

440/5-87-013

Draft  
9/24/87

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR  
DI-2-ETHYLHEXYL PHTHALATE

U.S. ENVIRONMENTAL PROTECTION AGENCY  
OFFICE OF RESEARCH AND DEVELOPMENT  
ENVIRONMENTAL RESEARCH LABORATORIES  
DULUTH, MINNESOTA  
NARRAGANSETT, RHODE ISLAND

## NOTICES

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

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

## FOREWORD

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

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

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

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

Martha G. Prothro  
Director  
Office of Water Regulations and Standards.

## ACKNOWLEDGMENTS

Larry T. Brooks  
(freshwater author)  
University of Wisconsin-Superior  
Superior, Wisconsin

Robert S. Carr  
(saltwater author)  
Battelle Ocean Sciences  
Duxbury, Massachusetts

Charles E. Stephan  
(document coordinator)  
Environmental Research Laboratory  
Duluth, Minnesota

David J. Hansen  
(saltwater coordinator)  
Environmental Research Laboratory  
Narragansett, Rhode Island

## CONTENTS

	<u>Page</u>
Notices.....	ii
Foreword.....	iii
Acknowledgments.....	iv
Tables.....	vi
 Introduction.....	 1
Acute Toxicity to Aquatic Animals.....	2
Chronic Toxicity to Aquatic Animals.....	3
Toxicity to Aquatic Plants.....	6
Bioaccumulation.....	6
Other Data.....	7
Unused Data.....	9
Summary.....	10
National Criteria.....	11
Implementation.....	12
 References.....	 26

## TABLES

	<u>Page</u>
1. Acute Toxicity of Di-2-ethylhexyl Phthalate to Aquatic Animals .....	14
2. Chronic Toxicity of Di-2-ethylhexyl Phthalate to Aquatic Animals ...	17
3. Toxicity of Di-2-ethylhexyl Phthalate to Aquatic Plants.....	19
4. Bioaccumulation of Di-2-ethylhexyl Phthalate by Aquatic Organisms...	20
5. Other Data on Effects of Di-2-ethylhexyl Phthalate on Aquatic Organisms.....	22

## Introduction

The chemicals commonly known as phthalates are esters of phthalic acid (1,2-benzenedicarboxylic acid). Phthalates are widely used in the manufacture of plastics. Phthalates are interfused with high molecular weight polymers to increase flexibility, extensibility, and workability of the plastic. It is a major constituent of polyvinyl chloride (PVC) (Daniel 1978; Graham 1973). Di-2-ethylhexyl phthalate (DEHP), also known as bis(2-ethylhexyl) phthalate, is the most produced phthalate (U.S. EPA 1980). The term dioctyl phthalate (DOP) is sometimes used to refer to di-n-octyl phthalate, but is sometimes also used to refer to DEHP; the term DEHP only will be used herein.

DEHP is a component of many products found in homes and automobiles as well as in the medical and packaging industries. Its wide use and distribution, as well as its high volatility and persistence, lead to its common occurrence in fish, water, and sediments (Burns et al. 1981; Corcoran 1973; Glass 1975; Hites 1973; Lindsay 1977; Mayer et al. 1972; Morris 1970; Petersen and Freeman 1982; Ray et al. 1983; Swain 1978; Williams 1973; Zitko 1972, 1973). DEHP has been detected in precipitation upon the remote Enewetok Atoll in the North Pacific Ocean (Atlas and Giam 1981). It occurs in sediments of Chesapeake Bay in concentration gradients proportional to the annual production of the compound (Peterson and Freeman 1982).

The reported values of the solubility limit of DEHP range from 50 to 1,300  $\mu\text{g/L}$ ; however, some of the best estimates of solubility are 360  $\mu\text{g/L}$  (Biesinger et al., Manuscript) and 400  $\mu\text{g/L}$  (Wolfe et al. 1980). The reported values of the log octanol-water partition coefficient range from 4.2 to 8.7 (Callahan et al. 1979; Fishbein and Albro 1972; Leyder and Boulanger 1983; Patty 1967).

Persistence of DEHP has been measured in freshwater hydrosols (Johnson and Lulves 1975). Under aerobic conditions, the half-life was 14 days.

whereas no degradation was observed in 30 days under anaerobic conditions. Wolfe et al. (1980a) found very little transformation and volatilization of DEHP in several computer simulated ecosystems.

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), hereinafter referred to as the Guidelines, and the response to public comment (U.S. EPA 1985a) is necessary to understand the following text, tables, and calculations. Results of such intermediate calculations as recalculated LC50s and Species Mean Acute Values are given to four significant figures to prevent roundoff error in subsequent calculations, not to reflect the precision of the value. The criteria presented herein supersede previous national aquatic life water quality criteria for DEHP (U.S. EPA 1978, 1980) because these new criteria were derived using improved procedures and additional information. The latest comprehensive literature search for information for this document was conducted in February, 1986; some more recent information was included.

#### Acute Toxicity to Aquatic Animals

Some data that are available on the acute toxicity of DEHP are useable according to the Guidelines in the derivation of Final Acute Values (FAV) for DEHP (Table 1). In only four of twenty-one acute tests with freshwater animal species was enough toxicity observed to permit calculation of an acute value. In a 48-hr exposure of Daphnia magna the acute value was 11,000  $\mu\text{g/L}$  (LeBlanc 1980). Adams and Heidolph (1985) obtained a 48-hr EC50 of 2,000  $\mu\text{g/L}$  with the same species. Cary et al. (Manuscript) reported LC50s of 240,000  $\mu\text{g/L}$  for an amphipod and 2,100  $\mu\text{g/L}$  for larvae of a midge. In the other seventeen freshwater tests with five invertebrate species and five fish species little or no toxicity was observed at the highest tested



concentrations, which ranged from 89 to 1,500  $\mu\text{g/L}$ . In addition, DEHP was not lethal to the nonresident amphipod, Ampelisca pulex, at concentrations up to 400  $\mu\text{g/L}$  (Stephenson 1983).

The acute toxicity of DEHP has been determined with three species of saltwater animals (Table 1). No effects were detected at 300,000  $\mu\text{g/L}$  with the harpacticoid copepod, Nitocra spinipes (Iden et al. 1979) nor at 550,000  $\mu\text{g/L}$  with the sheepshead minnow, Cyprinodon variegatus (Heitmuller et al. 1981). DEHP concentrations as high as 450  $\mu\text{g/L}$  were not lethal to larvae of the grass shrimp, Palaemonetes pugio (Laughlin et al. 1978).

Because so few quantitative Species Mean Acute Values are available for freshwater and saltwater species, the procedure described in the Guidelines cannot be used to calculate Final Acute Values. However, the data strongly suggest that acute toxicity does not occur at concentrations below the water solubility of DEHP (400  $\mu\text{g/L}$ ). The only uncertainties in this assessment are the two species, Hydra oligactis and Loricifer variegatus, for which the highest concentration tested was 89  $\mu\text{g/L}$ . However, there is no reason to believe that these two species would have been affected by concentrations up to 400  $\mu\text{g/L}$ . The Criterion Maximum Concentration for both fresh and salt water is set at 400  $\mu\text{g/L}$ , although it is possible that even higher concentrations of DEHP would be acutely toxic to few, if any, species of freshwater or saltwater fish or invertebrates.

