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Office of Natural
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Muscle Shoals AL 35660

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United States
Environmental Protection
Agency

Office of Environmental
Processes and Effects Research
Washington DC 20460

EPA-600/7-84-040
March 1984

Research and Development

Chlorine Effects on Aquatic Organisms:

Evaluation of Selected Toxicity Models

Interagency Energy/Environment R&D Program Report

Chlorine Effects on Aquatic Organisms
Evaluation of Selected Toxicity Models

by

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Interagency Agreement No. EPA-IAG-82-D-X0511
Project No. E-AP 82 BDW
Program Element No. INE- CC2N1A

Project Officer

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U.S. Environmental Protection Agency
Washington, DC 20460

Prepared for

Office of Environmental Processes and Effects Research
Office of Research and Development

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ABSTRACT

Three toxicity models were examined and modified with respect to organisms associated with chlorinating power plants of the Tennessee Valley Authority. The three models examined were the Mattice-Zittel, Turner-Thayer, and Chen-Selleck. Results of the first two were prediction lines based on concentration and exposure duration of chlorine, whereas results of the latter were threshold concentrations for individual species. Because of differences in model formulations and objectives, as well as in biological responses used to test the models, it was only possible to generalize about the potential biological safety of the receiving waters.

Although the Mattice-Zittel model was very conservative and indicated potential biologically unsafe conditions with respect to chlorine for invertebrates at most of the power plants examined, the more statistically robust model of Turner-Thayer indicated biological safety for invertebrates at all but one of the power plants examined. Results were similar for both models for fish safety at the power plants. More data were available for invertebrate species than vertebrate species. The models predicted that invertebrates were more sensitive to chlorine than vertebrates. According to both the Turner-Thayer and Chen-Selleck models, the most sensitive invertebrate species included mayfly nymphs, particularly *Isonychia* sp., and scuds, *Gammarus* sp.

Indicator analysis, i.e. a modification of the Turner-Thayer model, was constructed to provide a predictive time/toxicity model for chlorine which would assure protection of a striped bass population at a designated power plant (Appendix D). The analysis proved insensitive and inconclusive. However, if the required adjustments are made for the Turner-Thayer model (Appendix C), all of the data points used for Appendix D fall inside the limiting curve produced by the Turner-Thayer model. Appendix C confirms that the Turner-Thayer model, when correctly and completely applied to species specific data, produces adequately protective results and provides a reasonably accurate prediction of chlorine toxicity at intermittent exposures.

ACKNOWLEDGMENTS

We gratefully acknowledge Billy G. Isom and R. J. Ruane for making this work possible. We especially thank D. M. Opresko for helping us with the literature survey, W. C. Barr for providing fisheries data, H. B. Flora II for providing power plant data, and Alta Turner for contractual services, in providing us with the Turner-Thayer model.

CONTENTS

SECTION 1

INTRODUCTION

The potential environmental impact of chlorine during water treatment continues to be a subject of public concern and scientific research (Jolley et al. 1980; Opresko 1980; Costle et al. 1980; Hall et al. 1981). An active area of scientific research is development of a toxicity model that can be used to aid in predicting environmentally acceptable chlorine levels in receiving waters. The ability to predict biological "safety" from chlorine levels in receiving waters should allow more diverse biological tests without a major field test program. This report presents and examines three toxicity models with special interest to the chlorinating power plants operated by the Tennessee Valley Authority (TVA). The models presented in this report were developed by Mattice and Zittel (1976), Chen and Selleck (1969), and Turner and Thayer (1980). Modifications and evaluations of these models are presented in Appendices A, B, C, and D, respectively.

SECTION 2

CONCLUSIONS

The toxicity models examined in this report, viz. the Mattice-Zittel, Chen-Selleck, and Turner-Thayer models, had different objectives and formulations. The Mattice-Zittel model was proposed to demonstrate a relationship between chlorine concentration and exposure time. The Chen-Selleck model was hypothesized to demonstrate a kinetic relationship between toxication and detoxication processes in individual species. The Turner-Thayer model was formulated to evaluate biological safety in the mixing zone. Because of the statistical robustness of the Turner-Thayer methods, this model was preferred to the others to project biological safety at the TVA chlorinating power plants. However, it is noteworthy to state that model reliability is limited by the data base used. Data are lacking with regard to vertebrate species, water quality characteristics, and life stages of the test organisms. This information needs to be factored in the model when it becomes available. Results of the analyses indicated that invertebrate species are more sensitive than vertebrate species. Biological safety was indicated for vertebrates at all chlorinating power plants and for invertebrates at all but one of the chlorinating power plants. Because of the precision and sensitivity of the Turner-Thayer model as well as its statistical robustness, it is concluded that this model provides a reasonably accurate prediction of chlorine toxicity at intermittent exposures.

SECTION 3

RECOMMENDATIONS

For the purposes of modeling, more data are needed using the same response criteria. In addition, more information needs to be supplied on acute chlorine toxicity effects with respect to water quality characteristics and life stage of the test organisms. The recommended model is the Turner-Thayer model. The Turner-Thayer model is designed to predict chlorine concentrations which adequately protect all species represented in the data base for a given exposure duration. It is statistically robust, sensitive and precise, and provides a reasonably accurate prediction of chlorine toxicity at intermittent exposures.

SECTION 4

METHODS

Mattice-Zittel model. The literature was examined with respect to chlorine toxicity effects on fish and invertebrates in the Tennessee Valley. This was done for the purpose of adding these additional data and deleting inappropriate data in the Mattice and Zittel report. This product was used to modify the model and apply the newly formed regression lines to representative organisms found in the TVA area. Each TVA chlorinating power plant was analyzed from this perspective in an effort to determine which combination of environmental conditions might be viewed as toxic to the organisms.

Turner-Thayer model. The data compiled from above were provided to Envirosphere Company, New York, New York, under subcontract to run the regression analyses for fish and/or zooplankton and benthic organisms associated with TVA and/or all available locations. Residual analyses were run to indicate sensitive species. Regression lines were generated from the model; toxicity effects were analyzed with respect to power plant conditions.

Chen-Selleck model. The Chen-Selleck model is based on least-squares analysis. However, the threshold concentration of the toxicant is determined by solving simultaneous equations. The principles of the Chen-Selleck model were used to predict threshold concentrations of chlorine for fish and invertebrates. The information resulted in a list of species ranging from sensitive to resistant species for any one TVA power plant site.

SECTION 5

RESULTS AND DISCUSSION

The Mattice-Zittel model (1976) was developed to demonstrate the general relationship between exposure time and chlorine concentration. Shortly after its publication, it was adapted for establishing regulatory criteria (Hall et al. 1980; Turner and Thayer 1980). Examination of the model shows it to be conservative and overly restrictive (Turner and Thayer 1980). A modification of the data base used to develop this model using data from only those species that have been found near the chlorinating TVA power plants is given in Appendix A. Based on available data from the literature, the model predicts biological safety for fish at most of these power plants but not for invertebrates at any of the plants. These predicted conclusions were not found at the plants. Because data are lacking for many important species as well as for more life stages, chlorine cannot be eliminated as a factor for the disappearance of fish species such as sauger and paddlefish at some power plant sites. Because of lacking available data and because the predictability of the Mattice-Zittel model was neither validated nor invalidated, in situ studies need to be performed on those species potentially impacted by chlorine for assessment of biological safety under appropriate environmental conditions of the power plants. A detailed analysis of the Mattice-Zittel model is given in Appendix A.

The Turner-Thayer model (1980) was proposed as an alternate model to the Mattice-Zittel model. Several improvements were implemented, such as selecting data with a common biological response (e.g., LC_{50}) and using more statistically based modeling techniques than those methods used by Mattice and Zittel. Turner and Thayer recognized that site-specific factors, such as sensitivity of resident species and water quality characteristics, may influence the toxicity of chlorine-induced oxidants. However, the current data base is lamentably insufficient to allow for the formulation of these factors in their general models. The Turner-Thayer model was used to determine relative chlorine sensitivities between fish and invertebrates for all available data as well as for species resident at TVA sites. The analysis is detailed in Appendix C. Results showed (1) that partitioning data on the basis of species residence at TVA sites did not substantially modify the results of the regression analysis, (2) invertebrate species exhibited greater variability and were more sensitive than vertebrate species, and (3) most of the data available were for invertebrate species, so that the invertebrate component tended to dominate the analytical results. According to the model, biological safety occurred at all TVA sites for fish and all but one TVA site for invertebrates. The most sensitive species to chlorine at the TVA sites was <u>Isonychia</u> sp. compared with <u>Iron humeralis</u> for all available data. These mayflies may be important indicator organisms for future work. Although the model predicts that fish were considered to be biologically safe, <u>Notropis atherinoides</u> showed the most sensitivity to chlorine exposure.

The Chen-Selleck model (1969) is a steady-state model based on the concept of a biochemical rate balance between toxication and detoxication processes. Because the two processes occur simultaneously, Chen and Selleck postulated that toxication processes will not produce mortality when the rates of toxication and detoxication are equal. Kinetic rates of toxication and detoxication reactions were formulated as a function of measurable parameters in a standard bioassay test resulting in the computation of the threshold concentration, i.e., the maximum concentration of toxicant that allows survival of all test organisms during infinite exposure time. This model allows for the prediction of safe toxicant concentrations for individual species. However, Chen and Selleck pointed out that other factors than the toxicant may either contribute to or cause the organism's death in the bioassay. They also noted that other factors need to be considered for predicting estimates of safe toxicant concentrations in receiving waters. This model was used to test chlorine toxicity in invertebrates and vertebrates using the data base given in Appendix A. Application of this model for chlorine toxicity is given in Appendix B. The model predicted that chlorine concentrations at all the power plants would probably be biologically unsafe for most invertebrates and fish associated with the power plants. Because these species do exist at the power plants, results from the Chen-Selleck model are too conservative because other factors, such as water dilution, water quality characteristics, etc., were not factored into the model. The biological sensitivity to chlorine shows three species of mayfly nymphs, and some other invertebrate genera to be indicator organisms for chlorine toxicity. Juvenile fish were also sensitive to chlorine. Discrepancies in biological sensitivity to chlorine between the Chen-Selleck and Turner-Thayer methods are probably due to differences in the data bases as well as methods used. Threshold concentrations were based on a very small amount of data in the Chen-Selleck method and were calculated individually for each species, whereas data were used for all species collectively for the residual analyses of the Turner-Thayer method.

Indicator analysis, i.e. a modification of the Turner-Thayer model, was constructed to provide a predictive time/toxicity model for chlorine which would assure protection of a striped bass population at a designated power plant. However, since data for striped bass are not available, data from the Turner-Thayer data base for the emerald shiner, bluegill, and channel catfish were used for the study presented in Appendix D. The analyses indicated that the three species do not exhibit the same expected toxicity reaction to various concentrations of chlorine. The analyses, therefore, proved insensitive and were inconclusive. However, if the required adjustments are made for the Turner-Thayer model (cf. Appendix C), none of the data points used in Appendix D fall outside the limiting curve produced by the Turner-Thayer model. Since the Turner-Thayer model is designed to predict chlorine concentrations which adequately protect all species represented in the data base (and probably some species not included) for a given exposure duration, the model may adequately show protection of a given species without predicting the exact time/toxicity relationship for that species.

Because of the robust statistical methods used to develop the Turner-Thayer model and the use of mean residuals to indicate chlorine sensitivity in the regression equation, this model seems to be credible and acceptable, provided a sufficient data base, which incidentally, is not available. This model seems to have more strengths than either the Mattice-Zittel or Chen-Selleck models for predicting potential biological safety in the mixing zone where chlorine is the only toxicant.

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Appendix A

CONSTRUCTION AND EVALUATION OF MATTICE-ZITTEL TYPE MODELS

Prepared by

Colette G. Burton

CONSTRUCTION AND EVALUATION OF
MATTICE-ZITTEL TYPE MODELS

By Colette G. Burton

INTRODUCTION

Chlorination is commonly used to prevent biofouling in the condenser cooling and service water systems of power plants within the USA. Since chlorine is an effective biocide, scientists have been concerned with the impact of chlorinated effluents on aquatic organisms.[66-73]* Several studies have examined the tolerance levels of aquatic organisms to different forms of chlorine residuals (free, combined, or total). In addition, some studies have investigated sublethal physiological and biochemical responses to chlorine exposure.

The current EPA guidelines are an average discharge of 0.2 mg/l free residual chlorine with an instantaneous maximum concentration of 0.5 mg/l free residual chlorine for a maximum discharge period of two hours (end of the pipe).[82] However, there has been some controversy regarding whether these levels are too lenient or too stringent.

In an attempt to predict levels of chlorine exposure which would not adversely impact freshwater organisms, some chlorine toxicity models have been developed. One such model was developed by Mattice and Zittel as a predictive tool for the assessment of site-specific chlorination levels.[66, 74-76] In this model, the acute and chronic toxicity threshold levels were determined using existing chlorine toxicity information on freshwater organisms.

The Tennessee Valley Authority (TVA) is interested in examining models to aid in predicting environmentally acceptable chlorination levels at TVA power plants. Since the Mattice and Zittel freshwater model utilized data from a variety of organisms, some of which are not present near TVA power generation facilities, these data needed to be deleted from the model and new data added to it. The purposes of this study are: to review chlorine toxicity information, to construct modified Mattice-Zittel type models for fish and invertebrates present in the TVA area, to apply these models to TVA power plants, and to report on the significance of these models to TVA.

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* It was necessary to construct tables 1 and 2 prior to writing this text; therefore, sequence of references cited follows these tables, the text does not.

LITERATURE SURVEY

The available literature on the impact of chlorination on fish and invertebrates was reviewed (table 1 and 2). All fish species taken in cove rotenone samples of TVA reservoirs[77] and located near power plants are listed in table 1. However, because of the large number of aquatic invertebrate genera present in the TVA area,[78] table 2 lists only the genera for which chlorine toxicity information was available.

The format of the tables is a modification of that of Mattice and Zittel.[66] Toxicity data for organisms exposed to either exposure type, viz. intermittent or continuous, are listed in the tables. Generally, the data point numbers were not assigned to data from intermittent chlorination studies. A different data point number was assigned to each species (table 1) or genus (table 2) exposed to a different experimental condition (such as chlorine concentration, chlorine form, and/or temperature) in each study. The concentration represents the chlorine levels, irrespective of chlorine form examined in these studies. The biological response or end-point found during the experimental or observational period is indicated under the "Effect" column. The biological responses were limited to changes in reproduction, spawning, or mortality, with 50 percent mortality being the most common response reported. Waste water chlorination studies are also indicated in the same column. The other categories are self-explanatory.

When these tables are examined, it is apparent that more information was available for fish than for invertebrates. In addition, within either fish or invertebrates there is an apparent paucity of information available for some species or genera, while there is an abundance of information available for others. It is also clear that there has been a recent trend towards examining intermittent chlorination effects. In addition, more attention has been focused on examining the effects of chlorine in conjunction with temperature.

CONSTRUCTION OF CHLORINE TOXICITY MODELS

The modified chlorine toxicity models, which were constructed using methods similar to those of Mattice and Zittel,[66], [74-76] are shown in figures 1 and 2 for fish and invertebrates, respectively. The data from intermittent chlorination studies generally were not incorporated into these models. The data point numbers in figures 1 and 2 correspond with the numbers in tables 1 and 2, respectively. The concentration and exposure duration of each data point were plotted on the respective log-log graphs. In cases where a single biological response was observed over a range of chlorine concentrations or exposure times, the combination of the lowest concentration and lowest exposure duration was plotted on the graph.

After all of the data were plotted, the acute and chronic toxicity thresholds were determined. The assumption that the relationship between log concentration-log exposure duration is inversely linear over a broad range was essential to the placement of the acute toxicity threshold.[66]

The major assumption in placing the chronic toxicity threshold was that it represents the maximum concentration below which no effect will occur regardless of the exposure duration.[66]

Several steps were involved in setting the acute toxicity thresholds. Initially, the data were enclosed between two intersecting lines. The log concentration-log exposure duration data within these lines usually were measured for median mortality, although the biological end-point ranged from sublethal effects to 100 percent mortality. Since the threshold represents the maximal time-concentration level below which no effect will occur,[66] the data needed to be converted, when possible, to reflect 0 percent mortality levels. Because of lack of data, the equation of Mattice and Zittel, $y = 0.37x$, was used in converting the time required to obtain 50 percent mortality (x) into the time required to obtain 0 percent mortality (y) for any given concentration.[66] After these conversions were completed, the top line was adjusted toward the left to enclose all converted data points. The slope of the original top line was retained.

The placement of the chronic toxicity threshold was somewhat arbitrary, since Mattice and Zittel did not disclose their methods.[66] To protect the most sensitive organisms represented in each model, the chronic toxicity threshold of the model was obtained by adjusting the initial bottom line to approximately three-quarters of the lowest concentration eliciting a biological response (see data points 34 and 9 in figures 1 and 2, respectively).

Upon close examination of the models, some differences were observed between the fish and invertebrate toxicity models. The chronic toxicity threshold of fish (0.015 mg/l) was approximately 10 times that of invertebrates (0.0015 mg/l). The models also revealed that the acute toxicity threshold of fish (which represents the line connecting 5.4 mg/l--0.12 min with 0.015 mg/l--3,800 min) was much greater than that of invertebrates (which represents the line connecting 0.07 mg/l--5.0 min with 0.015 mg/l--8,400 min).

APPLICATIONS OF THESE MODELS

General

This type of toxicity model is relatively easy to interpret.[66] To determine whether a chlorine concentration-exposure time is potentially harmful to fish or invertebrates, the combination may be compared to the acute and chronic toxicity thresholds of the respective graph. If the combination is below or to the left of the toxicity thresholds, it theoretically will not be harmful to the organisms. If it falls to the right or above these thresholds, the combination may be potentially injurious to the organisms.

These models should not be used to try to identify the "sensitive" species or genera, which might be impacted by the proposed chlorination practices for reasons discussed below. One limitation of this model is that, due to the variability in techniques and biological end-points, an organism may appear to be "sensitive" in some studies, but "tolerant" in other studies. This, in fact, does appear to be the case for some of the species and genera having low data points on the graphs (figures 1 and 2).

In spite of the fact that intermittent chlorination studies were not used to construct the models, the potential effects of intermittent chlorination on fish and invertebrates can be assessed using these models, although the models may be somewhat conservative.[80] To determine whether the intermittent chlorination practice may be potentially harmful the combination of chlorine concentration-total chlorination exposure time daily is compared with the graphs as above. The total chlorination exposure time daily is equal to the number of chlorine pulses per day times the average duration of each pulse.

Specifics

Theoretically, models of this type may be useful in specific site-assessment of environmentally acceptable chlorination schedules, if the chlorine concentrations and dilution dynamics of a particular site are known.[66] Thus, since these models are based on data from the organisms present in the TVA area, it would seem that the toxicity models would be useful to TVA for assessing the impact of chlorination practices at TVA power plants, assuming that chlorination schedules and plume dynamics are known for the plants. Since the dilution dynamics of these power plants are not known, an in-depth analysis of the impact of the chlorine plume on aquatic organisms was not possible. However, given the chlorination levels and exposure times at the power plants, an alternative method was used to estimate the impact of the chlorine plume near the mouth of the discharge canal on aquatic organisms. The pertinent chlorination information for each power plant is listed in table 3. The following assumptions were made in estimating the average free and total residual chlorine concentrations at the mouth of the discharge canal: (a) there is no chlorine demand, (b) mixing is uniform in the discharge canal, (c) only one unit chlorinates at any one time, (d) dilution is attained solely by the addition of water at the same rate and at all times during chlorination, (e) all units are pumping water at the same rate and at all times during chlorination, and (f) the background chlorine levels of non-chlorinating units are 0.00 mg/l of chlorine. The estimated average total residual chlorine concentrations at the mouth of the discharge canal for each power plant, determined by dividing the concentration at the outlet by the number of units, are compared with the chlorine toxicity thresholds for fish and invertebrates in figures 3 and 4, respectively. As can be seen in figure 3, no effect would be expected for fish species, in the vicinity of the discharge canal, except for those at power plant B. However, invertebrate genera present near the mouth of the discharge canal would probably be impacted by the chlorination practices at all four power plants (figure 4).

EVALUATION OF THESE MODELS

One way of evaluating the use of these models in adequately assessing the impact of chlorination practices at TVA power plants on aquatic organisms is to examine power plant effects on the organisms present in the vicinity of these power plants. Theoretically, 316(a) reports could be used to document any power plant impact on these organisms. However, the 316(a) reports for power plants A and B, which are the only two chlorinating TVA power plants requiring these reports, were prepared from data accumulated during 1973 to 1975. Since the chlorine practices at the plants during this period[83, 84] were evidently different from those summarized in table 3, the 316(a) reports could neither substantiate nor negate the predictability of these models.

ATTRIBUTES AND CRITICISMS OF THESE MODELS

Since the models presented in this paper were developed using procedures similar to those of Mattice and Zittel, the same attributes and criticisms that apply to the Mattice-Zittel models also apply to the models prepared for this study. This method is one of the few available for assessing site-specific sublethal effects of chlorine exposure on aquatic organisms. The procedure using chlorine concentration and exposure time to assess these effects is still a valid approach. In addition, this procedure results in models that are probably conservative and, therefore, probably offer some degree of environmental protection beyond predictions. However, this procedure has been open to the following criticisms: (a) data were included from studies using inadequate experimental designs and/or inadequate or undisclosed methods of measuring chlorine concentrations; (b) chlorine concentrations used in preparing these models were not limited to one chlorine form; (c) information from observational, nonquantitative studies were not excluded from these models; (d) information was obtained from studies exhibiting a variety of biological end-points, rather than from studies exhibiting a specific biological response; (e) information usually was not included from studies on intermittent chlorination; (f) the toxicity thresholds were determined mainly by the lowest points on the graph (rather than the whole data set), which means that the validity of the model depends on relatively few data points; (g) the method of establishing the chronic toxicity threshold was somewhat arbitrary; and (h) the assumption that the chronic and acute toxicity thresholds are two distinct lines may not be valid, since it has been suggested that these lines actually represent parts of the same curve.[80, 81]

For the above reasons, the use of the toxicity models presented in this paper are somewhat limited. Recently some new procedures have been outlined by Turner and Thayer to assess lethal effects of chlorine exposure on aquatic organisms.[80] Perhaps these more refined procedures should be examined for developing assessments of potential chlorination effects on organisms located near TVA power plants. Until these new methods are examined, the models presented in this report offer the best available approach, representing a conservative site-specific estimate of potential sublethal effects of chlorination practices on aquatic organisms.

RECOMMENDATIONS ON CHLORINATION PRACTICES AT TVA POWER PLANTS

It is difficult to recommend any alterations in chlorination practices at TVA power plants, since the predictability of the Mattice-Zittel models was neither validated nor invalidated. Although application of the models predict mortality for invertebrates at all plants and for fish at power plant B, it should be remembered that the models are probably somewhat conservative and, therefore, the expected impacts at these plants may not occur. However, chlorine minimization studies by TVA have indicated efficient operations at lower chlorination levels than those existing for the 1973-1975 period used for this report. It is my recommendation that in situ studies be performed to assess chlorination effects on the organisms at each power plant or that laboratory studies be performed to substantiate or negate the adequacy of these models for predicting chlorination effects on aquatic organisms.

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TABLE 1. EFFECTS OF CHLORINE ON FISH SPECIES PRESENT WITHIN THE TVA WATERSHED

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Petromyzontidae									
	Ichthyomyzon castaneus	Chestnut lamprey								
	Polyodontidae									
	Polyodon spathula	Paddlefish								
	Lepisosteidae									
	Lepisosteus oculatus	Spotted gar								
	Lepisosteus osseus	Longnose gar								
	Lepisosteus platostomus	Shortnose gar								
	Amiidae									
	Amia calva	Bowfin								
	Anguillidae									
	Anguilla rostrata	American eel								
	Clupeidae									
	Alosa chrysochloris	Skipjack herring								
1	Dorosoma cepedianum	Gizzard shad		0.62	Continuous		10		Some mortality	1
	Dorosoma petenense	Threadfin shad								
	Hiodontidae									
	Hiodon alosoides	Goldeye								
	Hiodon tergisus	Mooneye								
	Umbridae									
	Umbra limi	Mudminnow								
	Esocidae									
2	Esox vermiculatus	Grass pickerel		1.0	Intermittent	1 pulse of 60 min.	1,440		100% mortality	2
	Esox niger	Chain pickerel								
	Cyprinidae									
	Campostoma anomalum	Stoneroller								
3	Not given	Goldfish		1.0	Continuous		480		Some mortality	3
4	Not given	Goldfish		0.3	Continuous		1,440		100% mortality	4
5	Carassius auratus	Goldfish		0.49	Continuous		1,440	20-22.5	50% mortality	5
6	Carassius auratus	Goldfish		0.38	Continuous		2,880	20-22.5	50% mortality	5
7	Carassius auratus	Goldfish		0.35	Continuous		4,320	20-22.5	50% mortality	5
8	Carassius auratus	Goldfish		0.35	Continuous		5,760	20-22.5	50% mortality	5
9	Carassius auratus	Goldfish		0.153-0.210	Continuous		5,760	25	50% mortality	6
10	Carassius auratus	Goldfish		0.27	Continuous		1,440		50% mortality	7,8
	Carassius auratus	Goldfish		0.44-15.85	Intermittent	1-8 pulses of 15-480 min.	1,440		50% mortality	8
11	Carassius auratus	Goldfish		1.18	Continuous		5,760		50% mortality	9
12	Carassius auratus	Goldfish		1.0	Continuous		5,760		100% mortality	10
13	Carassius auratus	Goldfish		1.6	Continuous		240		100% mortality	11
	Cyprinus carpio	Carp		1.85	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	0% mortality	12

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Cyprinus carpio	Carp		1.25	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	0% mortality	12
14	Cyprinus carpio	Carp		0.72	Continuous		65		Some mortality	1
	Cyprinus carpio	Carp		1.72	Intermittent	3 pulses daily of 200 min.	5,760		50% mortality	13
	Cyprinus carpio	Carp		0.2	Intermittent	3 pulses daily of 200 min.	5,760		50% mortality	13
15	Cyprinus carpio	Carp		0.800	Continuous		2,880	12	50% mortality	9
	Cyprinus carpio	Carp		2.37	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	50% mortality	12,14
	Cyprinus carpio	Carp		1.82	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12,14
	Cyprinus carpio	Carp		1.50	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	50% mortality	12,14
	Cyprinus carpio	Carp	Juvenile	0.403[b]	Intermittent	3 pulses daily of 200 min.	1,440	24	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.278[b]	Intermittent	3 pulses daily of 200 min.	2,880	24	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.219[b]	Intermittent	3 pulses daily of 200 min.	4,320	24	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.538[b]	Intermittent	3 pulses daily of 200 min.	5,760	6	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.219[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.400[b]	Intermittent	3 pulses daily of 200 min.	7,200	6	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.219[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.331[b]	Intermittent	3 pulses daily of 200 min.	8,640	6	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.283[b]	Intermittent	3 pulses daily of 200 min.	9,120	6	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.245[b]	Intermittent	3 pulses daily of 200 min.	9,960	6	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	0.219[b]	Intermittent	3 pulses daily of 200 min.	9,960	24	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	1.72[b]	Intermittent	3 pulses daily of 200 min.	5,760	6	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	1.60[b]	Intermittent	3 pulses daily of 200 min.	7,200	6	50% mortality	15

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Cyprinus carpio	Carp	Juvenile	1.40[b]	Intermittent	3 pulses daily of 200 min.	8,640	6	50% mortality	15
	Cyprinus carpio	Carp	Juvenile	1.19[b]	Intermittent	3 pulses daily of 200 min.	9,960	6	50% mortality	15
	Cyprinus carpio	Carp		0.70	Intermittent	3 pulses daily of 200 min.	6,000		80% mortality	16
	Cyprinus carpio	Carp		3.24	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	100% mortality	12
	Cyprinus carpio	Carp		2.38	Intermittent	4 pulses of 40 min. at 5 hr intervals	4,320	20	100% mortality	12
	Cyprinus carpio	Carp		1.96	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	100% mortality	12
	Hybopsis dissimilis	Streamline chub								
	Hybopsis amblops	Bigeye chub								
	Hybopsis storeriana	Silver chub								
	Nocomis micropogon	River chub								
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.84	Intermittent	3 pulses of 200 min.	1,800	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.257	Intermittent	3 pulses of 200 min.	1,800	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.162	Intermittent	3 pulses of 200 min.	10,080	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.177	Intermittent	3 pulses of 200 min.	10,080	24	50% mortality	15
16	Notemigonus crysoleucas	Golden shiner		0.040	Continuous		5,760	25	50% mortality	6
17	Notemigonus crysoleucas	Golden shiner		0.2	Continuous		5,760	25	50% mortality	17
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.84[b]	Intermittent	3 pulses daily of 200 min.	1,800	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.26[b]	Intermittent	3 pulses daily of 200 min	1,800	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.55[b]	Intermittent	3 pulses daily of 200 min.	2,880	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.22[b]	Intermittent	3 pulses daily of 200 min.	2,880	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.39[b]	Intermittent	3 pulses daily of 200 min.	4,320	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.21[b]	Intermittent	3 pulses daily of 200 min.	4,320	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.27[b]	Intermittent	3 pulses daily of 200 min.	5,760	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.19[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.21[b]	Intermittent	3 pulses daily of 200 min.	7,200	5	50% mortality	18

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.18[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.18[b]	Intermittent	3 pulses daily of 200 min.	8,640	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.18[b]	Intermittent	3 pulses daily of 200 min.	8,640	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.99[b]	Intermittent	3 pulses daily of 200 min.	2,880	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	1.09[b]	Intermittent	3 pulses daily of 200 min.	2,880	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.72[b]	Intermittent	3 pulses daily of 200 min.	5,760	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.93[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.67[b]	Intermittent	3 pulses daily of 200 min.	7,200	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.92[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.64[b]	Intermittent	3 pulses daily of 200 min.	8,640	5	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.92[b]	Intermittent	3 pulses daily of 200 min.	8,640	24	50% mortality	18
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.84[b]	Intermittent	3 pulses daily of 200 min.	1,800	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.257[b]	Intermittent	3 pulses daily of 200 min.	1,800	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.550[b]	Intermittent	3 pulses daily of 200 min.	2,880	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.222[b]	Intermittent	3 pulses daily of 200 min.	2,880	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.502[b]	Intermittent	3 pulses daily of 200 min.	3,360	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.212[b]	Intermittent	3 pulses daily of 200 min.	3,360	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.388[b]	Intermittent	3 pulses daily of 200 min.	4,320	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.212[b]	Intermittent	3 pulses daily of 200 min.	4,320	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.269[b]	Intermittent	3 pulses daily of 200 min.	5,760	5	50% mortality	15

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.193[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.205[b]	Intermittent	3 pulses daily of 200 min.	7,200	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.182[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.181[b]	Intermittent	3 pulses daily of 200 min.	8,640	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.177[b]	Intermittent	3 pulses daily of 200 min.	8,640	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.162[b]	Intermittent	3 pulses daily of 200 min.	10,080	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.177[b]	Intermittent	3 pulses daily of 200 min.	10,080	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.993[b]	Intermittent	3 pulses daily of 200 min.	2,880	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	1.094[b]	Intermittent	3 pulses daily of 200 min.	2,880	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.871[b]	Intermittent	3 pulses daily of 200 min.	4,320	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.979[b]	Intermittent	3 pulses daily of 200 min.	4,320	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.724[b]	Intermittent	3 pulses daily of 200 min.	5,760	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.930[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.763[b]	Intermittent	3 pulses daily of 200 min.	7,200	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.921[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.644[b]	Intermittent	3 pulses daily of 200 min.	8,640	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.921[b]	Intermittent	3 pulses daily of 200 min.	8,640	24	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.533[b]	Intermittent	3 pulses daily of 200 min.	10,080	5	50% mortality	15
	Notemigonus crysoleucas	Golden shiner	Juvenile	0.921[b]	Intermittent	3 pulses daily of 200 min.	10,080	24	50% mortality	15
18	Notemigonus crysoleucas	Golden shiner		>3,000	Continuous		0.17		Death	19

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
19	Notemigonus crysoleucas	Golden shiner		0.8	Continuous		240		100% mortality	11
	Notropis ardens	Rosefin shiner								
	Notropis atherinoides	Emerald shiner		0.46	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	0% mortality	12
	Notropis atherinoides	Emerald shiner		0.40	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	0% mortality	12
	Notropis atherinoides	Emerald shiner		0.21	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	0% mortality	12
	Notropis atherinoides	Emerald shiner		0.63	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	50% mortality	12,14
	Notropis atherinoides	Emerald shiner		0.51	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12,14
	Notropis atherinoides	Emerald shiner		0.35	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	50% mortality	12,14
	Notropis atherinoides	Emerald shiner	Juvenile	1.4	Intermittent	1 pulse of 30 min.	2,880	10	50% mortality	20
	Notropis atherinoides	Emerald shiner	Juvenile	0.3	Intermittent	1 pulse of 30 min.	2,880	25	50% mortality	
	Notropis atherinoides	Emerald shiner		0.85	Intermittent	1 pulse of 30 min.	2,880	10	50% mortality	21
	Notropis atherinoides	Emerald shiner		0.28	Intermittent	1 pulse of 30 min.	2,880	25	50% mortality	
				0.97	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	100% mortality	12
				0.59	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	100% mortality	12
	Notropis buchanani	Ghost shiner								
	Notropis coccogenis	Warpaint shiner								
	Notropis galacturus	Whitetail shiner								
	Notropis leuciodus	Tennessee shiner								
	Notropis photogenis	Silvershiner								
20	Notropis rubellus	Rosyface shiner		0.07	Continuous		1,180		100% mortality	2
21	Notropis rubellus	Rosyface shiner		0.7	Continuous		79		100% mortality	2
	Notropis spilopterus	Spotfin shiner		0.52	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	0% mortality	12
	Notropis spilopterus	Spotfin shiner		0.45	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	0% mortality	12
	Notropis spilopterus	Spotfin shiner		0.65	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	50% mortality	12,14
	Notropis spilopterus	Spotfin shiner		0.59	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12,14
	Notropis spilopterus	Spotfin shiner		0.41	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	50% mortality	12,14
	Notropis spilopterus	Spotfin shiner		0.90	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	100% mortality	12

