Common Implementation Strategy for the Water Framework Directive

Environmental Quality Standards (EQS)

Substance Data Sheet

Priority Substance No. 4

Benzene

CAS-No. 71-43-2

Final version
Brussels, 15 January 2005

Disclaimer

This data sheet provides background information on the setting of the Environmental Quality Standard in accordance with Article 16 of the Water Framework Directive (2000/60/EC). The information was compiled, evaluated and used as outlined in the Manual [4] and has been discussed in a consultative process with the Expert Advisory Forum on Priority Substances and the Expert Group on Quality Standards. Furthermore, it has been peer-reviewed by the SCTEE[7]. The substance data sheet may, however, not necessarily represent the views of the European Commission.

New upcoming information was considered and included up to the date of finalisation of this data sheet. Information becoming available after finalisation of this document will be evaluated in the review process of priority substances according to Art. 16(4) of the Water Framework Directive. If necessary, the Environmental Quality Standard substance data sheets will then be revised in the light of technical and scientific progress.

1 Identity of substance

Priority Substance No: 4	Benzene
CAS-Number:	71-43-2
Classification WFD Priority List *:	PS

* PS: priority substance; PHS: priority hazardous substance; PSR: priority substance under review according to Decision 2455/2001.

2 Proposed quality standards

2.1 Overall quality standards

Ecosystem	**Quality Standard**	**Quality Standard "rounded values"**	**Comment:**
AA-QS inland surface waters	10 µg/l	**10 µg/l**	In the EU risk assessment report it is concluded that there is reason for concern because benzene is carcinogenic to humans and no safe level of exposure can be recommended. In consideration of the precautionary principle it is therefore suggested to keep the levels of this substance in all surface water bodies as low as reasonably possible. The suggested quality standard is based on expert judgement; see 8.6
AA-QS other surface waters covered by the WFD	8 µg/l	**8 µg/l**	See 8.1
MAC-QS (ECO)	49 µg/l	**50 µg/l**	see 8.1

2.2 Specific quality standards

Protection Objective	**Quality Standard**	**Comment:**
Pelagic community (water)	(80 µg/l) 49 µg/l	The 80 µg/l are the result of the PNEC calculation based on long-term toxicity data in the EU risk assessment report. Short-term toxicity data were not considered for calculating the PNEC. However, as effects assessment for short-term effects in line with the provisions of the TGD for intermittent releases leads to a MAC-QS of only 49 µg/l, the annual average quality standard referring to the protection of the pelagic community should as well not exceed this value; see 8.1
Pelagic community (saltwater)	8 µg/l	see 8.1
Benthic community (sediment)	not required	trigger values to establish $QS_{sediment}$ are not met
Predators (second. poisoning)	not required	trigger values to establish $QS_{sec.poisoning}$ are not met
Food uptake by man	QS derivation not possible based on the information available	see 8.4
Abstraction of water intended for human consumption (AWIHC)	1.7 µg/l	No drinking water abstraction standard set in CD 75/440/EEC; drinking water abstraction standard derived on the basis of the drinking water standard and the fraction of benzene not removable from surface water by simple treatment technology in the course of drinking water processing; see 8.5
Water intended for human consumption (WIHC)	1.0 µg/l	Drinking water standard set in CD 98/83/EC

3 Classification

R-Phrases and Labelling	Reference:
F, T; R: 45(Cat. 1)-11-48/23/24/ (according to Annex 1)	[1]
F; R11 - Carc. Cat. 1; R45 - Muta. Cat. 2; R46 - T; R48/23/24/25 - Xn; R65 - Xi; R36/38	[8]

4 Physical and chemical properties

Property	Value:	Ref:	Comments:
Mol. Weight:	78.11 g/mol	[1]	
Water Solubility	1.8 g/l at 25 °C	[1]	
Vapour Pressure:	99.7 hPa at 20 °C	[1]	

