Draft
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AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

CHLORPYRIFOS

NOTE: This draft contains only freshwater data. The saltwater data will be incorporated later. The freshwater CCC is likely to change when the saltwater data are incorporated.

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NOTICES

This document has been reviewed by the Criteria and Standards Division, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, and approved for publication.

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FOREWORD

Section 304(a)(1) of the Clean Water Act of 1977 (P.L. 95-217) requires the Administrator of the Environmental Protection Agency to publish criteria for water quality accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that may be expected from the presence of pollutants in any body of water, including ground water. This document is a revision of proposed criteria based upon a consideration of comments received from other Federal agencies, State agencies, special interest groups, and individual scientists. The criteria contained in this document replace any previously published EPA aquatic life criteria.

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(1) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological effects. The criteria presented in this publication 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, they become enforceable maximum acceptable concentrations of a pollutant in ambient waters within that State. The water quality criteria adopted in the State water quality standards could have the same numerical values as the criteria developed under section 304. However, in many situations States may want to adjust water quality criteria developed under section 304 to reflect local environmental conditions and human exposure patterns before incorporation into water quality standards. It is not until their adoption as part of the State water quality standards that the criteria become regulatory.

Guidelines to assist the States in the modification of criteria presented in this document, in the development of water quality standards, and in other water-related programs of this Agency, have been developed by EPA.

Director
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Introduction*

Chlorpyrifos is one of several organophosphorus compounds developed in the 1960s to replace persistent organochlorine pesticides. It has been widely used as a broad spectrum insecticide for agricultural and domestic pests. It is directly applied to aquatic environments in mosquito, midge. and blackfly abatement projects.

Chlorpyrifos is produced by the Dow Chemical Company (Midland, MI, USA) under the trade names Dursban® and Lorsban®. Gray (1965) and Marshall and Roberts (1978) have reviewed its composition and physical and chemical properties. Its commercial formulations for pesticide application include emulsifiable concentrates (EC), wettable powders (WP), granules, and controlled-release polymers. The resulting concentration of chlorpyrifos in water and its persistence varies from one formulation to another. In general, emulsifiable concentrates and wettable powders produce a large pulse in chlorpyrifos concentrations immediately after application. Water concentrations rapidly decline as chlorpyrifos is taken up by the several natural sinks [discussed later]. Granules and controlled-release formulations do not produce as prominent an immediate pulse in water, but low. yet significant concentrations remain in the environment for a longer duration.

The percentage of active ingredient in the formulations can vary considerably, both between formulations and within a single formulation

* 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). hereafter referred to as the Guidelines, is necessary in order to understand the following text, tables, and calculations.

over time as manufacturers' specifications change. This results in a large percentage of often unspecified ingredients, many used as carriers, in commercial formulations. These ingredients are considered inert, although technical grade chlorpyrifos has generally been found to be more toxic than an equal quantity of active ingredient in formulation (Darwazeh and Mulla 1974; Jarvinen and Tanner 1982; Siefert et al. 1984). For this reason, the effect of the inert ingredients can not be discounted. Under normal application conditions, the commercial formulations are often combined with petroleum products, such as No. 2 diesel oil or kerosene, to increase the rate of dispersal. Solvents have been shown to have significant toxic effects separate from chlorpyrifos (Wallace et al. 1973: Jamnback and Frempong-Boadu 1966).

Numerical water quality criteria are derived herein solely for the chemical chlorpyrifos. Although some data obtained from studies using formulations are discussed, only data derived from toxicity tests utilizing an adequately high-quality chlorpyrifos are used in deriving criteria.

The toxic effect of chlorpyrifos is the result of metabolic conversion to its oxygen analogue, chlorpyrifos-oxon, and its subsequent inhibitive interaction with various enzyme systems (e.g., cholinesterases, carboxylases, acetylcholinesterases, mitochondrial oxidative phosphorylation). Its activity with acetylcholinesterase (AChE) is generally accepted to be its most critical toxic effect. AChE inhibition results in accumulation of the neurotransmitter, acetylcholine, in synapes, disrupting normal neural transmission. Although in fish even substantial reductions in brain AChE activity have not always been fatal, the effect of this condition on normal activity (e.g., feeding, reproduction, predator-prey relationships, etc.) in nature is not known.

