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AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

CHLORPYRIFOS

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NOTICES

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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 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, 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. Criteria contained in this document replace any previously published EPA aquatic life criteria for the same pollutant(s).

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. 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, they become enforceable maximum acceptable pollutant concentrations in ambient waters within that State. 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 and human exposure patterns before incorporation into water quality standards. It is not until their adoption as part of State water quality standards that criteria become regulatory.

Guidelines to assist 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.

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Introduction*

Chlorpyrifos** is one of several organophosphorus compounds developed in the 1960s to replace persistent organochlorine pesticides. It is the active ingredient in various products designed to control a variety of pests including fire ants, turf and ornamental plant insects, mosquitos, cockroaches, termites, lice and hornflies. In the agricultural industry in the United States, chlorpyrifos is used primarily to control pests on cotton, peanuts, and sorghum. It also is used extensively in the forest industry and is directly applied to aquatic environments in mosquito, midge, and blackfly abatement projects. Gray (1965) and Marshall and Roberts (1978) have reviewed its composition and physical and chemical properties.

Chlorpyrifos is available for pesticide applications as emulsifiable concentrates, wettable powders, dusts, granules, and controlled-release polymers. The resulting concentrations of chlorpyrifos in water and its persistence varies from one form to another. In general, emulsifiable concentrates and wettable powders produce a large increase in chlorpyrifos concentrations immediately after application. The concentration in water rapidly declines as chlorpyrifos is sorbed onto sediments and suspended organics. Granules and controlled-release forms do not produce as rapid an increase in the concentration in water, but the resulting concentration has a longer duration.

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* 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.

**Dursban® and Lorsban® are trade names owned by the Dow Chemical Company, Midland, MI for chlorpyrifos.

The percentage of active ingredient in available formulations varies considerably, both between formulations and within a single formulation over time as manufacturers' specifications change. Such variations presumably result in large changes in the amount, and possibly the identity, of the unspecified ingredients. 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 a formulation (Darwazeh and Mulla 1974; Jarvinen and Tanner 1982; Siefert et al. 1984). For this reason, the effects of the inert ingredients can not be discounted. Furthermore, under normal application conditions, the commercial formulations are often combined with petroleum products, such as No. 2 diesel oil and kerosene, to increase the rate of dispersal. Such solvents have been shown to have significant toxic effects in addition to those associated with chlorpyrifos (Jamnback and Frempong-Boadu 1966; Wallace et al. 1973).

The toxicity of chlorpyrifos is probably the result of metabolic conversion to its oxygen analogue, chlorpyrifos-oxon, and its subsequent inhibition of various enzymes (e.g., cholinesterases, carboxylases, acetylcholinesterases, and mitochondrial oxidative phosphorylases). Interference with acetylcholinesterase (AChE) is generally accepted to be the major mode of action of organophosphorus pesticides. AChE inhibition results in accumulation of the neurotransmitter, acetylcholine, in synapes, and disruption of normal neural transmission. Although even substantial reductions in brain AChE activity have not always been fatal to fish, the effect of this condition on such functions as feeding and reproduction in nature is not known.

Chlorpyrifos enters both freshwater and saltwater ecosystems primarily by direct application to mosquito habitats, as drift from spraying of agricultural areas, and on particles eroded from treated areas. Because of its affinity for organic soils, little leaching occurs. When unbound chlorpyrifos enters an aquatic system, it appears to be rapidly sorbed to suspended organics and sediment, although some is removed by volatilization and degradation. Its penetration into sediment appears to be shallow, with most occurring in the upper several millimeters. Menzie (1969) reported that chlorpyrifos remained stable for long periods of time under the acidic conditions (pH = 5 to 6) found in some salt marshes.

Use of slow-release polymers probably results in differential exposure, both in concentration and duration, between benthic and pelagic organisms. Organisms inhabiting the water-sediment interface probably receive larger and more sustained concentrations than free-swimming organisms. Evans (1977) found concentrations of chlorpyrifos that were still toxic to mosquito larvae one year after application of a slow-release polymer formulation to a natural pond.

Because chlorpyrifos is rapidly metabolized by fish, with 3,5,6-trichloro-2-pyridinol being the major product (Marshall and Roberts, 1978), concentrations in wild fishes (Clark et al. 1984; Mulla et al. 1973) and cultured or experimental fishes (Macek et al. 1972; Siefert et al. 1984; Winterlin et al. 1968) are generally low. Braun and Frank (1980), Hughes (1977), Hughes et al. (1980), Hurlbert et al. (1970), Macalady and Wolfe (1985), Nelson and Evans (1973), Rawn et al. (1978), Siefert et al. (1984), and Winterlin et al. (1968) have reported concentrations of chlorpyrifos in natural sediment and water samples.

Unless otherwise noted, all concentrations reported 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 excursions (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

Usable data on the acute toxicity, according to the Guidelines, of chlorpyrifos to freshwater animals is available for seven fish species and eleven invertebrate species. Although invertebrates are among the most sensitive and most resistant species, the nine most sensitive species are invertebrates. Although data are available for eighteen species, no data are available for a planktonic crustacean, and the snail, *Aplexa hypnorum*, is the only one of the eighteen that is not an arthropod or a fish. Within arthropods and fishes separately, and within all species combined, there appears to be an inverse relationship between size and sensitivity to chlorpyrifos.

Species Mean Acute Values (Table 1) were calculated as geometric means of the available acute values, and then Genus Mean Acute Values (Table 3) were calculated as geometric means of the available freshwater Species Mean Acute Values. 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. 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 for chlorpyrifos was calculated to be 0.1669 μg/L using the procedure described in the Guidelines and the Genus Man Acute Values in Table 3. Thus the freshwater Final Acute Value is higher than the Species Mean Acute Value for one of three amphipods in the genus Gammarus.