5 Environmental fate and partitioning

Property	Value:	Ref:	Comments:
Abiotic degradation Hydrolysis Photolysis (air, OH radicals) Photolysis (surface water)	 6.93 E-7 d^{-1} 1.2 E-12 cm^3 / molec s 6.93E-7 d^{-1}	[1]	 Default EUSES Experimental value Default EUSES
Biodegradation Surface water Soil Aerated sediment	 4.7 E-1 d^{-2} 2.31 E-1 d^{-2} 2.31 E-1 d^{-2}	[1]	 TGD-calculation TGD-calculation TGD-calculation
Partition coefficients Octanol - Water Koc (organic carbon-water) Kp_{soil} Kp sediment $K_{sediment/water}$ $K_{susp\text{-}water}$ (suspended matter-water)	 log Kow 2.13 18.2 - 1023 l/kg 134.15 l/kg 2.683 l/kg 13.415 l/kg 7.51 m^3/m^3 4.254 m^3/m^3	[1]	 Measured Measured TGD-calculation TGD-calculation TGD-calculation TGD-calculation
Bioaccumulation Bioconcentration Factor (BCF) Fish Mussel used in the Risk Assessment	 BCF = 13	[1]	The different experiments show that benzene has a low to moderate bioaccumulation potential. In all but one available tests conducted with fish BCFs were clearly below 100. Estimated from the log Kow of 2.13 using the linear relationship developed by Veith et al. (1979)

6 Effect data (aquatic environment)

The following text and tables – taken from [1] – summarises the most relevant effect data being the basis for the further risk assessment. Further short term and long term toxicity data evaluated in the risk assessment [1] are given in Appendix 1 to this data sheet.

Short term toxicity to fish

In seawater a LC_{50} of 4.9 mg/l was derived with *Oncorhynchus necra* in a static system. The effect value was determined from the initial benzene concentration. However, the authors found a decrease of benzene concentration to 75 % after 24 hours and to 10 % after 96 hours. Therefore, the real effect value may be significantly lower than the nominal value reported by Moles et al. (1979, full ref. in [1])

In freshwater, the lowest LC_{50} of 5.3 mg/l was obtained with *Oncorhynchus mykiss* in a flow-through system with analytical monitoring of the benzene concentration.

Long term toxicity to fish

Table 6.1: long term toxicity to fish

Species	Duration	Effect value [mg/l]	Test system	Reference *
Oncorhynchus mykiss eggs	23-27 days	EC10 – 3.5 µg/l; hatching (effective concentration)	ELS, flow-through system (temperature: 13 °C; dissolved oxygen: 9.8 mg/l; water hardness: 104.3 mg/l $CaCO_3$; pH: 8.0)	Black et al. (1982)
Pimephales promelas (larvae < 24 h old)	32 days	LOEC – 1.6 mg/l (wet weight, length) 0.8 mg/l ≈ NOEC according to TGD as the LOEC was in the 10-20% Effect range.	ELS, flow-through system, (temperature: 25.5 °C, dissolved oxygen: 6 mg/l, water hardness: 46 mg/l $CaCO_3$, pH: 7.7)	Russom and Broderius (1991)

* full reference given in [1]

Short-term toxicity to invertebrates

The lowest EC_{50} of 10 mg/l after 48 h was obtained by Janssen and Persoone (1993). Although this value is based on nominal concentrations and therefore the effective concentration could be significantly lower it is used as effect value for short-term toxicity with invertebrates in the assessment.

Long-term toxicity to invertebrates

Table 6.2: long term toxicity to invertebrates

Species	Duration	Effect value [mg/l]	Effect	Test system	Reference
Ceriodaphnia dubia	7 d	NOEC 3 mg/l LOEC 8.9 mg/l EC50 11.6 mg/l (effective conc.)	reproduction	day semi-static closed glass vial system	Niederlehner et al. 1998

* full reference given in [1]

Toxicity to aquatic plants

Among the available algae toxicity tests only 2 studies with a standardised exposure period of 72 hours are available. In both studies closed systems were employed and the effect values are based on measured concentrations. The results of the 72 h growth inhibition text with *Selenastrum capricornutum, i.e.* E_bC_{50} = 28 mg/l, E_rC_{50} = 100 mg/l, E_bC_{10} = 8.3 mg/l and E_rC_{10} = 34 mg/l (effective conc.), are used for the assessment.

