State of California
The Resources Agency
DEPARTMENT OF FISH AND GAME

HAZARD ASSESSMENT OF THE INSECTICIDE MALATHION TO AQUATIC LIFE IN THE SACRAMENTO-SAN JOAQUIN RIVER SYSTEM

Office of Spill Prevention and Response
Administrative Report 98-2
1998

PREFACE

The California Department of Fish and Game (CDFG) is responsible for the protection and management of fish and wildlife. The CDFG protects fish and wildlife from pesticide hazards through consultation with the California Environmental Protection Agency's Department of Pesticide Regulation (DPR) Pesticide Registration and Evaluation Committee. The State Water Resources Control Board and the Regional Water Quality Control Boards also protect fish and wildlife by promulgating and enforcing water quality standards for pesticides and other toxic materials. In recognition of the need for applicable environmental standards for fish and wildlife, DPR contracted with the CDFG to assess the effects of pesticides on fish and wildlife and to facilitate development of water quality criteria to protect aquatic organisms.

This document is the tenth in a series of pesticide hazard assessments. Hazard assessments have also been prepared for the herbicides molinate and thiobencarb, and for the insecticides methyl parathion, carbofuran, chlorpyrifos, diazinon, methidathion, methomyl, dimethoate, and carbaryl.

Hazard Assessment of the Insecticide Malathion
to Aquatic Organisms in the Sacramento-San Joaquin River System

by

Stella Siepmann and Steven B. Slater
Pesticide Investigations Unit
1701 Nimbus Road, Suite F
Rancho Cordova, California 95670

SUMMARY

Freshwater and saltwater toxicity data for the insecticide malathion were reviewed, and a hazard assessment was performed for California's Sacramento-San Joaquin River system.

Two hundred and seventy-five tests on the acute and chronic toxicity of malathion to aquatic animals were reviewed and evaluated. Invertebrates were more sensitive to malathion than were fish. Eight of the eight required species were available for calculation of a freshwater Final Acute Value (FAV). However, only six of the eight required species were available for calculation of a saltwater FAV. The most acutely sensitive freshwater species tested was the stonefly *Isoperla sp.* with a Genus Mean Acute Value (GMAV) of 0.69 µg/L malathion. The most acutely sensitive saltwater species tested was the mysid *Mysidopsis bahia* with a GMAV of 5.20 µg/L for malathion. The lowest Maximum Acceptable Toxicant Concentration (MATC) for malathion was 5.16 µg/L for the bluegill *Lepomis macrochirus*. No chronic toxicity data for malathion were available for either freshwater or saltwater invertebrates. The freshwater FAV for malathion was 0.86 µg/L and the interim saltwater FAV for malathion was 0.67 µg/L. The lack of chronic toxicity data for invertebrates to malathion prevented the calculation of a Final Acute-Chronic Ratio (FACR) and thus, saltwater and freshwater Final Chronic Values (FCV).

Freshwater organisms should not be affected unacceptably if the one-hour average concentration of malathion does not exceed the Criterion Maximum Concentration (CMC) of 0.43 µg/L , which is one-half of the freshwater FAV. Malathion appears to be present periodically in acutely toxic levels in the rice-growing region of the Sacramento Valley during the spring. The CMC was exceeded seven times from April 1990 to June 1996 (DPR 1990-1996) within the Colusa Basin Drain and once in Butte Slough. The CMC has not been exceeded in the San Joaquin River System; the maximum concentration of malathion was 0.28 µg/L in Del Puerta Creek in 1992. Malathion was not detected from 1991 to 1994 in the Sacramento River at Sacramento. Malathion does not appear to pose an acute toxicity hazard to aquatic organisms in the majority of the Sacramento-San Joaquin River system. The lack of chronic toxicity data of invertebrates to malathion prevents an assessment of chronic toxicity in the surface waters of the Sacramento-San Joaquin River System. However, malathion may pose an acute and chronic toxicity hazard to aquatic organisms in the agricultural drains of the rice-growing region of the Sacramento Valley during the spring.

Chronic toxicity data for invertebrates to malathion are necessary to define the FACR and thus, the freshwater and saltwater FCV and Water Quality Criteria. At least one chronic toxicity test on either the cladoceran *Daphnia magna* or the mysid *Mysidopsis bahia* is required. Two additional acute toxicity tests using saltwater species such as the dungeness crab *Cancer magister* and the rotifer *Brachionus plicatilis* are required to determine saltwater criteria using EPA methods. Paired acute and chronic toxicity tests should be conducted on fish and invertebrates to better determine acute-to-chronic ratios. The hazard assessment procedure is an iterative process by which new data are evaluated to refine water quality criteria. A criterion may be generated when chronic data becomes available.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF ABBREVIATIONS

ACR: Acute-to-Chronic Ratio
ASTM: American Society of Testing and Materials
CBD: Colusa Basin Drain
CCC: Criterion Continuous Concentration
CDFG: California Department of Fish and Game
CDHS: California Department of Health Services
CMC: Criterion Maximum Concentration
CVRWQCB: Central Valley Regional Water Quality Control Board
DPR: California Department of Pesticide Regulation
EPA: U.S. Environmental Protection Agency
FACR: Final Acute-to-Chronic Ratio
FAV: Final Acute Value
FCV: Final Chronic Value
FPV: Final Plant Value
FRV: Final Residue Value
GMAV: Genus Mean Acute Value
MATC: Maximum Acceptable Toxicant Concentration
SJR: San Joaquin River
SMAV: Species Mean Acute Value
TID: Turlock Irrigation Drain
USGS: U.S. Geological Survey
WQC: Water Quality Criterion

ACKNOWLEDGMENTS

This assessment was funded by a reimbursable contract (FGR7921ES) with the Department of Pesticide Regulation of the California Environmental Protection Agency. We appreciate the comments on this document from the California Department of Pesticide Regulation, State Water Resources Control Board, and the Central Valley Regional Water Quality Control Board.

INTRODUCTION

The organophosphate insecticide malathion is used on fruit and vegetable crops, ornamentals, rangeland, and stored products (California Department of Pesticide Regulation (DPR) 1995). From 1990 to 1995, the amount of malathion used in California ranged from 716,926 to 1,896,106 pounds per year (Table 1) (DPR 1990-1996).

The U.S. Geological Survey (USGS) took samples of water several times per week from the San Joaquin River (SJR) at Vernalis from January 1991 to April 1994 and found no malathion (detection limit 0.031 μg/L). The Central Valley Regional Water Quality Control Board (CVRWQCB) took approximately 150 samples of water in the SJR system between March 1991 and March 1992. From March 1991 to February 1993, DPR took samples of water twice per week during the winter months at one site on the SJR and performed Langranian sampling when pesticide concentrations began to rise. Data from the CVRWQCB and DPR monitoring programs were pooled (Table 2). DPR and the California Department of Fish and Game (CDFG) have monitored the Colusa Basin Drain, Sacramento Slough, and Butte Slough for rice pesticide concentrations in water since the early 1980s. Results from April 1990 to June 1996 are given in Table 3. The USGS monitored the Sacramento River at Sacramento from May 1991 through April 1994 (detection limit $\leq$0.019) and found no malathion concentrations in water (USGS 1995).

Hazards from malathion to aquatic life in the Sacramento-San Joaquin River system were assessed by comparing expected toxic effects with malathion concentrations detected in the Sacramento-San Joaquin River drainage. The toxic effects of malathion were assessed by evaluating toxicity tests for conformance with specific criteria adapted from the US. Environmental Protection Agency (EPA) and the American Society for Testing and Materials (ASTM). Toxicity tests were rejected if they did not observe certain fundamental procedures, such as maintaining sufficient organism survival in control treatments. The CDFG assessments are based on data from accepted tests and procedures adapted from EPA (1985) guidelines (Appendix A). The U.S. EPA has established a lifetime health advisory of 0.2 mg/L for malathion in drinking water (EPA 1996). The CDFG assessed a malathion aerial application program in South San Francisco Bay inland streams and found no accumulation of malathion in the sediment or biota but several occurrences of acute toxicity to fish as a result of runoff during the rainy season (Finlayson et al. 1982).

Table 1. Malathion use in California 1990-1995[a]

Year	Number of applications	Pounds used
1990	16,801	1,896,106.49
1991	17,417	900,042.55
1992	18,524	792,463.68
1993	16,793	716,926.48
1994	20,036	782,433.65
1995	17,746	826,756.45

[a]California Department of Pesticide Regulation Pesticide Use Reports 1989-1995

Table 2. Concentrations of malathion (µg/L) detected in the San Joaquin River System (SJR), March 1991 through April 1994.

Date	Location[a]	Concentration
3/04/91	TID #3	0.01 [b]
2/17/92	TID #3	0.02 [b]
3/23/92	Orestimba Creek	0.18[c]
3/23/92	Ingram/Hospital Creeks	0.42[c]
5/4/92	Ingram/Hospital Creeks	2.0[c]
5/11/92	Ingram/Hospital Creeks	2.8[c]
5/18/92	Ingram/Hospital Creeks	0.6[c]
3/18/91	SJR at Laird Park	0.06 [c]
4/01/91	SJR at Laird Park	0.05 [c]
3/16/92	SJR at Laird Park	0.08 [b]
3/23/92	SJR at Laird Park	0.01[c]
3/19/91	TID #5	0.01 [b]
4/04/91	TID #5	0.01 [b]
4/23/91-4/26/91	SJR at Fremont Ford Park	0.01 [c]
2/03/92	Del Puerto Ck.	0.01 [b]
2/10/92	Del Puerto Ck.	0.28 [b]
3/23/92	Del Puerto Ck.	0.01[c]
2/17/92	TID #6	0.01 [b]
3/16/92	Salt Slough at HWY 165	0.16 [b]
3/16/92	SJR at Hills Ferry Rd.	0.16 [b]
5/11/92	Stanislaus River	0.01 [b]

[a] These and other locations were sampled 1991-1994. Only the dates on which malathion were detected are listed
[b] Unpublished DPR data

[c]Central Valley Regional Water Quality Control Board (CVRWQCB) 1995

Table 3. **Concentrations of malathion (µg/L) detected in the Colusa Basin Drain, Sacramento Slough, and Butte Slough**

Date	Location	Concentration
6/27/95	Butte Slough	0.639
5/24/90	CBD#1	0.59
6/2/90	CBD#1	0.12
6/4/90	CBD#1	0.15
5/27/91	CBD#1	0.11
5/20/91	CBD#5	0.05
5/27/91	CBD#5	0.12, 0.20[a]
5/30/91	CBD#5	0.20[b]
6/18/92	CBD#5	0.1[a]
5/31/93	CBD#5	0.15
5/22/94	CBD#5	0.05
5/30/94	CBD#5	0.2
6/2/94	CBD#5	0.07
6/6/94	CBD#5	0.08
6/9/95	CBD#5	0.32
5/16/95	CBD#5	1.033
5/18/95	CBD#5	0.245
4/23/96	CBD#5	0.990
4/25/96	CBD#5	0.856
5/14/96	CBD#5	0.594
5/23/96	CBD#5	0.368
5/28/96	CBD#5	6.00
6/4/96	CBD#5	0.125
6/6/96	CBD#5	0.684
6/27/96	CBD#5	0.06
5/16/91	Sacramento Slough	0.30[b]
5/23/93	Sacramento Slough	0.08
5/27/93	Sacramento Slough	0.10

[a] Unpublished DPR data 1990-96
[b]Analysis by CDFG laboratory

ENVIRONMENTAL FATE

The water solubility of malathion is 125 mg/L at a temperature of 25° C (Farm Chemicals Handbook 1997). Malathion soil adsorption is relatively low, with a soil adsorption coefficient (K_{oc}) of 291 cm^3/g (Johnson 1991). The aerobic $t_{1/2}$ of malathion is 2 days and the anaerobic $t_{1/2}$ is 30 days (Johnson 1991). Hydrolysis $t_{1/2}$ is 6 days at 25°C and pH 7 (DPR 1994). The high water solubility and low K_{oc} of malathion indicate that the chemical has the potential to be carried in field runoff water or to leach to groundwater (Johnson 1991).

TOXICITY TO AQUATIC ORGANISMS

Acute Toxicity to Aquatic Animals

Two hundred and seventy-one tests on the acute toxicity of malathion to aquatic animals were evaluated (Appendix B). One hundred and seventeen of these tests were accepted (Appendix B-1) and one hundred and fifty-four were not accepted (Appendix B-2).

EPA (1985) guidelines recommend eight families of freshwater organisms for which acceptable data should be available for deriving a freshwater Final Acute Value (FAV) (Table 4). Acceptable data were available for all of the recommended eight freshwater families. Genus Mean Acute Values (GMAV) were calculated using data from accepted acute toxicity tests and were ranked in ascending order (Table 6). The freshwater GMAVs for malathion ranged from 0.69 µg/L, the 96-h LC_{50} value for the stonefly *Isoperla sp*. to 34,500 µg/L, the 96-h LC_{50} value for the rotifer *Brachionus sp.* Usually the four lowest GMAVs are the most significant determinants of the FAV. For malathion, the lowest for GMAVs for freshwater organisms were for the stonefly *Isoperla sp*., amphipod *Gammarus fasciatus,* copepod *Eucyclops sp.*, and caddisfly *Limnephilus sp*. The freshwater FAV for malathion was 0.86 µg/L.

Of the eight recommended families for calculation of a saltwater WQC, toxicity data were available for six of the eight families (Table 5). GMAVs were calculated using data from accepted acute toxicity tests and are ranked in ascending order (Table 7). The four lowest GMAVs for saltwater organisms were for mysid *Mysidopsis bahia*, the shrimp *Penaeus duorarum*, the longnose killifish *Fundulus similis*, and spot *Leiostomus xanthurus*. The interim saltwater FAV for malathion was 0.67 µg/L.

Table 4. Eight families of freshwater aquatic animals recommended by EPA (1985) for use in deriving the freshwater FAV and representative species for which malathion acute toxicity data were available.

Family	Available species
1. One Salmonid	Rainbow Trout
2. Another family in class Osteichthyes	Bluegill
3. Another family in phylum Anthropoda or Chordata	Fathead minnow
4. One family not in phylum Anthropoda or Chordata	Rotifer
5. One insect family or any phylum not already represented	Midge
6. One planktonic crustacean	Cladoceran
7. One benthic crustacean	Amphipod
8. One insect	Stonefly

Table 5. Eight families of saltwater aquatic animals recommended by EPA (1985) for use in deriving the saltwater FAV and representative species for which malathion acute toxicity data were available.

Family	Available Species
1,2. Two families in phylum Chordata	Longnose killifish Striped mullet
3. One family not in phylum Anthropoda or Chordata	Eastern oyster
4, 5, 6. Three other families not in phylum Chordata	Blue crab Pink shrimp N/A[a]
7. A mysid or penaeid	Mysid
8. One other family not already represented	N/A[a]

[a]Not available

Table 6. Ranked Genus Mean Acute Values (GMAV) and Species Mean Acute Values (SMAV) from accepted acute toxicity tests with freshwater species to malathion used to calculate the freshwater Final Acute Value (FAV).

Rank	GMAV µg/L	Organisms	Species
1	0.69	Stonefly	*Isoperla sp.*
2	0.70	Amphipod	*Gammarus fasciatus*[a]
3	1.0	Copepod	*Eucyclops sp.*
4	1.3	Caddisfly	*Limnephilus sp.*
5	1.3[a]	Cladoceran	*Daphnia magna* (SMAV = 1.0 µg/L) *Daphnia pulex* (SMAV = 1.8 µg/L)
6	1.7	Mysid	*Neomysis mercedis*[a]
7	2.0	Cladoceran	*Alonella sp.*
8	2.0	Ostracod	*Cypria sp.*
9	2.0	Copepod	*Diaptomus sp.*
10	2.3	Cladoceran	*Simocephalus serrulatus*[a]
11	2.8	Stonefly	*Claassenia sabulosa*
12	3.9	Stonefly	*Pteronarcella badia*[a]
13	5.0	Caddisfly	*Hydropsyche sp.*
14	10	Damselfly	*Lestes congener*
15	10	Stonefly	*Pteronarcys californica*
16	33	Prawn	*Palaemonetes kadiakensis*[a]
17	36	Striped bass	*Morone saxatilis*[a]
18	47	Ostracod	*Cypridopsis vidua*
19	64	Walleye	*Stizostedion vitreum*
20	83	Sunfish	*Lepomis macrochirus*[a] (SMAV = 57 µg/L) *Lepomis cyanellus*[b] (SMAV = 163 µg/L) *Lepomis microlophus* (SMAV = 62 µg/L)
21	101	Trout (Old World)	*Salmo trutta*
22	114	Char	*Salvelinus fontinalis*[a] (SMAV = 125 µg/L) *Salvelinus namaycush*[a] (SMAV = 104 µg/L)
23	160	Mussel	*Anodonta anatina* (SMAV = 80 µg/L) *Anodonta cygnea* (SMAV = 310 µg/L)
24	180	Crayfish (early instar)	*Orconectes nais*
25	200	Chorus frog	*Pseudacris triseriata*
26	200	Trout (New World)	*Onchorhynchus kisutch*[a] (SMAV = 200 µg/L) *Onchorhynchus clarki*[a] (SMAV = 216 µg/L) *Onchorhynchus mykiss*[a] (SMAV = 208 µg/L)
27	263	Perch	*Perca flavescens*
28	267	Bass	*Micropterus salmoides*[a]

29	349	Flagfish	*Jordanella floridae*
30	385	Snipefly	*Atherix variegata*

Table 6. (continued) Ranked Genus Mean Acute Values (GMAV) and Species Mean Acute Values (SMAV) from accepted acute toxicity tests with freshwater species to malathion used to calculate the freshwater FAV.

