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BIOACCUMULATION AND EFFECTS ON  
REPRODUCTION IN AQUATIC ORGANISMS:  
AN ASSESSMENT OF THE  
CURRENT LITERATURE

by

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## PREFACE

This report discusses a review of the open literature conducted at the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, during the period from October 1984 to February 1985. The review was conducted as part of the Long-Term Effects of Dredging Operations (LEDO) Program, which is sponsored by the Office, Chief of Engineers (OCE), U. S. Army. The LEDO Program is managed through the Environmental Effects of Dredging Programs, Dr. R. M. Engler, Manager, and Mr. R. L. Lazor, LEDO Coordinator. The Technical Monitors were Dr. Robert Pierce and Dr. William L. Klesch of OCE, and Mr. Charles W. Hummer, Dredging Division, Water Resources Support Center.

Section 103 of Public Law 92-532 (Marine Protection, Research, and Sanctuaries Act of 1973) and Section 404 of Public Law 92-500 (Federal Water Pollution Control Act of 1972) require, among other things, that certain ecological evaluations be made prior to disposal of dredged materials in ocean or inland environments. As part of these evaluations, an estimation of the potential for bioaccumulation of environmental contaminants is often carried out. At present there is insufficient interpretive guidance to relate the results of bioaccumulation tests to the potential for unacceptable adverse environmental impact in the aquatic environment.

This report represents the second document produced under Work Unit 31773, Environmental Interpretation of Consequences from Bioaccumulation, of the LEDO program. Work Unit 31773 was designed, in part, to help provide that interpretive guidance. As a first step, the open literature was reviewed to examine the relationship, if any, between bioaccumulation and sublethal biological effects in aquatic organisms. One of the conclusions of that review was that evaluating effects on reproduction appeared to hold greater promise, in terms of interpretability and usage in a regulatory environment, than many other sublethal effects assessments appearing in the published literature. The review reported herein was designed to provide an initial compilation of information on the association between bioaccumulation and effects on reproduction and to help guide future research conducted under this LEDO work unit.

The review was conducted by Dr. T. M. Dillon and Ms. A. B. Gibson of the Ecosystems Research and Simulation Division (ERSD), EL. The work was

performed under the general supervision of Dr. R. K. Peddicord, Team Leader, Biological Evaluation and Criteria Team, EL, and Dr. C. R. Lee, Group Chief, CMRCG, EL. The Chief of ERSD was Mr. D. L. Robey and Chief of EL was Dr. John Harrison.

COL Robert C. Lee, CE, was Commander and Director of WES during the conduct of the study. COL Allen F. Grum, USA, was Director of WES during the preparation and publication of this report. Mr. Fred R. Brown and Dr. Robert W. Whalin were Technical Directors.

This report should be cited as follows:

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BIOACCUMULATION AND EFFECTS ON REPRODUCTION IN AQUATIC ORGANISMS:  
AN ASSESSMENT OF THE CURRENT LITERATURE

PART I: INTRODUCTION

Background

1. The aquatic disposal of dredged material is regulated by two Federal laws: Section 404 of the Federal Water Pollution Control Act, as amended (PL 92-500), and Section 103 of the Marine Protection, Research, and Sanctuaries Act, as amended (PL 92-532). The regulations implementing these laws generally require, among other things, an evaluation of sediment toxicity and bioaccumulation potential prior to dredging and aquatic disposal. Because relatively few dredged materials have been found to be acutely toxic in regulatory testing programs, decisionmakers have had to rely less on toxicity and more heavily on bioaccumulation information. Unfortunately, there is little generally accepted interpretive guidance regarding the biological importance of bioaccumulation in aquatic organisms (Peddicord and Hansen 1983).

2. In an effort to provide guidance in this area, an assessment of the literature was recently conducted in which the association between bioaccumulation and biological effect was examined (Dillon 1984). Dillon's study found that only a small minority (6 percent) of published papers that dealt with the biological effects of environmental contaminants also contained tissue residue information. Because of this relatively narrow database, detailed guidance could not be provided regarding the biological importance of specific tissue concentrations of environmental contaminants.

3. However, several general conclusions were reached by Dillon (1984). A broad spectrum of biological effects assessments including both organismic (reproduction, growth, metabolism, morphology/histology, behavior, and osmoregulation) as well as biochemical (enzymes, biochemical composition, and blood chemistry) end points were evaluated for their ecological interpretability and their potential use in a regulatory context. Dillon (1984) concluded that, at present, organismic parameters would generally be of greater utility than biochemical ones and that measures of reproduction, growth, or overall metabolic indices appeared particularly promising. He also concluded that

aquatic animals generally appeared to show effects in association with lower body burdens of chlorinated hydrocarbons than petroleum hydrocarbons and that effects of heavy metals were intermediate.

#### Purpose

4. The purpose of this literature assessment was threefold:
  - Select one of the more promising biological end points, (reproduction), and examine its relationship with bioaccumulation.
  - Broaden the base of technical information by including those numerous published papers that contained effects assessment data but no tissue residues information.
  - Provide an initial source of information for decisionmakers who have site-specific concerns (e.g., reproductive effects in a particular organism exposed to a specific contaminant).

## PART II: APPROACH

### Literature Review

5. The literature was examined for papers dealing with the sublethal effects of heavy metals and organic contaminants on reproduction in fish and aquatic invertebrates. Citations dealing with petroleum hydrocarbons will be addressed in a separate report. References dealing with reproductive effects reported by Dillon (1984) that contain empirically derived tissue residue data are included in this report.

6. For every paper that was reviewed, the following information was recorded: contaminant, test animal, exposure time, exposure concentration, resultant tissue concentration if reported or empirically derived, and any observed change in reproductive activity. The test animal was identified by common name and/or phylogenetic group. Tissue concentrations were all expressed on a wet-weight basis. If the original citation reported tissue concentrations on a dry-weight basis, they were converted to wet weight using the value of 80 percent body water (Emerson 1969, Tucker and Harrison 1974, Florey 1966, Lagler et al. 1962). While the body water percentages of different animals can and do differ somewhat from this representative value of 80 percent, the quantitative variability due to interspecific differences is much less than that due to expressing some tissue concentrations on a wet-weight basis and some on a dry-weight basis. Exposure concentrations were all given in micrograms per liter (parts per billion) unless noted otherwise.

7. All citations were examined for the highest whole-body tissue concentration at which no effect on reproduction was observed as well as for the lowest tissue concentration at which an effect was observed. These values are referred to as the highest no effects concentration (HNEC) and the lowest effects concentration (LEC). Some papers reported a dose-response and therefore contained both HNEC and LEC values. Other papers had only one or the other, depending on whether or not a significant response was detected.

8. The HNEC and LEC values were initially used to compare the different classes of contaminants. The second comparison, using only the LEC, evaluated the relative sensitivity of the phylogenetic groups (i.e., fish, crustaceans, and other invertebrates). Papers that reported contaminant concentrations in specific tissues or organs rather than in the whole animal were

not included in either of the two comparisons.

9. The HNEC and LEC values were extremely variable, as will be discussed later. For that reason, statistical comparison of the data was not conducted, but descriptive statistics (mean, standard deviation, etc.) were calculated.

