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Aquatic Life Ambient Water Quality Criteria

Diazinon

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U.S. Environmental Protection Agency
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NOTICE

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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 which 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 on consideration of comments received from independent peer reviewers and the public. 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 health or ecological effects. Criteria presented in this document are such scientific assessments. If water quality criteria associated with specific waterbody uses are adopted by a state or tribe as water quality standards under section 303, they become enforceable maximum acceptable pollutant concentrations in ambient waters within that state or tribe. Water quality criteria adopted in state or tribal water quality standards could have the same numerical values as criteria developed under section 304. However, in many situations states or tribes might want to adjust water quality criteria developed under section 304 to reflect local environmental conditions and exposure patterns. Alternatively, states or tribes may use different data and assumptions than EPA in deriving numeric criteria that are scientifically defensible and protective of designated uses. It is not until their adoption as part of state or tribal water quality standards that criteria become regulatory. Guidelines to assist the states and tribes in modifying the criteria presented in this document are contained in the Water Quality Standards Handbook (U.S. EPA 1994). The handbook and additional guidance on the development of water quality standards and other water-related programs of this agency have been developed by the Office of Water.

This final document is guidance only. It does not establish or affect legal rights or obligations. It does not establish a binding norm and cannot be finally determinative of the issues addressed. Agency decisions in any particular situation will be made by applying the Clean Water Act and EPA regulations on the basis of specific facts presented and scientific information then available.

Ephraim King, Director
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TABLE OF CONTENTS

NOTICE iii
FOREWORD iv
ACKNOWLEDGMENTS v
FIGURES vii
TABLES vii

1. INTRODUCTION 1
   1.1. Physical-Chemical Properties 1
   1.2. Diazinon in the Environment 2
   1.3. Toxicity of Diazinon 4
   1.4. Derivation of Aquatic Life Ambient Water Quality Criteria 5

2. ACUTE TOXICITY TO AQUATIC ANIMALS 6
   2.1. Freshwater 6
   2.2. Saltwater 7

3. CHRONIC TOXICITY TO AQUATIC ANIMALS 9
   3.1. Freshwater 9
   3.2. Saltwater 11
   3.3. Acute-Chronic Ratios 11

4. TOXICITY TO AQUATIC PLANTS 13

5. BIOACCUMULATION 14

6. OTHER DATA 15
   6.1. Freshwater 15
   6.2. Saltwater 20
   6.3. Olfactory Effects of Diazinon in Aquatic Organisms 21

7. UNUSED DATA 23

8. SUMMARY 26
   8.1. Freshwater Data 26
   8.2. Saltwater Data 26
   8.3. Plant Data 27
   8.4. Bioaccumulation Data 27

9. NATIONAL CRITERIA 28
   9.1. Freshwater 28
   9.2. Saltwater 28

10. IMPLEMENTATION 29

11. REFERENCES 60

FIGURES

Page

Figure 1. Summary of Ranked Diazinon GMAVs (Freshwater) 30

Figure 2. Summary of Ranked Diazinon GMAVs (Saltwater) 31

Figure 3. Chronic Toxicity of Diazinon to Aquatic Animals 32

TABLES

Table 1. Acute Toxicity of Diazinon to Aquatic Animals 33

Table 2. Chronic Toxicity of Diazinon to Aquatic Animals 40

Table 3. Ranked Genus Mean Acute Values with Species Mean Acute-Chronic Ratios 42

Table 4. Toxicity of Diazinon to Aquatic Plants 46

Table 5. Bioaccumulation of Diazinon by Aquatic Organisms 47

Table 6. Other Data on Effects of Diazinon on Aquatic Organisms 48

1. INTRODUCTION

1.1. Physical-Chemical Properties

Diazinon [Chemical Abstract Service registry number 333-41-5; O,O-diethyl O-(6-methyl-2-{1-methylethyl}-4-pirimidinyl) phosphorothioate] is a broad spectrum insecticide effective against adult and juvenile forms of flying insects, crawling insects, acarians and spiders (WHO 1998). Specific uses include the control of pest insects such as cutworms, wireworms, and maggots in soil (Farm Chemicals Handbook 2000) and ectoparasites on sheep (Virtue and Clayton 1997). It is also effective against many pests of fruits, vegetables, tobacco, forage, field crops, range, pasture, grasslands and ornamentals. Additional diazinon uses in urban areas include dormant sprays on fruit trees, professional landscape and maintenance, and structural pest control (Bailey et al. 2000). Until recently, most diazinon was used in and around the home and in other non-agricultural settings including treatment of lawns, gardens, and ornamentals, and indoor crack and crevice treatment. After December 31, 2004, it became unlawful to sell outdoor, non-agricultural diazinon products in the United States (i.e., all residential uses of the insecticide diazinon have been cancelled). However, it is lawful to use diazinon for non-residential agricultural or other uses in accordance with product labeling and precautions approved by EPA under the Federal Insecticide, Fungicide and Rodenticide Act.

Diazinon is an organophosphorus compound with the empirical formula of $C_{12}H_{21}N_2O_3PS$, a molecular weight of 304.35 g/mole and has a log octanol/water partition coefficient (log K_{ow}) of 3.40 (Hunter et al. 1985; WHO 1998). In its purest form diazinon is a colorless oil with a density greater than water (1.116-1.118 g/mL at 20°C) and is soluble in water at 20°C to 0.006 percent (40 mg/L, Farm Chemicals Handbook 2000; 40.5 mg/L, Kanazawa 1983b; 60 mg/L, WHO 1998). The technical product is a pale to dark brown liquid of at least 90 percent purity and has a faint ester-like odor. Diazinon decomposes above 120°C (Verschueren 1983, WHO 1998), is susceptible to oxidation above 100°C, is stable in neutral media, but slowly hydrolyzes in alkaline media and more rapidly in acidic media (WHO 1998). If stored properly, diazinon has a shelf-life of at least three years (SOLARIS Consumer Affairs for Ortho products, P.O. Box 5008, San Ramos, CA 94583, 1998).

Commercial formulations of diazinon previously contained the impurity sulfotepp (O,O,O,O-tetraethyl dithiopyrophosphate), but current diazinon formulations produced by

Makhteshim - Agan of North America do not contain sulfotepp (personal communication, Makhteshim - Agan of North America, 2004). Historically, sulfotepp was found at levels ranging from 0.20 to 0.71 percent of the diazinon concentrations (Meier et al. 1979). Allender and Britt (1994) conducted a screening program throughout Australia to determine the degree of breakdown products in diazinon formulations. Of the 169 samples evaluated, eight contained the degradates, O,S-TEPP and S,S-TEPP. The presence of the sulfotepp degradates was directly correlated with the presence of water in the container. Sulfotepp is more stable than diazinon and therefore should persist longer in the environment. It should be noted that sulfotepp is also used alone as a pesticide, marketed under the trade names ASP-47 and Bladafun by the Bayer Corporation for fumigation control in greenhouse crops and mushrooms (Agrochemicals Handbook 1991).

1.2. Diazinon in the Environment

Diazinon has been detected in freshwater (Bailey et al. 2000; Domagalski et al. 1997; Land and Brown 1996; Lowden et al. 1969; McConnell et al. 1998; Ritter et al. 1974). Organophosphorus pesticides, including diazinon, were found in almost all samples of seawater, but not in net plankton from the harbor of Osaka City, Japan (Kawai et al. 1984). Kawai et al. (1984) reported diazinon was applied from June to August to rice paddy fields resulting in concentrations in the Osaka City harbor greater than 0.1 μg/L.

Diazinon has been detected in point source (e.g., wastewater treatment plant effluents) discharges (Villarosa et al. 1994). U.S. EPA's National Effluent Toxicity Assessment Center investigated the occurrence of diazinon in 28 different publicly owned treatment works (POTW) effluents located across the country in 1988. Detectable levels were found in samples from 17 of the 28 facilities, primarily those located in southern states (Norberg-King et al. 1989). The authors concluded that the diazinon levels found in several effluents were sufficiently high to be a contributing factor to the toxicity observed to *Ceriodaphnia dubia*. The acute and chronic toxicity of other POTW effluents to *C. dubia* has also been attributed, in part, to diazinon (Amato et al. 1992; Bailey et al. 1997; Burkhard and Jensen 1993; Guinn et al. 1995).

Diazinon has also been detected in storm water runoff (non-point source) in urban and agricultural areas (Bailey et al. 1997, 2000; Domagalski et al. 1997; Kratzer 1999; McConnell et al. 1998; NCTCOG 1993; Waller et al. 1995). Domagalski et al. (1997) observed that in the

western valley streams of the San Joaquin River, California, diazinon concentrations peaked within hours of a rainfall event and decreased thereafter. Diazinon was also detected in air samples over the Mississippi River from St. Paul to New Orleans, most likely related to use on cropland within 40 km of the river (Majewski et al. 1998). Rainfall runoff of pesticides with water solubility exceeding 10 mg/L, such as diazinon, can cause toxic additions to freshwater ecosystems (Wauchope 1978). A study by Ritter et al. (1974) showed that the highest concentration of diazinon measured in field runoff (82 μg/L), occurred after a storm event and corresponded to 0.1% of the total amount of diazinon applied to the experimental watershed.

The mobility of diazinon in soil is influenced by the organic matter (OM) and carbonate content of the soil (WHO 1998). Arienzo et al. (1994a,b) found that diazinon is slightly mobile in soils with a low or medium (< 2 percent) OM content and immobile in those with high OM content (> 2 percent). The sorption of diazinon to OM was enhanced when a sandy loam soil was modified with different exogenous organic materials containing humic-like substances relative to unmodified sandy loam soil (Iglesias-Jimenez et al. 1997).

Martinez-Toledo et al. (1993) found that the presence of 10 to 300 μg/g of diazinon in soil increased the total number of bacteria and the population of denitrifying bacteria. However, aerobic dinitrogen fixing bacteria numbers and dinitrogen fixation rate decreased initially (3 days) at diazinon concentrations of 100 to 300 μg/g before recovering to control levels. Nitrifying bacteria and fungal soil populations were not affected by concentrations of 10 to 300 μg/g diazinon in soil.

The fate of diazinon in the aquatic environment is thought to be regulated by two main processes - chemical hydrolysis and microbial degradation. Both processes are influenced by the conditions of pH, temperature and the organic content of the water. Diazinon is stable at pH 7.0 and can persist in the environment for as long as six months. Ku et al. (1998b) found that cleavage of the phosphorous-oxygen bond was the critical step in the hydrolysis of diazinon. Diazinon half-life due to hydrolysis was 43.3 days in well water at pH 7.4 to 7.7 and 16°C (Morgan 1976) and 171 days at pH 7.3 and 21°C (Mansour et al. 1999). Diazinon, unlike other organophosphorus insecticides, hydrolyzes under both acidic and alkaline pH conditions (Gomaa et al. 1969). In the laboratory at 20°C the half-life was determined to be 12, 4436 and 146 hr at pH 3.1, 7.4 and 10.4, respectively (Faust and Gomaa 1972). Parkhurst et al. (1981) measured a degradation rate of two percent per day and a half-life of 39 days in diazinon treated river water

at summer temperatures. The breakdown of diazinon in soils of flooded rice fields occurs at similar rates as in water and is described in a review by Sethunathan (1973).

A less dominant process influencing the fate of diazinon in aquatic systems is photodegradation. Scheunert et al. (1993) found that when diazinon solutions were irradiated with UV light of different wave lengths, photodegradation was greater in river or lake water than in distilled water. Medina et al. (1999) compared the half-life of diazinon in filtered Limon River samples under light and dark conditions and found that sunlight exposed samples had a shorter half-life ($t_{1/2}$ = 31.13 days) than samples held in the dark ($t_{1/2}$ = 37.19 days).

An important factor regulating the rate of microbial decomposition of diazinon is adaptation of microbes to the chemical. Microbes exposed repeatedly to diazinon had a markedly increased capacity to degrade diazinon compared to microbes exposed once to diazinon (Sethunathan and MacRae 1969; Sethunathan and Pathak 1972; Forrest et al. 1981).

1.3. Toxicity of Diazinon

A primary mode of toxicity of organophosphorus insecticides is inhibition of cholinesterases present in the nervous system. Like most organophosphorous pesticides, oxidative desulfuration of diazinon to diazoxon results in greater anticholinesterase activity (Hill 1995). Margot and Gysin (1957) have reported that the cholinesterase inhibiting activity of diazoxon is about 4,000 times greater than that of the parent diazinon. Diazoxon has been identified as a metabolite of diazinon in the liver microsomes of channel catfish, *Ictalurus punctatus*, and bluegill, *Lepomis macrochirus* (Hogan and Knowles 1972). Insect enzymes efficiently convert diazinon to the toxic oxygen homolog, diazoxon (Albert 1981). Crustacea very likely have similar ability to metabolize organophosphates. Insects and crustacea are generally more sensitive to organophosphorous insecticides than vertebrates, presumably due to less efficient detoxification of diazoxon by the invertebrates.

Diazinon, on prolonged storage, may become more toxic due to transformation products. Monosulfotepp was shown to be 14,000 times more potent than diazinon in a test of enzyme inhibition (Singmaster 1990). The use of an improperly stored diazinon formulation in which diazinon had transformed into the more toxic products sulfotepp and monothiono-tepp, was cited by Soliman et al. (1982) as the most probable cause of two acute human poisoning cases in Egypt. Sulfotepp has been reported to be 58 times more toxic to fathead minnows (*Pimephales*

promelas), 75 times more toxic to bluegill (*Lepomis macrochirus*) and rainbow trout (*Oncorhynchus mykiss*), and 8.7 times more toxic to a cladoceran (*Daphnia magna*) than diazinon (Meier et al. 1979). The authors speculated that some of the toxicity attributed to diazinon is likely due to sulfotepp, which is no longer in commercial formulations of diazinon.

1.4. Derivation of Aquatic Life Ambient Water Quality Criteria

A comprehension 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 to fully understand the text, tables, and calculations presented in this criteria document. Results of intermediate calculations are presented to four significant figures to prevent round-off error in subsequent calculations, not to reflect the precision of the value. Final criteria values are presented to two significant figures.

The latest comprehensive literature search for information used in developing this document was conducted in November 1999. An additional literature search, limited to identifying information regarding diazinon effects on olfaction, was conducted in 2004. Data in the files of the U.S. EPA's Office of Pesticide Programs concerning the effects of diazinon on aquatic organisms have also been evaluated in deriving the aquatic life criteria for diazinon.