Rank	GMAV µg/L	Organisms	Species
31	420	Fowlers toad	*Bufo fowleri woodhousei*
32	2,200	Tilapia	*Tilapia mossambica*[a]
33	3,000	Isopod	*Asellus brevicaudus*
34	6,590	Carp	*Cyprinus carpio*
35	8,267	Catfish	*Ictalurus punctatus*[a]
36	9,140	Squawfish	*Ptychocheilus lucius*
37	>10,000	Crayfish (adult)	*Orconectes nais*
38	10,600	Planarian	*Dugesia dorotocephala*[a]
39	10,700	Goldfish	*Carassius auratus*
40	11,000	Fathead minnow	*Pimephales promelas*[a]
41	12,300	Bullhead	*Ameiurus melas*[a]
42	15,300	Bonytail	*Gila elegans*
43	34,500	Rotifer	*Brachionus calyciflorus* (SMAV = 33,720 µg/L) *Brachionus rubens* (SMAV = 35,300 µg/L)

[a]GMAV based on a geometric mean of more than one EC_{50} or LC_{50} for this species.

Table 7. Ranked Genus Mean Acute Values (GMAV) and Species Mean Acute Value (SMAV) from accepted acute toxicity tests on saltwater species with malathion used to calculate saltwater Final Acute Value (FAV).

Rank	GMAV µg/L	Organisms	Species
1	5	Mysid	*Mysidopsis bahia*[a]
2	12[a]	Shrimp	*Penaeus duorarum*[a]
3	150	Killifish	*Fundulus similis*
4	320	Spot	*Leiostomus xanthurus*
5	330	Striped mullet	*Mugil cephalus*
6	>1,000	Crab	*Callinectes sapidus*
7	>1,000	Oyster	*Crassostrea virginica*[a]

[a]GMAV based on a geometric mean of more than one EC_{50} or LC_{50} for this species.

Chronic Toxicity to Aquatic Animals

Four tests on the chronic toxicity of malathion to fish were evaluated (Appendix C). Three of these tests were accepted (Table C-1). The lowest Maximum Acceptable Toxicant Concentration value (MATC) for malathion was 5.16 µg/L for the bluegill *Lepomis macrochirus* (Table 8). There are no data available on the chronic toxicity of malathion to invertebrates.

The EPA (1985) guidelines specify calculating the Acute-to-Chronic Ratio (ACR) for a species using the geometric mean of LC_{50} values for the numerator and the geometric mean of MATC values for the denominator. Freshwater or saltwater Final ACR values are derived using ACR values of both freshwater and saltwater species, including at least a fish, an invertebrate, and an acutely sensitive species. With organophosphates and carbamates, the acutely sensitive species is usually an invertebrate. The FACR value used to derive a freshwater Final Chronic Value (FCV) should include an acutely sensitive freshwater species. The other species used may be either freshwater or saltwater. For malathion, chronic values were available for three freshwater fish, bluegill *Lepomis macrochirus,* bonytail *Gila elegans,* and Colorado squawfish *Ptychocheilus lucius,* but no invertebrates. None of these species are considered to be an acutely sensitive species. Thus, no FACR can be calculated.

Table 8. Acute-to-Chronic Ratios (ACR) of accepted tests.

Organism	Species	ACR
Colorado squawfish	*Ptychocheilus lucius*	9,140/2,428 = 3.76
Bonytail	*Gila elegans*	15,300/1407.12 = 10.87
Bluegill	*Lepomis macrochirus*	64.64 / 5.16 = 12.53

HAZARD ASSESSMENT

Water Quality Criteria

The EPA guidelines specify that a WQC consist of two concentrations, the Criterion Maximum Concentration (CMC) to protect against acute toxicity and the Criterion Continuous Concentration (CCC) to protect against chronic toxicity. The CMC is equal to one-half the FAV. The CCC is equal to the lowest of three values: the FCV, the Final Plant Value (FPV), or the Final Residue Value (FRV) (Appendix A). The FRV is intended to prevent pesticide concentrations in commercially or recreationally important species from affecting marketability because of excedence of applicable action levels and to protect wildlife that consume aquatic organisms (EPA 1985). Malathion does not appear to bioconcentrate to a significant degree (DPR 1994). Therefore, no FRV was calculated. No plant studies were found for malathion. However, as aquatic animals are generally more sensitive to insecticides than are aquatic plants, it is likely that criteria protective of aquatic animals will also be protective of aquatic plants.

The CMC for malathion is 0.43 µg/L for freshwater and the interim CMC is 0.34 µg/L for saltwater. A final CMC may be calculated for saltwater when data for the remaining two EPA (1985) categories are available. The FCV for either freshwater or saltwater organisms could not be calculated because no chronic toxicity data for invertebrates or a FACR were available. Thus, a CCC could not be calculated for either freshwater or saltwater.

Hazard to Aquatic Animals

During monitoring of the San Joaquin River from March 1991 through February 1993, the CMC for malathion was not exceeded (Table 2). Malathion was not detected in the Sacramento River at Sacramento from May 1991 through April 1994 or in the San Joaquin River at Vernalis from January 1991 through April 1994 (USGS 1995). Therefore, malathion does not appear to pose an acute hazard to aquatic organisms at these locations. However, malathion appears to be present periodically in acutely toxic levels in the Colusa Basin Drain during the spring. The CMC was exceeded seven times from April 1990 to June 1996 (DPR 1990-1996) within the Colusa Basin Drain. A comparison of detected concentrations with known toxicity data indicates that malathion appears to present an acute hazard to sensitive aquatic organisms in the Colusa Basin Drain and other agricultural drains containing rice return water during the spring months.

The lack of chronic toxicity data on invertebrates to malathion prevents an assessment of chronic toxicity in the surface waters of the Sacramento-San Joaquin System because a CCC can not be calculated.

Data Requirements

At least one chronic toxicity test on an acutely sensitive species, such as the cladoceran *Daphnia magna* or the mysid *Mysidopsis bahia*, is required so a FACR can be calculated. With the FACR, CCC can be calculated for both freshwater and saltwater organisms. Acute toxicity

data were available for six of the eight saltwater families recommended the U.S. EPA (1985) (Table 5). Two additional acute toxicity tests using saltwater species such as the dungeness crab *Cancer magister* and the rotifer *Brachionus plicatilis* are required to determine saltwater criteria using U.S. EPA methods. The FACR should include paired acute and chronic tests for an invertebrate, a fish, and an acutely sensitive species. Paired acute and chronic tests are critical to determine the relationship between acute and chronic toxicity for a given species. Acceptable chronic toxicity data were available for only fish species.

LITERATURE CITED

Ali, A. 1981. Laboratory evaluation of organophosphate and new synthetic pyrethroid insecticides against pestiferous chironomid midges of central Florida. Mosquito News 41(1): 157-161.

Ali, A. and M.S. Mulla. 1980. Activity of organophosphate and synthetic pyrethroid insecticides against pestiferous midges in some California flood control channels. Mosquito News 40(4):593-597.

Al-Khatib, Z.I. 1985. Isolation of an organophosphate susceptible strain of *Culex quinquefasciatus* from a resistant field population by discrimination against esterase-2. Journal of American Mosquito Control Association 1(1):105- 107.

Bahner, L.H. and D.R. Nimmo. 1975. Methods to assess effects of combinations of toxicants, salinity, and temperature on estuarine animals. Trace Substances in Environmental Health 9:169-177.

Bailey, H.C. and D.H.W. Liu. 1980. *Lumbriculus variegatus*, benthic oligochaete, as a bioassay organism. In: J.C. Eaton, P.R. Parish, and A.C. Hendricks (Eds.), Aquatic Toxicology and Hazard Assessment, Third Symposium, ASTM STP 707, Philadelphia, PA:205-215.

Bender, M.E. and J.R. Westman. 1976. The toxicity of malathion and its hydrolysis products to the eastern mudminnow, *Umbra pygmaea* (DeKay). Chesapeake Science 17(2):125-128.

Beyers, D.W. and P.J. Sikoski. 1994. Acetylcholinesterase inhibition in federally endangered Colorado squawfish exposed to carbaryl and malathion. Environmental Toxicology and Chemistry 13(6):935-939.

Beyers, D.W., T.J. Keefe, and C.A. Carlson. 1994. Toxicity of carbaryl and malathion to two federally endangered fishes, as estimated by regression and Anova. Environmental Toxicology and Chemistry 13(1):101-107.

Bhatia, H.L. 1971. Toxicity of some pesticides to *Puntius ticto* (Hamilton). Science and Culture 37(3):160-161.

Bills,T.D. and L.L. Marking. 1988. Control of nuisance populations of crayfish with traps and toxicants. The Progressive Fish Culturist 50:103-106.

Brandt, O.M., R.W. Fujimura, and B.J. Finlayson. 1993. Use of *Neomysis mercedis* (Crustacea: Mysidacea) for estuarine toxicity tests. Transactions of the American Fisheries Society 122:279-288.

California Department of Fish and Game (CDFG). 1988-1990. Acute toxicity tests on *Morone saxatilis*. Aquatic Toxicology Laboratory Test Numbers 1988: 60; 1989: 21, 30, 37, 41, 57. Unpublished.

California Department of Pesticide Regulation (DPR). n.d. Pesticide use report, annual 1990-1994: indexed by chemical. Sacramento, California.

DPR. 1994. Physico-Chemical Properties and Environmental Fate of Pesticides. Sacramento, California.

DPR. 1990-1996. Unpublished Data. Information on Rice Pesticides Submitted to the California Regional Water Quality Control Board Central Valley Region. Sacramento, California.

Carlson, C.A. 1966. Effects of three organophosporus insecticides on immature *Hexagenia* and *Hydropsyche* of the upper Mississippi river. Transactions of the American Fisheries Society 95(1):1-5.

Central Valley Regional Water Quality Control Board. 1995. Insecticide concentrations and invertebrate bioassay mortality in agricultural return water from the San Joaquin basin. Sacramento, California.

Cheah, M.L., J.W. Avault, Jr., and J.B. Graves. 1980. Acute toxicity of selected rice pesticides to crayfish *Procambarus clarkii*. The Progressive Fish Culturist 42(3):169-172.

Chitra, S. And M.K.K. Pillai. 1984. Development of organophosphorus and carbamate-resistance in Indian strains of *Anopheles stephensi* Liston. Indian Academy of Science and Animal Science, Proceedings 93(3):159-170.

Cripe, G.M. 1994. Comparative acute toxicities of several pesticides and metals to *Mysidopsis bahia* and postlarval *Penaeus duorarum*. Environmental Toxicology and Chemistry 13(11):1867-1872.

Cripe, G.M., A. Ingley-Guezou, L.R. Goodman, and J. Forester. 1989. Effect of food availability on the acute toxicity of four chemicals to *Mysidopsis bahia* (*Mysidacea*) in static exposures. Environmental Toxicology and Chemistry 8:333-338.

Desi, I., G. Dura, L. Gonczi, Z. Kneffel, A. Strohmayer, and Z. Szabo. 1976. Toxicity of malathion to mammals, aquatic organisms, and tissue culture cells. Archives of Environmental Contamination and Toxicology 3:410-425.

Dutta, H.M., J.S.D. Munshi, P.K. Roy, N.K. Singh, and C.R. Richmonds. 1992. Variation in toxicity of malathion to air and water-breathing teleosts. Bulletin of Environmental Contamination and Toxicology 49:279-284.

Eaton, J.G. 1970. Chronic malathion toxicity to the bluegill (*Lepomis macrochirus* Rafinesque). Water Research 4:673-684.

Eisler, R. 1970. Acute toxicities of organochlorine and organophosphorus insecticides to estuarine fishes. Technical Paper of the Bureau of Sport Fisheries and Wildlife. Technical Paper No. 46.

Farm Chemicals Handbook. 1997. Indexed by chemical.

Fernandez-Casalderry, A., M.D. Ferrando, and E. Andreu-Moliner. 1992. Acute toxicity of several pesticides to rotifer (*Brachionus calyciflorus*). Bulletin of Environmental Contamination and Toxicology 48:14-17.

Finlayson, B.J., G. Faggella, H. Jong, E. Littrell, and T. Lew. 1982. Impact of fish and wildlife from broadscale aerial malathion applications in south San Francisco Bay region, 1981. California Department of Fish and Game, Environmental Services Branch, Administrative Report 82-2. Sacramento, California.

Freeden, F.J.H. 1972. Reactions of the larvae of three rheophilic species of trichoptera to selected insecticides. The Canadian Entomologist 104:945-953.

Fujimura, R., B. Finlayson, and G. Chapman. 1991. Evaluation of acute and chronic toxicity tests with larval striped bass. Aquatic Toxicology: Fourteenth Volume 193-211.

Gaufin, A.R., L. Jensen, and T. Nelson. 1961. Bioassays determine pesticide toxicity to aquatic invertebrates. Water and Sewage Works 108:355-359.

Gaufin, A.R., L.D. Jensen, A.V. Nebeker, T. Nelson, and R.W. Teel. 1965. The toxicity of ten organic insecticides to various aquatic invertebrates. Water and Sewage Works 12:27-279.

Geiger, D.L., D.J. Call, and L.T. Brooke. 1988. Acute toxicities of organic chemicals to fathead minnows (*Pimephales promelas*). Center for Lake Superior Environmental Studies, University of Wisconsin, Superior. Volume 4. pp. 235- 236.

Goodman, L.R., G.M. Cripe, P.H. Moody, and D.G. Halsell. 1988. Acute toxicity of malathion, tetrabromobisphenol-a, and tributyltin chloride to mysids (*Mysidopsis bahia*) of three ages. Bulletin of Environmental Contamination and Toxicology 41:746-753.

Haider, S. and R.M. Inbaraj. 1986. Relative toxicity of technical material and commercial formulation of malathion and endosulfan to a freshwater fish, *Channa punctatus* (Bloch). Ecotoxicology and Environmental Safety 11:347- 351.

Hansen, C.R. and J.A. Kawatski. 1976. Application of 24-hour postexposure observation to acute toxicity studies with invertebrates. Journal of the Fisheries Resource Board, Canada 33:1198-1201.

Hermanutz, R.O. 1978. Toxicity of endrin and malathion mixtures to flagfish (*Jordanella floridae*). Archives of Environmental Contamination and Toxicology 17:159-168.

Hermanutz, R.O., J.G. Eaton, and L.H. Mueller. 1985. Toxicity of endrin and malathion mixtures to flagfish (*Jordanella floridae*). Archives of Environmental Contamination and Toxicology 14:307-314.

Holck, A.R. and C.L. Meek. 1987. Dose-mortality responses of crawfish and mosquitoes to selected pesticides. Journal of the American Mosquito Control Association 3(3):407-411.

Jacob, S.S., N.B. Nair, and N.K. Balasubramanian. 1982. Toxicity of certain pesticides in the habitat to the larvivorous fishes *Aplocheilus lineatus* (Cuv. and Val.) and *Macropodus cupanus* (Cuv. and Val.). Indian Academy of Science and Animal Science, Proceedings 91(3):323-328.

Jensen, L.D. and A.R. Gaufin. 1964. Long-term effects of organic insecticides on two species of stonefly naiads. Transactions of the American Fisheries Society 93(4):357-363.

Johnson, B. 1991. Setting revised specific numerical values. Department of Pesticide Regulation Environmental Hazards Assessment Program. Document EH 91-6. Sacramento, California.

Khangarot, B.S., A. Shegal, and M.K. Bhasin. 1985. Man and biosphere - studies on the Sikkim Himalayas. Part 6: Toxicity of selected pesticides to the frog tadpole *Rana hexadactyla* (Lesson). Acta Hydrochimica Et Hydrobiologica 13(3):391- 394.

Kimura, T. and H.L. Keegan. 1966. Toxicity of some insecticides and molluscides for the Asian blood sucking leech, *Hirudo nipponia* Whitman. American Journal of Tropical Medicine and Hygiene 15(1):113-115.

Korn, S. and R. Earnest. 1974. Acute toxicity of twenty insecticides to striped bass, *Morone saxatilis*. California Fish and Game 60(3):128-131.

Lewallen, L.L. and W.H. Wilder. 1962. Toxicity of certain organophosphorus and carbamate insecticides to rainbow trout. Mosquito News 22(4):369-372.

Mane, U.H., M.S. Kachole, and S.S. Pawar. 1979. Effect of pesticides and narcotants on bivalve molluscs. Malacologia 18:347-360.

Mayer, F.L. 1970. Chronic toxicity of pesticides to fish. Progress in Sport Fishery Research Resource Publication 106. p.10-15.

Mayer, F.L. 1987. Acute toxicity handbook of chemicals to estuarine organisms. United States Environmental Protection Agency. Environmental Research Laboratory, Gulf Breeze, Florida.

Mayer, F.L. and M.R. Ellersieck. 1986. Manual of acute toxicity: interpretation and database for 410 chemicals and 66 species of freshwater animals. U.S. Department of the Interior, Fish and Wildlife Service, Resource Publication 160. Washington, D.C.

Muncy, R.J. and A.D. Oliver, Jr. 1963. Toxicity of ten insecticides to the red crawfish, *Procambarus clarki* (Girard). Transactions of the American Fisheries Society 92(4):428-431.

Naqvi, S.M.Z. 1977. Toxicity of twenty-three insecticides to a tubificid worm *Branchiura sowerbyi* from the Mississippi Delta. Journal of Economic Entomology 70(4-6):70-74.

Naqvi, S.M. and R.H. Hawkins. 1989. Responses and LC_{50} values for selected microcrustaceans exposed to Spartan, malathion, Sonar, Weedtrine-D, and Oust pesticides. Bulletin of Environmental Contamination and Toxicology 43(3):386-393.

Naqvi, S.M. and R.H. Hawkins. 1987. Toxicity of several insecticides to mosquitofish, Gambusia affinis. Bulletin of Environmental Contamination and Toxicology 40(5):779-784.

Natarajan, E., R.S. Biradar, and J.P. George. 1992. Acute toxicity of pesticides to giant freshwater prawn *Macrobrachium rosenbergii* (De Man). Journal of Aquaculture Trop 7(2):183-187

Parkhurst, Z.E. and H.E. Johnson. 1955. Toxicity of malathion 500 to fall chinook salmon fingerlings. The Progressive Fish Culturist 17(3):113-116.

Perschbacher, P.W. and J. Sarkar. 1989a. Toxicity of selected organophosphorus insecticides to the backswimmer, *Notonecta* sp. Asian Fisheries Science 2:265-268.

Perschbacher, P.W. and J. Sarkar. 1989b. Toxicity of selected pesticides to the snakehead, *Channa punctata*. Asian Fisheries Science 2:249-254.