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Notropis spilopterus	Spotfin shiner		0.75	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	100% mortality	
	Notropis spilopterus	Spotfin shiner		0.54	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	100% mortality	12
	Notropis volucellus	Mimic shiner								
	Notropis whippeli	Steelcolor shiner								
	Notropis chrysocephalus	Striped shiner								
	Notropis telescopus	Telescope shiner								
	Opsopoeodus emiliae	Pugnose minnow		0.045	Continuous		5,760	25	50% mortality	6
	Phenacobius mirabilis	Suckermouth minnow								
	Phenacobius uranops	Stargazing minnow								
23	Pimephales notatus	Bluntnose minnow		0.7	Continuous		61		100% mortality	2
	Pimephales promelas	Fathead minnow		0.033-0.034	Continuous		NG		Retarded growth	6
24	Pimephales promelas	Fathead minnnow	Larvae	0.108	Continuous		43,200		68% reduced growth	22
	Pimephales promelas	Fathead minnow		0.085	Continuous		NG		Reduced spawning[a]	22
25	Pimephales promelas	Fathead minnow		0.043	Continuous		10,800		50% decreased spawning	22
26	Pimephales promelas	Fathead minnow		0.110	Continuous		433,440		No spawning	24
27	Pimephales promelas	Fathead minnow		0.110	Continuous		100,800		No spawning[a]	24
	Pimephales promelas	Fathead minnow		0.0165	Continuous		211,680		Safe concentration	22
28	Pimephales promelas	Fathead minnow		0.05	Continuous		5,760		Threshold mortality	26
29	Pimephales promelas	Fathead minnow		0.086-0.130	Continuous		5,760		50% mortality	24
30	Pimephales promelas	Fathead minnow		0.082-0.095	Continuous		7,200	25	50% mortality[a]	6
31	Pimephales promelas	Fathead minnow		0.08-0.19	Continuous		7,200		50% mortality	26
32	Pimephales promelas	Fathead minnow		0.082-0.115	Continuous		10,080		50% mortality	25
33	Pimephales promelas	Fathead minnow		0.05-0.16	Continuous		5,760		50% mortaltiy	26,27
34	Pimephales promelas	Fathead minnow		0.02	Continuous		7,200		50% mortality	28
35	Pimephales promelas	Fathead minnow		0.185	Continuous		720		50% mortality[a]	21
36	Pimephales promelas	Fathead minnow		>0.79	Continuous		60		50% mortality	25
37	Pimephales promelas	Fathead minnow		0.26	Continuous		720		50% mortality	25
38	Pimephales promelas	Fathead minnow		0.998	Continuous		5,760	12	50% mortality[a]	9
39	Pimephales promelas	Fathead minnow		0.504	Continuous		66		50% mortality[a]	29
40	Pimephales promelas	Fathead minnow		0.113	Continuous		840		50% mortality[a]	29
41	Pimephales promelas	Fathead minnow		0.512	Continuous		84		50% mortality[a]	29
42	Pimephales promelas	Fathead minnow		0.116	Continuous		3,390		50% mortality[a]	29
43	Pimephales promelas	Fathead minnow		0.306	Continuous		216		50% mortality[a]	29
44	Pimephales promelas	Fathead minnow		0.318	Continuous		156		50% mortality[a]	29
45	Pimephales promelas	Fathead minnow		0.241	Continuous		126		50% mortality[a]	29
46	Pimephales promelas	Fathead minnow		0.224	Continuous		180		50% mortality[a]	29
47	Pimephales promelas	Fathead minnow		0.359	Continuous		78		50% mortality[a]	29

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
48	Pimephales promelas	Fathead minnow		0.332	Continuous		90		50% mortality[a]	29
49	Pimephales promelas	Fathead minnow		0.262	Continuous		222		50% mortality[a]	29
50	Pimephales promelas	Fathead minnow		0.315	Continuous		162		50% mortality[a]	29
51	Pimephales promelas	Fathead minnow		0.233	Continuous		258		50% mortality[a]	29
52	Pimephales promelas	Fathead minnow		0.268	Continuous		222		50% mortality[a]	29
53	Pimephales promelas	Fathead minnow		0.185	Continuous		126		50% mortality[a]	29
54	Pimephales promelas	Fathead minnow		0.195	Continuous		126		50% mortality[a]	29
55	Pimephales promelas	Fathead minnow		0.239	Continuous		402		50% mortality[a]	29
56	Pimephales promelas	Fathead minnow		0.239	Continuous		372		50% mortality[a]	29
57	Pimephales promelas	Fathead minnow		0.268	Continuous		222		50% mortality[a]	29
58	Pimephales promelas	Fathead minnow		0.246	Continuous		258		50% mortality[a]	29
59	Pimephales promelas	Fathead minnow		0.166	Continuous		210		50% mortality[a]	29
60	Pimephales promelas	Fathead minnow		0.166	Continuous		240		50% mortality	29
61	Pimephales promelas	Fathead minnow	Larvae	0.108	Continuous		43,200		60% mortality	22
62	Rhinichthyes atratulus	Blacknose dace		0.74	Continuous		15		4% mortality	30
63	Rhinichthyes atratulus	Blacknose dace		0.15	Continuous		360		10% mortality	30
64	Rhinichthyes atratulus	Blacknose dace		6.6	Continuous		17		50% mortality	23
65	Rhinichthyes atratulus	Blacknose dace		0.15	Continuous		684		50% mortality	23
66	Rhinichthyes atratulus	Blacknose dace		5.25	Continuous		11		50% mortality	23
67	Rhinichthyes atratulus	Blacknose dace		0.19	Continuous		1,148		50% mortality	23
68	Rhinichthyes atratulus	Blacknose dace		1.35	Continuous		40		65% mortality	30
69	Rhinichthyes atratulus	Blacknose dace		0.74	Continuous		60		72% mortality	30
70	Rhinichthyes atratulus	Blacknose dace		0.15	Continuous		720		83% mortality	30
71	Rhinichthyes atratulus	Blacknose dace		6.6	Continuous		8		100% mortality	30
	Catostomidae									
	Carpiodes carpio	River carpsucker								
	Carpiodes cyprinus	Quillback carpsucker								
	Carpiodes velifer	Highfin carpsucker								
	Catostomus commersoni	White sucker		0.24	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	27	0% mortality	12
72	Catostomus commersoni	White sucker		0.379	Continuous		5,760	12	50% mortality	9
73	Catostomus commersoni	White sucker		0.132	Continuous		10,080		50% mortality	25
74	Catostomus commersoni	White sucker		0.248	Continuous		720		50% mortality	24
	Catostomus commersoni	White sucker		1.09	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	50% mortality	12
	Catostomus commersoni	White sucker		0.73	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12
	Catostomus commersoni	White sucker		0.36	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	27	50% mortality	12

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
75	Catostomus commersoni	White sucker		>0.560	Continuous		60	16	50% mortality	24
76	Catostomus commersoni	White sucker		0.245	Continuous		720	16	50% mortality	24
77	Catostomus commersoni	White sucker		0.138	Continuous		5,760	16	50% mortality	24
78	Catostomus commersoni	White sucker		0.132	Continuous		10,080	16	50% mortality	24
79	Catostomus commersoni	White sucker		1.0	Continuous		60		100% mortality	31
	Catostomus commersoni	White sucker		1.52	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	100% mortality	12
	Catostomus commersoni	White sucker		0.51	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	27	100% mortality	12
	Hypentelium nigricans	Northern hogsucker								
	Ictiobus bubalus	Smallmouth buffalo								
	Ictiobus cyprinellus	Bigmouth buffalo								
	Ictiobus niger	Black buffalo								
	Minytrema melanops	Spotted sucker								
	Moxostoma anisurum	Silver redhorse								
	Moxostoma macrolepidotum	Shorthead redhorse								
	Moxostoma carinatum	River redhorse								
	Moxostoma duquesnei	Black redhorse								
	Moxostoma erythrurum	Golden redhorse								
	Ictaluridae									
	Ictalurus furcatus	Blue catfish								
80	Ictalurus melas	Black bullhead		1.36	Continuous		25		Some mortality	1
81	Ictalurus melas	Black bullhead		~4.5	Continuous		1,440		50% mortality	
82	Ictalurus melas	Black bullhead		0.099	Continuous		5,760		50% mortality	11
83	Ictalurus melas	Black bullhead		1.41	Continuous		5,760	12	50% mortality	25
	Ictalurus natalis	Yellow bullhead								9
	Ictalurus nebulosus	Brown bullhead								
	Ictalurus punctatus	Channel catfish		0.49	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	0% mortality	12
	Ictalurus punctatus	Channel catfish		0.53	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	0% mortality	12
	Ictalurus punctatus	Channel catfish		0.78	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	50% mortality	12
	Ictalurus punctatus	Channel catfish		0.65	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12
	Ictalurus punctatus	Channel catfish		0.67	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	50% mortality	12
84	Ictalurus punctatus	Channel catfish		0.156	Continuous		5,760		50% mortality	9
85	Ictalurus punctatus	Channel catfish		0.09	Continuous		5,760		50% mortality	32
	Ictalurus punctatus	Channel catfish		1.1	Intermittent	6 pulses of 20-30 min.	2,880		50% mortality	33

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
86	Ictalurus punctatus	Channel catfish		0.082	Continuous		5,760		50% mortality	6
87	Ictalurus punctatus	Channel catfish		0.064	Continuous		5,760		50% mortality	6
	Ictalurus punctatus	Channel catfish	Juvenile	0.20[b]	Intermittent	3 pulses daily of 200 min.	2,880	5	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.14[b]		3 pulses daily of 200 min.	2,880	24	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.12[b]	Intermittent	3 pulses daily of 200 min.	4,320	5	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.09[b]	Intermittent	3 pulses daily of 200 min.	4,320	24	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.08[b]	Intermittent	3 pulses daily of 200 min.	5,760	5	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.06[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.05[b]	Intermittent	3 pulses daily of 200 min.	7,200	5	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.05[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.45[b]	Intermittent	3 pulses daily of 200 min.	2,880	24	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.28[b]	Intermittent	3 pulses daily of 200 min.	4,320	6	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.33[b]	Intermittent	3 pulses daily of 200 min.	4,320	24	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.23[b]	Intermittent	3 pulses daily of 200 min.	5,760	6	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.26[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.21[b]	Intermittent	3 pulses daily of 200 min.	7,200	6	50% mortality	18
	Ictalurus punctatus	Channel catfish	Juvenile	0.25[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	18
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.143[b]	Intermittent	3 pulses daily of 200 min.	1,800	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.200[b]	Intermittent	3 pulses daily of 200 min.	2,800	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.152[b]	Intermittent	3 pulses daily of 200 min.	3,360	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.120[b]	Intermittent	3 pulses daily of 200 min.	4,320	5	50% mortality	15

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.093[b]	Intermittent	3 pulses daily of 200 min.	4,320	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.082[b]	Intermittent	3 pulses daily of 200 min.	5,760	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.064[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.050[b]	Intermittent	3 pulses daily of 200 min.	7,200	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.051[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.033[b]	Intermittent	3 pulses daily of 200 min.	8,640	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.032[b]	Intermittent	3 pulses daily of 200 min.	8,640	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.033[b]	Intermittent	3 pulses daily of 200 min.	9,120	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.030[b]	Intermittent	3 pulses daily of 200 min.	9,120	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.025[b]	Intermittent	3 pulses daily of 200 min.	10,080	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.447[b]	Intermittent	3 pulses daily of 200 min.	2,880	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.328[b]	Intermittent	3 pulses daily of 200 min.	4,320	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.313[b]	Intermittent	3 pulses daily of 200 min.	4,800	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.275[b]	Intermittent	3 pulses daily of 200 min.	5,760	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.260[b]	Intermittent	3 pulses daily of 200 min.	5,760	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.234[b]	Intermittent	3 pulses daily of 200 min.	7,200	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.246[b]	Intermittent	3 pulses daily of 200 min.	7,200	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.213[b]	Intermittent	3 pulses daily of 200 min.	8,640	5	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.246[b]	Intermittent	3 pulses daily of 200 min.	8,640	24	50% mortality	15
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.208[b]	Intermittent	3 pulses daily of 200 min.	10,080	5	50% mortality	15

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Ictalurus punctatus (Ictalurus lacustris)	Channel catfish	Juvenile	0.241[b]	Intermittent	3 pulses daily of 200 min.	10,080	24	50% mortality	15
	Noturus gyrinus	Tadpole madtom								
	Pylodictis olivaris	Flathead catfish								
	Aphredoderidae									
	Aphredoderus sayanus	Pirate perch								
	Cyprinodontidae									
	Fundulus catenatus	Northern studfish								
	Fundulus notatus	Blackstrip topminnow								
	Fundulus olivaceus	Blackspotted topminnow								
	Poeciliidae									
88	Gambusia affinis	Mosquito fish		0.5-1.0	Continuous		4,320		Mortality threshold	34
89	Gambusia affinis	Mosquito fish		0.5	Continuous		8,640		50% mortality	35
	Atherinidae									
	Labidesthes sicculus	Brook silverside								
	Cottidae									
	Cottus carolinae	Banded sculpin								
	Serranidae									
	Morone chrysops	White bass		1.45	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	0% mortality	12
	Morone chrysops	White bass		0.78	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	0% mortality	12
	Morone chrysops	White bass		2.87	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	50% mortality	12
	Morone chrysops	White bass		1.80	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12
	Morone chrysops	White bass		1.15	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	50% mortality	12
	Morone chrysops	White bass		2.08	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	100% mortality	12
	Morone chrysops	White bass		1.47	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	100% mortality	12
	Morone mississippiensis	Yellow bass								
90	Morone saxatilis	Striped bass		0.30	Continuous		1,440		50% mortality	36
91	Morone saxatilis	Striped bass		0.25	Continuous		2,880		50% mortality	36
92	Morone saxatilis	Striped bass	Larvae	0.5	Continuous		5,760		50% mortality	36
93	Morone saxatilis	Striped bass	Juvenile	0.25	Continuous		5,760		50% mortality	36
94	Morone saxatilis	Striped bass	Larvae	0.19-0.20	Continuous		1,440		50% mortality	37
95	Morone saxatilis	Striped bass	Embryo	0.20-0.22	Continuous		2,880		50% mortality	37
96	Morone saxatilis	Striped bass	Prolarvae	0.04	Continuous		2,880		50% mortality	38

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
97	Morone saxatilis	Striped bass	Larvae	0.07	Continuous		2,880		50% mortality	38
98	Morone saxatilis	Stripped bass	Juvenile	0.07	Continuous		2,880		50% mortality	38
	Centrarchidae									
	Ambloplites rupestris	Rock bass								
	Lepomis gibbosis	Pumpkinseed								
	Lepomis gulosus	Warmouth								
	Lepomis auritus	Redbreast								
	Lepomis cyanellus	Green sunfish		0.04	Continuous		NG		Eventual mortality	39
	Lepomis cyanellus	Green sunfish		1.28	Continuous		5,760	12	50% mortality	9
[illegible]	Lepomis cyanellus	Green sunfish		2.0	Continuous		1,440		60% mortality	11
	Lepomis humilis	Orange spotted sunfish								
	Lepomis macrochirus	Bluegill		2.35	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	4,320	10	0% mortality	12
	Lepomis macrochirus	Bluegill		1.35	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	4,320	20	0% mortality	12
	Lepomis macrochirus	Bluegill		1.07	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	4,320	30	0% mortality	12
	Lepomis macrochirus	Bluegill		3.00	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	4,320	10	50% mortality	12,14
	Lepomis macrochirus	Bluegill		1.72	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12,14
	Lepomis macrochirus	Bluegill		1.23	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	4,320	30	50% mortality	12,14
	Lepomis macrochirus	Bluegill		3.00	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	1,440	10	50% mortality	40
	Lepomis macrochirus	Bluegill		1.72	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	1,440	20	50% mortality	40
	Lepomis macrochirus	Bluegill		1.23	Intermittent	4 pulses daily of 40 min. at 5 hr. intervals	1,440	30	50% mortality	40
	Lepomis macrochirus	Bluegill	Juvenile	0.54[b]	Intermittent	3 pulses daily of 45 min.	2,880	25	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.47[b]	Intermittent	3 pulses daily of 45 min.	2,880	32	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.53[b]	Intermittent	3 pulses daily of 45 min.	4,320	6	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.41[b]	Intermittent	3 pulses daily of 45 min.	4,320	25	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.47[b]	Intermittent	3 pulses daily of 45 min.	4,320	32	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.45[b]	Intermittent	3 pulses daily of 45 min.	5,760	6	50% mortality	41

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Lepomis macrochirus	Bluegill	Juvenile	0.44[b]	Intermittent	3 pulses daily of 45 min.	5,760	15	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.39[b]	Intermittent	3 pulses daily of 45 min.	5,760	25	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.455[b]	Intermittent	3 pulses daily of 45 min.	5,760	32	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.33[b]	Intermittent	3 pulses daily of 45 min.	10,080	6	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.41[b]	Intermittent	3 pulses daily of 45 min.	10,080	15	50% mortality	41
	Lepomis macrochirus	Bluegill	Juvenile	0.37[b]	Intermittent	3 pulses daily of 45 min.	10,080	25	50% mortality	41
101	Lepomis macrochirus	Bluegill		0.33	Continuous		5,760	20	50% mortality	32
102	Lepomis macrochirus	Bluegill		0.18	Continuous		5,760	30	50% mortality	32
103	Lepomis macrochirus	Bluegill		0.555	Continuous		5,760	12	50% mortality	9
	Lepomis macrochirus	Bluegill		0.52	Intermittent	3 pulses daily	1,194-4,440	6-32	50% mortality	41
	Lepomis macrochirus	Bluegill		0.43-0.47	Intermittent	3 pulses daily	5,760	6-32	50% mortality	41
	Lepomis macrochirus	Bluegill		0.44	Intermittent	3 pulses daily	5,760	15-32	50% mortality	42
	Lepomis macrochirus	Bluegill		0.52	Intermittent	3 pulses daily	4,320		50% mortality	43
	Lepomis macrochirus	Bluegill		3.73	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	100% mortality	12
	Lepomis macrochirus	Bluegill		2.24	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	100% mortality	12
	Lepomis megalotis	Longear sunfish								
	Lepomis microlophus	Redear sunfish								
104	Micropterus dolomieui	Smallmouth bass		0.5	Continuous		900		50% mortality	44
	Micropterus punctulatus	Spotted bass								
105	Micropterus salmoides	Largemouth bass		0.494	Continuous		1,440		50% mortality	24
106	Micropterus salmoides	Largemouth bass		0.261	Continuous		10,080		50% mortality	25
107	Micropterus salmoides	Largemouth bass		> 0.74	Continuous		60		50% mortality	25
108	Micropterus salmoides	Largemouth bass		0.365	Continuous		720		50% mortality	25
109	Micropterus salmoides	Largemouth bass		> 0.574	Continuous		60	17	50% mortality	24
110	Micropterus salmoides	Largemouth bass		0.295	Continuous		5,760	17	50% mortality	24
111	Micropterus salmoides	Largemouth bass		0.261	Continuous		10,080	17	50% mortality	24
112	Micropterus salmoides	Largemouth bass		0.241	Continuous		5,760	25	50% mortality	6
	Pomoxis annularis	White crappie								
113	Pomoxis nigromaculatus	Black crappie		1.36	Continuous		25		Some mortality	1
	Percidae									
	Etheostoma asprigene	Mud darter								
	Etheostoma blennoides	Greenside darter								
	Etheostoma caeruleum	Rainbow darter								

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Etheostoma flabellare	Fantail darter								
	Etheostoma kennicolli	Stripetail darter								
	Etheostoma nigrum	Johnny darter								
	Etheostoma rufilineatum	Redline darter								
	Etheostoma simoterum	Tennessee snubnose darter								
	Etheostoma spectabile	Orange throat darter								
	Perca flavescens	Yellow perch		5.1	Intermittent	1 pulse of 30 min.	1,440-2,880	10	0% mortality	40
	Perca flavescens	Yellow perch		1.9	Intermittent	1 pulse of 30 min.	1,440-2,880	15	0% mortality	40
	Perca flavescens	Yellow perch		0.53	Intermittent	1 pulse of 30 min.	1,440-2,880	20	0% mortality	40
	Perca flavescens	Yellow perch		0.68	Intermittent	1 pulse of 30 min.	1,440-2,880	25	0% mortality	40
	Perca flavescens	Yellow perch		0.48	Intermittent	1 pulse of 30 min.	1,440-2,880	30	0% mortality	40
	Perca flavenscens	Yellow perch		1.7	Intermittent	3 pulses of 5 min. at 3 hr. intervals	1,440-2,880	10	0% mortality	40
114	Perca flavenscens	Yellow perch		0.72	Continuous		65		Some mortality	1
115	Perca flavescens	Yellow perch		0.365	Continuous		720		50% mortality[a]	24
116	Perca flavescens	Yellow perch		0.205	Continuous		10,080	17	50% mortality[a]	25
117	Perca flavescens	Yellow perch		>0.88	Continuous		60	17	50% mortality[a]	25
118	Perca flavescens	Yellow perch		0.464	Continuous		720		50% mortality[a]	25
119	Perca flavescens	Yellow perch		0.558	Continuous		5,760	12	50% mortality[a]	9
120	Perca flavescens	Yellow perch		7.7	Continuous		30	10	50% mortality	45
121	Perca flavescens	Yellow perch		1.0	Continuous		30	25	50% mortality	45
	Perca flavescens	Yellow perch		7.7	Intermittent	1 pulse of 30 min.	2,880	10	50% mortality	45
	Perca flavescens	Yellow perch		4.0	Intermittent	1 pulse of 30 min.	2,880	15	50% mortality	45
	Perca flavescens	Yellow perch		1.1	Intermittent	1 pulse of 30 min.	2,880	20	50% mortality	45
	Perca flavescens	Yellow perch		8.0	Intermittent	1 pulse of 30 min.	1,440-2,880	10	50% mortality	40
	Perca flavescens	Yellow perch		3.9	Intermittent	1 pulse of 30 min.	1,440-2,880	15	50% mortality	40
	Perca flavescens	Yellow perch		1.11	Intermittent	1 pulse of 30 min.	1,440-2,880	20	50% mortality	40
	Perca flavescens	Yellow perch		0.97	Intermittent	1 pulse of 30 min.	1,440-2,880	25	50% mortality	40
	Perca flavescens	Yellow perch		0.70	Intermittent	1 pulse of 30 min.	1,440-2,880	30	50% mortality	40
	Perca flavescens	Yellow perch		22.6	Intermittent	3 pulses of 5 min. at 3 hr. intervals	1,440-2,880	10	50% mortality	40
	Perca flavescens	Yellow perch		9.0	Intermittent	3 pulses of 5 min. at 3 hr. intervals	1,440-2,880	20	50% mortality	40
	Perca flavescens	Yellow perch		37.0	Intermittent	3 pulses of 5 min. at 3 hr. intervals	1,440-2,880	10	100% mortality	40
	Perca flavescens	Yellow perch		15.0	Intermittent	1 pulse of 30 min.	1,440-2,880	10	100% mortality	40
	Perca flavescens	Yellow perch		7.1	Intermittent	1 pulse of 30 min.	1,440-2,880	15	100% mortality	40
	Perca flavescens	Yellow perch		2.1	Intermittent	1 pulse of 30 min.	1,440-2,880	20	100% mortality	40
	Perca flavescens	Yellow perch		1.6	Intermittent	1 pulse of 30 min.	1,440-2,880	25	100% mortality	40
	Perca flavescens	Yellow perch		0.95	Intermittent	1 pulse of 30 min.	1,440-2,880	30	100% mortality	40
	Percina caprodes	Logperch								

(continued)

TABLE 1. (continued)

Data Point	Scientific Name	Descriptive Name	Life Stage (If not adult)	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Percina macrocephala	Longhead darter								
	Percina schumardi	River darter								
	Percina squamata	Olive darter								
	Stizostedian canadense	Sauger		0.75	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	0% mortality	12
	Stizostedian canadense	Sauger		0.49	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	0% mortality	12
	Stizostedian canadense	Sauger		0.53	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	0% mortality	12
	Stizostedian canadense	Sauger		1.14	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	50% motality	12
	Stizostedian canadense	Sauger		0.68	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12
	Stizostedian canadense	Sauger		0.71	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	50% mortality	12
122	Stizostedian canadense	Sauger		0.267	Continuous	4 pulses of 40 min. at 5 hr. intervals	720		50% mortality[a]	24
123	Stizostedian canadense	Sauger		0.150	Continuous	4 pulses of 40 min. at 5 hr. intervals	10,080		50% mortality[a]	25
124	Stizostedian canadense	Sauger		0.108	Continuous	4 pulses of 40 min. at 5 hr. intervals	5,760		50% mortality	6
	Stizostedian canadense	Sauger		1.54	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	100% mortality	12
	Stizostedian canadense	Sauger		1.15	Intermittent	4 pulses of 40 min. at 5 hr. intervlas	4,320	20	100% mortality	12
	Stizostedian canadense	Sauger		0.98	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	30	100% mortality	12
	Sciaenidae									
	Apoldinotus grunniens	Freshwater drum		1.73	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	0% mortality	12
	Aplodinotus grunniens	Freshwater drum		1.48	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	0% mortality	12
	Apoldinotus grunniens	Freshwater drum		2.45	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	50% mortality	12
	Aplodinotus grunniens	Freshwater drum		1.75	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	50% mortality	12
	Aplodinotus grunniens	Freshwater drum		2.84	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	10	100% mortality	12
	Aplodinotus grunniens	Freshwater drum		1.94	Intermittent	4 pulses of 40 min. at 5 hr. intervals	4,320	20	100% mortality	12

a Wastewater chlorination

b Concentration is reported as peak value of the pulse.

TABLE 2. EFFECTS OF CHLORINE ON INVERTEBRATES PRESENT WITHIN THE TVA AREA

Data Point	Scientific Name	Descriptive Name	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
	Arthropoda - Crustacea								
1	Asellus sp.	Sow-bug	0.5	Continuous		60		No reproduction	61
2	Asellus sp.	Sow-bug	0.7	Continuous		2,880	6	50% mortality	56
3	Asellus sp.	Sow-bug	0.3	Continuous		2,880	15	50% mortality	
4	Asellus sp	Sow-bug	0.13	Continuous		2,880	25	50% mortality	
5	Asellus sp	Sow-bug	0.613	Continuous		1,440	15	50% mortality	
6	Cyclops sp	Copepod	1.0	Continuous		30		Some mortality	47
7	Cyclops sp	Copepod	0.089	Continuous		5,760		50% mortality	51
	Cyclops sp	Copepod	0.069	Continuous		5,760		50% mortality	51
	Cyclops sp	Copepod	14.68	Intermittent	1 pulse of 30 min.	1,440	10	50% mortality	40,62 68
	Cyclops sp	Copepod	15.61	Intermittent	1 pulse of 30 min.	1,440	15	50% mortality	
	Cyclops sp	Copepod	5.76	Intermittent	1 pulse of 30 min.	1,440	20	50% mortality	
	Cyclops sp	Copepod	0.02	Continuous		-	15	100% mortality	51
	Cyclops sp	Copepod	0.03	Continuous		-	15	100% mortality	51
9	Daphnia sp	Water flea	0.002	Continuous		20,160		Decreased reproduction[a]	24
10	Daphnia sp.	Water flea	4.0	Continuous		2,880	23	Mortality threshold	49
11	Daphnia sp	Water flea	0.5	Continuous		60		Some mortality	47
12	Daphnia sp	Water flea	0.017	Continuous		2,880		50% mortality	46
13	Daphnia sp	Water flea	0.25	Continuous		240		100% mortality	EAP unpub. in 48
14	Daphnia sp.	Water flea	0.5	Continuous		4,320		100% mortality	10
	Eurytemora sp.	Copepod	1.0	Intermittent	1 pulse of 360 min.	1,440	15	50% mortality	57
	Eurytemora sp	Copepod	2.5	Intermittent	1 pulse of 9 min.	1,440	15	50% mortality	
15	Gammarus sp.	Scud	0.135	Continuous		43,200	17-18	No effect[a]	24
16	Gammarus sp	Scud	0.0034	Continuous		151,200		Almost no reproduction	22
17	Gammarus sp	Scud	0.019	Continuous		201,600	17-18	Decreased reproduction[a]	24
18	Gammarus sp.	Scud	0.054	Continuous		161,280	17-18	Decreased survival[a]	24
	Gammarus sp.	Scud	2.5	Intermittent	1 pulse of 180 min.	180	6-8	27% mortality	65
19	Gammarus sp	Scud	0.22	Continuous		5,760		50% mortality	22
20	Gammarus sp	Scud	0.900	Continuous		1,440	17-18	50% mortality[a]	24
21	Gammarus sp.	Scud	0.330	Continuous		5,760		50% mortality[a]	24
22	Gammarus sp	Scud	0.215	Continuous		5,760		50% mortality[a]	24
23	Gammarus sp	Scud	0.177	Continuous		8,640-10,080		50% mortality[a]	24
24	Gammarus sp	Scud	0.210	Continuous		8,640-10,080		50% mortality[a]	24
25	Gammarus sp	Scud	0.2-0.9	Continuous		480	6-25	50% mortality	56
26	Gammarus sp	Scud	0.05-0.1	Continuous		1,440	6-25	50% mortality	56
27	Gammarus sp	Scud	0.01	Continuous		5,760	6-25	50% mortality	56
28	Gammarus sp	Scud	0.023	Continuous		2,880	15	50% mortality	56
	Gammarus sp.	Scud	2.5	Intermittent	1 pulse of 180 min.	2,880	6-8	79% mortality	65
29	Gammarus sp.	Scud	0.035	Continuous		151,200		80% mortality	22
	Gammarus sp	Scud	2.5	Intermittent	1 pulse of 180 min.	5,760	6-8	97% mortality	65

(continued)

TABLE 2. (continued)

Data Point	Scientific Name	Descriptive Name	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
30	Orconectes sp.	Crayfish	0.780	Continuous		10,080	17	50% mortality[a]	24
31	Orconectes sp.	Crayfish	2.70	Continuous		1,440		50% mortality	52
32	Palaemonetes sp.	Shrimp	2.5	Continuous		180	12	2% mortality	65
33	Palaemonetes sp.	Shrimp	0.38	Continuous		1,440		50% mortality	55
34	Palaemonetes sp.	Shrimp	0.22	Continuous		5,760		50% mortality	55
35	Palaemonetes sp.	Shrimp	2.5	Continuous		2,880	12	72% mortality	65
36	Palaemonetes sp.	Shrimp	2.5	Continuous		5,760	12	98% mortality	
	Arthropoda - Insecta								
37	Centroptilium sp.	Mayfly	0.071	Continuous		1,440	6	50% mortality	56
38	Chironomus sp.	Midge	7.0	Continuous		1,440		80% mortality	50
39	Ephemerella sp.	Mayfly	0.027	Continuous		2,880	15	50% mortality	56
40	Ephemerella sp.	Mayfly	5.67	Continuous		480	6	50% mortality	56
41	Ephemerella sp.	Mayfly	1.33-1.38	Continuous		720	6,15	50% mortality	56
42	Ephemerella sp	Mayfly	0.02-0.08	Continuous		2,880	6,15	50% mortality	56
43	Hydropsyche sp.	Caddisfly	0.03	Continuous		5,760	32	50% mortality	56
44	Hydropsyche sp.	Caddisfly	0.05	Continuous		10,080	32	50% mortality	56
45	Hydropsyche sp.	Caddisfly	0.396	Continuous		480	25	50% mortality	56
46	Hydropsyche sp	Caddisfly	>0.28	Continuous		480-10,080	25,32	50% mortality	56
47	Hydropsyche sp	Caddisfly	>0.74	Continuous		8,640	18	50% mortality[a]	24
48	Hydropsyche sp.	Caddisfly	>0.55	Continuous		10,080	18	50% mortality[a]	24
49	Isonychia sp.	Mayfly	0.0093	Continuous		2,880	6	50% mortality	56
50	Isonychia sp.	Mayfly	0.08-0.3	Continuous		480	6-32	50% mortality	56
51	Peltoperla sp.	Stonefly	0.5-0.7	Continuous		720	6-25	50% mortality	56
52	Peltoperla sp.	Stonefly	0.020	Continuous		2,880	15	50% mortality	56
53	Psephenus sp.	Water pennies	0.256	Continuous		2,880		50% mortality	56
54	Psephenus sp.	Water pennies	0.089	Continuous		10,080		50% mortality	56
55	Pteronarcys sp.	Stonefly	>0.780	Continuous		2,880	18	50% mortality[a]	24
56	Pteronarcys sp.	Stonefly	0.480	Continuous		4,320	18	50% mortality[a]	24
57	Pteronarcys sp.	Stonefly	0.400	Continuous		5,760	18	50% mortality[a]	24
58	Pteronarcys sp.	Stonefly	0.195	Continuous		10,080	18	50% mortality[a]	24
59	Stenonema sp.	Mayfly	0.502	Continuous		480	25	50% mortality	56
60	Stenonema sp.	Mayfly	0.5-0.6	Continuous		480	25,32	50% mortality	56
61	Stenonema sp.	Mayfly	0.3-4.8	Continuous		720	6-32	50% mortality	56
62	Stenonema sp.	Mayfly	0.016-0.10	Continuous		5,760	6-32	50% mortality	56
	Annelida								
63	Nais sp.	Oligochaete worm	1.0	Continuous		35		95% mortality	64
64	Nais sp.	Oligochaete worm	1.0	Continuous		34		100% mortality	53
65	Nais sp.	Oligochaete worm	3.5	Continuous		25		100% mortality	53
66	Nais sp.	Oligochaete worm	5.0	Continuous		17		100% mortality	53
67	Nais sp	Oligochaete worm	1.2	Continuous		10		100% mortality	53

(continued)

TABLE 2. (continued)

Data Point	Scientific Name	Descriptive Name	Concentration (mg/l)	Exposure Type	Intermittent Pulses Characteristics	Test Duration (min.)	Temperature (°C)	Effect	Reference Number
68	Nais sp.	Oligochaete worm	2.0	Continuous		15		100% mortality	64
69	Nais sp.	Oligochaete worm	0.5	Continuous		30		Disintegration	60
	Rotifera								
	Branchionus sp.	Rotifer	<1.0	Intermittent	1 pulse of 30 min.	2,880	20	<50% mortality	58
	Branchionus sp.	Rotifer	>0.2	Intermittent	1 pulse of 30 min.	2,880	20	>50% mortality	58
70	Keratella sp.	Rotifer	0.032	Continuous		60	15	50% mortality	59
71	Keratella sp.	Rotifer	0.027	Continuous		240	15	50% mortality	59
72	Keratella sp.	Rotifer	0.0135	Continuous		1,440	15	50% mortality	59
73	Keratella sp.	Rotifer	0.019	Continuous		240		50% mortality	51
	Mollusca								
	Anculosa sp	Operculate snail	<0.04[b]	Intermittent	2 hrs. per day	4,320		50% mortality	54
74	Campeloma sp.	Operculate snail	>0.810	Continuous		20,160		50% mortality[a]	24
	Goniobasis sp.	Operculate snail	0.144[b]	Intermittent	3 pulses daily of 45 min.	10,080	6	50% mortality	56
	Goniobasis sp.	Operculate snail	2.55[b]	Intermittent	3 pulses daily of 45 min.	10,080	15	50% mortality	56
	Goniobasis sp.	Operculate snail	0.367[b]	Intermittent	3 pulses daily of 45 min.	10,080	25	50% mortality	56
75	Goniobasis sp.	Operculate snail	0.044	Continuous		5,760	25	50% mortality	56
76	Goniobasis sp.	Operculate snail	0.014	Continuous		10,080	6	50% mortality	56
77	Goniobasis sp.	Operculate snail	0.006	Continuous		10,080	32	50% mortality	56
78	Nitocris sp.	Operculate snail	0.086	Continuous		5,760	25	50% mortality	56
79	Nitocris sp.	Operculate snail	0.370	Continuous		10,080	6	50% mortality	56
80	Nitocris sp.	Operculate snail	0.023	Continuous		10,080	32	50% mortality	56
	Nitocris sp.	Operculate snail	216.5[b]	Intermittent	3 pulses daily of 45 min.	10,080	6	50% mortality	56
	Nitocris sp.	Operculate snail	0.043[b]	Intermittent	3 pulses daily of 45 min.	10,080	32	50% mortality	56
81	Physa sp.	Pulmonate snail	0.258	Continuous		5,760	25	50% mortality	56
82	Physa sp.	Pulmonate snail	0.436	Continuous		10,080	6	50% mortality	56
83	Physa sp.	Pulmonate snail	0.131	Continuous		10,080	32	50% mortality	56
	Physa sp.	Pulmonate snail	0.425[b]	Intermittent	3 pulses daily of 45 min.	10,080	25	50% mortality	56
	Physa sp.	Pulmonate snail	0.413[b]	Intermittent	3 pulses daily of 45 min.	10,080	32	50% mortality	56
84	Physa sp.	Pulmonate snail	>0.810	Continuous	3 pulses daily of 45 min.	20,160		50% mortality[a]	24

a Wastewater chlorination
b Concentration is reported as peak value of the pulse

TABLE 3. AVERAGE CHLORINE CONCENTRATION AND EXPOSURE TIMES FOR TVA POWER PLANTS

		Chlorination Regime			Average Chlorine Residuals (mg/l)					
					Free			Total		
Power Plant[1]	Number of Units	Number of Pulses Daily	Pulse Time (min)	Total Exposure Time Daily (min)	Inlet	Outlet	Estimated Levels in Discharge[2]	Inlet	Outlet	Estimated Levels in Discharge[2]
A	9	1	30	30	0.313	0.324	0.036	0.461	0.484	0.054
B	4	3	20	60	0.360	0.295	0.074	0.856	0.816	0.204
C	3	1	30	30	0.173	0.134	0.045	0.425	0.333	0.111
D	10	1	45	45	0.35	0.28	0.028	0.54	0.48	0.048

1. Power plants, which reflect the estimated average residual chlorine in the discharge, were plotted in figures 3 and 4.