Summary on Endocrine Disrupting Potential

Not relevant.

6.1 Predicted no-effect concentrations (aquatic environment)

PNECs

Compartment	Value	Reference
Surface water	80 µg/l	[1]
Sediment	Quantitative risk assessment not needed	[1]
$PNEC_{oral}$ (secondary poisoning)	Quantitative risk assessment not needed	[1]

6.1.1 Calculation of PNEC surface water [1]

With regard to short-term exposure of animals and algae the available valid LC/EC_{50} values point to similar susceptibility of sensitive taxa in fish and invertebrates (crustaceae), comparing to a somewhat lower overall sensitivity of algae.

The lowest long term effect value was obtained in an embryo-larval-test conducted with *Oncorhynchus mykiss*. In this test Black et al. (1982) found a 23-27 d EC_{10} for hatching and survival of 3.5 µg/l. **The effect values found by Black et al. for several substances (e.g. toluene) are usually very low compared to effect values found by other authors. No explanation for these large discrepancies could be found. However, as it was not possible**

to reproduce the effect values found by Black and his co-workers, Member State's and industry experts advised not to use these data for a derivation of a PNECaqua if other valid fish early life stage tests are available. Therefore, the effect values found by Black et al. for *Oncorhynchus mykiss* and for the amphibian species *Rana pipiens* and *Ambystoma gracile* are not employed in the further effects assessment.

Instead, the NOEC of 0.8 mg/l found by Russom and Boderius in the ELS test with *Pimephales promelas* is used as basic value for the PNECaqua derivation.

Long-term tests with species from three trophic levels are available. Therefore, the application of an assessment factor of 10 on the lowest NOEC is justified [1].

$PNEC_{aqua}$ = 0.08 mg/l

6.1.2 Calculation of PNEC sediment

There are no results from sediment tests with benthic organisms available. According to the physico-chemical properties currently known, there is nothing indicating that benzene accumulates in sediment. Therefore a quantitative risk assessment seems not to be necessary for this compartment. [1]

6.1.3 Calculation of the PNEC for non compartment specific effects relevant for the food chain (secondary poisoning)

As benzene has only a low bioaccumulation potential it is not required to carry out a risk characterization for secondary poisoning. [1]

7 Effect data (human health) [1]

Summary human health

Man exposed indirectly via the environment:

Conclusion iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

Due to the genotoxic and carcinogenic effects of benzene there is reason for concern. Benzene is carcinogenic to humans and no safe level of exposure can be recommended [1].

Consumers oral:

Intake of benzene by food and water is only a minor source and can be neglected here [1] (i.e. in the risk assessment).

8 Calculation of quality standards

8.1 Quality standards for water

Freshwater

It is suggested to impose the aquatic PNEC derived in the risk assessment as quality standard for freshwater.

$QS_{freshwater}$ = 80 µg benzene L^{-1}

As the log Kow is <3 and the partition coefficient water-SPM is low it is not deemed sensible to calculate a corresponding QS_{water} referring to the concentration of benzene in suspended particulate matter (SPM). (Normally, benzene is analysed in water.)

Transitional, coastal and territorial waters

Some effect data for saltwater species (fish, crustaceans, algae) are available and (no)effect concentrations do not obviously differ from those obtained for freshwater species of the same taxonomic groups. Therefore, the $QS_{saltwater}$ can be derived from the same data set as the $QS_{freshwater}$. To this end, the TGD assessment factor method as proposed for the marine effects assessment is used (section 4.3.2.2 of the Manual [4]).