#### Estimation of Tissue Concentrations

10. Many of the papers examined reported effects on reproduction but did not report body burden information. In an effort to utilize the biological effects information in these references and therefore broaden the technical base, tissue concentrations were estimated for those papers.

11. All the papers reviewed that did not report tissue residues involved exposure of animals to contaminants in aqueous solution. If a suitable bioconcentration factor (BCF) could be identified, then an estimation of tissue residues was calculated for each contaminant according to the following formula:

$$BCF = \frac{\text{Concentration in Tissues}}{\text{Concentration in Water}}$$

where both concentrations are in the same dimension of magnitude.

12. BCFs for a wide variety of environmental contaminants have been reported in the US Environmental Protection Agency's Water Quality Documents (Environmental Protection Agency 1980). These documents (one for each of 64 selected contaminants) are compilations of the available technical information upon which the Federal Water Quality Criteria were developed. Each of these documents contains a list of BCFs for aquatic animals. For purposes of this report, a mean BCF was calculated for each contaminant of interest using all values for both freshwater and saltwater animals. The mean BCFs were then used to estimate tissue concentrations from aqueous exposure concentrations reported in those papers containing reproductive effects but no bioaccumulation information.

13. This estimation assumes equilibrium conditions, i.e., constancy of level of exposure and steady-state concentration in the tissues of the organism. While this is undoubtedly not the case for all BCF values and all papers

included in this review, it was believed to be an acceptable assumption given the results of the calculated mean BCFs (see Results) and because it resulted in a substantial increase in the amount of information associating bioaccumulation with biological change.

### PART III: RESULTS AND ANALYSIS

#### Results

14. A total of 66 citations that examined the association between bioaccumulation of contaminants and changes in reproduction in aquatic animals were identified and are shown in Table 1. Entries dealing with heavy metals appear first, chlorinated hydrocarbons next, and other contaminants last. Citations that evaluated the effects of more than one type of contaminant appear more than once in the table. Consequently, the number of entries found in Table 1 (hereafter referred to as table entries) is greater than the actual number of literature citations.

15. Heavy metals (especially cadmium and mercury) were the most frequently studied class of contaminant and appeared in 71 percent of the table entries (Table 2). Chlorinated hydrocarbons appeared in 22 percent of the entries while other organic contaminants appeared in 7 percent. No one particular type of nonmetal contaminant dominated these latter two classes of contaminants. There was a total of five table entries involving polychlorinated biphenyls. Table 2 also indicates that more data are available for fish, which appeared in 61 percent of the entries followed by crustaceans (27 percent) and other invertebrates (12 percent).

16. A wide variety of techniques were used to assess reproductive success. Table 3 gives a semiquantitative summary of the frequency with which those techniques were used. Hatching success was the most frequently reported parameter of reproduction followed closely by eggs and progeny. A large number of investigators utilized some integrated measure of reproduction such as young produced/female/lifetime. The least examined parameters of reproduction were abnormal eggs or larvae, fish spawns, and time to reproductive maturity.

17. Mean BCF values calculated for a number of contaminants from the US Environmental Protection Agency's Water Quality Documents are shown in Table 4. Although there was considerable variation around the mean BCF calculated for each contaminant, the ranking of BCFs appears quite reasonable. Contaminants whose bioaccumulation is generally of low concern had mean BCFs between 1 and 100, while those whose bioaccumulation is generally of highest concern had mean BCFs greater than 10,000. This relationship between mean BCF and general level of concern is very encouraging. It is also somewhat

surprising given the range of species tested and the diversity of investigative centers generating the data.

18. The mean BCF values in Table 4 were used to estimate tissue concentrations in those papers not reporting tissue residues. The tissue concentration in 40 out of the 71 (approximately 56 percent) entries in Table 1 were estimated in this manner. This estimation of body burden more than doubled the number of reproductive effects information available for analysis and therefore satisfied one of the three purposes of this report.

### Analysis

19. The HNEC and the LEC for all entries from Table 1 were grouped according to class of contaminant (Table 5). Both HNEC and LEC were extremely variable regardless of contaminant as evidenced by high coefficients of variation, which ranged from 142 percent to 231 percent. There was no obvious reduction in this variation when the more frequently examined contaminants (cadmium and mercury) were considered separately.

20. The mean HNEC was slightly lower than the mean LEC within each class of contaminant. This would be expected, considering what each term represents, but it contrasts with results reported by Dillon (1984) in which no clear pattern of lower mean HNEC values emerged. However, the HNEC and LEC mean values in Table 5 should not be interpreted too strictly due to the large amount of variation. One should not, for example, assume that any tissue concentration less than the HNEC is acceptable while all those above the LEC are not. This current data set is simply too variable to make those specific deductions.

21. Despite the high degree of variation within each class of contaminant, the mean HNEC and LEC for all contaminants varied over a relatively narrow range of values (7.86 to 60.1  $\mu\text{g/g}$ ). Corresponding mean HNEC and LEC values (Dillon 1984) taken from papers examining a variety of biological effects including reproduction and based strictly on reported rather than estimated tissue residues, varied in a similar manner and ranged from 6.82 to 64.8  $\mu\text{g/g}$ .

22. Dillon (1984) also reported an overall mean LEC taken from citations that examined reproductive effects, regardless of contaminant. That value corresponds very closely to a similar overall mean LEC that was

calculated from all the citations included in this report, as shown in the following tabulation. It should also be noted that in the present report, variation associated with the mean decreased while the total number of table entries greatly increased.

| Value                                        | LEC For All Contaminants<br>Reproductive Effects |               |
|----------------------------------------------|--------------------------------------------------|---------------|
|                                              | Dillon and<br>Gibson (1985)                      | Dillon (1984) |
| Mean                                         | 46.4                                             | 40.4          |
| ± Standard deviation                         | ± 78.9                                           | ± 106         |
| Coefficient of variation, %<br>(100 SD/mean) | 170                                              | 262           |
| Number of table entries                      | 70                                               | 20            |

23. The similarity in mean HNEC and LEC values reported in this paper and in Dillon (1984) tends to substantiate both the BCF values and the method employed here to estimate tissue concentrations from BCFs.

24. In an attempt to reduce the variability observed in Table 5, mean LEC values were calculated for the three major phylogenetic groups (fish, crustaceans, and other invertebrates) within each major class of contaminants (Table 6). There was no consistent decrease in variability as a result of this treatment except perhaps for the most frequently studied general category of organism (fish) and contaminant (heavy metals). Several of the animal-contaminant groupings contained too few LEC values to allow valid comparison.

25. The data in Table 6 also allow one to compare the three major groups of organisms in terms of overall sensitivity to bioaccumulation and observed changes in reproduction. The mean LEC values for all contaminants combined were 48.0, 46.2, and 41.8 µg/g for fish, crustacea, and other invertebrates, respectively. There is an appearance of greater sensitivity among invertebrates compared to fish. However, the database is too small and variable to imply discreet differences at this time. In addition, these data do not allow one to examine intraspecific differences at various life stages, which may be greater than any possible phylogenetic differences.

