryo toxicity test
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Natural seawater from pristine site
Test concentrations used	Nominal concentration range 2.9–24 mg l^{-1}
Number of replicates per concentration	3
Number of organisms per replicate	250–300 fertilised eggs, observations made on 100 randomly chosen individuals
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Yes
Water quality criteria satisfied	Not stated
Endpoint comment	Experiment carried out 13 times and 11 used to produce a mean value since those not meeting test validity criteria excluded
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	107

Information on the test species	
Test species used	*Portunus pelagicus*
Life stage of the test species used	Megalopa (final larval stage)
Holding conditions prior to test	Held at 26°C; 33 g l^{-1} salinity; substrate clean beach sand
Source of the test organisms	Crab larvae hatched in laboratory from eggs extruded by mature *P. pelagicus* females captured in Moreton Bay, Queensland, Australia

Information on the test design	
Methodology used	Non standard
Form of the test substance	Potassium dichromate (analytical grade)
Source of the test substance	Not stated
Type and source of the exposure medium	Seawater pumped ~1 km offshore Moreton Bay, Queensland, Australia
Test concentrations used	Test concentrations based on logarithmic scale of cation
Number of replicates per concentration	5
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Semi-static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Yes
Endpoint comment	Geometric mean of NOEC and LOEC
Study conducted to GLP	Not stated

Reliability of study	Reliable with restrictions
Relevance of study	**Relevant**
Klimisch Code	**3**

Reference	108

Information on the test species	
Test species used	*Daphnia magna*
Life stage of the test species used	<24 hours
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Sodium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Flow-through
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Relevant**
Klimisch Code	**4** (ECOTOX database document code C)

Reference	110

Information on the test species	
Test species used	*Daphnia magna*
Life stage of the test species used	<24 hours
Holding conditions prior to test	Not state
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Chromium
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	After 21 days of exposure to 5 ppb Cr, the descendants of a single chromium-tolerant individual of *Daphnia magna* produced 67% more neonates than animals of the same age from the stock culture. At the end of the experiment, 93% of the chromium-tolerant descendants were still alive, but no individual from the stock culture survived.
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Relevant**
Klimisch Code	**4** (ECOTOX database document code C)

Reference	111

Information on the test species	
Test species used	*Spirostomum ambiguum*
Life stage of the test species used	Not stated
Holding conditions prior to test	Static renewal; pH 7.5; hardness 150 mg l^{-1} $CaCO_3$; 20–25°C
Source of the test organisms	Established laboratory culture

Information on the test design	
Methodology used	Test performed in 24-well polystyrene multiwell plate
Form of the test substance	Chromic nitrate
Source of the test substance	Not stated
Type and source of the exposure medium	
Test concentrations used	Control + five toxicant concentrations
Number of replicates per concentration	3
Number of organisms per replicate	10
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	EC50 determined by graphical interpolation of test response versus toxicant concentration (log scale)
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	117

Information on the test species	
Test species used	*Oncorhynchus tshawytscha* *Oncorhynchus mykiss*
Life stage of the test species used	Egg
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Sodium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Flow-through
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Supporting information**
Klimisch Code	**4**

Reference	118

Information on the test species	
Test species used	*Salmo trutta* L *Cyprinus carpio*
Life stage of the test species used	>1 year: 105–176 g >3 year: 57–190 g
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Flow-through
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	WRc EQS reduction in body weight, suppression of immune response (*Salmo trutta*)
Study conducted to GLP	Not stated

Reliability of study	Unknown
Relevance of study	**Supporting information**
Klimisch Code	**4**

Reference	129

Information on the test species	
Test species used	*Glaucocystis nostochinearum*
Life stage of the test species used	Not recorded
Holding conditions prior to test	Axenic cultures in modified Chu-10 medium at 26 ± 2°C
Source of the test organisms	Organism field collected from a Cr polluted pond, Unnao, UP, India).

Information on the test design	
Methodology used	Not carried out to a standardised methodology, but the test procedure was described.
Form of the test substance	Potassium chromate
Source of the test substance	Not stated
Type and source of the exposure medium	Algal medium
Test concentrations used	0, 0.01, 0.05, 0.1, 1.0, 2.5, 5.0 and 10 mg l^{-1}
Number of replicates per concentration	Not stated
Number of organisms per replicate	15 µg protein/ml of algal inoculum
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	No
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Unreliable**
Relevance of study	**Relevance unknown**
Klimisch Code	**3**

Reference	134

Information on the test species	
Test species used	*Euglena gracilis*
Life stage of the test species used	In exponential growth
Holding conditions prior to test	Mineral medium (Buetow 1982), with sodium acetate as a carbon source, pH 7 at 24 ± 1°C
Source of the test organisms	Axenic culture, strain UTEX 364 from the Culture collection of Algae of the Texas University