Tests of the acute toxicity of chlorpyrifos to saltwater animals have been conducted with three species of invertebrates and ten species of fish (Table 1). The range of acute values extends from 0.01 µg/L for adult Korean shrimp, Palaemon macrodactylus, (Earnest 1970) to 1,991 µg/L for larvae of the eastern oyster, Crassostrea virginica, (Borthwick and Walsh 1981). Only two species of saltwater arthropods have been tested and were up to 40 times more sensitive than the most sensitive fish species. The range of acute toxicity values for fish is narrower than for invertebrates, with LC50s extending from 0.4 µg/L for 14-day-old larvae of the tidewater silverside, Menidia peninsulae, (Borthwick et al. 1985) to 520 µg/L for juveniles of the Gulf toadfish, Opsanus beta, (Hansen et al. 1986).

Borthwick et al. (1985) conducted a series of 96-hr acute tests under both static and flow-through conditions with four different ages of larvae of three estuarine fishes (Table 1). LC50s ranged from 0.4 to 5.0 µg/L for all tests. In static tests, 14-day-old larvae were more sensitive than newly hatched or 28-day larvae of all species. In flow-through tests, relative sensitivities of the ages were similar to those in static tests for tidewater silverside, decreased with age for Atlantic silverside, and differed little for California grunion (Table 1).

Of the ten genera for which saltwater Genus Mean Acute Values are available, the most sensitive genus, Mysidopsis, is about 57,000 times more sensitive than the most resistant genus, Crassostrea (Table 3). 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 5.7. Although values are available for ten genera, and eight families, five of the eight families are in the phylum Chordata. A saltwater Final Acute Value of 0.007591 μg/L was calculated using the Genus Mean Acute Values in Table 3. Because values are available for only ten genera and the range of values for the four most sensitive genera is a factor of 30, the saltwater FAV is a factor of 4.6 lower than the lowest Genus Mean Acute Value.

Chronic Toxicity to Aquatic Animals

Usable data on the chronic toxicity of chlorpyrifos are available for only one freshwater 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 with 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.

Data on the chronic toxicity of chlorpyrifos to saltwater animals are available for the mysid, *Mysidopsis bahia*, and six fishes. In the 28-day life-cycle test with the mysid, survival and reproduction were reduced at 42 μg/L, and growth was significantly reduced at a nominal concentration of 0.004 μg/L (McKenney et al. 1981). This nominal concentration, which was less than the limit of detection of the analytical method used, is likely representative of the actual concentration because the test concentrations that could be measured averaged 10 ± 2.5% of the nominal concentrations. Of the six saltwater fishes exposed to chlorpyrifos in early life-stage toxicity tests, the California grunion was the most sensitive. Decreased weight was the most sensitive endpoint for this species (Goodman et al. 1985a), the sheepshead minnow (Cripe et al. Manuscript), and the gulf toadfish (Hansen et al. 1986). Decreased survival was the most sensitive endpoint with the three species of *Menidia*, although growth was also affected with two of these species (Goodman et al. 1985b).

The Species Mean Acute-Chronic Ratios for the seven saltwater species range from 2.388 to 228.5, whereas that for the freshwater fathead minnow is greater than 1,417. However, the ratios for the five most sensitive species only range from 2.388 to 12.50. Thus it seems reasonable to calculate the Final Acute-Chronic Ratio for chlorpyrifos as the geometric mean of these five. Division of the freshwater and saltwater Final Acute Values by the Final Acute-Chronic Ratio of 5.016 results in Final Chronic Values of 0.03327 μg/L and 0.001513 μg/L, respectively. The freshwater value is about a factor of four lower than the 0.12 μg/L that affected the fathead minnow, which is an acutely insensitive species. The saltwater value is a factor of two lower than the chronic value for the most acutely sensitive saltwater species, *Mysidopsis bahia*.

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 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 application of chlorpyrifos. This change is generally accepted not to be a direct effect, but rather a result of changes in the herbivore-algal relationship caused by large reductions in predatory zooplankton populations. Papst and Boyer (1980) attempted to substantiate this hypothesis experimentally by following concentrations of pheopigments, the major chlorophyll degradation product of herbivory, after chlorpyrifos application. Although they found reductions in pheopigments, the effect was delayed. They did observe 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 is increased phosphate concentration from decomposition of chlorpyrifos and from decomposition of intoxified organisms (Butcher et al. 1977).

The concentrations of chlorpyrifos reducing growth or survival of six saltwater species of phytoplankton range from 138 to 10,000 µg/L (Tables 4 and 6). These concentrations are well above those that are acutely lethal to saltwater animals. Therefore, criteria derived using data on the toxicity of chlorpyrifos to saltwater animals will probably also protect saltwater plants.

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). With the fathead minnow, Jarvinen et al. (1983) found a mean bioconcentration factor (BCF) of 1,673 after 60 days (Table 5). In a review, Kenaga and Goring (1980) cite results of an unpublished study reporting a BCF in an unnamed fish of 450.

Data on the uptake of chlorpyrifos are available for five species of saltwater fish (Table 5). In two early life-stage tests with the gulf toadfish, *Opsanus beta*, the BCF increased from 100 to 5,100 as the concentration of chlorpyrifos in the test solution increased from 1.4 to 150 µg/L (Hansen et al. 1986). Cripe et al. (Manuscript) found that the BCF with the sheepshead minnow depended on the availability of food as well as the concentration of chlorpyrifos in water (Tables 5 and 6).

No U.S. FDA action level or other maximum acceptable concentration in tissue is available for chlorpyrifos, and, therefore, no Final Residue Value can be calculated.

Other Data

Additional data on the lethal and sublethal effects of chlorpyrifos on aquatic organisms are given in Table 6. Because both chlorpyrifos and the mosquitofish are used in mosquito control programs, several studies have been conducted on the effects of chlorpyrifos on the survival and effectiveness of mosquitofish as a predator of mosquito larvae. Hansen et al. (1972) reported a 24-hr LC50 of 4,000 µg/L for this fish. A 36-hr LC50 of 215 to 230 µg/L was reported by Ferguson et al. (1966), whereas a 72-hr LC50 of 0.19 to 0.22 µg/L was reported by Ahmed (1976). After a 24-hr exposure to 5.0 µg/L, Johnson (1977a,1978a) observed a decreased thermal tolerance in mosquitofish. Hansen et al. (1972) found that mosquitofish chose clean water when given a choice between clean water and 100 µg chlorpyrifos/L in laboratory experiments.

