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AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

HEXACHLOROBENZENE

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NOTICES

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FOREWORD

Section 304(a)(1) of the Clean Water Act requires the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water. Pursuant to that end, this document proposes water quality criteria for the protection of aquatic life. These criteria do not involve consideration of effects on human health.

This document is a draft, distributed for public review and comment. After considering all public comments and making any needed changes, EPA will issue the criteria in final form, at which time they will replace any previously published EPA aquatic life criteria for the same pollutant.

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(1) and section 303(c)(2). In section 304, the term represents a non-regulatory, scientific assessment of effects. Criteria presented in this document are such scientific assessments. If water quality criteria associated with specific stream uses are adopted by a State as water quality standards under section 303, then they become maximum acceptable pollutant concentrations that can be used to derive enforceable permit limits for discharges to such waters.

Water quality criteria adopted in State water quality standards could have the same numerical values as criteria developed under section 304. However, in many situations States might want to adjust water quality criteria developed under section 304 to reflect local environmental conditions before incorporation into water quality standards. Guidance is available from EPA to assist States in the modification of section 304(a)(1) criteria, and in the development of water quality standards. It is not until their adoption as part of State water quality standards that the criteria become regulatory.

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Introduction

Hexachlorobenzene (HCB) has been detected in environmental samples from around the world in recent years, and is recognized as a global pollutant (Ballschmiter and Zell 1980; Brevik 1981; Brunn and Manz 1982; Chovelon et al. 1984; Galassi et al. 1981; Jan and Malnersic 1980; Johnson et al. 1974; Kaiser 1977; Kuehl et al. 1983,1984; Laska et al. 1976; Niimi 1979; Paasivirta et al. 1981; Sackmauerova et al. 1977; Schmitt et al. 1985; Skaftason and Johannesson 1982; Tsui and McCart 1981; Veith et al. 1979b). Contamination of Lake Ontario with hexachlorobenzene and other chlorobenzenes has occurred since 1915, but at a much greater rate in the past three decades (Oliver and Nicol 1982). HCB is soluble in water to about 6 μg/L (Abernethy et al. 1986; Metcalf et al. 1973), and its concentrations in rivers and lakes are generally reported in terms of ng/L (Niimi and Cho 1981). It has an octanol/water partition coefficient of 6.18 (Neely et al. 1974). The common occurrence of HCB in tissues of aquatic organisms can be attributed to its high affinity for lipids and its persistence in the environment (Callahan et al. 1979). Connor (1984) estimated that HCB contributed little to increased risk of cancer associated with consumption of freshwater fish from contaminated water.

HCB is used as a seed grain fungicide, a peptizing agent in the production of nitroso and styrene rubber for tires, a wood preservative, a porosity controller in the manufacture of graphite electrodes, a fluxing agent in aluminum smelting, and in pyrotechnics manufacture (Courtney 1979; Quinlivan et al. 1975/1977; U.S. EPA 1980; Young et al. 1980). HCB wastes also originate from the production of certain pesticides (Cleveland et al. 1982), chlorinated solvents, vinyl chloride monomers, and chlorine or sodium chlorate when produced electrolytically (Quinlivan et al. 1975/77). Some of the commercial formulations of HCB contain toxic impurities, including

pentachlorobenzene, polychlorinated dibenzo-p-dioxins, and polychlorodibenzofurans (Villanueva et al. 1974).

This document does not contain information concerning the effects of HCB on saltwater species and their uses because adequate data and resources were not available. An understanding of the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985), hereinafter referred to as the Guidelines, and the response to public comment (U.S. EPA 1985a), is necessary in order to evaluate the following text, tables, and calculations. Results of such intermediate calculations as recalculated LC50s and Species Mean Acute Values are given to four significant figures to prevent roundoff error in subsequent calculations, not to reflect the precision of the value. The criteria presented herein supersede previous information on HCB (U.S. EPA 1980) because these criteria were derived using additional information. The latest comprehensive literature search for information for this document was conducted in February, 1986. Some more recent information was also included. Data in the files of the U.S. EPA's Office of Pesticide Programs concerning the effects of hexachlorobenzene on aquatic organisms and their uses have not been evaluated for possible use in the derivation of aquatic life criteria.