Information on the test design	
Methodology used	US EPA/600/4-85/014/:76–103 Assay repeated three times
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Culture medium as above
Test concentrations used	0, 2, 4, 6, 8 and 12 µM Cr(VI)
Number of replicates per concentration	2
Number of organisms per replicate	10^4 cells/ml
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	NA
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	NA
Endpoint comment	IC50 obtained using the Probit Algae program (Walsh *et al.* 1987)
Study conducted to GLP	Not stated

Reliability of study	Reliable
Relevance of study	Relevant
Klimisch Code	2

Buetow D E, 1982 Editor *The Biology of Euglenoids Volume III*. New York: Academic.
Walsh G E, Deans C H and McLaughlin L L, 1987 *Comparison of the EC50s of algal toxicity tests calculated by four methods*. Environmental and Toxicological Chemistry, **6**, No. 10, 767–770.

Reference	141

Information on the test species	
Test species used	*Hydrilla verticillata*
Life stage of the test species used	Not stated
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Chromium
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Not stated
Measurement of exposure concentrations	No
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Supporting information**
Klimisch Code	**4** (ECOTOX database document code M)

Reference	143

Information on the test species	
Test species used	*Lemna gibba* *Lemna minor*
Life stage of the test species used	Not stated
Holding conditions prior to test	Standard growth conditions with sterile, 7-day renewed nutrient solution. Clones acclimated for 1 month at assay conditions.
Source of the test organisms	*L. gibba* field collected El Pescado stream, Buenos Aires Province, Argentina, *L. gibba* clone (G3) and *L. minor* provided by Institute of General Botany, Friedrich-Schiller-University of Jena, Germany

Information on the test design	
Methodology used	Non standard
Form of the test substance	Potassium dichromate
Source of the test substance	Anedra
Type and source of the exposure medium	Nutrient solution
Test concentrations used	Nominal as Cr^{6+} six concentrations in range 0.1–5 mg l^{-1} (*L. gibba*) 0.05–3 mg l^{-1} (*L. minor*)
Number of replicates per concentration	3–4
Number of organisms per replicate	4–8 fronds
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static partial renewal every 2–3 days.
Measurement of exposure concentrations	No (total metal concentration verified in stock solution by atomic absorption spectrophotometry.
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	Taken from graph – question as to relevancy as grown in nutrient solution
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Unknown**
Klimisch Code	**3**

Reference	145

Information on the test species	
Test species used	*Ampelisca araucana*
Life stage of the test species used	Not stated
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Not stated
Measurement of exposure concentrations	No
Measurement of water quality parameters	Temperature
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	Not stated
Study conducted to GLP	Not stated

Reliability of study	Unknown
Relevance of study	**Relevant**
Klimisch Code	**4** (ECOTOX database document code M)

Reference	146

Information on the test species	
Test species used	*Pimephales promelas*
Life stage of the test species used	30 day, 0.15 g
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Sodium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Flow-through
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Unknown**
Relevance of study	**Supporting information**
Klimisch Code	**4**

Reference	175

Information on the test species	
Test species used	*Mesocyclops pehpeiensis*
Life stage of the test species used	3–4-day-old nauplii: 48-hour test <12-hour-old: 9-day test
Holding conditions prior to test	Filtered water
Source of the test organisms	Laboratory culture derived from single egg-bearing female from reservoir in the northern part of Hong Kong

Information on the test design	
Methodology used	Non-standard but adequately described
Form of the test substance	Potassium dichromate
Source of the test substance	Not stated
Type and source of the exposure medium	Moderately hard synthetic water solution (APHA 1995)
Test concentrations used	Control + five test concentrations
Number of replicates per concentration	5
Number of organisms per replicate	6
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static (48-hour test) Semi-static (24-hour renewal) 9-day test
Measurement of exposure concentrations	No
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Yes
Water quality criteria satisfied	Not stated
Endpoint comment	
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Relevant**
Klimisch Code	**2**

American Public Health Association (APHA), 1995 *Standard methods for the examination of water and waste water* (14th edn.). Washington: APHA.

Reference	**179**

Information on the test species	
Test species used	*Mytilus edulis*
Life stage of the test species used	Not stated
Holding conditions prior to test	Not stated
Source of the test organisms	Not stated

Information on the test design	
Methodology used	Not stated
Form of the test substance	Chromium(VI)
Source of the test substance	Not stated
Type and source of the exposure medium	Not stated
Test concentrations used	Not stated
Number of replicates per concentration	Not stated
Number of organisms per replicate	Not stated
Nature of test system (static, semi-static or flow-through, duration, feeding)	Static
Measurement of exposure concentrations	Not stated
Measurement of water quality parameters	Not stated
Test validity criteria satisfied	Not stated
Water quality criteria satisfied	Not stated
Endpoint comment	Bioconcentration study. No effects on growth at highest concentration tested.
Study conducted to GLP	Not stated