Whenever adequately justified, a national criterion may be replaced by a site-specific criterion (U.S. EPA 1983), which may include not only site-specific criterion concentrations (U.S. EPA 1994), but also site-specific averaging periods and frequencies of allowed excursions (U.S. EPA 1991).

2. ACUTE TOXICITY TO AQUATIC ANIMALS

2.1. Freshwater

The acute toxicity of diazinon to freshwater animals has been determined for 13 invertebrate species, 10 fish species and one amphibian species (Table 1). Acute toxicity values ranged from 0.25 µg/L for the cladoceran, *Ceriodaphnia dubia* (Norberg-King 1987), to 11,640 µg/L for planaria, *Dugesia tigrina* (Phipps 1988). The most sensitive organisms tested were invertebrates in the Class Crustacea. The cladoceran, *C. dubia*, had the lowest Genus Mean Acute Value (GMAV) which was calculated from 14 tests (0.3773 µg/L; Table 3), ten of which were conducted by the U.S. EPA's Office of Research and Development (Norberg-King 1987; Ankley et al. 1991). Results from these 14 tests were relatively consistent (acute values ranged from 0.25 to 0.59 µg/L) considering that different water sources were used and organism age at test initiation ranged from < 6 hr-old to < 48 hr-old. *C. dubia* data were included in Table 1 when the organisms received food during the exposure, but these data were not used to calculate the Species Mean Acute Value (SMAV), as per the Guidelines (Stephan et al. 1985). Three other cladoceran species (*Daphnia pulex*, *Daphnia magna*, and *Simocephalus serrulatus*) were tested and their sensitivity to diazinon found to be similar to that of *C. dubia* with EC50s ranging from 0.65 to 1.8 µg/L. The toxicity of diazinon to three species of amphipods (*Gammarus faciatus, Gammarus pseudolimneaus*, and *Hyallela azteca*) was tested, and the 96-hr LC50s ranged from 2.04 to 16.82 µg/L. Toxicity test data were available for two insect species. LC50s of 10.7 µg/L for the midge, *Chironomus tentans*, and 25 µg/L for the stonefly, *Pteronarcys californica*, were reported. These data show that insect sensitivity to diazinon toxicity is in the same range as amphipods.

The least sensitive species tested with diazinon was also an invertebrate. The planarian, *Dugesia tigrina*, had the highest observed diazinon 96-hr LC50 of 11,640 µg/L. Other invertebrate species exhibiting relatively low sensitivity to diazinon included the snail, *Gillia altilis* (96-hr LC50 of 11,000 µg/L), the oligochaete worm, *Lumbriculus variegatus* (individual test 96-hr LC50 values of 9,980 and 6,160 µg/L, and SMAV of 7,841 µg/L) and the apple snail, *Pomacea paludosa* (individual test 96-hr LC50 values of 2,950, 3,270 and 3,390 µg/L and SMAV of 3,198 µg/L).

The only amphibian toxicity test available was for the green frog, *Rana clamitans*. The frog

embryos were exposed to three concentrations of diazinon (0.5, 5.0 and 50 µg/L). The 96-hr LC50 was reported as > 50 µg/L (Harris et al. 1998).

Freshwater fish species that were tested showed moderate sensitivity to diazinon. SMAVs ranged from 425.8 µg/L for the rainbow trout, *Oncorhynchus mykiss*, to 9,000 µg/L for the goldfish, *Carassius auratus* (Table 1). Diazinon toxicity to rainbow trout was evaluated in five tests with LC50 values ranging from 90 µg/L (Cope 1965b; Ciba-Geigy 1976; Johnson and Finley 1980; Mayer and Ellersieck 1986) to 3,200 µg/L (Bathe et al. 1975a). The cutthroat trout, *Oncorhynchus clarki*, was generally less sensitive (SMAV = 2,166 µg/L) to diazinon than rainbow trout (SMAV = 425.8 µg/L). Certain species of warmwater fish, flagfish *(Jordanella floridae*), fathead minnow (*Pimephales promelas*), goldfish (*Carassius auratus*), and zebrafish (*Danio rerio*; formerly *Brachydanio rerio*) are less sensitive to diazinon than the coldwater species, rainbow trout, brook trout (*Salvelinus fontinalis*), and lake trout (*Salvelinus namaycush*). Two exceptions include the warmwater bluegill, which is more sensitive to diazinon than the coldwater fish species, and the coldwater cutthroat trout, which is less sensitive than the warmwater flagfish. For the four most sensitive genera, all crustaceans, the GMAVs differed by a factor of 15.5 (Table 3 and Figure 1). Based on available data for freshwater organisms, as summarized in Table 1, the freshwater Final Acute Value (FAV) is 0.3397 µg/L.

2.2. Saltwater

The acute toxicity of diazinon to saltwater animals has been determined for 7 invertebrate species and 2 fish species (Table 1). SMAVs ranged from 2.57 µg/L for the copepod, *Acartia tonsa* (Khattat and Farley 1976), to > 9,600 µg/L for embryos of the sea urchin, *Arbacia punctulata* (Thursby and Berry 1988), which is a difference among species of >3,735-fold. Acute values for the mysid, *Americamysis bahia* (formerly *Mysidopsis bahia*), determined from a renewal, unmeasured test (8.5 µg/L) were approximately two-fold higher than those determined from a flow-through measured test (4.82 µg/L). Acute toxicity test data available for other saltwater invertebrates include an annelid worm (*Neanthes arenaceodentata*), an amphipod (*Ampelisca abdita*), and two species of shrimp, grass shrimp *(Palaemonetes pugio*) and pink shrimp (*Penaeus duorarum*) (Table 1). The saltwater fish, inland silverside (*Menidia beryllina*), was relatively insensitive to diazinon with a LC50 of 1,170 µg/L. The remaining fish species, the sheepshead minnow (*Cyprinodon variegatus*), had an LC50 value of 1,400 µg diazinon/L,

and is the only saltwater fish with a corresponding chronic value. Acute values for the four most sensitive genera, all invertebrates, differed by only a factor of 2.6 (Table 3 and Figure 2). Based on available data for saltwater organisms, as summarized in Table 1, the saltwater Final Acute Value (FAV) is 1.637 µg/L.

3. CHRONIC TOXICITY TO AQUATIC ANIMALS

3.1. Freshwater

The chronic toxicity of diazinon was determined for 4 freshwater species, 3 fish and 1 invertebrate (Table 2). A life-cycle test consisting of a 7-day exposure period was conducted with *C. dubia* (Norberg-King 1987). Diluted mineral reconstituted water was used to culture and expose the organisms. All organisms survived in the control and the three lowest diazinon exposures (0.063, 0.109, and 0.220 µg/L). There also was no effect on reproduction in the three lowest diazinon exposures. No organisms survived at diazinon concentrations ≥ 0.520 µg/L. The chronic value for *C. dubia* was 0.3382 µg/L. Dividing the acute value derived from ten 48-hr acute tests (0.3760 µg/L; Table 1) conducted in the same laboratory with the same dilution water (Norberg-King 1987; Ankley et al. 1991) by the chronic value (0.3382 µg/L; Table 2) results in an Acute-Chronic Ratio (ACR) of 1.112 for *C. dubia* (Table 2).

Allison and Hermanutz (1977) conducted a partial life-cycle test with brook trout, *Salvelinus fontinalis*. The test began with yearlings, which were exposed for 173 days to measured concentrations ranging from 0.55 to 9.6 µg/L. Each replicate was thinned to two males and four females, and exposure continued during spawning for an additional two months, during which time eggs were collected and viability (% hatch) determined. Larvae were thinned to 25 per chamber and exposure continued for 122 additional days. Average measured concentrations during egg viability and larval growth periods ranged from 0.8 to 11.1 µg/L. After 173 days, survival of parental stock was significantly reduced at 9.6 µg/L, but not at 4.8 µg/L. However, some deformities were seen and the instantaneous growth rate was reduced by 4.8 µg/L diazinon. The authors state that high within-treatment variance in egg viability prevented any accurate analysis of egg production, egg viability or hatch, but there were viable eggs produced at every concentration. Brook trout progeny from the 122 day larval exposure showed some measurable effects after 30 days. At 122 days post-hatch, fish in all exposure concentrations had average weights significantly less than the control fish. The chronic value for this species is < 0.8 µg/L, which is the lowest exposure concentration for the progeny in which growth effects were observed. Dividing the acute value (723.0 µg/L; Table 1) calculated from three 96-hr acute tests (Allison and Hermanutz 1977) by the chronic value (< 0.8 µg/L; Table 2) results in an ACR of > 903.8 for brook trout (Table 2).

Norberg-King (1989) exposed fathead minnow embryos and the resulting larvae to diazinon for 32 days in an early-life stage test. At test termination, wet weight and survival of fish exposed to only the highest exposure concentration (285 µg/L) were significantly different from that of the control fish. Total length was significantly affected at concentrations ≥ 60 µg/L and dry weight was significantly reduced at 37.8 µg/L, but not at 16.5 µg/L. Based on reduced dry weight, the chronic value for the test was 24.97 µg/L. Dividing the acute value (9,350 µg/L; Table 1), determined by another group of researchers (University of Wisconsin-Superior 1988) at the same laboratory using the same water supply and the same genetic stock of fish, by the chronic value (24.97 µg/L; Table 2) results in an ACR of 374.4 for fathead minnow (Table 2).

In another test, fathead minnow embryos (< 24-hr old) and the resulting larvae were exposed to diazinon for a total of 32 days (Jarvinen and Tanner 1982). Results of the early-life stage test were reduced survival at diazinon concentrations ≥ 290 µg/L and reduced weight (10.1% reduction) at 90 µg/L, but no weight difference from the control fish at 50 µg/L. Based on reduced weight, the chronic value for the test was 67.08 µg/L. Dividing the acute value (6,900 µg/L), determined from a flow-through test in which toxicant concentration was measured (Jarvinen and Tanner 1982; Table 1), by the chronic value (67.08 µg/L; Table 2) results in an ACR of 102.9 for fathead minnow. Calculating the geometric mean of the two ACRs for fathead minnow (374.4 and 102.9) results in a species mean acute-chronic ratio (SMACR) of 196.3 for the fathead minnow (Table 2).

The flagfish, *Jordanella floridae*, was expsosed to diazinon in a life-cycle test (Allison 1977). The study began with one-day-old larvae and continued through spawning, which occurred at about 60 days, and then continued with the fish progeny for 35 days post-hatch. The only significant effect on the parental stock was a reduction (23.3%) in the average wet weight of the male fish after 61 days of exposure to 88 µg/L diazinon. This effect is based on only two fish per replicate because the fish were culled to two males and five females per treatment (from 30 fish per treatment at start of test) prior to spawning. Weight of the female fish was not significantly different from controls at any exposure concentration although there was a 21.4% reduction in the average weight of female fish exposed to 88 µg/L diazinon. There was a significant reduction in percent hatch at diazinon concentrations of 88 µg/L. Average weight at 35 days post-hatch was significantly reduced in the two lower diazinon exposure groups (14 and 26 µg/L), but not in the two higher diazinon exposure groups (54 and 88 µg/L), hence, a dose-

dependent effect on this endpoint was not observed. The chronic value for flagfish, based on hatch success, is the geometric mean of 54 µg/L (NOEC) and 88 µg/L (LOEC), or 68.93 µg/L. Dividing the acute value (1,643 µg/L; Table 1), which is the geometric mean of results from two tests conducted in the same water supply and using fish from the same culture as used in the chronic test (Allison and Hermanutz 1977), by the chronic value (68.93 µg/L; Table 2) results in an ACR of 23.84 for the flagfish (Table 2).

3.2. Saltwater

The chronic toxicity of diazinon to saltwater organisms has been determined in a life-cycle test with the mysid, *A. bahia*, and a partial life-cycle test with the sheepshead minnow (Table 2). The mysid test (Nimmo et al. 1981) was of 22 days duration, and the authors' original data was used to recalculate the chronic limits (Berry 1989). There was no statistical difference in survival observed at any of the concentrations tested (0.54, 1.2, 2.1, 4.4 µg/L). The number of young per female was not significantly reduced relative to controls at diazinon concentrations ≤ 2.1 µg/L. There were no young produced by females exposed to the highest concentration tested (4.4 µg/L). Based on reproduction, the chronic value for the mysid is the geometric mean of the chronic limits, 2.1 and 4.4 µg/L, or 3.040 µg/L. Dividing the acute value (4.82 µg/L; Table 1), determined by the same authors (Nimmo et al. 1981), by the chronic value (3.040 µg/L) results in an ACR of 1.586 for the mysid, *A. bahia* (Table 2).

Sheepshead minnow, *Cyprinodon variegates*, reproduction was significantly reduced in all diazinon exposure concentrations during a partial life-cycle test (Goodman et al. 1979). The number of eggs spawned per female in the 0.47, 0.98, 1.8, 3.5 and 6.5 µg/L (average measured) diazinon concentrations were 69, 50, 50, 55 and 45 percent of control fish, respectively. Neither survival nor growth was affected by diazinon exposures ≤ 6.5 µg/L. Based on reduction of eggs spawned, the chronic value for sheepshead minnow is < 0.47 µg/L (Table 2). Dividing the acute value (1,400 µg/L; Table 1) determined by the same authors (Goodman et al. 1979) by the chronic value (< 0.47 µg/L) results in an ACR of > 2,979 for sheepshead minnow.

3.3. Acute-Chronic Ratios

Chronic toxicity tests have been conducted on six aquatic species and chronic values ranged from 0.3882 µg/L for Ceriodaphnia, *C. dubia*, to 68.93 µg/L for flagfish (Table 2). The chronic

values for brook trout (< 0.8 µg/L) and sheepshead minnow (< 0.47 µg/L) cannot be determined accurately because all concentrations tested affected reproduction and growth. Acute-chronic ratios for acutely sensitive crustacean invertebrates were 1.586 for mysids and 1.112 for *C. dubia* (Table 2). In contrast, ratios are markedly higher for relatively acutely insensitive fishes: 23.84 for flagfish, 102.9 and 374.4 for fathead minnow (*Pimephales promelas*), > 903.8 for brook trout (*Salvelinus fontinalis*), and > 2,979 for sheepshead minnow.