Acute Toxicity to Aquatic Animals

Data that may be used, according to the Guidelines, in the derivation of a freshwater Final Acute Value for HCB are presented in Table 1. The only experimentally determined acute values were at concentrations that are at least 1000 times the solubility limit. Although the quantitative value of these measurements might be suspect, they do indicate that concentrations near solubility should not cause acute toxicity. Some acute exposures were

continued for longer than 96 hr with no resultant mortalities. For example, adult crayfish, Procambarus clarki, were unaffected over a period of 20 days at a mean HCB concentration of 27.3 μg/L, and largemouth bass, Micropterus salmoides, were unaffected over 10 days at 25.8 μg/L (Laseter et al. 1976; Laska et al. 1978). Because an acute value is not available for any species at or below solubility, a freshwater Final Acute Value cannot be determined. If one could be determined, it would be higher than 6 μg/L, which was reported by Metcalf et al. (1973) to be the solubility of HCB in water.

Chronic Toxicity to Aquatic Animals

The available data that are useable according to the Guidelines concerning the chronic toxicity of HCB are presented in Table 2. Rainbow trout, Salmo gairdneri, were exposed to HCB in a 90-day early life-stage test (Spehar 1986). No adverse effects on hatching, survival, or growth were observed at the highest tested concentration of 3.68 μg/L (Table 2). Similarly, fathead minnows, Pimephales promelas, were not affected at exposures up to 4.8 μg/L in a 32-day early life-stage test (Ahmad et al. 1984; Carlson and Kosian 1987). Survival at hatch, survival at 32 days, and wet weight were the same at all exposure concentrations as in the control.

In a 7-day life-cycle test with the cladoceran, Ceriodaphnia dubia, HCB did not cause any measurable effect upon survival or reproduction at concentrations as high as 7.0 μg/L (Spehar 1986). Because a chronic value is not available for any species, no Final Chronic Value can be calculated. If one could be calculated, it would be higher than 3.68 μg/L.

Toxicity to Aquatic Plants

Geyer et al. (1985) reported that the green alga, Scenedesmus subspicatus, was not affected in 4 days by HCB at a concentration of

10 μg/L (Table 3). A 4-day exposure of Selenastrum capricornutum to 30 μg/L caused a 12% inhibition of population growth (Calamari et al. 1983). A Final Plant Value, as defined in the Guidelines, cannot be obtained because no test in which the concentrations of HCB were measured and the endpoint was biologically important has been conducted with an important aquatic plant species.

Bioaccumulation

HCB concentrations in tissues of aquatic organisms appear to equilibrate very slowly with concentrations in the water. Uptake via the food might be more important than direct uptake from water for top carnivores, particularly in waters where HCB concentrations are very low (Niimi and Cho 1980). Oliver and Niimi (1983) reported that equilibration had not yet occurred after a 119-day exposure of rainbow trout to HCB at a concentration of 0.00032 μg/L, at which time the bioconcentration factor was 12,000 (Table 4). An exposure to 0.008 μg/L resulted in a bioconcentration factor of 20,000 with the trout. HCB residues in fathead minnows continually increased in 28-day tests to concentrations that were from 32,000 to 39,000 times greater than the concentrations of HCB in water (Kosian et al. 1981). Following a rapid uptake during the first week of exposure, HCB residues in fathead minnows gradually increased through 115 days (Veith et al. 1979a). HCB residues in the minnows were from 16,200 to 45,700 times greater than concentrations in water following exposures of 32 to 115 days. Carlson and Kosian (1987) obtained similar results with a BCF of 22,000 for fathead minnows exposed for 32 days.

Green sunfish, Lepomis cyanellus, bioconcentrated HCB approximately 22,000 times, whereas fingerling rainbow trout bioconcentrated HCB considerably lower at 5,500 times (Veith et al. 1979a). In a test with a

mixture of chlorinated benzenes, a BCF of 15,660 was obtained for HCB with the guppy, Poecilia reticulata (Konemann and Van Leeuwen 1980). An apparent steady-state between HCB residues in guppy tissue and concentration in the water occurred within 7 days.

Coho salmon (Oncorhynchus kisutch) and green sunfish accumulated HCB when fed contaminated food (Leatherland and Sonstegard 1982; Sanborn et al. 1977). Crayfish (Procambarus clarki) exposed at a contaminated field site to a mean HCB concentration of 74.9 μg/L had a mean whole-body concentration factor of 1,464 (Laseter et al. 1976). Fox et al. (1983) found a direct correlation between HCB concentrations in surficial sediments of Lake Ontario and HCB concentrations in oligochaetes that inhabit the sediments. They also reported that HCB accumulation was greater at the higher trophic levels.