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 either increased metabolism producing lower concentrations of dissolved oxygen 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).

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 test duration, making results unusable for derivation of water quality criteria.

As would be expected, chlorpyrifos is highly toxic to mosquitos. Rettich (1977) reported 24-hr LC50s 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. Reports of 24-hr LC50s for 4th instars of various *Culex* species range from 0.41 µg/L to 2.0 µg/L (Ahmed 1976; Helson et al. 1979; Rettich 1977). For *C. pipiens* Saleh et al. (1981) found a 24-hr LC50 of 0.0052 µg/L.

Chlorpyrifos is also used to control noxious midge populations (Ali and Mulla 1978a,1980; Mulla and Khasawinah 1969; Mulla et al. 1971;

Thompson et al. 1970). The 24-hr LC50s 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 with 6 species of aquatic coleoptera and observed a range of 4.6 to 52 µg/L. Levy and Miller (1978) observed the delayed effects of 24-hr exposures to 1.0 and 4.0 µg/L on a planarian, Dugesia dorotocephala, over 108 hr. They reported no significant effects at either concentration.

Winner et al. (1978) used a single concentration of an emulsifiable concentrate in a study of the effects on 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 concentrations in water 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 methods employed by pest control authorities. Their study included analysis of water quality, fish and invertebrate populations, and associated laboratory studies.

Schaefer and Dupras (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.

Among saltwater species, juvenile brown shrimp, _Penaeus aztecus_, were the most sensitive with a 48-hr EC50 of 0.32 µg/L (U.S. Bureau of Commercial Fisheries 1965; Lowe et al. 1970). Other 48-hr EC50s are 1.5 µg/L for juvenile grass shrimp, _Palaemonetes pugio_, 2.4 µg/L for the pink shrimp, _Penaeus duorarum_, and 5.2 µg/L for the blue crab, _Callinectes sapidus_. For the eastern oyster the 96-hr EC50s based on shell deposition range from 270 to 340 µg/L.

The 48-hr LC50s for fish ranged from 3.2 µg/L for the longnose killifish, _Fundulus similis_, to 7 µg/L for the spot, _Leiostomus xanthurus_, to over 1,000 µg/L for the sheepshead minnow, _Cyprinodon variegatus_. The most sensitive effect on a fish species was a reduction in growth of the California grunion, _Leuresthes tenuis_, exposed to 0.62 µg/L for 26 days (Goodman et al. 1985a). Acetylcholinesterase activity in the brain of adult mummichogs, _Fundulus heteroclitus_, was inhibited by 2.1 µg/L (Thirugnanam and Forgash 1977).

The effect of chlorpyrifos on benthic communities was investigated by Togatz et al. (1982). In communities exposed in the laboratory for 8 weeks during colonization, total faunal species richness and the abundance of arthropods and molluscs were reduced by concentrations from 0.1 to 8.5

μg/L. For communities previously colonized in the field, the number of arthropods was reduced by 5.9 μg/L, but not by 1.0 μg/L.

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. Marshall and Roberts (1978) and Ramke (1969) only presented data that had 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; Muirhead-Thomson 1970; Mulla et al. 1973; Rettich 1979; 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., Herin et al. 1978; Wilton et al. 1973), if chlorpyrifos was a component of a mixture (Meyer 1981), or if the organisms were fed during exposure in short term tests (Karnak and Collins 1974).

The concentration of solvent was too high in the tests of Al-Khatib (1985) and Davey et al. (1976). 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 test chambers 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; Rongsriyam 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).

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). Data from field studies and measurements of chlorpyrifos in wild organisms were not used if the concentrations of chlorpyrifos in water were not measured (e.g., Ali and Mulla 1976,1977,1978a,b; Axtell et al. 1979; Best 1969; Campbell and Denno 1976; Carter and Graves 1972; Chang and Lange 1967; Chatterji et al. 1979; Cooney and Pickard 1974; Evans et al. 1975; Fitzpatrick and Sutherland 1978; Frank and Sjogren 1978; Hazeleur 1971; Hoy et al. 1972; Jamnback 1969; Lembright 1968; Linn 1968; McNeill et al. 1968; Morganian and Wall 1972; 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 freshwater species in fifteen genera range from 0.11 μg/L for an amphipod to greater than 806 μg/L for two fishes and a snail. The bluegill is the most acutely sensitive fish species with an acute value of 10 μg/L, but seven invertebrate genera are more sensitive. Smaller organisms seem to be more acutely sensitive than larger ones.

Chronic toxicity data are available for one freshwater 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 1,417.

Little information is available on the toxicity of chlorpyrifos to aquatic plants, although algal blooms frequently follow field applications of chlorpyrifos. The only available bioconcentration test on chlorpyrifos with a freshwater species was with the fathead minnow and resulted in a bioconcentration factor of 1,673.

The acute toxicity of chlorpyrifos has been determined with 13 species of saltwater animals in 10 genera, and the acute values ranged from 0.01 μg/L for the Korean shrimp, Palaemon macrodactylus, to 1,911 μg/L for larvae of the eastern oyster, Crassostrea virginica. Arthropods are particularly sensitive to chlorpyrifos. Among the 10 species of fish tested, the 96-hr LC50s range from 0.58 μg/L for striped bass to 520 μg/L for gulf toadfish; larvae are more sensitive than other life stages. Growth of the mysid, Mysidopsis bahia, was reduced at 0.004 μg/L in a life-cycle test. In early life-stage tests, the California grunion, Leuresthes tenuis, was the most sensitive of the six fishes, with growth being reduced at 0.30 μg/L. Of the seven acute-chronic ratios that have

been determined with saltwater species, the five lowest range from 2.388 to 12.50, whereas the highest is 228.5.

Concentrations of chlorpyrifos affecting six species of saltwater phytoplankton range from 138 to 10,000 µg/L. BCFs ranged from 100 to 5,100 when the gulf toadfish was exposed to concentrations increasing from 1.4 to 150 µg/L. Steady-state BCFs averaged from 100 to 757 for five fishes exposed in early life-stage tests.