2. These levels reflect the estimated average concentrations at the mouth of the discharge canal. All other data was calculated from information supplied by Hollis B. Flora II, of the Office of Power. The chlorine levels were measured during February 1978 to December 1978, for power

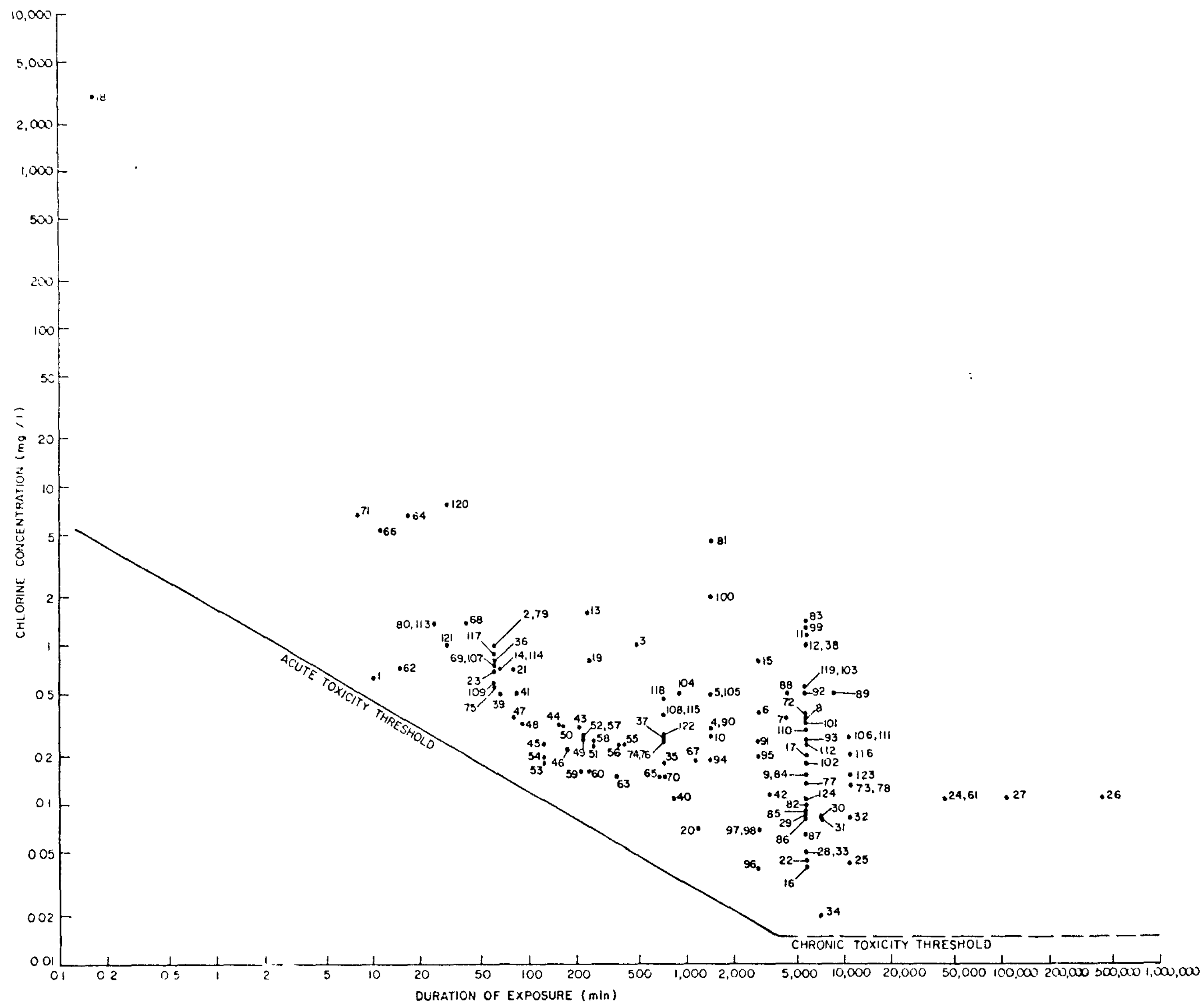

FIGURE 1
TOXICITY OF CHLORINE TO FISH SPECIES PRESENT WITHIN THE TENNESSEE VALLEY AUTHORITY WATERSHED

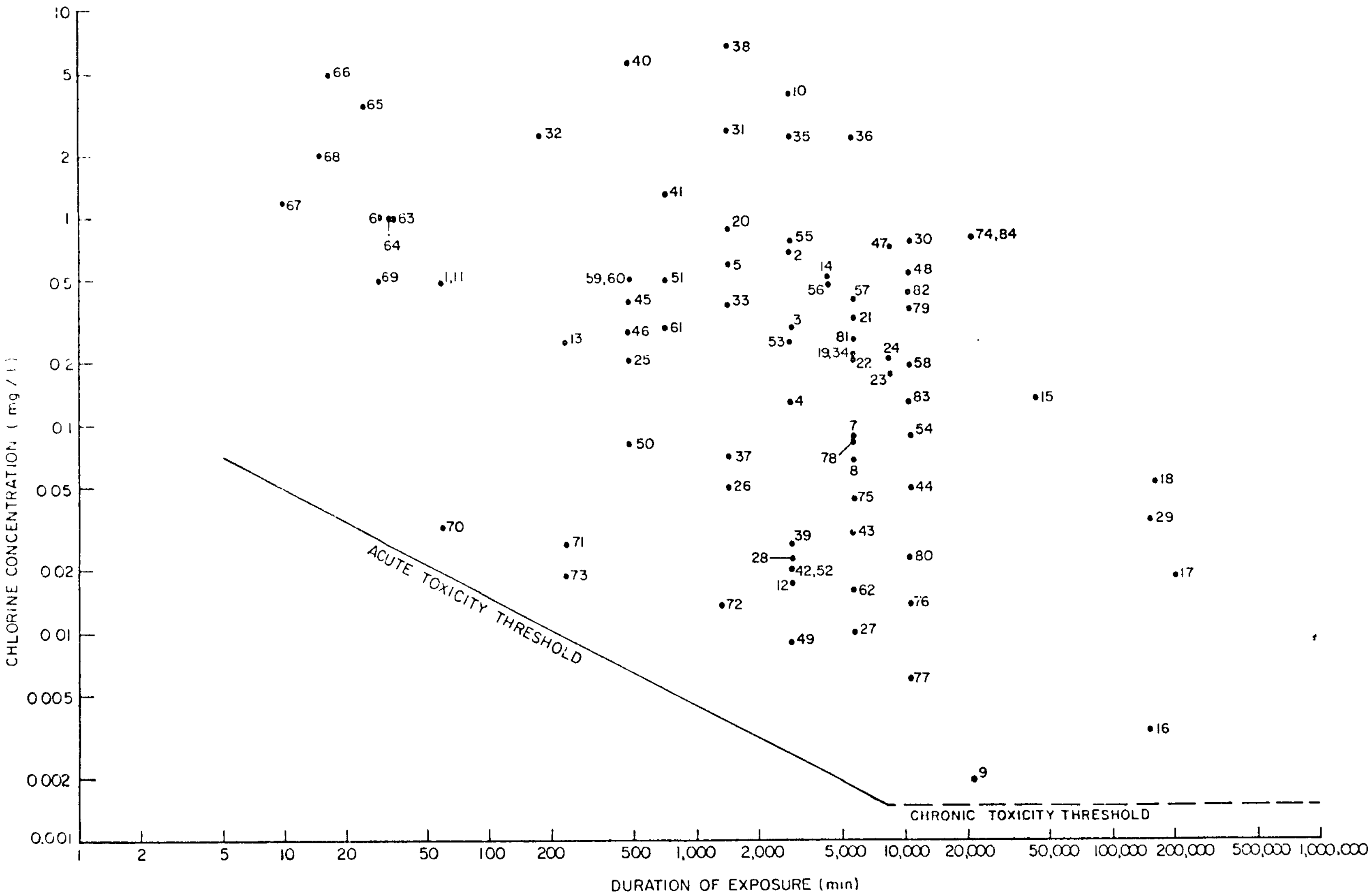

FIGURE 2

TOXICITY OF CHLORINE TO INVERTEBRATES PRESENT WITHIN THE TENNESSEE VALLEY AREA

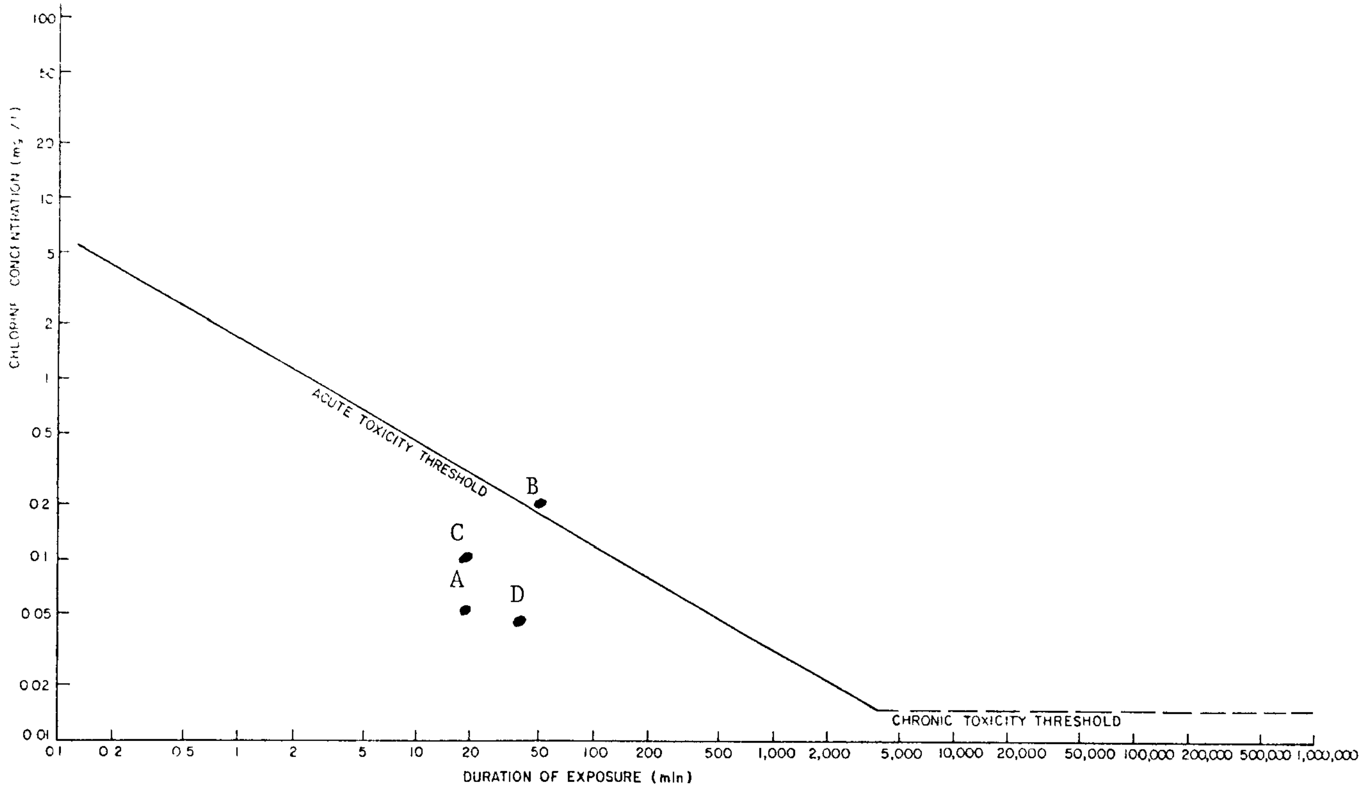

Figure 3. Comparison of estimated chlorine concentrations-exposure time in the discharge area of TVA power plants with the toxicity thresholds of fish within the TVA watershed.

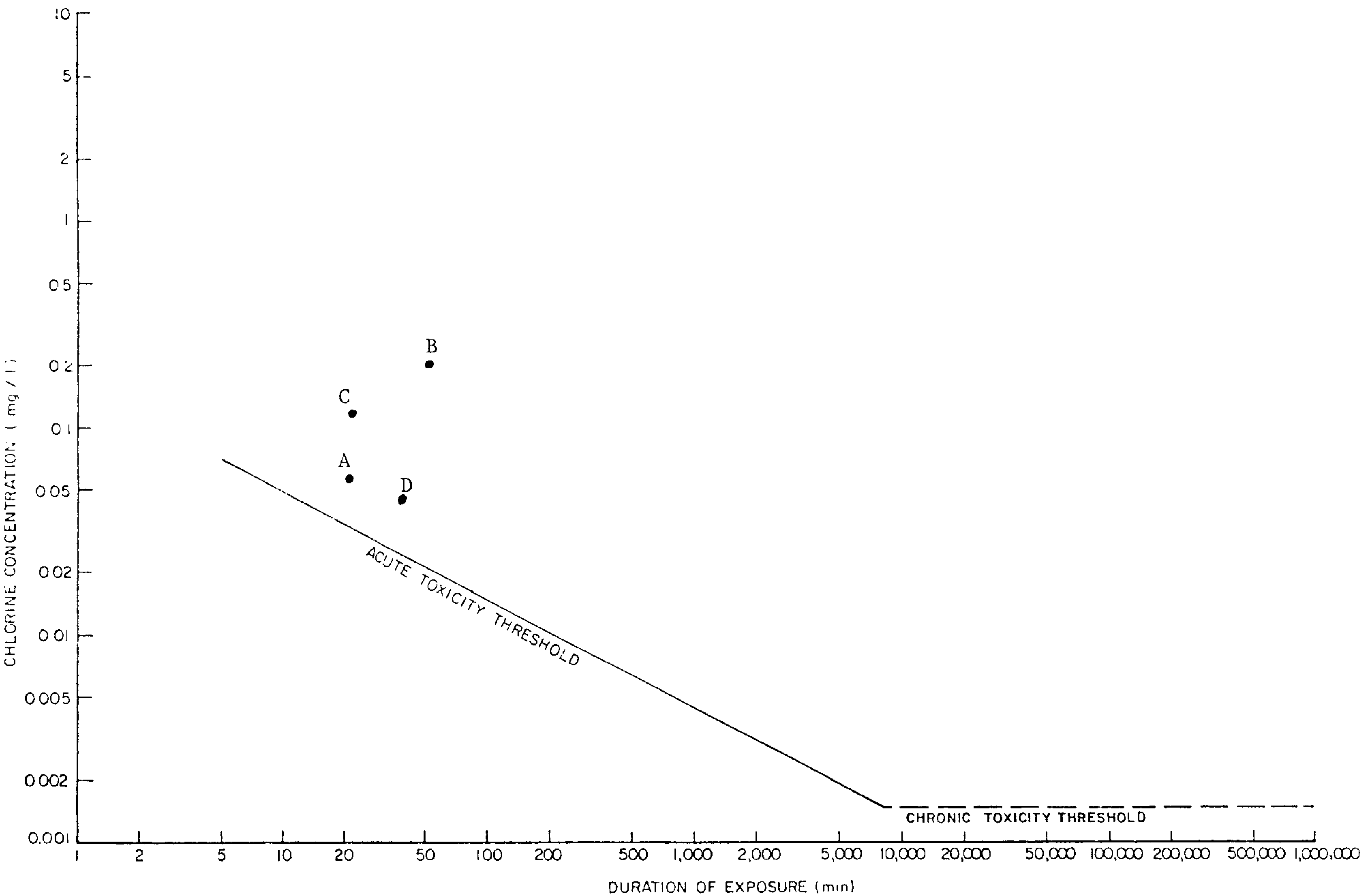

Figure 4. Comparison of estimated chlorine concentrations-exposure times in the discharge area of TVA power plants with the toxicity thresholds of invertebrates within the TVA area.

Appendix B

SELECTED INVERTEBRATE AND FISH CHLORINE BIOASSAYS: THEIR APPLICATION TO A KINETIC MODEL

Prepared by

Anthony H. Rhodes

ACKNOWLEDGMENTS

This work was conducted as part of the Federal Interagency Energy/ Environmental Research and Development Program with funds administered through the Environmental Protection Agency (EPA Contract No. EPA-IAG-D9-E721-DR, TVA Contract No. TV-41967A).

The author is glad to acknowledge Billy G. Isom and Richard J. Ruane for making this study possible. I am especially grateful to Sylvia A. Murray, for her constant encouragement and advice throughout the study. Thanks are also expressed to Suzanne R. Hunter, and Neil E. Carriker for their mathematical understanding and help. I am very grateful to Gregory T. Miles and Lanny McCaig for their enthusiastic and valuable assistance throughout the project.

Special thanks are extended to Dr. Kenneth J. Tennessen and Johnny L. Miller for their help in the collection of the mayflies.

I also acknowledge Thomas W. Toole and Hollis E. Lindley for their efforts in converting the Chen-Selleck Program to SAS.

SELECTED INVERTEBRATE AND FISH CHLORINE BIOASSAYS: THEIR APPLICATION TO A KINETIC MODEL

By Anthony H. Rhodes

SECTION I

INTRODUCTION

I. RATIONALE

Chlorine is an effective biocide that is widely used in many power plants. Operators of these chlorinating power facilities must be able to predict safe levels of chlorine to avoid detrimental effects on aquatic organisms in the ecosystem.

Current Environmental Protection Agency (EPA) discharge limits on chlorine levels in power plant effluents require that free available chlorine shall not exceed an average concentration of 0.2 mg/l and a maximum instantaneous concentration of 0.5 mg/l for a maximum of two hours (39 Fed. Reg., p. 36185) or 0.01 mg/ℓ continuous concentration at the edge of the mixing zone. The predictions of environmentally safe concentrations of residual chlorine discharged from power plants are currently based on the work of Mattice (1976), and Mattice and Zittel (1976). In their models the mortality threshold levels were based on the data for which the chlorine concentration did not result in death. The Mattice-Zittel model is based on the regression equation, Y = 0.37X, to convert the time required to obtain 50-percent mortality (X) into the time required to obtain 0-percent mortality (Y) for any given concentration. However, duration of chlorine exposure was not integrated into the model when measuring the threshold concentration.

The Chen-Selleck kinetic toxicity model (1969) does utilize duration in the integration. It is based on the survival versus exposure time in proportion to the toxicant concentration and induction period. The Chen-Selleck toxicity model is based on the following general observations: (1) percent survival versus exposure time yields a straight line relationship when plotted on semi-log paper, (2) there is an initial period of exposure (induction period) during which no mortality is manifested. The equation is as follows:

$$\frac{dN}{dt} = 0; \quad 0<t<t_i$$

and (3) the slope of the survival-exposure time curves are proportional to the toxicant concentration where N is the number of fish surviving at exposure time such as:

$$\frac{dN}{dt} = (-KC^{n}N + HN);\ t>t_{i}$$

where t, K, and H are rate coefficients, and n is the order of reaction. Integrating the above equation, the threshold concentration (C_t) of chlorine toxicity is then defined by the following relationships: $C_t = (H/K)^{1/n}$, where H represents the rate of detoxication, K represents the rate of toxication, and n is the order of the reaction. Because of the first observation above, where the test results were linear when plotted, the reaction is first order and n equals unity.

II. OBJECTIVES

The purposes of this study are as follows:

1. Determine chlorine toxicity and LC_{50} values from bioassays using daphnids (Daphnia pulex), mayflies (Hexagenia bilineata), and channel catfish (Ictalurus punctatus).

2. Establish chlorine toxicity threshold values by using the Chen-Selleck model on bioassay data from this laboratory and from the literature.

3. Evaluate the model as it applies to TVA power plant conditions.

SECTION II

MATERIALS AND METHODS

I. EXPERIMENTAL DESIGN

These experiments were designed to determine the median lethal concentration (LC_{50}) and empirical threshold concentrations of chlorine for *Daphnia* instars, mayfly nymphs, and channel catfish larvae. Test results from the studies and the literature data were applied to a kinetic model. Most of the literature data came from reports on chlorine toxicity for aquatic organisms (Mattice 1976, Mattice and Zittel 1976, and Opresko 1980). Current literature was also reviewed to include the latest data.

II. TEST ORGANISMS

A. Description and Key Role

Daphnids, *Daphnia pulex* Leydig, and mayfly nymphs, *Hexagenia bilineata* (Say) were used as the representative invertebrates found in the TVA area. The channel catfish, *Ictalurus punctatus* (Rafinesque) was the representative fish. Daphnids are macroscopic organisms that can easily be identified by their helmet-shaped head. The ephippium in the gravid female is also a good means for identification (Pennak 1978). Mayfly nymphs, which vary in size, are familiar aquatic insects found only in freshwater. Mayfly nymphs play an important role in the aquatic ecosystem by transforming plant tissues into animal tissues (Usinger 1963). These common aquatic invertebrates are important in the food chain because they utilize microscopic particles which larger aquatic animals cannot use (Kaestner 1970).

Channel catfish are important food and game fish, commonly found in TVA reservoirs. They can be identified by their barbels, smooth scaleless skin, and spiney fins (Jones et al. 1978). Catfish complete a link in the aquatic food chain between the invertebrates and humans.

B. Collection and Acclimation

Daphnia were collected with a plankton net, No. 20 mesh (80 µm), from a local pond and acclimated at 21^{o}C for 24 hours. Mayflies were collected at night, after their nuptial flight, by the light attraction method. Gravid females were placed in a container of dechlorinated tap water to deposit their eggs. After oviposition, the eggs were transferred, via pipette, to specimen dishes (100 x 15 mm) and incubated at 28°C for 17 hours. The catfish were obtained from a local commercial fish pond and acclimated for 48 hours at 27°C.

III. EXPERIMENTAL PROCEDURES

The organisms were tested in chlorine concentrations ranging from 0.025 to 1.0 mg/l and compared to controls with no chlorine. A 12-hour photoperiod was maintained for the catfish and daphnids, but not for the mayfly nymphs because they burrow into the substrate. The number of dead organisms was determined by teasing with a dissecting needle for a response, then counted and percent survival calculated for each of the four replicates at 24, 48, and 96 hours.

A. Daphnia Bioassay

The procedure for this invertebrate was as follows: Thirty organisms were placed in each 250 ml beaker of dechlorinated tap water by pipette. Chlorine was added daily, via pipette, to each beaker and dispersed by swirling with a glass rod. This swirling also enhanced dissolved oxygen (DO) saturation. Only juvenile instars were used in the bioassays, daphnids with ephippia were rejected.

B. Mayfly Nymph Bioassay

Thirty nymphs were placed in each petri dish filled with dechlorinated water. Following static renewal of chlorine each day, samples were returned to an environmental chamber where the temperature was a constant 28°C.

C. Fish Bioassay

Twenty fish larvae were placed in each of the 30 flow-through containers (modified milk jugs with 4-inch x 4-inch, 1-mm mesh fiberglass screens in each 757-liter galvanized-steel (epoxy coated) tank. A continuous flow with a turnover rate of 12 hours (1 ℓ/min) was maintained. Charcoal filter cartridges were placed in each tank to aid in waste and chlorine removal.

IV. WATER QUALITY MEASUREMENTS

Alkalinity, DO, pH, hardness, carbon dioxide (CO_2), and temperature were monitored daily before, during, and after chlorination. Ammonia nitrogen, acidity, conductivity, and salinity were measured twice during each experiment. Chlorine was measured by the DPD ferrous and colormetric methods (Standard Methods 1976), and DO and alkalinity were determined titrimetrically. The Hach® water chemistry tests were used to determine hardness, CO_2, and ammonia nitrogen. Hydrogen ion concentration was measured with an Orion® pH meter, and temperature with a mercury bulb Celsius (Centigrade) hand thermometer.

V. STATISTICAL METHODS

Linear and family regression analyses were used to determine the best (of eight) regression models for describing the net mortality rate coefficients and induction periods. The assay data were calculated and plotted with an HP 9825® computer. The rate of detoxication (H), and rate of toxication (K) were determined by solving simultaneous equations.

The estimation of LC_{50} (median lethal concentration) were made by the probit analysis method. Probit analysis calculates the maximum likelihood estimates of the intercept, slope, and natural (threshold) response rate for biological assay data (Finney 1971).

SECTION III

RESULTS

I. APPLICATION OF THE CHEN-SELLECK MODEL

The kinetic toxicity model as developed by Chen and Selleck (1969) was based on the concept of physiological balance between the rate of toxication and the rate of detoxication in the organism. The rate balance was derived from knowledge of the induction period of the toxicant, the survival ratio of the organisms to the toxicant, and the net mortality rate coefficients. The threshold concentration of the toxicant could be determined from the above knowledge.

A. Induction Period (t_i)

The induction period is the initial period after application of the toxicant during which no mortality occurs and is expressed mathematically as follows:

$$\frac{dN}{dt} = 0; \; 0<t<t_i$$

where N is the number of organisms surviving between the induction period t_i and the exposure time t, where mortality does occur. Chen and Selleck found that the greater the toxicant concentration the shorter was the induction period. The daphnids and mayfly nymphs' shortest induction periods (13 hours) were at 1.0 mg/ℓ (Table 1), and 1.0 and 0.5 mg/ℓ (Table 2), respectively. However, the channel catfish's shortest induction period (10 hours) was at 0.1 mg/ℓ (Table 3). The correlation coefficient for 0.1 mg/ℓ was much lower than the other concentration correlation coefficients, which could be attributed to a higher than expected mortality rate. More studies on induction periods may be required.

B. Survival Ratio ($\ell n\ N/N_o$)

The ratio between the total number of organisms tested and the number of surviving organisms can be expressed as follows:

$$\ell n\ N/N_o = (-KC^n + H)\ t + t_i\ (KC^n - H)$$

where $t_i\ (KC^n - H)$ = Tc for convenience, and $(-KC^n + H)$ is the net mortality rate coefficient, N_o is the total number of organisms at the beginning of the study, N is the number of surviving organisms for the time of the bioassay t, and other terms as described above.

C. Net Mortality Rate Coefficient ($-KC^n + H$)

The net mortality rate coefficient or NMRC calculation was based on the following relationship:

$$dN/dt = -KC^nN + HN; \; t>t_i.$$

Integration of this relationship yields:

$$\ell n \; N/N_o = (-KC^n + H)\, t + Tc$$

Tc is constant for a given bioassay. The terms K and H are determined by simultaneous equations from the coefficient ($-KC^n + H$), where K approximates the rate of toxication and H approximates the rate of detoxication.

D. Threshold Concentration (C_t)

The threshold concentration is the maximum toxicant concentration which will kill none of the organisms during an infinite exposure time, and is determined by the following relationship:

$$C_t = (H/K)^{1/n}$$

where n is the order of the reaction. Since the percent survival vs exposure time yields a straight line when plotted on semi-log paper, the reaction is first order.

II. BIOASSAYS AND LC_{50} DETERMINATIONS

The bioassay data collected on the fish, mayflies, and daphnids were calculated and plotted by computer. All the principles of the Chen-Selleck model as outlined above were used. Standard bioassay techniques were employed for testing to determine LC_{50} values. The resulting LC_{50} values or percent mortalities (inverse of percent survival) were used to determine the induction periods, survival ratios, net mortality rate coefficients, and threshold concentrations for these aquatic animals.

A. Fish Larvae

Table 4 indicates the analysis of variance results (ANOVA). The exposure and concentration were significant, but the interaction was not. The rate of detoxication and rate of toxication (derived from Figure 1) were 0.00069 hr^{-1} and 0.03263 $(mg/\ell \; hr)^{-1}$, respectively, with a threshold concentration of 0.021 mg/ℓ. The survival rates for all concentrations, and for the control, decreased uniformly (in time) and linearly. Although the percent survival for 0.1 mg/ℓ was lower than that for 0.5 mg/ℓ at 96 hours, there was no significant difference in their averages (Table 5). This table also shows that no catfish survived beyond 48 hours at 1.0 mg/ℓ. However, the catfish still had the best survival of all the organisms tested, 38 percent of the fish survived beyond 96 hours.

The calculated LC_{50} (by probit analysis) for the fish was 0.53 mg/ℓ (Table 6). Figure 2 shows a linear decrease in the survival ratio, based on the least squares fit.

B. Daphnids

The ANOVA data for these invertebrates are found in Table 7, where the exposure and concentration were significant, but the interaction was not. The daphnids rate of detoxication was 0.03964 hr^{-1} and rate of toxication was 0.27119 $(mg/ℓ\ hr)^{-1}$, with a threshold concentration of 0.15 mg/ℓ. The detoxication and toxication rates were derived from Figure 3. Figure 4 shows the decrease in the survival ratios, based on the least squares fit. Table 8 shows no survival for 0.5 (except at 48 hours) and 1.0 mg/ℓ. Also, that there was a significant difference, an average of 88 percent, in the control and lowest treatment (0.5 mg/ℓ) survival rates. However, there was no significant difference in exposure, especially for 24 and 48 hours (20.14 and 19.18 percent, respectively), and very little for 96 hours (15.97 percent). All concentrations, including control, decreased linearly, and only the control had more than 50-percent survival for all three exposure times. The LC_{50} for the daphnids was 0.032 mg/ℓ based on the probit analysis (Table 9).

C. Mayfly Nymphs

The NMRC values (derived from Figure 5) for the mayflies were 0.00360 hr^{-1} for the rate of detoxication and 0.18400 $(mg/ℓ\ hr)^{-1}$ for the rate of toxication, resulting in a threshold concentration of 0.020 mg/ℓ. Table 10 contains the ANOVA data for the mayfly nymphs, where the concentration, exposure, and their interactions were significant. The survival ratio of this invertebrate (Figure 6) decreased less gradually than that for the Daphnia. Table 11 shows that the average survival for 24 hours was near 50 percent (53.19). Also, that 0.025 mg/ℓ at 48 hours had less survival than 0.05, and was the same as 0.1 mg/ℓ at 48 hours. All test concentrations survival rate decreased linearly, with less than 50 percent survival after 48 hours. However, the ambient or control, survival rate was curvilinear, where 62 percent survived at 96 hours.