As no acute or long term tests for additional marine taxonomic groups (beside fish, crustaceans, algae) are available in the risk assessment [1], an assessment factor of 100 is applied to the most sensitive species in long term studies (*Pimephales promelas* ELS, NOEC 0.8 mg/l).

$QS_{saltwater}$ = 8 µg benzene L^{-1}

Quality standard accounting for transient concentration peaks (MAC-QS)

Acute toxicity data are available for freshwater and marine fish, crustaceans and algae. Further test results for amphibians are available. The lowest acute toxicity value obtained in a standard test is a 96 hr LC_{50} of 4.9 mg/l derived with *Oncorhynchus necra* in a static system (seawater). (Moles et al. 1979, full ref. in [1]).

The MAC-QS is derived based on the LC_{50} for *Oncorhynchus necra* and the guidance given in the TGD on the effects assessment for intermittent releases (section 3.3.2 of part II of [3]). The standard assessment factor of 100 is applied.

MAC-QS = 49 µg benzene L^{-1}

8.2 Quality standard for sediment

Since the log Kow is only 2.13 and the partition coefficient water – SPM is also very low the calculation of sediment quality standards is not required (trigger values are not met).

8.3 Secondary poisoning of top predators

As benzene has only a low log Kow (2.13) and a low bioconcentration potential (BCF ≈ 13) it is not required to calculate a standard accounting for secondary poisoning (trigger values are not met).

8.4 Quality standard referring to food uptake by humans

Benzene is carcinogenic to humans and no safe level of exposure can be recommended [1]. Intake of benzene by food and water is only a minor source and can be neglected according to the opinion stated in the risk assessment [1].

As adequate threshold levels cannot be calculated based on the data available in the risk assessment report, no quality standard can be derived by the method proposed in the manual (section 4.3.2.6) [4].

Consultation of experts in human toxicology is required with regard to the necessity of a quality standard referring to human health as well as with regard to a possible methodological approach.

8.5 Quality standard for drinking water abstraction

No "A1 value" for drinking water abstraction has been set in the context of Council Directive 75/440/EEC, but a drinking water standard (DWS) is in place (1 µg benzene L^{-1}, CD 98/83/EC). This drinking water standard is by far lower than the quality standard required for the protection of the freshwater community.

The DWS is a limit value never to be exceeded at the tap. The MAC-QS (ECO) derived for the protection of the freshwater community (49 µg/l) may therefore not suffice to allow for compliance with the DWS if only simple purification techniques (category A1 of CD 75/440/EEC, i.e. filtration and disinfection) are used for the abstraction of drinking water from surface water bodies according to Art. 7 of the WFD.

An assessment by experts in drinking water technology with regard to the question which fraction of the amount of benzene present in raw water can be removed by usual simple treatment procedures might be helpful. According to French experts [5] the percentage of benzene in surface water that cannot be removed by simple treatment during drinking water processing is 40% (i.e. fraction 0.4). Based on this figure and the drinking water standard, a maximum acceptable concentration in surface water bodies designated for the **a**bstraction of **w**ater **i**ntended for **h**uman **c**onsumption (AWIHC) can be calculated:

MAC-QS (AWIHC) = DWS (1 µg/l) / fraction not removable by simple treatment (0.4) = **1.7 µg/l**

8.6 Overall quality standard

In the case of benzene the protection of human health from adverse effects due to drinking water uptake or the ingestion of food originating from aquatic environments is the most relevant objective of protection. In the EU risk assessment report it is stated that due to the genotoxic and carcinogenic effects of benzene there is reason for concern. **Benzene is carcinogenic to humans and no safe level of exposure can be recommended** [1].

In the light of this conclusion in the RAR it is suggested to keep in accordance with the precautionary principle the environmental concentration of Benzene in surface water bodies as low as reasonably possible. In consideration of the drinking water standard in place (1 µg/l), the surface water standard proposed by the former CSTÉ [6] (10 µg/l) and the surface water quality standards derived by the Member States (2-240 µg/l, see Annex 1 of [4]) it is therefore proposed that an annual average quality standard of 10 µg/l may be set for inland surface waters. For the other surface waters covered by the WFD an AA-QS of 8 µg/l as derived by the agreed methodology my apply. In areas designated in accordance with Art. 7 of the WFD for abstraction of water intended for human consumption, specific measures with the objective to achieve compliance with the drinking water standard at the tap may be applied if this standard is exceeded in the raw water.