#### PART IV: SUMMARY AND CONCLUSIONS

26. Published references in the literature dealing with the effects of environmental contaminants on potential changes in reproductive activity in aquatic animals were identified and reported herein. The association between bioaccumulation and changes in reproductive activity was examined.

27. The most frequently examined class of contaminants (71 percent) was heavy metals, especially cadmium. Chlorinated hydrocarbons were the next most frequently studied contaminant (22 percent), followed by other organic contaminants (7 percent).

28. Fish were the most frequently studied organism and appeared in 61 percent of the table entries, followed by crustaceans (27 percent) and other invertebrates (12 percent). There was no clear indication that one phylogenetic group was any more sensitive than another.

29. Hatching success was the most frequently used method to evaluate reproduction. Effects on eggs, progeny, or larvae were the next most frequently examined aspect of reproduction. The least utilized were integrated reproductive rate functions, effects on spawning, abnormal eggs or larvae, and time to reproductive maturity.

30. Mean BCFs were calculated from data reported in the US Environmental Protection Agency's Water Quality Documents. Although there was considerable variation, the hierarchy of mean BCF values corresponded quite well to the levels of concern normally associated with the bioaccumulation of various contaminants. For example, larger BCF were associated with chlorinated hydrocarbons such as dioxin and polychlorinated biphenyls while lower values were generally associated with heavy metals such as antimony and thallium.

31. The mean BCF values were used to calculate estimated tissue concentrations from data in those publications that contained reproductive effects information but no measured tissue concentrations. This greatly increased the number of data sets available for analysis.

32. Within each class of contaminant, the calculated mean HNECs and LECs were quite variable. The variability was decreased only slightly when the most frequently examined class of contaminant (heavy metals) and phylogenetic group (fish) were considered together. Other groupings did not appear to appreciably decrease the level of variability.

33. The mean HNEC and LEC for the different classes of contaminants

varied over a relatively narrow range (7.86 to 60.1  $\mu\text{g/g}$ ), although large variation was associated with these means. This range is remarkably similar to the range reported by Dillon (1984): 6.82 to 64.8  $\mu\text{g/g}$ . The overall mean LEC for citations involving reproduction, regardless of contaminant, reported here (46.4  $\mu\text{g/g}$ ) is also similar to that reported by Dillon (1984): 46.4 versus 40.4  $\mu\text{g/g}$ . These similarities in mean values between the two reports tend to support the method used here to calculate estimated tissue concentrations since values in Dillon (1984) were based exclusively on empirically derived tissue concentration while only about 44 percent of the data in this report was so based.

34. Within each class of contaminant, the mean HNEC was always lower than the LEC. However, due to the variability associated with these values, it would be scientifically irresponsible to identify specific mean tissue concentrations in this report and conclude that all values above are unacceptable and all values below are acceptable. Rather, these data should be viewed in their entirety, providing readers and potential users a general perspective on relative tissue concentrations. However, the compilation of data contained in this report will provide a valuable initial source of information for those who have site-specific concerns.

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Table 1

Biological Effects of Exposure to Environmental Contaminants on Reproduction of Aquatic Animals as Reported in the Literature

| Contaminant | Organism*                       | Exposure                     |                    | Tissue Concentration†                | Biological Effect                                                                                      | Reference                                         |
|-------------|---------------------------------|------------------------------|--------------------|--------------------------------------|--------------------------------------------------------------------------------------------------------|---------------------------------------------------|
|             |                                 | Time                         | Concentration**    |                                      |                                                                                                        |                                                   |
| Cadmium     | Herring (M)                     | 30 hours                     | 50-10,000          | 73-14,610                            | Decreased total egg volume                                                                             | Alderdice et al. (1979)                           |
|             | Flounder (M)                    | 8 days                       | 100-1,000          | 146-1,461                            | Reduction in percent viable hatch                                                                      | Voyer et al. (1982)                               |
|             | Trout (Fw)                      | 156 weeks<br>(3 generations) | 0-3.4              | 0-10† (range in gill, kidney, liver) | No effect on percent hatched                                                                           | Benoit et al. (1976)                              |
|             |                                 |                              | 6.3                | No data                              | 100% mortality                                                                                         |                                                   |
|             | Crustacea (M)<br>(mysid shrimp) | 51 days                      | 5.1<br>10<br>25-53 | 7.5<br>14<br>33,077                  | No effect on reproduction<br>Reproductive rate enhanced<br>Inhibition of reproduction                  | Gentile et al. (1982)                             |
|             | Crustacea (M)<br>(mysid shrimp) | 23 days                      | 4.8<br>6.4-10.6    | 7<br>9.4-16                          | No reproductive effect<br>Delayed formation of brood<br>pouches and decreased number of young produced | Nimmo et al. (1978)                               |
|             | Crustacea (M)<br>(copepod)      | 21 days                      | 28                 | 41                                   | 100% mortality                                                                                         |                                                   |
|             | Crustacea (M)<br>(amphipod)     | 265 days                     | 5-150              | 7.3-220                              | Reduction in the daily rate of reproduction<br>Increase in abnormal eggs in a dose-response manner     | Paffenhofer and Knowles (1978)<br>Sundelin (1983) |

(Continued)

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\* Parenthetical entries after name of organism are defined as follows: (Fw) - Freshwater; (M) = Marine

\*\* Entries for exposure concentration are in units of micrograms per liter (ug/l) unless noted otherwise.

† Entries for tissue concentration in units of micrograms per gram (ug/g) wet weight whole animal unless noted otherwise. Annotations as follows:

†† Data originally reported on a dry-weight basis were converted to wet weight assuming 80 percent body water.

‡ Empirically derived tissue concentrations reported in original citation.

Table 1 (Continued)

| Contaminant         | Organism*                     | Exposure                                |                 | Tissue Concentration†         | Biological Effect                                                                                     | Reference                          |
|---------------------|-------------------------------|-----------------------------------------|-----------------|-------------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------|
|                     |                               | Time                                    | Concentration** |                               |                                                                                                       |                                    |
| Cadmium (continued) | Crustacea (M)<br>(amphipod)   | 460 days                                | 5-50            | 7.3-73                        | No surviving young produced                                                                           | Sundelin (1983)                    |
|                     | Crustacea (Fw)<br>(cladocera) | 72 hours                                | 0.2-0.8         | 0.29-1.2                      | Decreased size and number of broods                                                                   | Hatakeyama and Yasuno (1981a)      |
|                     |                               |                                         | 1.2-1.6         | 1.8-2.3                       | Decreased number of young and broods                                                                  |                                    |
|                     | Crustacea (Fw)<br>(cladocera) | Not reported<br>(at least 1 generation) | 5               | 7.3                           | Reduced number of young/female/lifetime                                                               | Kettle et al. (1980)               |
|                     | Sea Urchin (M)                | 30 days                                 | 100             | 146                           | Increased number of fertilized eggs that resulted in abnormal larvae. No mortality of adults          | Khristoforova et al. (1984)        |
|                     |                               |                                         | 500             | 730                           | Increased number of fertilized eggs that failed to develop into viable larvae. No mortality of adults |                                    |
|                     |                               |                                         | 1000            | 1460                          | 100% mortality of adults                                                                              |                                    |
|                     | Herring (M)                   | 14 days                                 | 0.1-5.0         | 0.04-0.76††, ‡                | No effect on hatching rate                                                                            | Westernhagen et al. (1974)         |
|                     | Garpiki (M)                   | 24 days                                 | 0-1<br>2-5      | 0-0.19††, ‡<br>0.19-0.36††, ‡ | No effect on reproduction<br>Percent viable hatch increased                                           | Westernhagen et al. (1975)         |
|                     | Flounder (M)<br>(eggs)        | 10 days                                 | 0-1.0           | 0-0.06††, ‡                   | Percent hatched and hatch rate unaffected                                                             | Westernhagen and Bethlefsen (1975) |
|                     |                               |                                         | 2-5             | 0.04-0.16††, ‡                | Percent hatched and hatch rate reduced                                                                |                                    |
|                     | Flagfish (Fw)                 | 100 days                                | 0-4.1           | 0-6‡                          | No effect on reproduction                                                                             | Spehar (1976)                      |