III. CHLORINE TOXICITY THRESHOLD CONCENTRATIONS BASED ON LITERATURE

Results in Tables 13, 14, and 15 are based on data compiled from available literature on aquatic species which occur within the TVA area. The detoxication and toxication rates, and threshold concentrations in these tables were calculated according to the principles of the Chen-Selleck model as outlined above.

A. Invertebrate Data

All the data compiled for the invertebrates, except for the one genus of operculate snail, were for continuous chlorine exposure (Table 13). The operculate snail, Goniobasis, had the lowest threshold concentration at 0.008 mg/ℓ, which was 0.293 mg/ℓ less than its counterpart in intermittent chlorine. This snail also had the lowest rate of detoxication at 0.00016 hr^{-1}. The pulmonate snail, Physa, had the highest threshold concentration at 0.432 mg/ℓ, and the lowest rate of toxication, which was shared with two genera of operculate snails, at 0.00595 $(mg/\ell\ hr)^{-1}$. Rotifers had the highest rate of toxication at 17.29322 $(mg/\ell\ hr)^{-1}$, and rate of detoxication at 0.22035 hr^{-1}.

B. Vertebrate Data

The vertebrate data were compiled for both continuous and intermittent chlorination. For continuous exposure (Table 14) the general observations were as follows:

1. The black bullhead catfish had the highest threshold concentration at 0.861 mg/ℓ, and the lowest rate of toxication at 0.00468 $(mg/\ell\ hr)^{-1}$.

2. Larval striped bass had the lowest threshold concentration and rate of detoxication at 0.006 mg/ℓ and 0.00065 hr^{-1}, respectively.

3. The blacknose dace had the highest rate of toxication and rate of detoxication at 21.39216 $(mg/\ell\ hr)^{-1}$ and 3.16768 hr^{-1}, respectively.

Highlights of the intermittent chlorine (Table 15) data collected are as follows:

1. The highest and lowest chlorine toxicity threshold concentrations were 2.343 mg/ℓ for the freshwater drum and 0.028 mg/ℓ for the juvenile channel catfish, respectively.

2. The juvenile bluegill had the lowest rate of toxication at 0.01042 $(mg/\ell\ hr)^{-1}$ and the juvenile catfish had the lowest rate of detoxication at 0.00102 hr^{-1}.

3. The adult emerald shiner had the highest rate of toxication and rate of detoxication at 20.00000 $(mg/\ell\ hr)^{-1}$ and 6.02060 hr^{-1}, respectively.

DISCUSSION

Chen and Selleck (1969) plotted the net mortality rate coefficients for their test data and subjectively fit a straight line through the points by eye. This gave values of H and K equal to 0.00796 hr^{-1} and 0.0236 $(mg/\ell\ hr)^{-1}$, respectively. Using these values in Equation 3, $C_t = (H/K)^{1/n}$, from their model they got a threshold concentration of 0.33 mg/ℓ zinc. When their data were calculated and plotted (Figure 7) according to a linear regression model, the H (detoxication) and K (toxication) values were 0.0166 hr^{-1} and 0.00312 $(mg/\ell\ hr)^{-1}$, respectively, with a threshold concentration of 0.19 mg/ℓ zinc. The linear model Y = A + BX was the best fit, having the highest F value. The second-best model, with the next highest F value, was a curvilinear model ($Y = A + B\sqrt{X}$). Both models were significant. Therefore, one would expect some variance of the calculated threshold toxicity value, depending on the regression line used.

The bioassay data collected on the fish, mayflies, and daphnids were also calculated and plotted using family regression. The linear model was the best fit for the fish, and significant for all the organisms. Even though the curvilinear models were the best fit for the invertebrates, the straight regression line was valid, and for simplicity was used to obtain the NMR coefficients for C_t calculations.

The survival ratios for the Tennessee Valley organisms were plotted on semi-logarithmic paper. In each case, except for the fish, the survival was greater at the lowest concentrations. This exception for the fish could be attributed to either the biochemical action of the toxicant and/or the stress tolerance of the organisms tested.

The comparisons of the detoxication and toxication rates and threshold concentrations (Table 16) for the literature and bioassay data are as follows: (1) Daphnia detoxication and toxication rates from the bioassay values were 0.04 percent and 0.2 percent, respectively, greater than for the literature. The threshold concentration calculated from the literature, viz 0.011 percent, was greater than that from the bioassay threshold concentration; (2) Mayfly detoxication and toxication rates from the bioassay values were also greater, by 0.0003 percent and 0.05 percent, respectively, than the literature. There was only a 0.005 percent difference in threshold concentration between the literature and bioassay data; and (3) catfish rate of detoxication for the literature was 0.0003 percent greater than assayed detoxication rates. The rate of toxication was also greater, 0.004 percent, for the literature data. The threshold concentration from the literature, 0.007 percent, was also greater than the bioassay threshold concentration.

The fish literature data were based on the juvenile fish because there were insufficient data found on the larval fish to calculate toxication and detoxication rates, or the threshold concentration.

The LC_{50}'s were 0.53 mg/ℓ for the fish, 0.032 mg/ℓ for the Daphnia, and 0.022 mg/ℓ for the mayflies. The calculated C_t and LC_{50} values are shown in Table 17, and as expected, the LC_{50}'s were higher. However, for the Daphnia the threshold concentration was higher, and this exception could be attributed to the test results, viz more than 50 percent of the population died at the lowest concentration (0.05 mg/ℓ) tested.

Table 18 indicates chlorine sensitivity for selected invertebrates and fish at chlorinating power plants. Power plant B, with the highest total residual chlorine at 0.204 mg/ℓ, would have the greatest impact on the aquatic organisms. However, power plant D, with the lowest threshold concentration (0.048 mg/ℓ), would still impact enough aquatic organisms to be of concern.

For the organisms with a threshold concentration above 0.204 mg/ℓ two general observations were noted:

1. The majority of the fish and invertebrates with a high threshold concentration were adult.

2. Most of the fish data were for intermittent exposure instead of continuous exposure to chlorine. This included the hardy freshwater drum with a threshold concentration of 2.343 mg/ℓ.

According to Table 18, most of the aquatic organisms would be impacted by the power plant's chlorination. However, report data indicated that many of the organisms would not be impacted by chlorination (TVA 1977 and 1979). The data showed that even at power plant B (highest threshold concentration) many of the aquatic organisms were present in the plant's vicinity (discharge, intake, etc.). Most of the sensitive fish, except the larval striped bass (Morone saxatilis), the sauger (Stizostedian canadense), and yellow perch (Perca flavescens), were found at power plant B. Also, all of the invertebrates, except the shrimp (Palaemonetes), the snail (Goniobasis), two genera of mayflies (Ephemerella and Isonychia), and two genera of stoneflies (Peltoperla and Pteronarcys), were found at the plant. The absence of the organisms listed was not due to chlorination. The striped bass larvae and sauger are no longer found there, and the yellow perch and the invertebrates were never present. The absence or presence of aquatic organisms in the area of a plant, particularly the discharge, could depend on whether or not it is a suitable habitat, or on the organism's ability to avoid chlorine. Also, elevated temperature, which could act synergistically with chlorine to cause both acute and chronic effects on the organisms (Rhodes 1980), may be a determining factor for their presence or absence. Table 18 may not be a true representation for some of the aquatic organisms' sensitivity to chlorine because continuous chlorination would be required to impact most of the organism, while the four TVA steam plants' chlorination regimes are intermittent. Therefore, at power plant B, of the fish present, only the adult white sucker *Catostomus commersoni*, the juvenile golden shiner *Notemigonus crysoleucas*, and the larvae (bioassay data) and juvenile channel catfish *Ictalurus punctatus* should be impacted according to Table 18. Only the invertebrates from the bioassay, the waterflea *Daphnia pulex*, and the mayfly *Hexagenia bilineata*, should be impacted according to Table 18. Based on the above facts, the model appears to be too restrictive in establishing chlorine toxicity thresholds. Therefore, more studies are needed on the species in question for intermittent exposure to chlorine.

CONCLUSIONS

The Chen-Selleck model may be applied to measure toxicity thresholds for aquatic organisms. The incorporation of exposure time, induction period, and concentration is very advantageous for determining threshold concentration. This helps to account for some of the most important factors, excluding life stage, health, etc., which contribute to the organism's death while testing.

The larval catfish had a better survival ratio than the aquatic invertebrates tested in the laboratory. The threshold concentrations based on the literature and bioassays data were similar. In general, the rate of detoxication was less than the rate of toxication. The mayflies were more sensitive (22 percent) to chlorine than the *Daphnia* (32 percent) or fish (53 percent).

Based on the bioassay results from this study, TVA power plants utilizing chlorine as biocide may have an adverse impact on aquatic organisms. This is especially true for total residual chlorine where the lowest level discharged by any plant was 0.048 mg/ℓ. However, since many of the chlorine-sensitive species were present in the vicinity of these chlorinating plants, the model may be too restrictive.

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TABLE 1. CHLORINE TOXICITY TO DAPHNIDS (*DAPHNIA PULIX*)

Chlorine Concentration (mg/l)	Statistical Information: Number of Data Points	Statistical Information: Correlation Coefficient	Statistical Information: Standard Error of Estimate	Bioassay Information: $-KC^n + H$ (hr^{-1})	Bioassay Information: Standard Error of $-KC^n + H$	Bioassay Information: Induction Period t_i(hr)
1.00	11	0.920421	0.133349	-0.009925	0.001405	13.3
0.50	12	0.730796	0.498824	-0.016287	0.004811	21.2
0.30	12	0.824601	0.285440	-0.012689	0.002753	18.4
0.10	12	0.875113	0.181378	-0.010003	0.001749	15.4
0.05	12	0.892868	0.152153	-0.009200	0.001467	15.0

TABLE 2. CHLORINE TOXICITY TO MAYFLY NYMPHS (*HEXAGENIA BILINEATA*)

Chlorine	Statistical Information			Bioassay Information		
Concentration (mg/l)	Number of Data Points	Correlation Coefficient	Standard Error of Estimate	$-KC^n + H$ (hr^{-1})	Standard Error of $-KC^n + H$	Induction Period t_i (hr)
1.000	11	0.920421	0.133349	-0.009925	0.001405	13.3
0.500	11	0.920421	0.133349	-0.009925	0.001405	13.3
0.100	12	0.919645	0.059368	-0.004239	0.000573	18.8
0.050	12	0.911438	0.050071	-0.003383	0.000483	18.9
0.025	12	0.918411	0.054556	-0.003862	0.000526	20.2

TABLE 3. CHLORINE TOXICITY TO CHANNEL CATFISH (*ICTALURUS PUNCTATUS*)

Chlorine Concentration	Statistical Information			Bioassay Information		
	Number of Data Points	Correlation Coefficient	Standard Error of Estimate	$-KC^n + H$ (hr^{-1})	Standard Error of $-KC^n + H$	Induction Period t_i(hr)
1.000	12	0.802152	0.331673	-0.013588	0.003199	19.2
0.500	12	0.832291	0.036244	-0.001659	0.000350	24.2
0.100	12	0.375387	0.003498	-0.000043	0.000034	10.3
0.050	12	0.749015	0.006197	-0.000214	0.000060	33.6
0.025	12	0.566735	0.012382	-0.000260	0.000119	25.9

TABLE 4. ANOVA: CHLORINE TOXICITY TO CHANNEL CATFISH (_ICTALURUS PUNCTATUS_)

Variance Source (VS)	Degrees of freedom (df)	Sum of Square (SS)	Mean Square (MS)
Exposure (E)	2	9377.78	4688.89**
Concentration (C)	5	84027.78	16805.56**
Interaction (C X E)	10	9359.72	935.97
Error	54	16200.00	300.00

** F > 0.01

TABLE 5. PERCENT SURVIVAL OF CHANNEL CATFISH (*ICTALURUS PUNCTATUS*) TO CHLORINE

Chlorine Concentration (mg/ℓ)	Exposure (Hours) 24	48	96	Average
0.00	100.00	100.00	77.50	92.5a
0.025	98.75	98.75	68.75	88.75a
0.05	100.00	100.00	82.50	94.17a
0.1	98.75	100.00	0.0125	66.25b
0.5	91.23	83.75	1.50	58.83b
1.0	3.75	0	0	1.25c
Average	82.08a	80.42a	38.38b	

Similar letters on the marginal means indicate no difference between those means as determined by the 95 percent least significant difference test.

TABLE 6. LC_{50} PROBIT VALUES FOR CHLORINE TOXICITY TO CHANNEL CATFISH (ICTALURUS PUNCTATUS)

Chlorine Concentration* (Log Scale	N	Number Alive	Number Dead	Proportion Dead	Probit Value
-1.6021	240	213	27	0.11	3.77
-1.3010	240	226	14	0.06	3.46
-1.0000	240	238	2	0.008	2.59
-0.3010	240	152	88	0.37	4.67
0.0000	240	3	237	0.99	7.33

*Consecutive listing of 0.025, 0.05, 0.1, 0.5, and 1.0 mg/ℓ.

TABLE 7. ANOVA: CHLORINE TOXICITY TO DAPHNIDS (*DAPHNIA PULEX*)

Variance Source (VS)	Degrees of freedom (df)	Sum of Square (SS)	Mean Square (MS)
Exposure (E)	2	205.86	102.93**
Concentration (C)	5	85437.57	17087.51**
Interaction (C X E)	10	158.64	15.86
Error	54	555.25	10.26

** F > 0.01

TABLE 8. PERCENT SURVIVAL OF DAPHNIDS (DAPHNIA PULEX) TO CHLORINE

Chlorine Concentration (mg/ℓ)	Exposure (Hours)			Average
	24	48	96	
0.00	97.50	97.50	90.83	95.28a
0.05	12.50	8.33	1.67	7.50b
0.1	7.50	6.67	3.33	5.83b
0.3	3.33	2.50	0	1.94c
0.5	0	0.083	0	0.028c
1.0	0	0	0	0c
Average	20.14a	19.18a	15.97b	

Similar letters on the marginal means indicate no difference between those means as determined by the 95 percent least significant difference test.

TABLE 9. LC_{50} PROBIT VALUES FOR CHLORINE TOXICITY TO DAPHNIDS (*DAPHNIA PULEX*)

Chlorine Concentration* (Log Scale)	N	Number Alive	Number Dead	Proportion Dead	Probit Value
-1.3010	360	29	331	0.92	6.41
-1.0000	360	21	339	0.94	6.56
-0.5299	360	7	353	0.98	7.05
-0.3010	360	1	359	0.99	7.33
0.0000	360	0	360	100.00	-

*Consecutive listing of 0.05, 0.1, 0.3, 0.5, and 1.0 mg/ℓ.

TABLE 10. ANOVA: CHLORINE TOXICITY TO MAYFLY NYMPHS (*HEXAGENIA BILINEATA*)

Variance Source (VS)	Degrees of freedom (df)	Sum of Square (SS)	Mean Square (MS)
Exposure (E)	2	21086.86	10543.43**
Concentration (C)	5	51353.74	10270.75**
Interaction (C X E)	10	15180.14	1518.01**
Error	54	3059.25	56.65

** F > 0.01

TABLE 11. PERCENT SURVIVAL OF MAYFLY NYMPHS (*HEXAGENIA BILINEATA*) TO CHLORINE

Chlorine Concentration (mg/ℓ)	Exposure (Hours			Average
	24	48	96	
0.00	91.66	73.33	62.50	75.83a
0.025	81.66	34.16	0.0083	38.61b
0.05	75.00	46.67	0	40.56b
0.1	70.83	34.16	0.167	35.05b
0.5	0	0	0	0c
1.0	0	0	0	0c
Average	53.19a	31.39b	10.45c	

Similar letters on the marginal means indicate no difference between those means as determined by the 95 percent least significant difference test.

TABLE 12. LC_{50} PROBIT VALUES FOR CHLORINE TOXICITY TO MAYFLY NYMPHS (HEXAGENIA BILINEATA)

Chlorine Concentration* (Log Scale)	N	Number Alive	Number Dead	Proportion Dead	Probit Value
-1.6021	360	141	219	0.61	5.25
-1.3010	360	146	214	0.59	5.23
-1.0000	360	127	233	0.65	5.39
-0.3010	360	0	360	100.00	-
0.0000	360	0	360	100.00	-

*Consecutive listing of 0.025, 0.05, 0.1, 0.3, 0.5 and 1.0 mg/l.

TABLE 13. CHLORINE THRESHOLD DATA FOR INVERTEBRATES PRESENT WITHIN TVA AREA

Species	Life Stage	K $(mg/\ell\ hr)^{-1}$	H (hr^{-1})	C_t (mg/ℓ)
Arthropoda - Crustacea				
Asellus sp. Sow-bug	Adult	0.35012	0.03654	0.104
Cyclops sp. Copepod	Adult	1.00000	0.03103	0.031
Daphnia sp. Waterflea	Instar	0.02541	0.00399	0.157
Gammarus sp. Scud	Adult	1.34583	0.01021	0.008
Orconectes sp. Crayfish	Adult	0.01042	0.00314	0.301
Palaemonetes sp. Shrimp	Adult	0.35726	0.05689	0.159
Arthropoda - Insecta				
Ephemerella sp. Mayfly	Nymph	0.13106	0.00330	0.025
Hydropsyche sp. Caddisfly	Adult	0.22864	0.00341	0.015
Isonychia sp. Mayfly	Nymph	0.64294	0.02608	0.041
Peltoperla sp. Stonefly	Nymph	0.11554	0.00287	0.025
Psephenus sp. Water penny	Adult	0.34301	0.02821	0.082
Pteronarcys sp. Stonefly	Nymph	0.02770	0.00245	0.088
Stenonema sp. Mayfly	Nymph	0.24045	0.02038	0.085
Rotifers				
Keratella sp. Rotifer	Adult	17.29322	0.22035	0.013
Mollusca				
Goniobasis sp. Operculate snail	Adult	0.01974	0.00016	0.008
Goniobasis sp. Operculate snail[a]	Adult	0.00595	0.00179	0.301
Nitocris sp. Operculate snail	Adult	0.00595	0.00179	0.301
Physa sp. Pulmonate snail	Adult	0.00595	0.00258	0.434

a. Intermittent exposure.

TABLE 14. CHLORINE TOXICITY THRESHOLD DATA FOR FISH PRESENT WITHIN TVA AREA (CONTINUOUS EXPOSURE)

Species	Life Stage	Chlorine K $(mg/\ell\ hr)^{-1}$	H (hr^{-1})	Chlorine C_t (mg/ℓ)
Cyprinidae				
Carassius auratus (Goldfish)	Adult	0.04167	0.00165	0.040
Cyprinus carpio (Carp)	Adult	0.01469	0.00228	0.155
Pimephales promelas (Fathead minnow)	Larvae	0.01110	0.00245	0.221
Rhinichthys atratulus (Blacknose dace)	Adult	21.39216	3.16768	0.148
Catostomidae				
Catostomus commersoni (White sucker)	Adult	0.37726	0.04722	0.125
Ictaluridae				
Ictalurus melas (Black bullhead)	Adult	0.00468	0.00403	0.861
Poeciliidae				
Gambusia affinis (Mosquito fish)	Adult	2.02167	1.50165	0.743
Percichthyidae				
Morone chrysops (White bass)	Adult	0.01389	0.00416	0.299
Morone saxatilis (Striped bass)	Larvae	0.10113	0.00065	0.006
Micropterus salmoides (Largemouth bass)	Adult	0.83328	0.28159	0.338
Percidae				
Perca flavescens (Yellow perch)	Adult	0.00793	0.00139	0.175
Stizostedian canadense (Sauger)	Adult	0.27091	0.02410	0.089

TABLE 15. CHLORINE TOXICITY THRESHOLD DATA FOR FISH PRESENT WITHIN TVA AREA (INTERMITTENT EXPOSURE)

Species	Life Stage	Chlorine K $(mg/\ell\ hr)^{-1}$	H (hr^{-1})	Chlorine C_t (mg/ℓ)
Cyprinidae				
Cyprinus carpio (Carp)	Juvenile	0.04153	0.01260	0.303
Notemigonus crysoleucas (Golden shiner)	Juvenile	0.03426	0.00283	0.083
Notropis atherinoides (Emerald shiner)	Adult	20.00000	6.02060	0.301
Notropis atherinoides (Emerald shiner)	Juvenile	0.02083	0.00627	0.301
Notropis spilopterus (Spotfin shiner)	Adult	0.01389	0.00418	0.301
Catostomidae				
Catostomus commersoni (White sucker)	Adult	0.01389	0.00240	0.173
Ictaluridae				
Ictalurus punctatus (Channel catfish)	Adult	0.03551	0.00987	0.278
Ictalurus punctatus (Channel catfish)	Juvenile	0.03875	0.00229	0.059
Ictalurus punctatus (Channel catfish) (I. lacustris)	Juvenile	0.03701	0.00102	0.028
Centrarchidae				
Lepomis macrochirus (Bluegill)	Adult	0.04214	0.06380	1.514
Lepomis macrochirus (Bluegill)	Juvenile	0.01042	0.00314	0.301
Percidae				
Perca flavescens (Yellow perch)		0.02083	0.00627	0.301
Stizostedian canadense (Sauger)	Adult	0.01389	0.00482	0.347
Sciaenidae				
Aplodinotus grunniens (Freshwater drum)	Adult	2.00000	4.68573	2.343

TABLE 16. COMPARISON OF K, H, AND C_t VALUES FOR CHLORINE BIOASSAY AND LITERATURE DATA

Name of Organism	Calculated Values[a]	Source of Chlorine Data	
		Bioassay[b]	Literature
Ictalurus punctatus (Channel catfish)			
	K	0.03263	0.03701
	H	0.00069	0.00102
	C_t	0.021	0.028
Daphnia pulex (Waterflea)			
	K	0.27119	0.02541
	H	0.03964	0.00399
	C_t	0.146	0.157
Hexagenia bilineata (Mayflies)			
	K	0.18400	0.13106
	H	0.00360	0.00330
	C_t	0.020	0.025

a. $K = (mg/\ell\ hr)^{-1}$, $H = hr^{-1}$, and $C_t = (mg/\ell)$

b. Bioassay data were based on larval fish while literature data were based on juvenile fish.

TABLE 17. THRESHOLD CONCENTRATION (C_t) AND MEDIAN LETHAL CONCENTRATION (LC50) VALUES FOR CHLORINE BIOASSAY DATA

Organism	Life Stage	Chlorine	
		C_t[a]	LC_{50}[b]
Ictalurus punctatus (Channel Catfish)	Larval	0.021	0.53
Daphnia pulex (waterflea)	Instar (Juvenile)	0.146[c]	0.032
Hexagenia bilineata (Mayflies)	Nymph	0.020	0.022

a. C_t = the minimum concentration which kills none of the organisms

b. LC_{50} = the minimum concentration which will kill 50 percent of the population.

c. Due to the high mortality rates (over 50 percent) at the lower concentrations.

TABLE 18. CHLORINE SENSITIVITY FOR SELECTED INVERTEBRATES AND FISH AT CHLORINATING POWER PLANTS

Fish (Species)	C_t (mg/ℓ)	Chlorinating Power Plants	C_t (mg/ℓ)	Invertebrates (Species)
Morone saxatilis[a] (Larvae)	0.006			
			0.008	Gammarus sp.
			0.008	Goniobasis sp.
			0.013	Keratella sp.
			0.015	Hydropsyche sp.
			0.020	Hexagenia bilineata[d] (Nymph)
Ictalurus punctatus[d] (Larvae)	0.021			
			0.025	Ephemerella sp. (Nymph)
			0.025	Peltoperla sp. (Nymph)
Ictalurus punctatus[b] (Juvenile) (I. lacustris)	0.028			
			0.031	Cyclops sp.
Carassius auratus[a]	0.040			
			0.041	Isonychia sp. (Nymph)
	0.048	D	0.048	
	0.054	A	0.054	
Ictalurus punctatus[b] (Juvenile)	0.059			
			0.082	Psephenus sp.
Notemigonus crysoleucas[b] (Juvenile)	0.083			
			0.085	Stenonema sp. (Nymph)
			0.088	Pteronarcys sp. (Nymph)
Stizostedian canadense[a]	0.089			
			0.104	Asellus sp.
	0.111	C	0.111	
Catostomus commersoni[a]	0.125			
			0.146	Daphnia pulex[d] (Instar)
Rhinichthys atratulus[a]	0.148			
Cyprinus carpio[a]	0.155			
			0.157	Daphnia sp. (Instar)
			0.159	Palaemonetes sp.
Catostomus commersoni[b]	0.173			
Perca flavescens[a]	0.175			
	0.204	B	0.204	
Pimephales promelas[a] (Larvae)	0.221			
Ictalurus punctatus[b]	0.278			
Morone chrysops[a]	0.299			
Notropis spilopterus[b]	0.301		0.301	Goniobasis sp.[b]
Lepomis macrochirus[b] (Juvenile)	0.301		0.301	Nitocris sp.
Notropis atherinoides[c]	0.301		0.301	Orconectes sp.
Perca flavescens[b]	0.301			
Cyprinus carpio[b]	0.303			
Micropterus salmoides[a]	0.338			
Stizstedian canadense[b]	0.347			
			0.434	Physa sp.
Gambusia affinis[a]	0.743			
Ictalurus melas[a]	0.861			
Lepomis macrochirus[b]	1.514			
Aplodinotus grunniens[b]	2.343			

All species are adult except when indicated.

a. Continuous exposure

b. Intermittent exposure

c. Threshold concentration (intermittent exposure) was the same for the adult and juvenile.

d. Bioassay data (intermittent exposure)

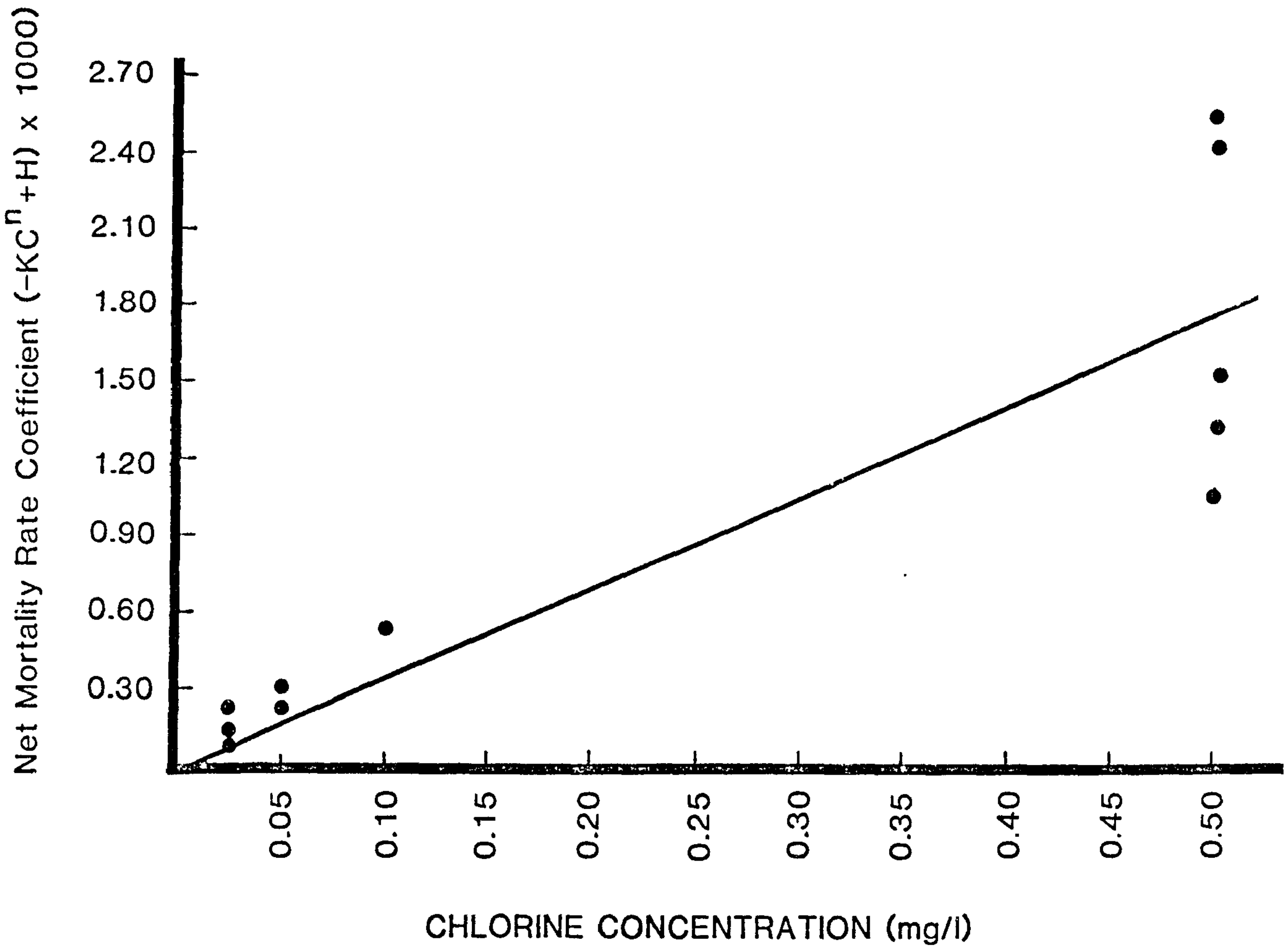

Figure 1. Linear Regression of Chlorine toxicity data for Ictalurus punctatus (Channel catfish)

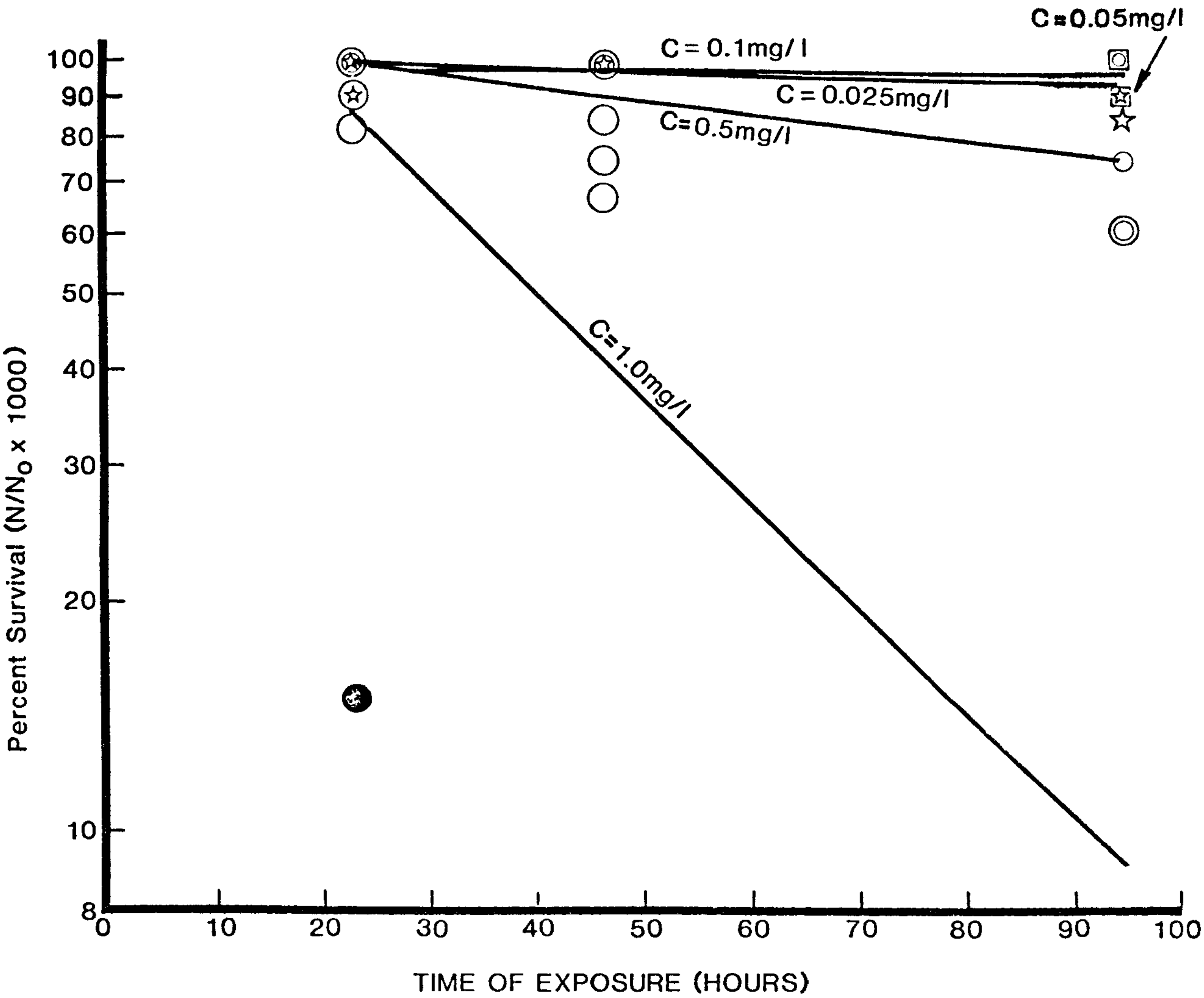

Figure 2. Percent Survival of Channel Catfish Larvae to Chlorine Based on Least Squares Fit.
☆ = 0.025mg/l ; ○ = 0.05mg/l ; □ = 0.1mg/l ; ◯ = 0.5mg/l ; ● = 0.1mg/l

