BASIS AND BACKGROUND DOCUMENT
NEW JERSEY-SPECIFIC UNIONIZED AMMONIA CRITERIA

STATE OF NEW JERSEY
DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF WATERSHED MANAGEMENT
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DETERMINING NEW JERSEY-SPECIFIC AMMONIA CRITERIA

I. INTRODUCTION

The New Jersey Department of Environmental Protection (Department) is contemplating a proposed amendment to delete the criteria for ammonia at N.J.A.C. 7:9B-1.14(c)14.vi. and add New Jersey-specific ammonia criteria for all the different classifications of surface water, where applicable.

New Jersey's currently promulgated surface water quality criteria for ammonia are based on the United States Environmental Protection Agency's (USEPA's) water quality criteria (USEPA, 1976). USEPA determined that ambient criteria for unionized ammonia (UIA) should be one-tenth the value of the LC_{50} for representative sensitive species. For New Jersey trout production (FW2-TP) and trout maintenance (FW2-TM) waters, a criterion of 0.02 mg/L was selected, based on a single LC_{50} value (0.2 mg/L) for Rainbow trout fry (*Oncorhynchus mykiss*) (Liebmann, 1960). For New Jersey nontrout waters (FW2-NT), a criterion of 0.05 mg/L was adopted. At the time, no criterion for saltwater organisms was developed by USEPA, due to insufficient information. However, the Department adopted a saltwater criterion of "0.1 of acute definitive LC_{50} or EC_{50}" to be protective of representative sensitive species.

Since promulgation of New Jersey's UIA criteria in 1981, the USEPA has updated and published 304(a) ammonia criteria documents for freshwater (USEPA, 1985 & 1999) and saltwater (USEPA, 1989). These USEPA criteria for UIA are based on a review of scientific studies up to 1984, whereas the previous criterion only used information published prior to 1975, and provide two types of calculated criteria based on methods presented by Stephan *et al*. (1985); a one-hour average concentration, based on results of acute toxicity analysis; and a four-day average concentration, based on long term chronic toxicity studies. Recently the USEPA has released a revised freshwater criteria based on a total ammonia approach (USEPA, 1999). The current USEPA criteria for total ammonia differs considerably from previous criteria by USEPA that are based on UIA.

Review of the current USEPA 304(a) ammonia criteria for freshwater and saltwater reveals that they are too general and are not representative of the various species assemblages found in the different waters of New Jersey (i.e., trout, nontrout, Pinelands, estuarine, and coastal waters). Since these different classifications contain biotic communities with assemblages of species that have different tolerances to ammonia, criteria for each surface water classification were needed to adequately protect the respective species and most sensitive life stages. In addition, the USEPA 304(a) ammonia criteria do not consider the presence or absence of sensitive early life stages during cold seasons.

During the previous reviews of New Jersey's Surface Water Quality Standards (SWQS) (N.J.A.C. 7:9B), several comments were submitted questioning the appropriateness of continuing to use USEPA's 1976 ambient water quality criterion for ammonia. Comments received stated that the 1976 USEPA criterion is not based on current scientific knowledge or methodology. Additionally, the comments received stated that criterion is too stringent and is inappropriate for blanket use in New Jersey because of the potential for large differences in toxicity among taxa indigenous to New Jersey and the taxa upon which the USEPA 1976 criterion is based. Finally, comments questioned any possible use of USEPA's 304(a) freshwater (USEPA, 1985 & 1999) or saltwater criteria (USEPA, 1989) for New Jersey waters.

To overcome the inappropriateness of New Jersey's existing ammonia criteria and the criteria presented in USEPA's 304(a) documents, the Department hired a consultant, Versar Inc. of Columbia, Maryland, to review New Jersey's currently promulgated criteria and to calculate recommended ambient water quality criteria for each of New Jersey's surface water classifications into which NJPDES discharges are allowed. These New Jersey surface water classifications, as listed in N.J.A.C. 7:9B-1.15(c)-(g), include:

FW2-TP -	freshwaters suitable for trout propagation;
FW2-TM -	freshwaters suitable for trout maintenance;
FW2-NT -	freshwaters suitable for maintenance, migration, and propagation of nontrout species;
PL -	Pineland waters;
SE1 & SE2 -	saline estuarine waters suitable for maintenance, migration, and propagation of the natural and established biota;
SE3 -	saline estuarine waters suitable for maintenance, and migration of fish populations; and
SC -	saline coastal waters suitable for maintenance, migration, and propagation of the natural and established biota.

The following steps were used to develop the New Jersey water classification-specific ammonia criteria:

1) List of aquatic organisms found in each of New Jersey's surface water classifications were assembled.
2) Literature search for studies addressing either acute or chronic ammonia toxicity were performed. Toxicity literature was technically reviewed to determine whether each of the studies is of sufficient technical quality and contains the correct type of information for use in establishing ammonia criteria.
3) Literature information was used to identify environmental and biological factors that are likely to affect ammonia toxicity.
4) Taxa lists for each water classification were merged with available toxicity information to determine whether each classification has adequate species-specific information from which to develop criteria. For water classifications for which toxicity data are unavailable for indigenous biota, species having similar physiological, toxicological, or ecological properties were selected.
5) Methods to be used to calculate ambient ammonia criteria were determined.

6) Three-hour and thirty-day average concentrations for each of New Jersey's surface water classifications were computed.

II. SELECTION OF SPECIES

The first step in development of criteria for New Jersey waters was identification of species of fish, invertebrates, algae, and macrophytes inhabiting each surface water classification in New Jersey. Versar identified and assigned species to one or more surface water classifications based on data from numerous references. Compiled lists contain considerable overlap of species due to similarities in water quality characteristics between classifications. In several instances, identical lists were compiled for similar water classifications (e.g., SE1, SE2 and SE3 classifications). These species lists were then used to identify ammonia toxicity data (species and life stage specific) appropriate for calculating classification-specific ambient ammonia criteria.

III. LITERATURE SELECTION

A. **LITERATURE SEARCH AND SELECTION**

A literature review pertaining to aquatic ammonia toxicity was conducted using a combination of manual and electronic database searches. The electronic search was primarily conducted using the Dialog Information Retrieval System (DIALOG). The USEPA AQUatic toxicity Information REtrieval (AQUIRE), an aquatic toxicity database, was also accessed through Computer Information Services (CIS) as part of the electronic search. Literature not identified by searches of these databases was obtained by manually searching literature cited in "Ambient Water Quality Criteria for Ammonia" (USEPA, 1985), "Ambient Water Quality Criteria for Ammonia (Saltwater)" (USEPA, 1989), and numerous other ammonia toxicity reviews. Unpublished reports and current or ongoing research were obtained by contacting cited scientists and organizations.

Due to the comprehensive nature of the search, literature dealing with both ammonia toxicity to aquatic life and other types of ammonia toxicity were identified. The titles obtained from each DIALOG database search were inspected manually to identify appropriate literature. Literature dropped covered subject areas unrelated to aquatic ammonia toxicity, such as human health effects, air pollution, acid rain, and terrestrial ecology and comprised approximately 75% of all titles. Once appropriate titles were identified, complete citations, including abstracts, were obtained from the DIALOG system.

The remaining literature was sorted by the taxon investigated in each study. These studies with genera occurring in New Jersey waters were selected for further examination. Additionally, studies conducted using congeneric species found in New Jersey were retained, unless data for a New Jersey resident member of the genus were available. For example, studies using Pacific Coast salmon (Oncorhynchus sp.) were eliminated due to availability of toxicity information for Rainbow trout (Oncorhynchus mykiss), a species found naturally reproducing in New Jersey. Also, a number of studies were published in foreign languages (e.g., Chinese and Japanese). Translation of these studies was beyond the scope of this project; therefore, these citations were eliminated.

The abstracts for the selected studies were scrutinized to determine whether the literature contained usable ammonia toxicity information. The abstracts were evaluated by visually scanning for indications of toxicological effects. Referenced literature in the USEPA documents was surveyed by determining whether information was presented and/or cited in the tables contained in either document. Literature identified by these steps was obtained from Versar's in house library, through Online Computer Library Center (a nationwide interlibrary network), and Maryland Interlibrary Organization, an interlibrary loan service provided by Pratt Library, Baltimore, Maryland.

B. **TECHNICAL REVIEW**

All of the selected studies for which reports could be obtained were further evaluated to determine adequacy of the methods and toxicological information contained in the studies. The literature was reviewed to evaluate the adequacy of the investigators' testing procedures, analytical methods, water quality data, ammonia calculation procedures, LC_{50} and EC_{50} calculation methods, and reporting of results.

Generally, studies conducted prior to 1960 were eliminated due to uncertainties in analytical techniques for pH and ammonia. Studies published before 1960 may have used unacceptable, unpublished methods inconsistent with presently accepted methods and may therefore contain suspect data or results.

Adequacy of testing procedures contained in the literature was determined by adherence of the investigators' procedures with those documented in "Standard Methods for the Examination of Water and Wastewater" (APHA, 1985) and guidelines issued by the American Society for Testing and Materials (ASTM, 1988). Generally, bioassay methods considered acceptable included flow-through, static, or static renewal tests. Analytical ammonia methods considered acceptable were ammonia-selective electrode method, nesslerization method, or phenate method, as presented in "Standard Methods for the Examination of Water and Wastewater" (APHA, 1985). Other methods were considered to be unacceptable due to unknown precision, accuracy, or interferences. A number of studies did not measure total ammonia but estimated ammonia based on known addition of ammonia salts to the test chamber. Such studies were used for criteria recommendations only if no other toxicity information for a species was available.

Methods for calculating UIA from total ammonia concentrations were evaluated either by determining adequacy of the method presented or the referenced method. The calculations were verified or corrected using equations and tables presented in Emerson et al. (1975) for freshwater, and Bower and Bidwell (1978) for saltwater.

Methods used in the toxicity studies for calculating LC_{50}s were evaluated by comparison to methods presented in a review by Stephan (1977).

Records were evaluated to determine the adequacy of water quality data presented in the studies. The water quality parameters reviewed included pH, temperature, and salinity/conductivity. Temperature and pH have been found to affect ammonia toxicity significantly and are the two most important factors in calculating UIA. The remaining parameters, salinity and conductivity, are less important for calculating UIA but were necessary for assigning the ammonia toxicity data to the proper surface water classification.

IV. EVALUATION OF FACTORS AFFECTING AMMONIA TOXICITY

In the establishment of water quality criteria, determination of the key factors that influence toxicity is essential. For certain chemicals, relationships between water quality parameters and toxicity are well supported and have been used for criteria calculation. For example, ambient water quality criteria for many metals (USEPA, 1986) are expressed as equations which relate the criteria to the water hardness. Examination of water quality parameters is particularly important for ammonia since previous investigations have found temperature and pH to influence ammonia toxicity. The USEPA has previously developed ambient ammonia criteria for freshwater that are pH and temperature dependent (USEPA, 1985).

A. **OVERVIEW**

In water, ammonia exists as both UIA (NH_3) and the ammonium ion (NH_4^+). Since UIA can diffuse across the gill membrane much more readily than NH_4^+, the early literature (reviewed by Thurston et al., 1981a) assumed that ammonia toxicity was entirely or nearly entirely attributable to UIA. Toxicity data were reported in terms of UIA, and pH dependence on toxicity was thought to result from the pH dependent equilibrium between the ionized and un-ionized forms.

Recent studies have indicated that more complex relationships exist between various water quality parameters and ammonia toxicity. Research reported by Thurston et al. (1981a) indicated that the toxicity of UIA to Rainbow trout and Fathead minnow increased with decreasing pH. On the basis of research and review of several previous studies, these authors theorized that ammonia toxicity is either potentiated by the increased hydrogen ion content of the water, or that NH_4^+ exerts some toxicity. In another study with Rainbow trout, Thurston et al. (1981b) reported that UIA toxicity increased with lowered dissolved oxygen (DO) content. Other water quality parameters that have been investigated as moderating factors for ammonia toxicity include temperature, carbon dioxide (CO_2) concentration, hardness, and salinity (reviewed by Haywood, 1983; USEPA 1985 and 1989).

USEPA (1985 and 1989) examined these relationships in the formulation of national ambient water quality criteria for ammonia. For fresh waters, USEPA (1985) concluded that within certain ranges the effects of pH and temperature on UIA toxicity were consistent and strongly documented. Mathematical relationships for these factors used in the criteria are listed in Table 1. These equations are slight modifications of models developed by Erickson (1985). In this proposal, the USEPA criteria models are referred to as the Erickson/USEPA models since analysis of the models requires reference to both Erickson (1985) and USEPA (1985) publications. For salt waters, USEPA (1989) concluded that data were inadequate to establish water quality dependent ammonia criteria.

The recently released criteria developed by USEPA (1999) are based on total ammonia and not UIA. This document uses a new approach that has not been widely reviewed or evaluated. Historically, it has been widely accepted by researchers and USEPA that aquatic life toxicity to ammonia is predominantly due to UIA (NH_3), which along with ammonium (NH_4^+) make-up total ammonia. The USEPA (1999) criteria document recognizes the relationship between UIA toxicity and temperature, but was unable to identify any relationship for total ammonia, may be the result of incorporation of additional variability and/or minimizing the relationship by converting reported UIA values in the literature to total ammonia. The total ammonia criteria approach would likely result in more stringent (i.e., lower) total ammonia levels at low temperatures than the approach by the Department using UIA (see Appendix A tables for UIA criteria and total ammonia concentrations). Finally, the USEPA (1999) approach does not consider the effects of ionic strength (i.e., conductivity, dissolved solids and/or salinity) which could result in more stringent criteria for some waterbodies. Ionic strength has been found to effect total ammonia calculated from UIA by as much as 20 percent (see Appendix A tables for total ammonia concentrations and various ionic strengths). As a result, the approach of using total ammonia as the criteria in place of UIA criteria was not considered appropriate, but may be considered in the future depending on reviews, evaluations and future investigations and changes.

In this section, the relationships between the various water quality parameters and UIA toxicity are examined using the literature selected for New Jersey criteria development. Since toxicity-water quality relationships are rarely examined in chronic studies, the bulk of the analysis was based on acute toxicity data.

A set of ground rules was established for determining the significance of results and the acceptability of studies. Whenever possible, statistical tests and regressions were used to indicate the significance of relationships. When single acute toxicity values were compared, differences were considered to be important and not attributable to inherent variability if the acute toxicity (i.e., LC_{50}) ratio was equal to or greater than 1.5. Selection of this value was based on a review by Sprague (1985) and an independent analysis of toxicity data conducted for this proposal. Sprague (1985) cited data from several series of replicate tests performed with eight compounds over a period of months in the same laboratories with the same dilution water in which the highest and lowest LC_{50} values differed by factors of 1.3-5.5. The selected ammonia literature was analyzed in a similar manner. Replicated UIA toxicity tests were found to have mean highest:lowest LC_{50} ratios of 1.36 for fresh water and 1.38 for saltwater (see section M). Therefore, the value of 1.5 was chosen as a reasonable threshold to exclude differences that are likely to result from inherent or unexplained variability.

A series of tests were judged to be acceptable for this analysis if one factor varied and the other parameters were more or less constant. Constancy was defined as follows:

- o average temperatures ± 3°C;
- o salinities ± 3 ppt;
- o pH values ± 0.4 standard units;
- o DO concentrations ± 0.4 mg/L; and
- o weight or length ratios no greater than 1.5:1.

For tests that reported ranges rather than averages, conditions were considered to be similar if at least one third of each range overlapped.

B. **TEMPERATURE**

Freshwater Data

The effects of temperature on UIA toxicity were examined in ten studies (Table 2). Nine of the ten studies were obtained and reviewed while data from the tenth study (Cary, 1976) was analyzed as reproduced in Erickson (1985) and USEPA (1985). The majority of the studies examined evaluated the effects of temperature on acute UIA toxicity; except the DeGreave et al. (1987) study which also examined chronic UIA toxicity for a single species.

The USEPA (1985) modified the mathematical model formulated by Erickson (1985) as the basis for temperature-dependent freshwater criteria. Since the publication of the USEPA (1985) criteria document, only the DeGraeve et al. (1987) study has analyzed temperature-UIA relationships. The study reported by Arthur et al. (1987) is discussed in the USEPA (1985) criteria document, as is West (1985). This section reviews the data from the original literature as well as the Erickson/USEPA model.

The ten studies cover a total of 15 species (8 fishes and 7 invertebrates). Two studies (Thurston et al., 1983 - 35 tests with the Fathead minnow; Thurston and Russo, 1983 - 18 tests with the Rainbow trout) reported significant linear regressions for log LC_{50} vs. temperature, with increased toxicity at lower temperatures. Significant linear regressions also appear to be present in the DeGraeve et al. (1987) studies for Channel catfish and Fathead minnow acute data and in the Cary (1976) Channel catfish acute data (based on the graph in Erickson 1985). For two of the remaining five fish species (Bluegill and White sucker), UIA was at least twice as toxic at the lowest vs. the highest tested temperature. For the Walleye, LC_{50} values were similar at 3.7° and 19.0°C. For the Threespine stickleback and the Striped bass, LC_{50} values were similar at 15° and 23°C. No relationship was observed by DeGreave et al. (1987) in 30-day test with Channel catfish.

The Erickson/USEPA model (Table 1) was primarily based on studies with Rainbow trout (Thurston and Russo, 1983), Fathead minnow (Thurston et al., 1983), and Channel catfish (Cary, 1976). It should be noted that the Cary (1976) research evaluated the toxicity of an effluent containing ammonia as the principal toxic component (USEPA 1985). Erickson (1985) also cited studies on Channel catfish (Colt and Tchobanoglous, 1976; Roseboom and Richey, 1977), Rainbow trout (Ministry of Technology, U.K., 1968); Fathead minnow (Reinbold and Pescitelli, 1982), and Bluegill (Reinbold and Pescitelli, 1982) as showing similar trends. Thus, this model is based on data for three taxonomically diverse fish species, with data for Bluegill also showing a similar trend.

Arthur et al. (1987) tested a total of five fish and seven invertebrate species. The investigators performed a small number of tests with each species (maximum of 6). For six of the seven invertebrate species, toxicity was either similar throughout the tested temperature ranges or showed no clear trend. For the crayfish, toxicity at 17.1°C was 1.6 times that at 4.6°C. In studies with fish, the data indicate a log-linear decrease in toxicity with increasing temperature in Rainbow trout, Channel catfish, and White sucker (Arthur et al., 1987). However, in contrast to Thurston et al. (1983), they did not observe a similar relationship with the Fathead minnow. They also observed no temperature-toxicity relationship for the Walleye. The Arthur et al. (1987) study tested organisms at different seasons of the year. Thus, the apparent deviation from the trends observed in other studies may be confounded by seasonal changes other than temperature.

In conclusion, there is still strong support for the Erickson temperature-LC_{50} model in the three fish species studied most intensively (Rainbow trout, Fathead minnow, and Channel catfish). Some support for the model is provided by the Bluegill and White sucker data. Restricting the database used to build the model to New Jersey species does not eliminate any key supporting studies. The three species that do not fit the model (Walleye, Striped bass, and Threespine stickleback) have received minimal testing (a total of 7 LC_{50} values between the three species). Although intensive tests have not been performed, Arthur et al. (1987) data suggest that the model may not apply to many invertebrates.

In section N, a statistical analysis was conducted to develop a temperature-LC_{50} model. The database for model development, restricted to New Jersey species, included the studies used by Erickson (1985), more recent studies, and other available data on the key species used by Erickson in formulating his model. The model forms the basis for the use of a temperature-toxicity relationship for criteria recommendations.

Saltwater Data

The effects of temperature on UIA toxicity were examined in three studies with six species of saltwater fish. No tests of temperature effects on UIA toxicity in invertebrates were found. In four fish species, there was greater toxicity at lower temperatures, while in two species toxicity was greater at the higher test temperature. A statistically significant regression was reported by Miller et al. (1990) for the Sheepshead minnow but not for the Inland silverside. Similarly, Goodfellow et al. (1989) reported a strong temperature dependence of UIA toxicity with the Atlantic silverside (with toxicity at 10.8°C about 5 times that at 24.8°C) and little temperature dependence for the Sheepshead minnow. Conversely, Hazel et al. (1971) found that, for the Threespine stickleback, there was 2-4 fold greater toxicity at 23°C than at 15°C. For the Striped bass, these authors found little difference in toxicity at 15°C vs. 23°C.

Analysis of these data indicates that relationships between temperature and UIA toxicity in saltwater are highly variable and species dependent. The database is quite sparse with no more than four values generated per species in a single study. The interspecies variability, coupled with the lack of invertebrate data, provide little support for the use of a temperature-UIA relationship in the development of saltwater criteria at this time.

C. **pH**

Freshwater Data

The effects of pH on acute UIA toxicity were examined in eleven studies (Table 3). Only one study (Broderius et al. 1985) examined the effects of pH on chronic UIA toxicity. One of the eleven studies (Tabata, 1962), written in Japanese, was accessible from summary data provided by USEPA (1985) and Erickson (1985). The USEPA (1985) modified the mathematical model formulated by Erickson (1985) as the basis for pH dependent freshwater criteria. Since the publication of the USEPA (1985) criteria, three new studies have been reported and evaluated for this project. Sheehan and Lewis (1986) examined pH-toxicity relationships in Channel catfish; Dabrowska and Sikora (1986) studied these effects in Common carp; and Schubauer-Berigan et al. (1995) studied the effects in two macroinvertebrate species, a midge and oligochaete. In this section, the original literature is reviewed and the Erickson/USEPA model discussed.