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 0.033 µg/L more than once every three years on the average and 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 0.0015 µg/L more than once every three years on the average and if the one-hour average concentration does not exceed 0.0038 µg/L more than once every three years on the average.

The allowed average excursion frequency of three years is the Agency's best scientific judgment of the average amount of time it will take an unstressed aquatic ecosystem to recover from a pollution event in which exposure to chlorpyrifos exceeds the criterion. Stressed systems, for example one in which several outfalls occur in a limited area, would be expected to require more time for recovery. The resiliencies of ecosystems and their abilities to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

Use of criteria for developing water quality-based permit limits and for 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 considerations might make their use impractical, in which case one must rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for the Criterion Maximum Concentration (CMC) design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration (CCC) design flow in steady-state models for unstressed and stressed systems respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA 1985).

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 (98.7%)	>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 (97%)	0.11	0.11	Sanders 1969; Johnson and Finley 1980
Amphipod, *Gammarus pseudolimnaeus*	F, M	Encapsulated****	0.18	0.18	Siefert et al. 1984
Crayfish (1.8 g), *Orconectes immunis*	F, M	Technical (98.7%)	6	6	Phipps and Holcombe 1985a,b
Stonefly (naiad), *Pteronarcella badia*	S, U	Technical (97%)	0.38	0.38	Sanders and Cope 1968
Stonefly (naiad), *Pteronarcys californica*	S, U	Technical (97%)	10	10	Sanders and Cope 1968; Johnson and Finley 1980
Stonefly (naiad), *Claassenia sabulosa*	S, U	Technical (97%)	0.57	0.57	Sanders and Cope 1968; Johnson and Finley 1980
Trichopteran, Leptoceridae sp.	S, M	Encapsulated****	0.77	0.77	Siefert et al. 1984
Pygmy backswimmer, *Neoplea striola*	S, M	Encapsulated****	1.22	-	Siefert et al. 1984
Pygmy backswimmer, *Neoplea striola*	S, M	Encapsulated****	1.56	1.38	Siefert et al. 1984
Crawling water beetle (adult), *Peltodytes* sp.	S, U	Chlorpyrifos	0.8	0.8	Federle and Collins 1976
Cutthroat trout (1.4 g), *Salmo clarkii*	S, U	Technical (97%)	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 (99.9%)	8.0	-	Holcombe et al. 1982
Rainbow trout (3.0 g), *Salmo gairdneri*	F, M	Technical (98.7%)	9	8.485	Phipps and Holcombe 1985a,b
Lake trout (2.3 g), *Salvelinus namaycush*	S, U	Technical (97%)	98	98	Johnson and Finley 1980
Goldfish (10.7 g), *Carassius auratus*	F, M	Technical (98.7%)	>806	>806	Phipps and Holcombe 1985a,b
Fathead minnow, *Pimephales promelas*	S, M	Technical (98.7%)	170	-	Jarvinen and Tanner 1982
Fathead minnow (juvenile), *Pimephales promelas*	F, M	Technical (99.9%)	203	-	Holcombe et al. 1982
Fathead minnow (0.5 g), *Pimephales promelas*	F, M	Technical (98.7%)	542	331.7	Phipps and Holcombe 1985a,b
Channel catfish (0.8 g), *Ictalurus punctatus*	S, U	Technical (97%)	280	-	Johnson and Finley 1980
Channel catfish (7.9 g), *Ictalurus punctatus*	F, M	Technical (98.7%)	>806	806	Phipps and Holcombe 1985a,b
Bluegill (0.6 g), *Lepomis macrochirus*	S, U	Technical (97%)	2.4	-	Johnson and Finley 1980
Bluegill (0.8 g), *Lepomis macrochirus*	F, M	Technical (98.7%)	10	10	Phipps and Holcombe 1985a,b

Table 1. (Continued)

Species	Method*	Chemical**	Salinity (g/kg)	LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)	Reference
			SALTWATER SPECIES			
Eastern oyster (larva), *Crassostrea virginica*	S, U	Technical (92%)	20	1,991	1,991	Borthwick and Walsh 1981
Mysid (juvenile), *Mysidopsis bahia*	S, U	Technical (92%)	20	0.056	-	Borthwick and Walsh 1981
Mysid (juvenile), *Mysidopsis bahia*	F, M	Technical (92%)	26.7	0.035	0.035	Schimmel et al. 1983
Korean shrimp (adult), *Palaemon macrodactylus*	S, U	Chlorpyrifos (99%)	15	0.25	-	Earnest 1970
Korean shrimp (adult), *Palaemon macrodactylus*	F, U	Chlorpyrifos (99%)	24	0.01	0.05	Earnest 1970
Gulf toadfish (juvenile), *Opsanus beta*	R, M	Technical (92%)	29-30	520	520	Hansen et al. 1986
Sheepshead minnow (juvenile), *Cyprinodon variegatus*	S, U	Technical (92%)	20	270	-	Borthwick and Walsh 1981
Sheepshead minnow (juvenile), *Cyprinodon variegatus*	F, M	Technical (92%)	10.3	136	136	Schimmel et al. 1983
Mummichog (adult), *Fundulus heteroclitus*	S, U	Technical (99.5%)	20-25	4.65	4.65	Thirugnanam and Forgash 1977
Longnose killifish (juvenile), *Fundulus similis*	F, M	Technical (92%)	25.9	4.1	4.1	Schimmel et al. 1983
California grunion (day 0 larva), *Leuresthes tenuis*	S, U	Technical (92%)	25	5.5	-	Borthwick et al. 1985
California grunion (day 7 larva), *Leuresthes tenuis*	S, U	Technical (92%)	25	2.7	-	Borthwick et al. 1985

Table 1. (Continued)