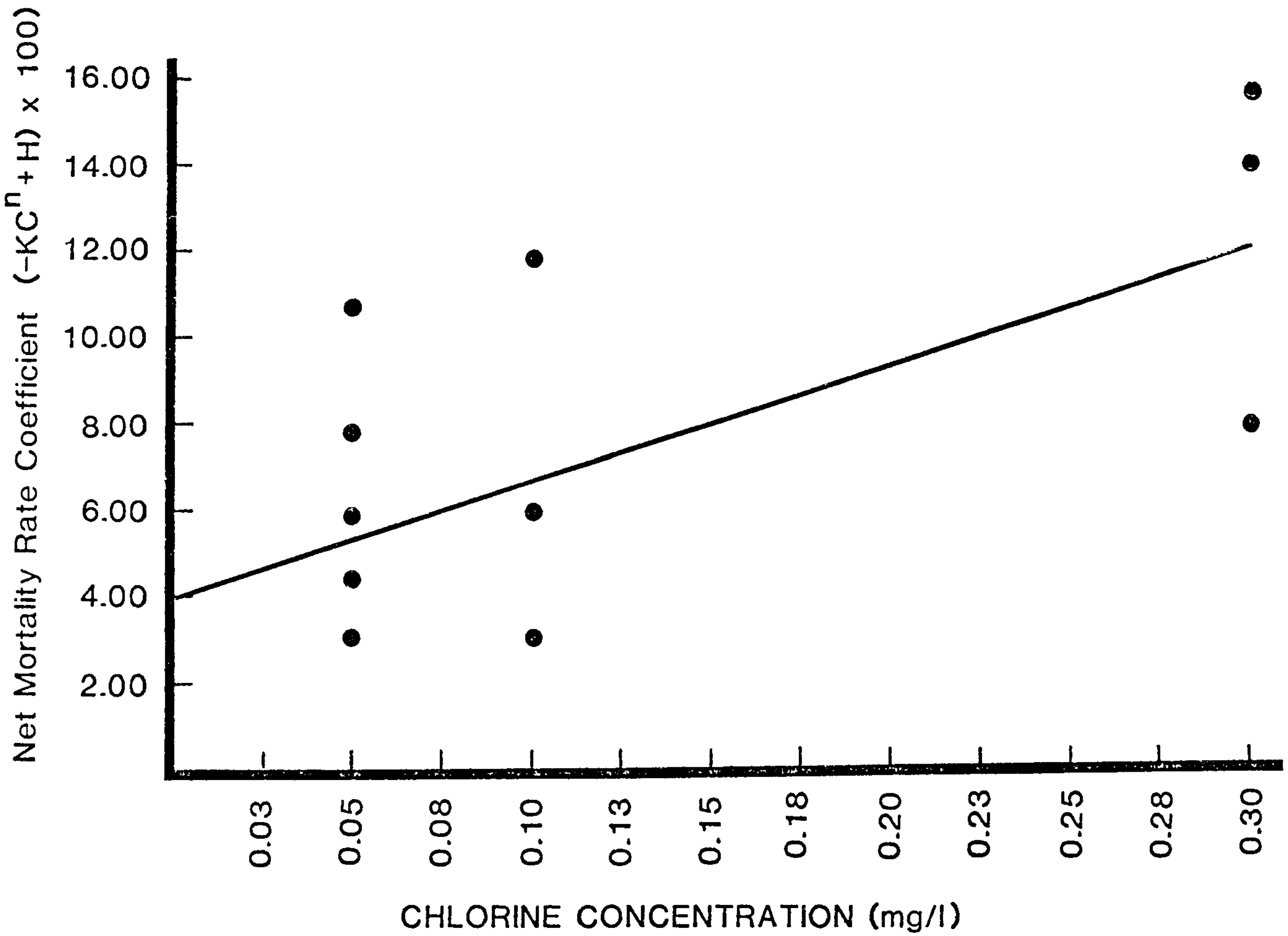

Figure 3. Linear Regression of Chlorine Toxicity Data for Daphnia pulex (Daphnids)

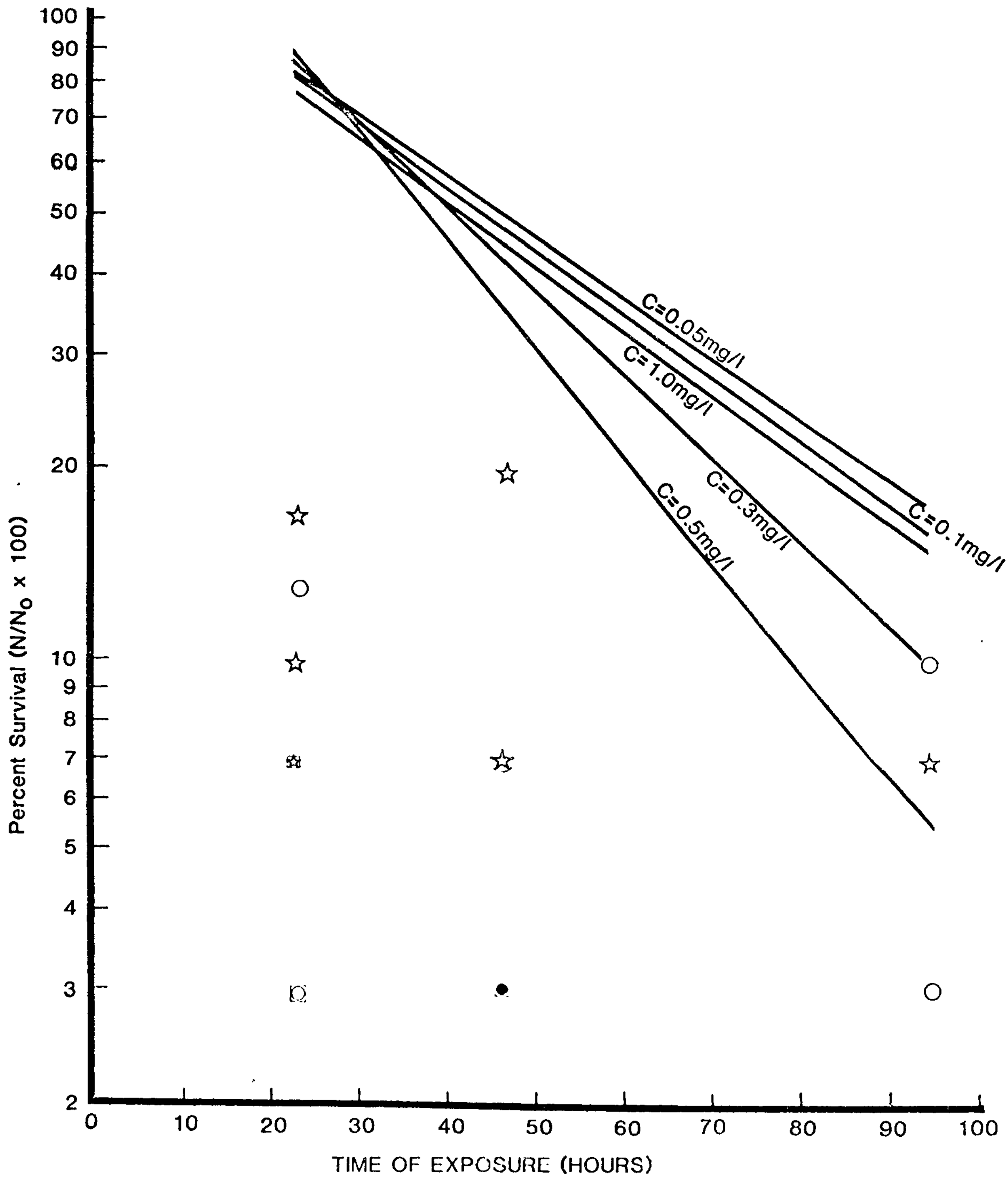

Figure 4. Percent Survival of Daphnids to Chlorine Based on Least Squares Fit.
☆= 0.05mg/l ; ○= 0.1mg/l ; □= 0.3mg/l ; ●= 0.5mg/l

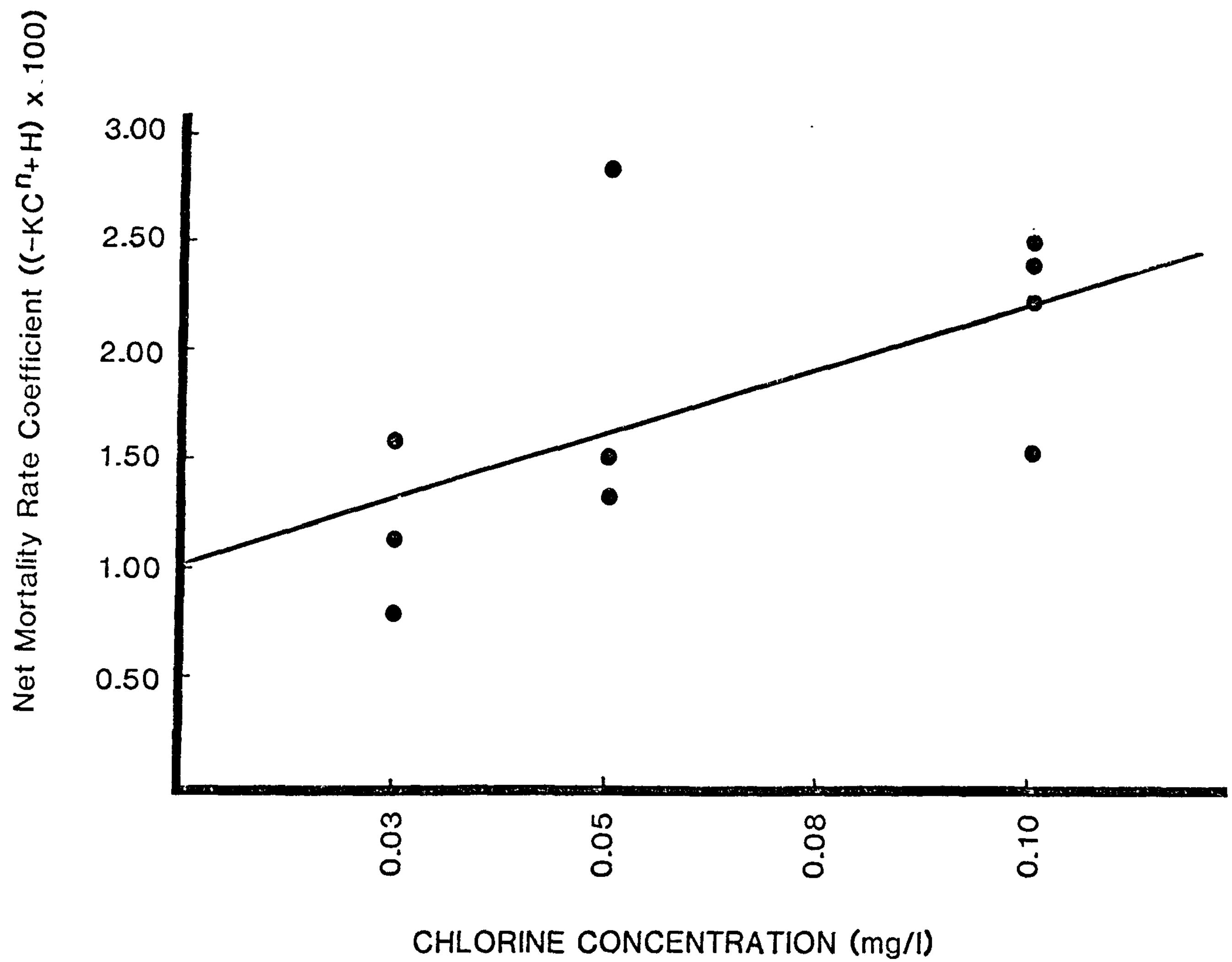

Figure 5. Linear Regression of Chlorine Toxicity Data for Hexagenia bilineata (Mayflies)

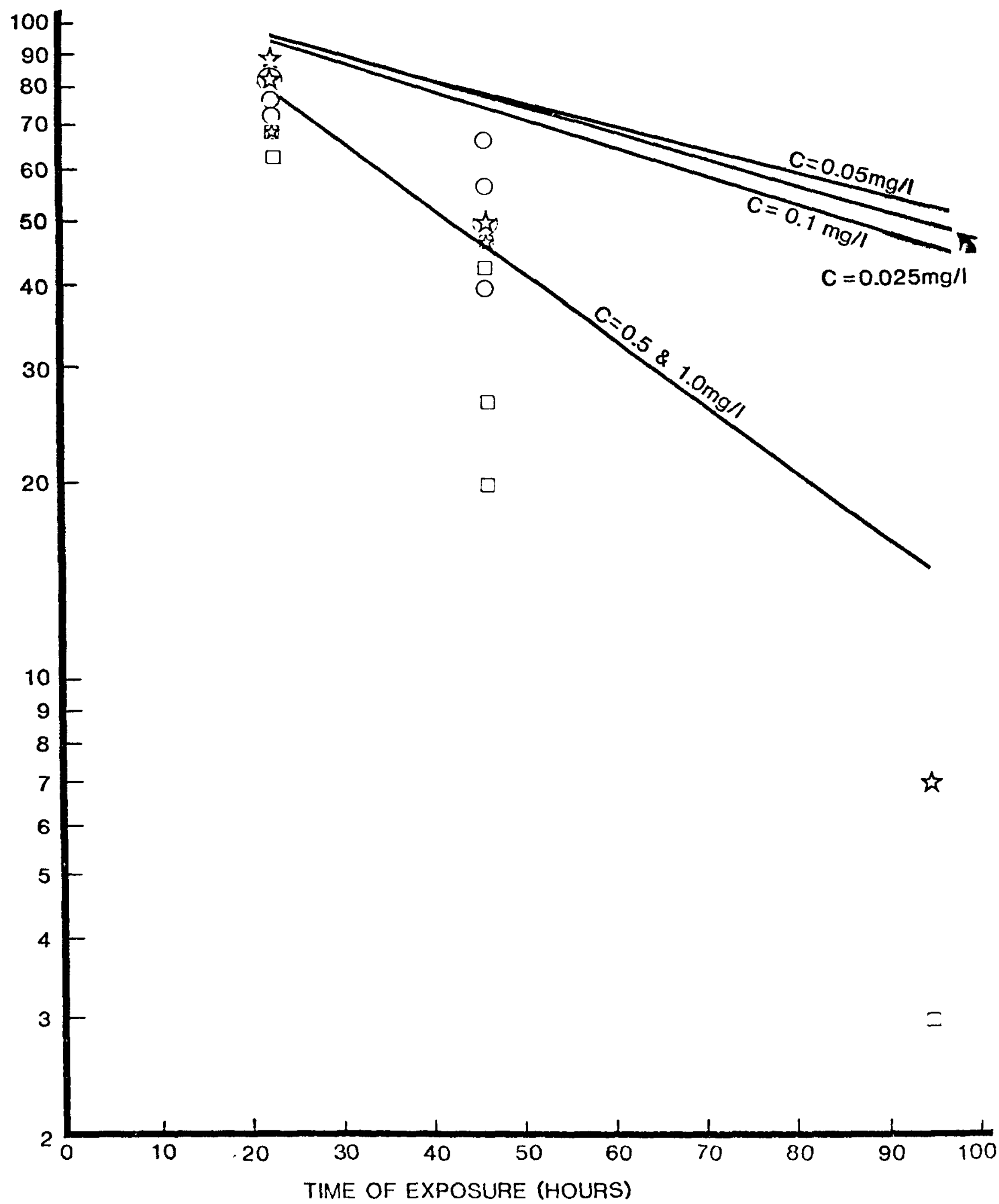

Figure 6. Percent of Survival of Mayfly Nymphs to Chlorine Based on Least Squares Fit.
☆= 0.025mg/l ; ○= 0.05mg/l ; □= 0.1mg/l

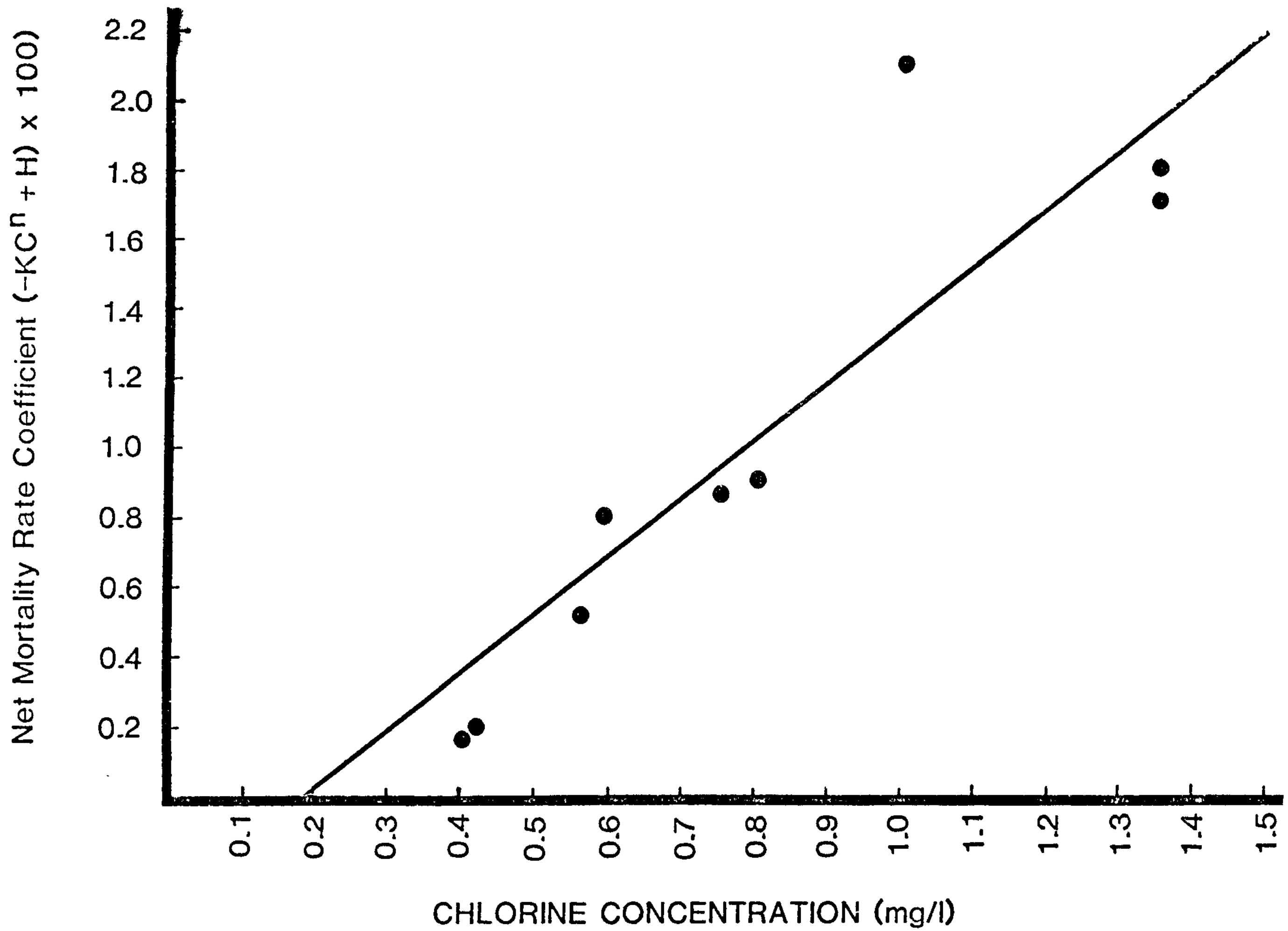

Figure 7. Linear Regression of Chen's Toxicity (Zinc) Data for Poecilia reticulata (Guppies)

Appendix C

SITE-SPECIFIC CONSIDERATION OF CHLORINE EFFLUENT LIMITATIONS

Prepared by

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SITE-SPECIFIC CONSIDERATION OF CHLORINE EFFLUENT LIMITATIONS

By Alta Turner[1] and Sylvia A. Murray

INTRODUCTION

In 1978, Envirosphere Company developed a methodology to derive chlorine discharge limitations from data recording lethal responses resulting from exposure to chlorinated effluents. This methodology was applied to a data base representative of all species for which chlorine sensitivity data were available and resulted in point-of-discharge limitations (recommended) for chlorine, appropriate to marine-estuarine or freshwater habitats.

In September 1980, Envirosphere was commissioned to conduct similar analyses on the available data base representative of species resident at TVA sites. The following presents the results and interpretation of these analyses.

DATA BASE

Appendix 1 lists data recording freshwater species' sensitivity to total residual chlorine (TRC) where chlorine residuals inducing a median lethal response (LC50) were measured by either the amperometric titration or ferrous DPD method. The data were consolidated from an extensive literature review, cumulative through May 1980. Standardization of data by chlorine form, chemical method, and biological response renders a data base composed of data which are comparable and conducive to statistical analysis. Rationale for these criteria are published elsewhere (Turner and Thayer 1980).

From the standardized freshwater data set, five subsets were partitioned on the basis of the following species groupings:

- Freshwater fish species
- Fish species resident at TVA sites
- Freshwater invertebrate species

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- Invertebrate species resident at TVA sites
- Fish and invertebrate species resident at TVA sites.

Species resident at TVA sites were provided by TVA; those species not resident at TVA but for which chlorine sensitivity data are available are designated in appendix 1 by asterisk (*).

The six data sets (the above five subsets plus the entire data base) were analyzed separately in order to compare effluent limitations determined by analysis of all available freshwater data to limitations determined by analysis of TVA-specific data. Secondary comparisons between vertebrate and invertebrate sensitivity were also made.

STATISTICAL ANALYSES

Concentration and duration variables were normalized to meet one assumption of regression by applying $\log_{10}$ transformations to the raw data, milligrams TRC per liter, and minutes exposure duration. Regression analyses were performed on each of the six data sets, utilizing concentration TRC and exposure duration as dependent and independent variables, respectively. Results are presented in tables 1-6 and graphically displayed in figures 1-6. The integers plotted on the figures represent the number of observations recorded at that concentration and exposure duration; asterisks indicate the number of observations exceeds nine.

The resulting regression equations provide a means of calculating TRC concentrations for given exposure durations which would induce a median lethal response in a species with average sensitivity to chlorine. (This theoretical average species represents no single species in the data set but, rather, exhibits the biological response intermediate of all those recorded.) To transform the LC_{50}s to concentrations which would elicit no mortality, an application factor of 0.59 was applied to the raw LC_{50} values. This factor was derived previously (Envirosphere Company 1979, Turner and Thayer 1980) by averaging the ratio of LC_{50} to lethal threshold concentrations where these data represented identical exposure periods for the same test species. Multiplying LC_{50}s by 0.59 is tantamount to reducing the intercept of the original regression equation (tables 1-6) by 0.23. Either method results in predictive equations which can be used to calculate concentrations which will induce no mortality in the "average species" for any given exposure duration.

Because regression determines central tendency through the data set analyzed, the resulting equation represents the cumulative biological sensitivity of all species within the data base. To account for the vulnerability of the most sensitive species represented in each data set, analysis of residual variance (that variance within the data set not accounted for by the regression model) was performed. First, the residual value for each datum was determined by finding the difference between observed and calculated (based on the regression equation) concentrations. Residuals were then partitioned by species and averaged. The lowest mean residual designated the most sensitive species as indicated in tables 1-6. To assure that the predictive equations adequately protect the most sensitive species in the data set, that species' mean residual was added to the intercept. (Because the average residual of the most sensitive species was the greatest negative number, adding the mean residual to the intercept repositioned the regression line by lowering it parallel to the original regression line [Turner and Thayer, 1980]).

RESULTS

Comparison of tables 1-6 and figures 1-6 indicates the following:

- Partitioning available data on the basis of species residence at TVA sites does not substantially modify the results of regression analysis although the number of observations represented in these subsets is reduced.
- Invertebrate species (within the TVA-resident subset or all available freshwater invertebrate subset) exhibit greater variability in response to chlorinated effluents than vertebrate species in complementary subsets.
- Because the number of the data representing invertebrate species exceeds that representing vertebrate species and because no "weighting" was applied to adjust for the difference in number of observations when invertebrate and vertebrate subsets were pooled, the invertebrate component tended to dominate the analytical results.

Additional comparisons can be made on the basis of no-mortality levels for given exposure durations as calculated with the different regression models. Table 7 exhibits calculated no-mortality concentrations for "average" and most-sensitive species for each data subset at 2- and 24-hour exposure durations. Although no-mortality levels derived from TVA-resident species subsets analyses are slightly higher than levels calculated from subsets including additional species which are not resident at TVA, the differences are not substantial. Conversely, invertebrate and vertebrate sensitivities differ widely with invertebrates as a group exhibiting increased sensitivity to chlorinated effluents.

APPLICATIONS

On the basis of these results, a case can be made for TVA-specific chlorine effluent limitations. Assuming that the intent of effluent limitations is to limit toxic discharges to concentrations which will induce no mortality within the mixing zone, the Envirosphere methodology applied to the TVA data set is a useful tool to determine nonlethal discharge concentrations for a wide range of discharge periods. The regression equation derived from the pooled TVA-resident invertebrate and vertebrate subsets which accounts for the LC50-LC00 translation (intercept-- 0.23) and for the most sensitive TVA species (intercept--0.73) is:

log concentration = 0.07 - (0.59) log duration.

Discharge concentrations calculated on the basis of this equation should eliminate mortality at the point of discharge throughout the discharge period. The estimated average total residual chlorine concentrations at the mouth of the discharge channel for each chlorinating TVA power plant are compared with the chlorine toxicity thresholds based on the regression equations in this report (table 8 and figure 7). As can be seen in figure 7, no effect would be expected for fish species in the vicinity of the discharge channel except for, perhaps, a marginal one for fish at power plant B. This effect, however, may be indirectly due to the expected impact of the invertebrate genera in the discharge channel. No effect would be expected for the invertebrate genera associated with the other TVA power plants.

One limitation of this method to determine chlorine discharge concentrations should be recognized. TVA species represent a substantial portion of the data within the freshwater data base; e.g., of 27 invertebrate species for which chlorine sensitivity data are available, 16 species are resident at TVA sites; similarly, of 32 fish species, 19 are found at TVA. However, considering all species which are recorded as occurring at TVA sites, chlorine sensitivity data are available for only 16 percent of the 126 fish species, approximately 1 percent of the 288 zooplankton species and less than 1 percent of the 1,302 macroinvertebrate species. Whereas this method adequately represents even the most sensitive species within the data base, it cannot account for the possibility that more sensitive species are resident at TVA sites. It is, therefore, strongly recommended that the data set be updated on a regular basis as additional chlorine sensitivity data become available.

REFERENCES

1. Turner, A. and T. A. Thayer. 1980. Chlorine toxicity in aquatic ecosystems. In: Water Chlorination Environmental Impact and Health Effects. Ed. R. L. Jolley, W. A. Brungs, R. B. Cummings, and V. A. Jacobs. Ann Arbor Science Publishers, Inc., vol. 3, pp. 607-630.

2. Envirosphere Company. 1979. Chlorine Toxicity in Freshwater Ecosystems, Edison Electric Institute.

TABLE 1. FRESHWATER SPECIES DATA ANALYSES

Regression Analysis

Data Restrictions: LC50/TRC/Amperometric Titration-Ferrous DPD

Dependent Variable: Concentration TRC (mg/l)

Independent Variable: Exposure Duration (minutes)

Regression Equation: Log Concentration = 0.96 - (0.57) Log Duration

Analysis of Variance for the Regression:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	Probability
Attributable to Regression	1	90.7596	90.7596	170.2444	P 0.001
Deviation from Regression	436	232.4375	0.5331		
Total	437	323.1970			

Correlation Coefficient: 0.53

Standard Error of Estimate: 0.73

Residual Analysis

Most Sensitive Species: *Iron humeralis*

Mean Residual: -0.95 (n = 22)

TABLE 2. FRESHWATER FISH SPECIES DATA ANALYSES

Regression Analysis

Data Restrictions:	LC50/TRC/Amperometric Titration-Ferrous DPD/Vertebrate
Dependent Variable:	Concentration TRC (mg/l)
Independent Variable:	Exposure Duration (minutes)
Regression Equation:	Log Concentration = 0.75 - (0.43) Log Duration

Analysis of Variance for the Regression:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	Probability
Attributable to Regression	1	26.5513	26.5513	166.1205	P 0.001
Deviation from Regression	136	21.7371	0.1598		
Total	137	48.2883			

Correlation Coefficient:	0.74
Standard Error of Estimate:	0.40

Residual Analysis

Most Sensitive Species:	*Notropis atherinoides*
Mean Residual:	-0.39 (n = 14)

TABLE 3. FRESHWATER INVERTEBRATE SPECIES DATA ANALYSES

Regression Analysis

Data Restrictions: LC50/TRC/Amperometric Titration-Ferrous DPD/Invertebrate

Dependent Variable: Concentration TRC (mg/l)

Independent Variable: Exposure Duration (minutes)

Regression Equation: Log Concentration = 1.10 - (0.63) Log Duration

Analysis of Variance for the Regression:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	Probability
Attributable to Regression	1	30.7391	30.7391	45.0904	P 0.001
Deviation from Regression	298	203.1533	0.6817		
Total	299	233.8924			

Correlation Coefficient: 0.36

Standard Error of Estimate: 0.83

Residual Analysis

Most Sensitive Species: *Iron humeralis*

Mean Residual: -0.91 (n = 22)

TABLE 4. TVA SPECIES DATA ANALYSES

Regression Analysis

Data Restrictions: LC50/TRC/Amperometric Titration-Ferrous DPD/TVA Species

Dependent Variable: Concentration TRC (mg/l)

Independent Variable: Exposure Duration (minutes)

Regression Equation: Log Concentration = 1.03 - (0.59) Log Duration

Analysis of Variance for the Regression:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	Probability
Attributable to Regression	1	58.7477	58.7477	103.1644	P 0.001
Deviation from Regression	263	149.7673	0.5695		
Total	264	208.5150			

Correlation Coefficient: 0.53

Standard Error of Estimate: 0.75

Residual Analysis

Most Sensitive Species: *Isonychia* sp.

Mean Residual: -0.73 (n = 58)

TABLE 5. TVA FISH SPECIES DATA ANALYSES

Regression Analysis

Data Restrictions: LC50/TRC/Amperometric Titration-Ferrous DPD/TVA Species/Vertebrate

Dependent Variable: Concentration TRC (mg/l)

Independent Variable: Exposure Duration (minutes)

Regression Equation: Log Concentration = 0.93 - (0.49) Log Duration

Analysis of Variance for the Regression:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	Probability
Attributable to Regression	1	19.1374	19.1374	100.4229	P 0.001
Deviation from Regression	87	16.5794	0.1906		
Total	88	35.7169			

Correlation Coefficient: 0.73

Standard Error of Estimate: 0.44

Residual Analysis

Most Sensitive Species: *Notropis atherinoides*

Mean Residual: -0.46 (n = 14)

TABLE 6. TVA INVERTEBRATE SPECIES DATA ANALYSES

Regression Analysis

Data Restrictions: LC50/TRC/Amperometric Titration-Ferrous DPD/TVA Species/Invertebrate

Dependent Variable: Concentration TRC (mg/l)

Independent Variable: Exposure Duration (minutes)

Regression Equation: Log Concentration = 0.75 - (0.52) Log Duration

Analysis of Variance for the Regression:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	Probability
Attributable to Regression	1	13.4623	13.4623	18.1032	P 0.001
Deviation from Regression	174	129.3940	0.7436		
Total	175	142.8563			

Correlation Coefficient: 0.31

Standard Error of Estimate: 0.86

Residual Analysis

Most Sensitive Species: *Isonychia* sp.

Mean Residual: -0.67 (n = 58)

TABLE 7. COMPARISON OF CONCENTRATIONS TRC (mg/l) INDUCING NO MORTALITY

Data	2-Hour Exposure		24-Hour Exposure	
	Average spp.[1]	Most sensitive spp.[2]	Average spp.[1]	Most sensitive spp.[2]
Freshwater spp.	0.35	0.04	0.09	0.01
Freshwater fish spp.	0.42	0.17	0.15	0.06
Freshwater invertebrate spp.	0.36	0.04	0.08	0.01
TVA-resident spp.	0.37	0.07	0.09	0.02
TVA-resident fish spp.	0.48	0.17	0.14	0.05
TVA-resident invertebrate spp.	0.27	0.06	0.08	0.02

1. Average species' sensitivity calculated from regression equation to determine concentration inducing no mortality, is representative of the entire data set.

2. Most sensitive species within each data set, determined by residual analysis, assures protection of all species represented in the data set.

Table 8. MEAN RESIDUAL FOR SPECIES RESIDENT AT TVA

(IN DECREASING SENSITIVITY)

Mean Residual	N	Species	
-.73	58	Isonychia spp.	(-.67)[1]
-.38	14	Notropis atherinoides	(-.46)[2]
-.36	25	Gammarus minus	(-.30)[1]
-.19	4	Centroptilium spp	(-.12)[1]
-.01	5	Notropis hudsonius	(-.06)[2]
-.01	6	Psephemis herricki	(-.01)[1]
.00	3	Notropis spilopterus	(-.12)[2]
.02	16	Ephemerella lata	(.08)[1]
.04	3	Notropis cornutus	(-.08)[2]
.09	3	Catastomus commersoni	(-.03)[2]
.13	6	Ictalurus punctatus	(-.07)[2]
.13	2	Notemigonus crysoleucas	(-.03)[2]
.18	3	Stizostedion canadense	(-.06)[2]
.24	22	Lepomis macrochirus	(.00)[2]
.27	13	Perca flavescens	(.21)[2]
.29	6	Daphnia pulex	(.32)[1]
.34	12	Goniobasis virginica	(.34)[1]
.35	7	Hydropsyche bifida	(.38)[1]
.38	2	Micropterus salmoides	(.10)[2]
.43	12	Nitrocris carinata	(.43)[1]
.44	9	Physa heterostropha	(.45)[1]
.45	7	Cyclops bicuspidatus thomasi	(.56)[1]
.53	3	Morone chrysops	(.41)[2]
.54	3	Cyprinus carpio	(.42)[2]
.59	2	Aplodinotus grunniens	(.47)[2]
1.90	10	Nitrocris spp	(1.95)[1]

[1]Mean Residual for Invertebrate TVA Species.
[2]Mean Residual for Vertebrate TVA Species.