HCB and other lipophilic, persistent chlorinated organics are passed from parent to offspring via the yolk and oil of the fish egg. Survival and growth of larvae might be affected by this route of uptake in some fish species (Niimi 1983; Westin et al. 1985).

Elimination of HCB from salmonids occurs slowly. Norheim and Roald (1985) determined the half-life of HCB in rainbow trout that had been injected intraperitoneally and maintained at a water temperature of 7°C to be 81, 146, and 139 days in liver, fat, and muscle, respectively. Niimi and Cho (1981) reported the biological half-life of HCB to be 224 to 770 days in rainbow trout fed HCB and maintained at a water temperature of 15°C. In a subsequent study (Niimi and Palazzo 1985), HCB-fed rainbow trout held at 12 and 18°C had half-lives of HCB of 173 and 198 days, respectively, whereas fish held at 4°C did not eliminate HCB. Thus, it appears that HCB is highly persistent in the tissues of fish inhabiting cold waters.

Crayfish that were exposed to 74.9 μg/L for 10 days under field conditions eliminated about 15% of the HCB after three days in clean water.

Males eliminated 47% and females 64% after 25 days (Laseter et al. 1976). Largemouth bass eliminated from 73.1 to 91.4% of the whole body HCB residue during 13 days in clean water (Laseter et al. 1976).

McKim et al. (1985) studied the uptake efficiency of HCB and 13 other chemicals by rainbow trout gills. HCB was among the chemicals most efficiently removed from water by gills. However, it was not much more efficiently removed than several chlorophenols which, by comparison to HCB, have a reduced capacity for bioaccumulation. The high accumulation levels of HCB can be explained by a slow rate of conversion to water soluble metabolites and subsequent elimination, combined with an efficient uptake from water and food due to its high n-octanol water partition coefficient of 6.18.

No U.S. FDA action level or other maximum acceptable concentration in tissue for HCB, as defined in the Guidelines, is available for HCB. Therefore, a Final Residue Value cannot be calculated.

Other Data

Additional data on the lethal and sublethal effects of HCB on freshwater species are presented in Table 5. A green alga, Ankistrodesmus falcatus, was unaffected in a 4-hr exposure to 3 µg/L (Wong et al. 1984). Daphnia magna were unaffected after 24 to 48 hr at concentrations that exceeded the solubility of HCB in water (Calamari et al. 1983; Sugatt et al. 1984). Exposure of Daphnia magna to HCB concentrations in excess of its solubility in water for a period of 14 days resulted in an EC50 of 16 µg/L and a reduced instantaneous growth rate at 23 µg/L (Calamari et al. 1983). Due to insufficient deaths, LC50s could not be determined for rainbow trout exposed to 30 µg/L for 24 hr (Calamari et al. 1983) or for guppies exposed to 730 µg/L for 14 days (Konemann 1979,1981). However, largemouth bass

had liver and kidney damage after 10 days of exposure to 3.5 μg/L (Laseter et al. 1976).

Unused Data

Some data on the effects of HCB on aquatic organisms and their uses were not used because the studies were conducted with species that are not resident in North America (e.g., Hattori et al. 1984; Sugiura et al. 1984). Data were not used when HCB was a component of a mixture or wettable powder (e.g., Gjessing et al. 1984; Mayer and Ellersieck 1986; Poels et al. 1980). Chiou (1985), Chiou et al. (1977), Davies and Dobbs (1984), Glass et al. (1977), Kaiser et al. (1984), Klein et al. (1984), Koch (1982a,b), Matsuo (1980,1981), Oliver (1984a), and Sabljic and Protic (1982) compiled data from other sources.

Tests were not used when only physiological effects or enzyme activity were measured (e.g., Gluth and Hanke 1984; Hanke et al. 1983; Law and Addison 1981). Schmidt-Bleek et al. (1982) did not adequately describe the methods used for the toxicity tests. Toxicity data were not used when the test was conducted in distilled water (e.g., Abernethy et al. 1986; Bobra et al. 1985).