Although less persistent than organochlorine compounds, chlorpyrifos is very immobile when applied to most terrestrial environments. Because of its affinity to organic soils, little to no leaching occurs. In lieu of direct application to aquatic environments, chlorpyrifos can enter through spray drift from adjacent agricultural areas or sorbed to entrained particles resulting from erosion of treated areas.

Once chlorpyrifos enters an aquatic system, it appears to be rapidly sorbed to suspended organics and sediments, although some is removed by volatilization and degradation. Its penetration into the sediment appears to be shallow, most occurring in the upper several milimeters. The equilibrium between sediment, suspended organics and the water is poorly understood. Chlorpyrifos residues in natural sediments and water samples have been reported by Braun and Frank (1980), Rawn et al. (1978), Winterlin et al. (1968), Nelson et al. (1973), Hughes et al. (1980), Hughes (1977), Hurlbert et al. (1970), Siefert et al. (1984), and Macalady and Wolfe (1985). Evans (1977) reported significant chlorpyrifos concentrations, still toxic to mosquito larvae, one year after application of a slow-release polymer formulation to a natural pond.

The use of slow-release polymers will probably result in differential exposure, both in concentration and duration, between benthic and pelagic organisms. Organisms inhabiting the water-sediment interface have the potential to receive larger and more sustained concentrations than free-swimming organisms.

Chlorpyrifos, although highly toxic, is rapidly metabolized by fish, 3,5,6-trichloro-2-pyridinol being the major product (Marshall and Roberts, 1978). Residues in fishes are generally low for this reason. Several studies have reported residues of chlorpyrifos in wild fishes (Clark et al. 1984, Mulla et al. 1973), and cultured or experimental fishes (Macek et al. 1972, Winterlin et al. 1968, Siefert et al. 1984).

All concentrations herein are expressed as chlorpyrifos, not as the material tested. Whenever adequately justified, a national criterion may be replaced by a site-specific criterion (U.S. EPA 1983a), which may include not only site-specific criterion concentrations (U.S. EPA 1983b), but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedences (U.S. EPA 1985). The latest literature search for information for this document was conducted in February, 1985; some newer information was also used.

Acute Toxicity to Aquatic Animals

Most of the available data on the acute toxicity of chlorpyrifos to freshwater animals is from the U.S. Fish and Wildlife Service Laboratory in Columbia, MO or the U.S. EPA Laboratory in Duluth, MN. The data from the Fish and Wildlife Service are contained in publications by Johnson and Finley (1980), Macek et al. (1969), Sanders (1969, 1972) and Sanders and Cope (1968) and include values for five invertebrates and five fishes. The data from the EPA were published by Holcombe et al. (1982), Jarvinen and Tanner (1982), Phipps and Holcombe (1985a, b), and Siefert et al. (1984), and also include values for five invertebrates and five fishes. The only other acute value is from a test with a beetle by Federle and Collins (1976).

Within arthropods and fishes separately, and within all species combined, there appears to be an inverse relationship between size and sensitivity to chlorpyrifos. The snail, Aplexa hypnorum, is the only species that is not either an arthropod or a fish for which an acute value is available.

The Species Mean Acute Values (Table 1) were used to calculate Genus Mean Acute Values (Table 3). Although values are available for 13 genera, none is a planktonic crustacean. The most sensitive genus, Gammarus, is more than 4,300 times more sensitive than the most resistant genera. Aplexa, Carassius, and Ictalurus, but the four most sensitive genera are within a factor of 4. and all are invertebrates. Mean acute values are available for more than one species in each of two genera, and the range of Species Mean Acute Values within each genus is less than a factor of 3. The freshwater Final Acute Value of 0.1669 μg/L was calculated from the Genus Mean Acute Values (Table 3) using the procedure described in the Guidelines. Criterion Maximum Concentration is 0.08345 μg/L, which is below the normal detection limits.