(Continued)

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Table 1 (Continued)

| Contaminant                     | Organism*                       | Exposure           |                            | Tissue Concentration†   | Biological Effect                                                                                                                                                                                                | Reference                        |
|---------------------------------|---------------------------------|--------------------|----------------------------|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
|                                 |                                 | Time               | Concentration**            |                         |                                                                                                                                                                                                                  |                                  |
| Cadmium (concluded)             | Flagfish (Fw)                   | 100 days           | 8.1-31                     | 10-35†                  | Reduced number of spawnings/<br>female and total embryos<br>produced                                                                                                                                             | Spehar (1976)                    |
|                                 | Crustacea (Fw)<br>(cladocera)   | 14 days            | 14.3-71.2 ug/g<br>dry food | 200-225††,‡             | No effect on number of young<br>produced                                                                                                                                                                         | Hatakeyama and<br>Yasuno (1981b) |
|                                 | Crustacea (Fw)                  | 14 days            | 341.3 ug/g<br>dry food     | 450††,‡                 | Decreased number of young<br>produced                                                                                                                                                                            | Hatakeyama and<br>Yasuno (1981b) |
|                                 | Crustacean (Fw)<br>(cladocera)  | 22 weeks           | 1-8                        | 3.5-10.3††,‡            | Reduced longevity and<br>increased mortality par-<br>tially offset by an<br>increase in brood size and<br>number of ovigerous<br>females; carrying capacity<br>(k) inversely related to<br>tissue concentrations | Marshall (1978)                  |
| Mercury                         | Mollusc (M)                     | 33-37 weeks        | 5-15                       | 18-54†                  | Production of abnormal larvae                                                                                                                                                                                    | Zaroogian and<br>Morrison (1981) |
|                                 | Rainbow Trout (Fw)              | 5 days<br>7.7 days | 13-4,020<br>3.8-850        | 293-90,730<br>86-19,180 | Decrease in number of hatches<br>Decreased median hatch time                                                                                                                                                     | Klaverkamp et al.<br>(1983)      |
|                                 | Lake Trout (Fw)                 | 24 days            | 5.2-14,600                 | 117-329,520             | High mortality                                                                                                                                                                                                   |                                  |
|                                 | Crustacea (M)<br>(mysid shrimp) | 44 days            | 0.05-0.08                  | 1.1-1.8                 | No effect on reproduction                                                                                                                                                                                        | Gentile et al.<br>(1983)         |
| Crustacea (M)<br>(brine shrimp) |                                 |                    | 1.6                        | 36                      | Delay in sexual maturation<br>and brood release                                                                                                                                                                  |                                  |
|                                 |                                 |                    | 2.5                        | 56                      | Doubling of brood development<br>time                                                                                                                                                                            |                                  |
|                                 |                                 | 24 hours           | 1-10                       | 23-226                  | Reduction in mean number of<br>broods and reproductive<br>lifespan                                                                                                                                               | Cunningham and<br>Grosch (1978)  |

(Continued)

(Sheet 3 of 11)

Table 1 (Continued)

| Contaminant                | Organism*                       | Exposure                     |                    | Tissue Concentration†                                                  | Biological Effect                                                        | Reference                  |
|----------------------------|---------------------------------|------------------------------|--------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------|----------------------------|
|                            |                                 | Time                         | Concentration**    |                                                                        |                                                                          |                            |
| Mercury (concluded)        | Mollusc (M)<br>(slipper limpet) | 16 weeks                     | 0.25-1.0           | 5.6-22                                                                 | Number of larvae released decreased in a dose-response manner            | Thain (1984)               |
|                            | Ricefish (Fw)                   | 16 days                      | 0-10<br>15         | 0-16†<br>29†                                                           | No effect on hatching<br>Reduced percent hatching                        | Heisinger and Green (1975) |
|                            | Trout (Fw)                      | 144 weeks<br>(3 generations) | 20-30<br>0-0.29    | 54-56†<br>0-3.4†                                                       | No hatching<br>No effect on reproduction and survival                    | McKim et al. (1976)        |
|                            |                                 |                              | 0.93               | 9.4†                                                                   | Reduced spawning and percent hatched                                     |                            |
|                            | Fathead minnow (Fw)             | 41 weeks                     | 2.93               | No data                                                                | Very high mortalities                                                    |                            |
|                            |                                 |                              | 0-0.5<br>1.02-3.69 | 0-2.84†<br>4.47-18.8†                                                  | No effect on reproduction<br>Spawning completely inhibited               | Snarski and Olson (1982)   |
|                            | Crustacea (Fw)<br>(cladocera)   | 21 days                      | 0.36-0.72          | 8.59-15.26†                                                            | No effect on number of young produced                                    | Biesinger et al. (1982)    |
|                            |                                 |                              | 1.28               | 23.28†                                                                 | Decreased number of young produced                                       |                            |
| Mercury<br>Zinc<br>Cadmium | Flounder (M)                    | Field collected              | 2.70               | No data                                                                | 100 percent mortality                                                    |                            |
|                            |                                 |                              | No data            | 0.0007-0.065(ovaries)†<br>3.7-31.7(ovaries)†<br>0.0004-0.012(ovaries)† | Viability of hatch did not correlate with metal concentration in ovaries | Westernhagen et al. (1981) |
|                            | Rainbow Trout (Fw)              | 42 days                      | 45.76-431.44       | 102-964                                                                | Reduction in the percent viable hatch                                    | Leland (1983)              |
|                            | Zebra fish (Fw)<br>(eggs)       | 48 hours                     | 16-32              | 36-71                                                                  | Reduced hatching                                                         | Ozoh and Jacobson (1979)   |
|                            | Trout (Fw)                      | 136 weeks<br>(3 generations) | 0-265<br>534       | No data<br>20-30†                                                      | No effect on reproduction<br>Slight reduction in percent hatched         | Holcombe et al. (1979)     |
|                            |                                 |                              | 1360               | No data                                                                | Severe reduction in percent hatched                                      |                            |

(Continued)