#### Chronic Toxicity to Aquatic Animals

Several tests have been conducted that are useable according to the Guidelines concerning the chronic toxicity of DEHP (Table 2). Four life-cycle tests have been conducted with the cladoceran, Daphnia magna. In the first test, all tested concentrations, including the lowest of 3  $\mu\text{g/L}$ , inhibited

reproduction by at least 60% (Mayer and Sanders 1973; Sanders et al. 1973). A comparable acute test was not conducted. Brown and Thompson (1982) found that concentrations up to 107  $\mu\text{g/L}$  did not reduce survival or reproduction of D. magna. Adams and Heidolph (1985) reported that 1,300  $\mu\text{g/L}$  significantly reduced survival and reproduction, whereas 640  $\mu\text{g/L}$  did not. The chronic value was 912.1  $\mu\text{g/L}$ . Because these authors did not conduct an acute test in the dilution water in which their chronic test was conducted, their acute-chronic ratio of 2.20 cannot be used. In the fourth test (Knowles et al. 1987), survival and reproduction were significantly reduced at 811  $\mu\text{g/L}$ , but not at 158  $\mu\text{g/L}$ . The chronic value was 358.0  $\mu\text{g/L}$ .

The early report that DEHP causes chronic toxicity to D. magna at concentrations of 3  $\mu\text{g/L}$  appears to be in error because three other tests found that concentrations above 100  $\mu\text{g/L}$  did not affect survival or reproduction.

Streufert and Sanders (1977) and Streufert et al. (1980) exposed midge larvae to DEHP for 35 days until emergence and then observed the animals until eggs were produced and hatched. The highest concentration tested (360  $\mu\text{g/L}$ ) increased emergence by 1%, reduced the total number of eggs by 15%, and reduced hatchability by 2%. At 200  $\mu\text{g/L}$ , emergence was increased by 5%, the total number of eggs was increased by 56%, and hatchability was decreased by 3%. Since the authors found none of these effects to be significant, the chronic value was  $> 360 \mu\text{g/L}$ , and an acute-chronic ratio cannot be calculated.

Three early life-stage tests have been conducted on DEHP with fish. Mehrle and Mayer (1978) exposed rainbow trout, Salmo gairdneri, embryos and fry for 100 days. No significant effects occurred in the embryos or in fry older than 24 days. However, fry between hatching and 24 days of age had a

significant increase in mortality at a DEHP concentration of 14  $\mu\text{g/L}$ . The calculated chronic value was 8.366  $\mu\text{g/L}$ . However, Spehar (1986) exposed rainbow trout embryos and fry to DEHP for 90 days. The average test concentrations ranged from 49 to 502  $\mu\text{g/L}$  and no significant effects were observed on embryo hatchability, larval or early juvenile survival or growth.

The very low values for both D. magna and rainbow trout were obtained in the same laboratory at about the same time. Subsequently, much higher values have been obtained in this and three other laboratories with these two species.

In a 32-day early-life stage test with the fathead minnow, Pimephales promelas, survival was reduced 1% by 23,800  $\mu\text{g/L}$  and was reduced 32% by 42,400  $\mu\text{g/L}$  (Horne et al. 1983). The mean weight of the fish in the control treatment at the end of the test was rather low, but the data indicate that the weight was higher than controls at 23,800  $\mu\text{g/L}$ , but was reduced 16% by 42,400  $\mu\text{g/L}$ . Higher concentrations of DEHP caused even greater reductions in survival and weight. The chronic value was 31,770  $\mu\text{g/L}$ , and the acute-chronic ratio was greater than 34.82.

No acceptable chronic tests have been conducted on DEHP with a saltwater species.

Useful chronic values are available for four freshwater species and no saltwater species. The chronic value for Daphnia magna is in the range of 358.0 to 912.1  $\mu\text{g/L}$  and the midge chronic value was greater than 360  $\mu\text{g/L}$ . The chronic values for the fathead minnow and rainbow trout are much higher, 31,770 and greater than 502  $\mu\text{g/L}$ , respectively. The only information available concerning the acute-chronic ratio for DEHP is greater than 34.82 for the fathead minnow. Acute-chronic ratios are not very useful, because DEHP is not acutely toxic enough to allow determination of a

quantitative Final Acute Value. Since DEHP does not ionize in water, it is assumed that it is equally toxic to freshwater and saltwater species. Because the lowest tested reliable chronic value is 358  $\mu\text{g/L}$  and it is with a sensitive species, the freshwater and saltwater Final Chronic Values are identical and set at 358.0  $\mu\text{g/L}$ .

#### Toxicity to Aquatic Plants

Richter (1982) exposed a green alga, Selenastrum capricornutum, for five days to concentrations up to 410  $\mu\text{g/L}$ , which was assumed to be the solubility limit of DEHP in the dilution water. The highest test concentration did not cause a 50% reduction in growth (Table 3). Davis (1981) conducted seven static tests with the duckweed, Lemna gibba, to study the effect of DEHP on frond production. The EC50s ranged from 408,000 to 7,492,000  $\mu\text{g/L}$ , and the mean EC50 was 2,080,000  $\mu\text{g/L}$ . A test with the saltwater diatom, Gymnodinium breve, resulted in a 96-hr EC50 of 31,000,000  $\mu\text{g/L}$  (Wilson et al. 1978).

A Final Plant Value, as defined in the Guidelines, cannot be obtained because no test in which the concentrations of DEHP were measured resulted in an adverse effect.

#### Bioaccumulation

Uptake of DEHP directly from water has been studied with a variety of freshwater species. Results of exposures that lasted for at least 28 days and results of tests in which the concentrations in tissue were shown to have reached steady-state are presented in Table 4; other results are presented in Table 5. All exposures were conducted with radiolabeled DEHP and the results are based on measurements of  $^{14}\text{C}$  in water and in tissue.

Mayer (1976) determined the percentage composition of DEHP and its metabolites in fathead minnows after 56 days of exposure to several concentrations. DEHP ranged from 33 to 79% and was inversely related to the concentration in water. The principal metabolite was 2-ethylhexyl phthalate. Tests with invertebrates resulted in bioconcentration factors (BCFs) ranging from 14 for an isopod, Asellus brevicaudus, to 3,600 for an amphipod, Gammarus pseudolimnaeus. Fish bioconcentrated  $^{14}\text{C}$ -labeled DEHP from 114 to 1,380 times. Fathead minnows showed a wide range of BCFs with a consistent inverse relationship between concentration in water and BCF (Mayer 1976; Mehrle and Mayer 1976).

BCFs for the soft tissues of M. edulis exposed to 4.1 and 42.1  $\mu\text{g/L}$  for 28 days in salt water were 2,366 and 2,627, respectively (Brown and Thompson 1982).

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

#### Other Data

Additional data concerning the lethal and sublethal effects of DEHP on aquatic species are presented in Table 5. A green alga showed a reduction of chlorophyll fluorescence after a two-hour exposure to 410  $\mu\text{g/L}$ . Cary et al. (Manuscript) reported that 207,000  $\mu\text{g/L}$  did not reduce survival of brook trout exposed for 144 hr. Exposure of the same species to 3,000  $\mu\text{g/L}$  for eight months had no effect on survival, growth rate, or spawning success. Cary et al. (Manuscript) also exposed bluegills to high concentrations of DEHP. A 9-day exposure to 1,175,000  $\mu\text{g/L}$  killed less than 50% of the fish. Exposure of bluegills for 90 days to 2,040  $\mu\text{g/L}$  caused no adverse

effects on survival, growth, or spawning success. In the tests conducted by Cary et al. (Manuscript), no effects on brook trout or bluegills were observed even though the fish were exposed to concentrations of Triton X-100 that were to 5 to 8% of the concentrations of DEHP. Mehrle and Mayer (1976) observed no effect on survival or growth of fathead minnows during exposure to 62  $\mu\text{g/L}$  for 56 days.