Reliability of study	**Unreliable**
Relevance of study	**Not relevant**
Klimisch Code	**3**

Reference	186

Information on the test species	
Test species used	1. *Physa fontinalis* 2. *Asellus aguaticus* 3. *Gammarus fossarum* 4. *Niphargus rhenorhodanensis* 5. *Hydropsyche pellucidula* 6. *Heptagenia sulphurea*
Life stage of the test species used	1–4. adult 5 and 6. last-instar larvae
Holding conditions prior to test	Acclimatised to laboratory conditions for 2 days prior to testing
Source of the test organisms	Organisms collected from field; Ain River 30 km upstream from Lyon (France) in July 1999; 240-hour test. River weakly contaminated but regularly used as test station.

Information on the test design	
Methodology used	Subacute toxicity test.
Form of the test substance	Potassium chromium stock solution
Source of the test substance	Not stated
Type and source of the exposure medium	Tests carried out with filtered river water collected at the same time as organisms
Test concentrations used	Three plus control – 2, 20 and 200 mg l^{-1} nominal mean measured 1.88, 19.92 and 207.2 mg l^{-1}
Number of replicates per concentration	3
Number of organisms per replicate	5
Nature of test system (static, semi-static or flow-through, duration, feeding)	Flow-through – fed every 48 hours with Tetramin
Measurement of exposure concentrations	Yes. Samples taken every 24 hours. Analysis – HACH colorimetric method*
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Yes
Water quality criteria satisfied	Yes
Endpoint comment	Spearman–Karber method used to calculate LC50 using measured concentrations of the metal ion. Only three test concentrations at wide intervals making LC50 calculation unsuitable for risk assessment.
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Supporting information**
Klimisch Code	**3**

***** Hach Company, 1992 HACH colorimetric method. *Chromium, hexavalent, for water and wastewater, Method 8023*, In DR/2000 Spectrophotometer Procedures Manual (7th edn.). pp. 113–117. Loveland, CO: Hach Company.

Reference	193

Information on the test species	
Test species used	*Daphnia magna*
Life stage of the test species used	<24 hours
Holding conditions prior to test	US EPA standard protocol
Source of the test organisms	Korea Research Institute of Chemical Technology, Taejon, South Korea

Information on the test design	
Methodology used	Not carried out to a standardised methodology, but the test procedure was described.
Form of the test substance	99.5% analytical grade potassium dichromate
Source of the test substance	Aldrich Chemical Co., Milwaukee, WI
Type and source of the exposure medium	Not stated
Test concentrations used	Control + nine concentrations
Number of replicates per concentration	4
Number of organisms per replicate	5
Nature of test system (static, semi-static or flow-through, duration, feeding)	static
Measurement of exposure concentrations	Yes
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Yes
Water quality criteria satisfied	Yes
Endpoint comment	Presence of Fe(II) decreased toxicity of Cr^{6+} due to reduction of Cr^{6+} to Cr^{3+} . Equilibration of Fe(II) prior to addition of organisms had no effect on Cr^{6+} toxicity. Lowest LC50 of 0.105 mg l^{-1} generated in the absence of iron.
Study conducted to GLP	Not stated

Reliability of study	Reliable
Relevance of study	**Relevant**
Klimisch Code	**2**

Reference	197

Information on the test species	
Test species used	*Moina-australiensis* (Sars)
Life stage of the test species used	<24 hours
Holding conditions prior to test	23°C, pH 7.2 and water hardness 36 mg l^{-1} as $CaCO_3$
Source of the test organisms	Laboratory culture origin not stated

Information on the test design	
Methodology used	Not carried out to a standardised methodology, but the test procedure was described. Each test repeated three times.
Form of the test substance	Potassium dichromate
Source of the test substance	Ajax Univar® BDH AnalaR® Mallinckrodt AR®
Type and source of the exposure medium	Not stated
Test concentrations used	0, 0, 15, 25, 37.5, 60 µg l^{-1} 0, 5, 10, 20, 40 and 80 µg l^{-1} 0, 10, 20, 30, 50 and 80 µg l^{-1}
Number of replicates per concentration	4
Number of organisms per replicate	5
Nature of test system (static, semi-static or flow-through, duration, feeding)	static
Measurement of exposure concentrations	Yes (Cr^{6+}) at end of test (48 hours) by ICP-AES*
Measurement of water quality parameters	Yes
Test validity criteria satisfied	Yes
Water quality criteria satisfied	Yes
Endpoint comment	Significant difference in EC50 for one of the sourced substances
Study conducted to GLP	Not stated

Reliability of study	**Reliable**
Relevance of study	**Relevant**
Klimisch Code	**2**

*ICP-AES = inductively coupled plasma atomic emission spectroscopy

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