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Table 1 (Continued)

| Contaminant      | Organism*                     | Exposure                   |                       | Tissue Concentration† | Biological Effect                                                                                                                        | Reference                                                 |
|------------------|-------------------------------|----------------------------|-----------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|
|                  |                               | Time                       | Concentration**       |                       |                                                                                                                                          |                                                           |
| Zinc (concluded) | Guppy (Fw)                    | 134 days<br>(1 generation) | 173-328<br>607        | 0.10-0.26<br>0.30     | No effect on reproduction<br>Slight reduction in number of<br>females producing broods;<br>slight increase in the time<br>to first brood | Pierson (1981)                                            |
| Copper           | Flagfish (Fw)                 | 100 days                   | 0-267                 | 0-300†                | No effect on reproduction                                                                                                                | Spehar (1976)                                             |
|                  | Fish (M)                      | 4 days                     | 1.27<br>6.35<br>31.77 | 5.0<br>25<br>124      | No effect on hatching<br>Hatching inhibited<br>Complete suppression of<br>hatching                                                       | Engel and Sunda<br>(1979)                                 |
|                  | Killifish (M)                 | 4 days                     | 1.27<br>2.54-20.33    | 5.0<br>9.9-79         | Hatching inhibited<br>Reduction in percent live<br>hatch                                                                                 |                                                           |
|                  | Rainbow Trout (Fw)            | 42 days                    | 3.18-17.16<br>31.13   | 13-67<br>121          | No effect on hatching<br>Reduced number of hatches                                                                                       | Leland (1983)                                             |
|                  | Zebra fish (Fw)<br>(eggs)     | 48 hours                   | 16<br>32              | 62<br>125             | Increased number of hatches<br>Reduced hatching                                                                                          | Ozoh and Jacobson<br>(1979)                               |
|                  | Crustacea (M)<br>(copepod)    | 4 days                     | 1-10                  | 3.9-39                | Egg production decreased in<br>a dose-response manner                                                                                    | Moraitou-<br>Apostolopoulou<br>and Verriopoulos<br>(1979) |
|                  | Crustacea (Fw)<br>(cladocera) | 88 days                    | 10<br>20-40           | 39<br>78-156          | No effect on reproduction<br>Decreased time to repro-<br>ductive maturity                                                                | Flickinger et al.<br>(1982)                               |
|                  | Crustacea (Fw)<br>(cladocera) | 41 days                    | 10<br>20              | 39<br>78              | No effect on reproduction<br>Reduced mean brood size                                                                                     |                                                           |

(Continued)

(Sheet 5 of 11)

Table 1 (Continued)

| Contaminant        | Organism*                     | Exposure                    |                            | Tissue Concentration**                    | Biological Effect                                                                                                                   | Reference                     |
|--------------------|-------------------------------|-----------------------------|----------------------------|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
|                    |                               | Time                        | Concentration**            |                                           |                                                                                                                                     |                               |
| Copper (concluded) | Crustacea (Fw)<br>(cladocera) | 76 days                     | 20-40<br>60-100<br>120-140 | 78-156<br>234-390<br>467-545              | Increased brood size<br>Shortened life-span of females<br>100 percent mortality                                                     | Winnar et al.<br>(1977)       |
|                    |                               | 127 days                    | 10<br>20-140               | 39<br>78-545                              | No effect on reproduction<br>Decreased time to reproductive maturity                                                                |                               |
| Chromium           | Bluegill fish (Fw)            | 88 weeks<br>(1 generation)  | 0-21<br>40-77              | 0.6-2.4*<br>1.0-11.4*<br>2.6-96**,*       | No effect on reproduction<br>Reduction in number of eggs/<br>spawn and number of spawns/<br>female<br>Spawning completely inhibited | Benoit (1975)                 |
|                    |                               |                             | 162                        | range in<br>liver,<br>gill, and<br>kidney |                                                                                                                                     |                               |
|                    | Fathead Minnow (Fw)           | 9 weeks                     | 18-3950                    | 1.8-383                                   | No effect on reproduction<br>or egg hatchability                                                                                    | Pickering (1980)              |
|                    | Steelhead Trout<br>(Fw)       | 96 hr                       | 9-495                      | 0.87-48                                   | Hatching reduced in a dose-<br>response manner                                                                                      | Stevens and Chapman<br>(1984) |
|                    | Worm (M)                      | 440 days                    | 125-50<br>100-200          | 1.2-4.8<br>9.7-19                         | Reduction in number of young<br>Cessation of reproduction                                                                           | Oshida et al. (1981)          |
| Selenium           | Worm (M)                      | 300 days<br>(2 generations) | 2.6-16.6<br>38.2           | 0.040-4.42*<br>6.03-8.28*                 | No effect on reproduction<br>Reduced number of offspring by<br>second-generation worms                                              | Oshida and Word<br>(1982)     |
|                    |                               |                             |                            |                                           |                                                                                                                                     |                               |
|                    | Rainbow Trout (Fw)            | 5 days<br>7.7 days          | 100-7600<br>5-1050         | 2.8-213<br>0.14-29.4                      | No effect on reproduction<br>No effect on hatching time                                                                             | Klaverkamp et al.<br>(1983)   |
|                    | Lake Trout (Fw)               | 24 days                     | 5-200,000                  | 0.14-5600                                 | Decreased median hatching<br>time                                                                                                   |                               |
|                    | Crustacea (Fw)<br>(cladocera) | 32 days                     | 250-1000<br>1500-2000      | 7.0-28<br>42-56                           | No effect on reproduction<br>Reduction in number of young<br>produced                                                               | Dunbar et al. (1983)          |

(Continued)

(Sheet 6 of 11)

Table 1 (Continued)