Collagen synthesis was reduced in the vertebrae of brook trout exposed to 3.7  $\mu\text{g/L}$  for 150 days (Mayer et al. 1977). They found the same effect in rainbow trout exposed for 90 days to 14  $\mu\text{g/L}$  and fathead minnows exposed for 127 days to 11  $\mu\text{g/L}$ . The heart-beat rate of goldfish was reduced when the fish were exposed to 200,000  $\mu\text{g/L}$  for 10 minutes (Pfuderer and Francis 1975; Pfuderer et al. 1975). Geyer et al. (1981, 1984) reported a 24-hour BCF of 5,400 for a green alga (Table 5). Cladocerans exposed for 7 days had BCFs of 1,040 (Sanders et al. 1973) and 420 (Mayer and Sanders 1973). Mayflies had BCFs of 460 and 575 in 7-day tests (Table 5).

The fate and effects of  $^{14}\text{C}$ -labeled DEHP were studied in a saltwater microcosm during 30-day experiments in the winter and summer (Perez et al. 1983). Ammonia flux from the benthic subsystem was reduced during the summer at a average temperature of 18°C in microcosms in which the DEHP concentration averaged 15.5  $\mu\text{g/L}$ . A similar effect was not observed at 58.9  $\mu\text{g/L}$  in the winter at an average temperature of 1°C. Average concentrations of DEHP in the molluscs, Pitar morrhuana and Mulinia lateralis, from the sediment compartment were 1.767 times the concentration in the overlying water and BCFs for the zooplankter Acartia sp. averaged 2,659 (Perez et al. 1983). Values for these three species differed little between tests run in the winter and summer. In contrast, BCFs for two infaunal polychaetes, Nucula annulata and Nephtys incisa, averaged 89.2 and 1,420 in the winter and summer experiments, respectively.

A steady-state BCF of 837 was predicted from uptake and depuration kinetics of DEHP in sheepshead minnows, Cyprinodon variegatus (Karara and Hayton 1984). In contrast, DEHP was not detected at 2 mg/kg in the tissues of post-larval grass shrimp exposed for 25 to 28 days to mean measured concentrations of 62 to 450  $\mu\text{g/L}$  (Laughlin et al. 1978).

#### Unused Data

Some data concerning the effects of DEHP on aquatic organisms and their uses were not used because the tests were conducted with species that are not resident in North America (e.g., Stephenson 1983). Results (e.g., Sugawara 1974) of tests conducted with brine shrimp, Artemia sp., were not used because these species are from a unique saltwater environment. Biddinger and Gloss (1984), Davies and Dobbs (1984), Environment Canada (1983), Johnson et al. (1977), Neely (1979), Peakall (1975), Thomas and Northrup (1982), Thomas and Thomas (1984), Thomas et al. 1978; and Veith et al. (1979) compiled data from other sources.

Results were not used when the test procedures or results were not adequately described (Group 1986; Parker 1984; Streufert and Sanders 1977). Tests conducted without controls were not used (Heitmuller et al. 1981). Data were not used when DEHP was a component of an effluent or sediment (Horning et al. 1984; Larsson and Thuren 1987; Pickering 1983; Woin and Larsson 1987). The concentration of dissolved oxygen was too low in the test chambers in a test conducted by Silvo (1974). Studies were not used when the test chemical was reported as dioctylphthalate (Birge et al. 1978, 1979; Black and Birge 1980; McCarthy et al. 1985; McCarthy and Whitmore 1985). Results of tests (e.g., Cary, Manuscript; Dumpert and Zietz 1984; Zitko 1972), in which the concentration of surfactant or organic solvent was too high were not used.

Reports of the concentrations of DEHP in wild aquatic organisms (DeVault 1985; Glass 1975; Kaiser 1977; Lindsay 1977; Murray et al. 1981; Musial et al. 1981; Ray and Giam 1984; Ray et al. 1983; Swain 1978; Williams 1973; Zitko 1973) were not used to calculate BCFs if the number of measurements of DEHP in water was too low or if the range of the concentration in water was too high. Studies of the metabolism of DEHP in aquatic organisms were not used (Henderson and Sargent 1983; Lech and Melancon 1980; Melancon and Lech 1976, 1977, 1979; Melancon et al. 1977; Stalling et al. 1973). Results of laboratory bioconcentration tests were not used when the test was not flow-through or renewal (e.g., Karara et al. 1984; Wofford et al. 1981). BCFs obtained from microcosm or model ecosystem studies were not used when the concentration of DEHP in water decreased with time (Metcalf 1975; Metcalf et al. 1973; Sodergren 1982).

#### Summary

Data on the acute toxicity of DEHP are available for twelve species of freshwater animals. The lowest reported acute value of 2,100  $\mu\text{g/L}$  was obtained with a midge. Higher concentrations were not acutely toxic to most species, but the high tested concentration was only 89  $\mu\text{g/L}$  in tests with two species. Chronic toxicity tests have been conducted with four species of freshwater animals, and conflicting results have been obtained with two of the species. The chronic value for Daphnia magna is in the range of 358.0 to 912.1  $\mu\text{g/L}$  and the midge chronic value is greater than 380  $\mu\text{g/L}$ . The chronic values for the rainbow trout and fathead minnow seem to be higher.

The green alga, Selenastrum capricornutum, was not affected by 410  $\mu\text{g/L}$ . The EC50s determined with duckweed ranged from 408,000 to 7,492,000  $\mu\text{g/L}$ . Bioaccumulation has been determined with a variety of



freshwater species using  $^{14}\text{C}$ -labeled DEHP. Invertebrate studies resulted in BCFs ranging from 14 for an isopod to 3,600 for an amphipod. Fish bioconcentrated DEHP from 114 to 1,380 times. Fathead minnows showed a wide range of BCFs with a inverse relationship between concentration in water and BCF.

The only data available on the acute toxicity of DEHP to saltwater animals shows that it was not acutely lethal to the harpacticoid copepod, Nitocra spinipes, at 300,000  $\mu\text{g/L}$  nor to larval grass shrimp, Palaemonetes pugio, at 450  $\mu\text{g/L}$ . Survival and development of P. pugio were not affected after 25 to 28 days in DEHP concentrations  $\leq 450 \mu\text{g/L}$ . Ammonia flux from sediments in microcosms was reduced after 30 days at 15.5  $\mu\text{g/L}$  in the summer but not at 58.9  $\mu\text{g/L}$  in the winter. BCFs averaged 89.2 in the winter and 1,420 in the summer for the polychaetes Nucula annulata and Nepturus incisa, 2,659 for the zooplankter Acartia sp., and for molluscs averaged 2,436 for Mytilus edulis, 881 for Pitar morrhuana and 2,560 for Mulinia lateralis. For the fish, Cyprinodon variegatus, the predicted BCF was 637.

#### National Criteria

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater and saltwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of di-2-ethylhexyl phthalate does not exceed 360  $\mu\text{g/L}$  more than once every three years on the average and if the one-hour average concentration does not exceed 400  $\mu\text{g/L}$  more than once every three years on the average.

### Implementation

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

Site-specific criteria may include not only site-specific criterion concentrations (U.S. EPA 1983b), but also site-specific, and possibly pollutant-specific, durations of averaging periods and frequencies of allowed excursions (U.S. EPA 1985b). The averaging periods of "one hour" and "four days" were selected by the U.S. EPA on the basis of data concerning how rapidly some aquatic species react to increases in the concentrations of some aquatic pollutants, and "three years" is the Agency's best scientific judgment of the average amount of time aquatic ecosystems should be provided between excursions (Stephan et al. 1985; U.S. EPA 1985b). However, various species and ecosystems react and recover at greatly differing rates. Therefore, if adequate justification is provided, site-specific and/or pollutant-specific concentrations, durations, and frequencies may be higher or lower than those given in national water quality criteria for aquatic life.