Species	Method*	Chemical**	Salinity (g/kg)	LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)	Reference
California grunion (day 14 larva), Leuresthes tenuis	S, U	Technical (92%)	25	1.8	-	Borthwick et al. 1985
California grunion (day 28 larva), Leuresthes tenuis	S, U	Technical (92%)	25	2.6	-	Borthwick et al. 1985
California grunion (day 0 larva), Leuresthes tenuis	F, M	Technical (92%)	25	1.0	-	Borthwick et al. 1985
California grunion (day 7 larva), Leuresthes tenuis	F, M	Technical (92%)	25	1.0	-	Borthwick et al. 1985
California grunion (day 14 larva), Leuresthes tenuis	F, M	Technical (92%)	25	1.0	-	Borthwick et al. 1985
California grunion (day 28 larva), Leuresthes tenuis	F, M	Technical (92%)	25	1.3	1.068	Borthwick et al. 1985
Inland silverside (juvenile), Menidia beryllina	F, M	Technical (92%)	5.0	4.2	4.2	Clark et al. Manuscript
Atlantic silverside (day 0 larva), Menidia menidia	S, U	Technical (92%)	20	4.5	-	Borthwick et al. 1985
Atlantic silverside (day 7 larva), Menidia menidia	S, U	Technical (92%)	20	2.8	-	Borthwick et al. 1985
Atlantic silverside (day 14 larva), Menidia menidia	S, U	Technical (92%)	20	2.4	-	Borthwick et al. 1985
Atlantic silverside (day 28 larva), Menidia menidia	S, U	Technical (92%)	20	4.1	-	Borthwick et al. 1985

Table 1. (Continued)

Species	Method*	Chemical**	Salinity (g/kg)	LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)	Reference
Atlantic silverside (juvenile) *Menidia menidia*	F, M	Technical (92%)	24.3	1.7	-	Schimmel et al. 1983
Atlantic silverside (day 0 larva), *Menidia menidia*	F, M	Technical (92%)	20	0.5	-	Borthwick et al. 1985
Atlantic silverside (day 7 larva), *Menidia menidia*	F, M	Technical (92%)	20	1.0	-	Borthwick et al. 1985
Atlantic silverside (day 14 larva), *Menidia menidia*	F, M	Technical (92%)	20	1.1	-	Borthwick et al. 1985
Atlantic silverside (day 28 larva), *Menidia menidia*	F, M	Technical (92%)	20	3.0	1.229	Borthwick et al. 1985
Tidewater silverside (day 0 larva), *Menidia peninsulae*	S, U	Technical (92%)	20	4.2	-	Borthwick et al. 1985
Tidewater silverside (day 7 larva), *Menidia peninsulae*	S, U	Technical (92%)	20	2.0	-	Borthwick et al. 1985
Tidewater silverside (day 14 larva), *Menidia peninsulae*	S, U	Technical (92%)	20	1.8	-	Borthwick et al. 1985
Tidewater silverside (day 28 larva), *Menidia peninsulae*	S, U	Technical (92%)	20	3.9	-	Borthwick et al. 1985
Tidewater silverside (day 0 larva), *Menidia peninsulae*	F, M	Technical (92%)	20	1.0	-	Borthwick et al. 1985
Tidewater silverside (day 7 larva), *Menidia peninsulae*	F, M	Technical (92%)	20	0.5	-	Borthwick et al. 1985

Table 1. (Continued)

Species	Method*	Chemical**	Salinity (g/kg)	LC50 or EC50 (µg/L)***	Species Mean Acute Value (µg/L)	Reference
Tidewater silverside (day 14 larva), *Menidia peninsulae*	F, M	Technical (92%)	20	0.4	-	Borthwick et al. 1985
Tidewater silverside (day 28 larva), *Menidia peninsulae*	F, M	Technical (92%)	20	0.9	-	Borthwick et al. 1985
Tidewater silverside (juvenile), *Menidia peninsulae*	F, M	Technical (92%)	19.3	1.3	0.7479	Clark et al. Manuscript
Striped bass (juvenile), *Morone saxatilis*	F, U	Chlorpyrifos (99%)	30	0.58	0.58	Earnest 1970; Korn and Earnest 1974
Striped mullet (juvenile), *Mugil cephalus*	F, M	Technical (92%)	24.7	5.4	5.4	Schimmel et al. 1983

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

** Percentage purity is given in parentheses when available.

*** If the concentrations were not measured and the published results were not reported to be adjusted for purity, the published results were multiplied by the purity if it was reported to be less than 97%.

**** The test material was dissolved from an encapsulated form of chlorpyrifos.

Table 2. Chronic Toxicity of Chlorpyrifos to Aquatic Animals

Species	Test*	Chemical**	Salinity (g/kg)	Limits (µg/L)***	Chronic Value (µg/L)	Reference
			FRESHWATER SPECIES			
Fathead minnow, *Pimephales promelas*	ELS	Technical (98.7%)	-	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†	-	<0.12††	<0.12	Jarvinen et al. 1983
			SALTWATER SPECIES			
Mysid, *Mysidopsis bahia*	LC	Technical (92%)	19-28	0.002-0.004	0.0028	McKenney et al. 1981
Gulf toadfish, *Opsanus beta*	ELS	Technical (92%)	25-34	1.4-3.7	2.276	Hansen et al. 1986
Sheepshead minnow, *Cyprinodon variegatus*	ELS	Technical (92%)	9-28	1.7-3.0	2.258	Cripe et al. Manuscript
Sheepshead minnow, *Cyprinodon variegatus*	ELS	Technical (92%)	9-28	1.7-3.0	2.258	Cripe et al. Manuscript
Sheepshead minnow, *Cyprinodon variegatus*	ELS	Technical (92%)	9-28	1.7-3.0	2.258	Cripe et al. Manuscript
California grunion, *Leuresthes tenuis*	ELS	Technical (92%)	24.5-34.0	0.14-0.30	0.2049	Goodman et al. 1985a
Inland silverside, *Menidia beryllina*	ELS	Technical (92%)	4-6	0.75-1.8	1.162	Goodman et al. 1985b
Atlantic silverside, *Menidia menidia*	ELS	Technical (92%)	18-27	0.28-0.48	0.3666	Goodman et al. 1985b

Table 2. (Continued)

Species	Test*	Chemical**	Salinity (g/kg)	Limits (µg/L)***	Chronic Value (µg/L)	Reference
Tidewater silverside, *Menidia peninsulae*	ELS	Technical (92%)	18-25	0.38-0.78	0.5444	Goodman et al. 1985b

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

** Percentage purity is given in parentheses when available.

*** Results are based on measured concentrations of chlorpyrifos.

† The test material was dissolved from an encapsulated form of chlorpyrifos.