Studies of HCB residues in aquatic organisms were not used when there were insufficient tissue residue data or accompanying data on HCB concentrations in the water to determine a bioconcentration or bioaccumulation factor (e.g., Atuma and Eigbe 1985; Clark et al. 1984; DeVault 1985; Evans et al. 1982; Giesy et al. 1986; Glass 1975; Heida 1983; Jaffe and Hites 1986; Kaiser 1982; Kaiser and Valdmanis 1978; Keck and Raffenot 1979; Kuehl et al. 1980,1981; Niimi 1979; Norstrom et al. 1978; Paasivirta et al. 1983a,b; Pennington et al. 1982; Schmitt et al. 1985;

Schuler et al. 1985; Swain 1978; Veith et al. 1977,1981; Wiemeyer et al. 1978; Zitko 1971). Results of studies in which HCB was administered by gavage or injection were not used (e.g., Ingebrigtsen and Skaare 1983; Safe et al. 1976). Studies using radiolabeled HCB in which only radioactivity was measured in the water or in exposed organisms were not used (e.g., Freitag 1987; Freitag et al. 1982,1984,1985; Geyer et al. 1981,1984; Schauerte et al. 1982).

Results of laboratory bioaccumulation tests were not used when the test was not flow-through or renewal (e.g., Belluck and Felsot 1981; Korte et al. 1978; Lu and Metcalf 1975; Metcalf et al. 1973; Zitko and Hutzinger 1976) or when the concentration of HCB in the test solution was not adequately measured (e.g., Isensee 1976; Isensee et al. 1976). A study of the bioaccumulation of HCB by organisms inhabiting contaminated sediment was not used (Oliver 1984b).

Results of bioconcentration tests were not used when the duration of exposure was not specified (e.g., Neely et al. 1974). Studies on the dynamics and transport of HCB at the sediment-water interface were not used (Baker et al. 1985; Karickhoff and Morris 1985).

Summary

Hexachlorobenzene at a concentration of 6 μg/L has been shown not to cause acute toxicity to any tested freshwater species and 3.68 μg/L has been shown not to cause chronic toxicity to any tested species. Freshwater plants were not affected at 10 μg/L. In a 14-day test, 16 μg/L caused a 50% reduction in the fertility of Daphnia magna. Bioconcentration factors ranged from 5,500 to 45,700 in tests with freshwater fish.

National Criteria

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of hexachlorobenzene does not exceed 3.68 μg/L more than once every three years on the average and if the one-hour average concentration does not exceed 6.0 μg/L more than once every three years on the average. The only adverse effects that have been observed in tests on hexachlorobenzene include a 50% reduction in fertility of Daphnia magna at 16 μg/L and organ damage to largemouth bass at 3.5 μg/L. However, histopathology data are not used to develop criteria and the available data do not justify establishing criteria different from those given above.

Implementation

As discussed in the Water Quality Standards Regulation (U.S. EPA 1983a) and the Foreword to this document, a water quality criterion for aquatic life has regulatory impact only after it has been adopted in a state water quality standard. Such a standard specifies a criterion for a pollutant that is consistent with a particular designated use. With the concurrence of the U.S. EPA, states designate one or more uses for each body of water or segment thereof and adopt criteria that are consistent with the use(s) (U.S. EPA 1983b,1987). In each standard a state may adopt the national criterion, if one exists, or, if adequately justified, a site-specific criterion.

Site-specific criteria may include not only site-specific criterion concentrations (U.S. EPA 1983b), but also site-specific, and possibly pollutant-specific, durations of averaging periods and frequencies of allowed excursions (U.S. EPA 1985b). The averaging periods of "one hour" and "four

days" were selected by the U.S. EPA on the basis of data concerning how rapidly some aquatic species react to increases in the concentrations of some aquatic pollutants, and "three years" is the Agency's best scientific judgment of the average amount of time aquatic ecosystems should be provided between excursions (Stephan et al. 1985; U.S. EPA 1985b). However, various species and ecosystems react and recover at greatly differing rates. Therefore, if adequate justification is provided, site-specific and/or pollutant-specific concentrations, durations, and frequencies may be higher or lower than those given in national water quality criteria for aquatic life.