Use of criteria, which have been adopted in state water quality standards, for developing water quality-based permit limits and for designing waste treatment facilities requires selection of an appropriate wasteload allocation model. Although dynamic models are preferred for the application of these

criteria (U.S. EPA 1985b), limited data or other considerations might require the use of a steady-state model (U.S. EPA 1986). Guidance on mixing zones and the design of monitoring programs is also available (U.S. EPA 1985b, 1987).

Table 1. Acute Toxicity of Di-2-ethylhexyl Phthalate to Aquatic Animals

Species	Method <sup>a</sup>	Hardness (mg/L as CaCO <sub>3</sub> )	LC50 or EC50 (µg/L)	Species Mean Acute Value (µg/L)	Reference
<u>FRESHWATER SPECIES</u>					
Hydra, <u>Hydra oligactis</u>	F, M	-	> 89	> 89	Sabourin 1986
Worm, <u>Lumbriculus variegatus</u>	F, M	-	> 89	> 89	Sabourin 1986
Cladocera (< 24 hr), <u>Daphnia magna</u>	S, U	173	11,000	-	LeBlanc 1980
Cladocera (< 24 hr), <u>Daphnia magna</u>	S, M	180	> 304	-	Brown and Thompson 1982
Cladocera, <u>Daphnia magna</u>	S, M	120-250	2,000	4,690	Adams and Heidolph 1985
Amphipod, <u>Gammarus fasciatus</u>	S, M	297	240,000	240,000	Cory et al., Manuscript
Amphipod, <u>Gammarus pseudolimnoides</u>	S, U	-	> 32,000	> 32,000	Sanders et al. 1973; Johnson and Finley 1980; Mayer and Ellerstreck 1986
Widge (3rd and 4th instar), <u>Chironomus plumosus</u>	S, U	270	> 18,000	> 18,000	Mayer and Ellerstreck 1986; Streufert et al. 1980
Widge (2nd instar), <u>Chironomus tentans</u>	S, M	297	2,100	2,100	Cory et al., Manuscript
Coho salmon (fingerling) <u>Oncorhynchus kisutch</u>	S, U	44	> 100,000	> 100,000	Johnson and Finley 1980; Ellerstreck

Table 1. (continued)

Species	Method <sup>a</sup>	Hardness (mg/L as CaCO <sub>3</sub> )	LC50 or EC50 (µg/L)	Species Mean Acute Value (µg/L)	Reference
Rainbow trout (fingerling). <u>Salmo gairdneri</u>	S, U	44	> 100,000	-	Johnson and Finley 1980; Moyer and Ellersieck 1986
Rainbow trout (fingerling). <u>Salmo gairdneri</u>	F, M	46.4	> 19,508	> 19,508	Spehar 1986
Fathead minnow (adult). <u>Pimephales promelas</u>	S, M	45.0	> 1,500,000	-	Horne et al. 1983
Fathead minnow (fingerling). <u>Pimephales promelas</u>	F, U	272	> 1,000	-	Moyer and Ellersieck 1986
Fathead minnow (adult). <u>Pimephales promelas</u>	F, M	44.0	> 1,106,200	> 1,106,200	Horne et al. 1983
Fathead minnow (30 days). <u>Pimephales promelas</u>	F, M	44	> 327	-	Biesinger et al., Manuscript
Channel catfish (fingerling). <u>Ictalurus punctatus</u>	S, U	44	> 100,000	-	Johnson and Finley 1980; Moyer and Ellersieck 1986
Channel catfish (fingerling). <u>Ictalurus punctatus</u>	F, U	272	> 200	> 100,000	Moyer and Ellersieck 1986
Bluegill (fingerling). <u>Lepomis macrochirus</u>	S, U	44	> 100,000	-	Johnson and Finley 1980; Moyer and Ellersieck 1986
Bluegill (young-of-year). <u>Lepomis macrochirus</u>	S, U	28-44	> 770,000	-	Buccafusco et al. 1981
Bluegill (fingerling). <u>Lepomis macrochirus</u>	F, U	272	> 200	> 770,000	Moyer and Ellersieck 1986

Table 1. (continued)

<u>Species</u>	<u>Method<sup>a</sup></u>	<u>Salinity</u> <u>(g/kg)</u>	<u>LC50</u> <u>or EC50</u> <u>(µg/L)</u>	<u>Species Mean</u> <u>Acute Value</u> <u>(µg/L)</u>	<u>Reference</u>
<u>SALTWATER SPECIES</u>					
Herpacticoid copepod (adult). <u>Mitocra spinipes</u>	S, U	7	> 300,000	> 300,000	Linden et al. 1979
Grass shrimp (larva). <u>Polaeomonetes pugio</u>	R, M	17	> 450	> 450	Leightlin et al. 1978
Sheepshead minnow (juvenile). <u>Cyprinodon variegatus</u>	S, U	-	> 550,000	> 550,000	Waltmuller et al. 1981; U.S. EPA 1978

<sup>a</sup> S = static; R = renewal; F = flow-through; M = measured; U = unmeasured.

Table 2. Chronic Toxicity of Di-2-ethylhexyl Phthalate to Aquatic Animals

Species	Test <sup>a</sup>	Hardness (mg/L as CaCO <sub>3</sub> )	Chronic Limits (µg/L) <sup>b</sup>	Chronic Value (µg/L)	Reference
<u>FRESHWATER SPECIES</u>					
Cladoceran, <u>Daphnia magna</u>	LC	270	< 3 <sup>c</sup>	< 3	Mayer and Sanders 1973; Sanders et al. 1973
Cladoceran (< 24 hr), <u>Daphnia magna</u>	LC	180	> 85.6 <sup>d</sup>	> 85.6	Brown and Thompson 1982
Cladoceran, <u>Daphnia magna</u>	LC	240-310	640-1,300	912.1	Adams and Heidolph 1985
Cladoceran, <u>Daphnia magna</u>	LC	300	158-811	358.0	Knowles et al. 1987
Widge (3rd and 4th instar), <u>Chironomus plumosus</u>	LC	270	> 360 <sup>d</sup>	> 360	Streufert et al. 1980
Rainbow trout (embryo, fry), <u>Salmo gairdneri</u>	ELS	270	5-14	8.366	Mehrle and Meyer 1976
Rainbow trout (embryo, fry), <u>Salmo gairdneri</u>	ELS	45.5	> 502 <sup>d</sup>	> 502	Spahr 1986
Fathead minnow, <u>Pimephales promelas</u>	ELS	43.7	23,800-42,400	31,770	Horne et al. 1983

Table 2. (continued)

Acute-Chronic Ratio

<u>Species</u>	<u>Hardness</u> <u>(mg/L as</u> <u>CaCO<sub>3</sub>)</u>	<u>Acute Value</u> <u>(µg/L)</u>	<u>Chronic Value</u> <u>(µg/L)</u>	<u>Ratio</u>
<u>Cladocera,</u> <u>Daphnia magna</u>	180	> 304	> 85.6	-
<u>Widge,</u> <u>Chironomus plumosus</u>	270	> 18,000	> 360	-
<u>Rainbow trout,</u> <u>Salmo gairdneri.</u>	45.5	> 19,508	> 502	-
<u>Fathead minnow,</u> <u>Pimephales promelas</u>	44-45	> 1,106,200	31,770	> 34.82

<sup>a</sup> LC = life-cycle or partial life-cycle; ELS = early life-stage.

<sup>b</sup> Measured concentrations of DEMP.

<sup>c</sup> Unacceptable effects occurred at all concentrations tested.

<sup>d</sup> The highest concentration tested did not cause an unacceptable effect.