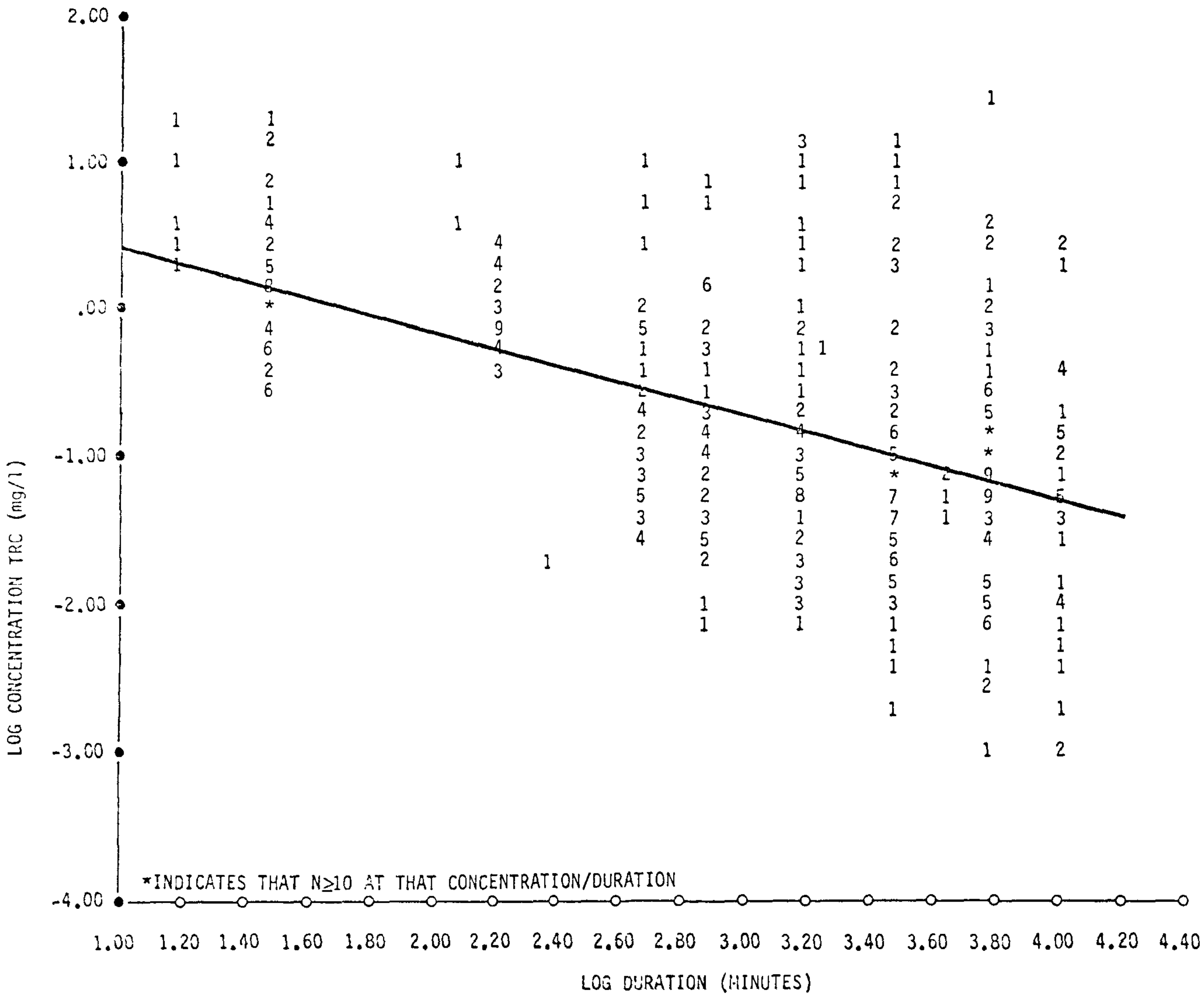


FIGURE 1. REGRESSION: FRESHWATER SPECIES

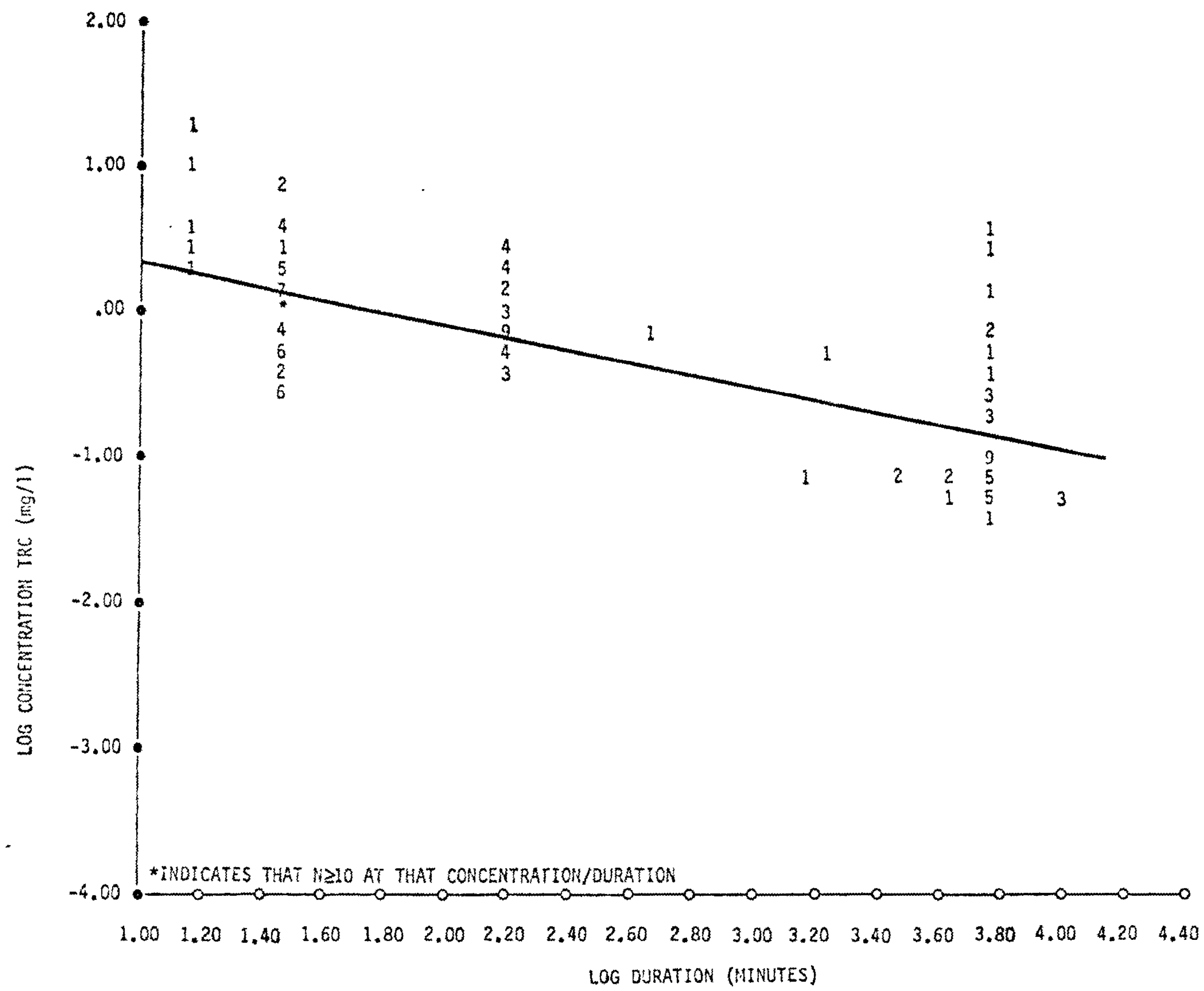


FIGURE 2. REGRESSION: FRESHWATER FISH SPECIES

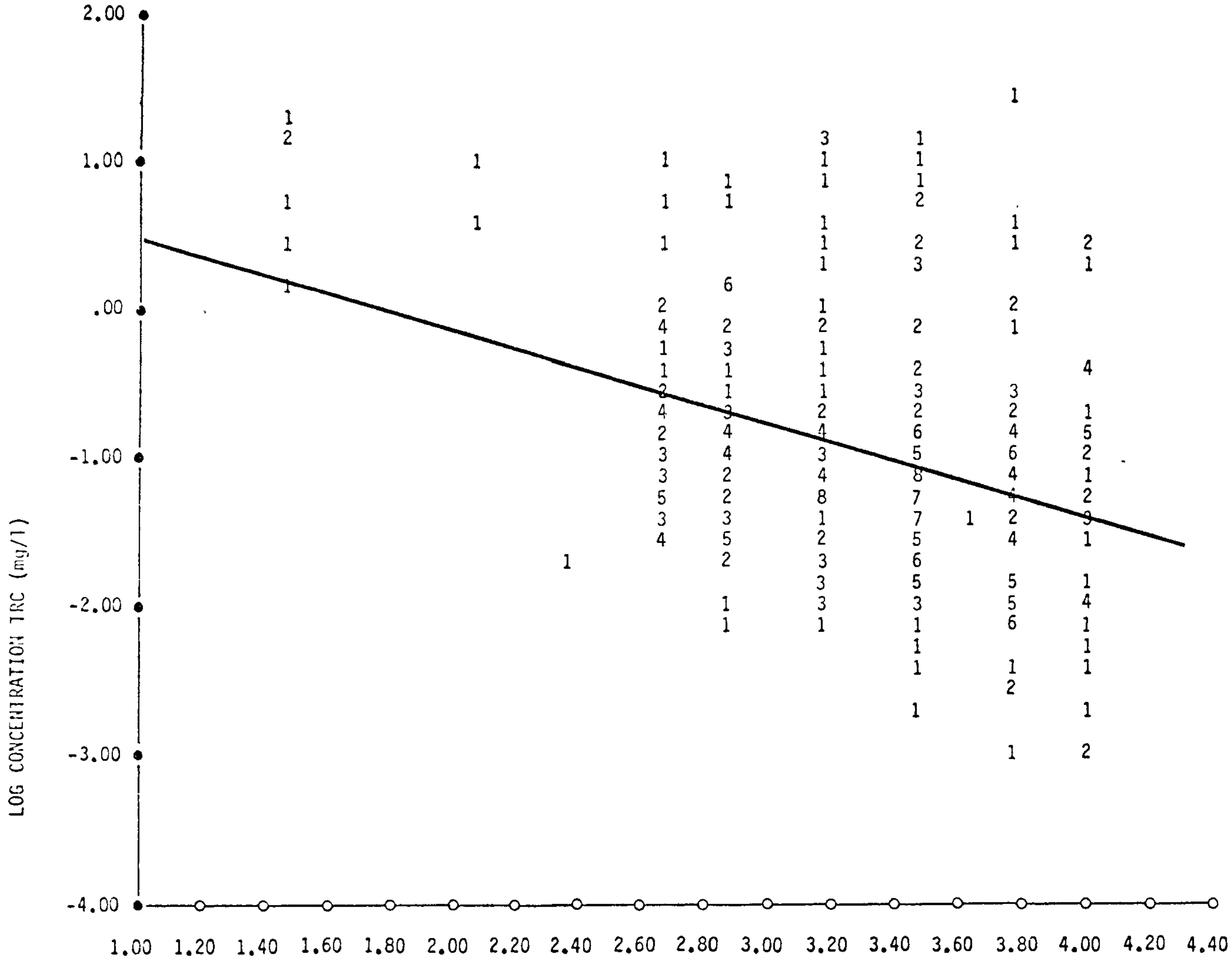


FIGURE 3. REGRESSION: FRESHWATER INVERTEBRATE SPECIES

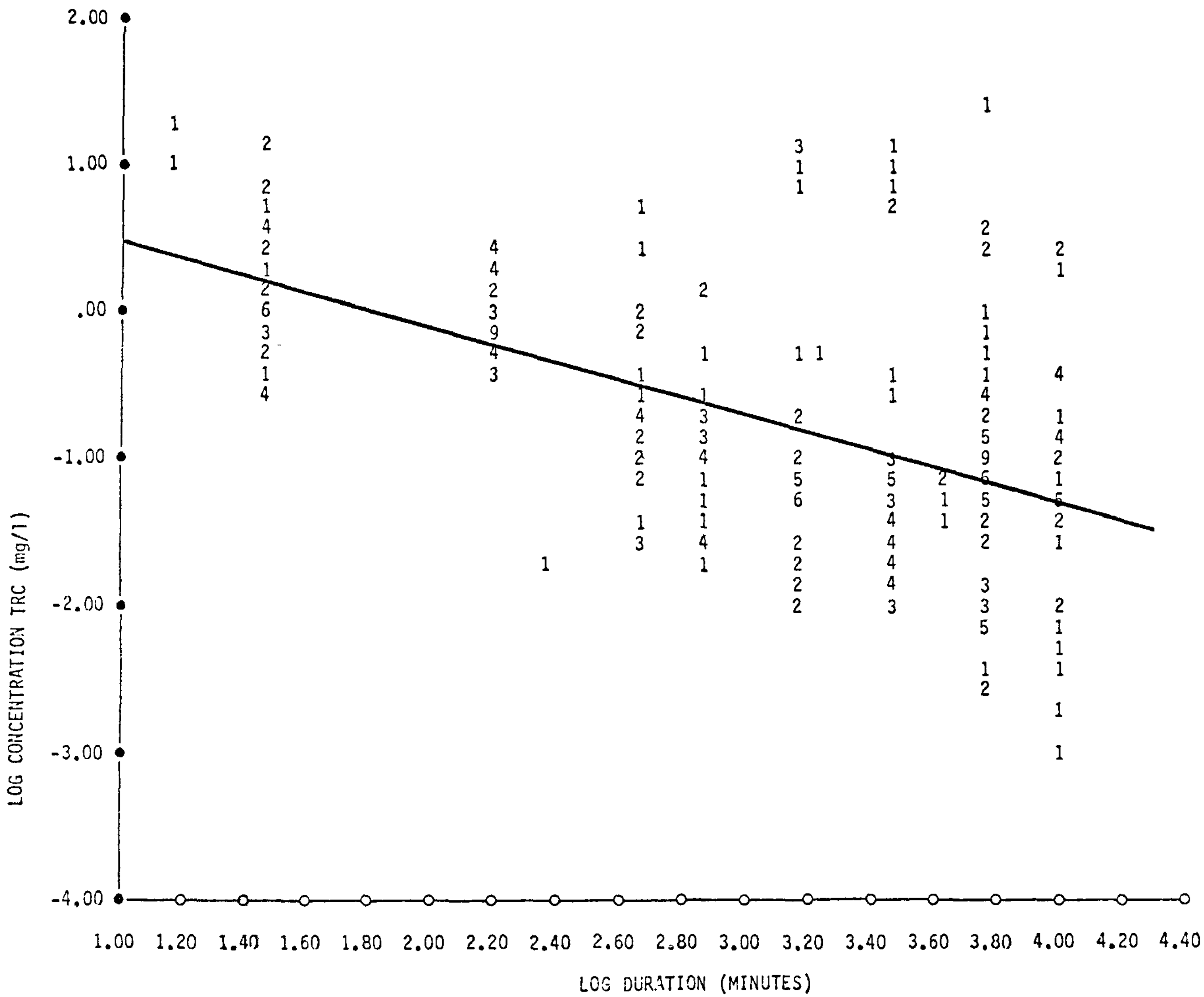


FIGURE 4. REGRESSION: SPECIES RESIDENT AT TVA SITES

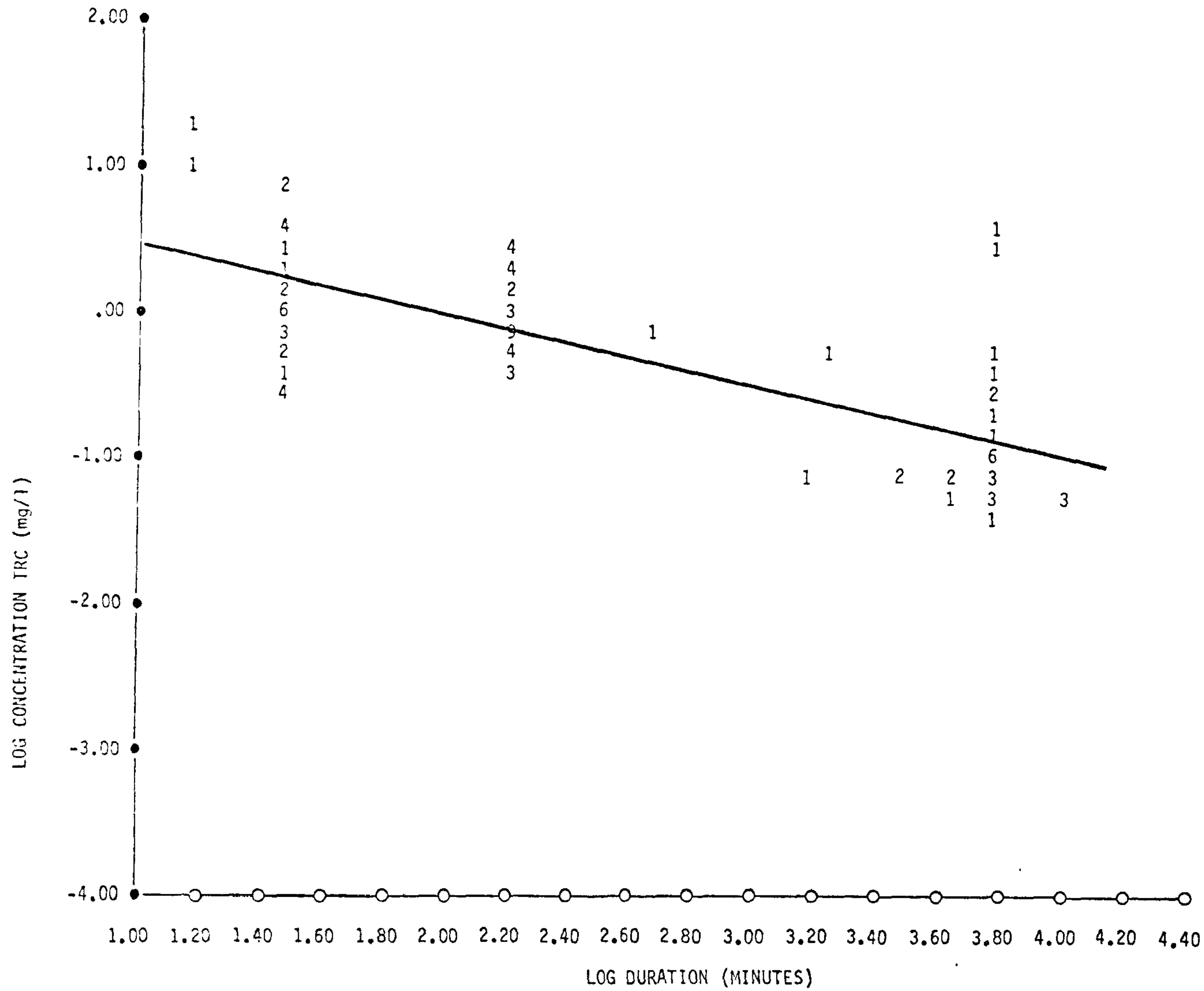


FIGURE 5. REGRESSION: TVA FISH SPECIES

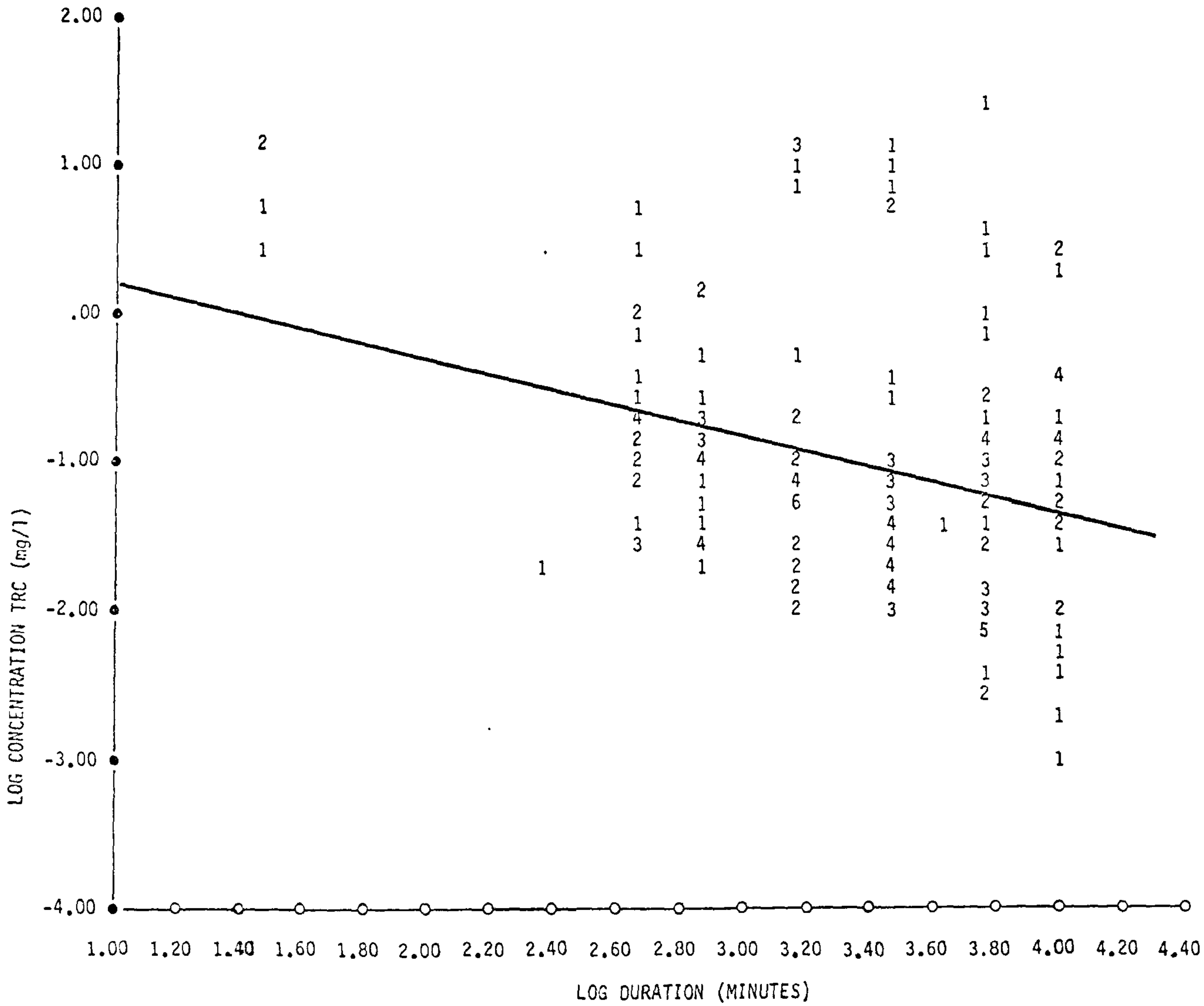


FIGURE 6. <u>REGRESSION: TVA INVERTEBRATE SPECIES</u>

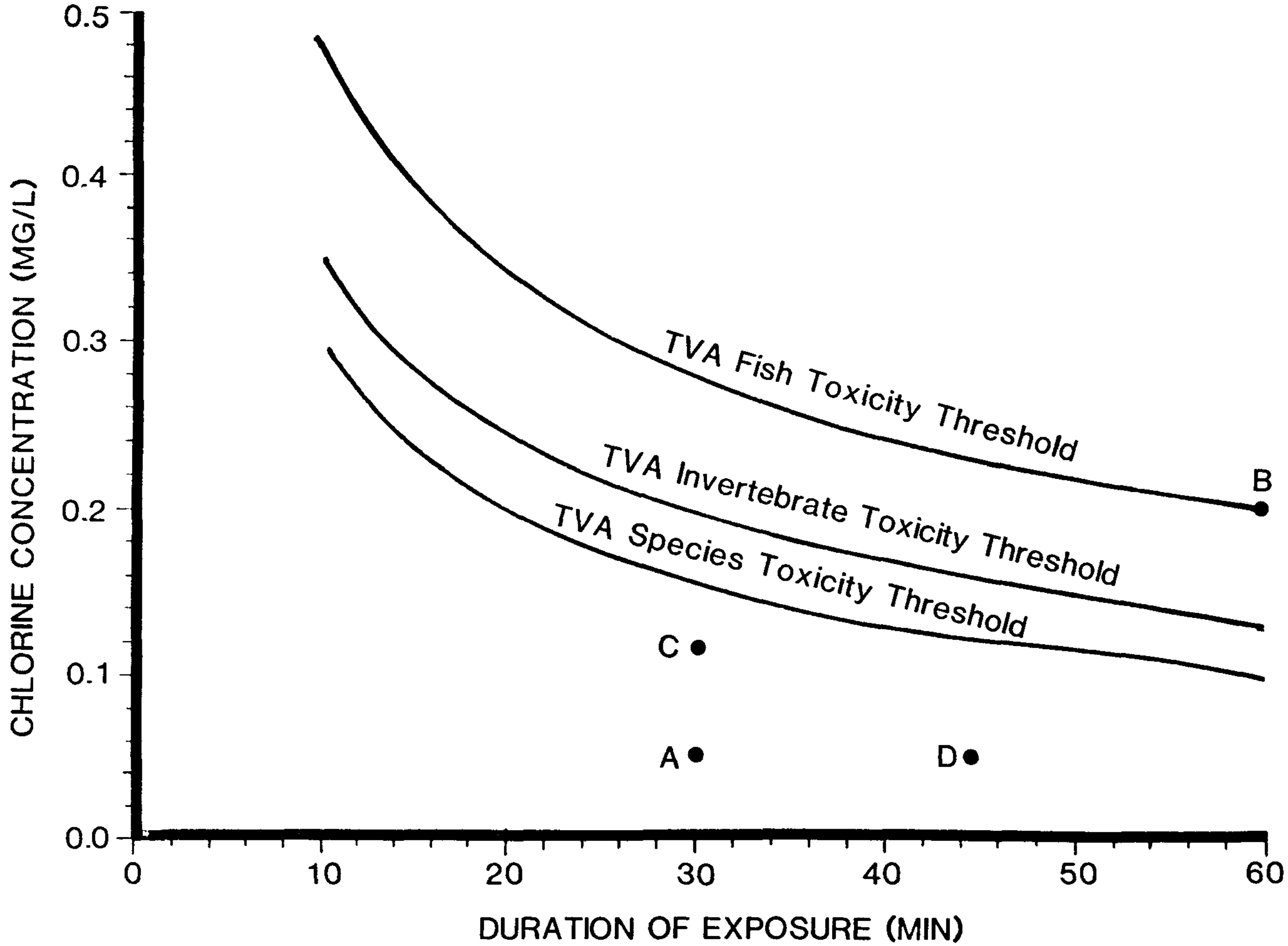


Figure 7. Toxicity thresholds of chlorine to fish and invertebrate species present within the Tennessee Valley Authority watershed.

APPENDIX 1: FRESHWATER DATA LIMITED TO LC50/TRC/AMPEROMETRIC TITRATION-FERROUS DPD

Species	Assay	Concent	Duration	Source
*Aeolosoma headly	Intermittent	2.6000	2,880.00	Cairns 1978
	Intermittent	2.3000	2,880.00	Cairns 1978
	Intermittent	2.0000	2,880.00	Cairns 1978
	Intermittent	1.8000	2,880.00	Cairns 1978
	Intermittent	1.7000	2,880.00	Cairns 1978
*Alosa pseudoharengus	Continuous	2.1500	30.00	Seegert - Brooks 1978
	Continuous	2.2700	30.00	Seegert - Brooks 1978
	Continuous	1.7000	30.00	Seegert - Brooks 1978
	Continuous	0.9600	30.00	Seegert - Brooks 1978
	Continuous	0.3000	30.00	Seegert - Brooks 1978
Anculosa sp.	Intermittent	0.0400	4,320.00	Dickson et al. 1974
Aplodinotus grunniens	Static	2.4500	160.00	Brooks - Seegert 1978
	Static	1.7500	160.00	Brooks - Seegert 1978
*Asellus racovitzai	Static	1.3300	720.00	Gregg 1974
	Static	3.8700	1,440.00	Gregg 1974
	Static	0.1200	1,440.00	Gregg 1974
	Static	0.0850	2,880.00	Gregg 1974
	Static	0.8380	2,880.00	Gregg 1974
	Static	0.0020	2,880.00	Gregg 1974
	Static	0.0320	5,760.00	Gregg 1974
	Static	0.2120	5,760.00	Gregg 1974
	Static	0.3130	5,760.00	Gregg 1974
	Static	0.0160	10,080.00	Gregg 1974
	Static	0.1410	10,080.00	Gregg 1974
	Continuous	0.0440	480.00	Gregg 1974
	Continuous	6.2800	720.00	Gregg 1974
	Continuous	1.4600	720.00	Gregg 1974
	Continuous	1.2600	720.00	Gregg 1974
	Continuous	0.6130	1,440.00	Gregg 1974
	Continuous	0.7520	2,880.00	Gregg 1974
	Continuous	0.3540	2,880.00	Gregg 1974
	Continuous	0.1360	2,880.00	Gregg 1974
	Continuous	0.0870	5,760.00	Gregg 1974
	Continuous	0.0920	5,760.00	Gregg 1974
Carrassius auratus	Continuous	0.1530	5,760.00	Ward & Degraeve
Catastomus commersoni	Static	1.0900	160.00	Brooks - Seegert 1978
	Static	0.7300	160.00	Brooks - Seegert 1978
	Static	0.3600	160.00	Brooks - Seegert 1978
Centroptilium sp.	Continuous	0.2780	480.00	Gregg 1974
	Continuous	0.1700	720.00	Gregg 1974
	Continuous	0.0700	1,440.00	Gregg 1974
	Continuous	0.0480	2,880.00	Gregg 1974
Cyclops bicuspidatus thomasi	Continuous	0.0840	5,760.00	Beeton et al. 1976
	Continuous	14.6800	30.00	Latimer et al. 1975
	Continuous	15.6100	30.00	Latimer et al. 1975
	Continuous	5.7600	30.00	Latimer et al. 1975
	Continuous	3.1500	30.00	Latimer et al. 1975
	Continuous	0.0690	5,760.00	Beeton et al. 1976
	Continuous	0.0720	5,760.00	Beeton et. al. 1976
Cyprinus carpio	Static	2.3700	160.00	Brooks - Seegert 1978
	Static	1.8200	160.00	Brooks - Seegert 1978

APPENDIX 1 (continued)

Species	Assay	Concent	Duration	Source
Cyprinus carpio	Static	1.5000	160.00	Brooks - Seegert 1978
*Daphnia magna	Intermittent	0.1500	2,880.00	Cairns 1978
	Intermittent	0.1300	2,880.00	Cairns 1978
	Intermittent	0.1200	2,880.00	Cairns 1978
	Intermittent	0.1200	2,880.00	Cairns 1978
	Intermittent	0.0800	2,880.00	Cairns 1978
	Continuous	0.0170	2,880.00	Ward & Degraeve
	Continuous	0.2200	2,880.00	Ward & Degraeve
	Continuous	0.0700	2,880.00	Ward & Degraeve
Daphnia pulex	Continuous	31.6000	5,760.00	Clark et al. 1977
	Intermittent	0.1100	2,880.00	Cairns 1978
	Intermittent	0.0900	2,880.00	Cairns 1978
	Intermittent	0.0800	2,880.00	Cairns 1978
	Intermittent	0.0400	2,880.00	Cairns 1978
	Intermittent	0.0300	2,880.00	Cairns 1978
Ephemerella lata	Static	2.4900	480.00	Gregg 1974
	Static	0.1230	720.00	Gregg 1974
	Static	0.2150	1,440.00	Gregg 1974
	Static	0.0850	1,440.00	Gregg 1974
	Static	0.0180	2,880.00	Gregg 1974
	Static	0.0330	2,880.00	Gregg 1974
	Static	0.0130	5,760.00	Gregg 1974
	Static	0.0140	5,760.00	Gregg 1974
	Static	0.0110	10,080.00	Gregg 1974
	Continuous	5.6700	480.00	Gregg 1974
	Continuous	1.3800	720.00	Gregg 1974
	Continuous	1.3300	720.00	Gregg 1974
	Continuous	0.5760	1,440.00	Gregg 1974
	Continuous	0.1830	1,440.00	Gregg 1974
	Continuous	0.0840	2,880.00	Gregg 1974
	Continuous	0.0270	2,880.00	Gregg 1974
Gammarus minus	Static	0.7170	480.00	Gregg 1974
	Static	1.0400	480.00	Gregg 1974
	Static	0.0760	480.00	Gregg 1974
	Static	0.1470	720.00	Gregg 1974
	Static	0.2720	720.00	Gregg 1974
	Static	0.0310	720.00	Gregg 1974
	Static	0.0820	1,440.00	Gregg 1974
	Static	0.0670	1,440.00	Gregg 1974
	Static	0.0190	1,440.00	Gregg 1974
	Static	0.0420	2,880.00	Gregg 1974
	Static	0.0180	2,880.00	Gregg 1974
	Static	0.0100	2,880.00	Gregg 1974
	Static	0.0100	5,760.00	Gregg 1974
	Static	0.0030	5,760.00	Gregg 1974
	Continuous	0.9600	480.00	Gregg 1974
	Continuous	0.2020	480.00	Gregg 1974
	Continuous	0.1910	720.00	Gregg 1974
	Continuous	0.1560	720.00	Gregg 1974
	Continuous	0.0750	1,440.00	Gregg 1974
	Continuous	0.1020	1,440.00	Gregg 1974

APPENDIX 1 (continued)