The Guidelines (Stephan et al. 1985) specify that if the species mean acute-chronic ratio (SMACR) seems to increase or decrease as the SMAV increases, the Final Acute-Chronic Ratio (FACR) should be calculated as the geometric mean of the ACRs for species whose SMAVs are close to the FAV. It does appear that ACR values are lower for species acutely sensitive to diazinon and higher for acutely insensitive species (Table 3). Therefore, only the acutely sensitive *C. dubia* and *A. bahia* ACRs were used to calculate the FACR of 1.328. The Guidelines also stipulate that if the most appropriate SMACRs are less than 2.0, acclimation has probably occurred during the chronic test and the FACR should be assumed to be 2.0. The low ACRs for *C. dubia* and *A. bahia* support the finding that diazinon toxicity is rapid for these sensitive invertebrates and extended periods of exposure do not increase toxicity for these sensitive species. Thus, the FACR for diazinon is 2.0. The Final Chronic Values (FCV) for freshwater and saltwater are 0.1699 and 0.8185 µg/L, respectively (FAVs divided by 2.0). Use of an FACR of 2.0 results in the same value for the Criteria Maximum Concentration (CMC; acute criterion) and the Criteria Continuous Concentration (CCC; chronic criterion).

It appears from available data that the freshwater Final Chronic Value will protect the tested freshwater species against adverse effects due to diazinon (Figure 3). Growth of offspring of exposed brook trout, a recreationally important freshwater fish species, was statistically significantly reduced by 40% at the lowest tested concentration of 0.8 µg/L, which is a factor of 4.7 times the CCC. However, the chronic value for this study is a less than value and it is uncertain how close to the freshwater CCC adverse effects may occur. Reproduction of the saltwater sheepshead minnow was statistically significantly reduced by 31% at the lowest tested concentration of 0.47 µg/L, which is below the saltwater CCC. Therefore, where exposure to diazinon at or near CCC levels may occur to this or similar saltwater fish species, states and tribes may want to consider site-specific criteria derivations for diazinon.

4. TOXICITY TO AQUATIC PLANTS

Acceptable data on the effects of diazinon to freshwater algae (nonvascular plant) are available for one species (Table 4), but no acceptable data are available regarding the toxicity to freshwater vascular plants. Hughes (1988) exposed the green alga, *Selenastrum capricornutum*, for seven days in a static test. A 7-day EC50 of 6,400 µg/L (measured concentration) was determined based on reduced cell numbers. No saltwater tests with plants are suitable, according to the Guidelines, for inclusion in this section. Some additional freshwater and saltwater plant toxicity information is included with "Other Data." Based on a single aquatic plant test, the Final Plant Value for diazinon is 6,400 µg/L.

5. BIOACCUMULATION

Three freshwater species of fish, rainbow trout (*Oncorhynchus mykiss*), carp (*Cyprinus carpio*) and guppy (*Poecilia reticulata*), were exposed to diazinon for 14 days and the whole body tissue concentrations were determined (Seguchi and Asaka 1981; Keizer et al. 1993). Diazinon accumulated rapidly in the fish and reached steady-state in approximately three days. The bioconcentration factor (BCF) for rainbow trout and carp exposed to 15 µg diazinon/L was 62 and 120, respectively (Table 5). The half-life for diazinon in these fish was less than seven days. The BCF for guppy exposed to 350 µg diazinon/L was 188 (Keizer et al. 1993).

In a 108-day saltwater exposure, uptake of diazinon by the sheepshead minnow was rapid, reaching steady state within 4 days (Goodman, et al. 1979). Whole body (less brain) bioconcentration factors for fish exposed to 1.8, 3.5 and 6.5 µg/L were 147, 147 and 213, respectively (Table 5).

6. OTHER DATA

6.1. Freshwater

Additional data on lethal and sublethal effects of diazinon on freshwater species are presented in Table 6. Sewage microbes (Bauer et al. 1981) and actinomycete bacteria (Sethunathan and MacRae 1969) appear to be unaffected or have growth enhancement at diazinon concentrations near water saturation.

Sensitivity to diazinon varies greatly among green plants and diatoms tested. The green algal (non-vascular plant) species, *Chlorella ellipsoidea* and *Chlamydomonas* sp., were affected only at concentrations of 100,000 µg/L. The green algae *Scenedesmus quadricauda* was not affected at 1,000 µg/L (Stadnyk and Campbell 1971), but a mixture of green alga and diatoms had reduced growth at < 10 µg/L (Butler et al. 1975a). Exposure of the vascular plant, duckweed (*Wolffia papulifera*), to diazinon for 11 days resulted in 100 percent mortality at 100,000 µg/L saturation and deformities at 10,000 µg/L (Worthley and Schott 1971).

Various species of protozoans and invertebrates have been tested and found to have relatively low sensitivity to diazinon compared to crustacean and vertebrate species. Adverse affects were reported for protozoans at approximately 3,000 µg/L (Evtugyn et al. 1997). The rotifer, *Brachionus calyciflorus*, was found to be substantially less sensitive than cladocerans and insects to diazinon with respect to survival (24-hr LC50 = 29,220 µg/L), filtration and ingestion rates (50 percent reduction at 14,000 µg/L), reproduction (decreased reproduction at < 5,000 µg/L), and median time to lethal effects (LT50 values ranged from 2.5 to 4 days for 14,000 and 5,000 µg/L, respectively) (Fernandez-Casalderrey 1992a,b,c,d). Juchelka and Snell (1994) estimated a 48-hr no effect concentration (NOEC) for ingestion rate of 20,000 µg/L and Snell and Moffat (1992) calculated a NOEC for reproduction of 8,000 µg/L for *B. calyciflorus*. Chatterjee and Konar (1984) determined a 96-hr LC50 of 2,220 µg/L for the tubificid worm, *Branchiura sowerbyi*. Rogge and Drewes (1993) determined that 20,000 µg/L diazinon was lethal to the oligocheate worm, *Lumbriculis variegatus*, in 4 hours. A snail species (*Physa acuta*) had a 48-hr LC50 of 4,800 µg/L (Hashimoto and Nishiuchi 1981) which is near the upper end of the range of fish 96-hr LC50s.

Dortland (1980) conducted a series of tests with the cladoceran, *Daphnia magna*, and found in one exposure that 0.2 µg/L did not affect the organisms during the 21-day exposure, but 0.3

µg/L reduced reproduction and mobility. In four other 21-day tests in which the *D. magna* were fed, EC50s ranged from 0.22 to 0.8 µg/L. In 21-day renewal tests with *D. magna*, Fernandez-Casalderrey et al. (1995) determined survival NOEC and LOEC of 0.15 µg/L and 0.18 µg diazinon/L (unmeasured concentrations), respectively. The mean total young per female (which was slightly less than that required by the ASTM test method) and mean brood size were both significantly reduced at the lowest exposure concentration (0.15 µg/L) when compared to the controls. A 24-hr LC50 of 0.86 µg/L for *D. magna* (unfed during test) was reported by the same authors. Sanchez et al. (1998, 1999 and 2000) reported chronic effects of diazinon to *D. magna* in a series of tests to evaluate the toxicity of this pesticide over several generations. Test solutions (which were reported mistakenly as ng/L instead of µg/L), were measured initially, but not thereafter during each test. Although test solutions were renewed daily, dissolved oxygen concentrations were not reported. The lowest test concentration (0.05 µg/L) significantly reduced survival, growth and the number of young per female of the parental generation (F_0) (Sanchez et al. 1998). The progeny (first and third broods), which were transferred to clean water in separate 21-day tests (Sanchez et al. 1999), showed similar responses to that of control animals, indicating that diazinon was being eliminated after parental exposure. However, adverse effects to progeny (first and third broods) that were continually exposed to the same test solutions as the parental generation for an additional 21-days were observed at the lowest tested concentration (0.05 µg/L) (Sanchez et al. 2000). A test in which *D. magna* were exposed to an insecticidal soap formulation of diazinon yielded similar results with a 48-hr LC50 of 0.74 µg/L and a 96-hr LC50 of 0.21 µg/L (Nishiuchi and Hashimoto 1967 and Hashimoto and Nishiuchi 1981).

Amphipods are generally very sensitive to diazinon toxicity. Collyard et al. (1994) compared the sensitivity of different *H. azteca* age groups to diazinon. The eight different age groups (0-2 to 24-26 days old at test initiation) had very similar 96-hr LC50 values that ranged from 3.8 to 6.2 µg/L. Werner and Nagel (1997) tested adult *Hyallela azteca* and reported an LC50 of 19 µg/L for this life stage.

Mosquito larvae appear to be about as sensitive to diazinon as cladocerans and amphipods. Yasuno and Kerdpibule (1967) exposed mosquito larvae (4th instar), *Culex pipiens fatigans*, to diazinon for 24 hr and measured LC50s ranging from 1.8 to 5.7 µg/L. Chen et al (1971) reported 24-hr LC50s of 61-350 µg/L for younger life stages (3rd-4th instar) of the same species. Klassen

et al (1965) found the mosquito species, *A. eqyptii*, to be less sensitive (24-hr LC50 = 350 µg/L) than *Culex pipiens fatigans*. Caddisfly larvae exposed to diazinon for 6 hr had highly variable LC50s, ranging from 500 to 2,500 µg/L for *Hydropsyche morosa* and > 500 µ/L for *H. recurvata* (Fredeen 1972). The EC50 for a species of stonefly, *Pteronarcys californicus*, exposed to diazinon for 48 hr was reported as 74 µg/L (Cope 1965a).

Rainbow trout fingerlings were exposed to diazinon concentration of 8, 40 and 200 µg/L (unmeasured) under flow-through conditions for 28 days (Bresch 1991). Survival and growth of rainbow trout in the three treatment groups after 28 days were not statistically ($p > 0.05$) different from the control group. The chronic value for rainbow trout in this test was > 200 µg/L diazinon. Rainbow trout were also exposed to an insecticidal soap formulation of diazinon for 96 hr (Mitchell 1985) and an unspecified form of diazinon for 48 hr (Cope et al 1965a), and the LC50s determined were 20 µg/L and 170 µg/L, respectively. Cutthroat trout of two sizes were exposed to an unspecified formulation of diazinon for 96 hr and LC50s of 3,850 µg/L for the smaller fish and 2,760 µg/L for the larger fish determined (Swedberg 1973). The LC50s for rainbow trout and cuttthroat trout were consistent with the values used in Table 1 for the same species. Brown trout, *Salmo trutta lacustris*, were also relatively sensitive to diazinon having a 96-hr LC50 value of 602 µg/L for an unspecified formulation of diazinon (Swedberg 1973).

Carp and goldfish are relatively tolerant of diazinon in acute exposures with 48-72 hr LC50s ranging from 1420 µg/L (carp) to 5100 (goldfish) µg/L (Table 6). Diazinon (technical grade) was toxic to newly hatched fathead minnow larvae at seven- and twelve-days exposure (Table 6), but the sensitivity increased as the exposure was continued to 32-days (Table 1) (Norberg-King 1989). The more sensitive timepoint was used in calculating the criteria.

Jarvinen and Tanner (1982) exposed fathead minnows to an encapsulated formulation of diazinon in acute and chronic exposures. The encapsulated formulation was less acutely toxic (5,100 and 6,100 µg/L; Table 6) than the technical grade (2,100 and 4,300 µg/L; Table 1) following 96-hr exposures. Exposure of embryo-larval stage fathead minnows for 32 days to the encapsulated formulation resulted in a chronic value of 55.14 µg/L. Dividing the acute value by the chronic value results in an ACR for the encapsulated formulation of 101.6, which is comparable to the ACR of 102.9 for the technical grade chemical (Table 2). Ciba-Geigy (1976) reported 96-hr LC50s of 8,000 µg/L and 150 µg/L for catfish (*Ictalurus sp.*) and Ide (*Leucisuc idus)* respectively, exposed to diazinon as an emulsifiable concentrate (60%).

Flagfish, *J. floridae*, have been exposed in a 21-day pulsed dose exposure with diazinon followed by a period without the chemical to observe effects (Allison 1977). Exposure of the parental stock beginning at hatch and lasting 21 days resulted in decreased egg production by the females at concentrations ≥ 290 µg/L. Exposure to diazinon for 21 days just prior to spawning resulted in decreased parental survival at concentrations ≥ 250 µg/L, but there were no effects on reproduction at the 250 and 450 µg/L exposure concentrations. Exposure of adults to diazinon for 21 days once spawning had initiated resulted in decreased survival of the parents at the highest exposure concentration (1,170 µg/L) and reduced survival of larval progeny at 1,170 µg/L.

Chen et al. (1971) exposed the guppy, *P. reticulata*, to diazinon and measured 24-hr LC50s of 3,700 and 3,800 µg/L. These values were in agreement with the work of Ciba-Geigy (1976) which measured a 96-hr LC50 of 3,000 µg/L for the same fish species. Ohayo-Mitoko and Deneer (1993) estimated a lethal body burden of 2,495 µg diazinon/L for the guppy. Relative to some other fish species, the guppy appears to be more tolerant of diazinon than trout species but less tolerant than tested cyprinid species (fathead minnow and goldfish).

Bluegill, *L. macrochirus*, was tested by two research groups with widely different results (Table 6). The results of Cope (1965a) indicate that the bluegill is a relatively sensitive species (48-hr EC50 = 30 µg/L), whereas the work of Li and Chen (1981) indicate intermediate sensitivity (48-hr LC50 = 1,493 µg/L) relative to other fish species.

Bresch (1991) evaluated the toxicity of diazinon to zebrafish in an early life-stage test. Zebrafish were exposed to diazinon from egg stage (approximately 2-3 hr after spawning) through juvenile stage to diazinon concentrations of 8, 40 and 200 µ g/L (unmeasured) for 42 days under flow-through conditions. Survival and growth in the three treatment groups were not statistically different ($p > 0.05$) from the controls. Thus, the zebrafish chronic value was > 200 µg/L.

Bioconcentration factors were determined for various aquatic species with a value of 4.9 for the crayfish, *Procambarus clarkii* (Kanazawa 1978), 17.5 for the guppy (Kanazawa 1978), 28 for oriental weatherfish, *Misgurnus anguillicaudatus* (Seguchi and Asaka 1981), 62 for rainbow trout (Seguchi and Asaka 1981), and for carp 20.9 (Tsuda et al. 1990), 65.1 (Kanazawa 1978) and 120 (Seguchi and Asaka 1981).