Chronic Toxicity to Aquatic Animals

Available data on the chronic toxicity of chlorpyrifos contains information on a single test species, the fathead minnow. Chronic values for technical grade and encapsulated material were 2.26 μg/L and 3.25 μg/L, respectively, in early life stage tests (Jarvinen and Tanner, 1982). Growth over the 32-day test was the most sensitive parameter using technical grade chlorpyrifos whereas with the encapsulated formulation, growth and survival were equally sensitive. In a life cycle test with the same species (Jarvinen et al. 1983) unacceptable effects occurred at 0.41 μg/L in the first generation and at 0.12 μg/L in the second generation, showing rather poor agreement between the early life-stage test and the life-cycle test. Based on these results the acute-chronic ratio for chlorpyrifos is greater than 1,417 with the fathead minnow. Jarvinen et al. (1983) also estimated the chronic effect of chlorpyrifos on the viable biomass recruitment of a natural population of the fathead minnow.

Requirements for an adequate data set for the calculation of Final Chronic Value as prescribed in the Guidelines are not met.

Toxicity to Aquatic Plants

Several field studies have examined the effects of chlorpyrifos on phytoplankton under more or less natural conditions (Brown et al. 1976; Butcher et al. 1975, 1977; Hughes et al. 1980; Hurlbert 1969; Hurlbert et al. 1972; Papst and Boyer 1980). All used an emulsifiable concentrate formulation of chlorpyrifos which makes them inappropriate for inclusion in Table 4, but the general trends identified are germaine to a discussion of the effects of chlorpyrifos under natural conditions. With the exception of Brown et al. (1976), all observed increased phytoplankton numbers after pesticide application. This change is generally accepted not to be a direct effect of chlorpyrifos, but rather a result of changes in the herbivore-algal relationship caused by large reductions in zooplankton populations. Reduced macrozooplankton numbers releases phytoplankton community from herbivory. Papst and Boyer (1980) attempted to substantiate this hypothesis experimentally by following concentrations of pheopigments, the major chlorophyll a degradation product of herbivory, after chlorpyrifos application. Although this study did identify reductions in pheopigments, the effect was delayed. They observed rapid increases in microzooplankton (e.g., rotifers) numbers immediately after chlorpyrifos application, presumably due to reduced competition with macrozooplankton. Other studies have also observed an increase in microzooplankton after chlorpyrifos treatment (Hughes 1977; Hurlbert et al. 1970, 1972; Siefert et al. 1984). Although increased phytoplankton numbers can be explained by release from herbivory, another possible factor may be increased phosphate concentration directly from the decomposition of chlorpyrifos and from the decomposition of intoxified organisms (Butcher et al. 1977).

Bioaccumulation

Although chlorpyrifos is hydrophobic, which would suggest its accumulation in tissues. this is offset by its rapid metabolism (Kenaga and Goring 1980; Marshall and Roberts 1978). In the fathead minnow, an average BAF at 60 days is 1673 (Jarvinen et al. 1983). Although this study used an encapsulated formulation, chlorpyrifos test concentrations were prepared separate from the test chamber. In a review, Kenaga and Goring (1980) cite results of an unpublished study reporting a bioconcentration factor in an unnamed fish of 450.

No U.S. FDA Action Level has been set for chlorpyrifos, therefore no Final Residue Value could be derived.

Other Data

Data in Table 6 include investigations utilizing technical grade chlorpyrifos, unless noted otherwise. Many were inadequate in duration or tested associated effects of chlorpyrifos toxicity. Because of its use as a biological control agent in mosquito abatement programs, the mosquitofish has been widely studied to determine the effects of chlorpyrifos applications on its survival and effectiveness as a mosquito larvae predator. Hansen et al. (1972) reported an LC50 of 4000 μg/L for this fish at 24 hr. At 36 hr. LC50 of 215-230 μg/L was reported (Ferguson et al. 1966), and at 72 hr. the LC50 was 0.19-0.22 μg/L (Ahmed and Washino 1977). After a 24 hr. exposure to 5.0 μg/L, Johnson (1978a) observed a decreased thermal tolerance in mosquitofish. Hansen et al. (1972) reported an avoidance of chlorpyrifos when mosquitofish were given a choice between clean water and a dosage of 100 μg/L in laboratory experiments. The authors noted that this result did not prove that avoidance of chlorpyrifos occurs in nature. The green sunfish was reported to have a 36-hr LC50 of 22.5-37.5μg/L (Ferguson et al. 1966). At the same exposure duration, the LC50 for the golden shiner was 35.0-45.0 μg/L. For rainbow trout, the 96 hr. LC50s at 1.6°, 7.2°, and 12.7° C were 51., 15., and 7.1 μg/L, respectively (Macek et al. 1969). Increased toxicity of chlorpyrifos with increased temperature was thought to be the result of increased metabolism producing lower DO levels and higher metabolic wastes, or increased enzyme activity converting chlorpyrifos to its more toxic form, chlorpyrifos-oxon. In a 24-hr. exposure to 100 μg/L, atlantic salmon had a 4° C lower temperature preference (Peterson 1976). Whether the preference for a lower, presumibly less toxic temperature regimen was of any survival benefit in nature is not known.