†† 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
Mysid, *Mysidopsis bahia*	0.035	0.0028	12.50
Gulf toadfish, *Opsanus beta*	520	2.276	228.5
Sheepshead minnow, *Cyprinodon variegatus*	136	2.258	60.23
Sheepshead minnow, *Cyprinodon variegatus*	136	2.258	60.23
California grunion, *Leuresthes tenuis*	1.3	0.2049	6.345
Inland silverside, *Menidia beryllina*	4.2	1.162	3.614
Atlantic silverside, *Menidia menidia*	1.7	0.3666	4.637
Tidewater silverside, *Menidia peninsulae*	1.3	0.5444	2.388

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, *Aplexa hypnorum*	>806	-
14	>806	Goldfish, *Carassius auratus*	>806	-
13	806	Channel catfish, *Ictalurus punctatus*	806	-
12	331.7	Fathead minnow, *Pimephales promelas*	331.7	>1,417
11	98	Lake trout, *Salvelinus namaycush*	98	-
10	12.36	Cutthroat trout, *Salmo clarki*	18	-
		Rainbow trout, *Salmo gairdneri*	8.485	-
9	10	Stonefly, *Pteronarcys californica*	10	-
8	10	Bluegill, *Lepomis macrochirus*	10	-
7	6	Crayfish, *Orconectes immunis*	6	-
6	1.38	Pygmy backswimmer, *Neoplea striola*	1.38	-
5	0.8	Crawling water beetle, *Peltodytes* 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	-
		SALTWATER SPECIES		
10	1,991	Eastern oyster, *Crassostrea virginica*	1,991	-
9	520	Gulf toadfish, *Opsanus beta*	520	228.5
8	136	Sheepshead minnow, *Cyprinodon variegatus*	136	60.23
7	5.4	Striped mullet, *Mugil cephalus*	5.4	-
6	4.366	Mummichog, *Fundulus heteroclitus*	4.65	-
		Longnose killifish, *Fundulus similis*	4.1	-
5	1.569	Inland silverside, *Menidia beryllina*	4.2	3.614
		Atlantic silverside, *Menidia menidia*	1.229	4.637
		Tidewater silverside, *Menidia menidia*	0.7479	2.388

Table 3. (continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio***
4	1.068	California grunion, *Leuresthes tenuis*	1.068	6.345
3	0.58	Striped bass, *Morone saxatilis*	0.58	-
2	0.05	Korean shrimp, *Palaemon macrodactylus*	0.05	-
1	0.035	Mysid, *Mysidopsis bahia*	0.035	12.50

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value. Inclusion of "greater than" values in the ranking does not necessarily imply a true ranking, but does allow use of all genera for which data are available so that the Final Acute Value is not unnecessarily lowered.

** From Table 1.

*** From Table 2.

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Fresh water

Final Acute Value = 0.1669 µg/L

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

Final Acute-Chronic Ratio = 5.016 (see text)

Final Chronic Value = (0.1669 µg/L) / 5.016 = 0.03327 µg/L

Salt water

Final Acute Value = 0.007591 µg/L

Criterion Maximum Concentration = (0.007591 µg/L) / 2 = 0.003796 µg/L

Final Acute-Chronic Ratio = 5.016 (see text)

Final Chronic Value = (0.007591 µg/L) / 5.016 = 0.001513 µg/L

Table 4. Toxicity of Chlorpyrifos to Aquatic Plants

Species	Chemical*	Duration (days)	Salinity (g/kg)	Effect	Result (µg/L)**	Reference
			SALTWATER SPECIES			
Golden-brown alga, *Isochrysis galbana*	Technical (92%)	4	30	EC50 (popla-lation growth)	138	Borthwick and Walsh 1981
Diatom, *Skeletonema costatum*	Technical (92%)	4	30	EC50 (popula-lation growth)	297.8***	Borthwick and Walsh 1981
Diatom, *Thalassiosira pseudonana*	Technical (92%)	4	30	EC50 (popula-lation growth)	148	Borthwick and Walsh 1981

* Percentage purity is given in parentheses when available.

** If the concentrations were not measured and the published results were not reported to be adjusted for purity, the published results were multiplied by the purity if it was reported to be less than 97%.

*** Geometric mean of five values.

Table 5. 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
			SALTWATER SPECIES			
Gulf toadfish, *Opsanus beta*	Technical (92%)	1.4-150	49	Whole body	100-5,100	Hansen et al. 1986
Sheepshead minnow, *Cyprinodon variegatus*	Technical (92%)	0.41 0.78	28	Whole body (n=6)	118[††]	Cripe et al. Manuscript
California grunion, *Leuresthes tenuis*	Technical (92%)	0.14-0.63	35	Whole body (n=3)	757[††] (from ELS test)	Goodman et al. 1985a
California grunion, *Leuresthes tenuis*	Technical (92%)	0.28-1.3	26	Whole body (n=3)	120[††] (from fry test)	Goodman et al. 1985a
Inland silverside, *Menidia beryllina*	Technical (92%)	0.18-1.8	28	Whole body (n=4)	186[††]	Goodman et al. 1985b
Tidewater silverside, *Menidia peninsulae*	Technical (92%)	0.093-0.38	28	Whole body (n=3)	456[††]	Goodman et al. 1985b

* Percentage purity is given in parentheses when available.

** Measured concentration of chlorpyrifos.

*** Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of chlorpyrifos in water and tissue.

† The test material was dissolved from an encapsulated form of chlorpyrifos.

†† Geometric mean of values from the listed concentrations in water.