The studies listed in Table 3 provide data on pH-UIA toxicity relations for seven species of fish and three invertebrate species. In six of the seven fish species and in the three invertebrate species, there is evidence of a pH-UIA toxicity relationship. The Thurston et al. (1981a) study with Fathead minnows and Rainbow trout found that UIA was 5-7 times more acutely toxic at pH 6.5 vs. pH 9.0. Both data sets show slight increases in acute toxicity above pH 8.50. Greater than five fold increases in acute toxicity at the lowest vs. highest pH were reported for Daphnia magna and Daphnia sp. (Tabata, 1962; Russo et al., 1985;). Fish species including Smallmouth bass (Broderius et al., 1985), Channel catfish (Sheehan and Lewis, 1986), Green sunfish (McCormick et al., 1984), and Bluegill (Emery and Welch, 1969) had acute toxicity increases over the pH ranges tested between two and four times. A 1.7 fold increase in acute toxicity in Rainbow trout was reported by Lloyd and Herbert (1960) at pH 7.0 vs. pH 8.2. Schubauer-Berigan et al. (1995) reported a 2.6 and 19 fold increase in 10-day LC_{50}s for Lumbriculus variegatus and Chironomus tentans over a pH range of 6.5 to 8.6. In the only test of pH-UIA effects on chronic toxicity (32 day growth test starting with Smallmouth bass embryos), Broderius et al. (1985) reported that toxicity was 14 times greater at pH 6.60 vs. pH 8.68.

A few studies did not find large differences in UIA toxicity at a range of pH values. Simco and Davis (1978) and Tomasso et al. (1980) both reported less than a 30% change in toxicity in Channel catfish tested at pH 7, 8, and 9. Dabrowksa and Sikora (1986) reported little change in UIA toxicity in Common carp tested at pH 7.8 and 9.1.

Erickson (1985) based his pH-LC_{50} model (Table 1) on three studies (Tabata, 1962-Daphnia sp.; Robinson-Wilson and Seim, 1975-Coho salmon; and Thurston et al., 1981a-Fathead minnow and Rainbow trout). He stated that the Green sunfish data of McCormick et al. (1984) and the Saltwater prawn (Macrobrachium rosenbergii-not a New Jersey genus) data of Armstrong et al. (1978) also strongly support the model. If, for the purposes of New Jersey criteria formulation, the Armstrong et al. (1978) saltwater study and the Robinson-Wilson and Seim (1975) Coho salmon (non-NJ species) data are not considered in the analysis, the model is still well supported.

Two of the three studies reported since the USEPA (1985) 304(a) criteria document was published support the model. Sheehan and Lewis (1986), found that UIA acute toxicity in Channel catfish was 2.6-2.8 times greater at pH 6.0 vs. 8.8. Two benthic macroinvertebrates, Lumbriculus variegatus and Chironomus tentans, studied by Schubauer-Berigan et al. (1995) were 2.6 and 19 fold more sensitive to UIA at a pH of 6.5 than 8.6. The Common carp study by Dabrowska and Sikora (1986) found little difference in toxicity, but only tested effects at pH 7.8 and pH 9.1.

In section N, a statistical analysis was conducted in order to develop a pH-LC_{50} model. A pH-chronic toxicity model was not evaluated due to the inadequacy of the database on which to base the model (three tests on one species in a study by Broderius et al. 1985). The database for pH-LC_{50} model development included the studies used by Erickson (1985), more recent studies, and other available data on the key species used by Erickson in formulating his model. The database was restricted to New Jersey species. The model forms the basis for the use of a pH-toxicity relationship for criteria recommendations.

In conclusion, the pH-UIA relationship formulated by Erickson (1985) and used in the USEPA (1985) criteria document appears to be well founded. Restricting the analysis to freshwater species found in New Jersey waters only removes a small portion of the supporting data.

Saltwater Data

The effects of pH on UIA toxicity were examined in three studies that evaluated a total of three fish and one invertebrate species. Greatly different patterns in the pH-UIA relationship were evident in the three tested fish species. In LC_{50} tests with White perch, Stevenson (1977) reported that UIA was about 11 times as acutely toxic at pH 6 than at pH 8. In the Inland silverside, Miller et al. (1990) reported a statistically significant increase in acute toxicity at pH 7 and 9 vs. pH 8. The toxicity at pH 7 was 1.8 times that at pH 8; the toxicity at pH 9 was 2.3 times that at pH 8. In the Atlantic silverside, there was no clear trend in acute toxicity at pHs ranging from 7.03 to 8.50. The toxicity at pH 7.03 was about 1.5 times that at pH 8.5 (Goodfellow et al., 1989).

In contrast to the fish data, two studies with a mysid shrimp (Mysidopsis bahia-a congener of the New Jersey species M. bigelowi) indicated a strong pH-UIA toxicity relationship (Goodfellow et al., 1989; Miller et al. 1990). Acute toxicity at pH 7.0 was about 6 times that at pH 9.0.

The acute database for saltwater species is limited and available data do not provide evidence of a consistent relationship between pH and acute toxicity. Although the mysid seems to show a strong relation, the data for fish species tested are highly variable. At this time, the rather sparse and inconsistent database does not support the use of a pH-toxicity relationship for saltwater criteria.

D. **DISSOLVED OXYGEN**

Freshwater Data

The effects of DO concentration on UIA toxicity were examined in three studies with New Jersey species (Fathead minnow and Rainbow trout). Several other studies are briefly discussed in the USEPA (1985) criteria document but do not meet the criteria for literature evaluation.

Thurston et al. (1981b) and Thurston and Russo (1983) examined the relationship between DO concentration and UIA toxicity in Rainbow trout. In 15 LC_{50} tests over a DO range of 2.6-8.6 mg/L, Thurston et al. (1981b) reported a statistically significant DO-UIA toxicity relationship with toxicity about twice as great at 2.6 vs. 8.6 mg/L. In 86 tests, at DO levels of 6.1-9.4 mg/L, Thurston and Russo (1983) found no significant relationship. Thurston and Russo (1983) attributed the contrasting results to the testing of fish of different strains as well as the narrow range of DO concentration tested in the later study.

In the Fathead minnow, Thurston et al. (1983) found no significant relationship between DO concentration (range: 2.6-8.9 mg/L) and UIA toxicity. Ten tests were specifically designed to test this relationship. The entire data set of 35 studies was examined and no significant relationship was found.

No consistent relationship between DO and UIA toxicity is evident from these data as the database is quite small. At the present time, the use of a DO-UIA relationship for freshwater criteria is not supported.

Saltwater Data

No studies testing the effects of DO concentration on UIA toxicity in saline waters were found in the selected literature.

E. **HARDNESS**

Only two studies were found which tested the effects of water hardness on UIA toxicity (Simco and Davis, 1978; Tomasso et al., 1980). Both studies reported that in Channel catfish there was slightly greater toxicity at lower hardness values (40 mg/L $CaCO_3$ vs. 200 or 440 mg/L $CaCO_3$). However, in both studies toxicity was only 1.3 times greater at the lower hardness; this difference is less than differences frequently reported under the same water quality conditions (review by Sprague 1985) and in replicate UIA toxicity tests.

There is little evidence of a relationship between hardness and UIA toxicity. Data are only available for a single fish species. Therefore, hardness dependent criteria are not well supported at the present time.

F. **CARBON DIOXIDE CONCENTRATION**

Several researchers have theorized that the CO_2 concentration in the water plays an important role in ammonia toxicity (reviewed by Szumski et al. 1982; Haywood 1983; USEPA 1985). According to the theory originally presented by Lloyd and Herbert (1960), ammonia toxicity is related to pH and CO_2 levels at the gill surface, rather than levels in the bulk water. Szumski et al. (1982) converted LC_{50} values from a number of studies to computed LC_{50} values for UIA at the gill surface using an equation that includes temperature, pH, alkalinity, and factors related to fish respiratory physiology.

According to USEPA (1985), there is little experimental evidence to support this model. USEPA (1985) raised serious questions about the model's interpretation of respiratory physiology. Whatever evidence there is to support the model is based solely on fish species. Finally, few studies have measured either CO_2 concentration or alkalinity of the test solutions, which are key model parameters. Therefore, criteria based on CO_2 levels or the proposed gill surface model are not well supported.

G. **SALINITY**

The effects of salinity on UIA toxicity were examined in three studies that included three fish and two invertebrate species. For criteria development, only data at salinities greater than 0.5 ppt were reviewed.

Of the three fish species, only Striped bass showed a consistent pattern (Hazel et al., 1971) in which there was slightly less toxicity at 11-12 ppt vs. 35 ppt. In the other species tested, the direction of the response varied with changes in temperature and pH (Hazel et al., 1971; Miller et al., 1990). In one invertebrate species (Mysidopsis bahia), toxicity was consistently greater at 11 ppt vs. 35 ppt (Miller et al., 1990). However, in the rotifer, Brachionus plicatilis, there was slightly less toxicity at 15 ppt than at 30 ppt (Snell and Persoone, 1989).

No consistent relationship between salinity and UIA toxicity is evident from these data. This lack of a significant relationship may be due to UIA being a free ion; free ion toxicity may be independent of salinity and hardness (Freedman et al. 1980). The existing data do not support the use of a salinity-UIA relationship in the development of saltwater criteria at this time.

H. **LIFE STAGE**

Since criteria are intended to protect 95% of all species through all life stages, the identification of especially sensitive life stages is important. For example, USEPA (1985) lowered the final acute freshwater value for ammonia to protect sensitive life stages of Rainbow trout. It was important to analyze the database to determine the relative sensitivities of different sizes and life stages of test species and determine if it was possible to establish mathematical functions relating life stage or size to UIA toxicity.

Freshwater Data

The effects of the size and life stage of the test organism on UIA toxicity were investigated in seven studies. Data were only collected for four fish species, Rainbow trout, Bluegill, Fathead minnow, and Common carp.

The most intensive studies were performed with Fathead minnows (35 tests) (Thurston et al., 1983) and with Rainbow trout (34 tests) (Thurston and Russo, 1983). Fathead minnows exhibited similar sensitivity across a weight range of 0.09-2.3 g. For 0.06-42 g Rainbow trout, Thurston and Russo (1983) reported a statistically significant quadratic relation between age and UIA toxicity, with sensitivity decreasing with age through the juvenile stage and increasing thereafter. These findings contrast with Rainbow trout LC_{50} data of Calamari et al. (1981) who reported that in 8 tests sensitivity increased with the age of the fry. Fifty-one day old fry were about 2-3 times as sensitive as eggs, hatching larvae, 1-day larvae, 5-day larvae, or fingerlings. The remaining four studies on Bluegill, Carp, Fathead minnow and Rainbow trout represent a total of nine LC_{50} values and show highly variable results. Several of the studies report data over a narrow size range; differences in these tests are more likely due to the inherent variability among LC_{50} data (e.g., Sprague, 1985).

The database does not indicate a consistent trend in toxicity with age or life stage. At the present time, it is not possible to establish a correction factor for the life stage or size of freshwater test organisms where data are only available for a single life stage.

Saltwater Data

The effects of the size and life stage of the test organism on UIA toxicity have been investigated in seven studies. Data were collected for four fish species, Red drum, Striped bass, Striped mullet, and Spotted seatrout, and four invertebrate species, Blue crab, Tiger prawn (Penaeus monodon-a congeneric of a New Jersey species), Hard clam, and American oyster. None of the studies performed more than five tests.

Several studies tested the effects on early life stages of fish. In general, eggs were much less sensitive than larvae or juveniles. In Spotted seatrout and Red drum, sensitivity of larvae decreased as age of the larvae increased (Holt and Arnold, 1983; Daniels et al., 1987). However, in Striped bass, nine-ten day old larvae were about twice as sensitive as one-two day old larvae (Poucher, 1986).

With respect to invertebrates, one study compared effects in various larval stages of Tiger prawn (Chin and Chen, 1987). Larval sensitivity decreased with increased age. The other studies examined older life stages. Epifanio and Srna (1975) reported that adult Hard clams were slightly more sensitive than juveniles, whereas juvenile American oysters were about twice as sensitive as adults. Lakshmi et al. (1984) found that premolt female Blue crab were about 1.5 times more sensitive than intermolt males.

The database comparing the sensitivity of different life stages of saltwater organisms to ammonia is sparse. No consistent relationship is apparent. Thus, it is not possible, at the present time, to establish a correction factor for the life stage or size of saltwater test organisms where data are only available for a single life stage.

I. **STRAIN AND SOURCE OF ORGANISMS**

The effects of using different strains of test organisms or different batches of the same strain of organism have not been well characterized. Most investigators tend to use single strains and single batches of fish to reduce variability in response. In the only study found that discussed this issue, Thurston and Russo (1983) partly attributed a lack of relationship between DO concentration and toxicity to the use of different strains of Rainbow trout.

In view of the sparse database on strain differences and source of organisms, it is not possible to consider these factors for criteria development at this time.

J. **ACCLIMATION AND PRE-EXPOSURE**

Acclimation refers both to the time period before a toxicity test in which organisms are maintained in water with similar characteristics to those maintained during the test, and adaptations that aquatic organisms can undergo in response to changes in water quality parameters or to sublethal toxicant exposure (Rand and Petrocelli, 1985). For example, the thermal tolerance of fish can be enhanced by slow acclimation to critical temperatures (Sprague, 1985). Pre-exposure of test organisms to sublethal concentrations of the test substance can increase or decrease tolerance.

For the establishment of water quality criteria it is important to analyze the effects of these factors on organism sensitivity. If laboratory toxicity studies are performed with animals that are stressed by an inadequate acclimation period, this factor may be responsible for lowered LC_{50} or chronic toxicity values. Also the sensitivity of aquatic organisms exposed to chronic sublethal levels of a toxicant in their habitat water may be quite different from that predicted by laboratory tests with no pre-exposure.

Miller et al. (1990), in analyzing the differences between temperature-UIA relationships between fresh and saltwater organisms, suggested that inadequate acclimation may be a confounding factor. The ASTM (1988) guidelines for acute toxicity testing specify that temperature acclimation for fish should be performed at a rate of $\leq$ 3°C over a 72-hour period, with subsequent maintenance at the test temperature for two days.

However, Thurston and Russo (1983) and Thurston et al. (1983) reported that toxicity decreased at the increased temperatures. If the animals were stressed by an inadequate acclimation period, one would expect an increase in toxicity at the increased temperatures. Thus, although the rate of acclimation was too rapid in these studies, their results are not invalidated.

In the only study that directly tested acclimation effects, Thurston and Russo (1983) compared acute toxicity in five tests with Rainbow trout. No statistically significant differences in toxicity were found in fish held at the test temperature for 22-24 hours vs. 64-69 hours prior to testing.

Pre-exposure to sublethal levels of ammonia may also affect toxicity. In the Rainbow trout, Schulze-Wieheenbrauck (1976, as reported in USEPA 1985) found that three-week pre-exposure to sublethal ammonia concentrations resulted in decreased acute toxicity. In one test, fish acclimated to 0.108 or 0.138 mg NH_3-N/L had 100% survival over an 8.5 hour exposure to approximately 0.37 mg NH_3-N/L and fish that were not acclimated only had 50% survival. Thurston et al. (1981c) reported that Rainbow trout subjected to fluctuating sublethal concentrations of ammonia were more resistant to higher fluctuating concentrations than unacclimated fish. With the exception of several studies that showed alterations in the time of the onset of symptoms (reviewed in USEPA 1985), no other studies of the effects of pre-exposure on ammonia toxicity were found.

In conclusion, the database on the effects of acclimation period or pre-exposure on ammonia toxicity is sparse. Although these are important factors to consider in the interpretation of individual studies, there are currently inadequate data to support use of these factors in the formulation of criteria.

K. **ACUTE TOXICITY END POINTS**

Stephan et al. (1985) suggested using immobilization rather than death as an end point in toxicity studies used for criteria development. If a sizable portion of the database reported both death and immobilization, it might be possible to develop a correction factor to relate the two. Unfortunately no such studies were found. Thus, it was not possible to develop a correction factor that relates these end points.

L. **STATIC VS. FLOW-THROUGH TESTS**

Stephan et al. (1985) suggest that for each species for which at least one acute value is available, the geometric mean of all flow through tests using measured concentrations should be used. For species with no such values, the geometric mean of all available acute values should be used (i.e., static tests, static renewal tests, and flow through tests with unmeasured concentrations). In the ammonia database, several investigators performed both static and flow through tests as part of a series of exposures. If a consistent, statistically significant relationship can be determined between the two types of tests, a correction factor could be used to remove this source of variability. Unfortunately only one saltwater study (Miller et al., 1990) was found in which static and flow-through tests on two species were performed under similar water quality conditions. In view of the lack of a sizable database, no correction factor was derived.

M. **ANALYSIS OF VARIABILITY OF THE DATA**

As indicated above, there is considerable unexplained variability in toxicity test data. Sprague (1985) summarized the results of LC_{50} values for 8 chemicals that were tested repeatedly over periods of months to several years in the same laboratories. These laboratories used the same dilution water and testing techniques. The ratio of the highest:lowest reported LC_{50} values in the series ranged from about 1.3 to 5.5. The variability in tests performed at different laboratories may be even higher. Sprague (1985) cited the results of round robin tests (tests performed at the same time with similar procedures at different laboratories) in which highest:lowest LC_{50} ratios ranged from 2.2 to 12.

It is important to analyze the variability of the selected database for two reasons. First, it is useful to determine if unexplained variability in the ammonia database differs greatly from the variability reported for other chemicals. Second, analysis of the variability of the data is useful in estimating the precision of the criteria.

Differences in results of replicate tests performed as part of a single study are evaluated by calculating highest:lowest acute value ratios. This analysis was restricted to acute data because no replicate chronic values were found in the literature.

Freshwater Data

Replicate tests were found in twelve studies from the database for ten fish and five invertebrate species. A total of 11 sets of replicates were found for the Fathead minnow and 20 sets for the Rainbow trout. Highest:lowest LC_{50} ratios ranged from 1.06 to 2.80 for the Fathead minnow and from 1.00 to 2.04 for the Rainbow trout. Geometric mean ratio values were calculated for each of the species. The geometric mean of all of the species mean ratio values was calculated to be 1.30.

This analysis indicates that the inherent variability in the freshwater UIA toxicity database is low in comparison to the 1.3-5.5 range of ratios reported by Sprague (1985). Therefore, for criteria development, the inherent variability of the freshwater database was determined not to be a cause for concern.

<u>Saltwater Data</u>

Replicate tests were found in four studies from the database for two fish and one invertebrate species. Highest:lowest LC_{50} ratios ranged from 1.16 for the Atlantic silverside data to 3.51 for one set of mysid shrimp replicates. The four sets of replicate test data for the mysid shrimp had highest:lowest LC_{50} ratios that ranged from 1.17 to 3.51. A geometric mean value of 2.04 for the mysid was used. The geometric mean for all of the species values was 1.44.

This analysis indicates that the inherent variability in the saltwater UIA toxicity database is low in comparison to the 1.3-5.5 range of ratios reported by Sprague (1985). Therefore, for criteria development, the variability of the saltwater database was determined not to be a cause for concern.

N. **STATISTICAL EVALUATION OF TEMPERATURE-TOXICITY AND pH-TOXICITY RELATIONSHIPS AND MODEL DEVELOPMENT**

As discussed in sections B and C, a review of the toxicity data indicates that the Erickson/USEPA models, which show temperature-LC_{50} and pH-LC_{50} relationships, appear to be well-supported for freshwater New Jersey species but not for saltwater New Jersey species. To insure that model-based criteria are defensible, a statistical analysis was performed on acute toxicity data. The database for the statistical analysis included the studies used by Erickson (1985), more recent studies, and other available data on the key species used by Erickson in formulating his model. Only New Jersey species were included in the database.

<u>1. Temperature and Toxicity Relationship</u>

The Erickson/USEPA model for a temperature-LC_{50} relationship was based on studies with Rainbow trout (Thurston and Russo, 1983), Fathead minnow (Thurston <u>et al</u>., 1983), and Channel catfish (Cary, 1976). Other studies were examined as supporting evidence for the model by Erickson (1985), but were not considered adequate for use in model development.

Acute toxicity data for the three above species and Bluegill included in the analysis combined information from different investigators in order to provide the largest possible database from which to construct the model. The advantage of a large database is that it is likely to include data for a variety of life stages tested under a variety of conditions. It is recognized that considerable variability may be introduced by different investigators using different sizes and strains of organisms; water of varying hardness, DO, conductivity, and pH; and different techniques for measuring ammonia. Of these factors, pH is known to have a definite effect on acute toxicity as indicated by the existence of the Erickson/USEPA pH-toxicity model. Therefore, in combining the data for all species, the regressions were performed separately at each pH unit (i.e., pH 7 = pH range of 6.5-7.4; pH 8 = pH range of 7.5-8.5; and pH 9 = pH range of 8.6-9.5).