Because of the widespread use of chlorpyrifos as a mosquito larvicide, many toxicity studies have used various species of mosquito larvae as test organisms. Unfortunately, many studies have followed guidelines set forth by the World Health Organization on testing of pesticides. These guidelines prescribe a 24-hr duration, making result unusable for derivation of numerical water quality criteria.

As would be expected, chlorpyrifos is highly toxic to mosquitos. Rettich (1977) reportd 24 hr. LC50's of 0.5 to 3.5 μg/L for 4th instars of 6 species of the genus _Aedes_. For _A. aegypti_, a species not tested by Rettich, Saleh et al. (1981) cited 24 hr. LC50s of 0.0011 and 0.0014 μg/L, for 2nd and 4th instars, respectively. Minimum lethal time (MLT) for this species at 10 μg/L is 18 hrs. (Verma and Rahman 1984). Reports of 24 hr. LC50s for 4th instars of various _Culex_ species range from 0.41 μg/L to 2.0 μg/L (Ahmed 1977; Helson et al. 1979; Rettich 1977). For _C. pipiens_, Saleh et al. (1981) found a 24-hr. LC50 of 0.0052 μg/L.

Use of chlorpyrifos as a pesticide in controlling noxious midge populations has been documented (Ali and Mulla 1978a. 1980; Mulla and Khasawinah 1969; Mulla et al. 1971; Thompson et al. 1970). LC50s at 24 hr. for various midges generally range from 0.5 µg/L to 40 µg/L (Ali and Mulla 1978a. 1980; Mulla and Khasawineh 1969) although a value of 1,470 µg/L was reported for Cricotopus decorus (Ali and Mulla 1980).

Ahmed (1977) determined 24 hr. LC50s in 6 species of aquatic coleopteran and observed a range of 4.6 µg/L to 52.0 µg/L; he also cited for the same test duration an LC50 of 15 µg/L for Belostoma sp. Levy and Miller (1978) observed the delayed effects of a 24-hr. exposure to 1.0 and 4.0 µg/L on a planarian, Dugesia dorotocephala over 108 hrs. They reported no significant effects at either concentration. Siefert et al. (1984) cited LC50s for various durations with Chaoborus. Daphnia, a pigmy backswimmer, an amphipod and a mayfly.

Several studies have provided interesting information of the effects of chlorpyrifos, although are not suited for inclusion in data used to derive numerical water quality criteria. Winner et al. (1978) used a single chlorpyrifos concentration (E.C.) in an experiment on the effects in a mermithid nematode parasite of mosquito larvae. They examined toxicity to infectious, parasitic, post-parasitic, and embryo stages of the nematode. Rawn et al. (1978) investigated the effect of various sediments on the toxicity of chlorpyrifos to larvae of a mosquito in artificial ponds. They found lower toxicity and lower water residues in sod-lined ponds compared to sand-lined ponds at equal application rates. Macek et al. (1972) conducted a field study which included analysis of fish brain AChE activity, fish stomach contents, residues in fish and water, numbers of larval insects, and numbers of emerging insects.

Siefert et al. (1984) conducted an extensive survey of changes within a natural pond after chlorpyrifos was applied using standard methods employed by pest control authorities. Their study included analysis of water quality, fish and invertebrate populations, and associated laboratory studies.