Table 3. Toxicity of Di-2-ethylhexyl Phthalate to Aquatic Plants

<u>Species</u>	<u>Hardness</u> <u>(mg/L as</u> <u>CaCO<sub>3</sub>)</u>	<u>Duration</u> <u>(days)</u>	<u>[Effect]</u>	<u>Concentration</u> <u>(µg/L)</u>	<u>Reference</u>
<u>FRESHWATER SPECIES</u>					
Green alga.	-	5	EC50	> 410	Richter 1982
<u>Selenastrum capricornutum</u>					
Duckweed,	331.9	7	EC50	2,060,000	Davis 1981
<u>Lemna gibba</u>					
<u>SALTWATER SPECIES</u>					
Diatom,	-	4	EC50	31,000,000	Wilson et al. 1978
<u>Gymnodinium breve</u>					

Table 4. Bioaccumulation of Di-2-ethylhexyl Phthalate by Aquatic Organisms

Species	Concentration in Water ( $\mu\text{g}/\text{l}$ ) <sup>a</sup>	Duration (days)	Tissue	Percent lipids	BCF or BAF <sup>b</sup>	Normalized BCF or BAF <sup>c</sup>	Reference
<u>FRESHWATER SPECIES</u>							
Cladoceran (< 24 hr). <u>Daphnia magna</u>	2.20	21	Whole body	-	241	-	Brown and Thompson 1982
Cladoceran (< 24 hr). <u>Daphnia magna</u>	7.35	21	Whole body	-	190	-	Brown and Thompson 1982
Cladoceran (< 24 hr). <u>Daphnia magna</u>	25.3	21	Whole body	-	330	-	Brown and Thompson 1982
Cladoceran (< 24 hr). <u>Daphnia magna</u>	85.6	21	Whole body	-	313	-	Brown and Thompson 1982
Isopod, <u>Asellus brevicaudus</u>	1.9	21	Whole body	-	14 <sup>d</sup>	-	Sanders et al. 1973
Isopod, <u>Asellus brevicaudus</u>	62.3	21	Whole body	-	50 <sup>d</sup>	-	Sanders et al. 1973
Amphipod, <u>Gammarus pseudolimnoides</u>	0.1	14	Whole body	-	3,600 (2,680 <sup>d</sup> )	-	Mayer and Sanders 1973; Mayer et al. 1972; Sanders et al. 1973
Amphipod, <u>Gammarus pseudolimnoides</u>	62.8	21	Whole body	-	52 <sup>d</sup>	-	Sanders et al. 1973
Widge (3rd and 4th instar). <u>Chironomus plumosus</u>	0.2	7	Whole body	-	408	-	Streufert et al 1980

Table 4. (continued)

Species	Concentration in Water ( $\mu\text{g/L}$ ) <sup>a</sup>	Duration (days)	Tissue	Percent Lipids	BCF or BAF <sup>b</sup>	Normalized BCF or BAF <sup>c</sup>	Reference
Fathead minnow, <u>Pimephales promelas</u>	1.9	28	Whole body	-	1,380	-	Mayer and Sanders 1973
Fathead minnow (7.5 mo), <u>Pimephales promelas</u>	1.9-62	56	Whole body	-	155-886	-	Mayer 1976; Mehrlie and Meyer 1976
Bluegill (juvenile), <u>Lepomis macrochirus</u>	5.82	42	Whole body	-	114	-	Barrons et al. 1980
<u>SALTWATER SPECIES</u>							
Blue mussel (adult), <u>Mytilus edulis</u>	4.1	28	Soft tissues	-	2,366	-	Brown and Thompson 1982
Blue mussel (adult), <u>Mytilus edulis</u>	42.1	28	Soft tissues	-	2,627	-	Brown and Thompson 1982

<sup>a</sup> Based on measured concentration of <sup>14</sup>C-labeled DHP.<sup>b</sup> Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of <sup>14</sup>C in water and in tissue (see text)<sup>c</sup> When possible, the factor was normalized to 1% lipids by dividing the BCF or BAF by the percent lipids.<sup>d</sup> Converted to wet weight basis

Table 5. Other Data on Effects of Di-2-ethylhexyl Phthalate on Aquatic Organisms

Species	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Concentration (µg/L)	Reference
<u>FRESHWATER SPECIES</u>					
Green alga, <u>Chlorocella fusca</u>	-	24 hr	BCF=5,400	50	Geyer et al. 1981, 1984
Green alga, <u>Selenastrum capricornutum</u>	-	2 hr	Reduced fluorescence	410	Richter 1982
Cladoceran, <u>Daphnia magna</u>	270	7 days	BCF=420 (BCF=1,040 <sup>o</sup> )	0.3	Mayer and Sanders 1973; Sanders et al. 1973
Cladoceran, <u>Moina macrocarpa</u>	-	3 hr	No effect	Water solubility	Yoshioka et al. 1986
Mayfly (nymph), <u>Hexagenia bilineata</u>	270	7 days	BCF=575 (BCF=460 <sup>o</sup> )	0.1	Mayer and Sanders 1973; Sanders et al. 1973
Widge (larva), <u>Chironomus plumosus</u>	270	7 days	BCF=350 (BCF=620 <sup>o</sup> )	0.3	Mayer and Sanders 1973; Sanders et al. 1973
Rainbow trout (eyed embryo, fingerling), <u>Salmo gairdneri</u>	-	90 days	Reduced collagen in backbone	14	Mayer et al. 1977
Brook trout (adult), <u>Salvelinus fontinalis</u>	-	150 days	Reduced collagen in backbone	3.7	Mayer et al. 1977

Table 5. (continued)

<u>Species</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Concentration (µg/L)</u>	<u>Reference</u>
Goldfish, <u>Carassius auratus</u>	-	10 min	Decreased heart rate	200,000	Pfuderer and Francis 1975; Pfuderer et al. 1975
Fathead minnow (7.5 mo), <u>Pimephales promelas</u>	270	56 days	Did not reduce survival or growth	62	Mehrle and Mayer 1976
Fathead minnow (fingertling, adult), <u>Pimephales promelas</u>	-	127 days	Reduced collagen in backbone	11	Mayer et al. 1977

Table 5. (continued)

<u>Species</u>	<u>Solinity (g/kg)</u>	<u>Duration</u>	<u>Effect</u>	<u>Concentration (µg/l)</u>	<u>Reference</u>
<u>SALTWATER SPECIES</u>					
Benthic nitrifiers	-	30 days	Reduced ammonia flux from sediments in summer	15.5	Perez et al. 1983
Benthic nitrifiers	-	30 days	No effect on ammonia flux in winter	58.9	Perez et al. 1983
Polychaete, <u>Nucula annulata</u>	-	30 days	BCF = 133 (winter)	0.575 to 58.9	Perez et al. 1983
Polychaete, <u>Nucula annulata</u>	-	30 days	BCF = 2,000 (summer)	0.186 to 15.5	Perez et al. 1983
Polychaete, <u>Nephtys incisa</u>	-	30 days	BCF = 45 (winter)	0.575 to 58.9	Perez et al. 1983
Polychaete, <u>Nephtys incisa</u>	-	30 days	BCF = 835 (summer)	0.186 to 15.5	Perez et al. 1983
Mollusk, Venus, <u>Pitar morrhuana</u>	-	30 days	BCF = 881	0.186 to 58.9	Perez et al. 1983
Clam, <u>Mytilus lateralis</u>	-	30 days	BCF = 2,506	0.186 to 58.9	Perez et al. 1983
Crustacean, shrimp (area to post-larvae), <u>Callinectes sapidus</u>	17	25 to 28 days	No effect on survival or growth	450	Laughlin et al. 1978

Table 5. (continued)

<u>Species</u>	<u>Solubility (g/kg)</u>	<u>Duration</u>	<u>Effect</u>	<u>Concentration (µg/L)</u>	<u>Reference</u>
Gross shrimp (zoea to post-larve). <u>Palaeomonetes pugio</u>	17	25 to 28 days	DHP not detected in tissues ≤ 2 mg/kg	62 to 450	Loughlin et al. 1978
Sheepshead mignon. <u>Cyprinodon variegatus</u>	10	4 days	Predicted steady-state BCF = 637	Variable	Karara and Mayton 1984

<sup>a</sup> Converted to wet weight basis.