Species	Assay	Concent	Duration	Source
Gammarus minus	Continuous	0.0520	1,440.00	Gregg 1974
	Continuous	0.0660	2,880.00	Gregg 1974
	Continuous	0.0230	2,880.00	Gregg 1974
	Continuous	0.0340	2,880.00	Gregg 1974
	Continuous	0.0140	5,760.00	Gregg 1974
Goniobasis virginica	Static	2.7900	5,760.00	Gregg 1974
	Static	0.1440	5,760.00	Gregg 1974
	Static	0.1440	10,080.00	Gregg 1974
	Static	2.5500	10,080.00	Gregg 1974
	Static	0.3670	10,080.00	Gregg 1974
	Continuous	0.1100	5,760.00	Gregg 1974
	Continuous	0.0440	5,760.00	Gregg 1974
	Continuous	0.0090	5,760.00	Gregg 1974
	Continuous	0.1360	10,080.00	Gregg 1974
	Continuous	0.0800	10,080.00	Gregg 1974
	Continuous	0.0420	10,080.00	Gregg 1974
	Continuous	0.0060	10,080.00	Gregg 1974
Hyalella azteca	Continuous	0.7400	5,760.00	Clark et al. 1977
Hydropsyche bifida	Continuous	0.3960	480.00	Gregg 1974
	Continuous	0.5250	720.00	Gregg 1974
	Continuous	0.3960	2,880.00	Gregg 1974
	Continuous	0.2830	5,760.00	Gregg 1974
	Continuous	0.0500	5,760.00	Gregg 1974
	Continuous	0.3850	10,080.00	Gregg 1974
	Continuous	0.0340	10,080.00	Gregg 1974
Ictaluras melas	Continuous	0.4400	5,760.00	Clark et al. 1977
Ictalurus nebulosus	Continuous	4.1000	5,760.00	Larson & Schlesinger 1977
Ictalurus punctatus	Continuous	0.0900	5,760.00	Roseboom - Richey 1977
	Continuous	0.0900	5,760.00	Roseboom - Richey 1977
	Continuous	0.0900	5,760.00	Roseboom - Richey 1977
	Static	0.7800	160.00	Brooks - Seegert 1978
	Static	0.6500	160.00	Brooks - Seegert 1978
	Static	0.6700	160.00	Brooks - Seegert 1978
*Iron humeralis	Static	0.0080	720.00	Gregg 1974
	Static	0.0230	720.00	Gregg 1974
	Static	0.0150	1,440.00	Gregg 1974
	Static	0.0080	1,440.00	Gregg 1974
	Static	0.0110	1,440.00	Gregg 1974
	Static	0.0070	2,880.00	Gregg 1974
	Static	0.0060	2,880.00	Gregg 1974
	Static	0.0040	2,880.00	Gregg 1974
	Static	0.0100	5,760.00	Gregg 1974
	Static	0.0010	5,760.00	Gregg 1974
	Static	0.0600	480.00	Gregg 1974
	Static	0.0440	480.00	Gregg 1974
	Static	0.0330	480.00	Gregg 1974
	Static	0.0310	480.00	Gregg 1974
	Static	0.0180	720.00	Gregg 1974
	Static	0.0100	720.00	Gregg 1974
	Continuous	0.0690	480.00	Gregg 1974
	Continuous	0.0460	480.00	Gregg 1974

APPENDIX 1 (continued)

Species	Assay	Concent	Duration	Source
*Iron humeralis	Continuous	0.1000	480.00	Gregg 1974
	Continuous	0.0510	720.00	Gregg 1974
	Continuous	0.0580	2,880.00	Gregg 1974
	Continuous	0.0230	5,760.00	Gregg 1974
Isonychia sp.	Static	0.0810	480.00	Gregg 1974
	Static	0.0290	480.00	Gregg 1974
	Static	0.0440	720.00	Gregg 1974
	Static	0.0230	720.00	Gregg 1974
	Static	0.0230	1,440.00	Gregg 1974
	Static	0.0150	1,440.00	Gregg 1974
	Static	0.0170	2,880.00	Gregg 1974
	Static	0.0140	2,880.00	Gregg 1974
	Static	0.0100	2,880.00	Gregg 1974
	Static	0.0110	2,880.00	Gregg 1974
	Static	0.0100	5,760.00	Gregg 1974
	Static	0.0070	5,760.00	Gregg 1974
	Static	0.0030	5,760.00	Gregg 1974
	Static	0.0020	10,080.00	Gregg 1974
	Static	0.0010	10,080.00	Gregg 1974
	Static	0.0380	480.00	Gregg 1974
	Static	0.0300	480.00	Gregg 1974
	Static	0.0290	720.00	Gregg 1974
	Static	0.0280	720.00	Gregg 1974
	Static	0.0150	1,440.00	Gregg 1974
	Static	0.0170	1,440.00	Gregg 1974
	Static	0.0120	2,880.00	Gregg 1974
	Static	0.0130	2,880.00	Gregg 1974
	Static	0.0040	5,760.00	Gregg 1974
	Static	0.0080	5,760.00	Gregg 1974
	Static	0.0040	10,080.00	Gregg 1974
	Static	0.0886	480.00	Gregg 1974
	Static	0.0235	480.00	Gregg 1974
	Static	0.0402	720.00	Gregg 1974
	Static	0.0179	720.00	Gregg 1974
	Static	0.0241	1,440.00	Gregg 1974
	Static	0.0108	1,440.00	Gregg 1974
	Continuous	0.1230	480.00	Gregg 1974
	Continuous	0.1020	480.00	Gregg 1974
	Continuous	0.1350	480.00	Gregg 1974
	Continuous	0.2030	480.00	Gregg 1974
	Continuous	0.0700	720.00	Gregg 1974
	Continuous	0.0940	720.00	Gregg 1974
	Continuous	0.1000	720.00	Gregg 1974
	Continuous	0.1080	720.00	Gregg 1974
	Continuous	0.0090	1,440.00	Gregg 1974
	Continuous	0.0590	1,440.00	Gregg 1974
	Continuous	0.0440	1,440.00	Gregg 1974
	Continuous	0.0500	1,440.00	Gregg 1974
	Continuous	0.0520	2,880.00	Gregg 1974
	Continuous	0.0300	2,880.00	Gregg 1974
	Continuous	0.0180	2,880.00	Gregg 1974

APPENDIX 1 (continued)

Species	Assay	Concent	Duration	Source
Isonychia sp.	Continuous	0.0300	5,760.00	Gregg 1974
	Continuous	0.0080	5,760.00	Gregg 1974
	Continuous	0.2210	480.00	Gregg 1974
	Continuous	0.2060	480.00	Gregg 1974
	Continuous	0.1070	720.00	Gregg 1974
	Continuous	0.2060	720.00	Gregg 1974
	Continuous	0.0570	1,440.00	Gregg 1974
	Continuous	0.0540	1,440.00	Gregg 1974
	Continuous	0.0480	2,880.00	Gregg 1974
	Continuous	0.0160	2,880.00	Gregg 1974
	Continuous	0.0070	5,760.00	Gregg 1974
Keratella cochlearis	Continuous	0.0190	240.00	Beeton et al. 1976
Lepomis macrochirus	Continuous	0.7900	460.00	Roseboom - Richey 1977
	Continuous	0.4900	1,650.00	Roseboom - Richey 1977
	Continuous	0.3300	5,760.00	Roseboom - Richey 1977
	Continuous	0.2500	5,760.00	Roseboom - Richey 1977
	Continuous	0.1800	5,760.00	Roseboom - Richey 1977
	Static	3.0000	160.00	Brooks - Seegert 1978
	Static	1.7200	160.00	Brooks - Seegert 1978
	Static	1.2300	160.00	Brooks - Seegert 1978
	Static	0.0640	5,760.00	Bass - Heath 1977
	Static	0.0480	10,080.00	Bass - Heath 1977
	Static	0.0600	10,080.00	Bass - Heath 1977
	Static	0.0760	2,880.00	Bass - Heath 1977
	Static	0.0590	4,320.00	Bass - Heath 1977
	Static	0.0570	5,760.00	Bass - Heath 1977
	Static	0.0540	10,080.00	Bass - Heath 1977
	Static	0.0710	1,440.00	Bass - Heath 1977
	Static	0.0670	2,880.00	Bass - Heath 1977
	Static	0.0670	4,320.00	Bass - Heath 1977
	Static	0.0650	5,760.00	Bass - Heath 1977
	Static	0.0750	4,320.00	Bass - Heath 1977
	Static	0.0630	5,760.00	Bass - Heath 1977
	Continuous	2.3200	5,760.00	Larson & Schlesinger 1977
*Lepomis sp.	Continuous	0.2780	5,760.00	Ward & Degraeve
*Limnocalanus macrurus	Continuous	1.5400	30.00	Latimer et al. 1975
Micropterus salmoides	Continuous	0.1000	5,760.00	Larson & Schlesinger 1977
	Continuous	0.2410	5,760.00	Ward & Degraeve
Morone chrysops	Static	2.8700	160.00	Brooks - Seegert 1978
	Static	1.8000	160.00	Brooks - Seegert 1978
	Static	1.1500	160.00	Brooks - Seegert 1978
Nitrocris carinata	Static	4.2200	5,760.00	Gregg 1974
	Static	0.0080	5,760.00	Gregg 1974
	Static	2.1170	10,080.00	Gregg 1974
	Static	2.7900	10,080.00	Gregg 1974
	Static	0.0070	10,080.00	Gregg 1974
	Continuous	0.1410	5,760.00	Gregg 1974
	Continuous	0.0860	5,760.00	Gregg 1974
	Continuous	0.0420	5,760.00	Gregg 1974
	Continuous	0.3700	10,080.00	Gregg 1974
	Continuous	0.1280	10,080.00	Gregg 1974

Species	Assay	Concent	Duration	Source
Nitocris carinata	Continuous	0.0880	10,080.00	Gregg 1974
	Continuous	0.0230	10,080.00	Gregg 1974
Nitocris sp.	Intermittent	15.6000	1,440.00	Cairns et al. 1978
	Intermittent	14.0000	1,440.00	Cairns et al. 1978
	Intermittent	11.9000	1,440.00	Cairns et al. 1978
	Intermittent	9.6000	1,440.00	Cairns et al. 1978
	Intermittent	8.3000	1,440.00	Cairns et al. 1978
	Intermittent	12.8000	2,880.00	Cairns et al. 1978
	Intermittent	10.0000	2,880.00	Cairns et al. 1978
	Intermittent	7.7000	2,880.00	Cairns et al. 1978
	Intermittent	6.0000	2,880.00	Cairns et al. 1978
	Intermittent	5.3000	2,880.00	Cairns et al. 1978
Notemigonus crysoleucas	Intermittent	3.3700	30.00	Spieler & Noeske 1977
	Continuous	0.0510	5,760.00	Ward & Degraeve
Notropis atherinoides	Continuous	0.7100	30.00	Fandrei 1977
	Continuous	0.2300	30.00	Fandrei 1977
	Continuous	0.4500	30.00	Fandrei 1977
	Continuous	0.2800	30.00	Fandrei 1977
	Static	0.6300	160.00	Brooks - Seegert 1978
	Static	0.5100	160.00	Brooks - Seegert 1978
	Static	0.3500	160.00	Brooks - Seegert 1978
	Continuous	1.3200	30.00	Fandrei & Collins 1979
	Continuous	0.7100	30.00	Fandrei & Collins 1979
	Continuous	0.8700	30.00	Fandrei & Collins 1979
	Continuous	0.3300	30.00	Fandrei & Collins 1979
	Continuous	0.2300	30.00	Fandrei & Collins 1979
	Continuous	0.2800	30.00	Fandrei & Collins 1979
	Continuous	0.0450	5,760.00	Ward & Degraeve
Notropis cornutus	Static	0.7800	160.00	Brooks - Seegert 1978
	Static	0.5900	160.00	Brooks - Seegert 1978
	Static	0.4500	160.00	Brooks - Seegert 1978
Notropis hudsonius	Continuous	2.4100	30.00	Seegert - Brooks 1978
	Continuous	1.0000	30.00	Seegert - Brooks 1978
	Continuous	0.5300	30.00	Seegert - Brooks 1978
	Continuous	3.2100	30.00	Brooks - Seegert 1977
	Continuous	1.3800	30.00	Brooks - Seegert 1977
Notropis rubellus	Continuous	0.0400	5,760.00	Ward & Degraeve
Notropis spilopterus	Static	0.6500	160.00	Brooks - Seegert 1978
	Static	0.5900	160.00	Brooks - Seegert 1978
	Static	0.4100	160.00	Brooks - Seegert 1978
*Oncorhynchus kisutch	Continuous	1.2600	30.00	Seegert - Brooks 1978
	Continuous	0.5600	30.00	Seegert - Brooks 1978
	Continuous	1.3800	30.00	Seegert - Brooks 1978
	Continuous	0.9000	30.00	Seegert - Brooks 1978
	Continuous	0.2900	30.00	Seegert - Brooks 1978
	Intermittent	1.2500	30.00	Seegert et al. 1977
	Continuous	0.6800	5,760.00	Larson & Schlesinger 1977
	Continuous	0.0590	5,760.00	Ward & Degraeve
Orconectes virilus	Continuous	1.0800	5,760.00	Clark et al. 1977
*Oronectes australis australis	Continuous	2.7000	1,440.00	Mathews el al. 1977
*Osmerus mordax	Continuous	1.2700	30.00	Seegert - Brooks 1978

Species	Assay	Concent	Duration	Source
*Osmerus mordax	Static	3.3000	15.00	Brooks - Seegert 1977
*Pacifasticus trowbridgi	Continuous	0.9000	5,760.00	Larsen et al. 1978
*Peltoperla maria	Static	0.6420	480.00	Gregg 1974
	Static	0.0410	480.00	Gregg 1974
	Static	0.6810	720.00	Gregg 1974
	Static	0.1570	720.00	Gregg 1974
	Static	0.0350	720.00	Gregg 1974
	Static	0.0590	1,440.00	Gregg 1974
	Static	0.1000	1,440.00	Gregg 1974
	Static	0.0350	1,440.00	Gregg 1974
	Static	0.0320	2,880.00	Gregg 1974
	Static	0.0490	2,880.00	Gregg 1974
	Static	0.0320	2,880.00	Gregg 1974
	Static	0.0110	5,760.00	Gregg 1974
	Continuous	8.4900	480.00	Gregg 1974
	Continuous	0.7100	480.00	Gregg 1974
	Continuous	0.6900	720.00	Gregg 1974
	Continuous	0.5050	720.00	Gregg 1974
	Continuous	0.1310	1,440.00	Gregg 1974
	Continuous	0.3380	1,440.00	Gregg 1974
	Continuous	0.1490	1,440.00	Gregg 1974
	Continuous	0.0200	2,880.00	Gregg 1974
Perca flavescens	Continuous	8.0000	30.00	Brooks - Seegert 1977
	Continuous	3.9000	30.00	Brooks - Seegert 1977
	Continuous	1.1100	30.00	Brooks - Seegert 1977
	Continuous	0.9700	30.00	Brooks - Seegert 1977
	Continuous	0.7000	30.00	Brooks - Seegert 1977
	Static	22.6000	15.00	Brooks - Seegert 1977
	Static	9.0000	15.00	Brooks - Seegert 1977
	Intermittent	7.7000	30.00	Seegert et al. 1977
	Intermittent	4.0000	30.00	Seegert et al. 1977
	Intermittent	1.1000	30.00	Seegert et al. 1977
	Intermittent	1.1000	30.00	Seegert et al. 1977
	Intermittent	2.2500	30.00	Seegert et al. 1977
	Continuous	0.1080	5,760.00	Ward & Degraeve
*Philodinia acuticornis	Intermittent	0.1000	2,880.00	Cairns 1978
	Intermittent	0.0800	2,880.00	Cairns 1978
	Intermittent	0.0700	2,880.00	Cairns 1978
	Intermittent	0.0500	2,880.00	Cairns 1978
	Intermittent	0.0500	2,880.00	Cairns 1978
Physa heterostropha	Static	0.0890	5,760.00	Gregg 1974
	Static	0.1550	5,760.00	Gregg 1974
	Static	0.0590	10,080.00	Gregg 1974
	Static	0.0610	10,080.00	Gregg 1974
	Continuous	0.2580	5,760.00	Gregg 1974
	Continuous	0.2210	5,760.00	Gregg 1974
	Continuous	0.4360	10,080.00	Gregg 1974
	Continuous	0.2180	10,080.00	Gregg 1974
	Continuous	0.1310	10,080.00	Gregg 1974
Pimepheles promeias	Continuous	0.0950	5,760.00	Ward & Degraeve
*Pomoxis sp.	Continuous	0.1270	5,760.00	Ward & Degraeve

APPENDIX 1 (continued)

Species	Assay	Concent	Duration	Source
*Pontoporeia affinis	Continuous	10.6000	120.00	Brooks - Seegert 1977
	Continuous	3.2000	120.00	Brooks - Seegert 1977
	Continuous	20.0000	30.00	Brooks - Seegert 1977
Psephemis herricki	Static	0.1000	2,880.00	Gregg 1974
	Static	0.0270	5,760.00	Gregg 1974
	Static	0.0090	10,080.00	Gregg 1974
	Continuous	0.2560	2,880.00	Gregg 1974
	Continuous	0.1440	5,760.00	Gregg 1974
	Continuous	0.0900	10,080.00	Gregg 1974
*Rhinichthys osculus	Continuous	0.7000	5,760.00	Larson & Schlesinger 1977
*Richardsonius balcatus	Continuous	1.6000	5,760.00	Larson & Schlesinger 1977
*Salmo clarki	Continuous	0.0840	5,760.00	Larson & Schlesinger 1977
*Salmo gairdnerii	Continuous	0.9900	30.00	Brooks - Seegert 1977
	Continuous	0.9400	30.00	Brooks - Seegert 1977
	Continuous	0.4300	30.00	Brooks - Seegert 1977
	Continuous	0.6000	30.00	Brooks - Seegert 1977
	Static	2.8700	15.00	Brooks - Seegert 1977
	Static	1.6500	15.00	Brooks - Seegert 1977
	Continuous	0.2200	5,760.00	Clark et al. 1977
	Intermittent	2.0000	30.00	Seegert et al. 1977
	Continuous	0.0690	5,760.00	Ward & Degraeve
*Salmo trutta	Continuous	0.9900	30.00	Basch - Truchan 1976
	Continuous	0.6700	30.00	Basch - Truchan 1976
	Continuous	0.5600	30.00	Basch - Truchan 1976
	Continuous	0.9900	30.00	Basch - Truchan 1976
	Continuous	1.1900	30.00	Basch - Truchan 1976
	Continuous	0.5600	30.00	Basch - Truchan 1976
*Salvelinus fontinalis	Continuous	0.1500	5,760.00	Schneider et al. 1975
	Continuous	0.1300	5,760.00	Schneider et al. 1975
	Continuous	0.1800	5,760.00	Schneider et al. 1975
	Continuous	0.1500	5,760.00	Schneider et al. 1975
	Continuous	0.1600	5,760.00	Schneider et al. 1975
	Continuous	0.1600	5,760.00	Schneider et al. 1975
	Continuous	0.1500	5,760.00	Schneider et al. 1975
	Continuous	0.1500	5,760.00	Schneider et al. 1975
	Continuous	0.1300	5,760.00	Schneider et al. 1975
	Continuous	0.1100	5,760.00	Schneider et al. 1975
	Continuous	0.1200	5,760.00	Schneider et al. 1975
	Continuous	0.1000	5,760.00	Schneider et al. 1975
	Continuous	0.0960	5,760.00	Larson & Schlesinger 1977
*Salvelinus namaycush	Continuous	0.0600	5,760.00	Ward & Degraeve
*Stenonema ithaca	Static	0.7920	1,440.00	Gregg 1974
	Static	0.0480	1,440.00	Gregg 1974
	Static	0.0210	1,440.00	Gregg 1974
	Static	0.0600	5,760.00	Gregg 1974
	Static	0.2630	2,880.00	Gregg 1974
	Static	0.0730	2,880.00	Gregg 1974
	Static	0.0240	2,880.00	Gregg 1974
	Static	0.0150	2,880.00	Gregg 1974
	Static	0.0240	5,760.00	Gregg 1974
	Static	0.0150	5,760.00	Gregg 1974

Species	Assay	Concent	Duration	Source
*Stenonema ithaca	Static	0.0070	5,760.00	Gregg 1974
	Static	0.0110	10,080.00	Gregg 1974
	Static	0.0090	10,080.00	Gregg 1974
	Static	0.0010	10,080.00	Gregg 1974
	Static	0.2690	480.00	Gregg 1974
	Static	0.0600	480.00	Gregg 1974
	Static	0.0820	720.00	Gregg 1974
	Static	0.0390	720.00	Gregg 1974
	Continuous	0.0376	2,880.00	Gregg 1974
	Continuous	0.1020	5,760.00	Gregg 1974
	Continuous	0.0510	5,760.00	Gregg 1974
	Continuous	0.0770	5,760.00	Gregg 1974
	Continuous	0.0160	5,760.00	Gregg 1974
	Continuous	0.0360	10,080.00	Gregg 1974
	Continuous	0.5020	480.00	Gregg 1974
	Continuous	0.6700	480.00	Gregg 1974
	Continuous	1.6100	720.00	Gregg 1974
	Continuous	4.8600	720.00	Gregg 1974
	Continuous	0.4750	720.00	Gregg 1974
	Continuous	0.3300	720.00	Gregg 1974
	Continuous	0.9530	1,440.00	Gregg 1974
	Continuous	2.0700	1,440.00	Gregg 1974
	Continuous	0.2800	1,440.00	Gregg 1974
	Continuous	0.1220	1,440.00	Gregg 1974
	Continuous	0.2780	2,880.00	Gregg 1974
	Continuous	0.2060	2,880.00	Gregg 1974
	Continuous	0.1200	2,880.00	Gregg 1974
Stizostedion canadense	Static	1.1400	160.00	Brooks - Seegert 1978
	Static	0.6800	160.00	Brooks - Seegert 1978
	Static	0.7100	160.00	Brooks - Seegert 1978

Appendix 2: Mean residuals.

MEAN RESIDUALS FOR TVAALL(CONVERTED)
TALLDAZ

MEAN RESIDUAL	SPECIES	TOTAL RESIDUAL	CALCULATED RESIDUAL	LOG CONCENTRATION	LOG DURATION
-.73	ISONYCHIA SP.	-42.16	-.54	-1.09	2.68
			-.99	-1.54	2.68
			-.70	-1.36	2.86
			-.98	-1.64	2.86
			-.80	-1.64	3.16
			-.99	-1.82	3.16
			-.76	-1.77	3.46
			-.84	-1.85	3.46
			-.99	-2.00	3.46
			-.95	-1.96	3.46
			-.81	-2.00	3.76
			-.97	-2.15	3.76
			-1.33	-2.52	3.76
			-1.37	-2.70	4.00
			-1.67	-3.00	4.00
			-.87	-1.42	2.68
			-.97	-1.52	2.68
			-.88	-1.54	2.86
			-.90	-1.55	2.86
			-.99	-1.82	3.16
			-.94	-1.77	3.16
			-.91	-1.92	3.46
			-.88	-1.89	3.46
			-1.21	-2.40	3.76
			-.91	-2.10	3.76
			-1.07	-2.40	4.00
			-.50	-1.05	2.68
			-1.08	-1.63	2.68
			-.74	-1.40	2.86
			-1.09	-1.75	2.86
			-.78	-1.62	3.16
			-1.13	-1.97	3.16
			-.36	-.91	2.68
			-.44	-.99	2.68
			-.32	-.87	2.68
			-.14	-.69	2.68
			-.50	-1.15	2.86
			-.37	-1.03	2.86
			-.34	-1.00	2.86
			-.31	-.97	2.86
			-1.21	-2.05	3.16
			-.40	-1.23	3.16
			-.52	-1.36	3.16
			-.47	-1.30	3.16
			-.27	-1.28	3.46
			-.51	-1.52	3.46
			-.73	-1.74	3.46
			-.33	-1.52	3.76

MEAN RESIDUALS FOR TVAALL(CONVERTED)
TALLDAZ

MEAN RESIDUAL	SPECIES	TOTAL RESIDUAL	CALCULATED RESIDUAL	LOG CONCENTRATION	LOG DURATION
-.73	ISONYCHIA SP.	-42.16	-.91	-2.10	3.76
			-.10	-.66	2.68
			-.13	-.69	2.68
			-.31	-.97	2.86
			-.03	-.69	2.86
			-.41	-1.24	3.16
			-.43	-1.27	3.16
			-.31	-1.32	3.46
			-.78	-1.80	3.46
			-.97	-2.15	3.76
-.38	NOTROPIS ATHERINOIDES	-5.33	-.31	-.15	1.48
			-.80	-.64	1.48
			-.51	-.35	1.48
			-.71	-.55	1.48
			.07	-.20	2.20
			-.02	-.29	2.20
			-.19	-.46	2.20
			-.04	.12	1.48
			-.31	-.15	1.48
			-.22	-.06	1.48
			-.64	-.48	1.48
			-.80	-.64	1.48
			-.71	-.55	1.48
			-.16	-1.35	3.76
-.36	GAMMARUS MINUS	-8.89	.41	-.14	2.68
			.57	.02	2.68
			-.57	-1.12	2.68
			-.18	-.83	2.86
			.09	-.57	2.86
			-.85	-1.51	2.86
			-.25	-1.09	3.16
			-.34	-1.17	3.16
			-.89	-1.72	3.16
			-.37	-1.38	3.46
			-.73	-1.74	3.46
			-.99	-2.00	3.46
			-.81	-2.00	3.76
			-1.33	-2.52	3.76
			.53	-.02	2.68
			-.14	-.69	2.68
			-.06	-.72	2.86
			-.15	-.81	2.86
			-.29	-1.12	3.16
			-.16	-.99	3.16
			-.45	-1.28	3.16
			-.17	-1.18	3.46
			-.63	-1.64	3.46
			-.46	-1.47	3.46

MEAN RESIDUALS FOR TVAALL(CONVERTED)
TALLDAZ

MEAN RESIDUAL	SPECIES	TOTAL RESIDUAL	CALCULATED RESIDUAL	LOG CONCENTRATION	LOG DURATION
-.36	GAMMARUS MINUS	-8.89	-.67	-1.85	3.76
-.19	CENTROPTILIUM SP.	-.75	-.00	-.56	2.68
			-.11	-.77	2.86
			-.32	-1.15	3.16
			-.31	-1.32	3.46
-.01	NOTROPIS HUDSONIUS	-.04	.22	.38	1.48
			-.16	.00	1.48
			-.43	-.28	1.48
			.35	.51	1.48
			-.02	.14	1.48
-.01	PSEPHENUS HERRICKI	-.03	.01	-1.00	3.46
			-.38	-1.57	3.76
			-.71	-2.05	4.00
			.42	-.59	3.46
			.35	-.84	3.76
			.29	-1.05	4.00
.00	NOTROPIS SPILOPTERUS	.01	.08	-.19	2.20
			.04	-.23	2.20
			-.12	-.39	2.20
.02	EPHEMERELLA LATA	.38	.95	.40	2.68
			-.25	-.91	2.86
			.17	-.67	3.16
			-.24	-1.07	3.16
			-.73	-1.74	3.46
			-.47	-1.48	3.46
			-.70	-1.89	3.76
			-.67	-1.85	3.76
			-.63	-1.96	4.00
			1.31	.75	2.68
			.80	.14	2.86
			.78	.12	2.86
			.59	-.24	3.16
			.10	-.74	3.16
			-.06	-1.08	3.46
			-.56	-1.57	3.46
.04	NOTROPIS CORNUTUS	.13	.16	-.11	2.20
			.04	-.23	2.20
			-.08	-.35	2.20
.09	CATOSTOMUS COMMERSONI	.27	.31	.04	2.20
			.13	-.14	2.20
			-.17	-.44	2.20
.13	ICTALURUS PUNCTATUS	.77	.14	-1.05	3.76
			.14	-1.05	3.76
			.14	-1.05	3.76
			.16	-.11	2.20
			.08	-.19	2.20
			.10	-.17	2.20
.13	NOTEMIGONUS CRYSOLEUCAS	.27	.37	.53	1.48

MEAN RESIDUALS FOR TVAALL(CONVERTED)
TALLDA7

MEAN RESIDUAL	SPECIES	TOTAL RESIDUAL	CALCULATED RESIDUAL	LOG CONCENTRATION	LOG DURATION
.13	NOTEMIGONUS CRYSOLEUCAS	.27	-.10	-1.29	3.76
.16	STIZOSTEDION CANADENSE	.55	.33	.06	2.20
			.10	-.17	2.20
			.12	-.15	2.20
.24	LEPOMIS MACROCHIRUS	5.25	.44	-.10	2.66
			.56	-.31	3.22
			.71	-.48	3.76
			.59	-.60	3.76
			.44	-.74	3.76
			.75	.48	2.20
			.51	.24	2.20
			.36	.09	2.20
			-.01	-1.19	3.76
			.01	-1.32	4.00
			.11	-1.22	4.00
			-.11	-1.12	3.46
			-.11	-1.23	3.64
			-.06	-1.24	3.76
			.06	-1.27	4.00
			-.32	-1.15	3.16
			-.16	-1.17	3.46
			-.06	-1.17	3.64
			.00	-1.19	3.76
			-.01	-1.12	3.64
			-.01	-1.20	3.76
			1.55	.37	3.76
.27	PERCA FLAVESCENS	3.57	.74	.90	1.48
			.43	.59	1.48
			-.11	.05	1.48
			-.17	-.01	1.48
			-.31	-.15	1.48
			1.02	1.35	1.18
			.62	.95	1.18
			.73	.89	1.48
			.44	.60	1.48
			-.12	.04	1.48
			-.12	.04	1.48
			.19	.35	1.48
			.22	-.97	3.76
.29	DAPHNIA PULEX	1.72	2.69	1.50	3.76
			.05	-.96	3.46
			-.03	-1.05	3.46
			-.09	-1.10	3.46
			-.39	-1.40	3.46
			-.51	-1.52	3.46
.34	GONIOBASIS VIRGINICA	4.08	1.63	.45	3.76
			.35	-.84	3.76
			.49	-.84	4.00

MEAN RESIDUALS FOR TVAALL(CONVERTED)
TALLDAZ

MEAN RESIDUAL	SPECIES	TOTAL RESIDUAL	CALCULATED RESIDUAL	LOG CONCENTRATION	LOG DURATION
.34	GONIOBASIS VIRGINICA	4.08	1.74	.41	4.00
			.90	-.44	4.00
			.23	-.96	3.76
			-.17	-1.36	3.76
			-.86	-2.05	3.76
			.47	-.87	4.00
			.24	-1.10	4.00
			-.04	-1.38	4.00
			-.89	-2.22	4.00
.35	HYDROPSYCHE BIFIDA	2.44	.15	-.40	2.68
			.38	-.28	2.86
			.61	-.40	3.46
			.64	-.55	3.76
			-.11	-1.30	3.75
			.92	-.41	4.00
			-.14	-1.47	4.00
.38	MICROPTERUS SALMOIDES	.76	.19	-1.00	3.76
			.57	-.62	3.76
.43	NITOCRIS CARINATA	5.10	1.81	.63	3.75
			-.91	-2.10	3.76
			1.66	.33	4.00
			1.78	.45	4.00
			-.82	-2.15	4.00
			.34	-.85	3.76
			.12	-1.07	3.76
			-.19	-1.38	3.76
			.90	-.43	4.00
			.44	-.09	4.00
			.28	-1.06	4.00
			-.31	-1.64	4.00
.44	PHYSA HETEROSTROPHA	3.96	.14	-1.05	3.76
			.38	-.81	3.76
			.10	-1.23	4.00
			.12	-1.21	4.00
			.60	-.59	3.76
			.53	-.66	3.76
			.97	-.36	4.00
			.67	-.66	4.00
			.45	-.88	4.00
.45	CYCLOPS BICUSPIDATUS THOMASI	3.17	.11	-1.08	3.76
			1.01	1.17	1.48
			1.03	1.19	1.48
			.60	.76	1.49
			.34	.50	1.48
			.03	-1.16	3.76
			.05	-1.14	3.76
.53	MORONE CHRYSOPS	1.59	.73	.46	2.20
			.53	.26	2.20

MEAN RESIDUALS FOR TVAALL(CONVERTED)
TALLDAZ

MEAN RESIDUAL	SPECIES	TOTAL RESIDUAL	CALCULATED RESIDUAL	LOG CONCENTRATION	LOG DURATION
.53	MORONE CHRYSOPS	1.59	.33	.06	2.20
.54	CYPRINUS CARPIO	1.62	.65	.37	2.20
			.53	.26	2.20
			.45	.18	2.20
.59	APLODINOTUS GRUNNIENS	1.17	.66	.39	2.20
			.51	.24	2.20
1.90	NITOCRIS SP	19.03	2.03	1.19	3.16
			1.98	1.15	3.16
			1.91	1.08	3.16
			1.82	.98	3.16
			1.75	.92	3.16
			2.12	1.11	3.46
			2.01	1.00	3.46
			1.90	.89	3.46
			1.79	.78	3.46
			1.74	.72	3.46

Appendix D

ANALYSIS OF CHLORINE TOXICITY FOR SEVERAL FISH SPECIES WITH POTENTIAL APPLICATION TO FISH MORTALITY AT A POWER PLANT

by

Robert W. Aldred

ANALYSIS OF CHLORINE TOXICITY FOR SEVERAL FISH SPECIES WITH POTENTIAL APPLICATION TO FISH MORTALITY AT A POWER PLANT

By Robert W. Aldred

SECTION I

INTRODUCTION

As a result of a fish kill in July 1977 involving a large number of striped bass near power plant B, there is an interest in establishing the relationship between chlorine concentrations in cooling water and the mortality of striped bass populations. In response to this goal, the applicability of the Envirosphere study described in reference 1 is examined as a first step.

The Envirosphere study provides several analyses of the effect of chlorinated cooling water on marine and freshwater organisms. The resulting general models, however, are not directly applicable to the species present at specific locations largely because of inadequacies in the available data. Yet despite the inadequacies, the data from reference 1 constitute the best available data, and the application of selected subsets of these data to the above objective is attempted in order to obtain, if possible, an appropriate model for the power plant B environment. The purpose of this study is to present the results of this analysis and to offer recommendations based on the results.