Schaeffer and Dupros (1970) examined the effect of polluted waters on the stability of chlorpyrifos in the field. As part of a laboratory study, El-Refai et al. (1976) tested the effectiveness of a simulated water treatment facility in lowering toxicity of Nile River water spiked with chlorpyrifos. They found a 33% decrease in toxicity with alum treatment. and no significant change with sand filtration.

Jamnback and Frempang-Boadu (1966), Mohsen and Mulla (1981). and Muirhead-Thomson (1978, 1979) observed delayed effects after short exposures.

Unused Data

Some data on the effects of chlorpyrifos on aquatic organisms were not used because the studies were conducted with species that are not resident in North America (e.g., Moorthy et al. 1982). Results of tests reported by Ali (1981). Ferguson et al. (1966); Naqvi (1973): and Nelson and Evans (1973) were not used because the test organisms probably had been previously exposed to pesticides or other pollutants. Ramke (1969) only presented data that have been published elsewhere.

Data were not used if the test was on a commercial formulation (e.g., Atallah and Ishak 1971; Birmingham and Colman 1977; Chang and Lange 1967; Hurlbert et al. 1970: Ledieu 1978; Mulla et al. 1973: Roberts and Miller 1971; Scirocchi and D'Erme 1980; Siefert et al. 1984; Smith et al. 1966) or if the source of the chlorpyrifos was not adequately described (e g., Ali and Mulla 1976, 1977: Boike and Rathburn 1969; Gillies et al. 1974;

Johnson 1977b, 1978b; Kenaga et al. 1965; Micks and Rougeau 1977; Muirhead-Thomson and Merryweather 1969; Ruber and Kocor 1976; Thayer and Ruber 1976; Wilder and Schaefer 1969; Zboray and Gutierrz 1979). Data were not used if the organisms were exposed to chlorpyrifos by injection or gavage or in food (e.g., Wilton et al. 1973) or if chlorpyrifos was a component of a mixture (Meyer 1981), or were fed during exposure in short term tests (Karnak and Collins 1974). The concentration of solvent was too high in the tests of Davey et al. (1976) and Al-Khatib (1985). Barton (1970) conducted a static chronic test with mosquito larvae. Because polyethylene sorbs chlorpyrifos (Brown et al. 1976; Hughes 1977; Hughes et al. 1980), toxicity tests conducted in polyethylene were not used (e.g., Brown and Chow 1975; Darwazeh and Mulla 1974; Dixon and Brust 1971; Hughes 1977; Miller et al. 1973; Roberts et al. 1973a, b). Results of some laboratory tests were not used because the tests were conducted in distilled or deionized water without addition of appropriate salts (e.g., Jones et al. 1976: Nelson and Evans 1973; Rongsreyam et al. 1968; Steelman et al. 1969). High control mortalities occurred in tests reported by Khudairi and Ruber (1974). Test procedures were inadequately described by Ruber and Baskar (1969). Roberts and Miller (1970) tested only one concentration of chlorpyrifos. BCFs obtained from microcosm or model ecosystem studies were not used if the concentration of chlorpyrifos in water decreased with time or if the exposure was too short (e.g., Metcalf 1974). Results of field tests were not used if the concentrations of chlorpyrifos were not measured (e.g., Ali and Mulla 1976, 1977, 1978a, b Axtell et al. 1979; Best 1969: Carter and Graves 1972; Chang and Lange 1967; Chatterji et al. 1979; Cooney and Pickard 1974; Evans et al. 1975; Frank and Sjogren 1978; Hazeleur 1971; Hoy et al. 1972: Jamnback 1969;

Lembright 1968; Linn 1968; McNeill et al. 1968; Moore and Breeland 1967; Mulla and Khasawinah 1969; Mulla et al. 1971; Nelson et al. 1976a, b; Polls et al. 1975; Roberts et al. 1984; Steelman et al. 1969; Stewart 1977; Tawfik and Gooding 1970; Taylor and Schoof 1971; Thompson et al. 1970; Wallace et al. 1973; Washino et al. 1968, 1972a, b; Wilkinson et al. 1971; Winterlin et al. 1968; Yap and Ho 1977) or if the concentration in water was not uniform enough (e.g., Macek et al. 1972).