| Contaminant          | Organism*                                    | Exposure                     |                     | Tissue Concentration† | Biological Effect                                                                                    | Reference                               |
|----------------------|----------------------------------------------|------------------------------|---------------------|-----------------------|------------------------------------------------------------------------------------------------------|-----------------------------------------|
|                      |                                              | Time                         | Concentration**     |                       |                                                                                                      |                                         |
| Selenium (concluded) | Crustacea (Fw)<br>(cladocera)                | 28 days                      | 200                 | 5.6                   | No effect on reproduction                                                                            | Reading and Buikema<br>(1983)           |
|                      |                                              |                              | 400-600             | 11.2-16.8             | Decrease in number of live<br>young per brood                                                        |                                         |
|                      |                                              |                              | 800                 | 22.4                  | Reproductive dysfunction (dead<br>young, deteriorated eggs,<br>abortion)                             |                                         |
| Silver               | Flounder (M)                                 | 8 days                       | 18-180              | 1.44-14.4             | No adverse effect on hatch-<br>ability                                                               | Voyer et al. (1982)                     |
|                      |                                              |                              |                     |                       |                                                                                                      |                                         |
|                      | Crustacea (Fw)<br>(cladocera)                | 21 days<br>(1 generation)    | 0.8-1.6<br>4.1-17.6 | 0.06-0.13<br>0.33-1.4 | No effect on reproduction<br>Reduction in total number of<br>young and young produced/<br>female/day | Nebeker et al.<br>(1983)                |
|                      |                                              | 21 days<br>(1 generation)    | 1.0-8.8<br>19.4     | 0.08-0.70<br>1.6      | No effect on reproduction<br>Reduction in total number of<br>young and young produced/<br>female/day |                                         |
|                      | Crustacea (Fw)<br>(cladocera)<br>(continued) | 21 days<br>(1 generation)    | 3.4<br>8.0-30.8     | 0.27<br>0.64-2.5      | No effect on reproduction<br>Reduction in total number of<br>young and young produced/<br>female/day | Nebeker et al.<br>(1983)<br>(continued) |
| Antimony             | Mollusc (M)<br>(surf clam)                   | 48 hours                     | 0.6<br>6.4-21       | 0.05<br>0.51-1.7      | No effect on reproduction<br>Increase in number of abnormal<br>larvae produced                       | Eyster and Morse<br>(1984)              |
|                      |                                              |                              |                     |                       |                                                                                                      |                                         |
|                      | Mollusc (M)<br>(snail)                       | 24 months<br>(2 generations) | 1<br>5-10           | 0.08<br>0.4-0.8       | No effect on reproduction<br>Reduction in number of larvae<br>released                               | Nelson et al.<br>(1983)                 |
|                      | Fathead minnow (Fw)                          | 30 days                      | 0.62-7.5            | 0.00060-0.0075        | No effect on hatching                                                                                | LeBlanc and Dean<br>(1984)              |

(Continued)

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Table 1 (Continued)

| Contaminant        | Organism*             | Exposure                     |                                                           | Tissue Concentration†                 | Biological Effect                                                                                                         | Reference                            |
|--------------------|-----------------------|------------------------------|-----------------------------------------------------------|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------|--------------------------------------|
|                    |                       | Time                         | Concentration**                                           |                                       |                                                                                                                           |                                      |
| Lead               | Trout (Fw)            | 144 weeks<br>(3 generations) | 0-58<br>119-235<br>473                                    | 4-12†<br>12-60†<br>No data            | No effect on reproduction<br>Reduced spawning and percent hatched<br>Complete inhibition of spawning and high mortality   | Holcombe et al.<br>(1976)            |
| Nickel             | Worm (M)              | 28 days                      | 100<br>500-1500<br>2000                                   | 22.8<br>114-342<br>456                | No effect on reproduction<br>Reduced number of progeny<br>No reproduction                                                 | Petrich and Reish<br>(1979)          |
| Thallium           | Fathead minnow (Fw)   | 30 days                      | 40-200<br>350-720                                         | 1.9-9.6<br>17-35                      | No effect on hatching<br>Percent hatch rate reduced                                                                       | LeBlanc and Dean<br>(1984)           |
| PCB (Aroclor 1016) | Hydra (Fw)            | 4 days                       | 1-4                                                       | 63-253                                | Decreased asexual reproduction                                                                                            | Adams and<br>Haileselassie<br>(1984) |
| PCB (Aroclor 1254) | Hydra (Fw)            | 4 days                       | 1-10                                                      | 63-632                                | Decreased asexual reproduction                                                                                            |                                      |
| PCB (Aroclor 1016) | Sheepshead minnow (M) | 29 days                      | 1-10                                                      | 5.4-110(adults)†<br>4.2-66(eggs)†     | No effect on egg fertility, hatching, or subsequent survival of progeny                                                   | Hansen et al.<br>(1975)              |
| PCB (C10phen A50)  | Minnow (Fw)           | 40 days                      | 32<br>125 µg/0.5 g<br>dry food/day/<br>fish               | 200-1100(adults)<br>1.3†              | 100 percent mortality in adults<br>No effect on reproduction                                                              | Bengtsson (1980)                     |
| PCB                | Flounder (M)          | Field collected              | 135-1250 µg/<br>0.5 g dry<br>food/day/<br>fish<br>No data | 10-100†<br>5000-317,000<br>(ovaries)† | Reduction in time to hatching with resultant fry dying<br>Reduced viable hatch at PCB tissue concentrations above 120,000 | Westernhagen et al. (1981)           |

(Continued)

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Table 1 (Continued)

| Contaminant         | Organism*                         | Exposure                |                 | Tissue Concentration†                 | Biological Effect                                                                 | Reference                 |
|---------------------|-----------------------------------|-------------------------|-----------------|---------------------------------------|-----------------------------------------------------------------------------------|---------------------------|
|                     |                                   | Time                    | Concentration** |                                       |                                                                                   |                           |
| DDD                 | Flounder (M)                      | Field collected         | No data         | 300-30,000(ovaries)†                  | Hatch viability not correlated with tissue concentration of any other contaminant | Westerhagen et al. (1981) |
| DDE                 | Hexachlorobenzene                 |                         |                 | 100-62,000(ovaries)†                  |                                                                                   |                           |
| Dieldrin            |                                   |                         |                 | 60-2000(ovaries)†                     |                                                                                   |                           |
| Heptachlorepoxyde   |                                   |                         |                 | 100-49,000(ovaries)†                  |                                                                                   |                           |
|                     |                                   |                         |                 | 80-3000(ovaries)†                     |                                                                                   |                           |
| PCB (Aroclor 1254)  | Salmon (Fw)                       | Field collected         | No data         | 0.23-0.42(eggs)†                      | No correlation between hatching success and tissue concentration                  | Zitko and Sanders (1979)  |
| Hexachlorobenzene   |                                   |                         |                 | 0.006-0.010(eggs)†                    |                                                                                   |                           |
| DDT and metabolites |                                   |                         |                 | 0.01-0.031(eggs)†                     |                                                                                   |                           |
| DDT                 | Fathead minnow (Fw)               | 266 days                | 0.5-2.0         | 70-140                                | Reduced hatching                                                                  | Jarvinen et al. (1977)    |
| Endrin              | Sheepshead minnow (M)             | 23 weeks (1 generation) | 0.027-0.12      | 0.20-1.0(adults)†<br>0.09-0.87(eggs)† | No effect on reproduction                                                         | Hansen et al. (1977b)     |
| Endrin              | Sheepshead minnow (M) (continued) | 23 weeks (1 generation) | 0.31            | 0.94(adults)†<br>1.80(eggs)†          | Reduced fertilization and early hatching; high mortalities                        | Hansen et al. (1977b)     |
|                     |                                   |                         | 0.72            | No data                               |                                                                                   |                           |
| Endrin              | Fathead minnow (Fw)               | 300 days                | 0.17-0.28       | 0.73-1.21                             | Reduction in larval survival                                                      | Jarvinen and Tyo (1978)   |
| Endrin              | Crustacea (M) (grass shrimp)      | 145 days                | 0.03-0.79       | 0.13-3.4                              | Reduction in time to egg release                                                  | Tyler-Schroeder (1979)    |
| Phthalates          | Crustacean (Fw) (cladocera)       | 21 days (1 generation)  | 1.33-115        | 0.32-26.8†                            | No effect on number of progeny produced                                           | Brown and Thompson (1982) |
| Kepone              | Sheepshead minnow (M)             | 90-133 days             | 0.041-0.074     | 0.15-0.56†                            | Increased number of eggs/female/day; fertility unaffected                         | Goodman et al. (1982)     |