Use of criteria, which have been adopted in state water quality standards, for developing water quality-based permit limits and for designing waste treatment facilities requires selection of an appropriate wasteload allocation model. Although dynamic models are preferred for the application of these criteria (U.S. EPA 1985b), limited data or other considerations might require the use of a steady-state model (U.S. EPA 1986). Guidance on mixing zones and the design of monitoring programs is also available (U.S. EPA 1985b,1987).

Table 1. Acute Toxicity of Hexachlorobenzene to Aquatic Animals

Species	Method[a]	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)	Species Mean Acute Value (µg/L)	Reference
		FRESHWATER SPECIES			
Hydra (adult), *Hydra* sp.	S, M	49.7	> 65.9	> 65.9	Sabourin et al. 1986
Leech (adult), *Nephelopsis obscura*	S, M	47.5	> 73.2[b]	> 73.2	Sabourin et al. 1986
Snail (adult), *Aplexa hypnorum*	S, M	49.5	> 77.6	> 77.6	Sabourin et al. 1986
Cladoceran, *Ceriodaphnia dubia*	S, M	45	> 7.0	> 7.0	Spehar 1986
Amphipod (adult), *Gammarus pseudolimnaeus*	S, M	49.5	> 77.6	> 77.6	Sabourin et al. 1986
Crayfish (adult), *Procambarus clarki*	F, M	-	> 27.3[d]	> 27.3	Laseter et al. 1976; Laska et al. 1978
Crayfish (juvenile), *Procambarus* sp.	S, M	-	> 5.2[c]	> 5.2	Laseter et al. 1976; Laska et al. 1978
Stonefly (nymph), *Pteronarcys* sp.	S, M	47.4	> 69.7	> 69.7	Sabourin et al. 1986
Midge (3rd-4th instar), *Tanytarsus dissimilis*	S, M	40.7	> 58.1	> 58.1	Call et al. 1983
Rainbow trout (0.5 g), *Salmo gairdneri*	F, M	44.3	> 80.9	-	Ahmad et al. 1984; Call et al. 1983
Rainbow trout (juvenile), *Salmo gairdneri*	F, M	45-46	> 3.76	> 80.9	Spehar 1986

Table 1. (Continued)

Species	Method[a]	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)	Species Mean Acute Value (µg/L)	Reference
Fathead minnow (30 days), *Pimephales promelas*	F, M	45	> 6[e]	-	Veith et al. 1983a,b; Ahmad et al. 1984; Carlson and Kosian 1987
Fathead minnow (0.7 g), *Pimephales promelas*	S, U	44	> 10,000 (22,000)[f]	> 10,000	Johnson and Finley 1980; Mayer and Ellersieck 1986
Channel catfish (0.8 g), *Ictalurus punctatus*	S, U	44	13,500 (14,000)[f]	-	Johnson and Finley 1980; Mayer and Ellersieck 1986
Channel catfish (1.3 g), *Ictalurus punctatus*	S, U	40	> 100,000[g]	-	Mayer and Ellersieck 1986
Channel catfish (sac fry), *Ictalurus punctatus*	S, U	272	7,000	9,721	Mayer and Ellersieck 1986
Bluegill (1.5 g), *Lepomis macrochirus*	F, M	45.4	> 78.4	-	Call et al. 1983
Bluegill (1 g), *Lepomis macrochirus*	S, U	272	12,000	-	Johnson and Finley 1980; Mayer and Ellersieck 1986
Bluegill (1.6 g), *Lepomis macrochirus*	F, U	272	> 1,000	12,000	Mayer and Ellersieck 1986
Largemouth bass, *Micropterus salmoides*	F, M	-	> 25.8[h]	-	Laseter et al. 1976; Laska et al. 1978
Largemouth bass (0.5 g), *Micropterus salmoides*	S, U	272	12,000	12,000	Johnson and Finley 1980; Mayer and Ellersieck 1986

Table 1. (Continued)

[a] S = static; R = renewal; F = flow-through; M = measured; U = unmeasured.

[b] Loading of 1.06 g/L exceeded the level recommended by ASTM (1986).

[c] The exposure was continued for a period of 8 days without any mortalities attributable to hexachlorobenzene.

[d] The exposure was continued for a period of 10 days without any mortalities attributable to hexachlorobenzene.

[e] The LC50 was above saturation, which was estimated to be 6 μg/L based on Metcalf et al. (1973).

[f] Value within parentheses is from same test as value outside parentheses, but was not used in calculation of Species Mean Acute Value.