Summary

The acute values for eighteen species in fifteen genera range from greater than 806 μg/L for two fishes and a snail to 0.11 μg/L for an amphipod. The bluegill is the most acutely sensitive fish species with an acute value of 10 μg/L, but seven invertebrate genera are more sensitive. Larger organisms seem to be less sensitive.

Chronic toxicity data are available for one species, the fathead minnow. Unacceptable effects occurred to second generation larvae at 0.12 μg/L, which was the lowest concentration tested. The resulting acute-chronic ratio was greater than 1.400.

Little information is available on the toxicity of chlorpyrifos to aquatic plants, although a consistent observation of increased algal blooms is frequently reported associated with chlorpyrifos application. The only available bioconcentration test on chlorpyrifos with freshwater species was with the fathead minnow and resulted in a BCF of 1,673.

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 chlorpyrifos does not exceed AAA μg/L more than once every three years on the average or if the one-hour average concentration does not exceed 0.083 μg/L more than once every three years on the average.

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, saltwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of chlorpyrifos does not exceed μg/L more than once every three years on the average and if the one-hour average concentration does not exceed yyy μg/L more than once every three years on the average.

The allowed excursion frequency of three years is based on the Agency's best scientific judgment of the average amount of time it will take an aquatic ecosystem to recover from a pollution event in which exposure to chlorpyrifos exceeds the criterion. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one must rely on a steady-state model. The Agency recommends interim use of 1Q10 for Criterion Maximum Concentration (CMC) design flow and 7Q10 for the Criterion Continuous Concentration (CCC) design flow in steady-state models. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA 1985) and the Design Flow Manual (U.S. EPA 1986).

Table 1. Acute Toxicity of Chlorpyrifos to Aquatic Animals

Species	Method*	Chemical	LC50 or EC50 (µg/L)	Species Mean Acute Value (µg/L)	Reference
		FRESHWATER SPECIES			
Snail (adult), *Aplexa hypnorum*	F, M	Technical	>806	>806	Phipps and Holcombe 1985a,b
Amphipod, *Gammarus fasciatus*	S, U	Technical	0.32	0.32	Sanders 1972
Amphipod (2 mo. old), *Gammarus lacustris*	S, U	Technical	0.11	0.11	Sanders 1969; Johnson and Finley 1980
Amphipod, *Gammarus pseudolimnaeus*	F, M	Clarke**	0.18	0.18	Siefert et al. 1984
Crayfish (1.8 g), *Orconectes immunis*	F, M	Technical	6	6	Phipps and Holcombe 1985a,b
Stonefly (naiad), *Pteronarcella badia*	S, U	Technical	0.38	0.38	Sanders and Cope 1968
Stonefly (naiad), *Pteronarcys californica*	S, U	Technical	10	10	Sanders and Cope 1968; Johnson and Finley 1980
Stonefly (naiad), *Claassenia sabulosa*	S, U	Technical	0.57	0.57	Sanders and Cope 1968; Johnson and Finley 1980
Trichopteran, Leptoceridae sp.	S, M	Clarke**	0.77	0.77	Siefert et al. 1984
Pygmy backswimmer, *Neoplea striola*	S, M	Clarke**	1.22	-	Siefert et al. 1984
Pygmy backswimmer, *Neoplea striola*	S, M	Clarke**	1.56	1.38	Siefert et al. 1984
Crawling water beetle (adult), *Peltodytes* sp.	S, U	-	0.8	0.8	Federle and Collins 1976
Cutthroat trout (1.4 g), *Salmo clarkii*	S, U	Technical	18	18	Johnson and Finley 1980