Outdoor experimental channels at EPA's Monitcello Ecological Research Station

(Mississippi River water) were used by Arthur et al. (1983) to evaluate the effects of diazinon on macroinvertebrates. One channel served as a control and two other channels as low and high treatments. The low and high treatment channels were continuously treated to achieve either 0.3 or 3 µg/L nominal diazinon concentrations for 12 weeks, then increased to 6 and 12 µg/L nominal diazinon concentrations for four weeks, and finally the high treatment channel was increased to 30 µg/L and the low treatment channel allowed to returned to ambient conditions. Only the first 12 week dosing regime achieved nominal diazinon levels as indicated by analytical measurements. During the latter two dosing regimes the channel water did not reach the intended concentrations. No consistent interchannel differences were observed in total macroinvertebrate abundance or in species diversity indices. *Hyalella* was the most sensitive species in the test, exhibiting substantially higher (5 to 8 times) drift rates in the 0.3 µg/L diazinon treated channel relative to the control channel, and had sharply reduced population levels at diazinon concentrations of 5 µg/L. Macroinvertebrate tolerance to diazinon treatment was observed as: flatworms, physid snails, isopods and chironomids (most tolerant); leeches and the amphipod *Crangonyx* (less tolerant); the amphipod *Hyalella*, mayflies, caddisflies and damselflies (least tolerant).

An aquatic pulsed exposure microcosm study was conducted with technical grade diazinon by Giddings et al. (1996). The objectives of the study were to measure the effects of a range of diazinon exposure regimes to many taxonomic groups under simulated field conditions and to determine the relationship between the level of diazinon exposure and the magnitude of ecological response. Eighteen fiberglass tanks, each 3.2 m in diameter and 1.5 m in depth, were established with sediment and water (11.2 m^3) from natural ponds and stocked with 40 juvenile bluegill sunfish *(L. macrochirus*). Diazinon was applied in aqueous solution three times at 7-day intervals. Eight loading rates were used, with two microcosms at each load rate plus two controls. The amount of diazinon added during each application corresponded to nominal concentrations ranging from 2.0 µg/L to 500 µg/L. The most sensitive ecological components of the microcosms were zooplankton (Cladocera) and chironomid insects (Pentaneurini and Ceratopogonidae), which were reduced at all treatment levels. Effects on many zooplankton and macroinvertebrate taxa occurred at diazinon concentrations (time-weighted averages) of 9.2 µg/L and higher. Total fish biomass was reduced at 22 µg/L and higher, and fish survival was reduced at 54 µg/L and higher. Odonates, some dipterans, and plants were not adversely affected by

diazinon at 443 µg/L, the highest concentration tested. Microcosm results were consistent with laboratory toxicity data for some taxa (e.g., cladocerans, Ephemeroptera, and bluegill sunfish), but differed substantially for others (e.g., rotifers, Chironomini, and odonates). The NOEC for the microcosms study (70-d time-weighted average) was reported as 4.3 µg/L.

6.2. Saltwater

Other data on the lethal and sublethal effects of diazinon on saltwater species (Table 6) did not indicate greater sensitivities than data represented in Tables 1 and 2. Saltwater algae appear to be less sensitive to diazinon than most aquatic animals. Photosynthesis of natural phytoplankton was essentially unaffected by a 4-hr exposure to 1,000 µg/L diazinon (Butler 1963). There was no effect of diazinon at 1,000 µg/L on sexual reproduction of the red alga, *Champia parvula* (Thursby and Tagliabue 1988). A 24-hr exposure of the red alga, *Chondrus crispus*, to 10,000 µg/L diazinon had no effect on the growth of the alga in a subsequent 18-day grow-out period (Shacklock and Croft 1981). Rotifers, *Brachionis plicatilis*, were also not acutely sensitive to diazinon (Thursby and Berry 1988; Guzzella et al 1997). No effect on growth of eastern oysters, *Crassostrea virginica*, was observed following a 96-hr exposure to 1,000 µg/L diazinon (Butler 1963), however, an LC50 of 1,115 µg/L was reported by Williams (1989). Shacklock and Croft (1981) reported that two days after a 3-hr exposure to 1,000 µg/L diazinon, mortality of the saltwater snail, *Lacuna vincta*, test organisms was 88% whereas mortality of the amphipod, *Gammarus oceanicus*, and the isopod, *Idotea baltica*, was 100%. Longer exposure (48-hr) of the adult amphipods, *Ampelisca aldita* and *Rheopoxynius abronius*, resulted in LC50 values of 10 and 9.2 µg/L, respectively. The brown shrimp, *Penaeus aztecus*, had a 24-hr EC50 of 44 µg/L (Butler 1963) and a 48-hr EC50 of 28 µg/L (Mayer 1987). Similarly, an acute (48-hr) EC50 of 28 µg/L has been reported for for grass shrimp, *Palaemonetes pugio* (Mayer 1987). The 24- and 48-hr LC50s for the white mullet, *Mugil curema*, were both 250 µg/L (Butler 1963) and the 48-hr LC50 for striped mullet, *Mugil cephalus*, was 150 µg/L (Mayer 1987). In the partial life-cycle test conducted with sheepshead minnow by Goodman et al. (1979), acetylcholinesterase activity in fish exposed to 0.47 µg/L diazinon were consistently less than control fish activity and averaged 71% inhibition in the fish exposed to 6.5 µg/L diazinon. A BCF of 56 was reported for Eastern oyster exposed to diazinon for 5 days (Williams 1989).

6.3. Olfactory Effects of Diazinon in Aquatic Organisms

Olfaction (the sense of smell) is important to aquatic organisms, especially fish, because feeding, defense, schooling, spawning and migration are significantly influenced by olfactory cues (Hara et al. 1976). A well known example of the importance of olfaction in aquatic organisms is the ability of salmon and other migratory fish to follow scents in the water to find natal streams after an extended stay in the distant ocean.

Several studies have been conducted to explore whether certain chemicals may alter detection of olfactory cues by damaging organelles, interacting with membrane receptor sites, or masking biologically important chemical signals. A laboratory technique for measuring peripheral olfactory function in fish is the use of electric field potential recordings (Baatrup et al. 1990, Winberg et al. 1992). The amplitude of the EOG reflects the summed electrical response of olfactory receptor neurons as they bind to molecules in the surrounding environment. Short-term exposure of the olfactory epithelium of mature male Atlantic salmon (*Salmo salar*) parr to $\geq$ 1.0 µg/L of diazinon reduced the olfactory electrophysiological response to pheromonally-mediated endocrine system (prostaglandin $F_{2\alpha}$) as measured by their olfactory epithelium EOG electrical response (Moore and Waring 1996, 1998; Moore and Lower 2001).

The majority of studies associated with olfactory effects do not report effects on olfactory organs or physiology directly, but rather evaluate the effects of chemicals on the behavior of fish that are associated with olfactory cures, including preference/avoidance reactions, feeding and swimming responses. Chu and Lau (1994) studied the effect of diazinon on the behavioral response of the shrimp *Metapenaeus ensis* to a known amino acid attractant. They found that exposure to 0.1 µg/L diazinon significantly reduced the shrimp's ability to find and grasp the food source. Scholz et al. (2000) found that the diazinon significantly disrupts olfactory-mediated anti-predator responses and homing behavior of chinook salmon (*Oncorhynchus tshawytscha*) at 1.0 and 10.0 µg/L, respectively. Swimming behavior and visually guided food capture were not affected at diazinon concentrations as high as 10.0 µg/L.

In several other laboratory studies, researchers have attempted to link affects on biochemical and physiological responses (e.g., receptor cell loss, neuron degeneration or depressed EOG/neurotransmission) with abnormal fish behavior including disruption of preference/avoidance reactions, depressed feeding and erratic swimming (Beyers and Farmer

2001; Hansen et al. 1999; Saglio et al. 2001). Beauvais et al. (2000) exposed larval rainbow trout (*Oncorhynchus mykiss*) for 96 hours to 250 µg/L diazinon and observed significant AChE inhibition accompanied by decreased swimming speed, demonstrating association between diazinon-induced AChE inhibition and a specific behavioral effect in fish.

Based on these short-term laboratory exposure results, many authors have speculated that since fish feeding, defense, schooling, spawning and migration are significantly influenced by olfactory cues, disruption of this sensory function would place the organism at a competitive disadvantage in the natural environment. However, an important aspect of the findings to date is that the effects are, for the most part, reversible. Once the animal is removed from the chemical exposure, recovery was observed for the vast majority of the chemicals evaluated. In addition, some studies showed that over an extended exposure period, the fish adapted to the chemical-induced change by partially regenerating lost cells or damaged neurons leading to partial recovery of normal olfactory function.

In the absence of confirmatory field exposure studies, whether effects of chemicals on the olfactory system structures or function of aquatic organisms result in adverse outcomes cannot be substantiated (no articles were obtained that evaluated this issue). The primary unanswered question is whether temporary damage to olfactory structures or loss of olfactory function affect homing, migratory patterns, feeding activity of exposed organisms in the wild, and more importantly, whether these behavioral changes affect the ability of the exposed population to reproduce, grow and ultimately survive in the wild. The impact of sublethal effects on the long-term survival of an exposed aquatic population is difficult to determine from laboratory studies. Long-term, field and laboratory studies are needed to provide the weight of evidence necessary to use such endpoints in risk assessment and criteria derivation. However, it should be noted that the freshwater and saltwater criteria recommended in this document are below the concentrations reported to affect a variety of olfactory endpoints in several salmonid species.

7. UNUSED DATA

Data from some studies were not used in this document, as they did not meet the criteria for inclusion as specified in the Guidelines (Stephan et al. 1985). The reader is referred to the Guidelines for further information regarding these criteria.

Studies were Conducted with Species that are Not Resident in North America

Alabaster (1969)
Alam and Maughan (1993)
Alam et al. (1995)
Anees (1974, 1976, 1978)
Arab et al. (1990)
Asaka et al. (1980)
Bajpai and Perti (1969)
Boumaiza et al. (1979)
Ceron et al. (1996a,b)
Chu and Lau (1994)
El-Elaimy et al. (1990)
Ferrando et al. (1991)
Hamm et al. (1998)
Hidaka et al. (1984)
Hirayama and Tamanoi (1980)
Hirose and Kawakami (1977)
Hirose and Kitsukama (1976)
Hirose et al. (1979)
Iqbal et al. (1992)
Kabir and Ahmed (1979)
Kabir and Begum (1978)
Kanazawa (1975, 1980, 1981a,b, 1983a)
Khalaf-Allah (1999)
Kikuchi et al. (1992)
Kimura and Keegan (1966)
Kobayashi et al. (1993)
Miah et al. (1995)
Morale et al. (1998)
Niforos and Lim (1998)
Nishiuchi and Yoshida (1972)
Rompas et al. (1989)
Sakr and Gabr (1992)
Sakr et al. (1991)
Sancho et al. (1992a,b, 1993a,b, 1994)
Setakana and Tan (1991)
Shigehisa and Shiraishi (1998)
Sinha et al. (1987)
Stevens (1991, 1992)
Stevens and Warren (1992)
Tsuda et al. (1989, 1992, 1995a,b, 1997a,b)
Uno et al. (1997)
Van der Geest et al. (1999)
Yasutomi and Takahashi (1987)

Data were Compiled from Other Sources

Bay et al. (1993)
Connolly (1985)
Dyer et al. (1997)
Eisler (1986)
Garten and Trabalka (1983)
Kaiser et al. (1997)
Kanazawa (1982)
Kenaga (1979, 1982)
Robinson (1999)
Roex et al. (2000)
Steen et al. (1999)
Van der Geest et al. (1997)
Vighi and Calamari (1987)
Vittozzi and DeAngelis (1991)
Yoshioka et al. (1986)
Zaroogian et al. (1985a)

Diazinon was a Component of a Drilling Mud, Effluent, Mixture, Sediment or Sludge

Alam and Maughan (1992)
Amato et al. (1992)
Bailey et al. (1996, 2000)
Bathe et al. (1975a,b)
Bishop et al. (1999)
Burchfield and Storrs (1954)
Burkhard and Jenson (1993)
Deanovic et al. (1996, 1997)
Dennis et al. (1979a,b)
DeVlaming et al. (2000)
Doggett and Rhodes (1991)
Duursma and Hanafi (1975)
Foe (1995)
Foe et al. (1998)
Glass et al. (1995)
Gruber and Munn (1998)
Hashimoto et al. (1982)
Hatakeyama et al. (1997)
Hendriks et al. (1998)
Hilsenhoff (1959)
Kikuchi et al. (1996)
Kuivila and Foe (1995)
LaBrecque et al. (1956)
Larsen et al. (1998)
Lehotay et al. (1998)
McLeay and Hall (1999)
Macek (1975)
Malone and Blaylock (1970)
Matsuo and Tamura (1970)
Mazidji et al. (1990)
Mulla et al. (1963)
Nishiuchi (1977)
Pan and Dutta (1998)
Rettich (1979)
Singh (1973)
Steinberg et al. (1992)
Tripathi (1992)
Tsuda et al. (1997a,b)
Verma et al. (1982)
Werner et al. (2000)
Wong (1997)
Wong and Chang (1988)

Results of tests conducted with brine shrimp, *Artemia* sp. (e.g. Kuwabara et al. 1980), were not used because these species are from a unique saltwater environment.

Results were not used when either the test procedures, test material, or dilution water was not adequately described (e.g., Adlung 1957; Ansari et al. 1987; Butler et al. 1975a,b; Chatterjee 1975; Hashimoto and Fukami 1969; Hatakeyama and Sugaya 1989; Kaur and Toor 1980; Murray and Guthrie 1980; Oh et al. 1991; Qadri and Anjum 1982).

Results of some laboratory tests were not used because the tests were conducted in distilled or deionized water without addition of appropriate salts or were conducted in chlorinated or "tap" water (e.g., Mulla et al. 1962; Rettich 1977; Yasuno et al. 1965), or the concentration of a water-miscible solvent used to prepare the test solution exceeded 0.5 mL/L (Beauvais et al. 2000). Hirakoso 1968; Lee et al. 1993; Jamnback and Frempong-Boadu 1966; Klassen et al. 1965; Kok 1972; Lilly et al. 1969; Mulla 1963; Nishiuchi and Asano 1979; O'Kelley and Deason 1976; Steinberg et al. 1993 were not used because the results were not adequately described or could not be interpreted.

Tests conducted without controls, with unacceptable control survival, or with too few test organisms were not used (e.g., Applegate et al. 1957; Devillers et al. 1985; Federle and Collins 1976; Allison and Hermanutz 1977). Data of Norland et al. (1974) were not used because they

were derived using organisms preconditioned to organophosphorus chemicals.