Pickering, Q.H., C. Henderson, and A.E. Lemke. 1962. The toxicity of organic phosphorus insecticides to different species of warm water fishes. Transactions of the American Fisheries Society 91(2):175-184.

Post, G. and T. Shroeder. 1971. The toxicity of four insecticides to four Salmonid species. Bulletin of Environmental Contamination and Toxicology 6(2):144-155.

Rao, K.V.R., K.S. Rao, I.K.A. Sahib, and S. Sivaiah. 1987. Differential toxicity of methyl parathion and malathion on some selected aquatic species. Proceedings of the National Academy of Science, India 57 (B) IV:367-370.

Rawash, I.A., I.A. Gaaboub, F.M. El-gayar, and A.Y. El-Shazli. 1975. Standard curves for Nuvacron, malathion, Sevin, DDT, and Kelthane tested against the mosquito *Culex pipiens* L. and the microcrustacean *Daphnia magna* Straus. Toxicology 4:133-144.

Rehwoldt, R.E., E. Kelley, and M. Mahoney. 1977. Investigations into the acute toxicity and some chronic effects of selected herbicides and pesticides on several freshwater fish species. Bulletin of Environmental Contamination and Toxicology 18(3):361-365.

Rettich, F. 1977. The susceptibility of mosquito larvae to eighteen insecticides in Czechoslovakia. Mosquito News 37(2): 252-257.

Rettich, F. 1979. Laboratory and field investigations in Czechoslovakia with fenitrothion, pirimiphos-methyl, temephos and other organophosphorous larvicides applied as sprays for control of *Culex pipiens* Molestus Forskal and *Aedes cantans* Meigen. Mosquito News 39(2): 320-328.

Rongsriyam, Y., S. Prownebon, and S. Hirakoso. 1968. Effects of insecticides on the feeding activity of the guppy, a mosquito-eating fish, in Thailand. Bulletin of the World Health Organization 39:977-980

Sahib, I.K.A. and K.V.R. Rao. 1980. Toxicity of malathion to the freshwater fish *Tilapia mossambica*. Bulletin of Environmental Toxicology 24:870-874.

Sailatha, D., I.K.A. Sahib, and K.V.R. Rao. 1981. Toxicity of technical and commercial grade malathion to the fish, *Tilapia mossambica*. Proceedings of the Indian Academy of Sciences 90(1):87-92.

Sanders, H.O. 1970. Pesticide toxicities to tadpoles of the western chorus frog, *Pseudacris triseriata* and fowler's toad *Bufo woodhousii* fowlerii. Copeia 2:246-251.

Sanders, H.O. and O.B. Cope. 1966. Toxicities of several pesticides to two species of cladocerans. Transactions of the American Fisheries Society 95(2):165-169.

Singh, S. and T.P. Singh. 1987. Evaluation of toxicity limit and sex hormone production in response to Cythion and BHC in the vitellogenic catfish *Clarias batrachus*. Environmental Research 42(2):482-488.

Singh, V.P., S. Gupta, and P.K. Saxena. 1984. Evaluation of acute toxicity of carbaryl and malathion to freshwater teleosts, *Channa punctatus* (Bloch) and *Heteropneustes fossilis* (Bloch). Toxicology Letters 20:271-276.

Smith, J.W. and S.G. Grigoropoulos. 1968. Toxic effects of odorous trace organics. American Water Works Association 60(2):969-979.

Snell, T.W. and G. Persoone. 1989. Acute toxicity bioassay using rotifers. A freshwater test with *Brachionus rubens*. Aquatic Toxicology 14(1):79-91.

Strickman, D. 1985. Aquatic bioassay of 11 pesticides using larvae of the mosquito, *Wyeomyia smithii* (Diptera: Culicidae). Bulletin of Environmental Contamination and Toxicology 35:133-142.

Tchounwou, B., A.J. Englande, Jr., and E.A. Malek. 1991. Toxicity evaluation of bayluscide and malathion to three developmental stages of freshwater snails. Archives of Environmental Contamination and Toxicology 21:351-358.

Tchounwou, P.B. and A.J. Englande, Jr. 1992. The effects of bayluscide and malathion on the mortality and infectivity of *Schistosoma mansoni* Cercariae. Environmental Toxicology and Water Quality 7:107-117.

Tietze, N.S., E.T. Shreiber, P.G. Hester, C.F. Hallmon, M.A. Olson, and K.R. Shaffer. 1993. Susceptibility of first instar *Toxorhynchites splendens* to malathion, naled and resmethrin. Journal of American Mosquito Control Association 9(1):97-99.

Toor, H.S., K. Mehta, and S. Chhina. 1973. Toxicity of insecticides (commercial formulations) to the exotic fish, common carp, *Cyprinus carpio* communis linnaeus. Journal of Research 10(3):341-345.

U. S. Environmental Protection Agency (EPA). 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. Office of Research and Development, Washington, D.C.

U.S. EPA. 1996. Drinking water regulations and health advisories. Office of Water. EPA 822-R-96-001.

U.S. Geological Service. 1995. Dissolve pesticide data for the San Joaquin River at Vernalis and the Sacramento River at Sacramento, California, 1991-94. Report 95-110. Sacramento, California.

Varanka, I. 1986. Toxicity of mosquitocides on freshwater mussel larvae. Acta Biologica Hungarica 37(2):143-158.

Venturino, A., L.E. Guana, R.M. Bergoc, and A.M.P. D'Angelo. 1992. Effect of exogenously applied polyamines on malathion toxicity in the toad *Bufo arenarum* Hensel. Archives of Environmental Contamination and Toxicology 22:135-139.

Villar, D., M.H. Li, and D.J. Schaeffer. 1993. Toxicity of organophosphorus pesticides to *Dugesia dorotocephala*. Bulletin of Environmental Contamination and Toxicology 51:80-87.

Whitten, K. and C.J. Goodnight. 1966. Toxicity of some common insecticides to tubificids. Journal of the Water Pollution Control Federation 38(2):227-235.

Wildish, D.J., W.G. Carlson, T. Cuningham, and N.J. Lister. 1971. Toxicological effects of some organophosphate insecticides to Atlantic salmon. Fisheries Research Board of Canada. Manuscript Report Series No. 1157.

Womeldorf, D.F., R.K. Washino, K.E. White, and P.A. Gieke. 1970. Insecticide susceptibility of mosquitoes in California: response of *Anopheles freeborni* aitken larvae to organophosphorus compounds. Mosquito News 30(3): 375-382.

APPENDIX A. Procedures used by the California Department of Fish and Game to prepare hazard assessments.

The California Department of Fish and Game (CDFG) Pesticide Investigations Unit assesses the hazard of pesticides to aquatic organisms. The hazard assessment procedure includes evaluation of toxicity studies, establishment of the Water Quality Criterion (WQC), and assessment of potential hazards.

Acute and chronic toxicity data are obtained from studies published in scientific literature and laboratory reports required in scientific literature and laboratory reports required by the U.S. Environmental Protection Agency for pesticide registration. The CDFG evaluates the quality of these data by evaluating the tests for compliance with standards for test type, method, design and species, and for water quality standards and toxicant monitoring and maintenance. Although a study need not comply with every standard, tests are rejected if they do not observe certain fundamental procedures, or if several important standards are not met. Studies are also rejected if they do not contain sufficient information to be properly evaluated and the necessary information cannot be obtained from the researcher.

Acute toxicity data from acceptable tests on freshwater and saltwater organisms are used to determine a Final Acute Value (FAV). The EPA (1985) guidelines recommend eight categories of freshwater organisms for which data should be available for deriving a freshwater FAV, and eight categories of saltwater organisms for deriving a saltwater FAV.

The FAV is calculated as follows:

1. The Species Mean Acute Value (SMAV) is the geometric mean of EC_{50} values and LC_{50} values from all accepted toxicity tests performed on that species.

2. The Genus Mean Acute Value (GMAV) is the geometric mean of all SMAVs for each genus.

3. The GMAVs are ranked (R) from "1" for the lowest to "N" for the highest. Identical GMAVs are arbitrarily assigned successive ranks.

4. The cumulative probability (P) is calculated for each GMAV as R/(N+1).

5. The four GMAVs with cumulative probabilities closest to 0.05 are selected. If fewer than 5 GMAVs are available, these will always be the four lowest GMAVs.

6. The FAV is calculated using the selected GMAVs and Ps, as follows:

$$S^2 = \frac{3((\ln GMAV)^2)-((3(\ln GMAV))^2/4)}{3(P) - ((3(\%P))^2/4)}$$

$$L = (3(\ln GMAV) - S(3(\%P)))/4$$

$$A = S(\%0.05) + L$$

$$FAV = e^A$$

Chronic toxicity data from acceptable tests on freshwater and saltwater organisms are used to determine a Final Chronic Value (FCV). If data are available for the eight families, the FCV is calculated using the same procedure as described for the FAV. If sufficient data are not available, the following procedure is used:

1. Chronic values are obtained by calculating the geometric mean of the No Effect Observable Effect Concentration (NOEC) and the Lowest Observable Effect Concentration (LOEC) values from accepted chronic toxicity tests.

2. Acute-Chronic Ratios (ACR) are calculated for each chronic value for which at least one corresponding acute value is available. Whenever possible, the acute test(s) should be part of the same study as the chronic test.

3. The Final ACR (FACR) is calculated as the geometric mean of all the species mean ACRs available for both freshwater and saltwater species.

4. FCV = FAV / FACR

Plant toxicity data from algae or aquatic vascular plants are used to determine a Final Plant Value (FPV). The FPV is the lowest result from a test with a biologically important endpoint.

The EPA guidelines specify that a WQC consists of two concentrations, the Criterion Maximum Concentration (CMC), and the Criterion Continuous Concentration (CCC). The CMC is equal to one-half the FAV. The CCC is equal to the lowest of three values: The FCV, the FPV, or the Final Residue Value (FRV). The FRV is intended to prevent pesticide concentrations in recreational or commercially important species from affecting marketability because of excedence of applicable action levels, and to protect important resident species (EPA 1985).

The WQC is stated as follows: (Freshwater / Saltwater) aquatic organisms should not be affected unacceptably if the four-day average concentration of (pesticide) does not exceed (CCC

value), and if the one-hour average concentration does not exceed (CMC value) more than once every three years on the average.

Hazard assessment is an iterative process by which new data are evaluated to refine the WQC. Hazard assessments frequently recommend additional toxicity tests with sensitive native species and commonly used test organisms listed by ASTM.

APPENDIX B. Abstracts of accepted and unaccepted acute toxicity tests reviewed for hazard assessment.

Accepted acute toxicity tests- The following tests used accepted test methods:

Bahner and Nimmo. (1975) - In 1975, a 48-h static acute toxicity test was performed by the U.S. EPA, Environmental Research Laboratory in Gulf Breeze, Florida on technical grade malathion with pink shrimp *Penaeus duorarum.* Four concentrations and a control were tested with 20 organisms per replicate. Water quality parameters during the test were: temperature of 25 ± 2°C and salinity of 20 ± 2°/$_{oo}$. Control survival was 100%. The 96-h LC_{50} value for *P. duorarum* was 12.50 µg/L.

Beyers et al. (1994) - In 1989, a 96-h static acute toxicity test was performed at Colorado State University, Colorado on technical grade malathion (93%) with Colorado squawfish *Ptychocheilus lucius*. Five concentrations and solvent and water controls were used. There were two replicates per treatment with 10 organisms per replicate. Water quality parameters during the test were: temperature of 22°C; pH of 7.9-8.6; dissolved oxygen of 6.1-7.2 mg/L; and hardness of 344-378 mg/L as $CaCO_3$. Control survival was statistically checked with a T-test a = 0.05. The 96-h LC_{50} was 9,140 µg/L, the NOEC was 1,680 µg/L, and the LOEC was 3,510 µg/L.

Brandt et al. (1993) - In 1993, three 96-h static acute toxicity tests were performed on malathion (94.2%) with the neonates of the mysid *Neomysis mercedis.* Five concentrations and solvent and water controls were tested in replicate. Control survival was ≥90%. Water quality parameters during the test were: temperature of 17 ± 0.5° C; pH of 8.2; and a salinity of 2± 1°/$_{oo}$. The 96-h LC_{50} values for *N. mercedis* were 1.4, 1.5, and 2.2 µg/L.

Cripe (1994) - In 1994, a 96-h static acute toxicity test performed by Environmental Research Laboratory, Gulf Breeze, Florida on malathion (99%) was performed with the juvenile mysid *Mysidopsis bahia* and the post-larval pink shrimp *Penaeus duorarum*. Five concentrations and seawater and solvent controls were used. Two replicates per treatment with 10 organisms per replicate were used. Water quality parameters during the test were: temperature of 25°C; pH of 7.8-8.1; salinity of 25%; mean dissolved oxygen of 5.9 mg/L for mysids and 5.6 mg/L for shrimp. Control survival was 95% for both *M. bahia* and *P. dourarum* in seawater and 100% in solvent control. The 96-h LC_{50} was 11 µg/L for *M. bahia* and 12 µg/L for *P. duorarum*.

Cripe et al. (1989) - In 1989, five 96-h static acute toxicity tests were performed by the Environmental Research Laboratory, Gulf Breeze, Florida on malathion (92%) with mysid *Mysidopsis bahia*. Five concentrations and seawater and solvent controls were used. Ten organisms per concentration were used. Water quality parameters during the test

were: temperature of 25^{o}C; pH of 7.8-8.3; dissolved oxygen of 5.9-7.0 mg/L as

$CaCO_3$ and a salinity of 20%. Control survival was >90% in seawater and solvent controls. The 96-h LC_{50} values for *M. bahia* were 3.2, 4.0, 5.0, 5.2, and 5.4 µg/L.

Fernandez-Casalderry et al. (1992) - In 1990, a 24-h static acute toxicity test was performed by the University of Valencia, Spain on malathion (95%) with the rotifer *Brachionus calyciflorus*. Five concentrations of malathion and an acetone control were used. Nine replicates per treatment with approximately 30 organisms per replicate were used. Water quality parameters during the test were: temperature of 25°C; pH of 7.4-7.8; and hardness of 80-100 mg/L as $CaCO_3$. Control survival was 100%. The 24-h LC_{50} for *B. calyciflorus* was 33,720 µg/L.

Fujimura et al. (1991) - In 1988-1989, six 96-h flow-through acute toxicity tests were performed by the California Department of Fish and Game Aquatic Toxicology Laboratory in Elk Grove on malathion (94.2%) with larval striped bass *Morone saxatilis*. Five concentrations of malathion and solvent and water controls were used. Two replicates per treatment with 20 to 25 organisms per replicate were used. Water quality parameters during the test were: temperature of 20°C; pH of 7.8 to 8.2; and salinity of 1-2°/$_{oo}$. Control survival was ≤90%. The 96-h LC_{50} for *M. saxatilis* in 1988 was 12, 16, 25, and in 1989 was 64, 66, and 100 µg/L.

Geiger et al. (1988) - In 1984, a 96-h static acute toxicity test was performed by Lake Superior Center for Environmental Studies, University of Wisconsin-Superior on malathion (95%) with fathead minnow *Pimephales promelas*. Five concentrations and a control were used. Twenty organisms per concentration were used. Water quality parameters during the test were: temperature of 25.1°C; pH of 7.7; dissolved oxygen of 6.8 mg/L; and a hardness of 46.9 mg/L as $CaCO_3$. Control survival was 100%. The 96-h LC_{50} for *P. promelas* was 14,100 µg/L.

Hermanutz (1978) - In 1978, a 96-h flow-through acute toxicity test was performed by Environmental Research Laboratory in Duluth, Minnesota, U.S. E.P.A. on malathion (95%) with flagfish *Jordanella floridae*. Seven concentrations and an acetone control were used. There were 40 organisms per replicate. Water quality parameters were: temperature of 24.4-25.5°C; pH of 7.3-7.6; dissolved oxygen of 95-102% of saturation; and hardness of 41-44 mg/L as $CaCO_3$. The control survival was 100%. The 96-h LC_{50} value for *J. floridae* was 349 µg/L.

Mayer (1987) - From 1961 to 1986, 48-h and 96-h flow-through toxicity tests were performed by the Environmental Research Laboratory of the U.S. E.P.A. in Gulf Breeze, Florida with technical grade malathion (95%) on: pink shrimp *Penaeus duorarum*, blue crab *Callinectes sapidus*, eastern oyster *Crassostrea virginica*, longnose killifish *Fundulus similis*, spot *Leiostomus xanthurus*, and striped mullet *Mugil cephalus*. Four or more concentrations were tested in replicate and acetone controls were used. Water

quality parameters during the tests were: temperature of 17°C for pink shrimp, 30°C for blue crab and eastern oyster, 16°C for eastern oyster, 27°C for longnose killifish, 19°C for spot and striped mullet. The salinity was 19 ppt for pink shrimp, 25 ppt for blue crab, 24 ppt for eastern oyster, 14 ppt for eastern oyster, 19 ppt for longnose killifish, 24 ppt for spot, and 27 ppt for striped mullet. Control survival was acceptable in all tests. The EC_{50} and LC_{50} values are listed in Table B-1.

Mayer and Ellersieck (1986) - From 1965 to 1986, 48-h and 96-h static toxicity tests were performed by the Columbia National Fisheries Laboratory of the U.S. Fish and Wildlife Laboratory of the U.S. Fish and Wildlife Service on technical grade malathion (95%). The species tested were: first-instar cladocerans *Daphnia magna, D. pulex, Simocephalus serrulatus* (three tests); mature ostracod *Cypridopsis vidua*, mature isopod *Asellus brevicaudus*, mature amphipod *Gammarus fasciatus* (3 tests), stoneflies *Claassenia sabulosa* (second year class), *Isoperla sp., Pteronarcella badia* (first and second year class) (3 tests), *Pteronarcys californica* (second year class), crayfish *Orconectes nais* (two tests), early instar damselfly *Lestes congener*, caddisfly *Hydropsyche* sp. (early instar) and *Limnephilus sp*. (late instar), mature prawn *Palaemonetes kadiakensis* (3 tests), late instar snipe fly *Atherix variegata,* coho salmon *Oncorhyncus kisutch* (two tests), cutthroat trout *Oncorhynchus clarki* (five tests), rainbow trout *Oncorhynchus mykiss* (seven tests), brown trout *Salmo trutta*, lake trout *Salvelinus namaycush* (two tests), goldfish *Carassius auratus*, carp *Cyprinus carpio*, fathead minnow *Pimephales promelas* (two tests), black bullhead *Ameiurus melas* (two tests), channel catfish *Ictalurus punctatus* (two tests), green sunfish *Lepomis cyanellus* (three tests), bluegill *Lepomis macrochirus* (eight tests), redear sunfish *Lepomis microlophus*, largemouth bass *Micropterus salmoides* (2 tests), yellow perch *Perca flavescens*, walleye *Stizostedion vitreum*, freshwater fish *Tilapia mossambica* (two tests), Fowlers toad tadpoles *Bufo fowleri woodhousei, and* western chorus frog tadpoles *Pseudacris triseriata*. Four or more concentrations were tested in replicate and solvent (acetone) controls were used. Malathion concentrations were not measured during the tests. Water quality parameters during the tests were dependent upon species. Control survival was acceptable in all tests. The EC_{50} and LC_{50} values are given in Table B-1.