Table 1. (continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)	Species Mean Acute Value (µg/L)	Reference
Rainbow trout (0.6-1.5 g), *Salmo gairdneri*	S, U	Technical	7.1	-	Macek et al. 1969; Johnson and Finley 1980
Rainbow trout (juvenile), *Salmo gairdneri*	F, M	Technical	8.0	-	Holcombe et al. 1982
Rainbow trout (3.0 g), *Salmo gairdneri*	F, M	Technical	9	8.485	Phipps and Holcombe 1985a,b
Lake trout (2.3 g), *Salvelinus namaycush*	S, U	Technical	98	98	Johnson and Finley 1980
Goldfish (10.7 g), *Carassius auratus*	F, M	Technical	>806	>806	Phipps and Holcombe 1985a,b
Fathead minnow, *Pimephales promelas*	S, M	Technical	170	-	Jarvinen and Tanner 1982
Fathead minnow (juvenile), *Pimephales promelas*	F, M	Technical	203	-	Holcombe et al. 1982
Fathead minnow (0.5 g), *Pimephales promelas*	F, M	Technical	542	331.7	Phipps and Holcombe 1985a,b
Channel catfish (0.8 g), *Ictalurus punctatus*	S, U	Technical	280	-	Johnson and Finley 1980
Channel catfish (7.9 g), *Ictalurus punctatus*	F, M	Technical	>806	806	Phipps and Holcombe 1985a,b
Bluegill (0.6 g), *Lepomis macrochirus*	S, U	Technical	2.4	-	Johnson and Finley 1980
Bluegill (0.8 g), *Lepomis macrochirus*	F, M	Technical	10	10	Phipps and Holcombe 1985a,b

* S = static; R = renewal; F = flow-through; U = unmeasured; M = measured.

** Clarke = encapsulated technical chlorpyrifos; doses prepared separate from test chamber.

Table 2. Chronic Toxicity of Chlorpyrifos to Aquatic Animals

Species	Test*	Chemical	Limits (µg/L)	Chronic Value (µg/L)	Reference
		FRESHWATER SPECIES			
Fathead minnow, Pimephales promelas	ELS	Technical	1.6-3.2	2.263	Jarvinen and Tanner 1982
Fathead minnow, Pimephales promelas	ELS	Encapsulated	2.2-4.8	3.250	Jarvinen and Tanner 1982
Fathead minnow, Pimephales promelas	LC	Encapsulated	0.27-0.63	0.4124	Jarvinen et al. 1983
Fathead minnow (second generation), Pimephales promelas	ELS	Encapsulated	<0.12**	<0.12	Jarvinen et al. 1983

* LC = life-cycle or partial life-cycle; ELS = early life-stage.

** Unacceptable effects occurred at all tested concentrations.

Acute-Chronic Ratio

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
Fathead minnow, Pimephales promelas	170	<0.12	>1,417

Table 3. Ranked Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio***
		FRESHWATER SPECIES		
15	>806	Snail, <u>Aplexa hypnorum</u>	>806	-
14	>806	Goldfish, <u>Carassius auratus</u>	>806	-
13	806	Channel catfish, <u>Ictalurus punctatus</u>	806	-
12	331.7	Fathead minnow, <u>Pimephales promelas</u>	331.7	>1,417
11	98	Lake trout, <u>Salvelinus namaycush</u>	98	-
10	12.36	Cutthroat trout, <u>Salmo clarki</u>	18	-
		Rainbow trout, <u>Salmo gairdneri</u>	8.485	-
9	10	Stonefly, <u>Pteronarcys californica</u>	10	-
8	10	Bluegill, <u>Lepomis macrochirus</u>	10	-
7	6	Crayfish, <u>Orconectes immunis</u>	6	-
6	1.38	Pygmy backswimmer, <u>Neoplea striola</u>	1.38	-
5	0.8	Crawling water beetle, <u>Peltodytes</u> sp.	0.8	-
4	0.77	Trichoptera Leptoceridae sp.	0.77	-

Table 3. (continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio***
3	0.57	Stonefly, *Claasenia sabulosa*	0.57	-
2	0.38	Stonefly, *Pteronarcella badia*	0.38	-
1	0.1850	Amphipod, *Gammarus fasciatus*	0.32	-
		Amphipod, *Gammarus lacustris*	0.11	-
		Amphipod, *Gammarus pseudolimnaeus*	0.18	-