[g] Not used in calculation of Species Mean Acute Value.

[h] The exposure was continued for a total of 10 days without any mortalities attributable to hexachlorobenzene.

Table 2. Chronic Toxicity of Hexachlorobenzene to Aquatic Animals

Species	Test[a]	Hardness (mg/L as $CaCO_3$)	Chronic Limits (µg/L)[b]	Chronic Value (µg/L)	Reference
			FRESHWATER SPECIES		
Cladoceran, *Ceriodaphnia dubia*	LC	45	> 7.0[c]	> 7.0	Spehar 1986
Rainbow trout, *Salmo gairdneri*	ELS	43-47	> 3.68[c]	> 3.68	Spehar 1986
Fathead minnow, *Pimephales promelas*	ELS	44-46	> 4.8[c]	> 4.8	Ahmad et al. 1984; Carlson and Kosian 1987

[a] LC = life-cycle or partial life-cycle; ELS = early life-stage.

[b] Measured concentrations of hexachlorobenzene.

[c] Highest tested concentration; no tested concentration caused an unacceptable effect.

Table 3. Toxicity of Hexachlorobenzene to Aquatic Plants

Species	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)	Reference
			FRESHWATER SPECIES		
Alga, *Scenedesmus subspicatus*	-	4	EC10	> 10	Geyer et al. 1985
Alga, *Scenedesmus subspicatus*	-	4	EC50	> 10	Geyer et al. 1985
Alga, *Selenastrum capricornutum*	-	4	EC50	> 30	Calamari et al. 1983

Table 4. Bioaccumulation of Hexachlorobenzene by Aquatic Organisms

Species	Concentration in Water (µg/L)[a]	Duration (days)	Tissue	Percent Lipids	BCF or BAF[b]	Normalized BCF or BAF[c]	Reference
			FRESHWATER SPECIES				
Green alga, *Oedogonium cardiacum*	11.5	7	Whole body	-	623	-	Laseter et al. 1976
Crayfish (male), *Procambarus clarki*	27.3	10	Whole body	-	149	-	Laseter et al. 1976
Crayfish (female), *Procambarus clarki*	27.3	10	Whole body	-	83	-	Laseter et al. 1976
Crayfish (male), *Procambarus clarki*	36.1	10	Whole body	-	112	-	Laseter et al. 1976
Crayfish (female), *Procambarus clarki*	36.1	10	Whole body	-	75	-	Laseter et al. 1976
Rainbow trout (juvenile), *Salmo gairdneri*	0.00032	119	Whole body less digestive tract	8.5	12,000[d]	1,412	Oliver and Niimi 1983
Rainbow trout (juvenile), *Salmo gairdneri*	0.008	105	Whole body less digestive tract	8.5	20,000	2,353	Oliver and Niimi 1983
Rainbow trout (fingerling), *Salmo gairdneri*	-	32	Whole body	-	5,500	-	Veith et al. 1979a
Fathead minnow (juvenile), *Pimephales promelas*	0.17	28	Whole body	9.22	33,000[e]	3,579	Kosian et al. 1981
Fathead minnow (juvenile), *Pimephales promelas*	0.16	28	Whole body	9.52	32,000[e]	3,361	Kosian et al. 1981
Fathead minnow (juvenile), *Pimephales promelas*	0.15	28	Whole body	8.52	39,000[e]	4,577	Kosian et al. 1981

Table 4. (Continued)