The Channel catfish database consisted of 37 LC_{50} data points. The Cary (1976) study cited by Erickson (1985) was not used because a complex effluent of which ammonia was the principal toxic component was tested rather than a single ammonia compound. However, the database included a study of the temperature-toxicity relationship in this species conducted by DeGraeve et al. (1987) (eight data points). The Fathead minnow database contained 69 LC_{50} data points with major temperature-toxicity studies conducted by Thurston et al. (1983) (35 data points) and DeGraeve et al. (1987) (eight data points). The Rainbow trout database contained 118 LC_{50} data points with the major temperature-toxicity study performed by Thurston and Russo (1983) (18 data points). The Bluegill database contained 21 LC_{50} data points from seven different investigators with Emery and Welch (1969) providing seven of the LC_{50} points.

The regressions of temperature (independent variable) and the log-transformed 96-hour LC_{50} (dependent variable) are shown in Figs. 1 through 5. For Channel catfish and Fathead minnow, sufficient data were available to perform regressions at pH 7 and pH 8. For Rainbow trout and Bluegill, data were sufficient to run the regressions at pH 8 only. All of the regressions were significant, with p values ranging from 0.0001 to 0.0014. For three out of the six regressions, greater than 50% of the variability was explained by the model (i.e., r-squared values greater than 0.50). For the Bluegill at pH 8, the model explained 45% of the variability. For the Fathead minnow at pH 8, the model explained only 25% of the variability. For the Rainbow trout at pH 8, the model explained only 15% of the variability. These regression data are summarized in Table 4.

The slopes of the regressions were in a rather narrow range (0.0222-0.0301), that indicates that similar relationships occurred with different species at different pH values. The low r-squared value for the Rainbow trout data may be attributed partially to the testing of a very large size range (<0.1 gram to 2.6 kg) by Thurston and Russo (1983). There appears to be considerable variability in ammonia toxicity among different size/age classes of Rainbow trout. The USEPA (1985) freshwater criteria were lowered to protect Rainbow trout larger than one kg, which appear to be particularly sensitive.

The results of the regression analyses indicate that a temperature-LC_{50} model is warranted. The model is convincing when it is considered that, despite the use of data from many investigators, regressions yielded similar slopes and explained greater than 50% of the variability in three out of five cases.

The temperature-LC_{50} linear equation was derived by arithmetically averaging the regression slopes for Rainbow trout, Channel catfish, Bluegill and Fathead minnow at each pH where significant relationships were determined which resulted in a pooled slope of 0.026. Averaging of the regression parameters was the method used in the formulation of the Erickson (1985) model, which recommended a pooled slope of 0.03. The model is used to adjust freshwater toxicity data to a reference temperature for calculation of the acute criteria and as temperature correction in formula criteria.

The model for standardizing freshwater data was derived using the pooled slope and the ratio of the LC_{50} at a reference temperature (20°C) and the LC_{50} at the temperature tested. The New Jersey standardization equation is:

$$LC_{50}\ (REF) = LC_{50}\ (TEMP) * 10^{0.026(20-TEMP)}$$

where LC_{50}(REF) is the LC_{50} at 20°C, LC_{50}(TEMP) is the LC_{50} at the temperature tested and TEMP is the test temperature. The above temperature-toxicity model is very similar to the Erickson/USEPA (1985) model (Table 1).

2. pH and Toxicity Relationship

The Erickson pH-LC_{50} model was based on studies with the Rainbow trout (Thurston *et al*., 1981a), Fathead minnow (Thurston *et al*., 1981a), *Daphnia* sp. (Tabata, 1962), and Coho salmon (Robinson-Wilson and Seim, 1975). Other studies were examined as supporting evidence by Erickson (1985) for the model but were considered inadequate for use in model development

Data for two of the four species used by Erickson (1985) were examined. The data not used were: the Coho salmon data because Coho is not a New Jersey species; and the Tabata (1962) study cited by Erickson because the species was not identified. For each species, data from different investigators were combined in order to assemble the largest possible database (69 data points for Fathead minnow, and 118 for Rainbow trout). In addition, sufficiently large databases were available for the Channel catfish (37 points), Bluegill (21 points) and *Daphnia magna* (13 points) to be used in model development.

The database for Common carp (12 data points) was also considered for use in model development. However, only the study by Dabrowska and Sikora (1986) examined pH effects. In this study, only two pHs (7.6-7.8 and 9.1) were tested providing a total of six data points. Thus, the Common carp database was considered inadequate for model development.

Regression analyses were performed to evaluate the pH-toxicity relationships for each of the five species with adequate databases-Channel catfish, Daphnia magna, Fathead minnow, Rainbow trout and Bluegill. The dependent variable was the log-transformed, temperature corrected LC_{50} value and the independent variable was pH. The Erickson/USEPA models fit a second order polynomial to the data. For the present analysis, only linear regressions and second order polynomial regressions were run.

There is uncertainty as to the effect of pH values greater than 8.0 on ammonia toxicity. Thurston et al. (1981a) stated that they were uncertain whether LC_{50} values peaked at 8.0-8.5 and then decreased or whether a plateau was reached. Because of this uncertainty, the USEPA (1985) criteria model imposed a plateau at pH 8.0. All LC_{50} values at pHs above 8.0 were made to equal the LC_{50} at pH 8.0. The effects of pH values above 8.0 on ammonia toxicity were examined by plotting the linear regressions for each species (Figs. 6 through 10). For the two species with the largest databases (i.e., Fathead minnow and Rainbow trout), there is a flattening of the data above pH 8.30, however, the small amount of data above pH 8.3 limits the ability to draw conclusions. In contrast, for the Channel catfish data, LC_{50} values continued to increase above pH 8.30. These data indicate that the effect of pH above 8.30 may vary considerably between species and that additional data are required for higher pH.

In order to measure the effect of including values greater than 8.30 on the regressions, these data were deleted and the regressions were run again (Figs. 11 through 14). Regression statistics for both the entire pH range and the restricted pH range are given in Table 5. Restricting the pH range to values less than 8.30 slightly improved the regressions for the two species with the largest databases. The r-squared values for the linear regressions for Fathead minnow increased from 0.36 to 0.38. The regression for Rainbow trout increased from 0.41 to 0.48. The regression for Daphnia magna decreased from 0.74 to 0.69, for Channel catfish from 0.41 to 0.23, and for Bluegill from 0.16 to 0.12 (Table 5).

The r-squared values for the second order polynomial regressions did not substantially improve the r-squared values for the regressions. Therefore, a linear regression model was chosen for the sake of simplicity. The model is convincing when it is considered that, despite the use of data from different investigators, it accounts for 12-69% of the variability in three of the four species.

The slopes for the five species varied from a low of 0.1252 for Channel catfish to a high of 0.7422 for Daphnia magna, which is considerably greater variability than observed for the temperature slopes. The y-intercepts ranged from -0.8872 to -5.7159. The pH-toxicity linear model was derived by arithmetically averaging the slopes from the regression analysis for Daphnia magna, Rainbow trout, Channel catfish, Bluegill and Fathead minnow, which produced a pooled slope of 0.41.

The model for pH standardizing freshwater data was derived from this slope and the ratio of the LC_{50} at a reference pH (7.80) and the LC_{50} at the pH tested. The standardization equations for LC_{50} data conducted at pH < 8.30 is:

$$LC_{50}(REF) = LC_{50}(pH) * 10^{0.41(7.80 - \text{tested pH})}$$

and for tests conducted at pH $\geq$ 8.30 the equation is:

$$LC_{50}(REF) = LC_{50}(pH) * 10^{0.41(7.90-8.30)}$$

where $LC_{50}(REF)$ is the LC_{50} at pH 7.90, $LC_{50}(pH)$ is the LC_{50} at the pH tested.

The pH-toxicity linear model differs slightly from the model developed by Erickson/USEPA, which is a nonlinear polynomial up to pH 8. Above pH 8, the test pH is set equal to pH 8. The present model uses a linear function for pH values up to and including pH 8.30. Above pH 8.30, the test pH is set equal to 8.30. Since there was no clear indication of the direction of the curve above this pH, a horizontal line is assumed, as in the USEPA criteria model.

3. Criteria Models

The temperature and pH models developed above will be used to standardize freshwater LC_{50} data which will be used to calculate the Final Acute Value (FAV) at the reference (REF) temperature (20^{o} C) and pH (7.80) for each freshwater classification (see section VII. B.). The FAVs will be formulated, according to Stephan et al. (1985), from the calculated FAV(REF) and the temperature and pH models. The formulated FAVs will have the form:

$$FAV = FAV(REF) * 10^{0.026(TEMP-20) + 0.41(pH-7.80)}$$

New Jersey freshwater criteria recommendations will be derived from this above equation. The Criterion Maximum Concentration (CMC) is defined by Stephan et al. (1985) as one-half the FAV, which will result in the equation for freshwater criteria:

$$CMC = CMC(REF) * 10^{0.026(TEMP-20) + 0.41(pH-7.80)}$$

for pH < 8.30 and;

$$CMC = CMC(REF) * 10^{0.026(TEMP-20) + 0.41(8.30-7.80)}$$

or

$$CMC = CMC(REF) * 10^{0.026(TEMP-20) + 0.20}$$

for pH $\geq$ 8.3. The CMC, recommended as a one-hour average concentration in Stephan et al. (1985), is a water quality criterion for the highest instream concentration of a toxicant or an effluent to which organisms can be exposed for a brief period of time without causing an acute effect.

The Criterion Continuous Concentration (CCC), recommended as a four-day average concentration in Stephan et al. (1985), is a water quality criterion for the highest instream concentration of a toxicant or an effluent to which organisms can be exposed indefinitely without causing an unacceptable effect (e.g., survival, growth, or reproduction). Due to the limited chronic toxicity data, at least 30 day toxicity tests that estimate the maximum allowable tolerance concentration (MATC), a procedure using Acute to Chronic Ratios (ACRs) will be used to develop the CCC (see the following section V.) according to procedures in Stephan et al. (1985). Using this procedure the CCC is derived in the equation:

$$CCC(REF) = FAV(REF)/ACR$$

Since the FAV is formulated for freshwater classifications (see above) the resulting CCC will be an equation of the form:

$$CCC = CCC(REF) * 10^{0.026(TEMP-20) + 0.41(pH-7.80)}$$

for pH < 8.30 and;

$$CCC = CCC(REF) * 10^{0.026(TEMP-20) + 0.41(8.30-7.80)}$$

or

$$CCC = CCC(REF) * 10^{0.026(TEMP-20) + 0.20}$$

for pH $\geq$ 8.3.

V. COMPLETENESS OF THE DATABASE

Development of New Jersey-specific ammonia criteria requires sufficient ammonia toxicity information about taxa inhabiting surface water classifications or a procedure for substituting toxicity information about taxa that are ecologically, physiologically, or taxonomically similar. The following discussion explains how the species lists developed were combined with the list of usable toxicity information to evaluate whether such substitutions were necessary.

Assessment criteria are required to evaluate the adequacy of available ammonia toxicity information. Stephan et al. (1985) proposed a series of guidelines (summarized in Tables 6 and 7) for assessing data adequacy for the USEPA national criteria and these guidelines were used in the evaluation of the ammonia toxicity data. The adequacy of the data for each surface water classification was analyzed by comparing the family acute data, chronic data, and acute-chronic ratio data with these guidelines. The national guidelines were used only for the initial assessment and should not be regarded as requirements for development of New Jersey criteria.

Following these procedures, usable acute ammonia toxicity data were found for a total of 58 New Jersey species, including 24 invertebrates and 34 fish species. The taxa for which data were available include members that inhabit the full range of New Jersey surface water quality classifications, which permitted calculation of individual

FAVs and CMCs. The only taxonomic group not included in the available acute data is mysid species for estuarine/salt waters. The need for a mysid species is easily resolved by substitution of acute toxicity information for a close congener to the mysid species that occurs in New Jersey waters.

The chronic data available for New Jersey species were much more limited with data available for only 12 species, including nine fish and three invertebrate species. Numerous deficiencies in the chronic toxicity information prevented calculation of individual Final Chronic Values (FCRs). However, chronic toxicity data were sufficient, according to Table 6 and 7, to calculate a statewide ACR by procedures described in Stephan et al. (1985). The ACR procedure can be used in a place of FCVs for calculating CCC. Acute to chronic ratio data were available for seven New Jersey species including one invertebrate and six fish species which is sufficient for the ACR procedure.

The acute and chronic toxicity data available or missing are discussed below for each classification. Where data are missing, measures taken to overcome the deficiencies are discussed.

A. **TROUT WATERS (FW2-TP, FW2-TM)**

There is a substantial database of acute toxicity values for species inhabiting New Jersey's trout waters. The database for New Jersey species contains acute toxicity values for 29 species representing 15 families with representation in all categories. However, based on the established guidelines for national freshwater criteria (Table 6), the chronic database assembled is deficient in several categories. The database only contains toxicity values for a total of six families with no representatives for either the benthic crustacean or insect categories. This lack of information can be overcome by using the statewide ACR (discussed above), which serves as an acceptable substitute when the chronic database is inadequate.

B. **NONTROUT WATERS (FW2-NT)**

The acute database for nontrout waters was represented by a greater number of species (35) and families (16) than for trout waters. All categories for the acute database were filled with New Jersey species. Similar to the trout waters, the chronic database for nontrout waters was missing data for both the benthic crustacean and insect categories. However, similar to trout waters the limitations of the chronic data can be overcome by using the statewide ACR.

C. **PINELAND WATERS (PL)**

The database for Pineland waters, similar to the first two freshwater classifications, contained adequate acute values for 25 species. As in the case of the trout and nontrout waters, all categories for the acute database were filled with New Jersey species. The chronic database contained representatives from only four families and was deficient for both the insect and benthic crustacean categories. However, as for the other two freshwater classifications, the ACR can satisfactorily substitute for the insufficient chronic database.

D. **SALINE ESTUARIES (SE1, SE2, SE3)**

The requirements for database adequacy for saltwater as presented in Table 7 are slightly different than the freshwater requirements (Table 6). The acute database contained 17 species and 15 families. The acute data fulfilled all the categories except the mysid requirement. However, acute data for a congener to the New Jersey species Mysidopsis bigelowi were available (i.e., Mysidopsis bahia). The chronic database for SE waters contained values for three fish species, Channel catfish, Inland silverside, and Striped mullet. This database did not meet the guidelines for the chronic data categories. However, the limitation can be overcome using the statewide ACR procedure similar to freshwater classifications.

E. **SALINE COASTAL WATERS (SC)**

The ammonia toxicity database for the saline coastal waters contained the least data of all the surface water classifications. The acute database contained values for 16 species in 11 families. The 16 species met all of the guideline categories except the mysid requirement, which can be met (as discussed for saline estuaries) by substituting acute toxicity data for the congener Mysidopsis bigelowi. Chronic data were only available for one species listed in this classification, Striped mullet. This lack of data necessitated substituting the statewide ACR to calculate the CCC.

VI. CALCULATION OF CRITERIA

The procedures used to calculate the criteria followed the methods presented in Stephan et al. (1985), except where indicated.

A. **CRITERION MAXIMUM CONCENTRATION**

For the freshwater classifications, LC_{50} data were corrected to a standard pH (7.80) and temperature (20°C) using the pH and temperature relationships developed from the database (see Chapter IV). As previously mentioned the saline classification (SE & SC) LC_{50} data were not corrected because information was insufficient to demonstrate any dependence on water quality parameters.

Following these steps, the species mean acute values for each surface water classification were calculated. Data used to calculate the species mean acute values were selected by duration of test, with 96-hour duration results selected first. When 96-hour test results were not available, shorter duration results were considered based on the species and life stage of the test organisms. Toxicity data used to calculate the species mean acute values were selected according to a set of priority guidelines based on the thoroughness of the experimental procedures used to test for ammonia toxicity. These were, in order of priority:

- o flow through tests with measured ammonia concentrations;
- o static-renewal tests with measured ammonia concentrations;
- o static tests with measured ammonia concentrations; or
- o flow-through, static-renewal, or static tests with nominal (unmeasured) ammonia concentrations.

If 96-hour data were available from several categories, only toxicity results from the highest priority were used to calculate the species mean acute value. For many species, LC_{50} and EC_{50} results, which met the above criteria, were available from multiple investigators and for several life stages. For these species, the species mean acute value was determined by calculating the geometric mean of all values. For species represented by a single result, this single result became the species mean acute value.

Several taxa for which toxicity data are available have salinity tolerances that permit them to occur in both fresh (FW2-NT) and saline (SE and SC) environments (e.g., Striped bass). Available evidence indicates there either is no or only a weak relationship between salinity and UIA toxicity. To be consistent with procedures used by the Department for evaluating New Jersey-specific ambient water quality criteria for pollutants, toxicity data conducted from tests with salinity above 3.5 ppt were not used for freshwater classifications. Similarly, toxicity data from tests conducted at salinity less than 3.5 ppt were not selected for saline classifications.

The Stephan et al. (1985) method calls for calculating genus mean acute values from species mean acute values. The purpose of this step is to eliminate bias in the calculation of the CMC that results from a genus that is represented by numerous species. Species from the same genus tend to be quite similar in toxicity response, usually varying by less than a factor of two (Erickson and Stephan; 1988). In these instances (e.g., Lepomis, Morone, and Menidia), the geometric means of the species mean acute values were calculated and used as the genus mean acute value. However, for most genera, there were only mean acute values available for a single species, which became the genus mean acute value.

Water quality criteria are designed to provide adequate protection for 95% of aquatic species (Stephan et al., 1985). As a result, the Final Acute Value (FAV) was calculated from the genus mean acute values by statistically estimating the fifth percentile of the toxicity values. Erickson and Stephan (1988) calculate the fifth percentile based on the ranking of the genus mean acute values and a linear estimation based on the smallest four toxicity values. They determined that this was the best method for calculating FAVs because of concerns regarding the normality of the toxicity databases for most chemicals (i.e., they were highly skewed). However, their estimation method may not be the best method if the toxicity data are normally distributed, therefore, this would permit the use of population statistics to estimate the fifth percentile.

To evaluate whether the ammonia toxicity data were normally distributed, each database was statistically analyzed using procedures outlined in SAS (1985). Results of the statistical analyses for skewness (asymmetry), kurtosis (peakedness), and normality for log-transformed genus mean acute values for each classification are summarized in Table 8. In general, log-transformation of data for small data sets is necessary to normalize the data. The analyses for skewness and kurtosis resulted in values approaching zero, indicating that the databases were only slightly skewed and/or kurtic. The Shapiro-Wilk's test (W) is a statistical indicator of normality that yields a rank between 0 and 1, where 1 is a normal distribution. The Shapiro-Wilk's test (W) values were approximately 1 and were not significant ($p > 0.05$) for all databases. These results suggest that the databases were normally distributed; therefore the use of population statistics to estimate the fifth percentile is appropriate.

The log-transformed genus mean acute values for each database were used to estimate the mean and standard deviation of the data. The fifth percentile (FAV) was estimated using the equation:

Fifth Percentile = $10^{Y-1.645s}$ (Sokal and Rohlf, 1981)

where Y is the log-transformed mean, s is the log-transformed standard deviation, and 1.645 is the number of standard deviations above which 95% of the values of a normally distributed population are found.

The Stephan et al. (1985) method calls for equating the FAV to the fifth percentile, unless it can be demonstrated that sensitive life stages of recreational or commercially important species are not protected by this value. For this evaluation, the calculated FAV was systematically compared to the database for that classification by:

- identifying all acute toxicity data below the FAV;
- examining the identified data for repeated values for a single life stage;
- determining whether the species is commercially or recreationally important; and
- computing the geometric mean of the acute data for that sensitive life stage of the species.

Once each of these steps was accomplished, the FAV was adjusted (where appropriate) to the calculated mean.

The FAV is based on toxicity data where 50% mortality occurs. To ensure survival of sensitive species in the vicinity of the FAV, Stephan et al. (1985) recommends setting the CMC at one half of the FAV. In instances where environmental factors affect toxicity of ammonia (i.e., pH and temperature), the CMC was merged with correction formulae to provide recommended criteria that are responsive to these environmental factors.

The recommended averaging period in Stephan et al. (1985) for the CMC is one-hour. This is based on the necessity for the averaging period to be substantially less than the duration of the toxicity tests on which it is based (i.e., 48 to 96 hours) to prevent mortality of organisms exposed to concentrations near or above the CMC. Recent evaluation has indicated that the one-hour averaging period may be overly restrictive, particularly in the case of a number of USEPA promulgated metals criteria. To evaluate whether this is also the case for the New Jersey ammonia criteria the Stakeholders examined the exposure period versus mortality/effects in the ammonia acute toxicity studies. The studies indicate ammonia is relatively fast acting with observable exposure effects occurring at much less than the total test duration, but at a considerably longer period (greater than or equal to six hours) than the one-hour averaging period recommended by Stephan et al. (1985). Based on the Stakeholders' evaluation and discussion, an averaging period of three-hours was recommended and agreed upon for the CMC.