9. References

[1] European Union Risk Assessment Report: Benzene (CAS No: 71-43-2). Draft report (part environment, May 8th, 2001, file R063_0105_env; part human health - 03 May 2001 (file R063_0105_hh).)

[2] COM(2001)262 final: Communication from the Commission to the Council and the European Parliament on the implementation of the Community Strategy for Endocrine Disrupters – a range of substances suspected of interfering with the hormone system of humans and wildlife. (*Table 2:* substances with evidence of ED or evidence of potential ED which are neither restricted nor currently being addressed under existing Community legislation. *Table 3:* Substances with evidence of ED or evidence of potential ED, already regulated or being addressed under existing legislation. *Table 4:* Substances with insufficient data in the BKH Report)

[3] Technical Guidance Document on Risk Assessment in Support of Commission Directive 93/67/EEC on Risk Assessment for New Notified Substances and Commission Regulation (EC) No 1488/94 on Risk Assessment for Existing Substances and Directive 98/8/EC of the European Parliament and the Council Concerning the placing of biocidal products on the market. Part II. European Commission Joint Research Centre, EUR 20418 EN/2, © European Communities 2003. Available at the internet-site of the European Chemicals Bureau: http://ecb.jrc.it/existing-chemicals/

[4] Manual of the Methodological Framework Used to Derive Environmental Quality Standards for Priority Substances of the Water Framework Directive. Peter Lepper, Fraunhofer-Institute Molecular Biology and Applied Ecology, 15 November 2004. Available at the internet-site of the European Commission: http://europa.eu.int/comm/environment/water/water-dangersub/pri_substances.htm

[5] Additional comments by France on Quality Standards for Benzene, Chloroform, Anthracene and Mercury. Submitted by e-mail 29.06.2003 by Vincent Bonnomet, INERIS DRC/ECOT, Verneuil-en-Halatte, France

[6] F. Bro-Rasmussen et al., EEC Water Quality Objectives for Chemicals Dangerous to Aquatic Environment (List 1). Reviews of Environmental Contamination and Toxicology Vol. 137, pp.83-110, Springer-Verlag, New York (1994)

[7] Opinion of the Scientific Committee on Toxicity, Ecotoxicity and the Environment (SCTEE) on "The Setting of Environmental Quality Standards for the Priority Substances included in Annex X of Directive 2000/60/EC in Accordance with Article 16 thereof", adopted by the CSTEE during the 43rd plenary meeting of 28 May 2004, European Commission Health & Consumer Protection Directorate General, Brussels. http://europa.eu.int/comm/health/ph_risk/committees/sct/documents/out230_en.pdf

[8] ESIS: European Chemicals Bureau – ESIS (European Substances Information System), July 2005. http://ecb.jrc.it/existing-chemicals/ ⇒ tick ESIS button, then enter CAS or EINECS number of substance.

ANNEX 1:

Further short term and long term toxicity data evaluated in the European Union Risk Assessment Report [1]

Criteria for validation of toxicity test results [1]

Studies are classed as valid if they fully describe the test material used, the test organism, the test method and conditions and the if endpoint concentration is based upon measured levels. Where only some of these criteria are described the tests may be used with care or considered not valid. Studies marked 'use with care' can be used to support valid studies. For some studies a 'lack of data' marking is given. In these cases the original paper has not been received but only a citation. However the results from these non-validated studies are higher than those from the studies already checked so validating such references will not change the outcome of the PNEC derivation.

A1.1 Fish

Table A.1 summarises the acute toxicity test results for fish exposed to benzene.

Other test results are available in addition that could not be checked on validity due to missing information on test conditions.