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

** From Table 1.

*** From Table 2.

Fresh water

Final Acute Value = 0.1669 µg/L

Criterion Maximum Concentration = (0.1669 µg/L) / 2 = 0.08345 µg/L

Table 4. Bioconcentration of Chlorpyrifos by Aquatic Organisms

Species	Chemical*	Concentration in Water (µg/L)**	Duration (days)	Tissue	BCF or BAF***	Reference
		FRESHWATER SPECIES				
Fathead minnow, *Pimephales promelas*	Encapsulated	0.12-2.68	60	Whole body	1,673	Jarvinen et al. 1983

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

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
			FRESHWATER SPECIES		
Planaria, *Dugesia dorotocephala*	-	108 hr	Delayed effects after 24 hr exposure	No effect detected at 1.0 and 4.0	Levy and Miller 1978
Cladoceran, *Daphnia* sp.	Clarke*	4 hr	LC50	0.88	Siefert et al. 1984
Amphipod, *Hyalella azteca*	Clarke*	24 hr	LC50	1.28	Siefert et al. 1984
Mayfly, *Ephemerella* sp.	Clarke*	72 hr	LC50	0.33	Siefert et al. 1984
Pygmy backswimmer, *Neoplea striola*	Clarke*	144 hr	LC50	0.97	Siefert et al. 1984
Giant water bug (adult), *Belostoma* sp.	Technical	24 hr	LC50	15	Ahmed 1977
Predaceous diving beetle (adult), *Hygrotus* sp.	Technical	24 hr	LC50	40	Ahmed 1977
Predaceous diving beetle (adult), *Laccophilus decipiens*	Technical	24 hr	LC50	4.6	Ahmed 1977
Predaceous diving beetle (adult), *Thermonectus basillaris*	Technical	24 hr	LC50	6	Ahmed 1977
Water scavenger beetle (adult), *Berosus styliferus*	Technical	24 hr	LC50	9	Ahmed 1977
Water scavenger beetle (larva), *Hydrophilus triangularis*	Technical	24 hr	LC50	20	Ahmed 1977

Table 5. (continued)

Species	Chemical	Duration	Effect	Result (µg/L)[a]	Reference
Water scavenger beetle (adult), *Hydrophilus triangularis*	Technical	24 hr	LC50	30	Ahmed 1977
Water scavenger beetle (larva), *Tropisternus lateralis*	Technical	24 hr	LC50	52	Ahmed 1977
Water scavenger beetle (adult), *Tropisternus lateralis*	Technical	24 hr	LC50	8	Ahmed 1977
Mosquito (3rd and 4th instar), *Aedes aegypti*	Technical	18 hr	LT50	10	Verma and Rahman 1984
Mosquito (2nd instar), *Aedes aegypti*	Technical	24 hr	LC50	0.0011	Saleh et al. 1981
Mosquito (4th instar), *Aedes aegypti*	Technical	24 hr	LC50	0.0014	Saleh et al. 1981
Mosquito (4th instar), *Aedes cantans*	Technical	24 hr	LC50	1.1	Rettich 1977
Mosquito (4th instar), *Aedes communis*	Technical	24 hr	LC50	3.5	Rettich 1977
Mosquito (4th instar), *Aedes excrucians*	Technical	24 hr	LC50	3.3	Rettich 1977
Mosquito (4th instar), *Aedes punctor*	Technical	24 hr	LC50	2.7	Rettich 1977
Mosquito (4th instar), *Aedes sticticus*	Technical	24 hr	LC50	0.5	Rettich 1977
Mosquito (4th instar), *Aedes vexans*	Technical	24 hr	LC50	1.0	Rettich 1977
Mosquito (larva), *Anopheles freeborni*	Technical	24 hr	LC50	3	Ahmed 1977

Table 5. (continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Mosquitofish, *Gambusia affinis*		24 hr	LC50	4,000	Hansen et al. 1972
Guppy, *Poecilia reticulata*	Technical	24 hr	LC50	220	Rongsriyam et al. 1968
Green sunfish, *Lepomis cyanellus*	Technical	36 hr	LC50	37.5 22.5	Ferguson et al. 1966

* Clarke = encapsulated technical chlorpyrifos; doses prepared separate from test chamber.

** Aged 11 weeks.

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