B. **CRITERION CONTINUOUS CONCENTRATION**

The CCC can be calculated similarly to the manner described for the CMC if sufficient chronic data are available. However, the available chronic data were determined to be inadequate to support the use of these methods for all of the water classifications. As a result, the CCC was determined for each surface water classification using the acute to chronic ratio (ACR) method outlined by Stephan et al. (1985) and summarized below.

In general, the method requires calculation of a mean ACR from species ACRs which are determined by dividing an acute toxicity value (i.e., a 96 hour LC_{50}) by a chronic toxicity value for a single species (i.e., a MATC). Chronic end points described as appropriate for criteria formulation by Stephan et al. (1985) include survival of adults and young, growth of adults and young, maturation of males and females, eggs spawned per female, and embryo viability. Since extremely small changes in these parameters can be statistically significant, the magnitude of these changes was evaluated for each chronic study before determining their biological significance.

Several studies have documented gross or histopathological lesions in tissues of organisms chronically exposed to ammonia (Thurston et al., 1984 and 1986). Histopathology occurred at concentrations below those reported to cause adverse changes in survival, growth, or reproductive end points in both studies. This suggests that histopathological effects may not affect the long-term survival of individuals or populations. In view of the controversial nature of histopathological studies, the Department is proposing that the ammonia criteria be based on survival, growth, and reproductive end points outlined by Stephan et al. (1985) to ensure more defensible criteria.

Before the species ACRs were calculated, the acute value had to meet a specific set of guidelines (Stephan et al., 1985). These guidelines prefer that the acute test was part of the same study as the chronic test, conducted in the same laboratory with the same dilution water, or conducted in the same dilution water at a different laboratory. If data were available for several of the categories, only data from the highest priority were used to calculate the species ACR. Once the acute value was selected the LC_{50} was adjusted using the previously developed models to the pH and temperature of the chronic value. The ACR was calculated by dividing the acute value (LC_{50}) by the chronic value (MATC).

For several species, more than one ratio was available because of either multiple studies by different investigators, studies with several life stages, or tests under different environmental conditions. For these species, the species mean ACR was determined by calculating the geometric mean of all ACRs for the species. For species, which were represented by a single result, the single result, became the species mean ACR.

The species mean ACRs for all New Jersey species were used to calculate final ACR applicable to all New Jersey surface water classifications. The statewide ACR was determined by calculating the geometric mean of all species mean ACRs occurring in New Jersey surface water classifications. This method is based on recommended procedures contained in Stephen et al. (1985). The final chronic value (FCV) for each New Jersey water classification was obtained by dividing the water classification specific FAV by the statewide ACR.

Stephan et al. (1985) calls for equating the FCV to the CCC, except where recreational or commercially important species and aquatic macrophytes and algae are not protected. To evaluate this, the calculated FCV was systematically compared to the database for that classification by identifying all chronic toxicity data below the final chronic value for recreational or commercially important species and examining toxicity data for alga or aquatic macrophytes.

Once these steps were accomplished, the FCV was adjusted (where appropriate) to protect any recreationally or commercially important organisms. Stephan et al. (1985) recommends use of formula to correct for environmental factors that have been demonstrated to affect UIA toxicity. In instances where relationships are determined for acute toxicity, but chronic data are insufficient to determine any relationships, the application of the models developed for acute toxicity are to be applied to the CCC. In the case of freshwater classifications the temperature-pH correction model was applied to the freshwater CCC. This is reasonable since the CCC is the dividend of the FAV, which varies with pH and temperature, and the statewide ACR, which is a constant.

The recommended averaging period in Stephan et al. (1985) for the CCC is four-days. This is also based on the necessity for the averaging period to be substantially less than the duration of the toxicity tests on which it is based to prevent chronic effects of organisms exposed to concentrations near or above the CCC. This four-day averaging period may also be overly restrictive for New Jersey waters for a number of reasons including: chronic exposure periods are substantially longer, ranging from a minimum of 30 days to full life cycle (more than one year) for fish (the most sensitive aquatic life to ammonia); chronic endpoints in the database are non-mortality effects, e.g., growth and reproduction; and the CCC is derived from the FAV, resulting in a CCC that should be one-half (½) most chronic endpoints. Based on the Stakeholders' evaluation and discussion of the chronic toxicity results and endpoints, an averaging period of 30-days was recommended and agreed upon for the CCC.

VII. RECOMMENDED CRITERIA

A. **SENSITIVITY ANALYSIS**

To evaluate the degree of confidence that should be placed in the FAVs for each surface water classification, a series of sensitivity analyses were performed by:

- o excluding the maximum genus mean acute values from the database;
- o excluding the minimum genus mean acute values from the database; and
- o calculating the FAV using the method of Stephen et al. (1985) for estimating the 5% value.

Estimating the FAV for each database by alternately excluding the maximum and minimum genus mean acute values was conducted to evaluate the effects of the extremes on the estimate of the FAV. Slight changes in the recalculated FAV would suggest that the database is adequate and that additional data probably would not improve the estimate of the FAV. Significant changes in the FAV indicate that the database is not adequate and that future additions of acute toxicity data would produce more reliable estimate of the FAV.

A sensitivity analysis was also conducted by calculating FAV using the method of Stephen et al. (1985). This method uses the probability distribution of the genus mean acute values and the lowest four genus mean acute value to estimate the FAV. This estimate was compared with the estimate using the distribution equation to evaluate differences between the two procedures. The two values also were compared to species mean acute values for each classification to evaluate whether the values were over protective or under protective for species of each classification.

The results of the statistical analyses of the acute and chronic toxicity data and recommended CMCs and CCCs for each classification are presented below. All criteria are presented in milligrams of UIA as nitrogen (NH_3-N) and freshwater criteria are presented at the reference water quality conditions of 20^{o}C and pH 7.8.

B. **RECOMMENDATIONS FOR CRITERION MAXIMUM CONCENTRATIONS**

1. Trout Waters (FW2-TP and FW2-TM)

The freshwater trout classifications (FW2-TP and FW2-TM) were grouped together due to the high degree of overlap of the aquatic species found in each classification. The acute ammonia toxicity database for trout waters contained 33 species and 27 genera. The species mean and genus mean acute values are summarized in Table 9. The geometric mean of the genus mean acute values (Y) is 1.31 mg NH_3-N/L, with a log-transformed standard deviation ($\log_{10}$ s) of 0.280. Based on these population estimates, the fifth percentile or FAV at the reference condition is 0.455 mg NH_3-N/L.

The FW2-TP classification was developed to provide protection for the propagation and maintenance of all species (including trout) in the waterbody. In order to insure protection of this classification, the FAV was compared to early and reproductive size life stage LC_{50} data for all species found in FW2-TP waters. Two life stages of Rainbow trout, a recreationally and commercially important species, were found to have numerous LC_{50} results below the FAV. These LC_{50} values were for large reproductive sized adults (> 1000g) and early life stages (0.1-0.2g larvae). The geometric means of the adult and larval life stages for Rainbow trout were 0.358 mg NH_3-N/L (n=5) and 0.420 mg NH_3-N/L (n=6), respectively. The FAV for FW2-TP waters was lowered to 0.358 mg NH_3-N/L to protect the reproduction of Rainbow trout in these waters. The freshwater national criterion (EPA 1985) was adjusted similarly to protect reproductive sized trout (> 1000 g).

The FW2-TM water classification is intended to provide protection for the maintenance of trout populations, and propagation and maintenance of all other species inhabiting these waters. Since rainbow trout greater than 1000 g have LC_{50} results below the FAV, the FAV for FW2-TM waters was lowered to 0.358 mg NH_3-N/L to protect these large Rainbow trout.

The recommended CMC for the FW2-TP and FW2-TM water classifications, which is one half the FAV, is 0.179 mg NH_3-N/L at 20°C and pH 7.80. The recommended models for temperature and pH corrections of the CMC are:

$$\mathrm{CMC}(\mathrm{mg\ NH_3\text{-}N/L}) = 0.179 * 10^{0.026(\mathrm{TEMP}-20)+0.41(\mathrm{pH}-7.80)}$$

for pHs below 8.30 and:

$$\mathrm{CMC}(\mathrm{mg\ NH_3\text{-}N/L}) = 0.179 * 10^{0.026(\mathrm{TEMP}-20)+0.20}$$

for pHs equal to or greater than 8.30.

2. <u>Nontrout Waters (FW2-NT)</u>

<u>a. Summer Criteria:</u>

The acute ammonia toxicity database for FW2-NT waters contained 38 species and 30 genera. The species mean and genus mean acute values are summarized in

Table 10. The geometric mean of the genus mean acute values (Y) is 1.28 mg NH_3-N/L with a log-transformed standard deviation ($\log_{10}$ s) of 0.276. The estimate of the fifth percentile or FAV, based on these population values, is 0.452 mg NH_3-N/L, which is similar to the estimate of 0.455 mg NH_3-N/L for trout waters.

The FW2-NT water classification is designed to provide for the propagation and maintenance of all nontrout species of the waterbody. To provide this protection, the FAV was compared to early and reproductive size life stage LC_{50} data of all species found in waters classified as FW2-NT. Early life stage LC_{50} results for Green sunfish (9-day-old larvae) and Bluegill (0.2-0.3 g; 20-40 mm), are below the FAV. The geometric mean of the acute values of early juvenile Bluegill and Green sunfish are 0.402 mg NH_3-N/L (n=5) and 0.394 mg NH_3-N/L (n=1), respectively. The FAV for nontrout waters should be lowered to 0.402 mg NH_3-N/L to protect the reproduction of Bluegill, a recreationally important species. However, since the above sensitive early life stages do not occur during cold season periods this adjustment should only be for the summer period, defined as March 1 through October 31.

The recommended Summer CMC for the FW2-NT classification is 0.201 mg NH_3-N/L at 20°C and pH 7.80. The recommended models for temperature and pH correction of the CMC are:

$$CMC(mg\ NH_3\text{-}N/L)= 0.201*10^{0.026(TEMP-20)+0.41(pH-7.80)}$$

for pHs below 8.30 and:

$$CMC(mg\ NH_3\text{-}N/L)= 0.201*10^{0.026(TEMP-20)+0.20}$$

for pHs equal to or greater than 8.30.

<u>b. Winter Criteria</u>:

The acute ammonia toxicity database for FW2-NT waters contained 38 species and 30 genera. Of the 38 species, 19 were fish species that may have contained early life stage toxicity data that would not be appropriate for a winter period. Toxicity data for each species was reviewed to eliminate data on early life stages and life stages earlier than juvenile for recalculation of the winter FW2-NT criterion. Of the 19 fish species, early life stage toxicity data was available for only 6 of the fish species and 25 toxicity values were removed from the total of 199. The winter period species mean and genus mean acute values are summarized in Table 10a. The revised geometric mean of the genus mean acute values (Y) is 1.30 mg NH_3-N/L with a log-transformed standard deviation ($\log_{10}$ s) of 0.272. The estimate of the fifth percentile or FAV, based on these population values, is 0.464 mg NH_3-N/L, which is slightly higher than the summer criterion of 0.452 mg NH_3-N/L for FW2-NT waters.

The recommended Winter (defined as November 1 through February 28/29) CMC for this FW2-NT water classification is 0.232 mg NH_3-N/L at 20°C and pH 7.80. The recommended models for temperature and pH correction of the CMC are:

$$CMC(mg\ NH_3\text{-}N/L) = 0.232 * 10^{0.026(TEMP-20)+0.41(pH-7.80)}$$

for pHs below 8.30 and:

$$CMC(mg\ NH_3\text{-}N/L) = 0.232 * 10^{0.026(TEMP-20)+0.20}$$

for pHs equal to or greater than 8.30.

<u>3. Pineland Waters (PL)</u>

The Pineland (PL) waters were represented in the ammonia toxicity database by 26 species and 20 genera (Table 11). Species mean and genus mean acute values are summarized in Table 11. The geometric mean of the genus mean acute values (Y) is 1.46 mg NH_3-N/L, with a log-transformed standard deviation ($\log_{10}$ s) of 0.296. The resulting estimate of the fifth percentile or FAV is 0.476 mg NH_3-N/L, which is approximately the same as the FAVs of the previous waterbody types.

To insure protection of propagation and maintenance of all PL waters species, the FAV was compared to early and reproductive size life stage LC_{50} data of all species found in this water classification. Early life stage LC_{50} results for Bluegill (0.2-0.3 g; 20-40 mm) are below the FAV. However, this species is not distributed evenly throughout PL waters, occurring only in waters where the normally acidic conditions have been neutralized. Therefore a FAV of 0.476 mg NH_3-N/L is recommended for the PL water classification.

The recommended CMC for this classification, which is one half the FAV, is 0.238 mg NH_3-N/L at 20°C and pH 7.80. The recommended models for temperature and pH correction of the CMC are:

$$CMC(mg\ NH_3\text{-}N/L) = 0.238 * 10^{0.026(TEMP-20)+0.41(pH-7.80)}$$

for pHs below 8.30 and:

$$CMC(mg\ NH_3\text{-}N/L) = 0.238 * 10^{0.026(TEMP-20)+0.20}$$

for pHs equal to or greater than 8.30.

The majority of PL waters are in the pH range of 3.5 to 5.5. The low ambient pH of this classification is below the range for which the pH adjustment model has been validated; a result of the general absence of toxicity studies below pH 6.0 (see Section O, Chapter IV). The limitation of the correction model to estimate a criterion at low pH is likely to be of little consequence at the pH of PL waters. Metcalf and Eddy (1979) have summarized available data to show how secondary wastewater treatment results in a maximum discharge concentration of 45 mg/L as NH_4-N (total ammonia). The fraction of total ammonia (NH_4-N) that is UIA is dependent on pH, with the UIA fraction decreasing by a factor of ten with each whole unit drop in pH. At pH 5 the recommended criterion (estimated from the model) is 0.017 mg/L as UIA. Under worst case conditions in a PL waterbody (i.e., 45 mg/L total ammonia or 100% wastewater effluent), the maximum UIA concentration would be 0.003 mg/L as UIA, which is almost an order of magnitude lower than the recommended criterion. Therefore, based on this analysis, the Department is proposing using the pH-temperature correction model to estimate the criterion below pH 6.

Recalculation of the fifth percentile analysis by dropping the minimum or maximum genus values resulted in estimates of 0.514 and 0.516 mg NH_3-N/L respectively. The difference between these values and the FAV (0.478) is less than 0.050. These differences are minimal, indicating that the extremes of the distribution have minimal affect on the estimate of the fifth percentile. The FAV estimated using Stephan et al. (1985) methodology resulted in an estimate of 0.543 mg NH_3-N/L, which is somewhat higher than the FAV estimated using population statistics. However, this estimate is near the genus mean acute value of Yellow perch (Table 11), indicating that this estimate may not be protective of this recreationally important species.

4. Saline Estuaries (SE1, SE2, SE3)

The acute ammonia toxicity database for SE waters contained mean acute values for 20 species and 18 genera (Table 12). The geometric mean of the genus mean acute values (Y) is 1.53 mg NH_3-N/L with a log-transformed standard deviation ($\log_{10}$ s) of 0.501. These population estimates result in an estimate of 0.230 mg NH_3-N/L for the fifth percentile, or FAV, which is much lower than the estimates for freshwater.

The designated uses of each of the SE classifications differ. However, the current toxicological database is insufficient to differentiate between functions of each classification. As a result, the FAV estimate was applied to each SE classification. The lack of temperature and pH relationships results in a recommended CMC of 0.115 mg NH_3-N/L for all pH and temperature values.

The recommended CMC for SE waters (0.115) is lower than the previously calculated criteria (0.236) for PL classification at 20^{o}C and pH 7.8. However, this recommended criterion for SE waters may not be overprotective. The CMC for PL waters, using the temperature (10^{o}C) and pH (5.5) correction model, is 0.015 mg NH_3-N/L. The lower estimate for SE waters may be due, in part, to the lack of temperature and/or pH correction models. This lack of correction likely caused greater variability in the database, resulting in a larger standard deviation, thereby lowering the estimate of the fifth percentile (FAV).

In the sensitivity analysis, recalculating the fifth percentile by dropping the minimum or maximum genus values resulted in estimates of 0.258 and 0.251 mg NH_3-N/L, respectively. The difference between these values and the FAV (0.230) is less than 0.030. These slightly higher estimates indicate these two extremes of the distribution have little effect in estimating the fifth percentile. The FAV estimated using Stephan et al. (1985) methodology resulted in an estimate of 0.353mg NH_3-N/L. This estimate is above the genus mean acute value for Yellow perch (0.29 mg NH_3-N/L), a freshwater species commonly inhabiting higher salinity environments in estuaries, indicating that this estimate may not be protective. The fifth percentile was also estimated after Mysidopsis bahia acute toxicity data was substituted to fulfill the mysid requirement (see Chapter V). This analysis resulted in an estimate of 0.226 mg NH_3-N/L, indicating the addition of the mysid does not significantly change the estimate.

5. Saline Coastal (SC) Waters

The acute ammonia toxicity database for SC waters contained mean acute values for 15 species and 14 genera (Table 13). The geometric mean of the genus mean acute values (Y) is 1.55 mg NH_3-N/L, with a log-transformed standard deviation ($\log_{10}$ s) of 0.556. These population estimates result in an estimate of 0.189 mg NH_3-N/L for the fifth percentile or FAV.

The FAV was compared to the database for SC waters to evaluate whether life stages of the organisms are protected. However, the SC database does not address all the life stages for a sufficient number of species to make this determination. As a result, the FAV can not be adjusted at this time and is assumed to be protective until further toxicity testing demonstrates otherwise. Similar to SE waters, the recommendation of 0.094 mg NH_3-N/L is only a single CMC for all pH and temperature values. Also similar to SE waters, the effect of not adjusting for pH and/or temperature, as well as the small size of the database, likely resulted in this lower estimate of the fifth percentile.

Recalculation of the fifth percentile, after dropping the minimum or maximum genus values resulted in slightly higher estimates of 0.215 and 0.202 mg NH_3-N/L, respectively. These estimates are only slightly higher than the FAV (0.189), suggesting that the extremes of the distribution have little effect on the estimate of the fifth percentile. The FAV estimated using Stephan et al. (1985) methodology resulted in a value of 0.322 mg NH_3-N/L, which is below all species mean acute values of the database. Similar to SE waters, the fifth percentile was re-estimated after Mysidopsis bahia acute toxicity data was substituted to fulfill the mysid requirement (see Chapter V). This substitution resulted in an estimate of 0.184 mg NH_3-N/L for the fifth percentile, which is very similar to the FAV (0.189).

C. **RECOMMENDATIONS FOR CRITERION CONTINUOUS CONCENTRATIONS**

The CCC for each classification was calculated by estimating a FCV (see Chapter VI) using the statewide final ACR. The acute and chronic data used to calculate species mean ACR are summarized in Table 14. Individual acute chronic ratios and species mean ACRs used to calculate the final ACR for all surface water classifications are presented in Table 15. Acute and chronic data were available to compute ACRs for seven species including one invertebrate, five freshwater fish and one saltwater fish species. Four of the species contained multiple ACRs requiring computation of species mean ACRs. The geometric mean of the species mean ACRs is 7.75, which is the statewide final ACR. The FCVs calculated for the New Jersey water classifications using the statewide ACR are: 0.046 mg NH_3-N/L for freshwater trout classifications (FW2-TP and FW2-TM); 0.054 mg NH_3-N/L during summer periods; 0.060 mg NH_3-N/L during winter periods for Nontrout Waters (FW2-NT); 0.061 mg NH_3-N/L for Pineland Waters (PL); 0.030 mg NH_3-N/L for Saline Estuaries (SE1, SE2, SE3); and 0.024 mg NH_3-N/L for Saline Coastal waters (SC).

Each of the FCVs was compared to the chronic toxicity data from the database to determine whether the criteria were protective of recreationally or commercially important species. However, the FCVs were all less than the lowest chronic values contained in the database for these important species. The criteria were also compared to toxicity data from studies conducted on algae and aquatic macrophytes. For the data available, the lowest chronic values for fish and invertebrates are less than the lowest values for algae and macrophytes. Therefore, the FCVs based on fish and invertebrates were protective for important species, algae and macrophytes and were established as the CCC for each classification.

The CCC for each freshwater classification were merged with the pH and temperature correction models developed using the acute data (see section IV. N.) to obtain formulated CCC. As discussed in Chapter VI, Section B application of the correction models was determined to be appropriate based on guidance in Stephan et al. (1985). CCC for saltwater classifications were not merged since the pH and temperature models were not supported by acute data for saltwater species. Tables 16 and 17 summarize the recommended CMC and CCC for each surface water classification.

A number of concerns regarding the appropriateness of the above approach for nontrout waters (FW2-NT) during winter periods were raised by several stakeholders. Their concerns were based upon the inclusion: of studies conducted with fish early life stages, which do not occur during winter periods in nontrout waters, in the chronic database used to derive the statewide ACR; and chronic invertebrate studies, which tend not to follow the pH toxicity model used in the criteria. Based on the concerns of stakeholders, the Department requested Versar to conduct additional investigations:

- to evaluate the effects of chronic data on the winter CMC and CCC for nontrout waters,
- recalculate Winter CMC and CCC for nontrout waters, if possible, without the early life stage toxicity, and
- recommend alternative winter criteria for the nontrout waters if sufficient information is available.