Table 6. Other Data on Effects of Chlorpyrifos on Aquatic Organisms

Species	Chemical*	Duration	Effect	Result (µg/L)**	Reference
			FRESHWATER SPECIES		
Diatoms, Unidentified	-	10 days	Reduced growth	400	Rogers and Miller 1970
Planarian, *Dugesia dorotocephala*	Chlorpyrifos	24 hr	None	4.0	Levy and Miller 1978
Cladoceran, *Daphnia* sp.	Encapsulated***	4 hr	LC50	0.88	Siefert et al. 1984
Amphipod, *Hyalella azteca*	Encapsulated***	24 hr	LC50	1.28	Siefert et al. 1984
Mayfly, *Ephemerella* sp.	Encapsulated***	72 hr	LC50	0.33	Siefert et al. 1984
Pygmy backswimmer, *Neoplea striola*	Encapsulated***	144 hr	LC50	0.97	Siefert et al. 1984
Giant water bug (adult), *Belostoma* sp.	Technical	24 hr	LC50	15	Ahmed 1976
Predaceous diving beetle (adult), *Hygrotus* sp.	Technical	24 hr	LC50	40	Ahmed 1976
Predaceous diving beetle (adult), *Laccophilus decipiens*	Technical	24 hr	LC50	4.6	Ahmed 1976
Predaceous diving beetle (adult), *Thermonectus basillaris*	Technical	24 hr	LC50	6	Ahmed 1976
Water scavenger beetle (adult), *Berosus styliferus*	Technical	24 hr	LC50	9	Ahmed 1976
Water scavenger beetle (larva), *Hydrophilus triangularis*	Technical	24 hr	LC50	20	Ahmed 1976

Table 6. (continued)

Species	Chemical*	Duration	Effect	Result (µg/L)**	Reference
Water scavenger beetle (adult), *Hydrophilus triangularis*	Technical	24 hr	LC50	30	Ahmed 1976
Water scavenger beetle (larva), *Tropisternus lateralis*	Technical	24 hr	LC50	52	Ahmed 1976
Water scavenger beetle (adult), *Tropisternus lateralis*	Technical	24 hr	LC50	8	Ahmed 1976
Mosquito (3rd and 4th instar), *Aedes aegypti*	Technical	18 hr	LT50	10	Verma and Rahman 1984
Mosquito (2nd instar), *Aedes aegypti*	Technical (96%)	24 hr	LC50	0.0011	Saleh et al. 1981
Mosquito (4th instar), *Aedes aegypti*	Technical (96%)	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 1976

Table 6. (continued)

Species	Chemical*	Duration	Effect	Result (µg/L)**	Reference
Mosquito (4th instar), *Anopheles freeborni*	Technical	24 hr	LC50	1.3 0.9 2.5 1.2 1.2 1.9 1.3 1.2 2.8 3.3 7.0	Womeldorf et al. 1970
Mosquito (3rd and 4th instar), *Anopheles stephensi*	Technical	6.5 hr	LT50	25	Verma and Rahman 1984
Phantom midge, *Chaoborus* sp.	Encapsulated***	18 hr 42 hr 114 hr	LC50 LC50 LC50	2.36 1.29 0.85	Siefert et al. 1984
Mosquito (4th instar), *Culex pipiens*	Technical (99%	24 hr	EC50	0.46	Helson et al. 1979
Mosquito (2nd instar; DDT susceptible), *Culex pipiens*	Technical (96%)	24 hr	LC50	0.0022	Saleh et al. 1981
Mosquito (4th instar; DDT susceptible), *Culex pipiens*	Technical (96%)	24 hr	LC50	0.0052	Saleh et al. 1981
Mosquito (4th instar), *Culex pipiens*	Technical	24 hr	LC50	1.2	Rettich 1977
Mosquito (4th instar), *Culex pipiens*	Technical	24 hr	LC50	1.6	Rettich 1977
Mosquito (3rd and 4th instar), *Culex quinquefasciatus*	Technical	5 hr	LT50	10	Verma and Rahman 1984

Table 6. (continued)

Species	Chemical*	Duration	Effect	Result (µg/L)**	Reference
Mosquito (4th instar), *Culex restuans*	Technical (99%)	24 hr	LC50	0.41	Helson et al. 1979
Mosquito (larva), *Culex tarsalis*	Technical	-	LC50	2	Ahmed 1976
Mosquito (4th instar), *Culiseta annulata*	Technical	24 hr	LC50	3.5	Rettich 1977
Midge (4th instar), *Chironomus* sp.	Technical	24 hr	LC50	0.42	Mulla and Khasawinah 1969
Midge (4th instar), *Chironomus decorus*	Technical	24 hr	LC50	7.0	Ali and Mulla 1978a
Midge (4th instar), *Chironomus utahensis*	Technical	24 hr	LC50	1.2	Ali and Mulla 1978a
Midge (4th instar), *Cricotopus decorus*	Technical	24 hr	LC50	1,470	Ali and Mulla 1980
Midge (4th instar), *Dicrotendipes californicus*	Technical	24 hr	LC50	40.0	Ali and Mulla 1980
Midge (4th instar), *Goeldichironomus holoprassinus*	Technical	24 hr	LC50	0.97	Mulla and Khasawinah 1969
Midge (4th instar), *Procladius* spp.	Technical	24 hr	LC50	0.5	Ali and Mulla 1978a
Midge (4th instar), *Tanypus grodhausi*	Technical	24 hr	LC50	29.0	Ali and Mulla 1980
Midge (4th instar), *Tanypus grodhausi*	Technical	24 hr	LC50	0.5	Mulla and Khasawinah 1969
Midge (4th instar), *Tanygus grodhausi*	Technical	24 hr	LC50	5.7	Mulla and Khasawinah 1969
Rainbow trout, *Salmo gairdneri*	Technical	96 hr	LC50 (7.2°C) (1.6°C)	15 51	Macek et al. 1969

Table 6. (continued)