Naqvi and Hawkins (1989) - In 1989, a 48-h acute static toxicity test was performed at the Southern University, Baton Rouge, Louisiana, on malathion (91.3%) with microcrustaceans *Diaptomus sp., Eucyclops sp., Alonella sp.,* and *Cypria sp.* tested together. Five concentrations and a water control were used. The water quality parameters were: temperature of 20-22°C; pH of 8.0-8.5; dissolved oxygen of 6.6-7.5 mg/L, and a hardness of 4 mg/L as $CaCO_3$. The control survival was >91.3%. The 48-h LC_{50} values for the microcrustaceans were: 2.0 µg/L for *Diaptomus sp*., 1.0 µg/L for *Eucyclops sp*., 2.0 µg/L for *Alonella sp*., and 2.0 µg/L for *Cypria sp*.

Post and Schroeder (1971) - In 1971, 96-h static acute toxicity tests were performed by Colorado State University in Fort Collins, on malathion (95%) with brook trout *Salvelinus fontinalis* (2 tests), rainbow trout *Oncorhynchus mykiss*, cutthroat trout *Oncorhynchus clarki* (2 tests), and coho salmon *Oncorhynchus kisutch*. There were 2 replicates per treatment with 10 organisms per replicate. Water quality parameters during the test were: temperature of 13.6-14.6°C; pH of 7.2-7.6; dissolved oxygen of 5.9-6.0 mg/L; and hardness of 318-348 mg/L as $CaCO_3$. The LC_{50} mg/L values were: *S. fontinalis* 120 and 130 µg/L; *O. mykiss* 122 µg/L; *O. clarki* 150 and 201 µg/L; and *O. kisutch* 265 µg/L.

Snell and Persoone (1989) - In 1987, a 24-h static toxicity test was performed by University of Tampa, Florida on malathion (95%) with neonate rotifer *Brachionus rubens*. Five concentrations were tested and a control was used. There were 7 replicates per treatment and 10 organisms per replicate. Water quality parameters during the test were: temperature of 25°C; pH of 7.4-7.8; and hardness of 80-100 mg/L as $CaCO_3$. Control survival was 100%. The 24-h LC_{50} for *B. rubens* was 35,300 µg/L.

Varanka (1986) - In 1986, 96-h static acute toxicity tests were performed by Balaton Limnological Research Institute of the Hungarian Academy of Sciences in Thany on malathion (95%) with larvae of freshwater mussels *Anodonta cygnea* and *Anodonta anatina*. There were 50 organisms per replicate. Water quality parameters were: temperature of 22°C; pH of 8.40; and a hardness of 295.5 mg/L as $CaCO_3$. Control survival was 100%. The LC_{50} value for *A. cygnea* was 310 µg/L and for *A. anatina* 80 µg/L.

Villar et al. (1993) - In 1993, 7-d static toxicity tests were performed by the University of Illinois in Urbana on technical grade malathion (percent active ingredient not given) with planarian *Dugesia dorotocephala*. Nine concentrations were tested and a control was used. There were 10 organisms per replicate and 1-2 replicates per treatment. Concentrations were not measured. Temperature during the test was 27°C. Other water quality parameters were not given. Control survival was 100%. The 7-d LC_{50} for *D. dorotocephala* was 8,600 µg/L for dark strains and 13,100 µg/L for light strains.

Unaccepted acute toxicity tests- The following tests did not use accepted methods and/or produce acceptable results.

Ali (1981) - In 1981, 24-h static acute toxicity tests were performed by the University of Florida, in Sanford on technical grade malathion (percent active ingredient not given) with the fourth instar midges *Glyptotendipes paripes*, *Chironomus decorus*, *C. crassicaudatus*, *Goeldichironomus holoprasinus*, and *Tanytarsus sp.* Five to six concentrations were tested in triplicate with ten organisms per replicate. Water quality parameters during the tests were not given with the exception of temperature which was 27 ± 2°C. The 24-h LC_{50} values were: 4 µg/L for *G. paripes*, 32 µg/L for *C. decorus*,56 µg/L for *C. crassicaudatus*, 28 µg/L for *G. holoprasinus*, and 32 µg/L for *Tanytarsus sp..* These values were not used because control survival and dissolved oxygen levels were not reported. Attempts to contact the author were unsuccessful.

Ali and Mulla (1980) - In 1980, 24-h toxicity tests were performed by the University of California in Riverside on malathion (percent active ingredient not given) with the fourth instar midges *Cricotopus bicinctus, C. sylvestris, Dicrotendipes californicus,* and *Chironomus decorus*. Test design and water quality parameters were not given. The LC_{50} values were: *Cricotopus spp.* 30-90 µg/L*, D. californicus* 80 µg/L, and *Chironomus decorus* 70 µg/L. These values were not used because the midges were collected in the field and may have already been exposed to various chemicals.

Al-Khatib (1985) - In 1985, a 24-h static toxicity test was performed by University of California in Riverside on malathion (technical grade) with three strains of mosquito *Culex quinquefasciatus*. Five concentrations were tested with four replicates. No control was mentioned. Water quality parameters were not given. Control survival was not given. The LC_{50} values ranged from 75 to 500 µg/L for the three strains. These values were not used because the study lacked important information such as control survival and mortality range.

Bailey and Liu (1980) - A 96-h static acute toxicity test was performed by SRI International in Menlo Park, California on malathion (reagent grade) with oligochaete *Lumbriculus variegatus*. Control survival was 100%. Water quality parameters were: dissolved oxygen of >40%; temperature of 19 to 21°C; pH of 6.8 to 8.2; and hardness of 30 mg/L as Ca CO_3. The LC_{50} was 20.5 mg/L. This value was not used because the dissolved oxygen was too low and the mortality range was not available.

Bender and Westman (1976) - In 1976, 96-h static and 14-day continuous acute toxicity tests were performed by Rutgers University in New Bruswick on malathion (99.5%) with the eastern mudminnow *Umbra pygmaea.* Five concentrations were tested in triplicate with ten organisms per replicate. Water quality parameters during the test were: temperature of 16-17°C; pH of 7.0-7.3; dissolved oxygen of 6-8 mg/L. The 96-h LC_{50} for

U. pygmaea was 240 µg/L and the 14-day LC_{50} was 140 µg/L. These values were not used because control survival was not given for either test. Attempts to contact the author were unsuccessful.

Bhatia (1971) - In 1971, a 96-h static acute toxicity test was performed by the Fisheries Research Laboratory, Bhopal on malathion (96.45%) with the freshwater fish *Puntius ticto.* Ten concentrations were tested with ten organisms per concentration. Water quality parameters during the test were: temperature of 10.5-29°C; pH of 7.6-8.3; dissolved oxygen of 7.2-9.2 mg/L; and hardness of 68-88 mg/L as $CaCO_3$. The 96-h LC_{50} value for *P. ticto* was 7,400 µg/L. This value was not used because control survival was not reported and the temperature range was in excess of guidelines.

Bills and Marking (1988) - In 1984, a 96-h static toxicity test was preformed by the U.S. Fish and Wildlife Service in LaCrosse, Wisconsin on malathion (percent active ingredient not given) with adult crayfish *Orconectes rusticus*. The number of concentrations and controls were not given. Concentrations were not measured. Water quality parameters during the test were: temperature of 12°C; pH of 7.98; and hardness of 256 mg/L as $CaCO_3$. The LC_{100} value for crayfish was 1.00 mg/L. This value was not used because essential information, such as control survival and percent active ingredient, was not given and no LC_{50} was determined.

CDFG (1988-1989) - From 1988 to 1989, five 96-h flow-through toxicity tests were conducted by the Aquatic Toxicology Laboratory, Elk-Grove, California on malathion (94.2%) with the *Morone saxatilis*. Five concentrations and controls were tested in replicate. Control survival was 15% and 94% in the first two tests and 100% in the other three. Water quality parameters were: temperature of 17.3-18.4° C, pH of 7.65-7.99, dissolved oxygen levels of 8.04-8.8 mg/L, and hardness levels of 398-492mg/L as $CaCO_3$. The first three tests were not used because no LC_{50} values were calculated. The 96-h LC_{50} values for *M. saxatilis* in the fourth and fifth tests were 17.6 and 34 µg/L. These values were not used because the control survival was too low.

Carlson (1966) - In 1966, 24-h toxicity tests were performed on malathion (95%) with naiads of mayfly *Hexagenia spp.* and caddisfly *Hydropsyche spp.* The number of concentrations and controls tested were not given. Temperature during the tests was 22-25°C, and dissolved oxygen levels ranged from 2.8-8.0 mg/L. The LC_{50} values for *Hexagenia spp.* and *Hydropsyche spp*. were 630 µg/L and 12 µg/L. These values were not used because the number of concentrations tested and control survival were not given and dissolved oxygen levels were too low.

Cheah et al. (1980) - In 1979, a 96-h static acute toxicity test was performed by Louisiana State University in Baton Rouge on field grade malathion (percent active ingredient not given) on the crayfish *Procambarus clarki.* Four to seven concentrations were tested in triplicate with ten organisms per replicate. Water quality parameters during the test were: temperature of 20 ± 3°C; pH of 8.4; and hardness of 100 mg/L as $CaCO_3$. Control survival was $ 86.7%. Dissolved oxygen levels were not given. The LC_{50} value for *P. clarki* was 50,000 µg/L. This value was not used because the percent

active ingredient was not given.

Chitra and Pillai (1984) - In 1984, 24-h static acute toxicity tests and generation of resistance tests were performed by the University of Delhi, India on malathion (95-98%) with the fourth instar larvae of the mosquito *Anopheles stephensi* (Delhi and Haryana stains). Water quality parameters during the test were not reported with the exception of temperature, which was 28 ± 2° C. The number of concentrations tested was not given. Four replicates were tested with each replicate containing 20 organisms. The 24-h LC_{50} values for *A. stephensi* were 4 µg/L (Delhi) and 10 µg/L (Haryana.) These values were not used because too few concentrations were tested and control survival was not reported. The generation of resistance tests were inappropriate for hazard assessment review.

Cripe et al. (1989) - A 96-h static acute toxicity test was performed by the Environmental Research laboratory in Gulf Breeze, Florida on malathion (92%) with mysid *Mysidopsis bahia*. EPA (1985) test standards were used. Five concentrations and a saltwater and a solvent control were used. Ten organisms per concentration were used. Water quality parameters during the test were: temperature of 25° C; pH of 7.8-8.3; dissolved oxygen of 5.9-7.0 mg/L and a salinity of 20%. Control survival was 100% in seawater and the solvent control survival was 70%. The 96-h LC_{50} value was 5.7 µg/L. This value was not used because percent survival in the solvent control was too low.

Desi et al. (1976) - In 1976, static acute toxicity tests (duration unknown) were performed by the National Institute of Public Health and Hygiene in Budapest, Hungary on malathion (95%) with freshwater mussel *Anodonta cygnea*, guppy *Lebistes reticulatus*, and cladoceran *Daphnia magna.* Water quality parameters during the tests were not reported. No LC_{50} values were reported.

Dutta et al. (1992) - In 1992, a 96-h static acute toxicity test was performed by Kent State University in Ohio on malathion (50%) with the freshwater fish *Heteropneustes fossilis.* No recognized test standards were mentioned during the test. Nine concentrations were tested in replicate with ten organisms each. Water quality parameters during the test were: temperature of 29°C; dissolved oxygen of 7.5 mg/L; pH of 7.35; and hardness of 140 mg/L as $CaCO_3$. The 96-h LC_{50} for *H. fossilis* was 11,800 µg/L. This value was not used because the percent active ingredient was too low and essential information, such as control survival, was not given.

Eaton (1970) - In 1970, 96-h flow-through acute toxicity tests were performed by the National Water Quality Laboratory at Duluth, Minnesota on malathion (95%) with bluegill *Lepomis macrochirus*. Four to five concentrations were used with 10 organisms per replicate. Water quality parameters for the three tanks were: temperature of 20°C, pH of 7.2-7.75; dissolved oxygen of 3.5 -10.8; and hardness of 194-220 mg/L as $CaCO_3$. Control survival was >85%. The 96-h TL_m for *L. macrochirus* was 89 µg/L and 131 µg/L. These values were not used because there was too much variation in dissolved oxygen

levels.

Eisler (1970) - From 1964 to 1966, 96-h static acute toxicity tests were performed by Sandy Hook Marine Laboratory, New Jersey on malathion (percent active ingredient not given) with American eel *Anguilla rostrata*, mummichog *Fundulus heteroclitus* (2 tests), striped killifish *F. majalis*, bluehead *Thalassoma bifasciatum*, striped mullet *Mugil cephalus*, Atlantic silverside *Menidia menidia*, and northern puffer *Sphaeroides maculatus*. A minimum of five concentrations were tested. Five to ten organisms per replicate were used. Water quality parameters during the test were: temperature of 20°C; pH of 8.0; and a salinity of 24%. The 96-h LC_{50} for the species were: *A. rostrata* LC_{50} of 82 µg/L, *F. heteroclitus* LC_{50} of 50 and 400 µg/L, *F. majalis* LC_{50} of 250 µg/L, *T. bifasciatum* LC_{50} of 27 µg/L, *M. cephalus* LC_{50} of 550 µg/L, *M. menidia* LC_{50} of 125 µg/L, *S. maculatus* LC_{50} of 3,250 µg/L. These values were not used because the toxicant formulation and the mortality range were not given. Attempts to contact the author were unsuccessful.

Fredeen (1972) - In 1965, 3 and 6-h static acute toxicity tests were performed by the Canada Department of Agriculture in Saskatoon, Saskatchewan on malathion (percent active ingredient not given) with the caddisfly larvae *Hydropsyche morosa* and *Hydropsyche recurvata*. Six replicates of two concentrations were tested with five organisms each. Water quality parameters during the tests were: temperature of 11 and 21°C (three replicates each); pH of 8.5. Dissolved oxygen levels were not given. LC_{50} values were reported only as equal to, less than, or greater than 500 µg/L. These values were not used because there were too few concentrations and the duration of the tests was inadequate.

Gaufin et al. (1961) - In 1961, 96-h toxicity tests were performed by the University of Utah on malathion (percent active ingredient not given) with the caddisflies *Arctopsyche grandis* and *Hydropsyche californica*; and the stoneflies *Acroneuria pacifica, Claassenia sabulosa,* and *Pteronarcys californica*. Five concentrations were tested. Water quality parameters during the tests were: temperature of 52-53 °F; pH of 8.3; dissolved oxygen of 8.5 mg/L; and hardness of 8.0 mg/L as $CaCO_3$. The 96-h TL_m values were: 32 µg/L for *A. grandis*; 22.5 µg/L for *H. californica*; 7.2 µg/L for *A. pacifica*; 100 µg/L for *P. californica*, and 56 µg/L for *C. sabulosa*. These values could not be used because the percent active ingredient and control survival were not reported. Attempts to contact the author were unsuccessful.

Gaufin et al. (1965) - In 1965, 96-h toxicity tests were performed by the Department of Zoology and Entomology, University of Utah on malathion (percent active ingredient not given) with caddisflies *Arctopsyche grandis* and *Hydropsyche californica*; stoneflies *Acroneuria pacifica* and *Pteronarcys californica*; the amphipod *Gammarus lacustris*; and mayfly *Ephemerella grandis*. Five concentrations were tested in replicate with ten

organisms per replicate. Water quality parameters during the tests were not given with the exception of temperature which was 51-54^{o}C. The 96-h TL_m values were: *A. grandis* 23 µg/L ; *H. californica* 7.2 µg/L; *A. pacifica* 7 µg/L ; *P. californica* 50 µg/L; *G. lacustris* 1.62 µg/L; and *E. grandis* 100 µg/L. These values could not be used because

the percent active ingredient and control survival were not reported. Attempts to contact the author were unsuccessful.

Goodman et al. (1988) - In 1988, 96-h flow-through toxicity tests were performed by the Environmental Research Laboratory of the U.S. EPA in Gulf Breeze, Florida on malathion (71.5%) with 1-d, 5-d, and 10-d old mysids *Mysidopsis bahia.* Concentrations were measured. Water quality parameters during the test were: temperature of 25±1°C; dissolved oxygen of 7.2 to 7.6 mg/L; pH of 7.90 to 8.01; and salinity of 20.3 to 21.4 $^{o}/_{oo}$. Control survival was >94%. The 96-h LC_{50} values for *M. bahia* were 3.0 µg/L for 1-d olds, 3.1 µg/L for 5-d olds, and 2.6 µg/L for 10-d olds. These values were not used because the percent active ingredient in the formulated product was too low.

Haider and Inbaraj (1986) - In 1985, 96-h static acute toxicity tests were performed by Banaras Hindu University, Varanasi, India on technical and commercial grades of malathion with the snakehead catfish *Channa punctatus.* Water quality parameters during the tests were: temperature of 18 ± 2° C; pH of 7.2; dissolved oxygen of 9-10 mg/L; and hardness of 18 mg/L as $CaCO_3$. The LC_{50} values for *C. punctatus* were 4,510 - 4,600 µg/L with technical grade malathion and 3,890 - 3,910 µg/L with field grade malathion. These values were not used because control survival and the number of concentrations tested were not given. Attempts to contact the author were unsuccessful.