The CCC for the summer period FW2-NT classification was calculated by estimating a FCV using the statewide final ACR. This statewide ACR was evaluated to determine if it is appropriate for the winter period and whether any adjustment is justifiable. This evaluation was necessary since the majority of species ACR data contained in the statewide ACR are based on early life stage data for fish, which may not be present during winter periods in warmwater fisheries.

Examination of the toxicity data reveals that only one species ACR contained a juvenile ACR and that was for fathead minnow (*Pimephales promelas*) in a study by Mayes *et al* (1986), which was 7.57. The other two ACRs for fathead minnow were from early life stage studies and were 8.28 and 10.3. The remaining ACRs for the fish species were all from early life stage studies. A number of studies examined chronic toxicity for fish life stages (juvenile and adult) that may be present during the winter period, but were not included in the statewide ACR because the test conditions did not meet the criteria specified in Stephan *et al* (1985). These studies will be discussed below to evaluate whether statewide ACR containing early life stage ACRs for fish may be overly protective.

Juvenile channel catfish chronic toxicity studies have been conducted by a number of investigators. DeGraeve *et al* (1987) evaluated ammonia toxicity to 15-week old channel catfish (*Ictalurus punctatus*) at low temperatures and reported a survival LOEC of 0.039 mg NH_3-N/L and 0.036 mg NH_3-N/L at 6 and 10ºC, respectively. Using the acute 96-hour LC_{50}s reported in the same report results in ACRs of 9.2 and 18.6, which are similar to ACRs reported in Table 14 for this species. The ACRs from this study are particularly compelling since the life stage and test temperatures are close to winter conditions expected to occur during this period. Colt and Tchobangoleous (1976) also studied ammonia toxicity to juvenile channel catfish growth in 31-day trials and found a linear relationship between ammonia concentration and growth. Using a growth EC_{20} (20% decrease in growth) of 0.195 mg NH_3-N/L, estimated from their regression model, and the 96-hour acute LC_{50} of 2.39 mg NH_3-N/L (T=26ºC and pH=8.7) yields an ACR of 12.2. Although this short-term growth reduction may be compensated in later development periods, it may be relevant given reduced growth during short periods could equate to lowered fish condition and result in increased losses from predation and disease and reduced reproduction in the following year from lower fertility and egg survival.

As previously discussed, a juvenile fathead minnow ACR was contained in the statewide ACR database. DeGraeve *et al* (1987) also evaluated ammonia toxicity to juvenile fathead minnows, similar to channel catfish, at low temperatures and reported a survival MATC of 0.112 mg NH_3-N/L and 0.068 mg NH_3-N/L at 6 and 10ºC, respectively. Higher temperature data were also available in this study, but may not be representative of conditions expected during winter periods. Using the acute 96-hour LC_{50}s reported in the same report results in ACRs of 3.36 and 7.95. The 7.95 ACR is similar to ACRs reported in Table 14 for this species and the 3.36, although lower than other ACRs for this species, is well within the variability of ACRs that can be expected in toxicity studies (see ACRs for *Micropterus dolomieu*). An additional life cycle study conducted by Thurston *et al* (1986) provided a long term chronic LC_{20} of 0.44 mg NH_3-N/L, which when used to compute an ACR using a representative acute value of 2.25 mg NH_3-N/L from Thurston *et al* (1983) yields an ACR of 5.1. However, this study was conducted at 25ºC and may no be particularly relevant to low temperature winter condition.

Thurston *et al* (1984) also examined chronic toxicity of ammonia to rainbow trout (*Onchorhynchus mykiss*) in full life cycle investigations conducted at 10ºC. Unfortunately ammonia concentrations investigated for non-early life stages were insufficient to produce a growth or mortality toxicological response. The highest test chamber concentration in the study was 0.061 mg NH_3-N/L, although the author reports a short-term (98 days) higher exposure of 0.091mg NH_3-N/L in one test chamber containing trout with ages between 15 and 19 months. Using these values as no effect concentrations (NOEC) and a size and water quality appropriate acute 96-hour LC_{50} (0.38 NH_3-N/L) yields ACRs of 6.2 and 4.2, similar to ACRs reported for other fish species.

The final ACR was calculated, using acute and chronic data summarized in Table 14 and 15, resulted in a statewide ACR of 7.75. Comparing the data used to compute this statewide ACR with the non-early life stage and low temperature chronic toxicity fish information indicates the available data (and estimated ACR) are similar to the statewide ACR – geometric mean of the three species (low temperature only) yields an ACR of 6.8 or 7.5 (depending on which ACR for rainbow trout). Given that this data does not conform to the requirements in Stephan *et al* (1985) for chronic toxicity data, the proximity of this additional data to the statewide value, and to be protective until adequate information is available, the use of the statewide final ACR for the winter period is reasonable and appropriate.

When the statewide ACR is applied to the FCV calculated for the FW2-NT classification for the winter period results in a CCC of 0.060 mg NH_3-N/L. The FCV was compared to the chronic toxicity data from the database to determine whether the FW2-NT CCC for the winter period was protective of recreationally or commercially important species. However, the FCV was less than the lowest chronic values contained in the database for these important species. For the data available, the lowest chronic values for fish are less than the lowest values for algae and macrophytes. Therefore, the FCV based on fish (and invertebrate) data are protective for important species and algae and was established as the CCC for the winter period.

The CCC was merged with the pH and temperature correction models developed using the acute data (see section IV. N.) to obtain formulated CCC. As discussed in Chapter VI, Section B application of the correction models was determined to be appropriate based on guidance in Stephan et al. (1985). The recommended Winter CMC for this water classification is 0.232 mg NH_3-N/L at 20°C and pH 7.80. The recommended models for temperature and pH correction are:

$$\text{CCC(mg NH}_3\text{-N/L)} = 0.060 * 10^{0.026(\text{TEMP}-20)+0.41(\text{pH}-7.80)}$$

for pHs below 8.30 and:

$$CCC(\text{mg } NH_3\text{-N/L}) = 0.060*10^{0.026(TEMP-20)+0.20}$$

for pHs equal to or greater than 8.30.

Comparison of Summer and Winter Period CMC and CCC

A comparison was conducted to evaluate differences in the FW2-NT criteria during the summer and winter period. The Delaware River at Trenton U.S. Geological Survey (ID# 01463500) was used for water quality data (temperature, pH and conductivity) to evaluate potential differences in the CCC and CMC during the summer versus winter periods. The water quality data for the station and the resulting criteria comparison are summarized in the following tables.

Average Daily Water Quality for the Delaware River at Trenton, New Jersey U.S. Geological Survey station (ID# 01463500)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (ºC)	1.9	2.6	5.8	10.9	16.8	22.7	25.8	25.3	21.6	14.8	8.8	3.7
pH	7.8	7.9	7.8	7.8	7.7	8.1	8.2	8.1	7.9	8.0	7.7	7.6
Conductivity (μmhos)	176	171	154	135	150	172	186	206	204	192	166	157

Un-ionized Ammonia Criteria and Total Ammonia Concentrations for Freshwater Nontrout (FW2-NT) Waters During Summer (March 1- October 31) and Winter (November 1- February 28)

Periods Based on Data for the Delaware River

Criterion	Un-ionized Ammonia Reference Value		Un-ionized Ammonia Adjusted Value		Total Ammonia Translated Value	
	Summer Value	Winter Value	Summer Value	Winter Value	Summer Value	Winter Value
Criterion Maximum Conc.	0.201	0.232	0.420	0.089	5.09	13.2
Criterion Continuous Conc.	0.054	0.060	0.113	0.023	1.37	3.41

Conductivity = 250 μmhos; Winter Temp.= 4ºC; Summer Temp.= 26ºC; Winter pH = 7.8; and Summer pH = 8.2.

As can be seen in the above table the un-ionized ammonia CMC and CCC are much lower, approximately 5 times, in the winter versus the summer for conditions observed in the Delaware River at Trenton. This is due to both temperature and pH being lower during winter, which results in a decrease in the criteria - the criteria decrease with both temperature and pH decreases. However, when translated to a total ammonia value, using the model developed for NJDEP, the total ammonia associated with the un-ionized ammonia criteria increases from the summer to the winter period – winter total ammonia is approximately 2.5 times greater than summer total ammonia. This increase is within the range of the 2 to 3 fold increase that Mr. Tudor Davis suggested for a winter versus summer total ammonia criteria adjustment in the cover letter to the interim total ammonia criteria published by U.S. Environmental Protection Agency (USEPA 1998).

VIII. COMPLIANCE OF NEW JERSEY WATERS WITH UIA CRITERIA

In the following sections, historical water quality monitoring data were used to evaluate current compliance and historical trends of New Jersey waterbodies with the UIA water quality criteria. Additionally, environmental factors that affect compliance of New Jersey waterbodies with the UIA water quality criteria were evaluated by using the monitoring data.

A. **METHODS**

The water quality database examined consisted of data from the Department's water quality monitoring program, obtained from USEPA's STORET national computer database. Parameters obtained from the STORET included those necessary to adjust the ambient UIA criteria (i.e., temperature and pH), estimate UIA concentrations from total ammonia concentrations (e.g., hardness conductivity, and total dissolved solids), and parameters for evaluating environmental factors.

To analyze compliance for New Jersey waters with the criteria, each monitoring station's location on a waterbody was determined using latitude and longitude and site descriptions. These locations were then used to determine the appropriate surface water classification from the "Surface Water Quality Standards, Surface Water Classifications" (NJDEP, 1989) and the reclassifications adopted on August 16, 1993. Ammonia criteria for each water classification were selected for each station and adjusted using the pH and temperature data for each monitoring date and the correction models. Compliance was determined by comparing the adjusted criteria to the estimated UIA concentration for each monitoring date at each station in the water quality database.

Environmental conditions are known to affect total ammonia concentrations in the water and compliance with the proposed criteria. The water quality database was used to investigate the importance of specific environmental conditions by comparing total ammonia and UIA to other parameters in the water quality database. Parameters were selected to reflect factors that may affect calculation of UIA (i.e., pH, temperature, ionic strength) and total ammonia concentrations (i.e., temperature, flow, tidal stage, dissolved oxygen, and total nitrogen).

Environmental factors were evaluated for stations with historical UIA concentrations that exceeded the proposed criteria to ensure levels of total ammonia and UIA were well above detection limits. UIA and total ammonia were compared to each of the other water quality parameters using correlation analysis to determine if there was interdependence between the other water quality parameters and ammonia concentrations. A Pearson correlation coefficient (Sokal and Rohlf, 1981), which indicates the degree of association between two variables, was calculated and the significance of the correlation was determined for each pair (e.g., UIA vs. temperature). Slopes of the significant correlations were determined using regression methods (SAS, 1985) to determine whether the relationships were significantly different from zero and from each other.

Historical trends were evaluated by plotting UIA and total ammonia for the ten years of water quality data for stations where UIA concentrations exceeded the proposed criteria. Historical trends in ammonia are waterbody specific, and observed trends may be functions of changing land use, increases or decreases in industrial discharges, and improved wastewater treatment. Graphic presentations were examined to determine whether ammonia concentrations have increased, decreased or remained unchanged for these stations.

B. **RESULTS OF COMPLIANCE EVALUATION**

The stations found to have UIA concentrations greater than the proposed CCC and CMC during the years 1987 to 1990 are summarized in Table 18 and Table 19.

Evaluation of compliance using the existing database is only a preliminary assessment due to the nature of the monitoring data and monitoring requirements necessary for evaluating compliance using the proposed criteria (Stephan et al., 1985). The CMC requires an averaging of hourly samples, and the CCC requires an averaging of daily sampling to evaluate compliance. The water quality database only contained monthly and quarterly grab samples.

To improve confidence in this preliminary compliance assessment, certain guidelines were used to select stations from the water quality database. To be certain noncompliance is a recent condition of the waterbody, only samples collected during the years 1987 to 1990 were used. Each station selected had at least one sampling date with UIA concentrations greater than the criterion. Finally, at least five of the remaining UIA concentrations that were below the criterion had to fall within a factor of five of the criterion to ensure that the single high value was not due to analytical error or sample contamination.

A total of 46 stations sampled in the last ten years were found to have UIA above the proposed CCC, but only ten of these stations had been sampled in the last three years (Table 18). Of the ten stations, four had no UIA concentrations above the criteria for the last three years and two stations had no UIA concentrations above the criterion for the past two years. Only four of all monitored stations had a sufficient number of UIA concentrations greater than the CCC or in close proximity to the CCC to be considered potentially out of compliance with the proposed criterion.

A total of 11 stations sampled in the last ten years had UIA above the proposed CMC; however, only two of the stations were sampled during the last three years (Table 19). Both stations had UIA observations within a factor of five of the CMC, but neither of the two stations contained any UIA concentrations above the criterion during the last three years.

This compliance analysis may not adequately represent actual numbers of waterbodies out of compliance with the proposed criteria for a couple of reasons. First, the number of samples collected decreased from 2,989 in 1979 to 749 in 1989. Secondly, the number of stations sampled also decreased during this period from 435 in 1979 to 173 in 1989. These numbers show the sampling effort has declined (1/3 of 1979 sampling) significantly in the last ten years.

Although the exact number of waterbodies anticipated to be out of compliance with the proposed criteria can not be precisely determined, the numbers of waterbody areas in the vicinity of discharges that are not in compliance with the proposed criteria can be inferred. The four stations potentially out of compliance with the CCC are approximately 3% of the total number of stations (140) sampled in the last three years. Historically, a total of 46 stations had UIA above the proposed CCC criteria, which is approximately 5% of the total number of stations monitored (873). Therefore, approximately 3% to 5% of waterbodies located in the vicinity of a discharge containing ammonia potentially will be out of compliance.

To evaluate differences in compliance between the proposed UIA criteria and the current ambient ammonia criteria, stations that had at least one observation greater than the current criteria were identified. This list of stations was compared to the lists of stations with at least one observation above the proposed criteria (Table 18 and 19). Stations with UIA observations above the current criteria that were not identified using the proposed criteria are summarized in Table 20, and stations with observations above the proposed criteria that did not exceed the current standard are summarized in Table 21.

Seven stations in trout waters had observations above the current criterion (0.02 mg/L) that did not exceed the proposed criteria. This suggests that the proposed criteria for trout waters are less stringent than the current UIA criterion for these waters. For FW2-NT waters, 12 stations had at least one UIA observation above the current criterion (0.05) that did not exceed the proposed CCC and 10 stations had at least one UIA observation above the proposed CCC that did not exceed the current criteria. This suggests that the proposed criteria for FW2-NT waters are no more and no less stringent than the current criterion and that the differences in identified stations are due to adjusting the proposed criteria for water conditions (i.e., temperature and pH).

Both the proposed CCC and CMC for FW2-NT waters were compared graphically to the current criteria (Figs. 15 and 16). These two figures clearly demonstrate the effect of pH and temperature on the proposed criteria. These figures also indicate that at lower temperatures and pH, the proposed criteria are more stringent than the current criteria, and at high temperatures and pH, the current criteria are more stringent than the proposed criteria.

Evaluation of compliance using the current and the proposed criteria (0.05) indicate the criteria are similar but vary somewhat from waterbody to waterbody. The graphic presentation of the criteria (Figs. 15 and 16) suggests that the proposed criteria cannot be characterized as more or less stringent than the current criteria, and that differences in compliance between the current and proposed criteria are due to temperature and pH differences of the waterbodies.

C. **HISTORICAL TRENDS**

Historical trends in concentrations of total ammonia and UIA were evaluated by station. The monthly and quarterly sampling program limits the conclusions that can be made regarding historical trends. When historical trends in ammonia concentrations are observed for a station, a high degree of confidence can be placed in the conclusions; however, when no changes are observed, historical changes may have occurred although they were not detected. The stations with UIA above the proposed CCC sampled within the last three years are presented in Figs. 17 through 26. Changes in total ammonia and UIA with time differ greatly among stations.

Trends observed at stations 01467140 and 7296000076 (Figs. 17 and 18), located on the Cooper River were slightly similar. Concentrations of total ammonia in monthly grab samples fluctuated from 1979 to 1987 but increased steadily overall. The total ammonia concentration decreased suddenly, by at least an order of magnitude, between August and October of 1987. This dramatic decrease is directly due to facilities along this stretch of the river connecting their discharges to Camden County MUA over the summer months.

Stations 01381200 on the Rockaway River (Fig. 19) and 01407997 on Marsh Bog Brook (Fig. 20) had historical trends for total ammonia similar to the two stations discussed previously. The periodic peaks in total ammonia for these two stations tended to increase from 1979 to 1985. The concentrations at both these stations dropped too much lower levels between the end of 1985 and the beginning of 1986. The drop in total ammonia levels at Station 01381200 on Rockaway River is due to an upgraded facility of the Rockaway Valley Sewerage Authority. The Department is unsure why the ammonia levels dropped at Station 01407997 on Marsh Bog Brook.

The historical trends in total ammonia at Station 01399200 on the Lamington (Black) River (Fig. 21) differed from all other stations. Total ammonia concentrations in the monthly grab samples remained relatively low (< 1 mg/L) from 1979 to 1984. From 1985 to 1987, increasing periodic peaks in total ammonia were monitored during the spring of each year. These peaks gradually declined over the next two years of monitoring. The cause of periodic peaks is difficult to assess, but since they are typically found during the spring period, they may be associated with agricultural runoff occurring during rainfall events.

Historical total ammonia and UIA concentrations showed parallel trends at two stations on the Saddle River, Stations 01391200 and 01391500 (Figs. 22 and 23), except that concentrations at Station 01391500, located downstream of Station 01391200, were 1 to 3 mg/L lower. These lower concentrations probably were due to dilution or instream nitrification during downstream transport. Periodic and somewhat seasonal peaks in total ammonia occurred during late fall and early spring, over the period 1979 to 1990. No identifiable changes in total ammonia were apparent in the database for these two stations, suggesting that the water quality remained relatively constant over the last decade.

Two of the remaining three stations examined, Station 01381800 on the Whippany River (Fig. 24) and Station 01467081 on the South Branch of Pennsauken Creek (Fig. 25), are similar to the two stations on the Saddle River. These two stations also have periodic fluctuations in total ammonia and have remained relatively unchanged over the past decade. The last station, Station 01398000 on the Neshanic River (Fig. 26), had a total ammonia value of approximately 1 mg/L in 1979; the remaining values typically were less than 0.2 mg/L.

D. **ENVIRONMENTAL FACTORS**

Seven parameters correlated significantly with total ammonia for the ten stations with UIA concentrations exceeding the proposed criteria; however, only four of these parameters correlated repeatedly (Table 22). Seven parameters also correlated significantly with UIA for the different waterbodies, and six of these correlated repeatedly (Table 23). There was insufficient data for four parameters, acidity, salinity, total dissolved solids, and tidal stage, to evaluate relationships to either total ammonia or UIA for any of the stations. Each of the water quality parameters, found to be significantly correlated with total ammonia and UIA, are discussed below.

1. Conductivity

Conductivity, a measure of the concentration of charged ions in an aqueous solution, correlated with total ammonia for nine of the ten stations (Table 24) and with UIA for six of the ten stations (Table 25). The correlation coefficients, which indicate the degree of closeness of the data, for conductivity and ammonia varied from 0.3 to 0.9, indicating a high degree of variability between streams. To determine whether the correlations were different from one another, regression analysis was used to compare slopes for the correlations of different stations. Many of the slopes differed significantly from each other, including stations 7296000076 and 01467140 on the Cooper River, and 01391200 and 01391500 on the Saddle River. These results suggest that the relationships are waterbody and site-specific and that no general relationship holds for all New Jersey waterbodies.

The number of stations with significant correlations between ammonia and conductivity suggest that stream flow is a major environmental factor affecting ambient ammonia concentrations and compliance of New Jersey waterbodies. Conductivity fluctuates with increases and decreases in flow (Campbell et al., 1987). Further, treated wastewater, which are relatively high in total dissolved solids and higher in conductivity than receiving freshwaters (Metcalf and Eddy, 1979), will comprise a greater proportion of receiving waterbody flow as flow decreases. Thus, ammonia concentrations due to treated wastewater discharges are likely to increase as conductivity increases, which is demonstrated by the number of significant correlations found for conductivity.

Instream flow may fluctuate seasonally or on multiyear cycles in response to short and long-term meteorological conditions. These fluctuations in flow will affect the dilution of ammonia discharged to the receiving waterbody; much higher concentrations are expected during low flow extremes. Stephan et al. (1985) considered flow of the receiving waterbody to be important in determining compliance. Therefore, flow conditions of the receiving waterbody should be considered when evaluating and monitoring compliance.

2. Alkalinity and Hardness

Alkalinity and hardness commonly correlate with each other in freshwater aqueous systems, as alkalinity increases hardness increases. This is due to both parameters being related to solubilization of limestone minerals (calcium carbonate) associated with rocks of the watershed. Therefore, these parameters are analyzed and discussed together.

Total ammonia correlated with alkalinity at six stations and with hardness at five stations; five of these stations were in common (Tables 26 and 27). These two parameters also correlated with UIA at five stations (alkalinity) and four stations (hardness), with two of the stations in common (Tables 28 and 29). As for conductivity, many of the regression slopes for total ammonia were significantly different, suggesting the relationships are waterbody specific. The slopes of the significant correlations for UIA were homogeneous for alkalinity and hardness; however, the slopes were not significantly different from zero, indicating weak relationships.