Species	Chemical*	Duration	Effect	Result (µg/L)**	Reference
Atlantic salmon (juvenile), *Salmo salar*	Technical (>95%)	24 hr	Temperature selection	100	Peterson 1976
Golden shiner, *Notemigonus crysoleucas*	Technical (99%)	36 hr	LC50	45	Ferguson et al. 1966
Golden shiner, *Notemigonus crysoleucas*	Technical (99%)	36 hr	LC50	35	Ferguson et al. 1966
Fathead minnow, *Pimephales promelas*	Technical****	96 hr	LC50	150	Jarvinen and Tanner 1982
Fathead minnow, *Pimephales promelas*	Encapsulated***	96 hr	LC50	130	Jarvinen and Tanner 1982
Fathead minnow, *Pimephales promelas*	Encapsulated***, ****	96 hr	LC50	280	Jarvinen and Tanner 1982
Mosquitofish, *Gambusia affinis*	Chlorpyrifos	-	Avoidance	100	Hansen et al. 1972
Mosquitofish (DDT susceptible), *Gambusia affinis*	Technical	48 hr	LC50	1,018	Culley and Ferguson 1969
Mosquitofish (DDT resistant), *Gambusia affinis*	Technical	48 hr	LC50	1,291	Culley and Ferguson 1969
Mosquitofish, *Gambusia affinis*	Chlorpyrifos	24 hr	Decreased thermal tolerance	5	Johnson 1978a
Mosquitofish (adult), *Gambusia affinis*	Technical	72 hr	LC50	0.22 0.20 0.20 0.19 0.20 0.20	Ahmed 1976
Mosquitofish, *Gambusia affinis*	Technical (99%)	36 hr	LC50	230 215	Ferguson et al. 1966

Table 6. (continued)

Species	Chemical*	Duration	Effect	Result (µg/L)**	Reference
Mosquitofish, *Gambusia affinis*	Chlorpyrifos	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 (99%)	36 hr	LC50	37.5 22.5	Ferguson et al. 1966

Species	Chemical*	Salinity (g/kg)	Duration	Effect	Result (µg/L)**	Reference
			SALTWATER SPECIES			
Green alga, *Chlorococcum* sp.	Chlorpyrifos	27	48 hr	Reduced growth	10,000	Maly and Ruber 1983
Diatom, *Skeletonema costatum*	Technical (92%)	30	48 hr	100% mortality	5,000	Walsh 1981,1983
Diatom, *Amphiprora* sp.	Chlorpyrifos	27	48 hr	Reduced growth	10,000	Maly and Ruber 1983
Dinoflagellate, *Gonyaulax* sp.	Chlorpyrifos	27	48 hr	Reduced growth	10,000	Maly and Ruber 1983
Benthic macrofauna	Technical (92%)	26.5 (14.5-34.0)	8 wk	Significant reduction in total faunal species richness and in abundance of arthropods and molluscs for laboratory-colonized benthos	0.1	Tagatz et al. 1982
Benthic macrofauna	Technical (92%)	27.5 (18.0-32.5)	1 wk	Significant reduction in abundance of arthropods for field-colonized benthos	5.9	Tagatz et al. 1982

Table 6. (continued)

Species	Chemical*	Salinity (g/kg)	Duration	Effect	Result (µg/L)**	Reference
Eastern oyster (juvenile), Crassostrea virginica	Chlorpyrifos (99%)	24	96 hr	EC50 (shell deposition)	270	U.S. Bureau of Commercial Fisheries 1965; Lowe et al. 1970
Eastern oyster (juvenile), Crassostrea virginica	Chlorpyrifos (99%)	28	96 hr	EC50 (shell deposition)	34	U.S. Bureau of Commercial Fisheries 1967
Brown shrimp (juvenile), Penaeus aztecus	Chlorpyrifos (99%)	26	48 hr	EC50 (mortality and loss of equilibrium)	0.20	U.S. Bureau of Commercial Fisheries 1965; Lowe et al. 1970
Pink shrimp (juvenile), Penaeus duorarum	Chlorpyrifos (99%)	26	48 hr	EC50	2.4	U.S. Bureau of Commercial Fisheries 1967
Grass shrimp (juvenile), Palaemonetes pugio	Chlorpyrifos (99%)	26	48 hr	EC50 (mortality and loss of equilibrium)	1.5	U.S. Bureau of Commercial Fisheries 1967)
Grass shrimp (adult), Palaemonetes pugio	Chlorpyrifos (99%)	20	1 hr	No avoidance of pesticide	0.01-1.0	Hansen et al. 1973
Blue crab (juvenile), Callinectes sapidus	Chlorpyrifos (99%)	20	48 hr	EC50	5.2	U.S. Bureau of Commercial Fisheries 1967
Atlantic salmon (juvenile), Salmo salar	Chlorpyrifos (>95%)	-	24 hr	Altered preferred temperature	100-250	Peterson 1976
Sheepshead minnow (juvenile), Cyprinodon variegatus	Technical (92%)	9-30	28 days	BCF = 42-660 (low food); 69-1,000 (med. food); 120-1,830 (high food)	0.41-52	Cripe et al. Manuscript
Sheepshead minnow (adult), Cyprinodon variegatus	Chlorpyrifos (99%)	20	1 hr	Avoidance of pesticide	100-250	Hansen 1969,1970
Sheepshead minnow (juvenile), Cyprinodon variegatus	Chlorpyrifos (99%)	24	48 hr	LC50	1,000	U.S. Bureau of Commercial Fisheries 1967

Table 6. (continued)

Species	Chemical*	Salinity (g/kg)	Duration	Effect	Result (µg/L)**	Reference
Mummichog (adult), *Fundulus heteroclitus*	Technical (99.5%)	20-25	24 hr	100% inhibition of acetylcholinesterase activity in brain	>2.1	Thirugnanam and Forgash 1977
Longnose killifish (juvenile), *Fundulus similis*	Chlorpyrifos (99%)	24	48 hr	LC50	3.2	U.S. Bureau of Commercial Fisheries 1967; Lowe et al. 1970
California grunion, *Leuresthes tenuis*	Technical (92%)	24.5-31.5	26 days	Significantly reduced growth of fry	0.62	Goodman et al. 1985a
Spot (juvenile), *Leiostomus xanthurus*	Chlorpyrifos (99%)	26	48 hr	LC50	7	U.S. Bureau of Commercial Fisheries 1965

* Percentage purity is given in parentheses when available.

** If the concentrations were not measured and the published results were not reported to be adjusted for purity, the published results were multiplied by the purity if it was reported to be less than 97%.

*** The test material was dissolved from an encapsulated form of chlorpyrifos.

**** Aged 11 weeks.

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