Experimental Model was Plasma, Enzymes, Tissue, or Cell Cultures

Anjum and Siddiqui (1990)
Ansari and Kumar (1988)
Ariyoshi et al. (1990)
Burbank and Snell (1994)
Christensen and Tucker (1976)
Dutta et al. (1992a,b, 1993, 1994, 1997)
Dyer et al. (1993)
Fujii and Asaka (1982)
Garrood et al. (1990)
Hiltibran (1974)
Keizer et al. (1995)
Kraus (1985)
Mitsuhashi et al. (1970)
Moore and Waring (1996)
Olson and Christensen (1980)
Qadri and Dutta (1995)
Sastry and Malik (1982a,b)
Sastry and Sharma (1980, 1981)
Vigfusson et al. (1983)
Weiss (1959, 1961)
Weiss and Gakstater (1964)
Whitmore and Hodges (1978)

BCFs and BAFs from laboratory tests were not used when the tests were static or when the concentration of diazinon in the test solution was not adequately measured or varied too much (e.g., Khattat and Farley 1976). Toxicity data were not used if they were generated with a photoluminescence assay utilizing lyophilized marine bacteria that had been rehydrated (e.g., Curtis et al. 1982). Reports of the concentration of diazinon in wild aquatic organisms (e.g., Clark et al. 1984) were not used to calculate BAFs when either the number of measurements of the concentration in water was too small or the range of the measured concentrations in water was too large. BCFs obtained from microcosm or model ecosystem studies were not used when the concentration of diazinon in water decreased with time (e.g., Miller et al. 1966).

8. SUMMARY

8.1. Freshwater Data

The acute toxicity of diazinon to freshwater organisms was determined for 13 invertebrate species from 11 genera, 10 fish species from 8 genera, and one amphibian species (Figure 1 and Table 3). Nine of the invertebrate species (seven crustaceans and two insects) were the most sensitive organisms tested (SMAV = 0.38 to 25 µg/L) and one invertebrate species (planarian) was the most tolerant species tested (SMAV = 11,640 µg/L). Freshwater fish and the amphibian (green frog) were intermediate in sensitivity to the two groups of invertebrates. Rainbow trout (*Oncorhynchus mykiss*) was the most sensitive (SMAV = 425.8 µg/L) and goldfish (*Carassius auratus*) was the most tolerant fish tested (SMAV = 9,000 µg/L). No relationships have been demonstrated between diazinon toxicity and water quality characteristics such as hardness. The freshwater Final Acute Value is 0.3397 µg/L.

The chronic toxicity of diazinon to freshwater organisms was determined for four species (Figure 3 and Table 2). Chronic values ranged from 0.3382 to 68.93 µg/L (Table 2), and the Acute-Chronic Ratios (ACRs) ranged from 1.112 for *Ceriodaphnia dubia* to > 903.8 for brook trout (*Salvelinus fontinalis*) (Table 3). The Final Acute-Chronic Ratio for diazinon was derived using two ACRs for tested species with acute values near the FAV (*C. dubia* and *A. bahia*) because the ACRs decreased with SMAVs. The calculated FACR was less than 2.0, indicating that the organisms may have become acclimated to diazinon during the study. Therefore, the FACR value was changed to 2.0 (Stephan et al. 1985). Thus, the freshwater Final Chronic Value (FCV) for diazinon is 0.1699 µg/L (FAV ÷ FACR, or 0.3397 µg/L ÷ 2.0 = 0.1699 µg/L).

8.2. Saltwater Data

The acute toxicity of diazinon to saltwater organisms was determined for 7 invertebrate species from 7 genera and 2 fish species from 2 genera (Figure 2 and Table 3). Five of the invertebrates were crustaceans and the most sensitive species tested (SMAV = 2.57 to 21 µg/L) and two species (an annelid and an echinoderm) were the most tolerant species tested (SMAVs > 2,880 and > 9,600 µg/L, respectively). The two saltwater fish species tested were intermediate in sensitivity with acute values of 1,170 and 1,400 µg/L. No relationships have been demonstrated between diazinon toxicity and water quality characteristics such as salinity.

The saltwater Final Acute Value is 1.637 µg/L.

Chronic values were determined for two species of saltwater organisms (Figure 3 and Table 2). The mysid, *Americamysis bahia*, and the sheepshead minnow, *Cyprinodon variegatus*, had chronic values of 3.040 and < 0.47 µg/L, respectively (Table 2). ACRs for these speces were 1.586 for the mysid and > 2,979 for the sheepshead minnow (Table 3). The Final Acute-Chronic Ratio for diazinon was derived using two ACRs for tested species with acute values near the FAV (*C. dubia* and *A. bahia*) because the ACRs decreased with SMAVs. The calculated FACR was less than 2.0, indicating that the organisms may have become acclimated to diazinon during the study. Therefore, the FACR value was changed to 2.0 (Stephan et al. 1985). Thus, the saltwater Final Chronic Value (FCV) for diazinon is 0.8185 µg/L (FAV ÷ FACR, or 1.637 µg/L ÷ 2.0 = 0.8185 µg/L).

8.3. Plant Data

Only one acceptable test with a freshwater algal species *(Selenastrum capricornutum*) was available, whereas no acceptable toxicity data are available for freshwater vascular plants. No saltwater tests with aquatic plants were suitable for consideration when estimating the Final Plant Value. Therefore, based on the single test with the freshwater algae, the Final Plant Value is 6,400 µg/L.

8.4. Bioaccumulation Data

Bioaccumulation of diazinon was measured in three species of freshwater fish and steady-state concentrations were reached in about three days. Bioconcentration factors of 62, 120 and 188 were determined for rainbow trout, carp (*Cyprinus carpio*) and guppy (*Poecilia reticulata*), respectively. The tissue half-life of diazinon was less than seven days. Bioaccumulation of diazinon was determined in one saltwater species. The sheepshead minnow was exposed for 108 days to three concentrations of diazinon. The mean bioconcentration factor, based on the BCF for the three concentrations, was 169.

9. NATIONAL CRITERIA

9.1. Freshwater

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985) 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 one-hour average concentration does not exceed 0.17 µg/L more than once every three years on the average and if the four-day average concentration of diazinon does not exceed 0.17 µg/L more than once every three years on the average.

Growth of offspring of exposed brook trout, a recreationally important freshwater fish species, was statistically significantly reduced by 40% at the lowest tested concentration of 0.8 µg/L, which is a factor of 4.7 times the CCC. However, the chronic value for this study is a less than value and it is uncertain how close to the freshwater CCC adverse effects may occur.

9.2. Saltwater

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985) 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 one-hour average concentration does not exceed 0.82 µg/L more than once every three years on the average and if the four-day average concentration of diazinon does not exceed 0.82 µg/L more than once every three years on the average.

Reproduction of the saltwater sheepshead minnow was statistically significantly reduced by 31% at the lowest tested concentration of 0.47 µg/L, which is below the saltwater CCC. Therefore, where exposure to diazinon at or near CCC levels may occur to this or similar saltwater fish species, states and tribes may want to consider site-specific criteria derivations for diazinon. Because sensitive saltwater animals appear to have a narrow range of acute susceptibilities to diazinon, this criterion will probably be as protective as intended only when the magnitude and/or duration of excursions are appropriately small.

10. IMPLEMENTATION

As discussed in the Water Quality Standards Regulation (U.S. EPA 1983) 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 or tribal 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 and tribes 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 1994, 1987). In each standard a state or tribe may adopt the national criterion, if one exists, or, if adequately justified, a site-specific criterion (if the site is an entire state, the site-specific criterion is also a state-specific criterion).

Site-specific criteria may include not only site-specific criterion concentrations (U.S. EPA 1994), but also site-specific, and possibly pollutant-specific, durations of averaging periods and frequencies of allowed excursions (U.S. EPA 1991). 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 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 1991). However, various species and ecosystems react and recover at greatly different 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 into state or tribal water quality standards, for developing water quality-based permit limits requires selection of an appropriate wasteload allocation model. Although dynamic models are preferred for the application of these criteria (U.S. EPA 1991), 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 1987, 1991).

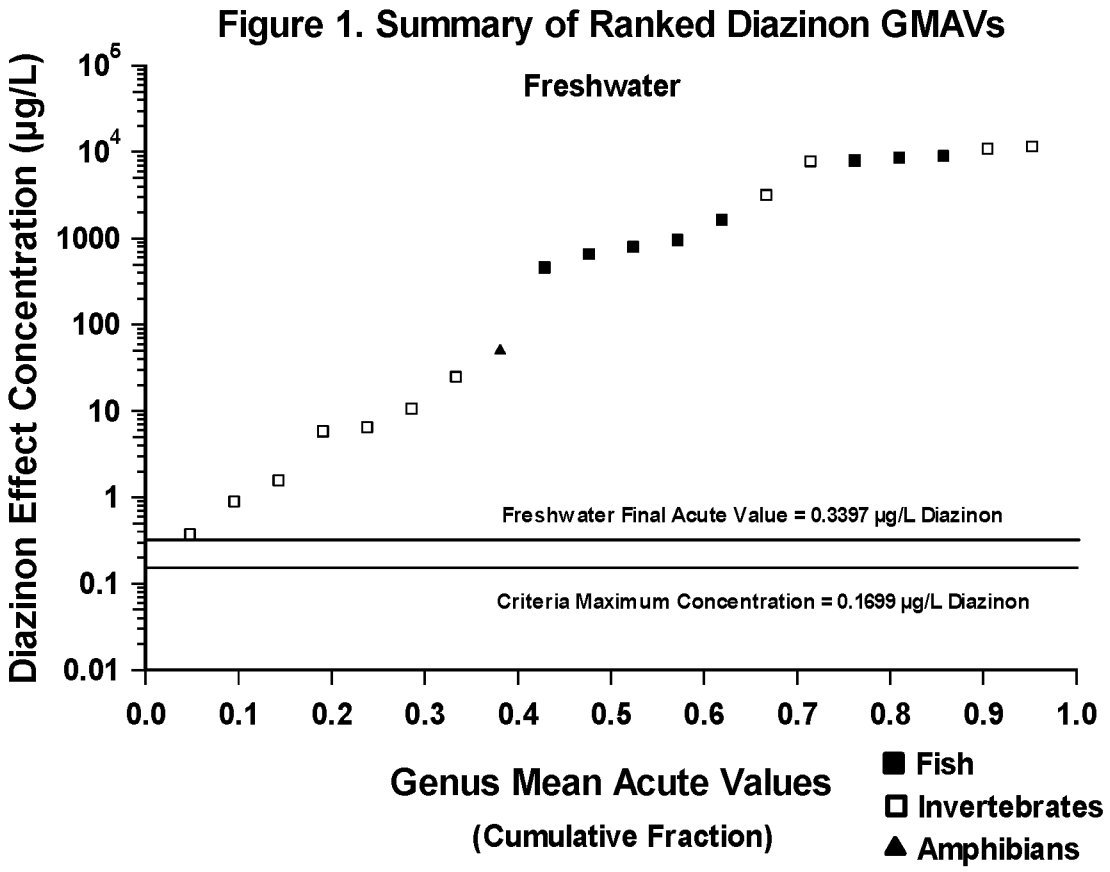
Figure 1. Summary of Ranked Diazinon GMAVs
Freshwater
Diazinon Effect Concentration (µg/L)
10^5
10^4
1000
100
10
1
0.1
0.01
Freshwater Final Acute Value = 0.3397 µg/L Diazinon
Criteria Maximum Concentration = 0.1699 µg/L Diazinon
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Genus Mean Acute Values
(Cumulative Fraction)
Fish
Invertebrates
Amphibians

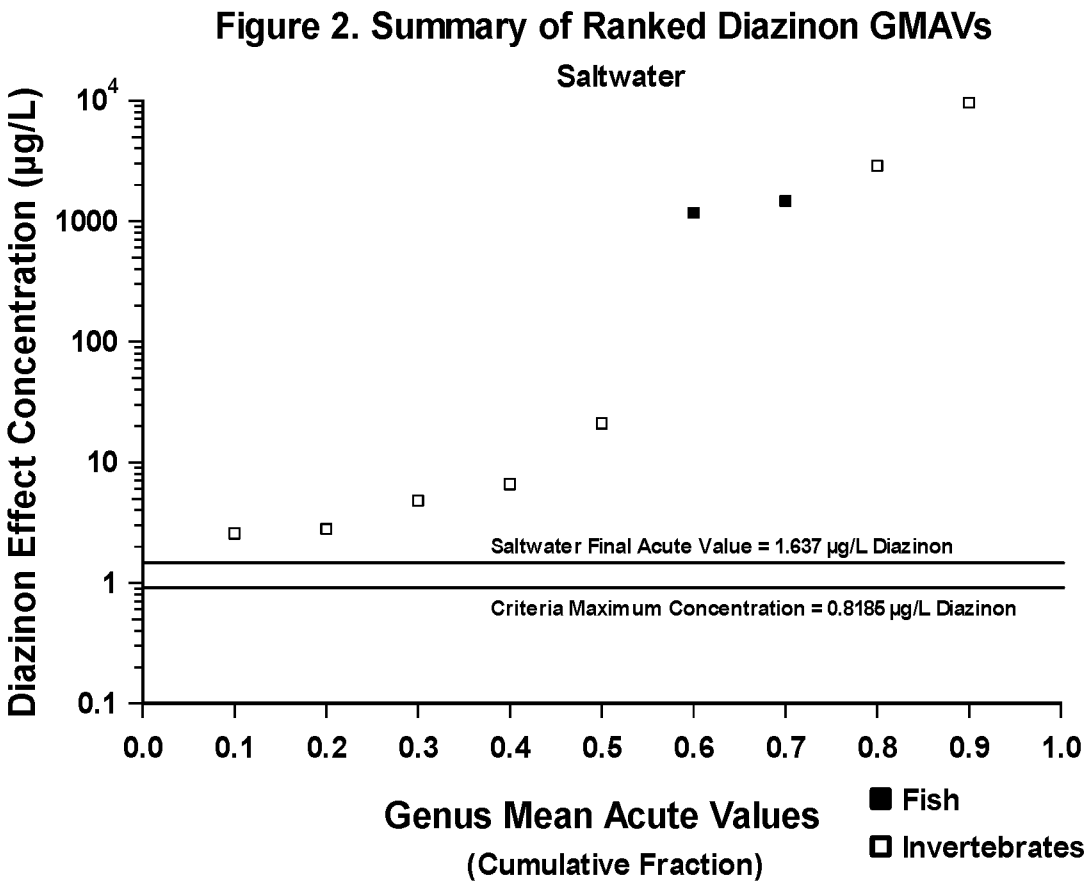
Figure 2. Summary of Ranked Diazinon GMAVs
Saltwater
Diazinon Effect Concentration (µg/L)
10^4
1000
100
10
1
0.1
Saltwater Final Acute Value = 1.637 µg/L Diazinon
Criteria Maximum Concentration = 0.8185 µg/L Diazinon
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Genus Mean Acute Values
(Cumulative Fraction)
Fish
Invertebrates