The number of stations with significant correlations between ammonia and these two parameters further indicate the importance stream flow may have as an environmental factor affecting ambient ammonia concentrations and compliance of New Jersey waters. These two parameters are directly related to conductivity, as conductivity increases hardness and alkalinity increase, which further suggests the importance of flow as an environmental factor.

3. Dissolved Oxygen

Seven of the ten stations had significant negative correlations between DO and UIA (Table 30), and four stations had significant negative correlations between DO and total ammonia (Table 31). Only three of the significant UIA correlations had slopes that were significantly different from zero, and these three were only slightly less than zero.

Three of the four total ammonia correlations had slopes significantly less than zero. One of these three slopes was significantly different from the other slopes.

DO correlation with ammonia further indicates the importance of stream flow as an environmental factor. The correlation of DO with ammonia indicates, particularly for total ammonia, that the lower the DO the greater the total ammonia concentration. Also, lower DO concentrations were found to be associated with higher conductivity. Lower ambient DO is expected when wastewater discharge comprises a greater proportion of flow. Low DO and high BOD (biochemical oxygen demand) in treated wastewater (Metcalf and Eddy, 1981) may cause this lower ambient DO, which would correspond with increased ammonia concentration.

4. Total Nitrogen

Total nitrogen correlated significantly with total ammonia for eight of the ten stations (Table 32) and with UIA for four of the stations (Table 33). The regression slopes of the correlations for total ammonia were homogeneous, indicating that the relationship between total ammonia and total nitrogen are similar for all waterbodies. The regression slopes of the correlations for UIA were also homogeneous; however, the majority of the slopes were not significantly different from zero.

Correlation between ammonia, both total and UIA, and total nitrogen is most likely an artifact of the total nitrogen measurement. Total nitrogen is comprised of organic nitrogen, nitrate, and ammonia. Therefore, the correlations appear because ammonia is a component of the total nitrogen concentration or that both variables have a common cause, such as a wastewater treatment facility discharge.

5. Temperature

Only three of the ten stations had significant correlations between temperature and total ammonia, and two of these were found to have negative slopes significantly different from zero (Table 34). Four stations had significant correlations with UIA, and only two of these had slopes significantly different for zero (Table 35).

The two negative correlations indicate that as the waterbody temperature decreases, the total ammonia concentration increases. Total ammonia increases at lower water temperatures may be related to wastewater treatment. Lower temperatures in wastewater over winter periods can result in reduced nitrification of ammonia. Reduced nitrification would increase ammonia in the discharge, resulting in higher total ammonia concentrations.

The significant positive correlations between temperature and UIA may be due to the contribution of temperature in the equilibrium model to estimate UIA from total ammonia (see Chapter X). As temperature increases the equilibrium is shifted toward UIA, which implies that if total ammonia concentrations remain constant, increasing temperature would result in greater UIA concentrations.

Temperature should be considered an important environmental factor affecting UIA compliance and should be monitored with total ammonia. Although only a low number of the stations showed any relation between temperature and ammonia, temperature was found to be an important factor in the toxicity of UIA to freshwater organisms (Dietz et al., 1990) and was a correction factor for the freshwater criteria. Stephan et al. (1985) also included a temperature correction factor for the national freshwater criteria. The importance of temperature on the freshwater criteria is demonstrated in Fig. 16, which indicates that as temperature decreases the criteria also decrease.

6. pH

Nine of the ten stations had significant positive correlations for pH with UIA (Table 36). Three stations had significant correlations with total ammonia; two of these had negative correlations (Table 37). Only two of the significant correlations with UIA had slopes that were not significantly different from zero. The remaining seven correlations with UIA had slopes that were significantly greater than zero. Two of the three correlations with total ammonia had slopes significantly less than zero. The correlations with non-significant slopes were significantly different from the other correlations.

The positive correlations of UIA with pH may be related to the effect pH has in the equilibrium of ammonium ion and UIA (see Chapter X); pH is one of the major factors affecting UIA concentrations. Under constant total ammonia, this equilibrium results in UIA concentrations that increase with increasing pH. Therefore, the numbers of UIA correlations with pH are likely related to the equilibrium equation.

The negative correlations of total ammonia with pH (i.e., as pH decreases total ammonia increases) may be due to washout of treatment facilities or agricultural/urban runoff during storm events. Receiving waterbodies, particularly streams and rivers, normally display a decrease in pH and increase in flow in response to rainfall (Lynch et al., 1986). Rainfall events can have serious consequences on treatment facilities serving combined sewer systems, resulting in washout of solids and high ammonia concentrations from the facility. Also, high concentrations of ammonia can occur in agricultural and urban runoff. During storm events, these sources could increase ammonia concentrations whereas pH would decrease.

pH should be considered an important environmental factor affecting UIA concentrations as well as compliance. The importance of pH in determining UIA concentrations is indicated by the large number of stations with positive correlations. Further, pH is an important factor affecting the toxicity of UIA to freshwater organisms and is used as a correction factor for the freshwater classifications (Dietz et al., 1990). Stephan et al. (1985) also included a pH correction for the national freshwater criteria. The importance of the pH correction factor on the criteria is demonstrated in Fig. 15, which demonstrates that as pH decreases the adjusted criteria also decreases.

E. **SUMMARY**

This section evaluated current compliance of waterbodies in New Jersey with the proposed ambient UIA water quality criteria, evaluated historical trends in ambient ammonia concentrations at stations with historical ammonia concentrations that exceeded the proposed criteria, and determined environmental factors that affect total ammonia and UIA concentrations and compliance with the proposed criteria. This investigation found:

- four stations monitored during 1987 to 1990 potentially are out of compliance with the proposed criteria, which equated to approximately 3% to 5% of all waters receiving a permitted ammonia discharge;

- a number of stations historically out of compliance showed decreases in total ammonia concentrations, which resulted from connections to local MUAs and improved treatment; and

- a number of water quality parameters correlated with total ammonia and UIA; of these, flow, pH, and temperature are likely to affect ammonia concentrations and compliance with the proposed criteria.

IX. ECONOMIC ASSESSMENT OF IMPLEMENTING THE RECOMMENDED CRITERIA

Ambient ammonia concentrations in waterbodies are affected by pollution from both non-point sources (NPS) and point sources (PS). NPS of ammonia are due to surface water runoff from agricultural areas and urban areas. NPS are difficult to eliminate, but they can be reduced through better management of agricultural practices and urban stormwater runoff. PS pollution from municipal and industrial sources is easier to focus on because it contributes much greater concentrations of ammonia and is easier to control.

PS pollution of ammonia can be reduced or eliminated by treatment of wastewater, using a variety of pollution control technologies. Water and wastewater treatment technologies are categorized as physical, chemical or biological, and land application. Control technologies for ammonia removal are available in all of these categories, depending on the characteristics of the wastewater to be treated.

Economic assessment of costs incurred when implementing new criteria is an integral part of determining whether new criteria are appropriate. Typically, as effluent quality from treatment facilities is improved, the capital costs (Fraas and Munley, 1984; and Eckenfelder and Ford, 1969) and operation costs (Burke, 1976) increase. Government managers and planners will require estimates of cost increases to determine whether the costs of the proposed criteria are too great an economic burden.

In the following sections the costs to the State and people of New Jersey of implementing the recommended New Jersey-specific ammonia criteria have been evaluated by comparing secondary advanced treatment costs to additional costs associated with ammonia removal.

A. **METHODS**

Costs of additional treatment to remove ammonia to achieve compliance with the proposed CMC and CCC were evaluated using unit annualized costs. The unit annualized cost is a cost per unit capacity (e.g., dollars per 1000 gallons wastewater treated) and is estimated by dividing annualized costs by the annual capacity. Annualized costs include: annual operating costs, costs of financing, depreciation costs, and income tax allowances (DeWolf et al., 1984). The approach will permit a general comparison to evaluate anticipated increases in treatment costs to remove ammonia, the potential effect to the rate payers, such as, the public for municipal wastewater treatment plants, and to assess whether costs, on a State wide basis, of implementing the recommended criteria are reasonable.

Unit annualized cost estimates associated with implementing the recommended criteria were determined by:

- identifying select control technologies that may be appropriate for ammonia removal;

- estimating unit annualized costs for the selected ammonia removal technologies;

- comparing the increased unit annualized costs to secondary and advanced wastewater treatment unit annualized costs.

The above economic assessment approach relies upon a number of assumptions that may either under or over estimate the unit annualized costs associated with implementing the recommended criteria for an individual discharge, which include:

- type of existing facility and compatibility of identified ammonia removal technologies;

- excess capacity within existing facilities and/or ability to achieve ammonia removal within existing facilities;

- inability to include site specific costs, e.g., land acquisition, local labor costs, local taxes, and other local effluent requirements.

In addition, the above evaluation only includes the increased costs associated with ammonia removal and does not consider potential economic gains (i.e., recreation, aesthetics, social, etc.) associated with improved water quality and fishery stocks.

Control Technologies for Ammonia Removal and Unit Process Costs

The control technologies for ammonia removal were identified by reviewing wastewater engineering literature. Each ammonia removal technology was evaluated for its feasibility and use in municipal and industrial wastewater treatment. The basic mechanisms of removal for remaining technologies were evaluated by examining literature pertaining to the technology.

Unit annualized costs for treatment plant upgrades with identified ammonia removal technologies were estimated based on information presented in "Cost Digest: Cost summaries of selected environmental control technologies" (DeWolf et al., 1984). The unit annualized costs in 1980 dollars were estimated using cost functions for the selected ammonia removal unit processes. The functions relate costs to design capacity (i.e., flow) of the treatment facility. The costs to upgrade unit processes were corrected to 1999 dollars using material and price indexes (i.e., Engineering New Record Construction Cost Index) and the equation (Metcalf and Eddy, 1979. Table 38):

Current Cost = Base Year Cost*(Current Index/Base Year Index).

The 1980 Base Year Index reported in DeWolf et al. (1984) was 3,150 and the Current Index of 8,434 was the average of the reported values for New York, NY (9,382) and Philadelphia, PA (7,486).

B. **RESULTS AND DISCUSSION**

1. Control Technologies for Ammonia Removal

The control technologies identified for ammonia reduction in wastewater treatment can be classified into one of four major categories. The categories are physical, chemical, biological, and land application treatment.

Several physical treatment methods for ammonia removal from water include air stripping, electrodialysis, and reverse osmosis; however, only air stripping has been used as a wastewater treatment process (Culp and Culp, 1971). The remaining technologies are used in drinking water and industrial water treatment. Air stripping is a modified aeration process used for the removal of dissolved gases (e.g., ammonia). Ammonium exists in equilibrium with UIA (a dissolved gas) and is shown in the following equation:

$$NH_3 + H_2O \longleftrightarrow NH_4^+ + OH^-$$

It is converted to UIA by elevating the pH with lime (Metcalf and Eddy 1979). The UIA is released to the atmosphere as a gas either by aeration in a basin or by cascading the wastewater down a tower. This method removes between 60% and 95% of ammonia in the wastewater (Metcalf and Eddy, 1979). This method may be limited by temperature where towers are employed and by the return of ammonia to the environment in precipitation (Hammer, 1975).

Two chemical treatment methods, selective ion exchange and breakpoint chlorination, were identified for ammonia removal from water. Selective ion exchange, uses an insoluble exchange material, typically a resin, which displaces ammonium ions with a different ion (e.g., hydrogen ion). This treatment method is used primarily for drinking or industrial process waters. Breakpoint chlorination, which has been used in wastewater treatment (Benefield et al., 1982), uses the oxidizing power of chlorine to convert ammonia in wastewater to nitrogen gas in the reaction:

$$2NH_3 + 3HOCL \longrightarrow N_2 + 3H_2O + 3HCl$$

This process can remove 100 % of ammonia from the wastewater and has the added advantage of disinfection of the wastewater. However, this process increases use of chlorine, increases dissolved solids, consumes alkalinity, produces carcinogenic trihalomethanes, and even with proper process control, will release residual chlorine compounds (e.g., chloramines and hypochlorous acid), which are acutely toxic to aquatic organisms (White, 1972). Residual chlorine compounds can be eliminated by using additional dechlorination processes.

Biological treatment to remove ammonia is performed by bacteria that convert ammonia to nitrate in a process called nitrification (Sharma and Ahlert, 1977).

Ammonia oxidation is a two step process in which ammonia is first converted to nitrite by bacteria of the genus Nitrosomonas by the reaction:

$$NH_4^+ + 3/2O_2 \text{ ---> } 2H^+ + H_2O + NO_2^-$$

The nitrite is then oxidized to nitrate by bacteria of the genus Nitrobacter by the reaction:

$$NO_2^- + 1/2O_2 \text{ ---> } NO_3^-$$

Both of these reactions yield energy that the bacteria use to fix carbon dioxide. The overall oxidation of ammonia is expressed by the reaction:

$$22NH_3^+ + 37O_2 + CO_2 + HCO_3^- \text{ ---> } C_5H_7NO_2 + 21NO_3^- + 20H_2O + 42H^+$$

This overall reaction shows that the energy bound in ammonia is converted to organic carbon (i.e., bacterial growth). Bacterial nitrification in wastewater treatment is the most accepted control technology for ammonia removal. Biological removal of ammonia is performed using either suspended growth or attached growth treatment systems (Parker et al., 1989; Metcalf and Eddy, 1979; Sharma and Ahlert, 1977; Weng and Molof, 1974). Suspended growth systems include: combined stage activated sludge; or separate stage activated sludge. Attached growth systems include: separate stage trickling filter; and rotating biological contact units. Combined stage activated sludge requires conditions conducive to nitrifying bacteria, such as minimum temperatures, increased mean cell residence times and increased aeration; therefore, combined stage can be considered a seasonal control process at best (Metcalf and Eddy, 1979).

The remaining technology is an alternative use of the discharge from the facility. This alternative technology eliminates discharge of treated wastewater to a surface water by application of the wastewater effluent to land through spray irrigation (OWPM, 1980). The ammonia in the effluent is oxidized to nitrate by nitrifying bacteria in the soil or used as a nutrient by plants. The use of this technology is limited by the extensive area of land required for spray irrigation.

Several control technologies in physical, chemical, and biological treatment were identified for ammonia removal at wastewater treatment plants. Of the identified technologies, air stripping, more commonly associated with industrial discharges, and biological treatment using bacterial nitrification, most commonly employed ammonia removal technology in municipal wastewater treatment, were considered for evaluating costs. Cost information was available for both separate stage activated sludge and air stripping technologies from an EPA publication (Figs. 27 and 28; DeWolf et al., 1984); due to the similarity in costs of the different biological removal processes (Tihansky, 1974), only separate stage activated sludge was used for cost estimation. The intent of the selection was not to identify technologies to be applied to specific discharges in New Jersey, but to identify various technologies for the purpose of providing a range of cost estimates (Table 38). It is likely the actual cost of compliance at an individual facility may be higher or lower depending on site specific factors, technologies deemed appropriate for removing ammonia, and impact of other permit limits, such as, total nitrogen.

2. Estimated Costs to Achieve Compliance

The unit annualized cost is a cost per unit capacity, in dollars per 1000 gallons wastewater treated, is estimated by dividing annualized costs by the annual capacity. The unit annualized costs were determined from the cost function figures (Figs. 27 and 28) and corrected to current 1999 dollars. The ammonia stripping unit annualized cost was calculated as the average of the four types of air stripping technologies presented in the figure. The unit annualized costs in 1999 dollars for separate-stage activated sludge nitrification and ammonia stripping for various wastewater treatment plant capacities are provided in Table 38. The unit annualized costs for secondary wastewater treatment and advanced wastewater treatment are also provided in the Table 38. The analysis indicates the increase in costs is related to type of wastewater treatment and wastewater flow with treatment costs likely increasing by approximately 11% to 37% at secondary wastewater treatment plants and 8% to 21% at advanced wastewater treatment plants where ammonia removal is required.

3. NJPDES Permittees with Potential Ammonia Discharge Impacts

The impact of the proposed ammonia criteria on existing NJPDES permittees varies considerably from water classification (i.e., fresh versus saltwater) and wastewater treatment type (i.e., municipal versus industrial). The potential impact of the proposed criteria on the various NJPDES permittees is briefly discussed below.

Municipal NJPDES permittees discharging into fresh waters have previously been regulated for ammonia, and it is expected that the discharges will not be appreciably impacted. Some facilities may receive more stringent ammonia limits while other facilities' limits will remain unchanged (due to antibacksliding provisions of the Clean Water Act). The impact will likely be dependent on site specific conditions (e.g., receiving waterbody characteristics and mixing) since the proposed criteria are more or less stringent depending on receiving stream conditions (i.e., temperature and pH). Decreases in Summer effluent ammonia limits are likely to have minimal impact since most facilities have effluent limits requiring ammonia removal and currently operate well below their existing summer ammonia limits. Decreases in winter effluent ammonia limits may pose a greater impact to facilities utilizing combined-stage biological nitrification for ammonia removal, because winter nitrification is limited at low water temperatures in this treatment process. Additional ammonia removal technologies may be required to achieve imposed winter ammonia limits at these facilities. However, it is difficult to assess whether the proposed criteria would result in additional treatment requirements over existing ammonia criteria, because existing procedures calculate winter limits from summer effluent limits.

Municipal NJPDES permittees discharging into saline waters have not previously been regulated for ammonia, and it is expected that they will be impacted more greatly than discharges to freshwaters who have been previously regulated for ammonia. As with freshwater permittees, additional ammonia removal treatment will be dependent, in part, on site-specific conditions that will have an effect on the effluent limits and level of ammonia removal required. In addition, the type of facility (e.g., activated sludge versus trickling filter) and capacity at the facility will be important in determining whether the facility can remove ammonia (via biological nitrification) and achieve effluent limits within existing facilities.

Industrial NJPDES permittees that either have ammonia permit limitations or discharge sanitary wastewater into fresh and saline waters are likely to be minimally impacted by the proposed criteria. Of all the industrial facilities with NPDES permits, only one industrial facility, Burlington County Resource Recovery Center, has water quality-based ammonia limitations. All other facilities' ammonia limitations are based on either ELGs, local regulations, or Best Professional Judgment, which tend to be more stringent than water-quality based ammonia limitations (i.e., effluent limits that would be derived from the proposed criteria). Comparison of the proposed criteria with existing discharge levels (taken from the DMRs over the past year), indicates that most of these facilities would not be effected by the new criteria.

4. Comparison of Promulgated Criteria and Recommended Criteria

The water quality database indicated that compliance of waters was somewhat different historically for the promulgated criteria in comparison to the recommended criteria; however, due to reduced sampling effort the same waterbodies are presently out of compliance with both current and recommended criteria. Therefore, the costs of ammonia reduction to achieve compliance would be the same for the current and the recommended criteria, if both were equally enforced.

C. **SUMMARY**

Economic costs associated with implementing the proposed UIA water quality criteria in New Jersey waterbodies were evaluated. It was found that:

- Both physical (ammonia stripping) and biological (fixed-film and suspended growth) ammonia control technologies may be acceptable technologies to remove ammonia and were selected to evaluate costs.

- Evaluation of costs to reduce ammonia concentrations and achieve compliance with the recommended ambient ammonia water quality criteria increase wastewater treatment costs from 8% to 37% for identified control technologies depending on existing facilities and wastewater flow.

- Costs associated with enforcement of the recommended ambient ammonia water quality criteria will not substantially differ from the old ambient ammonia water quality criteria.

X. MODELS USED TO ESTIMATE UIA FOR VARIABLE TEMPERATURE, pH, AND IONIC STRENGTH

Ammonia (total) occurs naturally in surface and ground waters at relatively low concentrations, typically less than 1 mg/L as NH4-N. Elevated concentrations of total ammonia in surface waters occur as a result of anthropogenic inputs. These elevated concentrations have significant toxic impacts on resident freshwater and saltwater populations (Alabaster and Lloyd, 1980; Haywood, 1983). The free base of total ammonia, UIA, comprises a small fraction of total ammonia and is the toxic agent to aquatic organisms (Thurston et al., 1981a).

Numerous analytical methods are available to determine total ammonia concentrations (APHA, 1985); however, none of the methods currently available can measure UIA. As a result, UIA must be estimated using ammonia-water equilibrium equations that are based on the relationship of UIA to ammonium ion. The equation expressing this equilibrium reaction is:

$$NH_4^+ + H_2O \Leftrightarrow NH_3 + H_3O^+ \tag{1}$$

This relationship indicates that the ratio of UIA (NH_3) to ammonium ion (NH_4^+) is dependent on the hydrogen ion concentration (i.e., pH) of the system. This relationship is also effected by the temperature and ionic strength of the system.

Several investigators have attempted to model UIA from total ammonia concentrations (UIA and ammonium ion) in freshwater and saltwater using a combination of empirical models and experimental data. Emerson et al. (1975) evaluated the equilibrium for freshwater using pH and temperature to correct for UIA concentration. Their model did not consider the effects of ionic strength on UIA concentrations and used an empirical correction for temperature. Messer et al. (1984) improved on the model by correcting for ionic strength using the Debye-Hueckel theory (Stumm and Morgan, 1981).