## REFERENCES

Adams, W.J. and B.B. Heidolph. 1985. Short-cut chronic toxicity estimates using Daphnia magna. In: Aquatic toxicology and hazard assessment: Seventh symposium. Cardwell, R.D., R. Purdy and R.C. Bahner (Eds.). ASTM STP 854. American Society for Testing and Materials. Philadelphia, PA. pp. 87-103.

Atlas, E. and C.S. Giam. 1981. Global transport of organic pollutants: Ambient concentrations in the remote marine atmosphere. *Science* 211:163-165.

Barrows, M.E., S.R. Petrocelli, K.J. Macek and J.J. Carroll. 1980. Bioconcentration and elimination of selected water pollutants by bluegill sunfish (Lepomis macrochirus). In: Dynamics, exposure and hazard assessment of toxic chemicals. Hague, R. (Ed.). Ann Arbor Science, Ann Arbor, MI. pp. 379-392.

Biddinger, G.R. and S.P. Gloss. 1984. The importance of trophic transfer in the bioaccumulation of chemical contaminants in aquatic ecosystems. *Residue Rev.* 91:104-145.

Biesinger, K.E., D.L. DeFoe and D.E. Hammermeister. Manuscript. Solubility and toxicity of eight phthalate esters. U.S. EPA, Duluth, MN.

Birge, W.J., J.A. Black and A.G. Westerman. 1978. Effects of polychlorinated biphenyl compounds and proposed PCB-replacement products on embryo-larval stages of fish and amphibians. PB-290711. National Technical Information Service, Springfield, VA.



Birge, W.J., J.A. Black and D.M. Bruser. 1979. Toxicity of organic chemicals to embryo-larval stages of fish. PB80-101637 or EPA-560/11-79-007. National Technical Information Service, Springfield, VA.

Black, J.A. and W.J. Birge. 1980. An avoidance response bioassay for aquatic pollutants. PB80-180490. National Technical Information Service, Springfield, VA.

Brown, D. and R.S. Thompson. 1982. Phthalates and the aquatic environment: Part I. The effect of di-2-ethylhexyl phthalate (DEHP) and di-isodecyl phthalate (DIDP) on the reproduction of Daphnia magna and observations on their bioconcentration. Chemosphere 11:417-428.

Buccafusco, R.J., S.J. Ellis and G.A. LeBlanc. 1981. Acute toxicity of priority pollutants to bluegill (Lepomis macrochirus). Bull. Environ. Contam. Toxicol. 26:446-452.

Burns, B.G., C.J. Musial and J.F. Uthe. 1981. A novel cleanup method for the routine quantitative gas chromatographic determination of trace amounts of di-2-ethylhexyl phthalate in fish lipid. J. Assoc. Off. Anal. Chem. 64:282-286.

Callahan, M.A., M.W. Slimak, N.W. Gabel, I.P. May, C.F. Fowler, J.R. Freed, P. Jennings, R.L. Durfee, F.C. Whitmore, B. Maestri, W.R. Mabey, B.R. Holt and C. Gould. 1979. Water-related environmental fate of 129 priority pollutants. Vol. II. EPA-440/4-79-029b. National Technical Information Service, Springfield, VA. pp. 94-1 to 94-28.

Cary, G.A., G.F. Doebbler, A. Spacie and A.G. Vilkas. Manuscript. Acute and chronic toxicity of di-2-ethylhexyl phthalate and di-n-butyl phthalate to fish and invertebrates. Office of Research and Monitoring, U.S. EPA, Washington, DC.

Corcoran E.F. 1973. Gas-chromatographic detection of phthalic acid esters. Environ. Health Perspect. 3:13-15.

Daniel, J.W. 1978. Toxicity and metabolism of phthalate esters. Clin. Toxicol 13:257-268.

Davies, R.P. and A.J. Dobbs. 1984. The prediction of bioconcentration in fish. Water Res. 18:1253-1262.

Davis, J.A. 1981. Comparison of static-replacement and flow-through bioassays using duckweed Lemna gibba G-3. PB81-187650. National Technical Information Service, Springfield, VA.

DeVault, D.S. 1985. Contaminants in fish from Great Lakes harbors and tributary mouths. Arch. Environ. Contam. Toxicol. 14:587-594.

Dumpert, K. and E. Zietz. 1984. Platanna (Xenopus laevis) as a test organism for determining the embryotoxic effects of environmental chemicals. Ecotoxicol. Environ. Saf. 8:55-74.

Environment Canada. 1983. Guidelines for surface water quality. Vol. 2. Organic chemical substances. Phthalic acid esters. Inland Waters. Water Quality Branch, Ottawa, Canada.

Fishbein, L. and P.W. Albro. 1972. Chromatographic and biological aspects of the phthalate esters. J. Chromatogr. 70:356-412.

Geyer, H., R. Viswanathan, D. Freitag and F. Korte. 1981. Relationship between water solubility of organic chemicals and their bioaccumulation by the alga Chlorella. Chemosphere 10:1307-1313.

Geyer, H., G. Politzki and D. Freitag. 1984. Prediction of ecotoxicological behavior of chemicals: Relationship between n-octanol/water partition coefficient and bioaccumulation of organic chemicals by alga Chlorella. Chemosphere 13:269-284.

Glass, G.E. 1975. Identification of thirty-eight chemical contaminants in Lake Superior lake trout and Lake Huron burbot. U.S. EPA, Duluth, MN.

Graham, P.R. 1973. Phthalate ester plasticizers - Why and how they are used. Environ. Health Perspect. 3:3-12.

Group, E.F., Jr. 1986. Environmental fate and aquatic toxicology studies on phthalate esters. Environ. Health Perspect. 65:337-350.

Heitmuller, P.T., T.A. Hollister and P.R. Parrish. 1981. Acute toxicity of 54 industrial chemicals to sheepshead minnows (Cyprinodon variegatus). Bull. Environ. Contam. Toxicol. 27:596-604.

Henderson, R.J. and J.R. Sargent. 1983. Studies on the effect of di-(2-ethylhexyl) phthalate on lipid metabolism in rainbow trout (Salmo gairdnerii) fed zooplankton rich in wax esters. Comp. Biochem. Physiol. 74C:325-330.

- Hites, R.A. 1973. Phthalates in the Charles and the Merrimack Rivers. *Environ. Health Perspect.* 3:17-21.
- Horne, J.D., M.A. Swirsky, T.A. Hollister, B.R. Oblad and J.H. Kennedy. 1980. Aquatic toxicity studies of five priority pollutants. Report No. 4398. NUS Corporation, Houston, TX.
- Horning, W.B., II, E.L. Robinson and A.C. Petrusek, Jr. 1984. Reduction in toxicity of organic priority pollutants by pilot-scale conventional wastewater treatment process. *Arch. Environ. Contam. Toxicol.* 13:191-196.
- Johnson, B.T. and W. Lulves. 1975. Biodegradation of di-n-butyl phthalate and di-2-ethylhexyl phthalate in freshwater hydrosol. *J. Fish. Res. Board Can.* 32:333-339.
- Johnson, B.T., D.L. Stalling, J.W. Hogan and R.A. Schoettger. 1977. Dynamics of phthalic acid esters in aquatic organisms. In: *Fate of pollutants in air and water environments. Part 2, Chemical and biological fate of pollutants in the environment.* Suffet, I.H. (Ed.). Wiley Interscience, New York, NY. pp. 283-300.
- Johnson, W.W. and M.T. Finley. 1980. Handbook of acute toxicity of chemicals to fish and aquatic invertebrates. Resource Publication 137. U.S. Fish and Wildlife Service, Columbia, MO. p. 65.
- Kaiser, K.L.E. 1977. Organic contaminant residues in fishes from Nipigon Bay, Lake Superior. *J. Fish. Res. Board Can.* 34:850-855.