SECTION II

SUMMARY OF RESULTS

Since a particular species, striped bass, is of concern at power, plant B, and since no data pertaining to striped bass are available, the intent of this analysis is to derive a single model which adequately describes the desired relationship for all the fish species in the local area of the power plant. The results indicate that fish mortality, related in terms of the maximum duration of time a fish can survive with negligible ill effects after chlorination, is significantly affected by the chlorine concentration. Water temperature, however, is not detected as an important factor in the chlorine toxicity. Unfortunately the distinct relationship between survival duration and chlorine concentration differs among the species analyzed. Therefore, in order to obtain data to construct an appropriate predictive model for striped bass at power plant B, it is recommended that experiments with this species be conducted under conditions suitable for the power plant's environment.

SECTION III

METHODS

Data Description

This section describes the available data and discusses the several problems found in these data. In addition, a number of biological statements are included for completeness.

The Envirosphere data base consists of the results of chlorine bioassays published through 1980 and is described in detail on page 3 of reference 1. The data concern experiments involving numerous marine and freshwater species for the three chlorine residual forms (free residual chlorine, combined residual chlorine, and total residual chlorine). For the subject study concerning power plant B, only the total residual chlorine (TRC) observations are considered, and of the original 438 TRC observations, only 74 observations representing 19 local fish species are included in the analysis. These 74 observations exclude all species not local to the power plant area as well as those invertebrate species which are local to the area. Also deleted are several outlier observations for which the chlorine concentrations are unusually large and outside the range of interest of this study. The final 74 observations are listed in Appendix A (this report).

Specific Goals and Data Relevance

The specific goal of the study is to model the effects of chlorine effluents on striped bass populations at power plant B. The desired model should describe the effect of total residual chlorine on the expected length of time after exposure that this species can survive with little or no adverse effect. Such a model would permit prediction of a maximum length of time that a striped bass could be safely exposed to a given concentration of TRC.

Unfortunately, striped bass are not included among the 19 species represented by the data. Hence, supplementary data for this species were sought through literature searches, but no useable data were found. Additionally, it is recognized that the experiments yielding the data were not necessarily conducted under comparable test conditions of chlorine residual measurement and temperature, nor are the important characteristics of health, life stage, or subspecies of the tested fish known. However, even though these data inadequacies limit the applicability of any modeling results obtained, the goal of determining what, if any, useful toxicity inferences can be drawn concerning striped bass is still important.

Selected Variables

In this analysis, the dependent (response) variable is the duration of time which a specimen can survive a given concentration of TRC with negligible ill effect. However, since the original data base of reference 1 contains durations required for 50 percent of the specimens to be killed by the given TRC dosage, a transformation of the data is necessary. In this case, the concentration independent variable is multiplied by a conversion factor of 0.59. This factor, which is explained in Figure 1, page ii of reference 2, converts each concentration of TRC to a lethal threshold concentration so that the corresponding duration can be assumed to represent the maximum survival time for which little adverse effect is experienced by the fish.

Another significant data problem which affects the analysis is apparent in the duration response values. Of the 74 responses, 69 of them are observed at only 5 levels, and 51 of them are described by the 2 extremes of 160 and 5760 minutes. This lack of variability in the responses casts considerable doubt on how accurately each duration measurement reflects the actual time required for a 50 percent lethal rate to be obtained.

The remaining independent variable considered in the analysis is the water temperature at which each experiment was conducted. The metabolism of an organism is closely tied to temperature. As temperature increases or decreases, the metabolic rate increases or decreases, respectively. Metabolic rates approximately double for each 10° Celsius rise in temperature. Ideally, therefore, the temperature should be controlled across experiments to a range of a few degrees Celsius, but such control was not possible under the circumstances of the reference 1 study. Thus, to evaluate the potential effect of temperature on the toxicity, this variable is considered.

SECTION IV

RESULTS

Analysis of the Data

The use of exposure duration as the dependent variable in this study represents a significant change in strategy from the reference 1 analysis in which TRC concentrations are used as the dependent variable. For the goals of this study, however, it is felt that duration is the appropriate response variable.

In this section, the two stages of the regression analysis are explained. The first discussion covers the search for the most reasonable model based on the complete data set of 74 observations, and the second subsection presents a more detailed analysis of some of the individual species.

Analysis of the Full Data Set

The first and most general model considers duration as a function of the lethal threshold concentrations (hereafter called threshold) and the test condition temperature. The results of this regression are given in Appendix B, Table 1 (this report), which provides the estimated parameters of the regression equation, the p-values resulting from the t-tests and F-test for parameter significance, and the coefficient of determination (R^2) value adjusted for the number of parameters in the model. As shown in the table, the temperature variable does not warrant inclusion in this model based on its insignificant p-value. This same fact is true for every other model in which temperature is considered, and this variable is, therefore, not considered in the remaining analysis.

The next attempted model, duration against threshold, reveals an extremely low R^2 value of 12.49 percent as its most noticeable drawback despite the strong significance of the independent variable (see Table 2 of Appendix B). A plot of these two variables showing the estimated regression line is provided in Appendix C, Figure 1 (this report). The very low R^2 appears to result from a relative scaling problem in the two variables which produces several large positive residuals, and it suggests two possible transformations. The first of these consists of inverting the threshold values and regressing duration against the inverted thresholds. In the second transformation, the log (base 10) of duration is modeled as a function of the log of threshold concentration.

Both these transformed models exhibit substantial improvement in the explanatory effectiveness measured by R^2 as shown in Tables 3 and 4 of Appendix B by a value of 53.24 percent for the inverse threshold model and 41.10 percent for the log model. Analysis of the residuals (quantities formed by subtracting each dependent variable response from its model-predicted value) for the duration vs. inverse threshold model reveals an undesirable pattern which severely affects the predictive capability of the model. This problem can be seen in the intercept estimate of approximately 555 minutes. No matter how large the threshold dosage (i.e., no matter how close the inverted threshold is to zero), the predicted exposure duration is always above 555 minutes. The unreasonableness of this limitation is illustrated by Figure 2 of Appendix C, which shows that 42 of the 74 duration observations in the data set are less than 555 minutes.

The scatter plot of log of duration against log of threshold with the estimated regression line is shown in Figure 3 of Appendix C. Although the R^2 value for this model is less than the R^2 for the previous model, the log model is selected as the most appropriate one given that a general model must be chosen to represent the 19 analyzed species. Its overall predictive consistency is better than that of any other model considered. However, for the two most represented species which account for exactly half the observations in the data base, the residuals from the log model are almost all positive for one of these species and almost all negative for the other species.

This pattern indicates that significantly different estimates of one or both parameters might be obtained if the species were analyzed separately using the log model. In other words, the general log model already estimated may not be very representative of many of the individual species and, therefore, may be site-specific like the Envirosphere models of reference 1. In order to more adequately determine if this phenomenon is true in this case, a species-specific regression analysis is presented in the next subsection.

Analysis of Individual Species

This stage of the analysis uses indicator variables which allow for the possibility that across individual species, the slope and/or intercept for the log model could have distinctly different values. In order to control the complexity of this stage of the analysis, only the three most represented species are included. These three species are *Lepomis macrochirus* (22 observations), *Notropis atherinoides* (15 observations), and *Ictalurus punctatus* (6 observations). None of the remaining 16 species contain more than three observations from the 74-observation data base.

For the three species (43 observations) three models are necessary to test two hypotheses which will be used to determine whether the 74-observation log model is species-dependent or adequately representative of all species in the data base. The first model contains two indicator variables for the intercept and two indicator variables for the slope in addition to log threshold and the usual intercept term. (Only two indicators each for the slope and intercept are required when three species are analyzed.) The results of this 5-variable model for 43 observations are provided in Table 5 of Appendix B. The next model deletes the two slope indicator variables, keeping the two intercept indicators plus log threshold. The third model uses only log threshold. Tables 6 and 7 of Appendix B show the results of these models.

The first hypothesis test assumes the 5-variable indicator model and tests the null hypothesis that all four indicator parameters are zero (i.e., that the simple regression model with log threshold is sufficient for all 43 observations). The resulting F-test yields a p-value (the probability of observing a larger F-statistic when the null hypothesis is actually true) of less than 0.0001. Thus, as a group, the four indicator variables appear to be extremely significant. The outcomes of both hypothesis tests are summarized in Appendix D. The other test is used to determine if the log threshold effects (slopes) differ among the three species while allowing for different intercepts for the three species. This time the F-test is not nearly as conclusive based on a p-value of approximately 0.04. However, the risk of incorrectly rejecting the three slopes' equivalence is still only 4 percent. Thus, the 5-variable indicator model is the most appropriate one for the 43 observations because the three species clearly do not exhibit the same expected toxicity reactions to TRC contaminations. The relative results of the two tests can be seen through an examination of the adjusted R2 values of 42.64 percent, 79.47 percent, and 81.85 percent for the simple log threshold model, the 3-variable model, and the 5-variable model based on the three selected species.

SECTION V

CONCLUSION

Since the indicator analysis shows that the simple regression model of log duration against log threshold is not an adequate representation for all three species examined, it can reasonably be assumed that the same conclusion applies to the 74-observation model for the same two variables. Thus, to use this general log model to represent the chlorine toxicity relationship for striped bass at a steam plant would be extremely unwise, and it is concluded that no model based on the available data would be useful. There are other possible models which this study has not considered, and there are other explanatory variables such as the water hardness and pH whose effect might be analyzed if better data were available. However, considering the stated goals of the study, the best recommendation appears to be to design and conduct experiments with striped bass under conditions appropriate for the steam plant's environment. Only then can a useful model be obtained.

SECTION VI

REFERENCES

1. Chlorine Toxicity as a Function of Environmental Variables and Species Tolerance, Edison Electric Institute (Submitted by Envirosphere Company), November 1981.

2. Chlorine Toxicity in Freshwater Ecosystems, Edison Electric Institute (Submitted by Envirosphere Company), March 1979.

APPENDIX A. LISTING OF DATA BASE (74 OBSERVATIONS)

Duration (min)	Log of duration	Threshold (mg/l)	Log of threshold	Inverse of threshold	Temperature (degrees C)	Species
160	2.20412	1.44550	0.1600	0.6918	10.3	*Aplodinotus grunniens*
160	2.20412	1.03250	0.0139	0.9685	20.0	*Aplodinotus grunniens*
5,760	3.76042	0.09027	-1.0445	11.0779	20.0	*Carrassius auratus*
160	2.20412	0.64310	-0.1917	1.5550	10.0	*Catastomus commersoni*
160	2.24012	0.43070	-0.3658	2.3218	20.0	*Catastomus commersoni*
160	2.20412	0.21240	-0.6728	4.7081	26.7	*Catastomus commersoni*
160	2.20412	1.39830	0.1456	0.7152	10.4	*Cyprinus carpio*
160	2.20412	1.07380	0.0309	0.9313	19.7	*Cyprinus carpio*
160	2.20412	0.88600	-0.0531	1.1299	29.3	*Cyprinus carpio*
5,760	3.76042	0.25960	-0.5857	3.8521	15.0	*Ictalurus melas*
5,760	3.76042	2.41900	0.3836	0.4134	19.0	*Ictalurus nebulosus*
5,760	3.76042	0.05310	-1.2749	18.8324	30.0	*Ictalurus punctatus*
5,760	3.76042	0.05310	-1.2749	18.8324	20.0	*Ictalurus punctatus*
5,760	3.76042	0.05310	-1.2749	18.8324	30.0	*Ictalurus punctatus*
160	2.20412	0.46020	-0.3371	2.1730	10.2	*Ictalurus punctatus*
160	2.20412	0.38350	-0.4162	2.6076	20.4	*Ictalurus punctatus*
160	2.20412	0.39530	-0.4031	2.5297	29.5	*Ictalurus punctatus*
460	2.66276	0.46610	-0.3315	2.1455	20.0	*Lepomis macrochirus*
1,650	3.21748	0.28910	-0.5390	3.4590	20.0	*Lepomis macrochirus*
5,760	3.76042	0.19470	-0.7106	5.1351	20.0	*Lepomis macrochirus*
5,760	3.76042	0.14750	-0.8312	5.7797	21.0	*Lepomis macrochirus*
5,760	3.76042	0.10620	-0.9739	9.4162	30.0	*Lepomis macrochirus*
160	2.20412	1.77000	0.2480	0.5650	10.2	*Lepomis macrochirus*
160	2.20412	1.01480	0.0064	0.9854	20.1	*Lepomis macrochirus*
160	2.20412	0.72570	-0.1392	1.3780	29.9	*Lepomis macrochirus*
5,760	3.76042	0.03776	-1.4239	25.4831	5.0	*Lepomis macrochirus*
10,080	4.00345	0.02832	-1.5479	35.3107	5.0	*Lepomis macrochirus*
10,080	4.00346	0.03540	-1.4510	28.2485	15.0	*Lepomis macrochirus*
2,880	3.45839	0.04484	-1.3483	22.3015	25.0	*Lepomis macrochirus*
4,320	3.63548	0.03481	-1.4583	28.7274	25.0	*Lepomis macrochirus*
5,760	3.76042	0.03363	-1.4733	29.7354	25.0	*Lepomis macrochirus*
10,080	4.00346	0.03186	-1.4968	31.3873	25.0	*Lepomis macrochirus*
1,440	3.15836	0.04189	-1.3779	23.8720	32.0	*Lepomis macrochirus*

(continued)

APPENDIX A (continued)

Duration (min)	Log of duration	Threshold (mg/l)	Log of threshold	Inverse of threshold	Temperature (degrees C)	Species
2,880	3.45939	0.03953	-1.4031	25.2972	32.0	*Lepomis macrochirus*
4,320	3.63548	0.03953	-1.4031	25.2972	32.0	*Lepomis macrochirus*
5,760	3.76042	0.03835	-1.4168	26.0756	32.0	*Lepomis macrochirus*
4,320	3.63548	0.04425	-1.3541	22.5989	5.0	*Lepomis macrochirus*
5,760	3.76042	0.03717	-1.4298	26.9034	15.0	*Lepomis macrochirus*
5,760	3.76042	1.36880	0.1363	0.7306	19.0	*Lepomis macrochirus*
5,760	3.76042	0.16402	-0.7851	5.0958	20.0	*Lepomis* sp
5,760	3.76042	0.05900	-1.2291	16.9492	19.0	*Micropterus salmoides*
5,760	3.76042	0.14219	-0.8471	7.0328	20.0	*Micropterus salmoides*
160	2.20412	1.69330	0.2287	0.5906	9.9	*Morone chrysops*
160	2.20412	1.06200	0.0261	0.9416	20.4	*Morone chrysops*
160	2.20412	0.67850	-0.1685	1.4738	29.4	*Morone chrysops*
30	1.47712	1.98830	0.2985	0.5029	10.0	*Notemigonus crysoleuc*
5,760	3.76042	0.03009	-1.5216	33.2336	20.0	*Notemigonus crysoleuc*
30	1.47712	0.41890	-0.3779	2.3872	10.0	*Notropis atherinoides*
30	1.47712	0.13570	-0.8674	7.3692	25.0	*Notropis atherinoides*
30	1.47712	0.26550	-0.5759	3.7665	10.0	*Notropis atherinoides*
30	1.47712	0.16520	-0.7820	6.0533	25.0	*Notropis atherinoides*
160	2.20412	0.37170	-0.4298	2.6903	10.2	*Notropis atherinoides*
160	2.20412	0.30090	-0.5216	3.3234	19.9	*Notropis atherinoides*
160	2.20412	0.20650	-0.6851	4.8426	29.7	*Notropis atherinoides*
30	1.47712	0.77880	-0.1086	1.2840	10.0	*Notropis atherinoides*
30	1.47712	0.41890	-0.3779	2.3872	10.0	*Notropis atherinoides*
30	1.47712	0.51330	-0.2896	1.9482	10.0	*Notropis atherinoides*
30	1.47712	0.19470	-0.7106	5.1361	25.0	*Notropis atherinoides*
30	1.47712	0.13570	-0.8674	7.3692	25.0	*Notropis atherinoides*
30	1.47712	0.16520	-0.7820	6.0533	25.0	*Notropis atherinoides*
5,760	3.76042	0.02655	-1.5759	37.6648	20.0	*Notropis atherinoides*
160	2.20412	0.46020	-0.3371	2.1730	10.5	*Notropis cornutus*
160	2.20412	0.34810	-0.4583	2.8727	19.7	*Notropis cornutus*
160	2.20412	0.26550	-0.5759	3.7655	29.7	*Notropis cornutus*
5,760	3.76042	0.02360	-1.5271	42.3729	20.0	*Notropis rubellus*
160	2.20412	0.38350	-0.4162	2.6076	10.3	*Notropis spilopterus*

(continued)

APPENDIX A (continued)

Duration (min)	Log of duration	Threshold (mg/l)	Log of threshold	Inverse of threshold	Temperature (degrees C)	Species
160	2.20412	0.34810	-0.4583	2.8727	20.1	*Notropis spilopterus*
160	2.20412	0.24190	-0.6164	4.1339	29.7	*Notropis spilopterus*
5,760	3.76042	0.05605	-1.2514	17.8412	20.0	*Pimepheles promelas*
5,760	3.76042	0.07493	-1.1253	13.3458	20.0	*Pomoxis* sp
160	2.20412	0.67260	-0.1722	1.4868	10.2	*Stizostedion canadens*
160	2.20412	0.40120	-0.3966	2.4925	20.5	*Stizostedion canadens*
160	2.20412	0.41890	-0.3779	2.3872	29.4	*Stizostedion canadens*
30	1.47712	0.19470	-0.7106	5.1361	25.0	*Notropis atherinoides*

Appendix B

Table 1

Duration vs. Threshold and Temperature
(74 Observations)

	Parameter Estimate	P-Value		Adjusted R^2
Intercept	4188.95	0.0003		
Threshold	-2324.65	0.0010	0.0012	0.1198
Temperature	- 35.3470	0.4471	(F-test)	

Table 2

Duration vs. Threshold
(74 Observations)

	Parameter Estimate	P-Value	Adjusted R^2
Intercept	3412.13	0.0001	
Threshold	-2156.08	0.0012	0.1249

Appendix B

Table 3

Duration vs. (1/Threshold)
(74 Observations)

	Parameter Estimate	P-Value	Adjusted R^2
Intercept	554.96	0.0853	
Inverse Threshold	194.10	0.0001	0.5324

Table 4

Log of Duration vs. Log of Threshold
(74 Observations)

	Parameter Estimate	P-Value	Adjusted R^2
Intercept	2.04086	0.0001	
Log Threshold	-1.03721	0.0001	0.4110

Appendix B

Table 5

Log of Duration vs. Log of Threshold and 4 Indicators
(43 Observations)

	Parameter Estimate	Type I Sum of Squares	P-Value		Adjusted R^2
Intercept	1.53407	335.357	0.0002		
Log Threshold	-1.74444	18.107	0.0001		
Intercept Indicator 1	1.20570	10.607	0.0050		0.8185
Intercept Indicator 2	-0.51212	4.585	0.2469	0.0001 (F-test)	
Slope Indicator 1	1.04017	1.037	0.0167		
Slope Indicator 2	0.57581	0.228	0.2643		

Sum of Squares for Error = 6.578

Appendix B

Table 6

Log of Duration vs. Log of Threshold and 2 Indicators
(43 Observations)

	Parameter Estimate	P-Value		Adjusted R^2
Intercept	2.24162	0.0001		
Log Threshold	-0.89216	0.0001		
Intercept Indicator	0.31268	0.1402	0.0001 (F-test)	0.7947
Intercept Indicator	-1.04157	0.0001		

Table 7

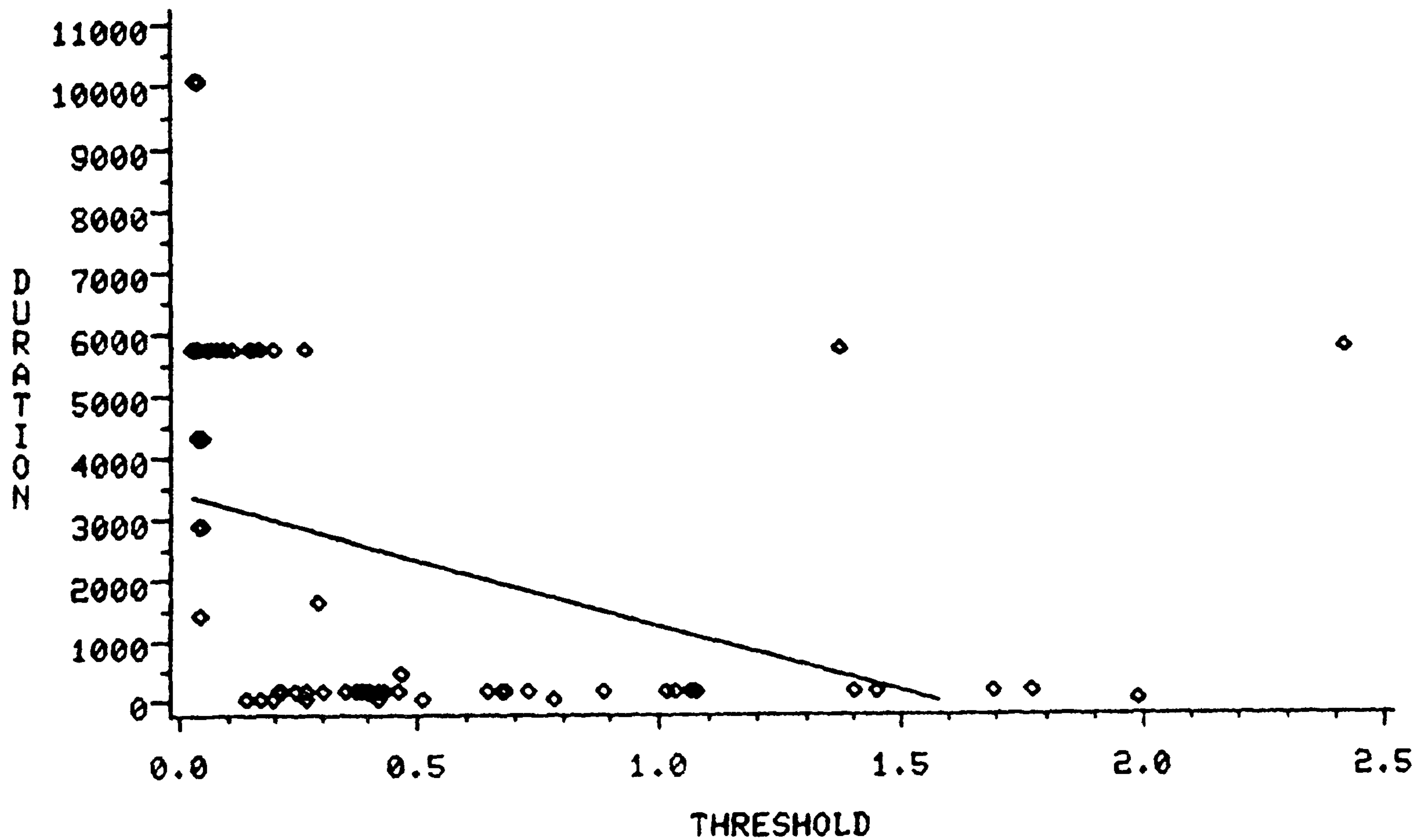
Log of Duration vs. Log of Threshold
(43 Observations)

	Parameter Estimate	P-Value	Adjusted R^2
Intercept	1.74002	0.0001	
Log Threshold	-1.24485	0.0001	0.4264

APPENDIX C

FIGURE 1

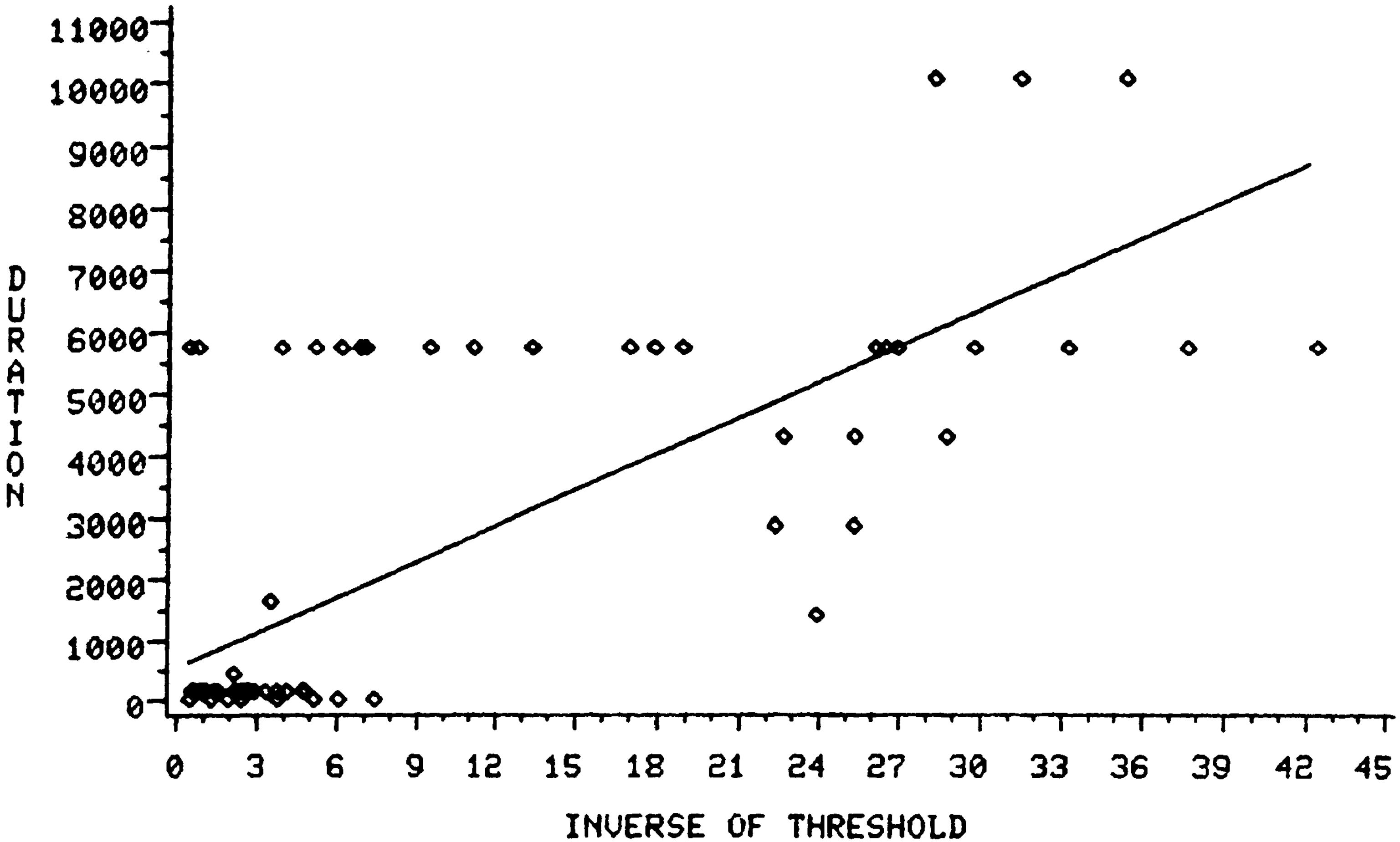
PLOT OF DURATION VS. THRESHOLD



APPENDIX C

FIGURE 2

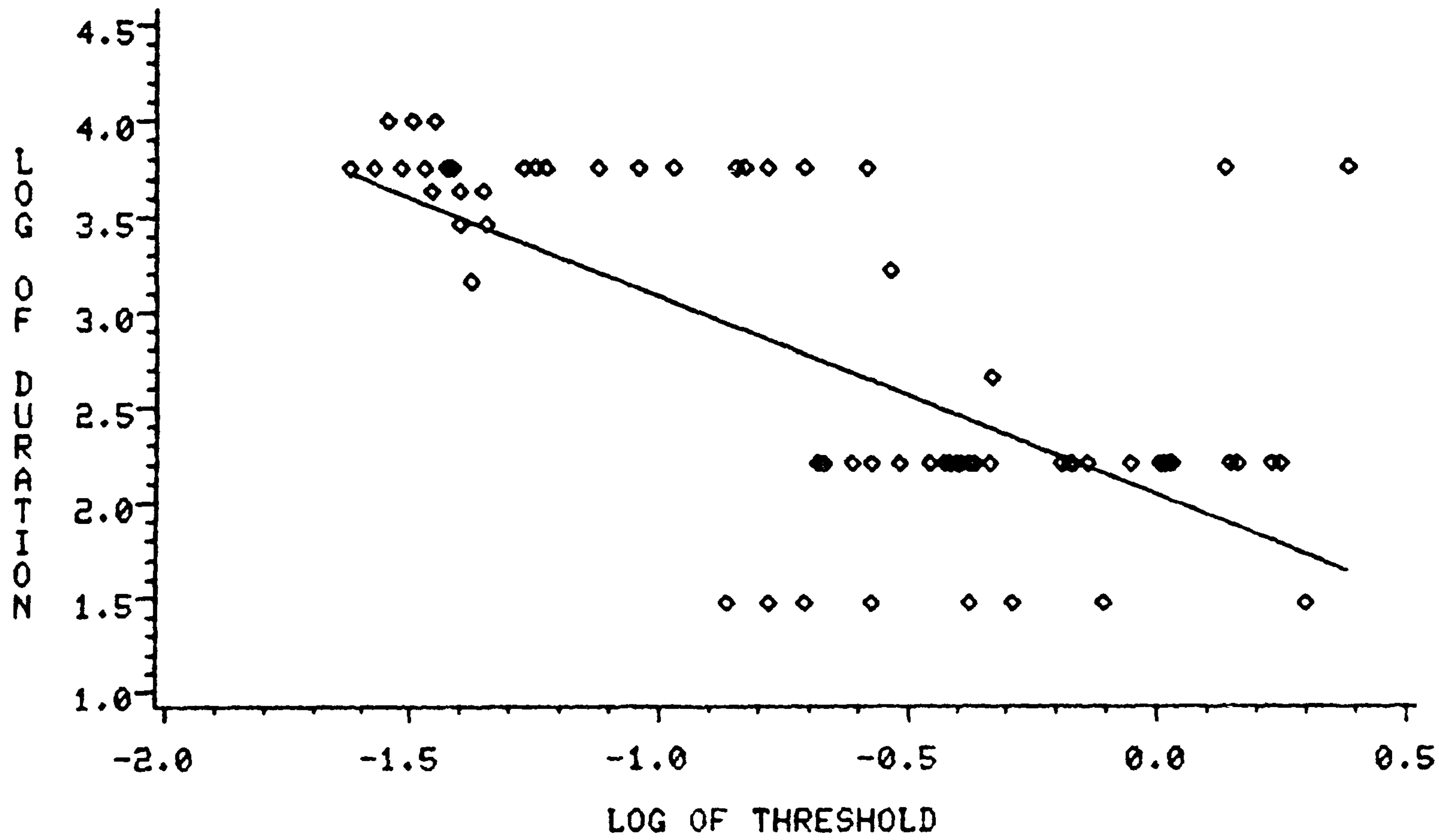
PLOT OF DURATION VS. INVERSE OF THRESHOLD



APPENDIX C

FIGURE 3

PLOT OF LOG OF DURATION VS. LOG OF THRESHOLD



Appendix D

A SUMMARY OF THE INDICATOR MODEL AND THE RELATED HYPOTHESIS TESTS

Variable Definitions:

X_1 = Log of Threshold

X_2 = 1, if *Lepomis macrochirus*
0, otherwise

X_3 = 1, if *Notropis atherinoides*
0, otherwise

$X_4 = X_1X_2$

$X_5 = X_1X_3$

Y = Log of Duration

Model:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \varepsilon$$

Hypothesis Tests:

A. H_0: $\beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$

H_a: At least two parameters unequal
p-value for F-test: 0.0001

B. H_0: $\beta_4 = \beta_5 = 0$

H_a: Either $\beta_4 \neq 0$ or $\beta_5 \neq 0$ (or both)
p-value for F-test: 0.04

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE CHLORINE EFFECTS ON AQUATIC ORGANISMS: EVALUATION OF SELECTED TOXICITY MODELS		5. REPORT DATE March 1984 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Sylvia A. Murray, Collette G. Burton, Anthony H. Rhodes, and Robert W. Aldred		8. PERFORMING ORGANIZATION REPORT NO
9. PERFORMING ORGANIZATION NAME AND ADDRESS Tennessee Valley Authority Office of Natural Resources Division of Air and Water Resources Muscle Shoals, Alabama 35660		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. IAG-82-D-X0511
12. SPONSORING AGENCY NAME AND ADDRESS Office of Environmental Processes and Effects Research Office of Research and Development Office of Environmental Process and Effects Research Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/16
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Three toxicity models were examined and modified with respect to organisms associated with chlorinating power plants of the Tennessee Valley Authority, viz those of Mattice-Zittel, Turner-Thayer, and Chen-Selleck. Results of the first two were prediction lines based on concentration and exposure duration of chlorine, whereas results of the latter were threshold concentrations for individual species. Because of differences in model formulations and objectives, it was only possible to generalize about the potential biological safety of the receiving waters.

The Mattice-Zittel model indicated potential biologically unsafe conditions with respect to chlorine for invertebrates at most of the power plants examined, whereas the Turner-Thayer indicated biological safety for invertebrates at all but one of the power plants examined. Results were similar for both models for fish safety at the power plants. The models predicted that invertebrates were more sensitive to chlorine than vertebrates, the most sensitive invertebrate species being Isonychia sp. and Gammarus sp.

The Turner-Thayer model seems to be the most credible and acceptable approach because of statistical robustness and the use of mean residuals to indicate chlorine sensitivity in the regression equation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Models Chlorine Toxicity Power Plants	Environmental Impact of Conventional and Advanced Energy Systems	6F

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 142
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)