(Continued)

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Table 1 (Continued)

| Contaminant                        | Organism*                  | Exposure    |                  | Tissue Concentration† | Biological Effect                                                   | Reference                   |
|------------------------------------|----------------------------|-------------|------------------|-----------------------|---------------------------------------------------------------------|-----------------------------|
|                                    |                            | Time        | Concentration**  |                       |                                                                     |                             |
| Kepone (concluded)                 | Sheepshead minnow (M)      | 90-133 days | 0.12-0.39        | 0.86-3.0‡             | Number of eggs/female/day unaffected; fertility                     | Goodman et al. (1982)       |
|                                    |                            |             | 0.78             | 5.0-6.8‡              | Decreased number of eggs/female/day; reduced fertility              |                             |
| Dichlorobenzene                    | Sheepshead minnow (M)      | 28 days     | 0.05-0.80<br>1.9 | 0.26-4.7‡<br>11‡      | Production of normal embryos<br>Production of abnormal embryos      | Hansen et al. (1977a)       |
|                                    | Crustacea (Fw) (cladocera) | 28 days     | 44-690<br>1500   | 3.2-50<br>108         | No effect on reproduction<br>Decreased number of young produced     |                             |
| Trichlorobenzene                   | Crustacea (Fw) (cladocera) | 28 days     | 18-360<br>690    | 3.2-66<br>126         | No effect on reproduction<br>Decreased number of young produced     | Richter et al. (1983)       |
|                                    | Guppy (Fw)                 | 8 weeks     | 500              | 274                   | Decreased number of young produced                                  |                             |
| Endosulfan                         | Tropical fish (Fw)         | 4 weeks     | 0.5              | 0.92                  | No effect on reproduction                                           | Virtanen and Hattula (1982) |
|                                    |                            | 6 weeks     | 0.2<br>0.6       | 0.37<br>1.10          | No effect on reproduction<br>Retarded time to reproductive maturity |                             |
| AC 222, 705 (Synthetic pyrethroid) | Sheepshead minnow (M)      | 9 weeks     | 0.6              | 1.10                  | Retarded time to reproductive maturity                              | Hansen et al. (1983)        |
|                                    |                            | 28 days     | 0.03-1.0         | No data               | Reduction in hatching                                               |                             |
| Permethrin (Synthetic pyrethroid)  | Sheepshead minnow (M)      | 28 days     | 1.6-42           | 0.46-5.7‡             | Reduced hatching                                                    |                             |

(Continued)

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Table 1 (Concluded)

| Contaminant                              | Organism*                | Exposure |                 | Tissue Concentration† | Biological Effect                                                                                             | Reference                |
|------------------------------------------|--------------------------|----------|-----------------|-----------------------|---------------------------------------------------------------------------------------------------------------|--------------------------|
|                                          |                          | Time     | Concentration** |                       |                                                                                                               |                          |
| Fenvalerate<br>(Synthetic<br>pyrethroid) | Sheepshead<br>minnow (M) | 28 days  | 0.28-7.6        | 0.13-3.2‡             | No effect on hatching                                                                                         | Hansen et al.<br>(1983)  |
| AC 222, 705<br>(Synthetic<br>pyrethroid) | Minnow (Fw)              | 32 days  | 0.02-0.07       | 0.06-0.17‡            | Normal larvae produced and<br>percent hatchability<br>unaffected                                              | Spehar et al.<br>(1983)  |
|                                          |                          |          | 0.13-0.29       | No data               | Abnormal larvae produced and<br>percent hatchability<br>unaffected; high mortalities                          |                          |
| Permethrin<br>(Synthetic<br>pyrethroid)  | Minnow (Fw)              | 32 days  | 0.11-0.66       | 0.19-2.19‡            | Normal larvae produced and<br>percent hatchability<br>unaffected                                              |                          |
|                                          |                          |          | 1.40            | 4.51‡                 | Abnormal larvae produced and<br>percent hatchability<br>unaffected                                            |                          |
| Diazinon<br>(organophosphate)            | Sheepshead<br>minnow (M) | 108 days | 0.47-6.50       | 0.05-2.4‡             | Number of eggs/female/day<br>inversely proportionate to<br>tissue concentrations; egg<br>fertility unaffected | Goodman et al.<br>(1979) |

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Table 2  
Frequency of the Type of Contaminants and Organisms  
Appearing in Table 1

| Contaminant                      | Organism |           |                        |       | Percent<br>of Overall<br>Total (85) |
|----------------------------------|----------|-----------|------------------------|-------|-------------------------------------|
|                                  | Fish     | Crustacea | Other<br>Invertebrates | Total |                                     |
| Cadmium                          | 8        | 9         | 2                      | 19    | 22                                  |
| Mercury                          | 6        | 3         | 1                      | 10    | 12                                  |
| Copper                           | 5        | 4         | 0                      | 9     | 11                                  |
| Zinc                             | 6        | 0         | 0                      | 6     | 7                                   |
| Chromium                         | 2        | 0         | 2                      | 4     | 5                                   |
| Selenium                         | 2        | 2         | 0                      | 4     | 5                                   |
| Silver                           | 1        | 1         | 2                      | 4     | 5                                   |
| Lead                             | 1        | 0         | 0                      | 1     | 1                                   |
| Nickel                           | 0        | 0         | 1                      | 1     | 1                                   |
| Antimony                         | 1        | 0         | 0                      | 1     | 1                                   |
| Thallium                         | 1        | 0         | 0                      | 1     | 1                                   |
| <hr/>                            |          |           |                        |       |                                     |
| Total heavy metals               | 33       | 19        | 8                      | 60    | 71                                  |
| Chlorinated hydrocarbons         | 13       | 4         | 2                      | 19    | 22                                  |
| Other organic contaminants       | 6        | 0         | 0                      | 6     | 7                                   |
| <hr/>                            |          |           |                        |       |                                     |
| TOTAL                            | 52       | 23        | 10                     | 85    | 100                                 |
| <hr/>                            |          |           |                        |       |                                     |
| Percent of overall total<br>(85) | 61       | 27        | 12                     | 100   |                                     |

Table 3  
Frequency of the Type of End Points Used to  
Assess Reproductive Success

| <u>Reproductive End Point</u>                                                                                  | <u>Frequency</u> |
|----------------------------------------------------------------------------------------------------------------|------------------|
| Hatching<br>(rate, quantity, viability, etc.)                                                                  | 31               |
| Eggs and broods<br>(rate, quantity, viability, size, etc.)                                                     | 20               |
| Progeny and larvae<br>(quantity, viability, etc.)                                                              | 18               |
| Integrated reproductive rate functions<br>(e.g., quantity of young produced/female/reproductive<br>days, etc.) | 11               |
| Abnormal eggs and larvae                                                                                       | 5                |
| Fish spawns<br>(rate, quantity, etc.)                                                                          | 4                |
| Time to reproductive maturity                                                                                  | 4                |