Hansen and Kawatski (1976) - In 1976, 72-h static acute toxicity tests were performed by the Department of Biology of Viterbo College in La Crosse, Wisconsin on malathion (99%) with the adult ostracod *Cypretta kawatai* and the fourth instar midge *Chironomus tentans.* Water quality parameters during the tests were: temperature of 20 ± 0.5° C; and hardness of 40-48 mg/L as $CaCO_3$. The 72-h LC_{50} values were: *C. kawatai* 51 µg/L, and *C. tentans* 620 µg/L. These values were not used because control survival, the number of concentrations tested, and dissolved oxygen levels were not reported. Attempts to contact the author were unsuccessful.

Hermanutz et al. (1985) - In 1985, 168-h acute toxicity tests were performed by the Environmental Research laboratory in Duluth, Minnesota on malathion (percent active ingredient not given) with flagfish *Jordanella floridae*. Three concentrations were tested. Water quality parameters during the tests were: temperature of 21.7-26.8°C; dissolved oxygen of 4.7-9.6 mg/L; and hardness of 43-48 mg/L as $CaCO_3$. Control survival was 97%. The LC_{50} for flagfish was 280 µg/L. This value was not used because too few concentrations were tested and mortality range was unacceptable.

Holck and Meek (1987) -In 1987, 96-h static acute toxicity tests were performed by the Louisiana Agricultural Experiment Station, Baton Rouge, Louisiana, on malathion (95%) with the crayfish *Procambarus clarkii*, and the fourth instar mosquitos *Anopheles quadrimaculatus, Culex salinarius*, and *Psorophora columbiae*. Five concentrations

were tested with four replicates. There were 40 organisms per replicate. Water quality parameters during the tests were not given with the exception of hardness which was 100 mg/L as $CaCO_3$. The 96-h LC_{50} values were: 49,170 µg/L for *P. clarkii*, 69 µg/L for *A. quadrimaculatus,* 53 µg/L for *C. salinarius*, and 11 µg/L for *P. columbiae*. These values were not used because control survival and water quality parameters such, as dissolved oxygen, were not reported. Attempts to contact the authors were unsuccessful.

Jacob et al. (1982) -In 1982, 48-h static toxicity tests were performed by the University of Kerala, Trivandrum, India on malathion (50%) with the larvivorous fishes *Aplocheilus lineatus* and *Macropodus cupanus*. Five concentrations were tested. Water quality parameters during the tests were: temperature of 28 ± 2°C; and pH of 7.1. Dissolved oxygen and hardness were not given. The LC_{50} values for *A. lineatus* and *M. cupanus* were 975 µg/L and 4,594 µg/L. These values were not used because the percent active ingredient was too low.

Jensen and Gaufin (1964) - In 1964, 4-d static and flow-through acute toxicity tests were performed by the University of Utah, Salt Lake City, Utah, on malathion (95%) with the stoneflies *Acroneuria pacifica* and *Pteronarcys californica*. There were 25 organisms per replicate used. The water quality parameters were: temperature of 12.8±0.6°C; pH of 7.8-8.2; and dissolved oxygen of 9-11 mg/L. The control survival was not given. The 4-d TL_m value for *A. pacifica* was 7.0-7.7 µg/L and the 4-d TL_m for *P. californica* was 50 µg/L. Values were not used because control survival and mortality range were not given.

Khangarot et al. (1985) - A 96-h static acute toxicity test was performed on malathion (50%) with the tadpole *Rana hexadactyla.* Seven to ten concentrations were run in triplicate with ten organisms per replicate. Water quality parameters during the test were: temperature of 12-17°C; pH of 6.0-6.4; dissolved oxygen of 5.5-8.0 mg/L; and hardness of 15-35 mg/L as $CaCO_3$. The 96-h LC_{50} value for *R. hexadactyla* was 0.59 µg/L. This value was not used because the percent active ingredient was too low and control survival was not given.

Kimura and Keegan (1966) - In 1963 and 1964, a 48-h static acute toxicity test was performed by the Department of Entomology, U.S. Army Medical Command of Japan on technical grade malathion with the leech *Hirudo nipponia*. Five organisms per replicate were tested. No water quality parameters or the number of concentrations tested were given. The LC_{50} value for *H. nipponia* was 17,000 µg/L. This value was not used because control survival, number of concentrations, and water quality parameters were not given.

Lewellan and Wilder (1962) - In 1962, 72-h static acute toxicity tests were performed by the Bureau of Vector Control in Fresno, California, on malathion (percent active

ingredient not given) with the rainbow trout *Oncorhynchus mykiss*. Tests were performed on one week old and one month old trout. In each test, there were six concentrations that were tested in triplicate with ten organisms per replicate. Water quality parameters were not given with the exception of temperature which was 14.4° C. Control survival was 100% in all controls. No LC_{50} values were given and the tests could not be used.

Mane et al. (1979) - In 1976, 80-h static acute toxicity tests were performed by Marathwada University, Aurangabad, India on malathion (percent active ingredient not given) with clams *Katelysia opima* and *Donax cuneatus.* No recognized test standards were mentioned. One concentration and water and solvent controls were tested with 160 organisms each. Water quality parameters during the test were: temperature of 31°C, and salinity of 33.5°/$_{oo}$. Dissolved oxygen and pH were not given. This test could not be used because no LC_{50} values were given.

Mayer (1970) - In 1970, 96-h static acute toxicity tests were performed by the U.S. Bureau of Fisheries and Wildlife in Tiburon, California on malathion (95%) on Korean shrimp *Palaemon macrodactylus,* chinook salmon *Oncorhyncus tshawytscha,* and striped bass *Morone saxatilis*. No commonly recognized testing standards were mentioned. Water quality parameters were: temperature of 15°C for Korean shrimp, 12.8°C striped bass, and for chinook 13.3°C; and salinity was 28-30 °/$_{oo}$ in all tests. The 96-h LC_{50} values were: *P. macrodactylus* 81.5 and 9.0 µg/L (two tests) *, O. tshawytscha* 33.7 µg/L, and *M. saxatilis* 14 µg/L. These values were not used because control survival, number of concentrations tested, and dissolved oxygen levels were not reported.

Muncy and Oliver (1963) - In 1963, a 72-h static acute toxicity test was performed by Louisiana State University, Baton Rouge, Louisiana on malathion (percent active ingredient not given) with the crayfish *Procambarus clarki.* Water quality parameters during the test were: temperature of 16-32° C; pH of 7.6. This test could not be used because no LC_{50} value, control survival, and toxicant formulation were reported.

Naqvi (1977) - In 1977, a 72-h static toxicity test was performed on technical grade malathion with the tubificid worm *Branchiura sowerbyi*. The number of concentrations tested was not given. Each replicate contained 50 organisms. Three temperatures were tested: 4.4, 21, and 32.2° C. No other water quality parameters were given. No LC_{50} values were given. An NOEC of 4,000 µg/L was reported. This value was not used because control survival and the number of concentrations tested were not given and no LC_{50} values were calculated.

Naqvi and Hawkins (1987) - In 1987, a 96-h toxicity test was performed by the Department of Biological Sciences and Health Research Center at Southern University in

Baton Rouge, Louisiana on malathion (56.1%) with adult mosquitofish *Gambusia affinis*. Concentrations were tested in replicate, controls were not mentioned. Water quality parameters were: temperature of 17-23°C; pH of 7.8; dissolved oxygen of 6.5-7.0 mg/L; and hardness of 12 mg/L as $CaCO_3$. The LC_{50} for *G. affinis* was 200 µg/L. This data was not used because the percent active ingredient was too low. Furthermore, information regarding concentrations tested and control survival was lacking.

Natarajan et al. (1992) - In 1992, a 96-h static acute toxicity test was performed by the Central Institute of Fisheries Education in Bombay, India on malathion (percent active ingredient was not given) with the freshwater prawn *Macrobrachium rosenbergii*. An unknown number of concentrations were tested in triplicate with 20 organisms per replicate. Water quality parameters during the test were: temperature of 24 ± 1° C; pH of 7.8 ± 0.4; and dissolved oxygen of 7.0 ± 0.5 mg/L. The 96-h LC_{50} value for *M. rosenbergii* was 9 µg/L. This value was not used because the percent active ingredient, control survival, and number of concentrations tested were not given. Attempts to contact the author were unsuccessful.

Parkhurst and Johnson (1955) - In 1954, 96-h toxicity tests were performed by the U.S. Fish and Wildlife Service in Cook, Washington on malathion (31%) with chinook salmon *Oncorhynchus tshawytscha*. No commonly recognized test standards were mentioned. Seven concentrations were tested with 20 organisms each. Water quality parameters during the test were not given with the exception of temperature which was 47-49°F. The 96-h LC_{50} for *O. tshawytscha* was 120 µg/L. This value was not used because the percent active ingredient was too low.

Perschbacher and Sarkar (1989a) - In 1989, a 24-h static acute toxicity test was performed by the Freshwater Aquaculture Research Station in Mymensingh, Bangladesh on malathion (percent active ingredient not given) with the beetle *Notonecta sp.* Four concentrations were tested in triplicate with 20 organisms per replicate. Water quality parameters during the test were: temperature of 32° C; pH of 7.3-7.7; and hardness of 160 mg/L as $CaCO_3$. Dissolved oxygen levels were not reported. There was no LC_{50} value reported and the test was not used.

Perschbacher and Sarkar (1989b) - In 1989, 48-h static acute toxicity tests were performed by the Freshwater Aquaculture Research Station in Mymensingh, Bangladesh on malathion (commercial preparation) with snakehead catfish *Channa punctata*. Three concentrations were tested and no controls were mentioned. Concentrations were not measured. Water quality parameters during the test were: temperature of 22 to 32°C; dissolved oxygen above 3 mg/L; pH of 7.0 to 8.0; and hardness of 120 mg/L as $CaCO_3$. No LC_{50} values were calculated. This test was not used because the LC_{50} value was not calculated, the percent active ingredient was not given, there was too much variation in water quality parameters, and the testing duration was too short.

Pickering et al. (1962) - In 1962, three 96-h static acute toxicity tests were performed by the R.A. Taft Sanitary Engineering Center in Cincinnati, Ohio on malathion (20%, 57%, and 100%) with fathead minnow *Pimephales promelas*, bluegill *Lepomis macrochirus*, green sunfish *Lepomis cyanellus*, largemouth bass *Micropterus salmoides*, goldfish *Carassius auratus*, and guppy *Lebistes reticulatus*. Five concentrations were tested in duplicate with 5-10 organisms per replicate. Water quality parameters during the tests were: temperature of 25°C; pH of 7.4-8.2; dissolved oxygen of 8.0 mg/L; and two hardness (18 and 360 mg/L as $CaCO_3$.) The LC_{50} are given in Table B-2. These values were not used because control survival was not given. In addition, the percent active ingredient was too low in some tests.

Rao et al. (1987) - In 1987, 48-h static acute toxicity tests were performed at the University of Mississippi Medical Center in Jackson on malathion (95%) with the freshwater fish *Saurotherodon mossambicus*, the Indian apple snail *Pila globosa*, and the mussel *Lamellidens marginalis*. Water quality parameters during the tests were: temperature of 26-28°C; pH of 7.0 ± 0.2; and hardness of 140 ± 20 mg/L as $CaCO_3$. Dissolved oxygen levels were not reported. The 48-h LC_{50} values were 5,620 µg/L for *S. mossambicus*, 15,490 µg/L for *P. globosa*, and 100,000 µg/L for *L. marginalis*. These values were not used because the test durations were too short and control survival was not reported.

Rawash et al. (1975) - In 1974, static acute toxicity tests were performed by the University of Alexandria in Egypt on malathion (percent active ingredient not given) with fourth instar mosquito *Culex pipiens* and adult cladoceran *Daphnia magna.* Six concentrations were tested. Water quality parameters during the tests were not given. The LC_{50} values were: 3.4 µg/L for *C. pipiens* and 0.098 µg/L for *D. magna*. These values were not used because the percent active ingredient, control survival, and water quality parameters were not given. Attempts to contact the author were unsuccessful.
Rehwoldt et al. (1977) - In 1977, 96-h static acute toxicity tests were performed by Marist College Poughkeepsie, New York with malathion (percent active ingredient not given) with striped bass *Morone saxatilis*, banded killifish *Fundulus diaphanus*, pumpkinseed *Lepomis gibbosus*, white perch *Roccus americanus* , American eel, *Anguilla rostrata*, carp *Cyprinus carpio*, and the guppy *Lebistes reticulatus.* Water quality parameters during the test were: temperature of 20°C; pH of 7.2; dissolved oxygen of 6.0 mg/L; and hardness of 50 mg/L as $CaCO_3$. The LC_{50} values were: 39 µg/L for *M. saxatilis*, 240 µg/L for *F. diaphanus*, 480 µg/L for *L. gibbosus*, 1,100 µg/L for *R. americanus*, 500 µg/L for *A. rostrata*, 1,900 µg/L for *C. carpio*, and 1,200 µg/L for *L. reticulatus*. These values were not used because the percent active ingredient and control survival were not given. Attempts to contact the author were unsuccessful.

Rettich (1979) - In 1979, 48-h static acute toxicity tests were performed by the Institute of Hygiene and Epidemiology in Prague, Czechoslovakia on malathion (30%) with the

mosquito *Culex pipiens molestus*. Water quality parameters during the tests were not given with the exception of temperature which was 20-22°C. The 48-h LC_{50} value for *C. pipiens molestus* was 24.0 µg/L. This value was not used because the percent active ingredient was too low.

Rettich (1977) - In 1974, 24-h static acute toxicity tests were performed by the Institute of Hygiene and Epidemiology, Prague, Czechoslovakia on malathion (percent active ingredient not given) with eight species of mosquitos *Aedas cantans, A. vexans, A. excrucians, A. communis, A. sticticus, A. punctor, Culex pipiens, and Culiseta annulata.* Five to six concentrations were tested in triplicate with 25 organisms each. Water quality parameters during the tests were not given with the exception of temperature which was 20-23 °C. The LC_{50} values were: *A. cantans* 48.8 µg/L, *A. vexans* 26.1 µg/L, *A. excrucians* 30.3 µg/L, *A. communis* 38.2 µg/L, *A. sticticus* 15.5 µg/L, *A. punctor* 44.1 µg/L, *C. pipiens pipiens* 32.2 µg/L, *C. pipiens molestus* 34.2 µg/L, and *C. annulata* 24.5 µg/L. These values were not used because percent active ingredient and control survival were not given. Attempts to contact the author were unsuccessful.

Rongsriyam et al. (1968) -In 1968, 24-h static acute toxicity tests were performed by the University of Medical Sciences in Bangkok, Thailand on malathion (percent active ingredient not given) with the guppy *Lebistes reticulatus* and the mosquito *Culex pipiens.* An unknown number of concentrations were tested in duplicate with 20 organisms per replicate. Water quality parameters during the tests were not given. The 24-h LC_{50} values were: *L. reticulatus* 50 µg/L, *C. pipiens* 50.µg/L. These values were not used because the percent active ingredient, control survival, and water quality parameters were not given. Attempts to contact the author were unsuccessful.

Sahib and Rao (1980) - A 48-h static acute toxicity test was performed by S.V. University, Tirupati, India on malathion (95%) with the freshwater fish *Tilapia mossambica.* Six concentrations were tested with ten organisms per replicate. Water quality parameters during the test were not reported. The 48-h LC_{50} for *T. mossambica* was 5,600 µg/L. This value was not used because the duration of the test was too short and control survival was not reported.

Sailatha et al. (1981) - In 1981, 48-h static acute toxicity tests were performed on malathion (95% and 50%) with the freshwater fish *Tilapia mossambica.* Five concentrations were tested with a total of 50-60 organisms. Water quality parameters were: temperature of 26-28° C; pH of 7.0 ± 0.2; and hardness of 20 mg/L as $CaCO_3$. The 48-h LC_{50} value for *T. mossambica* in was 5,592 ± 90 (95% malathion) and 377 ±40 µg/L (50% malathion). These values were not used because the test duration was too short and control survival was not given. In addition, the percent active ingredient was too low in the 50% malathion test.

Sanders (1970) - In 1970, a 96-h static acute toxicity test was performed by the Fish Pesticide Research Laboratory, Columbia, Missouri with technical grade malathion on tadpole western chorus frog *Pseudacris triseriata* and tadpole Fowler's toad *Bufo woodhousii*. Four to five concentrations were tested with 10 organisms each. Water quality parameters were: temperature of 15.5 ± 0.5° C; pH of 7.1. Dissolved oxygen and hardness were not given. The LC_{50} values were 420 µg/L for *B. woodhousii* and 200 µg/L for *P. triseriata.* These values were not used because control survival was not given. Attempts to contact the author were unsuccessful.

Sanders and Cope (1966) - In 1966, 48-h static acute toxicity tests were performed by the Bureau of Sport Fisheries and Wildlife in Denver, Colorado on malathion (percent active ingredient not given) with the cladocerans *Dapnia pulex* and *Simocephalus serrulatus*. Water quality parameters during the test were: temperature 50, 60, and 70 ± 1° F; and a pH of 7.4-7.8. Dissolved oxygen levels and hardness were not reported. The EC_{50} values were: *D. pulex* (60° F) 1.8 µg/L; and *S. serrulatus* (60° F) 3.5 µg/L, (70° F) 6.2 µg/L. These values were not used because the percent active ingredient and control survival were not given.

Singh et al. (1984) - In 1983, 96-h static acute toxicity tests were performed by the Punjab Agricultural University in Ludhiana, India on malathion (50%) with the catfish *Channa punctatus* and *Heteropneustes fossilis.* Water quality parameters during the tests were not given. An unknown number of concentrations were tested with ten organisms each. The 96-h LC_{50} values for *C. punctatus* and *Heteropneustes fossilis* were 2,900 µg/L and 5,000 µg/L. These values were not used because the percent active ingredient was too low, control survival was not given, and water quality parameters were not given.

Singh and Singh (1987) - In 1987, 96-h acute toxicity tests were performed by the Banarus Hindu University in India on malathion (50% active ingredient) with catfish *Clarias batrachus*. Information about water quality was not given. The 96-h LC_{50} was 12,000 µg/L. This value was not used because important information, such as control survival and number of concentrations tested, was not given.