Figure 3. Chronic Toxicity of Diazinon to Aquatic Animals

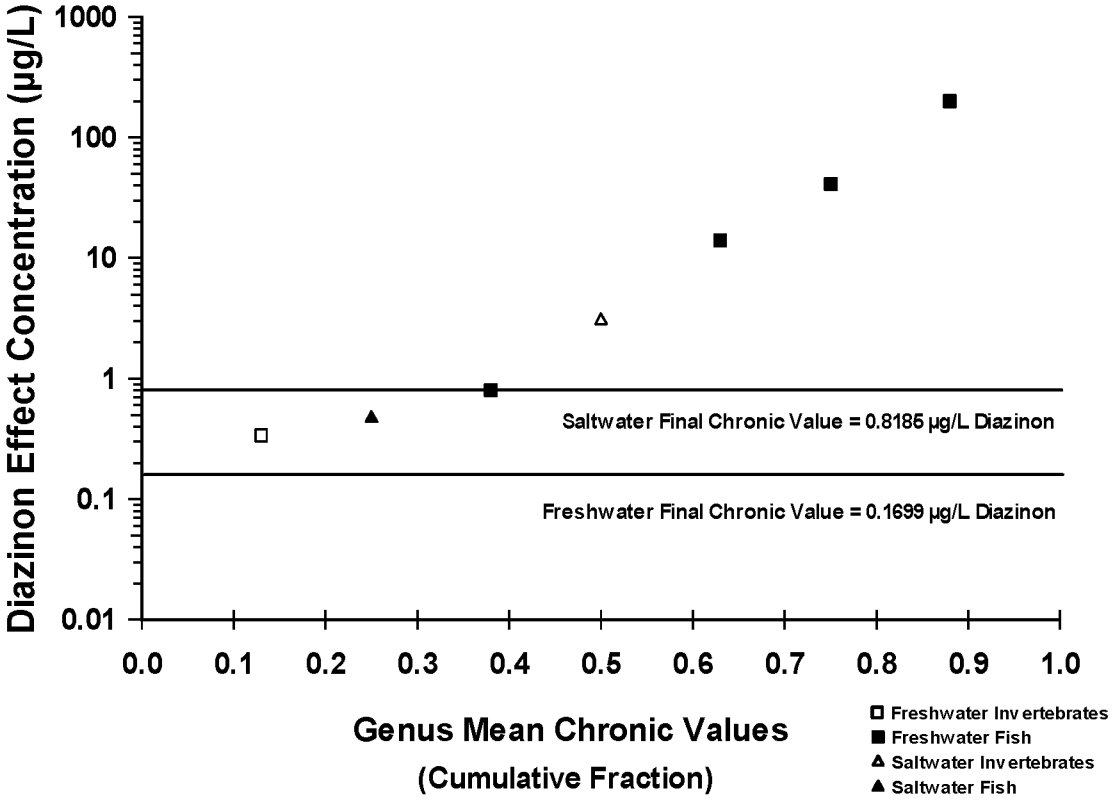

Table 1. Acute Toxicity of Diazinon to Aquatic Animals

Species	Method[a]	Chemical[b]	Hardness (mg/L as CaCO3)	LC50 or EC50 (µg/L)	Species Mean Acute Value[c] (µg/L)	Reference
			FRESHWATER SPECIES			
Planaria, *Dugesia tigrina*	S, M	Technical (85%)	46.5-47.5	**11,640**	11,640	Phipps 1988
Oligochaete worm, *Lumbriculus variegates*	S, M	Technical (85%)	46-48	**9,980**	-	Phipps 1988
Oligochaete worm, *Lumbriculus variegates*	S, U	Technical (95%)	42-47	**6,160**	7,841	Ankley and Collyard 1995
Snail (2.4 g), *Gillia altilis*	S, U	Technical (89%)	22-35	**11,000**	11,000	Robertson and Mazzella 1989
Apple snail (1-day), *Pomacea paludosa*	F, M	Technical (87%)	130.5	**2,950**	-	Call 1993
Apple snail (7-days), *Pomacea paludosa*	F, M	Technical (87%)	219	**3,270**	-	Call 1993
Apple snail (7-days), *Pomacea paludosa*	F, M	Technical (87%)	173.5	**3,390**	3,198	Call 1993
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	40	0.57[d,e]	-	Norberg-King 1987
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	45	0.66[d,e]	-	Norberg-King 1987
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	40-48	0.57 [d,e]	-	Norberg-King 1987
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	>1.0 [d,e]	-	Norberg-King 1987
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	40	>0.6 [d,e]	-	Norberg-King 1987
Cladoceran (<6 hr), *Ceriodaphnia dubia*	S, M	Technical (85%)	40	0.66 [d,e]	-	Norberg-King 1987
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.35**	-	Norberg-King 1987

Table 1. (continued)

Species	Method[a]	Chemical[b]	Hardness (mg/L as CaCO3)	LC50 or EC50 (µg/L)	Species Mean Acute Value[c] (µg/L)	Reference
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.35**	-	Norberg-King 1987
Cladoceran (<6 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.25**	-	Norberg-King 1987
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.33**	-	Norberg-King 1987
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.35**	-	Norberg-King 1987
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.59**	-	Norberg-King 1987
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.43**	-	Norberg-King 1987
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.35**	-	Norberg-King 1987
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, U	Technical (85%)	-	**0.36**	-	Norberg-King 1987
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, U	Technical (95%)	40-48	**0.5**	-	Ankley et al. 1991
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M	Analytical (99%)	80-100	**0.58**	-	Bailey et al. 1997
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M	Analytical (99%)	80-100	**0.48**	-	Bailey et al. 1997
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M	Analytical (99%)	80-100	**0.26**	-	Bailey et al. 1997
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M	Analytical (99%)	80-100	**0.29**	0.3773	Bailey et al. 1997
Cladoceran (<20 hr), *Daphnia magna*	S, U	Technical	50	**0.96**	-	Vilkas 1976

Table 1. (continued)

Species	Method[a]	Chemical[b]	Hardness (mg/L as CaCO3)	LC50 or EC50 (µg/L)	Species Mean Acute Value[c] (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia magna*	S, U	Analytical	200	**1.5**	-	Dortland 1980
Cladoceran (<48 hr), *Daphnia magna*	S, U	Technical (95%)	40-48	**0.8**	1.048	Ankley et al. 1991
Cladoceran (first instar), *Daphnia pulex*	S, U	Technical (89%)	47	**0.90**	-	Cope 1965a; Sanders and Cope 1966
Cladoceran (first instar), *Daphnia pulex*	S, U	Technical (89%)	47	**0.8**	-	Johnson and Finley 1980; Mayer and Ellersieck 1986
Cladoceran (<48 hr), *Daphnia pulex*	S, U	Technical (95%)	40-48	**0.65**	0.7764	Ankley et al. 1991
Cladoceran (first instar), *Simocephalus serrulatus*	S, U	Technical (89%)	47	**1.8**	-	Cope 1965a; Sanders and Cope 1966; Mayer and Ellersieck 1986
Cladoceran (first instar), *Simocephalus serrulatus*	S, U	Technical (89%)	47	**1.4**	1.587	Sanders and Cope 1966; Johnson and Finley 1980; Mayer and Ellersieck 1986
Amphipod (mature), *Gammarus fasciatus*	S, U	Technical (89%)	44	**2.04**	2.04	Johnson and Finley 1980; Mayer and Ellersieck 1986
Amphipod (mature), *Gammarus pseudolimnaeus*	R, M	Analytical (100%)	62.5	**16.82**	16.82	Hall and Anderson 2004
Amphipod (7-14 days), *Hyalella azteca*	S, U	Technical (95%)	42-47	**6.51**	6.51	Ankley and Collyard 1995
Stonefly (larva 30-35 mm), *Pteronarcys californica*	S, U	Technical (89%)	47	**25**	25	Cope 1965a; Sanders and Cope 1968; Johnson and Finley 1980; Mayer and Ellersieck 1986

Table 1. (continued)

Species	Method[a]	Chemical[b]	Hardness (mg/L as CaCO3)	LC50 or EC50 (µg/L)	Species Mean Acute Value[c] (µg/L)	Reference
Midge (third instar), *Chironomus tentans*	S, U	Technical (95%)	42-47	**10.7**	10.7	Ankley and Collyard 1995
Cutthroat trout (2.0 g), *Oncorhynchus clarki*	S, U	Technical (92%)	162	**1,700**	-	Johnson and Finley 1980; Mayer and Ellersieck 1986
Cutthroat trout (2.0 g), *Oncorhynchus clarki*	S, U	Technical (92%)	44	**2,760**	2,166	Mayer and Ellersieck 1986
Rainbow trout (3.7 cm), *Oncorhynchus mykiss*	S, U	Technical	-	**400**	-	Beliles 1965
Rainbow trout (1.20 g), *Oncorhynchus mykiss*	S, U	Technical (89%)	44	**90**	-	Cope 1965a; Johnson and Finley 1980; Mayer and Ellersieck 1986
Rainbow trout (25-50 g), *Oncorhynchus mykiss*	S, U	Technical	-	**3,200**	-	Bathe et al. 1975a
Rainbow trout, *Oncorhynchus mykiss*	S, U	Technical	-	**90**	-	Ciba-Giegy 1976
Rainbow trout, *Oncorhynchus mykiss*	S, U	Reagent	192	**1,350**	425.8	Meier et al. 1979; Dennis et al. 1980
Brook trout (1 yr), *Salvelinus fontinalis*	F, M	Technical (92.5%)	45	**800**	-	Allison and Hermanutz 1977
Brook trout (1 yr), *Salvelinus fontinalis*	F, M	Technical (92.5%)	45	**450**	-	Allison and Hermanutz 1977
Brook trout (1 yr), *Salvelinus fontinalis*	F, M	Technical (92.5%)	45	**1,050**	723.0	Allison and Hermanutz 1977
Lake trout (3.20 g), *Salvelinus namaycush*	S, U	Technical (92%)	162	**602**	602	Johnson and Finley 1980; Mayer and Ellerseick 1986
Zebrafish (0.4 g), *Danio rerio*	R, M	Technical (98%)	-	**8,000**	8,000	Keizer et al. 1991

Table 1. (continued)

Species	Method[a]	Chemical[b]	Hardness (mg/L as CaCO3)	LC50 or EC50 (µg/L)	Species Mean Acute Value[c] (µg/L)	Reference
Fathead minnow, *Pimephales promelas*	S, U	Reagent	192	10,300[e]	-	Meier et al. 1979; Dennis et al. 1980
Fathead minnow (newly hatched larva), *Pimephales promelas*	S, M	Technical (87.1%) (fresh stock solution)	45.8	4,300[e]	-	Jarvinen and Tanner 1982
Fathead minnow (newly hatched larva), *Pimephales promelas*	S, M	Technical (87.1%) (aged stock solution)	45.8	2,100[e]	-	Jarvinen and Tanner 1982
Fathead minnow (juvenile), *Pimephales promelas*	F, M	Technical (92.5%)	45	**6,600**		Allison and Hermanutz 1977
Fathead minnow (juvenile), *Pimephales promelas*	F, M	Technical (92.5%)	45	**6,800**		Allison and Hermanutz 1977
Fathead minnow (juvenile), *Pimephales promelas*	F, M	Technical (92.5%)	45	**10,000**	-	Allison and Hermanutz 1977
Fathead minnow (newly hatched larva), *Pimephales promelas*	F, M	Technical (87.1%)	45	**6,900**	-	Jarvinen and Tanner 1982
Fathead minnow (juvenile), *Pimephales promelas*	F, M	Technical (87.1%)	43.6	**9,350**	7804	University of Wisconsin-Superior 1988
Goldfish (2.5-6.0 cm), *Carassius auratus*	S, U	Technical (91%)	-	**9,000**	9,000	Beliles 1965
Flagfish (6 wk), *Jordanella floridae*	F, M	Technical (92.5%)	45	**1,500**	-	Allison and Hermanutz 1977
Flagfish (7 wk), *Jordanella floridae*	F, M	Technical (92.5%)	45	**1,800**	1,643	Allison and Hermanutz 1977
Guppy (0.6 g), *Poecilia reticulata*	R, M	Technical (98%)	-	**800**	800	Keizer et al. 1991
Bluegill (2.5-5.0 cm), *Lepomis macrochirus*	S, U	Technical	-	136[e]	-	Beliles 1965
Bluegill (0.87 g), *Lepomis macrochirus*	S, U	Technical	-	22[e]	-	Cope 1965b

Table 1. (continued)

Species	Method[a]	Chemical[b]	Hardness (mg/L as CaCO3)	LC50 or EC50 (µg/L)	Species Mean Acute Value[c] (µg/L)	Reference
Bluegill, *Lepomis macrochirus*	S, U	Technical	-	22[e]	-	Ciba-Geigy 1976
Bluegill (0.8 g), *Lepomis macrochirus*	S, U	Reagent	192	120[e]	-	Meier et al. 1979; Dennis et al. 1980
Bluegill (1.00 g), *Lepomis macrochirus*	S, U	Technical (92%)	44	168.0[e]	-	Johnson and Finley 1980; Mayer and Ellersieck 1986
Bluegill (1 yr.), *Lepomis macrochirus*	F, M	Technical (92.5%)	45	**480**	-	Allison and Hermanutz 1977
Bluegill (1 yr.), *Lepomis macrochirus*	F, M	Technical (92.5%)	45	**440**	459.6	Allison and Hermanutz 1977
Green frog (stage 8), *Rana clamitans*	R, U	Technical	-	**>50**	>50	Harris et al. 1998

Species	Method[a]	Chemical[b]	Salinity (g/kg)	LC50 or EC50 (µg/L)	Species Mean Acute Value[c] (µg/L)	Reference
			SALTWATER SPECIES			
Annelid worm (juvenile), *Neanthes arenaceodentata*	R, U	(96%)	30	**>2,880**	>2,880	Thursby & Berry 1988
Copepod (adult), *Acartia tonsa*	S, M	Technical (97.6%)	20	**2.57**	2.57	Khattat & Farley 1976
Mysid (juvenile), *Americamysis bahia*	R, U	(96%)	29	8.5[e]	-	Thursby & Berry 1988
Mysid (juvenile), *Americamysis bahia*	S, U	Technical	25	8.5[e]	-	Cripe 1994
Mysid (juvenile), *Americamysis bahia*	F, M	Diazinon	17	**4.82**	4.82	Nimmo et al. 1981
Amphipod (juvenile), *Ampelisca abdita*	R, U	(96%)	30	**6.6**	6.6	Thursby & Berry 1988
Pink shrimp (larval), *Penaeus duorarum*	S, U	Technical	25	**21**	21	Cripe 1994
Grass shrimp (larval), *Palaemonetes pugio*	R, U	(96%)	30	**2.8**	2.8	Thursby & Berry 1988

Table 1. (continued)

Species	Method[a]	Chemical[b]	Salinity (g/kg)	LC50 or EC50 (µg/L)	Species Mean Acute Value[c] (µg/L)	Reference
Sea urchin (embryo/larval), *Arbacia punctulata*	S, U	(96%)	31	**>9,600**	>9,600	Thursby & Berry 1988
Sheepshead minnow (juvenile), *Cyprinodon variegatus*	F, M	(92.6%)	23	**1,400**	1,400	Goodman et al. 1979; Mayer 1987
Inland silverside (juvenile), *Menidia beryllina*	R, U	(96%)	30	**1,170**	1,170	Thursby & Berry 1988

[a] S = static; R = renewal; F = flow-through; M = measured; U = unmeasured.
[b] Percent purity is given in parenthesis when available.
[c] Species Mean Acute Value was calculated from the underlined number(s) in the preceeding column.
[d] Animals were fed during the exposure.
[e] Results were not used in the calculation of the Species Mean Acute Value due to availability of data from more sensitive test conditions.