Table 4  
Bioconcentration Factors from USEPA  
Water Quality Documents+

| Ranking                              | Contaminant              | BCF*    |         |      | Range         | n  |
|--------------------------------------|--------------------------|---------|---------|------|---------------|----|
|                                      |                          | Mean    | SD      | % CV |               |    |
| BCFs from<br>1 to<br>100             | Antimony                 | 1       | -       | -    | -             | 1  |
|                                      | Arsenic                  | 18      | 68      | 378  | 1-350         | 26 |
|                                      | Selenium                 | 28      | 25      | 89   | 8-78          | 6  |
|                                      | Thallium                 | 48      | 55      | 114  | 12-130        | 4  |
|                                      | Dichlorobenzene          | 72      | 15      | 21   | 60-89         | 3  |
|                                      | Silver                   | 80      | 91      | 114  | 1-240         | 7  |
|                                      | Chromium                 | 97      | 80      | 82   | 1-200         | 9  |
| BCFs from<br>100 to<br>1000          | Trichlorobenzene         | 182     | -       | -    | -             | 1  |
|                                      | Nickel                   | 228     | 167     | 73   | 10-416        | 7  |
|                                      | Hexachlorocyclohexane    | 296     | 216     | 73   | 35-617        | 8  |
|                                      | Phthalate Esters         | 486     | 726     | 149  | 14-2,680      | 15 |
|                                      | Chlorinated Phenols      | 547     | 1,070   | 196  | 13-3,830      | 12 |
|                                      | Chlorinated Naphthalene  | 702     | 1,068   | 152  | 63-2,306      | 4  |
|                                      | Lead                     | 786     | 790     | 100  | 18-2,570      | 16 |
| BCFs from<br>1000 to<br>10,000       | Cadmium                  | 1,461   | 2,278   | 156  | 3-12,400      | 44 |
|                                      | Endosulfan               | 1,837   | 1,317   | 72   | 328-2,755     | 3  |
|                                      | Zinc                     | 2,234   | 4,948   | 221  | 20-16,700     | 13 |
|                                      | Copper                   | 3,895   | 7,967   | 204  | 1-28,200      | 17 |
|                                      | Endrin                   | 4,303   | 3,873   | 90   | 1,450-15,000  | 15 |
|                                      | Heptachlor               | 8,102   | 8,900   | 110  | 1,848-37,000  | 14 |
| BCFs from<br>10,000<br>to<br>100,000 | Aldrin/Dieldrin          | 11,344  | 19,560  | 172  | 400-68,286    | 12 |
|                                      | Chlordane                | 15,200  | 11,912  | 78   | 5,200-37,800  | 6  |
|                                      | Toxaphene                | 18,882  | 16,290  | 86   | 1,270-52,000  | 13 |
|                                      | Mercury                  | 22,570  | 20,948  | 93   | 129-64,000    | 9  |
|                                      | Polychlorinated biphenyl | 63,209  | 78,774  | 125  | 800-274,000   | 33 |
|                                      | DDT/DDE                  | 69,767  | 101,069 | 145  | 1,200-363,000 | 21 |
| BCFs<br>> 100,000                    | Dioxin                   | 173,348 | 217,426 | 125  | 2,870-915,000 | 24 |

+ Documents cited in US Environmental Protection Agency (1980).

\* Column headings are defined as follows:

SD =  $\pm$  standard deviation

% CV = % Coefficient of Variation ( $100 \text{ SD}/\bar{X}$ )

n = number of BCF values

Table 5  
Highest No Effect Concentration and Lowest Effects  
Concentration Grouped by Class of Contaminant

| Contaminant                       | Concentration<br>µg/g, wet weight |        |        |
|-----------------------------------|-----------------------------------|--------|--------|
|                                   | Value*                            | HNEC   | LEC    |
| All heavy metals                  | $\bar{x}$                         | 37.8   | 45.3   |
|                                   | ± SD                              | ± 86.9 | ± 80.0 |
|                                   | % CV                              | 230    | 177    |
|                                   | n                                 | 33     | 51     |
| Cadmium only                      | $\bar{x}$                         | 31.6   | 53.3   |
|                                   | ± SD                              | ± 74.3 | ± 113  |
|                                   | % CV                              | 235    | 202    |
|                                   | n                                 | 7      | 17     |
| Mercury only                      | x                                 | 7.86   | 60.1   |
|                                   | ± SD                              | ± 7.12 | ± 93.8 |
|                                   | % CV                              | 90.6   | 156    |
|                                   | n                                 | 5      | 9      |
| All nonmetal organic contaminants | $\bar{x}$                         | 18.7   | 49.5   |
|                                   | ± SD                              | ± 32.3 | ± 77.9 |
|                                   | % CV                              | 173    | 157    |
|                                   | n                                 | 18     | 19     |

\* Notations used in this column are defined as follows:

$\bar{x}$  = mean

± SD = ± standard deviation

% CV = coefficient of variation (100 SD/  $\bar{x}$ )

n = number table entries

Table 6  
Lowest Effects Concentration Grouped by Class  
of Contaminant and Test Organism

| Contaminant                         | Value*    | LEC        |            |                     |
|-------------------------------------|-----------|------------|------------|---------------------|
|                                     |           | Fish       | Crustacea  | Other Invertebrates |
| All heavy metals                    | $\bar{x}$ | 52.6       | 42.1       | 36.4                |
|                                     | $\pm$ SD  | $\pm$ 73.6 | $\pm$ 93.2 | $\pm$ 58.7          |
|                                     | % CV      | 140        | 221        | 161                 |
|                                     | n         | 20         | 23         | 8                   |
| Cadmium only                        | $\bar{x}$ | 45.8       | 51.3       | 82.0                |
|                                     | $\pm$ SD  | $\pm$ 63.7 | $\pm$ 140  | $\pm$ 90.5          |
|                                     | % CV      | 139        | 273        | 110                 |
|                                     | n         | 5          | 10         | 2                   |
| Mercury only                        | $\bar{x}$ | 90.6       | 27.4       | 5.64                |
|                                     | $\pm$ SD  | $\pm$ 122  | 7.43       | -                   |
|                                     | % CV      | 134        | 27.1       | -                   |
|                                     | n         | 5          | 3          | 1                   |
| All nonmetal contaminants           | $\bar{x}$ | 41.5       | 78.0       | 63.0                |
|                                     | $\pm$ SD  | $\pm$ 86.0 | $\pm$ 68.1 | $\pm$ 0.0           |
|                                     | % CV      | 207        | 87.3       | 0                   |
|                                     | n         | 14         | 3          | 2                   |
| All metal and nonmetal contaminants | $\bar{x}$ | 48.0       | 46.2       | 41.8                |
|                                     | $\pm$ SD  | $\pm$ 77.9 | $\pm$ 90.3 | $\pm$ 52.9          |
|                                     | % CV      | 162%       | 195%       | 127                 |
|                                     | n         | 34         | 26         | 10                  |

\* Notations used in this column are defined as follows:

- $\bar{x}$  = mean
- $\pm$  SD =  $\pm$  standard deviation
- % CV = coefficient of variation ( $100 \text{ SD}/\bar{x}$ )
- n = number table entries