Short-term effect values between 4.9 mg/l and 63.5 mg/l were reported. The most sensitive species seem to be the salmonids. In seawater a LC_{50} of 4.9 mg/l was derived with *Oncorhynchus necra* in a static system. The effect value was determined from the initial benzene concentration. However, the authors found a decrease of benzene concentration to 75 % after 24 hours and to 10 % after 96 hours. Therefore, the real effect value may be significantly lower than the nominal value reported by Moles et al. In freshwater, the lowest LC_{50} of 5.3 mg/l was obtained with *Oncorhynchus mykiss* in a flow-through system with analytical monitoring of the benzene concentration.

Results from early-life-stage tests with two fish species are available. Black et al. (1982) tested benzene in an embryo-larval test with *Oncorhynchus mykiss* as test organism.

In a flow-through system (temperature: 13 °C; dissolved oxygen: 9.8 mg/l; water hardness: 104.3 mg/l $CaCO_3$; pH: 8.0) eggs were exposed to the test substance within 30 minutes after fertilization. Four benzene concentrations between 0.013 mg/l and 5.02 mg/l were tested. Exposure was maintained through 4 days after hatching. Average hatching time for *Oncorhynchus mykiss* was 23 days. Benzene concentration was measured daily by GLC or HPLC.

One test parameter was the egg hatchability, including all embryos (normal or aberrant). Another test parameter was the survival of normal organisms, determined at hatching and 4 days posthatching. Normal organisms were defined as those animals that were free of gross teratic defects.

A.1.2 Aquatic invertebrates

Table A.2 summarises the short term toxicity data of benzene to aquatic invertebrates.

Short term toxicity:

The lowest EC_{50} of 10 mg/l after 48 h was obtained by Janssen and Persoone (1993). Although this value is based on nominal concentrations and therefore the effective concentration could be significantly lower it is used as effect value for short-term toxicity with invertebrates in the assessment.

Long-term toxicity:

Only one valid long term test for invertebrates. Therefore, the NOEC of 3 mg/l found for *Ceriodaphnia dubia* is used as long-term effect value for invertebrates in the further assessment.

A1.3 Aquatic algae and plants

Table A.3 summarises the toxicity of benzene to aquatic algae.

A1.4 Amphibians

In an embryo-larval test with the amphibian species *Rana pipiens* (Leopard frog) and *Ambystoma gracile* (Northwestern Salamander) different benzene concentrations were tested by Black et al. (1982).

In a flow-through system (temperature: 20.2 ± 0.5 °C; dissolved oxygen: 7.5 mg/l; water hardness: 96.6 ± 1 mg/l $CaCO_3$; pH: 7.7 ± 0.02) eggs were exposed to 5 resp. 6 different benzene concentrations within 30 minutes of fertilization for *Rana pipiens* and within 2-8 hours postspawning for *Ambystoma gracile*. Exposure was maintained through 4 days after hatching. Average hatching time was 5 days for *Rana pipiens* and 5.5 days for *Ambystoma gracile*. Benzene concentration was measured daily by GLC or HPLC.

Test parameters were egg hatchability, including all embryos (normal or aberrant) and survival of normal organisms determined at hatching and 4 days post hatching. Normal organisms were determined as those organisms that were free of gross teratic defects.

Log probit analysis was used by the authors to determine the LC_{50} at hatching and 4 days after hatching. For *Rana pipiens* values of 4.03 resp. 3.66 mg/l and for *Ambystoma gracile* of 6.68 and 5.21 mg/l were calculated.

Additionally, the authors determined with the same statistical method LC_1- and LC_{10}-values at 4 days posthatching. For *Rana pipiens* a LC_1-value of 3.2 µg/l and a LC_{10}-value of 75.6 µg/l was determined, while for *Ambystoma gracile* values of 68.2 resp. 478.1 µg/l were obtained.