Smith and Grigoropoulos (1968) - In 1968, 120-h static acute toxicity tests were performed on malathion (57% active ingredient) on rainbow trout *Oncorhynchus mykiss* and the red shiner *Cyprinella lutrensis*. Water quality parameters during the tests were: temperature of 12.2°C; pH of 7.4-8.2; dissolved oxygen 6.7-7.1 mg/L; and hardness of 95-170 mg/L of $CaCO_3$. The 120-h TL_m values for *Oncorhynchus mykiss* and *Cyprinella lutrensis* were 2.3 µg/L and 23 µg/L. These values were not used because the percent active ingredient was too low.

Snell and Persoone (1988) - In 1987, a 24-h toxicity test was performed by the Division of Science at the University of Tampa in Florida and the Laboratory for Biological Research in Aquatic Pollution on malathion with the hatchling rotifer *Brachionus rubens*. The number of concentrations tested and controls was not mentioned. Water quality parameters were: temperature of 25°C; pH of 7.4-7.8; hardness of 80-100 mg/L as $CaCO_3$. The LC_{50} for *B. rubens* was 35,300 µg/L. This data was not used because essential information such as control survival was lacking.

Strickman (1985) - In 1985, a 7-d static toxicity test was performed by USAF Occupational and Environmental Health Laboratory in Brooks Air Force Base, Texas on

technical grade malathion (93-100%) with 2nd instar mosquito *Wyeomyia smithii*. Three concentrations were tested and an acetone control was used. Temperature during the test was 27°C. Other water quality parameters were not given. No LC_{50} value was determined. Values from this test were not used because too few concentrations were tested and no LC_{50} value was determined.

Tchounwou et al. (1991) - In 1988, 48-h static toxicity tests were performed by Tulane University in New Orleans, Louisiana on malathion (91%) with egg, juvenile, and adult snails *Helisoma trivolvis* and *Biomphalaria havanensis*. Five concentrations were tested, but no controls were mentioned. Water quality parameters during the egg, juvenile, and adult tests were temperature of 20.05, 23.1, and 21.8°C; dissolved oxygen of 8.20, 7.78, and 7.89 mg/L; pH of 6.20, 6.62, and 6.42; and hardness 9.6, 12.3, and 10.8 mg/L as $CaCO_3$. The 24-h LC_{50} values for *H. trivolvis* and *B. havanensis* eggs were 187.65 and 94.78 mg/L, respectively. The 24-h LC_{50} values for *H. trivolvis* and *B. havanensis* juveniles were 268.11 and 149.10 mg/L, respectively. The 24-h LC_{50} values for *H. trivolvis* and *B. havanensis* adults were 478.65 and 202.93 mg/L, respectively. The 48-h LC_{50} values for *H. trivolvis* and *B. havanensis* adults were 228.84 and 126.27 mg/L, respectively. These values were not used because the test duration was too short and control survival was not given.

Tchounwou et al. (1992) - In 1992, a 4-h static toxicity test was performed by Tulane University in New Orleans, Louisiana on malathion (91%) with fluke *Schistosoma mansoni cercariae*. Five concentrations were tested, but no controls were reported. Water quality parameters were not given. The 4-h LC_{50} value for *S. mansoni cercariae* was 69,360 µg/L. This value was not used because the test duration was too short, and control survival and dissolved oxygen levels was not given.

Tietze et al. (1993) - In 1993, a 24-h static acute toxicity test was performed by the Florida Agricultural and Mechanical University, Panama City, Florida on malathion (percent active ingredient not given) with mosquito *Toxorhynchites splendens*. Six or seven concentrations were tested and a control was used. Water quality parameters were not given. Control survival was >90%. The LC_{50} for the mosquito was 2.87 µg/L. This value was not used because percent active ingredient was not given.

Toor et al. (1973) - In 1973, a 72-h static acute toxicity test was performed on malathion (50%) with the carp *Cyprinus carpio*. Five to seven concentrations were tested with 20-24 organisms each. Water quality parameters during the test were not given. No LC_{50} value was given. This test was not used because no LC_{50} was given and the percent active ingredient was too low.

Venturino et al. (1992) - In 1992, a 96-h static acute toxicity test was performed by the University of Argentina in Buenos Aires on malathion (technical) with toad *Bufo*

arenarum. Four concentrations were tested with three replicates and a control was used. Water quality parameters were not given. Control survival was >90%. This data was not used because no LC_{50} value was given.

Whitten and Goodnight (1966) - A 96-h static acute toxicity test was performed on malathion (99.6%) with the aquatic worms *Tubifex sp.* and *Limnodrilus sp.* Five concentrations and a solvent control were tested in duplicate with 50 organisms per replicate. Water quality parameters during the test were: temperature of 20° C; pH of 7.5; and dissolved oxygen of 4 mg/L. The 96-h LC_{50} for *Tubifex sp.* and *Limnodrilus sp.* (combined) was 16,700 ± 1,750 µg/L. This value was not used because control survival was not reported.

Wildish et al. (1971) - In 1971, a 96-h static acute toxicity test was performed by the Fisheries Research Board of Canada on malathion (95%) with the Atlantic salmon *Salmo salar.* Five concentrations and a solvent control were tested. Water quality parameters during the tests were not reported. The 96-h LC_{50} value for *Salmo salar* was 320 µg/L. This value was not used because control survival was not reported.

Womeldorf et al. (1970) - In 1969, a static acute toxicity test was performed on malathion (percent active ingredient not given) with the fourth instar mosquito *Anopheles freeborni*. No water quality parameters were reported. The LC_{50} value for *A. freeborni* was 130 µg/L. This value was not used because control survival, number of concentrations tested, and dissolved oxygen levels were not reported. Attempts to contact the author were unsuccessful.

B-1. Values (µg/L) from accepted tests on the acute toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Method	Salinity/ Hardness	Test Length	Values µg/L Effect	(95% C.L. [b])
Amphipod	Mature	S/U	44 mg/L	96-h	LC_{50}	0.76 (0.630-0.920)
		Mayer and				
Gammarus	Mature	S/U	272 mg/L	96-h	LC_{50}	0.90 (0.640-1.260)
		Ellersieck 1986				
fasciatus	Mature	F/U	272 mg/L	96-h	LC_{50}	0.50 (N/A[c])
Black bullhead	1.20 g	S/U	44 mg/L	96-h	LC_{50}	12,900
(10,700-15,600)	Mayer and					
Ameiurus melas	1.20 g	S/U	272 mg/L	96-h	LC_{50}	11,700
(9,600-14,100)	Ellersieck 1986					
Blue crab	Juvenile	F/U	25 mg/L	48-h	EC_{50}	>1,000 (N/A)
	Mayer 1987					
Callinectes sapidus						
Bluegill	10.0 g	F/U	194-220 mg/L	96-h	**TLm**	131 (N/A)
	Eaton 1970					
Lepomis	10.0 g	F/U	194-220 mg/L	96-h	**TLm**	89 (N/A)
macrochirus						
Bluegill	1.50 g	S/U	44 mg/L	96-h	LC_{50}	103 (87-122)
	Mayer and					
Lepomis	1.40 g	S/U	272 mg/L	96-h	LC_{50}	110 (84-143)
	Ellersieck 1986					
macrochirus	0.60 g	S/U	44 mg/L	96-h	LC_{50}	87 (71-107)
	0.60 g	S/U	44 mg/L	96-h	LC_{50}	84 (67-105)
	0.60 g	S/U	44 mg/L	96-h	LC_{50}	55 (50-60)
	0.60 g	S/U	44 mg/L	96-h	LC_{50}	40 (32-50)
	0.40 g	S/U	44 mg/L	96-h	LC_{50}	20 (16-25)
	1.10 g	S/U	44 mg/L	96-h	LC_{50}	30 (10-88)
Brook trout	1.15g	S/U	318-348 mg/L	96-h	LC_{50}	130.0 (110-154)
	Post and					
Salvelinus fontinalis	2.13g	S/U	318-348 mg/L	96-h	LC_{50}	120.0 (96-153)
	Schroeder 1971					
Brown trout	1.10 g	S/U	44 mg/L	96-h	LC_{50}	101 (84-115)
	Mayer and					
Salmo trutta						Ellersieck 1986

Caddisfly *Hydropsyche sp.*		Early instar	S/U	44 mg/L		96-h	LC_{50}	5.0 (2.9-8.6)	Mayer and Ellersieck 1986
Caddisfly *Limnephilus sp.*		Early instar	S/U	44 mg/L		96-h	LC_{50}	1.3 (0.77-2.0)	Mayer and Ellersieck 1986
Carp *Cyprinus carpio*	0.60 g		S/U	44 mg/L		96-h	LC_{50}	6,590 (4920-8820)	Mayer and Ellersieck 1986
Channel catfish *Ictalurus punctatus*	1.50 g		S/U	44 mg/L		96-h	LC_{50}	8,970 (6,780-12,000)	Mayer and Ellersieck 1986
	1.50 g		S/U	272 mg/L		96-h	LC_{50}	7,620 (5,820-9,970)	
Cladoceran *Alonella sp*.	N/A		S/U	26-28 mg/L	48-h	LC_{50}	2.0 (N/A)		Naqvi and Hawkins 1989
Cladoceran *Daphnia magna*	1st instar		S/U	44 mg/L	48-h	EC_{50}	1.0 (0.70-1.40)		Mayer and Ellersieck 1986
Cladoceran *Daphnia pulex*	1st instar		S/U	44 mg/L	48-h	EC_{50}	1.8 (1.40-2.40)		Mayer and Ellersieck 1986
Cladoceran *Simocephalus serrulatus*	1st instar		S/U	44 mg/L	48-h	EC_{50}	0.59 (0.440-0.790)		Mayer and Ellersieck 1986
	1st Instar		S/U	44 mg/L	48-h	EC_{50}	3.5 (2.60-4.80)		
	1st Instar		S/U	44 mg/L	48-h	EC_{50}	6.2 (4.40-8.70)		
Coho salmon *Oncorhynchus kisutch*	0.90 g		S/U	44 mg/L		96-h	LC_{50}	170 (246-602)	Mayer and Ellersieck 1986
	1.50 g		S/U	40 mg/L		96-h	LC_{50}	177 (116-271)	

Coho salmon 1.70 g		S/U	318-348 mg/L		96-h	LC_{50}	265 (208-388)
	Post and						
Oncorhynchus	Schroeder 1971						
kisutch							
Copepods	N/A	S/U	26-28 mg/L	48-h	LC_{50}	1.0 (N/A)	
	Naqvi and						
Eucyclops sp.							
Hawkins 1989							

[a] S = Static
F = Flow through
M = Measured concentrations
U = Unmeasured concentrations

[b] Confidence limits

[c] N/A = Not available

B-1. Continued. Values (µg/L) from accepted tests the acute toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Method	Salinity/ Hardness	Test Length		Values µg/L Effect	(95% C.L. [b])
		Reference					
Crayfish	Early	S/U	272 mg/L	96-h	LC_{50}	180 (140-230)	
	Mayer and						
Orconectes nais	instar						
Ellersieck 1986							
	Mature	S/U	272 mg/L	96-h	LC_{50}	>10,000 (N/A)	
Cutthroat trout	1.00 g	S/U	44 mg/L	96-h	LC_{50}	280 (270-310)	
	Mayer and						
Oncorhynchus	1.00 g	S/U	272 mg/L	96-h	LC_{50}	270 (250-290)	
	Ellersieck 1986						
clarki	0.30 g	S/U	162 mg/L	96-h	LC_{50}	174 (112-269)	
	0.50 g	S/U	162 mg/L	96-h	LC_{50}	237 (175-320)	
	2.90 g	S/U	162 mg/L	96-h	LC_{50}	230 (188-283)	
Cutthroat trout	0.33 g	S/U	318-348 mg/L	96-h	LC_{50}	150 (133-170)	
	Post and						
Oncorhynchus	1.25 g	S/U	318-348 mg/L	96-h	LC_{50}	201 (175-231)	
	Schroeder 1971						
clarki							
Damselfly	Early	S/U	44 mg/L	96-h	LC_{50}	10 (6.5-15)	

	Mayer and						
Lestes congener	instar						
Ellersieck 1986							
Eastern Oyster	Juvenile	F/U	24$^{o}/_{oo}$	96-h	EC_{50}	>1,000 (N/A)	
Mayer 1987							
Crassostrea			14$^{o}/_{oo}$	96-h	EC_{50}	>1,000 (N/A)	
virginica							
Fathead minnow	Juvenile	F/U	194-220 mg/L	96-h	**TLm**	10,800 (N/A)	
Eaton 1970							
Pimephales promelas			194-220 mg/L	96-h	**TLm**	10,100 (N/A)	
Fathead minnow	29-30-d	S/M	46.9 mg/L	96-h	LC_{50}	14,100	
(12,300-16,100)	Geiger et al.						
Pimephales			EC_{50}	10,600 (9,070-12,400)		1988	
promelas							
Fathead minnow	0.90 g	S/U	44 mg/L	96-h	LC_{50}	8,650 (6,450-	
11,500)	Mayer and						
Pimephales	0.90 g	S/U	272 mg/L	96-h	LC_{50}	11,000 (8,980-	
13,400)	Ellersieck 1986						
promelas							
Flagfish	33-day	F/U	39-44 mg/L	96-h	LC_{50}	349 (321-383)	
Hermanutz 1978							
Jordanella floridae							
Fowlers toad	Tadpole	S/U	44 mg/L	96-h	LC_{50}	420 (90-980)	
Mayer and							
Bufo woodhousii							
Ellersieck 1986							
Freshwater mussel	Larvae	S/U	295.5 mg/L	96-h	LC_{50}	80 (50-140)	
Varanka 1986							
Anodonta anatina							
Freshwater mussel	Larvae	S/U	295.5 mg/L	96-h	LC_{50}	310 (280, 360)	
Varanka 1986							
Anodonta cygnea							
Goldfish	0.90 g	S/U	44 mg/L	96-h	LC_{50}	10,700	
(8,340-13,800)	Mayer and						
Carassius auratus							
Ellersieck 1986							
Green sunfish	1.10 g	S/U	44 mg/L	96-h	LC_{50}	175 (134-	
228)	Mayer and						
Lepomis	1.10 g	S/U	272 mg/L	96-h	LC_{50}	170 (132-	
220)	Ellersieck 1986						
cyanellus	0.80 g	S/U	44 mg/L	96-h	LC_{50}	146 (91-234)	

Isopod	Mature	S/U	44 mg/L		96-h	LC_{50}	3,000 (1,500-8,500) Meyer and
Asellus brevicaudus	Ellersieck 1986						
Lake trout	0.30 g	S/U	162 mg/L		96-h	LC_{50}	76 (47-123) Mayer and
Salvelinus	4.50 g	S/U	162 mg/L		96-h	LC_{50}	142 (106-188) Ellersieck 1986
namaycush							
Largemouth bass	0.90 g	S/U	44 mg/L		96-h	LC_{50}	285 (254-320) Mayer and
Micropterus	1.40 g	S/U	272 mg/L		96-h	LC_{50}	250 (220-310) Ellersieck 1986
salmoides							
Longnose killifish	Juvenile	F/U	$19^{o}/_{oo}$		48-h	LC_{50}	150 (N/A) Mayer 1987
Fundulus similis							
Microcrustacean	N/A	S/U	4 mg/L		48-h	LC_{50}	2.0 (N/A) Naqvi and Hawkins 1989
Alonella sp.							

[a] S = Static
F = Flow through
M = Measured concentrations
U = Unmeasured concentrations
[b] Confidence limits
[c] N/A = Not available

B-1. Continued. Values (µg/L) from accepted tests the acute toxicity of malathion to aquatic animals.