Due to the greater number of interactions between ions in seawater, the Debye-Huckel theory has limited application for ionic strength correction in seawater. Bower and Bidwell (1978) and Whitfield (1974) used the Bronsted-Guggenheim hypothesis to estimate an ionic strength correction for UIA in seawater. Pitzer and Kim (1974) described a series of equations to estimate activity coefficients for major components of seawater. Whitfield (1975a) applied these equations to estimate activity coefficients for 23 trace components, including ammonia.

The models presented in the literature were reviewed and a model was developed for estimating UIA concentrations from total ammonia for saltwater and freshwater systems.

A. **MODEL DEVELOPMENT**

The equilibrium of UIA and ammonium ion is defined by the equilibrium reaction (equation 1). The equilibrium of this reaction is:

$$K_a^o = \frac{a_{NH_3} \times a_{H^+}}{a_{NH_4^+} \times a_{H_2O}} \qquad (2)$$

where K_a^o is the equilibrium constant, which is equal to $10^{-9.245}$ for ammonia at 25°C (Bates and Pinching, 1949), and a_i is equal to the activity of the compound *i*. Activity (a) is defined as:

$$a_i = \gamma_i \times m_i \qquad (3)$$

where γ is the activity coefficient, and *m* is the molarity of compound *i*. The activity of hydrogen ions and the equilibrium coefficient can be defined as:

$$a_{H^+} = 10^{-pH} \qquad (4)$$

and

$$K_a^o = 10^{-pK_a^o} \qquad (5)$$

which are negative logarithm transformations.

Substituting, using the above definitions, total ammonia ($m_T = m_{NH_3} + m_{NH_4^+}$) and solving for UIA ($m_{NH_3}$) results in the equation:

$$m_{NH_3} = m_T \Big/ 1 + \left[\left(10^{pK_T^o - pH}\right) \times \frac{\gamma_{NH_3}}{\gamma_{NH_4^+}} \times a_{H_2O} \right] \qquad (6)$$

Many of these variables require correction for temperature and/or ionic strength, that includes: pK_T^o for temperature; γ_{NH_3} and a_{H_2O} for ionic strength; and $\gamma_{NH_4^+}$ for ionic strength and temperature. The temperature and/or ionic strength correction models developed for estimating each of these parameters are discussed below.

<u>1. Temperature Correction of</u> pK_T^o

A different approach than previous models developed by Whitfield (1974) and Emerson et al. (1975) was taken to describe the effects of temperature on pK_T^o. A theoretical approach was considered to evaluate temperature effects on pK_T^o using the van't Hoff equation at constant pressure, which is:

$$\frac{\partial \ln K}{\partial T} = \frac{\Delta H^o}{RT^2} \tag{7}$$

Assuming the heat capacity (ΔC_p^o) is approximately zero, and the change in enthalpy (ΔH^o) is independent of temperature, which is true for many reactions, the van't Hoff equation can be written as:

$$pK_T^o = pK_a^o - \left[\frac{\Delta H_f^o}{2.303R} \times \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right] \tag{8}$$

Substituting the value for pK_a^o at 25°C (9.245) and the calculated H_f^o for ammonia (12.48 kcal/mol), the final temperature correction equation becomes:

$$pK_T^o = 9.245 + \left[2727.24 \times \left(\frac{1}{T + 273.16^o K} - \frac{1}{298.16^o K}\right)\right] \tag{9}$$

This model is very similar to the Emerson et al. (1975) empirical model:

$$pK_T^o = 0.09018 + \frac{2729.92}{T} \tag{10}$$

Estimates of the models were compared (Table 39) over a range of temperatures. The Emerson et al. (1975) model and the theoretical model developed are comparable, however, the Whitfield (1974) model deviates significantly at high and low temperatures.

2. Ionic Strength

Ionic strength (I), which is a measure of the effects of concentration and charge of all ions in an aqueous solution, can be determined using the equation (Bohn et al., 1985):

$$I = \tfrac{1}{2} \sum M_i Z_i^2 \tag{11}$$

where *M* is the molarity of ion *i* and *Z* is the charge of ion *i*. Determining ionic strength using this equation is impractical for monitoring programs because it requires determination of all ions found in a water sample. Equations found in the literature to estimate ionic strength from one or two commonly measured parameters are summarized in Table 40.

3. Ionic Strength Correction for Water

The activity of water (a_{H_2O}) decreases from unity with increasing ionic strength (Stumm and Morgan, 1981). The specific interaction model for seawater (Whitfield, 1973a) was used to estimate the effects of ionic strength on the activity of water. The complexity of this model prohibits its presentation within this proposal and its use in the ammonia model. However, a simpler model was developed by performing a regression on the results of the specific interaction model. The regression model:

$$a_{H_2O} = (-0.0260 \times I) + 1.000 \tag{12}$$

correlated ionic strength (I), significant to $p < 0.005$, to the activity of water ($R^2 = 99.9$). As a result of this linear relationship, this regression model was used to predict the activity of water at various I in the model.

4. Ionic Strength Correction of the Free Ammonia Activity Coefficient

The activity coefficient for UIA (γ_{NH_3}) is independent of temperature and increases from unity with increasing ionic strength (Stumm and Morgan, 1981). The non-linear relationship:

$$\gamma_i = 10^{k_m \times I} \tag{13}$$

is an equation to estimate activity coefficients for nonelectrolytes (Bohn et al., 1985), where k_m is the salting coefficient that ranges from 0.01 to 0.2. Data from several studies (Abegg and Riesenfield, 1902; Dawson and McCrea, 1901; and Matthews and Davies, 1933) that analyzed the activity coefficient of UIA at various ionic strengths using a variety of salts were summarized in Whitfield (1974). This data was used to determine a regression model for the activity coefficient, which was:

$$\gamma_{NH_3} = (0.0955 \times I) + 1.000 \tag{14}$$

This regression between ionic strength and the activity coefficient of UIA demonstrated a good fit to the experimental data ($R^2 = 65.8$). This regression was used to estimate the salting coefficient (k_m) in equation 12, which was determined to be approximately 0.04. The resulting equation to estimate the activity coefficient of UIA for the equilibrium model was:

$$\gamma_{NH_3} = 10^{0.04 \times I} \tag{15}$$

5. Ionic Strength and Temperature Correction of the Ammonium Ion Activity Coefficient

Activity coefficients for ions decrease with increasing ionic strength due to increasing interaction of charged ions with each other as the concentration of ions increase. The Debye-Hueckel theory (Stumm and Morgan, 1981) attempts to predict ionic interactions using the formula:

$$\log_{10} \gamma_i = -AZ_i^2 \sqrt{I} \tag{16}$$

where *A* is a value that varies slightly with temperature, and Z_i is the ionic charge of *i*. The value *A* can be computed using the equation (Stumm and Morgan, 1981):

$$A = \frac{1.82483 \times 10^6}{\left(\sqrt{E \times (T + 273.16)} \right)^3} \tag{17}$$

where *T* is the temperature (°C), and *E* is the dielectric constant that can be estimated using the equation (Truesdell and Jones, 1974):

$$E = 87.74 - \left(0.4008 \times T \right) + \left(9.398 \times 10^{-4} \times T^2 \right) - \left(1.41 \times 10^{-6} \times T^3 \right) \tag{18}$$

The Debye-Hueckel equation is limited to solutions of low ionic strength ($I < 0.01$). Several modifications of this model that extend its application include the Guntelberg approximation (Stumm and Morgan, 1981):

$$\log_{10} \gamma_i = -A \times Z_i^2 \times \frac{\sqrt{I}}{1 + \sqrt{I}} \tag{19}$$

and the Davies equation (Davies, 1962):

$$\log_{10} \gamma_i = -A \times Z_i^2 \times \left(\frac{\sqrt{I}}{1 + \sqrt{I}} - 0.2I \right) \tag{20}$$

These two methods of estimation are applicable to ionic strengths of 0.1 and 0.5, respectively.

Equations 18 and 19 are intended to estimate the activity coefficients in lower ionic strength waters. Seawater has an ionic strength of approximately 0.7, which is above the currently accepted range of these equations. Several models have been developed to estimate ion activity coefficients for trace compounds in seawater, including the Bronsted-Guggenheim theory (Whitfield, 1973b) and the Pitzer equations (Whitfield, 1975b). The Pitzer equations were used to estimate the activity coefficients for the ammonium ion in this proposal. These estimates were compared to coefficients computed using equations 18 and 19 to determine if any of these simpler models could be extended to encompass ionic strengths of seawater. The results, summarized in Table 41, indicate that the Guntelberg equation estimates coefficients for ammonium that are close to the Pitzer equation estimates. Due to the complexity of the Pitzer equation and the small difference between the estimates, the simpler Guntelberg approximation was selected to estimate the activity coefficient of ammonium over the range of ionic strengths found in most surface waters.

B. **SUMMARY**

The model developed for this proposal (Equation 6) to estimate UIA from total ammonia is significantly simpler than previous models. Simpler models, such as the model presented by Emerson et al. (1975) (the model presented by EPA in the "Ambient Water Quality Criteria for Ammonia") that correct for pH and temperature, can only be used to estimate UIA; however, as discussed by Messer et al. (1984), the UIA estimates using a simpler model may differ significantly (10%-20%) from estimates that correct for ionic strength in freshwater and by even greater amounts for saltwater. More precise estimates can be determined using more complex models, such as the Pitzer equations; however, this greater precision is not warranted considering the level of error expected in analytical measurements (e.g., pH).

The resulting model to estimate UIA, which is a combination of equations, contains four variables and can be used for most ionic strengths measured in surface waters. It should not, however, be used for evaporation basins with ionic strengths greater than 1.0. Three of these variables, total ammonia, pH and temperature, are easily measured in the field or laboratory. The remaining parameter, ionic strength, can be estimated from easily measured field (e.g., salinity and conductivity) and laboratory (e.g., calcium, magnesium, alkalinity, and total dissolved solids) parameters.

It is recommended that this model be used to estimate UIA in water quality programs designed to monitor compliance of dischargers with ambient water quality standards where measured concentrations would be expected to have a certain degree of error. This model can also be used in freshwater toxicological studies; however, a more complex model which will estimate the ammonium activity coefficient better is needed, for toxicological studies conducted in saltwater.

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XII. TABLES

Table 1. TEMPERATURE-TOXICITY AND pH-TOXICITY MODEL EQUATION USED BY USEPA (1985) FOR FRESHWATER CRITERIA

A. Model for temperature-toxicity relationship

(1) $LC_{50} = LC_{50}(\text{at } T = 20°C) * 10^{0.03(TCAP - 20°C)}$;
if $T \geq TCAP$

(2) $LC_{50} = LC_{50}(\text{at } T = 20°C) * 10^{0.03(T - 20°C)}$;
if $T < TCAP$

where TCAP = Highest temperature where relationship holds (20°C for waters with salmonids or other sensitive coldwater species; 25°C for waters without these species)

B. Model for pH-toxicity relationship

LC50 = LC(at pH = 8); if pH $\geq$ 8

$$LC_{50} = \frac{LC_{50}\ (\text{at pH} = 8) * 1.25}{1 + 10^{7.4-pH}}\text{, if pH} < 8$$

C. Equation for adjusting acute values to reference conditions (pH = 8.0; T = 20°C)

$AV_{ref} = AV(pH,T) * FT * FpH$

where:

AV_{ref} = acute value (LC_{50}) at pH 8.0, 20°C

$AV_{(pH,T)}$ = acute value (LC_{50}) at experimental pH and temperature

FT = temperature correction factor
= $10^{0.03(20-T)}$; for fish
= 1; for invertebrates

FpH = pH correction factor
= 1; if pH $\geq$ 8

$$= \frac{1 + 10^{7.4-pH}}{1.25}\text{; if pH} < 8$$

Table 2. **EFFECTS OF TEMPERATURE ON UIA TOXICITY IN FRESHWATER TESTS**

Species	# of Tests	Temp. Range (^{o}C)	pH Range	Stat. Sig. Regression or Between Group Dif.	Comments	Reference
Fingernail clam (*Musculium transversum*)	2	5.4, 14.6	8.1-8.2	Not testable	Toxicity was 1.4 times greater at 5.4^{o} vs. 14.6^{o}C.	Arthur *et al*., 1987
Snail (*Physa gyrina*)	6	4.0-24.9	8.0-8.2	Not tested	Similar toxicity throughout range.	Arthur *et al*., 1987
Snail (*Helisoma trivolvis*)	2	12.9-22.0	7.9-8.2	Not testable	Toxicity was 1.4 times greater at 22.0 ^{o} vs 12.9^{o}C.	Arthur *et al*., 1987
Amphipod (*Crangonyx pseudogracilis*)	5	4.0-24.9	8.0-8.2	Not tested	Toxicity was 1.7 times at 24.9^{o} vs. 4.0^{o}C but no clear trend was evident.	Arthur *et al*., 1987
Isopod (*Asellus racovitzai*)	2	4.0, 22.0	7.8-8.0	Not testable	Similar toxicity.	Arthur *et al*., 1987
Crayfish (*Orconectes immunis*)	2	4.6, 17.1	7.9-8.2	Not testable	Toxicity was 1.6 times greater at 17.1^{o} vs. 4.6^{o}C.	Arthur *et al*., 1987
Caddisfly (*Philartus quaeris*)	2	13.1, 21.9	7.8	Not testable	Similar toxicity.	Arthur *et al*., 1987
Bluegill (*Lepomis macrochirus*)	4	4.0-24.8	7.98-8.47	Not tested	Toxicity was 4.4 times greater at 4.0-4.5^{o} vs. 24.8-25.0^{o}C.	Reinbold and Pescitelli, 1982
Bluegill (*Lepomis macrochirus*)	2	22, 28	7.89- 8.28	Not testable	Toxicity was 2.6 times greater at 22^{o} vs. 28 ^{o}C.	Roseboom and Richey, 1977
Channel catfish (*Ictalurus punctatus*)	3	3.5-19.6	7.8-8.1	Not tested	Toxicity was 2.6 times greater at 3.5^{o} vs. 19.6^{o}C.	Arthur *et al*., 1987

Table 2. (continued)

Species	# of Tests	Temp. Range (^{o}C)	pH Range	Stat. Sig. Regression or Between Group Dif.	Comments	Reference
Channel catfish (*Ictalurus punctatus*)	17	4.67-21.3	7.80-8.30	?(b)	Appears to have statistically significant regression (based on Erickson 1985). Fish exposed to effluent containing ammonia as the principal toxic component (USEPA 1985).	Cary, 1976
Channel catfish (*Ictalurus punctatus*)	3	22-30	8.6-8.8	Not tested	Toxicity was 1.6 times greater at 22^{o} vs. $30^{o}C$.	Colt and Tchobanoglous ,1976
Channel catfish (*Ictalurus punctatus*)	8	6-30	7.21-7.71	Not tested	96-hr LC_{50} tests; toxicity steadily increased with temperature; toxicity was 3.9 times greater at 6^{o} vs. $30^{o}C$.	DeGraeve *et al*., 1987
	8	6-30	7.06-7.88	Not tested	30-day survival and growth tests; no relationship between temperature and toxicity.	
Fathead minnow (*Pimephales promelas*)	4	3.4-26.1	7.9-8.1	Not tested	Similar toxicity throughout range.	Arthur *et al*., 1987
Fathead minnow (*Pimephales promelas*)	8	6-30	7.21-7.71	Not tested	96hr-LC_{50} tests; toxicity steadily decreased with increased temperature; toxicity was 3.7 times greater at 6^{o} vs. $30^{o}C$.	DeGraeve *et al*., 1987

Table 2. (continued)

Species	# of Tests	Temp. Range (^oC)	pH Range	Stat. Sig. Regression or Between Group Dif.	Comments	Reference
Fathead minnow (*Pimephales promelas*)	8	6-30	7.19-7.91	Not tested	30-day survival and growth tests; toxicity decreased at increased temperature although trend not consistent; toxicity was 4 times greater at 6^o vs. 30^oC.	DeGraeve *et al.*, 1987
Fathead minnow (*Pimephales promelas*)	4	4.1-25.2	7.86-8.70	Not tested	Toxicity was 1.9 times greater at $4.1\text{-}4.6^o$ vs.$23.9\text{-}25.2^oC$.	Reinbold and Pescitelli, 1982
Fathead minnow (*Pimephales promelas*)	35	11.7-22.1	7.55-8.42	Yes; LC50 = 0.4304 + 0.1225 (^oC) r=0.716 p<.001	Toxicity was about twice as great at 12^o vs. 22^oC. Relationship based on tests with fish weight ranges of 0.09-2.3 g; includes 7 tests at 2-5 mg/L dissolved oxygen.	Thurston *et al.*, 1983
Rainbow trout (*Oncorhynchus mykiss*)	3	3.6-11.3	7.7-7.9	Not tested	Toxicity was 2.3 times greater at 3.6^o vs. 11.3^oC.	Arthur *et al.*, 1987
Rainbow trout (*Oncorhynchus mykiss)*	2	5, 18	7.8	Not testable	Toxicity was approximately 2 times greater at 5^o vs. 18^oC.	Ministry of Technology, U.K., 1968

Table 2. (continued)

Species	# of Tests	Temp. Range (^{o}C)	pH Range	Stat. Sig. Regression or Between Group Dif.	Comments	Reference
Rainbow trout (*Oncorhynchus mykiss)*	2	2-4, 12-13	8.1-8.3	Not testable	Toxicity was approximately 2 times greater at 2-4^{o} vs. 12-13^{o}C.	Ministry of Technology, U.K., 1968
Rainbow trout (*Oncorhynchus mykiss*)	2	5.0, 12.8	8.02-8.57	Not testable	Toxicity was 1.4 times greater at 5^{o} vs. 12.8^{o}C.	Reinbold and Pescitelli, 1982
	4	3.0-14.9	8.03-8.76	Not tested	Toxicity was 1.7 times greater at 3.0-3.3^{o} vs. 14.2-14.9^{o}C.	
Rainbow trout (*Oncorhynchus mykiss*)	18	9.7-19.2	7.65-7.96	Yes; Linear, equation not reported $p<0.002$	Toxicity was 2.9 times greater at 9.7^{o} vs. 19.2^{o}C.	Thurston and Russo, 1983
Walleye (*Stysostedian vitreum*)	3	3.7, 19.0	7.7-8.3	Not tested	Toxicity was 2.1 times greater at 3.7^{o} vs. 11.1^{o}C, but was similar at 3.7^{o} vs. 19.0^{o}C. Note that fish tested at 19.0^{o} were 13.4 g vs. 27.6 g at 3.7^{o}C	Arthur *et al*., 1987
White sucker (*Catostomus commersoni*)	2	3.6, 11.3	7.8-8.2	Not testable	Toxicity was 2.4 times greater at 3.6^{o} vs. 11.3^{o}C.	Arthur *et al*., 1987

(a) In the Arthur *et al*. (1987) study seasonal factors other than temperature may confound results.
(b) Study marked with ? was not available for review at this time; data are from review papers and EPA criteria documents.

Table 3. EFFECTS OF pH ON UIA TOXICITY IN FRESHWATER TESTS

Species	# of Tests	pH Range	Temp. Range (^oC)	Stat. Sig. Regression or Between Group Dif.	Comments	Reference
Water flea (*Daphnia magna*)	9	7.40-8.15	19.6-22.0	Not tested	Toxicity was about 5 times greater at pH 7.40 vs. pH 8.15.	Russo *et al*., 1985
Daphnia sp.	25	~5-~9	25.0	?(a)	Data from graph in Erickson (1985) and USEPA (1985). Toxicity was 30 times greater at pH 6.0 vs. pH 8.0.	Tabata, 1982
Bluegill (*Lepomis macrochirus*)	5	8.11-9.19	18.5	Not tested	Toxicity was similar at 8.29-9.05. Toxicity at 8.11 was about 4 times that at 8.29-9.05. Toxicity at 9.19 was about 1.6 times that at 8.29-9.05.	Emery and Welch, 1969
Carp (*Cyprinus carpio*)	46	7.8, 9.1	12.8-13.7	Not tested	Little difference in toxicity at pH 7.8 vs. 49.1.	Dabrowska and Sikora, 1986
Channel catfish (*Ictalurus punctatus*)	4	6.0-8.8	21.1	Not tested	Toxicity increased with decreasing pH. Toxicity at pH 6.0 was 2.6 times that at pH 8.8. (Test with ammonium chloride)	Sheehan and Lewis, 1986
	4	6.0-8.8	21.1	Not tested	Toxicity increased with decreasing pH. Toxicity at pH 6.0 was 2.6 times that at pH 8.8. (Test with ammonium sulfate)	
Channel catfish (*Ictalurus punctatus*)	3	7.0, 8.0, 9.0	21-24	Not tested	Toxicity was greatest at pH 7 &9. Toxicity was 1.3 times greater at pH 7 vs. 8 and 1.2 times greater at pH 9 vs. 8.	Simco and Davis, 1978

Table 3. (continued)

Species	**# of Tests**	**pH Range**	**Temp. Range (^{o}C)**	**Stat. Sig. Regression or Between Group Dif.**	**Comments**	**Reference**
Larval midge (*Chironomus tentans*)	4	6.5-8.6	25	Not tested	Toxicity was about 19 times greater at pH 6.5 vs. pH 8.6	Schubauer-Berigan *et al*., 1995
Fathead minnow (*Pimephales promelas*)	6	6.51-9.03	11.8-13.8	Not tested	Minimum toxicity at pH 8.51-9.03. Toxicity at pH 6.51 was about 6 times that at pH 9.01.	Thurston *et al*., 1981a
Green sunfish (*Lepomis cyanellus*)	4	6.6-8.7	22.4	Not tested	Toxicity was about 3.5 times greater at pH 6.6 vs. pH 8.7.	McCormick *et al*., 1984
Oligochaete (*Lumbriculus variegatus*)	4	6.5-8.6	25	Not tested	Toxicity was about 2.6 times greater at pH 6.5 vs. pH 8.6	Schubauer-Berigan *et al*., 1995
Rainbow trout (*Oncorhynchus mykiss*)	4	7.0-8.2	18.7-20.7	Not tested	Toxicity was greatest at pH 7.0 and 7.37. Toxicity was 1.7 times greater at pH 7.0 vs. pH 8.2.	Lloyd and Herbert, 1960.
Rainbow trout (*Oncorhynchus mykiss*)	9	6.51-9.01	12.9-14.5	Not tested	Minimum toxicity at pH 8.0-8.5. Toxicity at pH 6.51 was about 5 times that at pH 8.29. Slight increase in toxicity at pH>8.29.	Thurston *et al*., 1981a
Smallmouth bass (*Micropterus dolmieui*)	4	6.53-8.71	22.3	Not tested	Acute toxicity at pH 6.53 was 2.6 times that at pH 8.71. Consistent trend.	Broderius *et al*., 1985
	4	6.60-8.68	22.3	Not tested	Chronic toxicity increased consistently with decreased pH. Toxicity at pH 6.60 was 14 times that at pH 8.68.	