Table A.1: Acute toxicity of benzene to fish

Species	**Duration**	**Effect value [mg/l]**	**Test system**	**Reference****
Oncorhynchus mykiss	96 h	LC_{50} = 5.3 (effective conc.)	flow-through	DeGraeve et al. 1982
Oncorhynchus mykiss	96 h	LC_{50} = 5.9 (effective conc.)	semistatic	Galassi et al. 1988
Oncorhynchus mykiss	96 h	LC_{50} = 21.6 (effective conc.)	flow-through	Hodson et al. 1984
Oncorhynchus kisutsch (marine/ freshwater)	96 h	LC_{50} = 12.4 (nominal conc.)	static	Moles et al. 1979
Oncorhynchus nerca	96 h	LC_{50} = 9.4 (fresh water), LC_{50} = 4.9 (sea water) (nominal conc.)	static	Moles et al. 1979
Oncorhynchus tschawytscha	96 h	LC_{50} = 10.3 (nominal conc.)	static	Moles et al. 1979
Oncorhynchus gorbuscha	96 h	LC_{50} = 15 (fresh water), LC_{50} = 7.4 (sea water), (nominal conc.)	static	Moles et al. 1979
Salvelinus malma (marine)	96 h	LC_{50} = 10.5 (fresh water) LC_{50} = 5.5 (sea water) (nominal conc.)	static	Moles et al. 1979
Cottus cognatus	96 h	LC_{50} = 13.5 (nominal conc.)	static	Moles et al. 1979
Thymallus arcticus	96 h	LC_{50} = 12.9 (nominal conc.)	static	Moles et al. 1979
Gasterosteus aculeatus	96 h	LC_{50} = 21.8 (nominal conc.)	static	Moles et al. 1979
Pimephales promelas	96 h 7 d	LC_{50} = 15.6 (effective conc.) LC_{50} = 14.02 (effective conc.) NOEC = 10.02 (effective conc.)	flow-through larval test effect: growth/ survival	Marchini et al. 1992
Pimephales promelas	96 h	LC_{30} = 15.1 (effective conc.)	flow-through	DeGraeve 1982
Morone saxatilis (marine)	96 h	LC_{50} = 9.58 (effective conc.)	flow-through	Meyerhoff 1975
Poecilia reticulata	96 h	LC_{50} = 28.6 (effective conc.)	semistatic	Galassi et al. 1988
Pimephales promelas	24 h 48 h 96 h	LC_{50} = 34.4 - 35.6* LC_{50} = 32 - 35.1* LC_{50} = 32 - 33.5* (nominal conc.)	static	Pickering / Henderson 1966
Lepomis macrochirus	96 h	LC_{50} = 22.49 (nominal conc.)	static	Pickering / Henderson 1966
Carassius auratus	96 h	LC_{50} = 34.42 (nominal conc.)	static	Pickering / Henderson 1966
Poecilia reticulata	96 h	LC_{50} = 36.6 (nominal conc.)	static	Pickering / Henderson 1966
Lepomis macrochirus	24 h 48 h	LC_{50} = 20 LC_{50} = 20 (nominal conc.)	static	Turnbull et al. 1954
Poecilia reticulata	14 d	LC_{50} = 63.5 (nominal conc.)	semistatic	Koenemann 1981

* test results for hard resp. soft water; ** Full reference in [1]