Species	Concentration in Water (µg/L)[a]	Duration (days)	Tissue	Percent Lipids	BCF or BAF[b]	Normalized BCF or BAF[c]	Reference
Fathead minnow (juvenile), *Pimephales promelas*	0.18	28	Whole body	9.27	37,000[e]	3,991	Kosian et al. 1981
Fathead minnow (newly hatched fry), *Pimephales promelas*	~5	~115	Whole body	7.6[f]	45,700	6,013	Veith et al. 1979a
Fathead minnow (30 days), *Pimephales promelas*	~5	~40	Whole body	7.6[f]	18,200	2,395	Veith et al. 1979a
Fathead minnow (90 days), *Pimephales promelas*	~5	115	Whole body	7.6[f]	17,800	2,342	Veith et al. 1979a
Fathead minnow (adult), *Pimephales promelas*	~5	~32	Whole body	7.6[f]	18,500	2,434	Veith et al. 1979a
Fathead minnow (adult), *Pimephales promelas*	~5	~115	Whole body	7.6[f]	16,600	2,184	Veith et al. 1979a
Fathead minnow (adult), *Pimephales promelas*	~5	~32	Whole body	7.6[f]	16,200	2,132	Veith et al. 1979a
Fathead minnow (juvenile), *Pimephales promelas*	4.8	~32	Whole body	-	22,040[g]	-	Carlson and Kosian 1987
Green sunfish (juvenile), *Lepomis macrochirus*	-	32	Whole body	-	21,900	-	Veith et al. 1979a
Largemouth bass, *Micropterus salmoides*	2	15	Whole body	-	44,400	-	Laseter et al. 1976
Largemouth bass, *Micropterus salmoides*	2	15	Whole body	-	33,800	-	Laseter et al. 1976

Table 4. (Continued)

Species	Concentration in Water (µg/L)[a]	Duration (days)	Tissue	Percent Lipids	BCF or BAF[b]	Normalized BCF or BAF[c]	Reference
Largemouth bass, *Micropterus salmoides*	2	15	Whole body	-	18,200	-	Laseter et al. 1976
Largemouth bass, *Micropterus salmoides*	2	15	Whole body	-	32,500	-	Laseter et al. 1976

[a] Measured concentration of hexachlorobenzene.

[b] Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of hexachlorobenzene in water and in tissue.

[c] When possible, the factors were normalized to 1% lipids by dividing the BCFs and BAFs by the percent lipids.

[d] The hexachlorobenzene concentration had not equilibrated between water and fish at 119 days, and the value presented is based upon residues in the fish on day 119.

[e] The hexachlorobenzene concentration had not equilibrated between water and fish at 28 days, and the value presented is based upon residues in the fish on day 28.

[f] Reported by Veith (1980).

[g] A BCF of 23,392 was reported for the same study by Ahmad et al. (1984).

Table 5. Other Data on Effects of Hexachlorobenzene on Aquatic Organisms

Species	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)	Reference
FRESHWATER SPECIES					
Green alga, *Ankistrodesmus falcatus*	-	4 hr	EC50	> 3	Wong et al. 1984
Green alga, *Chlorella pyrenoidosa*	-	46 hr	Reduced chlorophyll	1	Geike and Parasher 1976
Green alga, *Chlorella pyrenoidosa*	-	76 hr	Reduced growth	10,000	Parasher et al. 1978
Protozoan, *Colpidium campylum*	-	43 hr	No effect	10,000	Dive et al. 1980
Protozoan, *Tetrahymena pyriformis*	-	24 hr	EC50	> 6[a]	Yoshioka et al. 1985
Cladoceran, *Daphnia magna*	-	24 hr	EC50	> 30	Calamari et al. 1983
Cladoceran, *Daphnia magna*	-	14 days	50% reduction in fertility	16	Calamari et al. 1983
Cladoceran, *Daphnia magna*	-	14 days	Reduced instantaneous growth rate	23	Calamari et al. 1983
Cladoceran (< 24 hr), *Daphnia magna*	134	28.3 hr	EC10 (immobilization)	> 6[a]	Sugatt et al. 1984
Cladoceran (~ 5 days), *Moina macrocopa*	-	3 hr	LC50	> 6[a]	Yoshioka et al. 1986

Table 5. (continued)

Species	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)	Reference
Crayfish (juvenile), *Procambarus clarki*	-	10 days	Damaged the hepatopancreas	5	Laseter et al. 1976
Rainbow trout, *Salmo gairdneri*	320	24 hr	LC50	> 30	Calamari et al. 1983
Atlantic salmon, *Salmo salar*	-	96 hr	Accumulation coefficient = 753	6.6	Zitko 1977
Guppy (2-3 mo), *Poecilia reticulata*	25	14 days	LC50	> 320	Konemann 1979,1981
Largemouth bass, *Micropterus salmoides*	-	10 days	Damaged the liver and kidney	3.5	Laseter et al. 1976
Largemouth bass, *Micropterus salmoides*	-	10 days	Damaged the gallbladder	25.8	Laseter et al. 1976

[a] The tested concentration was at saturation, which was estimated to be 6 µg/L based on Metcalf et al. (1973).

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