Table 2. Chronic Toxicity of Diazinon to Aquatic Animals

Species	Test[a]	Chemical[b]	Hardness (mg/L as CaCO3)	Chronic Limits (µg/L)	Chronic Value (µg/L)	Reference
			FRESHWATER SPECIES			
Cladoceran (<6-hr. old), *Ceriodaphnia dubia*	LC (7-day)	Technical (85%)	40	0.220-0.520	0.3382	Norberg-King 1987
Brook trout (yearling), *Salvelinus fontinalis*	PLC	Technical (92.5%)	45	0-0.8	< 0.8	Allison and Hermanutz 1977
Fathead minnow (embryo-larva), *Pimephales promelas*	ELS	Technical (88.2%)	44-49	16.5-37.8	24.97	Norberg-King 1989
Fathead minnow (embryo-larva), *Pimephales promelas*	ELS	Technical (87.1%)	45.8	50-90	67.08	Jarvinen and Tanner 1982
Flagfish (1-day old), *Jordanella floridae*	LC	-	-	54-88	68.93	Allison 1977
			SALTWATER SPECIES			
Mysid (juvenile), *Americamysis bahia*	LC	-	30-31[c]	2.1-4.4	3.040	Nimmo et al. 1981
Sheepshead minnow (juvenile), *Cyprinodon variegatus*	PLC	Technical (92.6%)	16.5[c]	0-0.47	< 0.47	Goodman et al. 1979

[a] PLC = partial life-cycle; ELS = early life-stage; LC = life cycle.
[b] Percent purity is listed in parentheses when available.
[c] Salinity (g/kg).

Table 2. (continued)

Acute-Chronic Ratio

Species	Hardness (mg/L as CaCO3)	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Mean Ratio
Cladoceran, *Ceriodaphnia dubia*	40	0.3760	0.3382	1.112	1.112
Mysid, *Americamysis bahia*	17[c]	4.82	3.040	1.586	1.586
Flagfish, *Jordanella floridae*	45	1,643	68.93	23.84	23.84
Fathead minnow, *Pimephales promelas*	44-49	9,350	24.97	374.4	-
Fathead minnow, *Pimephales promelas*	45.8	6,900	67.08	102.9	196.3
Brook trout, *Salvelinus fontinalis*	45	723.0	<0.8	>903.8	>903.8
Sheepshead minnow, *Cyprinodon variegatus*	16.5[c]	1,400	<0.47	>2,979	>2,979

[c] Salinity (g/kg).

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

Rank[a]	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)[b]	Species Mean Acute-Chronic Ratio[c,d]
		FRESHWATER SPECIES		
20	11,640	Planaria, *Dugesia tigrina*	11,640	-
19	11,000	Snail, *Gillia altilis*	11,000	-
18	9,000	Goldfish, *Carassius auratus*	9,000	-
17	8,000	Zebrafish, *Danio rerio*	8,000	-
16	7,841	Oligachaete worm, *Lumbricus variegatus*	7,841	-
15	7804	Fathead minnow, *Pimephales promelas*	7804	196.3
14	3,198	Snail, *Pomacea paludosa*	3,198	-
13	1,643	Flagfish, *Jordanella floridae*	1,643	23.84
12	960.4	Cutthroat trout, *Oncorhynchus clarki*	2,166	-
		Rainbow trout, *Oncorhynchus mykiss*	425.8	-
11	800	Guppy, *Poecilia reticulata*	800	-
10	659.7	Brook trout, *Salvelinus fontinalis*	723	> 903.8
		Lake trout, *Salvelinus namaycush*	602	-
9	459.6	Bluegill, *Lepomis macrochirus*	459.6	-

Table 3. (continued)

Rank[a]	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)[b]	Species Mean Acute-Chronic Ratio[c,d]
8	>50	Green frog *Rana clamitans*	>50	-
7	25	Stonefly, *Pteronarcys californica*	25	-
6	10.7	Midge, *Chironomus tentans*	10.7	-
5	6.51	Amphipod, *Hyalella azteca*	6.51	-
4	5.858	Amphipod, *Gammarus fasciatus*	2.04	-
		Amphipod, *Gammarus pseudolimnaeus*	16.82	-
3	1.587	Cladoceran, *Simocephalus serrulatus*	1.587	-
2	0.9020	Cladoceran, *Daphnia magna*	1.048	-
		Cladoceran, *Daphnia pulex*	0.7764	-
1	0.3773	Cladoceran, *Ceriodaphnia dubia*	0.3773	**1.112**

Table 3. (continued)

SALTWATER SPECIES

9	>9,600	Sea urchin, *Arbacia punctulata*	>9,600	-
8	>2,880	Annelid worm, *Neanthes arenaceodentata*	>2,880	-
7	1,400	Sheepshead minnow, *Cyprinodon variegatus*	1,400	>2,979
6	1,170	Inland silverside, *Menidia beryllina*	1,170	-
5	21	Pink shrimp, *Penaeus duorarum*	21	-
4	6.6	Amphipod, *Ampelisca abdita*	6.6	-
3	4.82	Mysid, *Americamysis bahia*	4.82	**1.586**
2	2.8	Grass shrimp *Palaemonetes pugio*	2.8	-
1	2.57	Copepod, *Acartia tonsa*	2.57	-

[a] Ranked from most sensitive to most resistant based on Genus Mean Acute Values.
[b] From Table 1.
[c] From Table 2.
[d] The Species Mean Acute-Chronic Values underlined and in bold font were used to calculate the Final Acute-Chronic Ratio.

Table 3. (continued)

Freshwater

Final Acute Value = 0.3397 µg/L

Criterion Maximum Concentration = 0.3397 µg/L ÷ 2 = 0.1699 µg/L

Final Acute-Chronic Ratio = 2.0 (see text)

Final Chronic Value = 0.3397 µg/L ÷ 2.0 = 0.1699 µg/L

Saltwater

Final Acute Value = 1.637 µg/L

Criterion Maximum Concentration = 1.637 µg/L ÷ 2 = 0.8185 µg/L

Final Acute-Chronic Ratio = 2.0 (see text)

Final Chronic Value = 1.637 µg/L ÷ 2.0 = 0.8185 µg/L

Table 4. Toxicity of Diazinon to Aquatic Plants

Species	Hardness (mg/L as CaCO3)	Duration (days)	Effect	Concentration (µg/L)	Reference
		FRESHWATER SPECIES			
Green algae, *Selenastrum capricornutum*	-	7	EC50 (cell numbers)	6,400	Hughes 1988

Table 5. Bioaccumulation of Diazinon by Aquatic Organisms

Species	Conc. in Water (µg/L)[a]	Duration (days)	Tissue	Percent Lipid	BCF or BAF[b]	Normalized BCF or BAF[c]	Reference
			FRESHWATER SPECIES				
Rainbow trout (16 g), *Oncorhynchus mykiss*	15	14	Whole body	-	62	-	Seguchi and Asaka 1981
Carp (8 g), *Cyprinus carpio*	15	14	Whole body	-	120	-	Seguchi and Asaka 1981
Guppy, *Poecilia reticulata*	350	14	Whole body	-	188	-	Keizer et al. 1993
			SALTWATER SPECIES				
Sheepshead minnow, *Cyprinodon variegatus*	1.8	108	Whole body (less brain)	-	147	-	Goodman et al. 1979
Sheepshead minnow, *Cyprinodon variegatus*	3.5	108	Whole body (less brain)	-	147	-	Goodman et al. 1979
Sheepshead minnow, *Cyprinodon variegatus*	6.5	108	Whole body (less brain)	-	213	-	Goodman et al. 1979

[a] Measured concentration of diazinon.
[b] Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of diazinon 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.

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

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
			FRESHWATER SPECIES			
Sewage microbes	Regent	-	22 hr	No reduction of oxygen consumption	40,000	Bauer et al. 1981
Actinomycete bacteria	Technical	-	20 days	Stimulated growth	40,000	Sethunathan and MacRae 1969
Green alga, *Chlorella ellipsoidea*	-	-	72 hr	Decreased ATP content	100,000	Clegg and Koevenig 1974
Green alga, *Chlamydomonas* sp.	-	-	72 hr	Decreased ATP content	100,000	Clegg and Koevenig 1974
Green alga, *Scenedesmus quadricauda*	-	-	10 days	No decrease in cell number, biomass, or photosynthesis	1,000	Stadnyk and Campbell 1971
Mixture of green alga and diatoms	(99.9%)	-	14 days	Decreased growth	<10	Butler et al. 1975a
Euglenoid, *Euglena elastica*	-	-	72 hr	Decreased ATP content	100,000	Clegg and Koevenig 1974
Duckweed, *Wolffia papulifera*	(97%)	-	11 days	Lethal	100,000	Worthley and Schott 1971
Duckweed, *Wolffia papulifera*	(97%)	-	11 days	Teratogenic effects	10,000	Worthley and Schott 1971
Protozan, *Paramecium caudatum*	-	-	1 hr	LC50	~3,000	Evtugyn et al. 1997
Rotifer, *Brachionus calyciflorus*	Technical (92%)	80-100	24 hr	LC50	29,220	Fernandez-Casalderrey et al. 1992a
Rotifer (16-18 hr), *Brachionus calyciflorus*	Technical (92%)	80-100	5 hr	Reduced (50%) filtration and ingestion ratios	14,000	Fernandez-Casalderrey et al. 1992b
Rotifer (<2 hr), *Brachionus calyciflorus*	Technical (92%)	80-100	10 days	Decreased reproduction	<5,000	Fernandez-Casalderrey et al. 1992c

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Rotifer (<2 hr), *Brachionus calyciflorus*	Technical (99%)	80-100	4.04 days	LT50	5,000	Fernandez-Casalderry et al. 1992d
Rotifer (<2 hr), *Brachionus calyciflorus*	Technical (99%)	80-100	4.66 days	LT50	7,000	Fernandez-Casalderrey et al. 1992d
Rotifer (<2 hr), *Brachionus calyciflorus*	Technical (99%)	80-100	2.49 days	LT50	14,000	Fernandez-Casalderry et al. 1992d
Rotifer (<2 hr), *Brachionus calyciflorus*	-	80-100	48 hr	NOEC Reproduction	8,000	Snell and Moffat 1992
Rotifer (<2 hr), *Brachionus calyciflorus*	-	80-100	48 hr	NOEC Ingestion	20,000	Juchelka and Snell 1994
Oligochaete worm, *Lumbriculus variegatus*	-	-	4 hr	Lethal	20,000	Rogge and Drewes 1993
Tubificid worm, *Branchiura sowerbyi*	-	-	96 hr	LC50	2,220	Chatterjee and Konar 1984
Snail, *(Physa acuta)*	-	-	48 hr	LC50	4,800	Hashimoto and Nishiuchi 1981
Cladoceran *Daphnia magna*	-	202	50 hr	EC50	4.3	Anderson 1959
Cladoceran (adult), *Daphnia magna*	-	-	24 hr	Adhesion of algal particles on 2nd antennae and immobilization	1	Stratton and Corke 1981
Cladoceran (<24 hr), *Daphnia magna*	Analytical (95%)	200	21 days	Reduced reproduction and mobility	0.3	Dortland 1980
Cladoceran (<24 hr), *Daphnia magna*	Analytical (99%)	200	21 days	No reduction in reproduction or mobility	0.2	Dortland 1980
Cladoceran (<24 hr), *Daphnia magna*	Analytical (99%)	200	21 days	EC50 (immobilization)	0.22	Dortland 1980
Cladoceran (<24 hr), *Daphnia magna*	Analytical (99%)	200	21 days	EC50 (immobilization)	0.24	Dortland 1980

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia magna*	Analytical (99%)	200	21 days	EC50 (immobilization)	0.7	Dortland 1980
Cladoceran (<24 hr), *Daphnia magna*	Analytical (99%)	200	21 days	EC50 (immobilization)	0.8	Dortland 1980
Cladoceran (<24 hr), *Daphnia magna*	Insecticidal soap	-	48 hr	LC50	0.74	Mitchell 1985
Cladoceran (<24 hr), *Daphnia magna*	Insecticidal soap	-	96 hr	LC50	0.21	Mitchell 1985
Cladoceran (adult), *Daphnia magna*	Technical	-	3 hr	LC50	7.8	Nishiuchi and Hashimoto 1967
Cladoceran, *Daphnia magna*	Technical	-	3 hr	LC50	80	Hashimoto and Nishiuchi 1981
Cladoceran, *Daphnia magna*	Technical (92%)	-	5 hr	Reduced (50%) filtration rate	0.47	Fernandez-Casalderrey et al. 1994
Cladoceran (<24 hr), *Daphnia magna*	Technical (92%)	250	21 days	NOEC survival	0.15	Fernandez-Casalderrey et al. 1995
Cladoceran (<24 hr), *Daphnia magna*	Technical (92%)	250	21 days	LOEC survival	0.18	Fernandez-Casalderrey et al. 1995
Cladoceran (<24 hr), *Daphnia magna*	Technical (92%)	250	21 days	LOEC reproduction	0.15	Fernandez-Casalderrey et al. 1995
Cladoceran (<24 hr), *Daphnia magna*	Technical (92%)	250	24 hr	LC50	0.86	Fernandez-Casalderrey et al. 1995
Cladoceran (<24 hr), *Daphnia magna*	Technical (96.1%)	182	21 days	Reduced survival, growth and reproduction	0.05	Sanchez et al. 1998, 1999, 2000
Cladoceran, *Daphnia magna*	Optimum	160-180	30 min	IC50	0.45	Fort et al. 1996
Cladoceran, *Daphnia pulex*	-	-	3 hr	LC50	80	Hashimoto and Nishiuchi 1981
Cladoceran, *Daphnia pulex*	-	-	3 hr	LC50	7.8	Nishiuchi and Hashimoto 1967