Species	**Life Stage/ Size**	**Method**	**Salinity/ Hardness**	**Test Length**	**Values µg/L Effect**	**(95% C.L. [b])**
	Reference					
Microcrustacean	N/A	S/U	4 mg/L	48-h	LC_{50}	2.0 (N/A) Naqvi and Hawkins 1989
Cypria sp.						
Microcrustacean						Naqvi and Hawkins

Diaptomus sp.	N/A	S/U	4 mg/L		48-h	LC_{50}	2.0 (N/A)
1989							
	N/A	S/U	26-28 mg/L	48-h	LC_{50}	2.0 (N/A)	
Eucyclops sp.	N/A	S/U	4 mg/L		48-h	LC_{50}	1.0 (N/A)
Mysid	Neonate	S/M	47.2 mg/L		96-h	LC_{50}	2.211 (1.989-2.493)
CDFG 1990							
Neomysis	Neonate	S/M	44.0 mg/L		96-h	LC_{50}	2.82 (2.473-3.283)
mercedis	Neonate	S/M	472 mg/L		96-h	LC_{50}	2.30 (2.08-2.59)
	Neonate	S/M	452 mg/L		96-h	LC_{50}	2.55 (2.25-2.92)
Mysid	Juvenile	S/M	250-400 mg/L		96-h	LC_{50}	3.8 (2.9-5.3)
Brandt et al. 1993							
Neomysis	Neonate	S/M	250-400 mg/L		96-h	LC_{50}	2.2 (2.0-2.5)
mercedis	Neonate	S/M	250-400 mg/L		96-h	LC_{50}	1.5 (1.2-1.8)
	Neonate	S/M	250-400 mg/L		96-h	LC_{50}	1.4 (1.3-1.5)
Mysid	Neonate	S/U	$20^{o}/_{oo}$		96-h	LC_{50}	4.0 (N/A)
Cripe et al.							
Mysidopsis bahia	Neonate	S/U	$20^{o}/_{oo}$		96-h	LC_{50}	5.2 (N/A)
1989							
	Neonate	S/U	$20^{o}/_{oo}$		96-h	LC_{50}	5.0 (N/A)
	Neonate	S/U	$20^{o}/_{oo}$		96-h	LC_{50}	3.2 (N/A)
	Neonate	S/U	$20^{o}/_{oo}$		96-h	LC_{50}	5.4 (N/A)
Mysid	Juvenile	S/U	$25^{o}/_{oo}$		96-h	LC_{50}	11 (N/A)
Cripe 1994 *Mysidopsis bahia*							
Ostracod	N/A	S/U	26-28 mg/L	48-h	LC_{50}	2.0 (N/A)	
Naqvi and							
Cypria sp.							
Hawkins 1989							
Ostracod	Mature	S/U	44 mg/L		48-h	LC_{50}	47 (32-69)
Mayer and							
Cypridopsis vidua							
Ellersieck 1986							
Pink shrimp	N/A	F/U	$20 \pm 2^{o}/_{oo}$		96-h	LC_{50}	12.50 (N/A)
Bahner and Nimmo							
Penaeus duorarum							1975
Pink shrimp	3-5 day	S/U	25%		96-h	LC_{50}	12 (N/A)
Cripe 1994							

Penaeus duorarum								
Pink shrimp	juvenile	F/U	19 $^{o}/_{oo}$		48-h	EC_{50}	280 (N/A)	
	Mayer 1987							
Penaeus duorarum								
Planarian	20-25 mg		S/U	N/A	7-d	LC_{50}	13,100 (N/A)	
	Villar et al. 1993							
Dugesia	20-25 mg		S/U	N/A	7-d	LC_{50}	8,600 (N/A)	
dorotocephala								
Prawn	Mature		S/U	44 mg/L		96-h	LC_{50}	32 (N/A)
	Mayer and							
Palaemonetes	Mature		S/U	272 mg/L		96-h	LC_{50}	90 (67-120)
	Ellersieck 1986							
kadiakensis	Mature	F/U	272 mg/L		96-h	LC_{50}	12 (N/A)	
Rainbow trout	1.40 g		S/U	44 mg/L		96-h	LC_{50}	200 (160-
240)	Mayer and							
Oncorhynchus	1.40 g		S/U	272 mg/L		96-h	LC_{50}	138 (110-
170)	Ellersieck 1986							
mykiss	1.00 g		S/U	44 mg/L		96-h	LC_{50}	80 (75-86)
	1.00 g	S/U	44 mg/L		96-h	LC_{50}	66 (61-72)	
	1.00 g	S/U	44 mg/L		96-h	LC_{50}	100 (90-110)	
	1.10 g	S/U	40 mg/L		96-h	LC_{50}	4.1 (2.2-7.4)	
	1.10 g	S/U	40 mg/L		96-h	LC_{50}	94 (N/A)	
Rainbow trout	0.41 g		S/U	318-348 mg/L		96-h	LC_{50}	122 (98-153)
	Post and							
Oncorhynchus								
Schroeder 1971								
mykiss								
Redear sunfish	3.20 g		S/U	44 mg/L		96-h	LC_{50}	62 (58-67)
	Mayer and							
Lepomis								
Ellersieck 1986								
microlophus								

[a] S = Static
F = Flow through
M = Measured concentrations
U = Unmeasured concentrations

[b] Confidence limits

[c] N/A = Not available

B-1. Continued. Values (µg/L) from accepted tests the acute toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Method	Salinity/ Hardness	Test Length	Values µg/L Effect	(95% C.L. [b])	Reference
Rotifer *Brachionus calyciflorus*	Neonate	S/U	80-100 mg/L	24-h	LC_{50}	33,720 (28,790-39,650)	Fernandez-Casalderry et al. 1992
Rotifer *Brachionus rubens*	Neonate	S/M	80-100 mg/L	24-h	LC_{50}	35,300 (33,100-37,500)	Snell et al. 1989
Snipefly *Atherix variegata*	Late instar	S/U	44 mg/L	96-h	LC_{50}	385 (246-602)	Mayer and Ellersieck 1986
Spot *Leiostomus xanthurus*	Juvenile	F/U	24 $^{o}/_{oo}$	48-h	LC_{50}	320 (N/A)	Mayer 1987
Stonefly *Acroneuria pacifica*	Naiad	S/U	N/A	96-h	**TLm**	7.0 (N/A)	Jensen and Gaufin 1964
	Naiad	F/U	N/A	96-h	**TLm**	7.7 (N/A)	
Stonefly *Claassenia sabulosa*	2nd year class	S/U	44 mg/L	96-h	LC_{50}	2.8 (1.40-4.30)	Mayer and Ellersieck 1986
Stonefly *Isoperla sp*.	Naiad	S/U	44 mg/L	96-h	LC_{50}	0.69 (0.2-2.4)	Mayer and Ellersieck 1986
Stonefly *Pteronarcella badia*	1st year class	S/U	170 mg/L	96-h	LC_{50}	8.8 (7.0-11.0)	Mayer and Ellersieck 1986
	1st year class	S/U	40 mg/L	96-h	LC_{50}	6.2 (5.2-7.4)	
	2nd year class	S/U	44 mg/L	96-h	LC_{50}	1.1 (0.78-1.5)	
Stonefly	Naiad	S/U	N/A	96-h	**TLm**	50 (N/A)	

								Jensen and Gaufin
Pteronarcys californica								1964
Stonefly		2nd year	S/U	44 mg/L		96-h	LC_{50}	10 (7.0-13.0)
								Mayer and
Pteronarcys californica		class						Ellersieck 1986
Striped bass	21-d	F/U	488 mg/L		96-h	LC_{50}	16 (13-19)	
Fujimura et al. 1991								
Morone saxatilis	45-d	F/U	387 mg/L			96-h	LC_{50}	25 (19-34)
	39-d	F/U	379 mg/L		96-h	LC_{50}	12 (11-14)	
	13-d	F/U	N/A	96-h	LC_{50}	64 (55-77)		
	45-d	F/U	N/A	96-h	LC_{50}	100 (87-150)		
	45-d	F/U	N/A	96-h	LC_{50}	66 (58-74)		
Striped mullet		Juvenile	F/U	$27^{o}/_{oo}$		48-h	LC_{50}	330 (N/A)
								Mayer 1987
Mugil cephalus								
Tilapia		0.80 g	S/U	44 mg/L		96-h	LC_{50}	<2,400 (N/A)
								Mayer and
Tilapia mossambica		0.80 g	S/U	272 mg/L		96-h	LC_{50}	2,000 (N/A)
		Ellersieck 1986						
Yellow perch	1.40 g	S/U	44 mg/L		96-h	LC_{50}	263 (205-338)	
								Mayer and
Perca flavescens								
Ellersieck 1986								
Walleye		1.30 g	S/U	272 mg/L		96-h	LC_{50}	64 (59-70)
								Mayer and
Stizostedion vitreum								
		Ellersieck 1986						
Western		Tadpole	S/U	44 mg/L		96-h	LC_{50}	200 (90-270)
								Mayer and
chorus frog								Ellersieck
1986								
Pseudacris triseriata								

[a] S = Static
F = Flow through
M = Measured concentrations
U = Unmeasured concentrations
[b] Confidence limits
[c] N/A = Not available

B-2. Values (µg/L of formulation given) from unaccepted tests on the acute toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Salinity/ Hardness	Test Length	Formulation (% malathion)	Values µg/L	Effect (95% C.L.[a])	Test Reference Deficiencies
American eel *Anguilla rostrata*	N/A	50 mg/L	96-h	N/A[b]	LC_{50} 500	Rehwoldt et al. 1977	1
American eel *Anguilla rostrata*	57 mm	24 ± 1%	96-h	N/A	LC_{50} 82	Eisler 1970	2, 3
Atlantic silverside *Menidia menidia*	50 mm	24 ± 1%	96-h	N/A	LC_{50} 125	Eisler 1970	2, 3
Atlantic salmon *Salmo salar* and Fry	Alaevins	N/A	96-h	95%	LC_{50} 320	Wildish et al 1971	1
Banded killifish *Fundulus diaphnus*	N/A	50 mg/L	96-h	N/A	LC_{50} 240	Rehwoldt et al 1977	1
Barilius vagra	Adult	N/A	96-h	57%	LC_{50} 5020 LC_{50} 6020	Alam and Maughan 1992	1, 2
Backswimmer beetle *Notoneca sp.*	N/A	160 mg/L	24-h	N/A	LC_{100} 400	Perschbacher and Sarkar 1989	1, 4
Bluegill *Lepomis macrochirus*	N/A	256 mg/L	96-h	N/A	LC_{100} 100	Bills and Marking 1988	1, 2, 3, 4, 5
Bluegill *Lepomis macrochirus*	1.5-2.5 inches	18 mg/L	96-h	100%	LC_{50} 90	Pickering et al 1962	1
Bluegill *Lepomis macrochirus*	1.5-2.5 inches	18 mg/L	96-h	57%	LC_{50} 88	Pickering et al 1962	1, 2
Bluegill *Lepomis macrochirus*	1.5-2.5 inches	18 mg/L	96-h	20%	LC_{50} 550	Pickering et al 1962	1, 2
Bluegill *Lepomis macrochirus*	3.5 inches	18 mg/L	96-h	20%	LC_{50} 1,200	Pickering et al 1962	1, 2
Bluehead *Thalassoma bifasciatum*	80 mm	24 ± 1‰	96-h	N/A	LC_{50} 27	Eisler 1970	2, 3
Caddisfly *Arctopsyche grandis*	2-5 cm	8.0 mg/L	96-h	N/A	**TLm** 32	Gaufin et al 1961	1, 2, 3
Caddisfly *Arctopsyche grandis*	Larvae	N/A	96-h	N/A	**TLm** 23	Gaufin et al 1965	1, 2
Caddisfly *Hydropsyche*	Naiads	N/A	24-h	95%	**TLm** 12	Carlson 1966	1
Caddisfly *Hydropsyche californica*	2-5 cm	8.0 mg/L	96-h	N/A	**TLm** 22.5	Gaufin et al 1961	1, 2, 3
Caddisfly *Hydropsyche californica*	Larvae	N/A	96-h	N/A	**TLm** 7.2	Gaufin et al 1965	1, 2
Caddisfly *Hydropsyche morosa*	24 mg	N/A	3-h 6-h 3-h 6-h	N/A	LC_{50} > 50 LC_{50} 50 LC_{50} 50 LC_{50} < 50	Fredeen 1972	1, 2

[a] Confidence limits

[b] N/A = Not available

1. Essential information lacking, such as control survival
2. Formulation too low 4. No effect criteria given, such as LC_{50} or EC_{50}
5. Dissolved oxygen levels fell bellow acceptable levels (60%) during test
6. Inadequate number of concentrations tested, must be four or greater

B-2. Continued. Values (µg/L of formulation given) from unaccepted tests on the acute toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Salinity/ Hardness	Test Length	Formulation (% malathion)	Effect	Values µg/L (95% C.L.[a])	Reference	Test Deficiencies
Caddisfly *recurvata*	24 mg 6-h	N/A	3-h LC_{50} 3-h	N/A 50	LC_{50} LC_{50}	> 50 < 50	Fredeen 1972	1, 2 *Hydropsyche* 6-h
Carp *Cyprinus carpio*	7.5-10.5 cm	N/A	72-h	50%	N/A		Toor et al. 1973	1, 2, 4
Carp	N/A	50 mg/L	96-h	N/A	LC_{50}	1,900	Rehwoldt et al 1977	1

Cyprinus carpio								
Catfish *Clarias batrachus*	N/A	N/A	96-h	50%	LC_{50}	12,000	Singh and Singh 1987b	1
Chinook salmon 1, 2 *Oncorhynchus kisutch*	Fingerlings	N/A	96-h	N/A	LC_{50}	120	Parkhurst and Johnson 1955	
Chinook salmon *Oncorhynchus kisutch*	N/A	27-28°/$_{oo}$	96-h	95%	**TLm**	33.7 (21.3-53.1)	Mayer 1970	1
Cladoceran *Daphnia magna*	Adult	N/A	N/A	N/A	LC_{50}	0.098 (0.074,-13)	Rawash et al 1975	1
Cladoceran *Daphnia pulex*	1st instar	N/A	48-h	N/A	EC_{50}	1.8 (1.4-2.4)	Sanders and Cope 1966	1
Cladoceran *Simocephalus serrulatus*	1st instar	N/A	48-h	N/A	EC_{50} EC_{50}	3.5 (2.6-4.8) 6.2 (4.4-8.7)	Sanders and Cope 1966	1
Clam *Donax cuneatus*	20-25 mm	33.5°/$_{oo}$	80-h	1 µg/L	N/A		Mane et al 1979	1, 2, 3, 4
Clam *Katelysia opima*	25-30 mm	33.5°/$_{oo}$	80-h	1 µg/L	N/A		Mane et al 1979	1, 2, 3, 4
Colorado squawfish *Ptychocheilus lucius*	Adult	361-379 mg/L	24-h	93%	N/A		Beyers and Sikoski 1994	1, 4
Crayfish *Orconectes rusticus*	N/A	256 mg/L	96-h	N/A	LC_{100}	1000	Bills and Marking 1988	1, 4
Crayfish *Procambarus clarkii*	Juvenile	4 mg/L	96-h	1%	LC_{50}	50,000	Cheah et al 1979	2, 3
Eastern mudminnow 1, 3 *Umbra pygmaea*		3-5 cm	N/A	96-h	99.5%	LC_{50}	240 ± 40 Bender and Westman 1976	
Fathead minnow *Pimephales promelas*	1.5-2.5 inches	18 mg/L 360 mg/L	96-h	100% 96-h	LC_{50} 100%	23,000 LC_{50} 16,000	Pickering et al 1962	
Fathead minnow *Pimephales promelas*	1.5-2.5 inches	18 mg/L	96-h	57%	LC_{50}	25,000	Pickering et al 1962	1, 2
Flagfish *Jordanella floridae*	37-d 37-d	43-48 mg/L 43-48 mg/L	168-h 48-h	N/A N/A	N/A LC_{50}	280	Hermanutz et al 1985	1, 3, 4
Fowler's toad *Bufo woodhousii*	4-5 weeks	N/A	96-h	Technical (N/A)	LC_{50}	420 (160-1,100)	Sanders 1970	1
Freshwater mussel *Lamellidens marginalis*	N/A ppm	140 ± 20	48-h	95%	LC_{50}	100,000	Rao et al 1987	1

[a] Confidence limits
[b] N/A = Not available

1. Essential information lacking, such as control survival
2. Formulation too low in percent active ingredient
3. Unacceptable mortality range, must be $\leq$ 30 % mortality to $\geq$ 60 % mortality
4. No effect criteria given, such as LC_{50} or EC_{50}
5. Dissolved oxygen levels fell bellow acceptable levels (60%) during test
6. Inadequate number of concentrations tested, must be four or greater

B-2. Continued. Values (µg/L of formulation given) from unaccepted tests on the acute toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Salinity/ Hardness	Test Length	Formulation (% malathion)	Effect	Values µg/L (95% C.L.[a])	Reference	Test Deficiencies
Freshwater prawn *Macrobrachium rosenbergii*	20 ± 2 mm	N/A	96-h	N/A	LC_{50}	9.0	Natarajan et al 1992	1
Amphipod N/A *Gammarus lacustris*	N/A	96-h	N/A	**TLm**		1.62	Gaufin et a. 1965	1, 2
Freshwater snail *Helisoma trivolvis*	Eggs 1 3-5 mm 8-10 mm 8-10mm	0.9 ± 1.35 mg/L	24-h	91%	LC_{50} LC_{50} LC_{50} LC_{50}	187,650 268,110 478,650 228,840	Tchounwou et al 1991	1
Freshwater snail	Eggs	10.9±1.35	24-h	91%	LC_{50}	94,780	Tchounwou et al 1991	1

Biomphalaria havanensis	2-3 mm 5-6 mm	mg/L		LC_{50}	LC_{50} LC_{50}	149,100 202,930 126,270		
Freshwater teleost *Heteropneustes fossilis*	15-20 g	140 mg/L	96-h	50%	LC_{50}	11,798	Dutta et al 1992	1, 2
Freshwater teleost *Heteropneustes fossilis*	23.0±3.5g	N/A	96-h	50%	LC_{50}	5,000	Singh et al 1984	1, 2
Frog *Rana hexadactyla*	Tadpole (20 mm)	20 mg/L	96-h	50%	LC_{50}	0.59 (0.43-0.78)	Jacob et al 1985	1, 2, 3
Goldfish *Carassius auratus*	1.5-2.5 inches	18 mg/L	96-h	57%	LC_{50}	790	Pickering et al 1962	1, 2
Green sunfish *Lepomis cyanellus*	4 inches	18 mg/L	96-h	20%	LC_{50}	600	Pickering et al 1962	1, 2
Guppy *Lebistes reticulatus*	N/A	N/A	168-h	95%	LC_{50}	819	Desi et al 1976	1, 3
Guppy *Lebistes reticulatus*	0 .75-1 inches	18 mg/L	96-h	100%	LC_{50}	840	Pickering et al 1962	1
Guppy *Libistes reticulatus*	N/A	50 mg/L	96-h	N/A	LC_{50}	1,200	Rehwoldt et al 1977	1
Guppy *Lebistes reticulatus*	3.0-3.8 cm	N/A	24-h	N/A	LC_{50}	50	Rongsriyam et al 1968	1
Mayfly *Hexagania*	Naiad	N/A	24-h	95%	**TLm**	630	Carlson 1966	1
Indian apple snail *Pila globosa*	N/A	140 ± 20 mg/L	48-h	95%	LC_{50}	5,620	Rao et al 1987	1
Korean shrimp *Palaemon macrodactylus*	N/A	28°/₀₀	96-h	95%	TL_{50} TL_{50}	81.5 (14.6-261) 9.0(4.4-18)	Mayer 1970	1
Largemouth bass *Micropterus salmoides*	3 inches	18 mg/L	96-h	20%	LC_{50}	250	Pickerings et al. 1962	1, 2
Larvivorous fish *Aplocheilus lineatus*	25-40 mm	N/A	48-h	50%	LC_{50}	975 ± 213	Jacob et al 1982	1, 2
Larvivorous fish *Macropodus cupanus*	20-28 mm	N/A	48-h	50%	LC_{50}	4,594 ± 557	Jacob et al 1982	1, 2
Leech *Hirundo nipponia*	4-5 cm	N/A	48-hr	Technical	LC_{50}	17,000	Kimura and Keegan 1966	1, 3, 6

[a] Confidence limits
[b] N/A = Not available

1. Essential information lacking, such as control survival
2. Formulation too low in percent active ingredient
3. Unacceptable mortality range, must be $\leq$ 30 % mortality to $\geq$ 60 % mortality
4. No effect criteria given, such as LC_{50} or EC_{50}
5. Dissolved oxygen levels fell bellow acceptable levels (60%) during test
6. Inadequate number of concentrations tested, must be four or greater