- Karara, A.H. and W.L. Hayton. 1984. Pharmacokinetic model for the uptake and disposition of di-2-ethylhexyl phthalate in sheepshead minnow Cyprinodon variegatus. Aquat. Toxicol. 5:181-195.
- Karara, A.H., W.L. Hayton and B.G. Archer. 1984. A separation and purification procedure for [ $C^{14}$ ] diethylhexyl phthalate in fish. J. Anal. Toxicol. 8:141-145.
- Knowles, C.O., M.J. McKee and D.U. Palawski. 1987. Chronic effects of di-2-ethylhexyl phthalate on biochemical composition, survival and reproduction of Daphnia magna. Environ. Toxicol. Chem. 6:201-208.
- Larsson, P. and A. Thuren. 1987. Di-2-ethylhexylphthalate inhibits the hatching of frog eggs and is bioaccumulated by tadpoles. Environ. Toxicol. Chem. 6:417-422.
- Laughlin, R.B., Jr., J.M. Neff, Y.C. Hsung, T.C. Goodwin and C.S. Giam. 1978. The effects of three phthalate esters on the larval development of the grass shrimp Palaemonetes pugio (Holthuis). Water Air Soil Pollut. 9:323-336.
- LeBlanc, G.A. 1980. Acute toxicity of priority pollutants to water flea (Daphnia magna). Bull. Environ. Contam. Toxicol. 24:684-691.
- Lech, J. and M. Melancon. 1980. Uptake, metabolism, and deposition of xenobiotic chemicals in fish. PB81-135329 or EPA-600/3-80-082. National Technical Information Service, Springfield, VA.

Leyder, F. and P. Boulanger. 1983. Ultraviolet absorption, aqueous solubility, and octanol-water partition for several phthalates. Bull. Environ. Contam. Toxicol. 30:152-157.

Linden, E., B.E. Bengtsson, O. Svanberg and G. Sundstrom. 1979. The acute toxicity of 78 chemicals and pesticide formulations against two brackish water organisms, the bleak (Alburnus alburnus) and the harpacticoid Nitocra spinipes. Chemosphere 11/12:843-851.

Lindsay, R.C. 1977. Identity, origin, and development of off-flavors in Great Lakes anadromous fish. Department of Food Science, University of Wisconsin-Madison, Madison, WI.

Mayer, F.L. 1976. Residue dynamics of di-2-ethylhexyl phthalate in fathead minnows (Pimephales promelas). J. Fish. Res. Board Can. 33:2610-2613.

Mayer, F.L., Jr. and M.R. Ellersiech. 1986. Manual of acute toxicity: Interpretation and data base for 410 chemicals and 66 species of freshwater animals. Resource Publication No. 160. U.S. Fish and Wildlife Service, Washington, DC. p. 394.

Mayer, F.L., Jr. and H.O. Sanders. 1973. Toxicology of phthalic acid esters in aquatic organisms. Environ. Health Perspect. 3:153-157.

Mayer, F.L., D.L. Stalling and J.L. Johnson. 1972. Phthalate esters as environmental contaminants. Nature 238:411-413.

Mayer, F.L., P.M. Mehrle and R.A. Schoettger. 1977. Collagen metabolism in fish exposed to organic chemicals. In: Recent advances in fish toxicology.

Tubb, R.A. (Ed.). PB-273500 or EPA-600/3-77-085. National Technical Information Service, Springfield, VA. pp. 31-54.

McCarthy, J.F. and D.K. Whitmore. 1985. Chronic toxicity of di-n-butyl and di-n-octyl phthalate to Daphnia magna and the fathead minnow. Environ. Toxicol. Chem. 4:167-179.

McCarthy, J.F., J.E. Caton, D.K. Whitmore, A.R. Jones, P.T. Singley, M.V. Buchanan, I.R. Rubin, C. Ho and G.B. Hurst. 1985. Support for establishing structure-activity relationship between a series of phthalate esters and toxicity to aquatic organisms. ORNL/TM-9254. National Technical Information Service, Springfield, VA.

Mehrle, P.M. and F.L. Mayer. 1978. Di-2-ethylhexyl phthalate: Residue dynamics and biological effects in rainbow trout and fathead minnows. In: Trace substances in environmental health - X. Hemphill, D.D. (Ed.). University of Missouri, Columbia, MO. pp. 519-524.

Melancon, M.J., Jr. and J.J. Lech. 1978. Distribution and biliary excretion products of di-2-ethylhexyl phthalate in rainbow trout. Drug Metab. Dispos. 4:112-118.

Melancon, M.J., Jr. and J.J. Lech. 1977. Metabolism of di-2-ethylhexyl phthalate by subcellular fractions from rainbow trout liver. Drug Metab. Dispos. 5:29-38.

Melancon, M.J., Jr. and J.J. Lech. 1979. Structural requirements for the inhibition of phthalate ester hydrolysis in rainbow trout by methylenedioxyphenyl compounds. Xenobiotica 9:317-322.

Melancon, M.J., Jr., J. Saybolt and J.J. Lech. 1977. Effect of piperonyl butoxide on deposition of di-2-ethylhexyl phthalate by rainbow trout. *Xenobiotica* 7:633-640.

Metcalf, R.L. 1975. Laboratory model ecosystem evaluation of the chemical and biological behavior of radiolabeled micropollutants. *Environ. Qual. Saf.* 5:141-151.

Metcalf, R.L., G.M. Booth, C.K. Schuth, D.L. Hansen and P. Lu. 1973. Uptake and fate of di-2-ethylhexyl phthalate in aquatic organisms and in a model ecosystem. *Environ. Health Perspect.* 4:27-33.

Morris, R.J. 1970. Phthalic acid in the deep sea jellyfish Atolla. *Nature* (London) 225:1264.

Murray, H.E., L.E. Ray and C.S. Giam. 1981. Analysis of marine sediment, water, and biota for selected organic pollutants. *Chemosphere* 10:1327-1334.

Musial, C.J., J.F. Uthe, G.R. Sirota, B.G. Burns, M.W. Gilgan, V. Zitko and R.A. Matheson. 1981. Di-n-hexyl phthalate (DHP), a newly identified contaminant in Atlantic herring (Clupea harengus harengus) and Atlantic mackerel (Scomber scombrus). *Can. J. Fish. Aquat. Sci.* 38:856-859.

Neely, W.B. 1979. Estimating rate constants for the uptake and clearance of chemicals by fish. *Environ. Sci. Technol.* 13:1506-1510.

Parker, P. (Ed.). 1984. Effects of pollutants on marine organisms. PB-259354. National Technical Information Service, Springfield, VA.



Patty, F.A. (Ed.). 1967. Industrial hygiene and toxicology, 2nd Rev., Vol. 2, Interscience, New York, NY. pp. 1906-1910.

Peakall, D.B. 1975. Phthalate esters: Occurrence and biological effects. Residue Rev. 54:1-41.

Perez, K.T., E.W. Davey, N.F. Lackie, G.E. Morrison, P.G. Murphy, A.E. Somper and D.L. Winslow. 1983. Environmental assessment of a phthalate ester, di(2-ethylhexyl) phthalate (DEHP), derived from a marine microcosm. In: Aquatic toxicology and hazard assessment: Sixth symposium. Bishop, W.E., R.D. Cardwell and B.B. Heidolph (Eds.). ASTM STP 802. American Society for Testing and Materials, Philadelphia, PA. pp. 180-191.