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Cladoceran (adult), *Moina macrocopa*	Technical	-	3 hr	LC50	26	Nishiuchi and Hashimoto 1967
Cladoceran, *Moina macrocopa*	Technical	-	3 hr	LC50	50	Hashimoto and Nishiuchi 1981
Copepod, *Cyclops vividis*	-	-	96 hr	LC50	2,600	Chatterjee and Konar 1984
Amphipod (adult), *Hyalella azteca*	Technical	160-180	48 hr	LC50	19 (measured)	Werner and Nagel 1997
Amphipod (0-2 days), *Hyalella azteca*	Technical	40	96 hr	LC50	6.2	Collyard et al. 1994
Amphipod (2-4 days), *Hyalella azteca*	Technical	40	96 hr	LC50	4.2	Collyard et al. 1994
Amphipod (6-8 days), *Hyalella azteca*	Technical	40	96 hr	LC50	4.3	Collyard et al. 1994
Amphipod (8-10 days), *Hyalella azteca*	Technical	40	96 hr	LC50	4.4	Collyard et al. 1994
Amphipod (12-14 days), *Hyalella azteca*	Technical	40	96 hr	LC50	3.8	Collyard et al. 1994
Amphipod (16-18 days), *Hyalella azteca*	Technical	40	96 hr	LC50	4.4	Collyard et al. 1994
Amphipod (20-22 days), *Hyalella azteca*	Technical	40	96 hr	LC50	4.6	Collyard et al. 1994
Amphipod (24-26 days), *Hyalella azteca*	Technical	40	96 hr	LC50	4.6	Collyard et al. 1994
Crayfish, *Procambarus clarkii*	-	-	7 days	BCF = 4.9	10	Kanazawa 1978
Stonefly (nymph), *Pteronarcys californicus*	-	-	48 hr	EC50	74	Cope 1965a

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Caddisfly (larva), *Hydropsyche morosa*	-	-	6 hr	LC50	2,500	Fredeen 1972
Caddisfly (larva), *Hydropsyche morosa*	-	-	6 hr	LC50	500	Fredeen 1972
Caddisfly (larva), *Hydropsyche recurvata*	-	-	6 hr	LC50	>500	Freeden 1972
Caddisfly (larva), *Hydropsyche recurvata*	-	-	6 hr	LC50	>500	Freeden 1972
Mosquito (4th instar), *Aedes aegypti*	Technical	-	24 hr	LC50	350	Klassen et al. 1965
Mosquito (3rd-4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	61	Chen et al. 1971
Mosquito (3rd-4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	80	Chen et al. 1971
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	3.5	Yasuno and Kerdpibule 1967
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	5.7	Yasuno and Kerdpibule 1967
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	2.2	Yasuno and Kerdpibule 1967
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	3.2	Yasuno and Kerdpibule 1967

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	4.6	Yasuno and Kerdpibule 1967
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	4.5	Yasuno and Kerdpibule 1967
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	1.9	Yasuno and Kerdpibule 1967
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	1.8	Yasuno and Kerdpibule 1967
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	5.4	Yasuno and Kerdpibule 1967
Mosquito (4th instar), *Culex pipiens fatigans*	Technical	-	24 hr	LC50	3.5	Yasuno and Kerdpibule 1967
Midge (1st instar), *Chironomus riparius*	Analytical (99.7%)	-	96 hr	LC50 (fed)	23	Stuijfzand et al. 2000
Midge (4th instar), *Chironomus riparius*	Analytical (99.7%)	-	96 hr	LC50 (fed)	167	Stuijfzand et al. 2000
Salmonidae	Emulsible concentrate (60%)	-	96 hr	LC50	8,000	Ciba-Geigy 1976
Brown Trout (3.22 g), *Salma trutta lacustris*	-	-	96 hr	LC50	602	Swedberg 1973
Cutthroat trout (0.52 g), *Oncorhynchus clarki*	-	-	96 hr	LC50	3,850	Swedberg 1973

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Cutthroat trout (2.02 g), *Oncorhynchus clarki*	-	-	96 hr	LC50	2,760	Swedberg 1973
Rainbow trout (fry), *Oncorhynchus mykiss*	Insecticidal soap	-	96 hr	LC50	20	Mitchell 1985
Rainbow trout, *Oncorhynchus mykiss*	-	-	48 hr	EC50	170	Cope 1965a
Rainbow trout (16 g), *Oncorhynchus mykiss*	Synthesized	-	14 days	BCF = 62	15	Seguchi and Asaka 1981
Rainbow trout, *Oncorhynchus mykiss*	Analytical	360	28 days	NOEC	200	Bresch 1991
Goldfish (4.01 cm), *Carassius auratus*	Technical	-	48 hr	LC50	5,100	Nishiuchi and Hashimoto 1967; Hashimoto and Nishiuchi 1981
Carp, *Cyprinus carpio*	-	-	7 days	BCF = 65.1	10	Kanazawa 1978
Carp (4.2 cm), *Cyprinus carpio*	Technical	-	72 hr	LC50	2,000	Nishiuchi and Asano 1981
Carp (6.0 cm), *Cyprinus carpio*	Technical	-	48 hr	LC50	3,200	Nishiuchi and Hashimoto 1967; Hashimoto and Nishiuchi 1981; Nishiuchi and Asano 1981
Carp (8 g), *Cyprinus carpio*	Synthesized	-	14 days	BCF = 120	18	Seguchi and Asaka 1981
Carp (1.1-1.4 g), *Cyprinus carpio*	-	-	72 hr	LC50	1,420	Dutt and Guha 1988
Carp (24-35 g), *Cyprinus carpio*	Reagent (98%)	-	7 days	BCF = 20.9	2.4	Tsuda et al. 1990
Fathead minnow (larva), *Pimephales promelas*	Technical (88.2%)	44-49	7 days	No reduction in growth or survival	277	Norberg-King 1989

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Fathead minnow (larva), *Pimephales promelas*	Technical (88.2%)	44-49	7 days	Reduction in dry weight	277	Norberg-King 1989
Fathead minnow (larva), *Pimephales promelas*	Technical (88.2%)	44-49	7 days	Reduction in dry weight	347	Norberg-King 1989
Fathead minnow (embryo-larva), *Pimephales promelas*	Technical (88.2%)	44-49	12 days	No reduction in growth or survival	285	Norberg-King 1989
Fathead minnow (newly hatched larvae), *Pimephales promelas*	Encapsulated formulation (fresh stock)	45.8	96 hr	LC50	6,100	Jarvinen and Tanner 1982
Fathead minnow (newly hatched larvae), *Pimephales promelas*	Encapsulated formulation (11 week-old stock)	45.8	96 hr	LC50	5,100	Jarvinen and Tanner 1982
Fathead minnow (embryo-larva), *Pimephales promelas*	Encapsulated formulation	45.8	32 days	No effect on weight	40	Jarvinen and Tanner 1982
Fathead minnow (embryo-larva), *Pimephales promelas*	Encapsulated formulation	45.8	32 days	Significant reduction in weight	76	Jarvinen and Tanner 1982
Catfish *Ictalurus* sp.	Emulsifiable concentrate (60%)	-	96 hr	LC50	8,000	Ciba-Geigy 1976
Ide *Leucisuc idus*	Emulsifiable concentrate (60%)	-	96 hr	LC50	150	Ciba-Geigy 1976
Flagfish (larva-juvenile), *Jordanella floridae*	-	-	21-day pulsed dose + recovery	Decreased egg production	290	Allison 1977
Flagfish (juvenile-adult), *Jordanella floridae*	-	-	21-day pulsed dose + recovery	Decreased parental survival	250	Allison 1977

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Flagfish (adult-spawning), *Jordanella floridae*	-	-	21-day pulsed dose + recovery	Decreased survival of parents and larvae	1,170	Allison 1977
Oriental weatherfish, *Misqurnus anguillicaudatus*	Technical	-	48 hr	LC50	500	Hashimoto and Nishiuchi 1981
Oriental weatherfish (2.6 g), *Misgurnus anguillicaudatus*	Synthesized	-	14 days	BCF = 28	14	Seguchi and Asaka 1981
Guppy (7 wk), *Poecilia reticulata*	Technical	-	24 hr	LC50	3,700	Chen et al. 1971
Guppy (7 wk), *Poecilia reticulata*	Technical	-	24 hr	LC50	3,800	Chen et al. 1971
Guppy (7 wk), *Poecilia reticulata*	Technical	-	30 min	Loss of equilibrium	7,000	Chen et al. 1971
Guppy, *Poecilia reticulata*	Emulsifiable concentrate (60%)	-	96 hr	LC50	3,000	Ciba-Geigy 1976
Guppy, *Poecilia reticulata*	-	-	7 days	BCF = 17.5	10	Kanazawa 1978
Guppy (2-3 mon), *Poecilia reticulata*	Technical (99%)	100	3 days	Lethal body burden	2,495	Ohayo-Mitoko and Deneer 1993
Guppy (2-3 mon), *Poecilia reticulata*	-	75	24 hr	Lethal body burden (@ 4,330 µg/L exposure)	2.1 (µmol/g)	Deneer et al. 1999
Guppy (2-3 mon), *Poecilia reticulata*	-	75	7 days	Lethal body burden (@ 2,420 µg/L exposure)	1.8 (µmol/g)	Deneer et al. 1999
Bluegill, *Lepomis macrochirus*	-	-	48 hr	EC50	30	Cope 1965a

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Bluegill, *Lepomis macrochirus*	Basudin (93%)	-	48 hr	LC50	1,493	Li and Chen 1981
Zebrafish, *Brachydanio rerio*	ELS	Analytical	360	200->200	>200	Bresch 1991
Tilapia, *Tilapia* sp.	-	-	48 hr	LC50	1,492	Li and Chen 1981
Mozambique tilapia (5-9 g), *Tilapia mossambica*	Technical	-	-	LC100	15,850	Mustafa et al. 1982
Mozambique tilapia (3.56 g), *Tilapia mossambica*	-	-	96 hr	LC50	2,280	Chatterjee and Konar 1984
Mozambique tilapia (1.4 g), *Tilapia mossambica*	-	-	72 hr	LC50	2,880	Dutt and Guha 1988
Experimental stream community	Technical (92.5%)	170-195	84 days	Increased drift rates for *Hyalella*	0.3	Arthur et al. 1983
Experimental stream community	Technical (92.5%)	170-195	112 days	Reduced *Hyalella* populations	5	Arthur et al. 1983
Experimental pond community	Technical (88%)	70-150	70 days	NOEC for phytoplankton and periphyton chlorophyll; macrophyte biomass	443	Giddings et al. 1996
Experimental pond community	Technical (88%)	70-150	70 days	LOEC for Cladocera, Pentaneurcini, Ceratopogonidae abundance	2.4	Giddings et al. 1996
Experimental pond community	Technical (88%)	70-150	70 days	LOEC for zooplankton and macroinvertebrate taxonomic richness	9.2	Giddings et al. 1996
Experimental pond community	Technical (88%)	70-150	70 days	Reduced bluegill sunfish biomass	22	Giddings et al. 1996

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO3)	Duration	Effect	Concentration (µg/L)	Reference
Experimental pond community	Technical (88%)	70-150	70 days	Reduced bluegill sunfish survival	54	Giddings et al. 1996

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)	Reference
			SALTWATER SPECIES			
Natural phytoplankton	-	-	4 hr	6.8% decrease in photosynthesis	1,000	Butler 1963
Red alga, *Champia parvula*	(96%)	-	48 hr exposure	No effect on sexual reproduction	1,000	Thursby & Tagliabue 1988
Red alga, *Chondrus crispus*	(12.5%)	-	24 hr exposure 18 day holding	No effect on growth	10,000	Shacklock & Croft 1981
Rotifer, *Brachionus plicatilis*	(96%)	-	24 hr	LC50	55,100	Thursby & Berry 1988
Rotifer, *Brachionus plicatilis*	Standard (95%)	-	24 hr	EC50	28,000	Guzzella et al. 1997
Snail, *Lacuna vincta*	(12.5%)	-	3 hr exposure, 48 hr holding	88% mortality	1,000	Shacklock & Croft 1981
Snail, *Lacuna vincta*	(12.5%)	-	3 hr exposure, 48 hr holding	75% mortality	10,000	Shacklock & Croft 1981
Eastern oyster, *Crassostrea virginica*	-	-	96 hr	No decrease in shell growth	1,000	Butler 1963; Mayer 1987
Eastern oyster (5-10 cm height), *Crassostrea virginica*	Technical and 14C-labeled	-	96 hr	LC50 shell growth	1,115	Williams 1989
Eastern oyster (6-10 cm height), *Crassostrea virginica*	Technical and 14C-labeled	-	5 days	BCF = 56	100	Williams 1989

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)	Reference
Amphipod (adult), *Ampelisea aldita*	Technical	25	48 hr	LC50	10	Werner & Nagel 1997
Amphipod, *Gammarus oceanicus*	(12.5%)	-	3 hr exposure	100% mortality	1,000	Shacklock & Croft 1981
Amphipod (adult), *Rhepoxynius abronius*	Technical	31	24 hr	LC50	9.2	Werner & Nagel 1997
Isopod, *Idotea baltica*	(12.5%)	-	3 hr exposure	100% mortality	1,000	Shacklock & Croft 1981
Brown shrimp, *Penaeus aztecus*	-	-	24 hr	EC50	44	Butler 1963
Brown shrimp, *Penaeus aztecus*	Technical 95.1% pure	-	48 hr	EC50	28	Mayer 1987
Grass shrimp, *Palaemonetes pugio*	Technical 95.1% pure	-	48 hr	EC50	28	Mayer 1987
White mullet, *Mugil curema*	-	-	24 & 48 hr	LC50	250	Butler 1963
Striped mullet, *Mugil cephalus*	Technical 95.1% pure	-	48 hr	LC50	150	Mayer 1987
Sheepshead minnow, *Cyprinodon variegatus*	92.6% pure	-	108 days	Decrease in acetylcholin-esterase activity	0.47	Goodman et al. 1979; Mayer 1987

[a] Percent purity is listed in parentheses when available.

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