Table A.2: Short term toxicity of benzene to aquatic invertebrates

Species	**Duration**	**Effect value [mg/l]**	**Effect**	**Test system**	**Reference***
Daphnia magna	24 h	EC_{50} = 18 (effective conc.)	immobilization	closed system	Galassi et al. 1988
Daphnia magna	24 h 48 h	EC_{50} = 10 EC_{50} = 10 (nominal conc.)	immobilization		Janssen/Persoone 1993
Daphnia pulex	96 h	LC_{50} = 15 mg/l (effective conc.)	mortality	closed system	Trucco et al. 1983
Ceriodaphnia dubia	48 h	LC50 = 17.2 (effective conc.)	mortality	closed system	Niederlehner et al. 1998
Ischnura elegans	48 h	LC_{50} = 10 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Gammarus pulex	48 h	LC_{50} = 42 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Cloëon dipterum	48 h	LC_{50} = 34 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Corixa punctata	48 h	LC_{50} = 48 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Chironomus gr. thummi	48 h	LC_{50} = 100 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Asellus aquaticus	48 h	LC_{50} = 120 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Erpobdella octoculata	48 h	LC_{50} > 320 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Lymnaea stagnalis	48 h	LC50 = 230 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Hydra oligactis	48 h	LC_{50} = 34 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Dugesia cf. lugubris	48 h	LC_{50} = 74 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Tubificidae (*Limnodrilus sp*. and *Tubifex sp.*)	48 h	LC_{50} > 320 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Nemoura cinerea	48 h	LC_{50} = 130 (nominal conc.)	mortality	closed system	Sloof et al. 1983
Artemia salina (hypersaline waters)	24 h 48 h	LC_{50} = 66 LC_{50} = 21 (nominal conc.)	mortality		Price et al. 1974
Nitocra spinipes (marine)	24 h	LC_{50} = 82 (salinity: 1.5 %) LC_{50} = 111.5 (salinity: 2.5 %) (nominal conc.)	mortality		Potera 1975
Palaemonetes pugio (marine)	24 h	LC_{50} = 38 (salinity: 1.5 %) LC_{50} = 33.5 (salinity: 2.5 %) (nominal conc.)	mortality		Potera 1975
Aedes aegypti (4th instar larvae)	24 h	LC_{0} = 12.9 LC_{50} = 59	mortality		Berry/Brammer 1977
Cancer magister (marine)	96 h	LC_{50} = 108 (nominal conc.)	mortality		Caldwell et al. 1977
Palaemonetes pugio (marine)	24 h 48 h 96 h	LC_{50} = 43.5 LC_{50} = 35 LC_{50} = 27 (nominal conc.)	mortality	open	Tatem et al. 1978

* Full reference in [1]

Table A.3: Toxicity of benzene to aquatic algae and plants

Species	Duration	Effect value [mg/l]	Effect	Test system	Reference*
Selenastrum capricornutum	72 h	E_bC_{50} = 28 E_rC_{50} = 100 E_bC_{10} = 8.3 E_rC_{10} = 34 (effective conc.)	growth inhibition	closed system	TNO 2000
Selenastrum capricornutum	72 h	EC_{50} = 29 (effective conc.)	growth inhibition	closed system	Galassi et al. 1988
Selenastrum capricornutum	8 d	EC_{50} = 41 (nominal conc.)	growth inhibition (biomass)	closed system	Herman et al. 1990
Selenastrum capricornutum	4 h	EC_5 = 10 EC_{16} = 100 EC_{95} = 1000 (nominal conc.)	inhibition of photosynthesis		Giddings 1979
Ankistrodesmus falcatus	4 h	EC_{50} = 310 (nominal conc.)	inhibition of ^{14}C-carbonate uptake	closed system	Wong et al. 1984
Chlamydomonas angulosa.	3 h	EC_{50} = 461 (nominal conc.)	inhibition of $^{14}CO_2$ uptake	closed system	Hutchinson et al. 1980
Chlorella vulgaris	3 h	EC_{50} = 312.5 (nominal conc.)	inhibition of $^{14}CO_2$ uptake	closed system	Hutchinson et al. 1980
Phaeodactylum tricornutum (marine)	2 h 24 h	LOEC = 100 LOEC = 50 (nominal conc.)	inhibition of photosynthesis	closed system	Kusk 1981
Phaeodactylum tricornutum (marine)	96 h	LOEC = 50 (nominal conc.)	growth inhibition	closed system	Kusk 1981
Akrosiphonia sonderi (marine)	2 h	$175<EC_{50}<350$ (nominal conc.)	inhibition of photosynthesis	closed system	Kusk 1980

- Full reference in [1]