B-2. Continued. Values (µg/L of formulation given) from unaccepted tests on the acute toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Salinity/ Hardness	Test Length	Formulation (% malathion)	Effect	Values µg/L (95% C.L.[a])	Reference	Test Deficiencies
Mayfly *Ephemerella grandis*	Nymphal	N/A	96-h	N/A	**TLm**	100	Gaufin et al 1965	1
Microcrustaceans	N/A	12 mg/L	48-h	56.1%	LC_{50}	8-2.7	Naqvi and Hawkins 1989	1
Midge *Glyptotendipes paripes*	4th instar	N/A	24-h	Technical	LC_{50}	4	Ali 1981	1
Midge *Chironomus decorus*	4th instar	N/A	24-h	Technical	LC_{50}	32	Ali 1981	1
Midge *Chironomus crassicaudatus*	4th instar	N/A	24-h	Technical	LC_{50}	56	Ali 1981	1
Midge *Chironomus tentans*	4th instar	40-48 mg/L	72-h	99%	LC_{50} EC_{50}	620 (460-835) 250 (923-6770)	Hansen, Jr. and Kawatski 1976	1
Midge *Goeldichironomus holoprasinus*	4th instar	N/A	24-h	Technical	LC_{50}	28	Ali 1981	1
Midge	4th instar	N/A	24-h	Technical	LC_{50}	32	Ali 1981	1

Tanytarsus spp.							
Midge *Cricotopus* (*sylvestri* and *bicinctus*)	4th instar	N/A	24-h	N/A	LC_{50} 30-90	Ali and Mulla 1980	1
Midge *Chironomus decorus*	4th instar	N/A	24-h	N/A	LC_{50} 70	Ali and Mulla	1
Midge *Dicrotendipes californicus*	4th instar	N/A	24-h	N/A	LC_{50} 80-220	Ali and Mulla	1
Midge *Tanypus grodhausi*	4th instar	N/A	24-h	N/A	N/A	Ali and Mulla	1, 4
Mosquito *Aedes cantans*	4th instar	N/A	24-h	N/A	LC_{50} 48.8 (24.9-74.1)	Rettich 1977	1
Mosquito *Aedes vexans*	4th instar	N/A	24-h	N/A	LC_{50} 26.1 (23.8-28.5)	Rettich 1977	1
Mosquito *Aedes excrucians*	4th instar	N/A	24-h	N/A	LC_{50} 30.3	Rettich 1977	1
Mosquito *Aedes communis*	4th instar	N/A	24-h	N/A	LC_{50} 38.2	Rettich 1977	1
Mosquito *Aedes sticticus*	4th instar	N/A	24-h	N/A	LC_{50} 15.5	Rettich 1977	1
Mosquito *Aedes punctor*	4th instar	N/A	24-h	N/A	LC_{50} 44.1	Rettich 1977	1
Mosquito *Anophelesis freeborni*	4th instar	N/A	N/A	N/A	LC_{50} 130	Wolmeldorf et al 1970	
Mosquito *Anopheles stephensi*	4th instar	N/A	24-h	$\geq$ 95%	LC_{50} 4-10	Chitra and Pillai 1984	1, 3, 6
Mosquito *Culiseta annulata*	4th instar	N/A	24-h	N/A	LC_{50} 24.5	Rettich 1977	1

[a] Confidence limits

[b] N/A = Not available

1. Essential information lacking, such as control survival
2. Formulation too low in percent active ingredient
3. Unacceptable mortality range, must be $\leq$ 30 % mortality to $\geq$ 60 % mortality
4. No effect criteria given, such as LC_{50} or EC_{50}
5. Dissolved oxygen levels fell bellow acceptable levels (60%) during test
6. Inadequate number of concentrations tested, must be four or greater

B-2. Continued. Values (µg/L of formulation given) from unaccepted tests on the acute toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Salinity/ Hardness	Test Length	Formulation (% malathion)	Effect	Values µg/L (95% C.L.[a])	Reference	Test Deficiencies
Mosquito *Culex pipiens molestus*	4th instar	N/A	24-h	N/A	LC_{50}	34.2	Rettich 1977	1
Mosquito *Culex pipiens molestus*	Larval	N/A	48-h	30%	LC_{50}	24.0	Rettich 1979	1, 2
Mosquito *Culex pipiens pipiens*	4th instar	N/A	24-h	N/A	LC_{50}	32.2 (8.8-65.6)	Rettich 1977	1
Mosquito *Culex pipiens*	4th instar	N/A	N/A	N/A	LC_{50}	3.4 (2.7-4.3)	Rawash et al 1975	1
Mosquito *Culex pipiens*	Final-instar	N/A	24-h	N/A	LC_{50}	50	Rongsriyam 1968	1
Mosquito *Culex quinquefasciatus*	N/A	N/A	24-h	Technical	LC_{50}	76-500	Al-Khatib 1985	1
Mosquito	N/A	N/A	24-h	N/A	LC_{50}	2.87	Tietze et al 1993	1

Toxorhynchites splendens							
Mosquito *Wyeomyia smithii*	2nd instar	N/A	7-day	Technical	N/A	Strickman 1985	1
Mosquito-fish *Gambusia affinis*	N/A	12 mg/L	96-h	56.1%	LC_{50} 200	Naqvi and Hawkins 1987	1, 2, 6
Mysids *Mysidopsis bahia*	<1 day 5-day 10-day	20.7°/$_{oo}$ (20.3-21.4)	96-h	71.5% LC_{50}	LC_{50} 3.0 (2.6-4.0) 3.1 (2.8-3.5) LC_{50} 2.6 (2.3-2.9)	Goodman et al 1988	2
Northern puffer *Sphaeroides maculatus*	183 mm	24 ± 1%	96-h	N/A	LC_{50} 3,250	Eisler 1970	2, 3
Oligochaete *Lumbriculus variegatus*	N/A	30 mg/L	96-h	reagent grade	LC_{50} 20,500	Bailey et al 1980	1
Ostracod *Cypretta kawatai*	Adult	40-48 mg/L	72-h	99%	LC_{50} 51 (38.8-76.9) EC_{50} 86 (6.06-12.2)	Hansen, Jr. and Kawatski 1976	1
Pumpkinseed *Lepomis gibbosus*	N/A	50 mg/L	96-h	N/A	LC_{50} 480	Rehwoldt et al 1977	1
Puntius ticto	50-68mm	68-88 mg/L	96-h	96.45%	LC_{50} 7.4	Bhatia 1971	1, 3
freshwater fish		50 mg/L 200 mg/L	96-h	N/A	N/A	Birge et al 1979	1
Rainbow trout *Oncorhynchus mykiss*	Fry	N/A	72-h	N/A	N/A	Lewallen and Wilder 1962	1, 4
Rainbow trout *Oncorhynchus mykiss*	10 cm 6.0 cm	140 mg/L (95-170)	120-h 96-h	57% 57%	**TLm** 2.3 **TLm** 2.8	Smith and Grigoropoulos 1968	1, 2
Red crawfish *Procambarus clarkii*	4-10 g	N/A	72-h	N/A	N/A	Muncy and Oliver, Jr. 1963	1, 2, 4
Red shiners *Cyprinella lutrensis*	4.8 cm	140 mg/L (95-170)	120-h	57%	**TLm** 23.0	Smith and Grigoropoulos 1963	1, 2

[a] Confidence limits

[b] N/A = Not available

1. Essential information lacking, such as control survival
2. Formulation too low in percent active ingredient
3. Unacceptable mortality range, must be $\leq$ 30 % mortality to $\geq$ 60 % mortality
4. No effect criteria given, such as LC_{50} or EC_{50}
5. Dissolved oxygen levels fell bellow acceptable levels (60%) during test
6. Inadequate number of concentrations tested, must be four or greater

B-2. Continued. Values (µg/L of formulation given) from unaccepted tests on the acute toxicity of malathion to aquatic animals.

Species	**Life Stage/ Size**	**Salinity/ Hardness**	**Test Length**	**Formulation (% malathion)**	**Effect**	**Values µg/L (95% C.L.[a])**	**Reference**	**Test Deficiencies**
Rotifer *Brachionus rubens*	Hatchling	80-100 mg/L	24-h	N/A	LC_{50}	35,300	Snell and Persoone 1989 B	1
Caddisfly *Hydropsyche morosa*	24 mg	N/A	3-h 6-h 3-h 6-h	N/A	LC_{50} LC_{50} LC_{50} LC_{50}	> 50 50 50 < 50	Fredeen 1972	1, 2
Caddisfly *Hydropsyche recurvata*	24 mg	N/A	3-h 6-h 3-h 6-h	N/A	LC_{50} LC_{50} LC_{50} LC_{50}	> 50 50 < 50 <50	Fredeen 1972	1, 2
Snakehead catfish *Channa punctatus*	13-18 cm	120 mg/L	48-h	commercial	N/A		Perschbacher and Sarkar 1989	1, 4
Snakehead catfish *Channa punctatus*	Adult (59.8±3g)	18 mg/L	96-h	Technical commercial	LC_{50} LC_{50}	4,510 (4110-4960) 3,890 (3460-4380)	Haider and Inbaraj 1986	1, 3 , 6 1, 2, 3, 6
Snakehead catfish	24.5±2.6g	N/A	96-h	50%	LC_{50}	2,900 (2870-2940)	Singh et al 1984	1, 2

Channa punctatus								
Stonefly *Acroneuria pacifica*	2-5 cm	8.0 mg/L	96-h	N/A	**TLm**	7.2	Gaufin et al 1961	1, 2, 3
Stonefly *Acroneuria pacifica*	2-2.5 cm	N/A	96-h	N/A	**TLm**	7	Gaufin et al 1965	1, 2
Stonefly *Acroneuria pacifica*	Naiads	N/A	30-d	95%	**TLm**	0.78	Jensen and Gaufin 1964	1
Stonefly *Claassenia sabulosa*	2-5 cm	8.0 mg/L	96-h	N/A	**TLm**	56	Gaufin et al 1961	1, 2, 3
Stonefly *Pteronarcys californica*	2-5 cm	8.0 mg/L	96-h	N/A	**TLm**	100	Gaufin et al 1961	1, 2, 3
Stonefly *Pteronarcys californica*	Naiads	N/A	30-d	95%	**TLm**	8.8	Jensen and Gaufin 1964	1
Stonefly *Pteronarcys californica*	4-6 cm	N/A	96-h	N/A	**TLm**	50	Gaufin et al 1965	1, 2
Striped bass *Morone saxatilis*	Larvae	488 mg/L	96-h	94.2%	LC_{50} NOEC LOEC	15.8 (13.2-18.8) 7.1 12.0	CDFG 1988-1989	1, 4
	Larvae	N/A	96-h	94.2%	N/A			
	Larvae	440 mg/L	96-h	94.2%	N/A			
	Larvae	492 mg/L	96-h	94.2%	N/A			
	Larvae	379 mg/L	96-h	94.2%	LC_{50} NOEC LOEC	17.6 < 2.4 2.4		
	Juvenile	398 mg/L	96-h	94.2%	LC_{50} NOEC LOEC	34 (29,38) 0 31		
Striped bass *Morone saxatilis*	N/A	30 mg/L	96-h	95%	TL_{50}	14 (13-15)	Mayer 1970	1
Striped bass *Morone saxatilis*	Juvenile (14-83 mm)	30 ± 1%	96-h	95%	TL_{50}	14 (13-15)	Korn and Earnest 1974	1, 3, 5, 6

[a] Confidence limits

[b] N/A = Not available

1. Essential information lacking, such as control survival
2. Formulation too low in percent active ingredient
3. Unacceptable mortality range, must be $\leq$ 30 % mortality to $\geq$ 60 % mortality
4. No effect criteria given, such as LC_{50} or EC_{50}
5. Dissolved oxygen levels fell bellow acceptable levels (60%) during test
6. Inadequate number of concentrations tested, must be four or greater

B-2. Continued. Values (µg/L of formulation given) from unaccepted tests on the acute toxicity of malathion to aquatic animals.

Species	**Life Stage/ Size**	**Salinity/ Hardness**	**Test Length**	**Formulation (% malathion)**	**Effect**	**Values µg/L (95% C.L.[a])**	**Reference**	**Test Deficiencies**
Striped bass *Marone saxatilis*	N/A	50 mg/L	96-h	N/A	LC_{50}	39.0	Rehwoldt et al 1977	1
Striped killifish *Fundulus majalis*	84 mm	24 ± 1%	96-h	N/A	LC_{50}	250	Eisler 1970	2, 3
Striped mullet *Mugil cephalus*	48 mm	24 ± 1%	96-h	N/A	LC_{50}	550	Eisler 1970	2, 3
Teleost *Saurotherodon mossambicus*	N/A	140 ± 20	48-h	95%	LC_{50}	5,620	Rao et al 1987	1
Tilapia *Tilapia mossambica*	8 ± 2 g	40 ± 20 mg/L	48-h	Technical (95%) Commercial (50%)	LC_{50} LC_{50}	5,592 ± 90 377 ± 40	Sailatha et al 1981	1

Tilapia *Tilapia mossambica*	8 ± 2 g	N/A	48-h	95%	LC50	5,600 ± 100	Sahib and Rao 1980	1
Toad *Bufo arenarum*	N/A	N/A	96-h	Technical	N/A		Venturino et al 1992	1, 4
Topminnow *Fundulus heteroclitus*	56 mm	24 ± 1%	96-h	N/A	LC_{50}	80,400	Eisler 1970	2, 3
Tubificid worm *Branchiura sowerbyi*	N/A	N/A	72-h	Technical	N/A		Naqvi 1977	1, 3, 4, 6
Tubificids *Tubificidae*	200 mm	N/A	96-h	99.6%	LC_{50}	16,700 ± 1750 1966	Whitten and Goodnight	1
Western chorus frog *Pseudacris triseriata*	1 week	N/A	96-h	Technical	LC_{50}	200 (90-270)	Sanders 1970	1
White perch *Roccus americanus*	N/A	50 mg/L	96-h	N/A	LC_{50}	1,100	Rehwoldt et al 1977	1

[a] Confidence limits

[b] N/A = Not available

1. Essential information lacking, such as control survival
2. Formulation too low in percent active ingredient
3. Unacceptable mortality range, must be $\leq$ 30 % mortality to $\geq$ 60 % mortality
4. No effect criteria given, such as LC_{50} or EC_{50}
5. Dissolved oxygen levels fell bellow acceptable levels (60%) during test
6. Inadequate number of concentrations tested, must be four or greater

APPENDIX C. Abstracts of accepted and unaccepted chronic toxicity tests reviewed for hazard assessment.

Accepted chronic toxicity tests - The following tests used accepted test methods.

Beyers et al (1994) - In 1992, a 32-d toxicity test was performed by the Larval Fish Laboratory, Department of Fishery and Wildlife Biology and Department of Environmental Health, Colorado State University in Fort Collins with technical malathion (93%) with young Colorado squawfish *Ptychocheilus lucius* and young bonytail *Gila elegans*. ASTM (1990) test guidelines followed. Water quality parameters were: temperature of 22.2 to 22.7°C; pH of 7.9 to 8.2; dissolved oxygen of 6.1 to 7.0 mg/L; and hardness of 344 to 378 mg/L as $CaCO_3$. There was no mention of control survival. The NOEC for *P. lucius* and *G. elegans* was 455 µg/L and 521 µg/L, respectively.

Eaton (1970) - In 1966, three flow-through chronic toxicity tests were performed at the National Water Quality Laboratory, Duluth, Minnesota on malathion (95%) with bluegill *Lepomis macrochirus*. APHA (1967) testing standards were used. Five concentrations plus a control were used. There were 10 organisms per replicate used. Water quality parameters during the tests were: temperature of 13-20°C, 20-25°C, 9-29°C; pH of 7.2-7.75; 7.45-7.90; 7.4-8.5; dissolved oxygen of 3.5 -10.8 mg/L, 3.3-9.2 mg/L , 4.2-16.3 mg/L; and a hardness of 194-220, 200-218, 200-218 mg/L as $CaCO_3$. Control survival was >85%. The Maximum Acceptable Toxicant Concentration (MATC) was between 3.6 and 7.4 µg/L and was determined by a geometric mean of the range as 5.16 µg/L for *L. macrochirus*. The MATC was between 200 and 580 µg/L and was determined by a geometric mean of the range as 340.59 µg/L for *P. promelas*.

Unaccepted chronic toxicity tests- The following chronic toxicity tests were deemed not acceptable due to test methods and/or availability for review.

Hermanutz et al (1985) - In 1985, 184-d chronic toxicity tests were performed by the Environmental Research laboratory, Duluth, Minnesota on malathion (percent active ingredient not given) with flagfish *Jordanella floridae*. An inadequate number of concentrations were tested.

C-1. Values (µg/L) from accepted tests on the chronic toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Method[a]	Salinity/ Hardness	Test Length	Effect	Values µg/L (95% C.L.[b])	Reference
Bluegill *Lepomis macrochirus*	Fry	F/U	194-220 mg/L	119-180-d	MATC	5.16	Eaton 1970
Bonytail *Gila elegans*	young	F/U	237-257 mg/L	32-d	MATC	1407.1	Beyers et al. 1994
Colorado squawfish *Ptychocheilus lucius*	young	F/U	237-257 mg/L	32-d	MATC	2428.3	Beyers et al. 1994
Fathead minnow *Pimephales promelas*	Fry	F/U	194-220 mg/L	119-180-d	MATC	340.59	Eaton 1970

[a] F = Flow through
U = Unmeasured concentrations
[b] Confidence limits

C-2. Values (µg/L) from unaccepted tests on the chronic toxicity of malathion to aquatic animals.

Species	Life Stage/ Size	Method	Salinity/ Hardness	Test Length	Effect	Values µg/L (95% C.L.[a])	Reference	Test Deficiencies[c]
Flagfish *Jordanella floridae*		F/U	43-48 mg/L	184-d			Hermanutz et al. 1985	1,2,3

[a] Confidence limits
[b] N/A = Not available
[c] Test deficiencies
1. Essential information lacking, such as control survival
2. Number of concentrations tested inadequate
3. No effect criteria given