Peterson, J.C. and D.H. Freeman. 1982. Phthalate ester concentration variations in dated sediment cores from the Chesapeake Bay. Environ. Sci. Technol. 16:464-469.

Pfuderer, P. and A.A. Francis. 1975. Phthalate esters: Heart rate depressors in the goldfish. Bull. Environ. Contam. Toxicol. 13:275-279.

Pfuderer, P., S. Janzen and W.T. Rainey, Jr. 1975. The identification of phthalic acid esters in the tissues of Cyprinodont fish and their activity as heart rate depressors. Environ. Res. 9:215-223.

Pickering, Q.H. 1983. Chronic toxicity to fathead minnow Pimephales promelas of wastewater from a conventional wastewater treatment system receiving organic priority pollutants. Environ. Pollut. 31A:105-117.

- Ray, L.E. and C.S. Giam. 1984. Organic pollutants in Texas coastal waters. Mar. Environ. Res. 14:513-514.
- Ray, L.E., H.E. Murray and C.S. Giam. 1983. Organic pollutants in marine samples from Portland, Maine. Chemosphere 12:1031-1038.
- Richter, J.E. 1982. University of Wisconsin-Superior, Superior, WI.  
(Memorandum to C.E. Stephan, U.S. EPA, Duluth, MN. June 30.)
- Sabourin, T.D. 1986. Battelle Memorial Research Institute, Columbus, OH.  
(Memorandum to L.T. Brooke, University of Wisconsin-Superior, Superior, WI, September 5.)
- Sanders, H.O., F.L. Mayer, Jr. and D.F. Walsh. 1973. Toxicity, residue dynamics, and reproductive effects of phthalate esters in aquatic invertebrates. Environ. Res. 8:84-90.
- Silvo, O.E.J. 1974. Preliminary studies on the acute toxicity of dioctylphthalate (DOP) to rainbow trout (Salmo gairdneri Richardson) and its effects on the phytoplankton and oxygen content of the water. Suom. Kalatalous 47:19-25.
- Sodergren, A. 1982. Significance of interfaces in the distribution and metabolism of di-2-ethylhexyl phthalate in an aquatic laboratory model ecosystem. Environ. Pollut. 27A:263-274.
- Spehar, R.L. 1986. U.S. EPA, Duluth, MN. (Memorandum to D.J. Call, University of Wisconsin-Superior, Superior, WI. September 16.)

Stalling, D.L., J.W. Hogan and J.L. Johnson. 1973. Phthalate ester residues - their metabolism and analysis in fish. Environ. Health Perspect. 3:159-173.

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85-227049. National Technical Information Service, Springfield, VA.

Stephenson, R.R. 1983. Effects of water hardness, water temperature, and size of test organism on the susceptibility of the freshwater shrimp, Gammarus pulex (L.), to toxicants. Bull. Environ. Contam. Toxicol. 31:459-466.

Streufert, J.M. and H.O. Sanders. 1977. Chronic effects of two phthalic acid esters on midge Chironomus plumosus. Trans. Mo. Acad. Sci. 10-11:297.

Streufert, J.M., J.R. Jones and H.O. Sanders. 1980. Toxicity and biological effects of phthalate esters on midges (Chironomus plumosus); Trans. Mo. Acad. Sci. 14:33-40.

Sugawara, N. 1974. Toxic effect of a normal series of phthalate esters on the hatching of shrimp eggs. Toxicol. Appl. Pharmacol. 30:87-89.

Swain, W.R. 1978. Chlorinated organic residues in fish, water, and precipitation from the vicinity of Isle Royale, Lake Superior. J. Great Lakes Res. 4:398-407.

Thomas, J.A. and S.J. Northrup. 1982. Toxicity and metabolism of monoethylhexyl phthalate and diethylhexyl phthalate: A survey of recent literature. J. Toxicol. Environ. Health 9:141-152.

Thomas, J.A. and M.J. Thomas. 1984. Biological effects of di-(2-ethylhexyl) phthalate and other phthalic acid esters. Crit. Rev. Toxicol. 13:283-317.

Thomas, J.A., T.D. Darby, R.F. Wallin, P.J. Garvin and L. Martis. 1978. A review of the biological effects of di-(2-ethylhexyl) phthalate. J. Toxicol. Appl. Pharmacol. 45:1-27.

U.S. EPA. 1978. Quality criteria for water. PB-283943 or EPA-440/9-76-023. National Technical Information Service, Springfield, VA. pp. 191-192.

U.S. EPA. 1978. In-depth studies on health and environmental impacts of selected water pollutants. (Table of data available from C.E. Stephan, U.S. EPA, Duluth, MN.)

U.S. EPA. 1980. Ambient water quality criteria for phthalate esters. EPA-440/5-80-067. National Technical Information Service, Springfield, VA.

U.S. EPA. 1983a. Water quality standards regulation. Federal Regist. 48:51400-51413. November 8.

U.S. EPA. 1983b. Water quality standards handbook. Office of Water Regulations and Standards, Washington, DC.

U.S. EPA. 1985a. Appendix B - Response to public comments on "Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses." Federal Regist. 50:30793-30796. July 29.

U.S. EPA. 1985b. Technical support document for water quality-based toxics control. EPA-440/4-85-032 or PB86-150067. National Technical Information Service, Springfield, VA.

U.S. EPA. 1986. Chapter 1 - Stream design flow for steady-state modeling. In: Book VI - Design conditions. In: Technical guidance manual for performing waste load allocation. Office of Water, Washington, DC. August.

U.S. EPA. 1987. Permit writer's guide to water quality-based permitting for toxic pollutants. EPA-440/4-87-005. Office of Water, Washington, DC.

Veith, G.D., D.L. DeFoe and B.V. Bergstedt. 1979. Measuring and estimating the bioconcentration factor of chemicals in fish. J. Fish. Res. Board Can. 36:1040-1048.

Williams, D.T. 1973. Dibutyl- and di-(2-ethylhexyl) phthalate in fish. J. Agric. Food Chem. 21:1128-1129.

Wilson, W.B., C.S. Giam, T.E. Goodwin, A. Aldrich, V. Carpenter and Y.C. Hrung. 1978. The toxicity of phthalates to the marine dinoflagellate Gymnodinium breve. Bull. Environ. Contam. Toxicol. 20:149-154.

Wofford, H.W., C.D. Wilsey, G.S. Neff, C.S. Giam and J.M. Neff. 1981. Bioaccumulation and metabolism of phthalate esters by oysters, brown shrimp and sheepshead minnows. Ecotoxicol. Environ. Saf. 5:202-210.

Woin, P. and P. Larsson. 1987. Phthalate esters reduce predation efficiency of dragonfly larvae, Odonata; Aeshna. Bull. Environ. Contam. Toxicol. 38:220-225.

Wolfe, N.L., L.A. Burns and W.C. Steen. 1980a. Use of linear free energy relationships and an evaluative model to assess the fate and transport of phthalate esters in the aquatic environment. Chemosphere 9:393-402.

Wolfe, N.L., W.C. Steen and L.A. Burns. 1980b. Phthalate ester hydrolysis: Linear free energy relationships. Chemosphere 9:403-408.

Yoshioka, Y., Y. Ose and T. Sato. 1986. Correlation of the five test methods to assess chemical toxicity and relation to physical properties. Ecotoxicol. Environ. Saf. 12:15-21.

Zitko, V. 1972. Determination, toxicity, and environmental levels of phthalate plasticizers. Technical Report No. 344. Fisheries Research Board of Canada.

Zitko, V. 1973. Determination of phthalates in biological samples. Int. J. Environ. Anal. Chem. 2:241-252.