(a) Studies marked with ? were not available for review at the time; data for these studies are from review papers and USEPA criteria documents.

Table 4. REGRESSION STATISTICS FOR TEMPERATURE-TOXICITY DATA*

	pH 7				pH 8			
Species	**Slope**	**Intercept**	**p**	**r^2**	**Slope**	**Intercept**	**p**	**r^2**
Channel catfish (Ictalurus punctatus)	0.0241	-0.4430	0.001	0.58	0.0264	-0.4221	0.0001	0.64
Fathead minnow (Pimephales promelas)	0.0301	-0.7622	0.0014	0.66	0.0222	-0.3186	0.0002	0.32
Bluegill sunfish (Lepomis machrochirus)	I/D	I/D	I/D	I/D	0.0268	-0.6631	0.0001	0.45
Rainbow trout (Oncorhynchus mykiss)	I/D	I/D	I/D	I/D	0.0285	0.0285	0.0001	0.15

* Regression of log transformed LC_{50} vs. ^{o}C
I/D Inadequate data for rainbow trout at pH 7

Table 5. REGRESSION STATISTICS FOR pH-TOXICITY DATA*

	Entire pH Range				pH $\leq$ 8.3			
Species	**Slope**	**Intercept**	**p**	**r^2**	**Slope**	**Intercept**	**p**	**r^2**
Channel catfish (*Ictalurus punctatus*)	0.1252	-0.8872	0.0001	0.41	0.1074	-0.7580	0.002	0.23
Water flea (*Daphnia magna*)	0.7422	-5.7159	0.0002	0.74	0.6873	-5.2965	0.0008	0.69
Bluegill sunfish (*Lepomis machrochirus*)	0.1416	-1.2407	0.0005	0.16	0.3099	-2.5896	0.0005	0.12
Fathead minnow (*Pimephales promelas*)	0.3575	-2.6966	0.0001	0.36	0.4141	-3.1320	0.0001	0.38
Rainbow trout (*Oncorhynchus mykiss*)	0.4205	-3.4882	0.0001	0.41	0.5386	-4.4031	0.0001	0.48

* Regression of log-transformed temperatuare adjusted LC_{50} versus pH.

Table 6. DATA REQUIREMENTS FOR FRESHWATER CRITERIA (Stephan *et al*. 1985)

Acute/Chronic Data	Acute-Chronic Ratios*
8 different families, such that:	3 different families such that:
One is a salmonid;	One is a fish;
One is a second fish (preferably a commercially or recreationally important warmwater species (e.g., bluegill, catfish);	One is an invertebrate; and
One comes from a third family in the phylum Chordata (e.g., fish, amphibian);	One is an acutely sensitive freshwater species (the other two may be saltwater species).
One is a planktonic crustacean (e.g., cladoceran, copepod);	
One is a benthic crustacean (e.g., amphipod, crayfish);	
One is an insect (e.g., mayfly, caddisfly);	
One is in a family in a phylum other than Arthropoda or Chordata (e.g., rotifera, and mollusca); and	
One is another insect or in any phylum not represented.	

* Use acute-chronic ratio if insufficient chronic studies are available.

Table 7. DATA REQUIREMENTS FOR SALTWATER CRITERIA (Stephan *et al*. 1985)

Acute/Chronic Data	Acute-Chronic Ratios*
8 different families such that:	3 different families such that:
Two families are in the phylum Chordata (e.g., fish, amphibian);	At least one is a fish;
One is in a family in a phylum other than Arthropoda or Chordata (e.g., rotifer and mollusca);	At least one is an invertebrate; and
One is a member of either the Mysidae or Panaeidae family (i.e., shrimp);	At least one is an acutely sensitive saltwater species (the other two may be freshwater species).
Three are from families not in the Phylum Chordata (may include Mysidae or Panaeidae, whichever was not used above); and	
One is in any family other than those above.	

* Use acute-chronic ratio if insufficient chronic studies are available.

Table 8. STATISTICAL ANALYSIS OF SKEWNESS, KURTOSIS, AND NORMALITY OF LOG-TRANSFORMED GENUS MEAN ACUTE VALUES FOR ALL SURFACE WATER CLASSIFICATIONS

Waterbody Classification	Skewness	Kurtosis	Shapiro-Wilk (W)	Nonnormal Distribution
Trout Waters (FW2-TP & TM)	0.85	0.66	0.95	p = 0.211
Nontrout Waters (FW2-NT)	0.83	0.67	0.95	p = 0.232
Pineland Waters (PL)	0.85	0.37	0.94	p = 0.185
Saline Estuarine Waters (SE1, SE2 & SE3)	0.88	-0.09	0.90	p = 0.078
Saline Coastal Waters (SC)	0.76	-0.65	0.89	p = 0.078

Table 9. SPECIES AND GENUS MEAN ACUTE VALUES FOR TROUT (FW2-TP AND FW2-TM) WATERS

Species	# of Tests	Species Geometric Mean	# of Species for Genus Geometric Mean	Genus Geometric Mean
Asellus aquaticus	1	2.87577	2	4.05598
Asellus racovitzia	2	5.72054		
Brachionus rubens	1	2.85499	2	3.26734
Brachionus calyciflorous	1	3.73924		
Campostoma anomalus	1	1.00235	1	1.00235
Catostomus commersoni	8	1.28137	1	1.28137
Ceriodaphnia reticulata	1	1.36276	1	1.36276
Chironomus riparius	1	2.05844	2	1.95125
Chironomus tentans	4	1.84964		
Crangonyx pseudogracilis	5	3.03066	1	3.03066
Daphnia magna	10	1.21305	1	1.21305
Etheostoma nigrum	4	0.47211	1	0.47211
Helisoma trivolvis	2	1.79667	1	1.79667
Lepomis cyanellus	5	1.00430	2	0.82870
Lepomis macrochirus	19	0.68380		
Limnodrilus hoffmeisteri	1	2.39143	1	2.39143
Lumbriculus variegatus	2	1.33885	1	1.33885
Lymnaea stagnalis	1	1.24112	1	1.24112
Micropterus dolomieui	4	1.12051	2	0.81346
Micropterus salmoides	2	0.59055		
Musculium transversum	3	0.91611	1	0.91611
Notemigonus crysoleucas	1	0.59821	1	0.59821
Oncorhynchus mykiss	118	0.62574	1	0.62574
Philodina acuticornis	1	7.60000	1	7.60000
Physa fontinalis	1	2.11899	2	2.07558
Physa gyrina	6	2.03307		
Pimephales promelas	66	1.28795	1	1.28795
Rhinichthys cataractae	2	0.68910	1	0.68910
Salmo trutta	3	0.74638	1	0.74638
Salvelinus fontinalis	2	1.15670	1	1.15670
Semotilus atromaculata	1	1.07035	1	1.07035
Simocepholus vetula	2	1.04383	1	1.04382
Stizostedion vitreum	6	0.61490	1	0.61490

Table 10. SPECIES AND GENUS MEAN ACUTE VALUES FOR NON-TROUT (FW2-NT) WATERS DURING THE SUMMER PERIOD

Species	# of Tests	Species Geometric Mean	# of Species for Genus Geometric Mean	Genus Geometric Mean
Asellus aquaticus	1	2.87577	2	4.05598
Asellus racovitzia	2	5.72054		
Brachionus rubens	1	2.85499	2	3.26734
Brachionus calyciflorous	1	3.73924		
Campostoma anomalus	1	1.00235	1	1.00235
Catostomus commersoni	8	1.28137	1	1.28137
Ceriodaphnia reticulata	1	1.36276	1	1.36276
Chironomus riparius	1	2.05844	2	1.95125
Chironomus tentans	4	1.84964		
Crangonyx pseudogracilis	5	3.03066	1	3.03066
Cyprinus carpio	5	1.21912	1	1.21912
Daphnia magna	10	1.21305	1	1.21305
Etheostoma nigrum	4	0.47211	1	0.47211
Gasterosteus aculeatus	2	1.93111	1	1.93111
Helisoma trivolvis	2	1.79667	1	1.79667
Ictalurus punctatus	18	1.28026	1	1.28026
Lepomis cyanellus	5	1.00430	3	0.85061
Lepomis gibbosus	3	0.89619		
Lepomis macrochirus	19	0.68380		
Limnodrilus hoffmeisteri	1	2.39143	1	2.39143
Lumbriculus variegatus	2	1.33885	1	1.33885
Lymnaea stagnalis	1	1.24112	1	1.24112
Micropterus dolomieui	4	1.12051	2	0.81346
Micropterus salmoides	2	0.59055		
Morone americana	2	0.61422	2	0.73642
Morone saxatilis	3	0.88294		
Musculium transversum	3	0.91611	1	0.91611
Notemigonus crysoleucas	1	0.59821	1	0.59821
Notropis spilopterus	1	0.71800	1	0.71800
Perca flavescens	1	0.55322	1	0.55322
Philodina acuticornis	1	7.60000	1	7.60000
Physa fontinalis	1	2.11899	2	2.07558
Physa gyrina	6	2.03307		
Pimephales promelas	66	1.28795	1	1.28795

Table 10. (continued)

Species	# of Tests	Species Geometric Mean	# of Species for Genus Geometric Mean	Genus Geometric Mean
Rhinichthys cataractae	2	0.68910	1	0.68910
Semotilus atromaculata	1	1.07035	1	1.07035
Simocepholus vetula	2	1.04382	1	1.04382
Stizostedion vitreum	6	0.61490	1	0.61490

Table 10a. SPECIES AND GENUS MEAN ACUTE VALUES FOR NON-TROUT (FW2-NT) WATERS DURING THE WINTER PERIOD

Species	# of Tests	Species Geometric Mean	# of Species for Genus Geometric Mean	Genus Geometric Mean
Asellus aquaticus	1	2.87577	2	4.05598
Asellus racovitzia	2	5.72054		
Brachionus rubens	1	2.85499	2	3.26734
Brachionus calyciflorous	1	3.73924		
Campostoma anomalus	1	1.00235	1	1.00235
Catostomus commersoni	8	1.28137	1	1.28137
Ceriodaphnia reticulata	1	1.36276	1	1.36276
Chironomus riparius	1	2.05844	2	1.95125
Chironomus tentans	4	1.84964		
Crangonyx pseudogracilis	5	3.03066	1	3.03066
Cyprinus carpio	1	0.91286	1	0.91286
Daphnia magna	10	1.21305	1	1.21305
Etheostoma nigrum	4	0.47211	1	0.47211
Gasterosteus aculeatus	2	1.93111	1	1.93111
Helisoma trivolvis	2	1.79667	1	1.79667
Ictalurus punctatus	17	1.31185	1	1.31185
Lepomis cyanellus	4	1.26897	3	0.98424
Lepomis gibbosus	3	0.89619		
Lepomis macrochirus	12	0.83841		
Limnodrilus hoffmeisteri	1	2.39143	1	2.39143
Lumbriculus variegatus	2	1.33885	1	1.33885
Lymnaea stagnalis	1	1.24112	1	1.24112
Micropterus dolomieui	4	1.12051	2	0.81346
Micropterus salmoides	2	0.59055		
Morone americana	2	0.61422	2	0.73642
Morone saxatilis	3	0.88294		
Musculium transversum	3	0.91611	1	0.91611
Notemigonus crysoleucas	1	0.59821	1	0.59821
Notropis spilopterus	1	0.71800	1	0.71800
Perca flavescens	1	0.55322	1	0.55322
Philodina acuticornis	1	7.60000	1	7.60000
Physa fontinalis	1	2.11899	2	2.07558
Physa gyrina	6	2.03307		
Pimephales promelas	57	1.40620	1	1.40620
Rhinichthys cataractae	2	0.68910	1	0.68910

Semotilus atromaculata	1	1.07035	1	1.07035
Simocepholus vetula	2	1.04382	1	1.04382
Stizostedion vitreum	4	0.81639	1	0.81639

Table 11. SPECIES AND GENUS MEAN ACUTE VALUES FOR PINELAND (PL) WATERS

Species	# of Tests	Species Geometric Mean	# of Species for Genus Geometric Mean	Genus Geometric Mean
Asellus aquaticus	1	2.87577	2	4.05598
Asellus racovitzia	2	5.72054		
Brachionus rubens	1	2.85499	2	2.85499
Brachionus calyciflorous	1	3.73924		
Catostomus commersoni	8	1.28137	1	1.28137
Ceriodaphnia reticulata	1	1.36276	1	1.36276
Chironomus riparius	1	2.05844	2	1.95125
Chironomus tentans	4	1.84964		
Crangonyx pseudogracilis	5	3.03066	1	3.03066
Cyprinus carpio	5	1.21912	1	1.21912
Daphnia magna	10	1.21305	1	1.21305
Gasterosteus aculeatus	2	1.93111	1	1.93111
Helisoma trivolvis	2	1.79667	1	1.79667
Lepomis gibbosus	3	0.89619	2	0.89619
Lepomis macrochirus	19	0.68380		
Micropterus dolomieui	4	1.12051	2	0.81346
Micropterus salmoides	2	0.59055		
Morone americana	2	0.61422	2	0.73642
Morone saxatilis	3	0.88294		
Musculium transversum	3	0.91611	1	0.91611
Notemigonus crysoleucas	1	0.59821	1	0.59821
Perca flavescens	1	0.55322	1	0.55322
Philodina acuticornis	1	7.60000	1	7.60000
Physa gyrina	6	2.03307	1	2.03307
Salvelinus fontinalis	2	1.15670	1	1.15670
Simocepholus vetula	2	1.04382	1	1.04382

Table 12. SPECIES AND GENUS MEAN ACUTE VALUES FOR SALINE ESTUARINE (SE1, SE2, AND SE3) WATERS

Species	# of Tests	Species Geometric Mean	# of Species for Genus Geometric Mean	Genus Geometric Mean
Acartia hudsonica	2	10.5431	2	9.5663
Acartia tonsa	1	8.6800		
Brachionus plicatilis	2	16.5674	1	16.5674
Callinectes sapidus	2	1.8983	1	1.8983
Crassostrea virginica	2	11.1292	1	11.1292
Cynoscion nebulosus	4	0.6029	1	0.6029
Cyprinodon variegatus	3	2.2571	1	2.2571
Fundulus heteroclitus	1	1.3000	1	1.3000
Gasterosteus aculeatus	4	1.6627	1	1.6627
Leiostomus xanthurus	1	0.7700	1	0.7700
Menidia beryllina	10	0.9943	2	0.9512
Menidia menidia	1	0.9100		
Mercenaria mercenaria	2	3.0268	1	3.0268
Monocanthus hispidus	1	0.6900	1	0.6900
Morone americana	2	0.5292	2	0.4576
Morone saxatilis	2	0.3957		
Mugil cephalus	4	1.5437	1	1.5437
Mysidopsis bahia[*]	7	0.6837	1	0.6837
Palaemonetes pugio	2	0.8485	1	0.8485
Pseudopleuronectes americanus	3	0.4052	1	0.4052
Scianeops ocellatus	1	0.3900	1	0.3900

* Species added during substitution sensitivity analysis.

Table 13. SPECIES AND GENUS MEAN ACUTE VALUES FOR SALINE COASTAL (SC) WATERS

Species	# of Tests	Species Geometric Mean	# of Species for Genus Geometric Mean	Genus Geometric Mean
Acartia hudsonica	2	10.5431	2	9.5663
Acartia tonsa	1	8.6800		
Brachionus plicatilis	2	16.5674	1	16.5674
Callinectes sapidus	2	1.8983	1	1.8983
Crassostrea virginica	2	11.1292	1	11.1292
Cynoscion nebulosus	4	0.6029	1	0.6029
Homarus americanus	7	1.7524	1	1.7524
Leiostomus xanthurus	1	0.7700	1	0.7700
Mercenaria mercenaria	2	3.0268	1	3.0268
Monocanthus hispidus	1	0.6900	1	0.6900
Morone saxatilis	2	0.3957	1	0.3957
Mugil cephalus	4	1.5437	1	1.5437
*Mysidopsis bahia**	7	0.6837	1	0.6837
Palaemonetes pugio	2	0.8485	1	0.8485
Pseudopleuronectes americanus	3	0.4052	1	0.4052
Scianeops ocellatus	1	0.3900	1	0.3900

* Species added during substitution sensitivity analysis.

TABLE 14. Acute & Chronic Data Used to Calculate Average Acute:Chronic Ratios (ACRs)

Species	Chronic Data				Acute Data			Corrected Acute Value	Reference
	pH	T (C)	Dur. (days)	Value	pH	T (C)	Value		
Daphnia magna	8.45	20	14	0.6	8.5	20	2.94	2.94	Gerish & Hopkins, 1986
Daphnia magna	8.1	22	28	0.43	7.95 8.07 8.09 8.15 8.04	22.0 19.6 20.9 22.0 22.8	2.02 2.22 2.06 2.28 1.96	2.26(a)	Russo *et al*., 1985
Daphnia magna	7.5	20	28	0.52	7.51 7.53 7.40 7.50	20.1 20.1 20.6 20.3	0.62 0.74 0.44 0.55	0.578(a)	Russo *et al*., 1985
Micropterus dolomieu	6.60	22.3	30	0.036	6.53	22.3	0.572	0.611	Broderius *et al*., 1985
Micropterus dolomieu	7.25	22.3	30	0.122	7.16	22.3	0.824	0.897	Broderius *et al*., 1985
Micropterus dolomieu	7.83	22.3	30	0.493	7.74	22.3	0.988	1.08	Broderius *et al*., 1985
Micropterus dolomieu	8.68	22.3	30	0.504	8.71	22.3	1.47	1.47	Broderius *et al*., 1985
Pimephales promelas	7.94	25.0	28	0.21	8.07	22.0	1.5	1.59	Mayes *et al*., 1986

TABLE 14. (continued)

Species	Chronic Data				Acute Data			Corrected Acute Value	Reference
	pH	T (C)	Dur. (days)	Value	pH	T (C)	Value		
Pimephales promelas	7.99	24.2	Life Cycle	0.22	8.03 8.06 7.83 8.04 8.08 8.16 7.88 7.84	22.1 22.0 22.0 22.4 21.4 21.4 21.7 21.7	2.25 2.13 1.52 1.78 2.25 2.83 1.68 1.67	2.27(a)	Thurston *et al*., 1986
Pimephales promelas	7.80	25.6	30	0.18	7.78 7.80	25.9 25.6	1.44 1.54	1.49(a)	Swigert & Spacie, 1983
Ictalurus punctatus	7.8	25.6	30	0.15	7.80	25.7	1.19	1.20	Swigert & Spacie, 1983
Ictalurus punctatus	8.36	27.9	30	0.22	8.70 8.70 8.70	22.0 30.0 26.0	1.98 3.13 2.39	2.75(a)	Colt & Tchobangoleus, 1976(b) & 1978(c)
Lepomis cyanellus	7.80	22.0	40	0.27	7.7	22.4	1.35	1.45	McCormick, 1984
Lepomis macrochirus	7.76	22.5	30	0.076	7.54	21.6	0.77	1.00	Smith *et al*., 1984
Menidia beryllina	7.66	24.0	28	0.050	7.90 8.00 7.95	26.0 25.5 24.0	1.60 1.46 0.72	0.84(a)	Miller *et al*., 1990

(a) The value presented is the geometric mean of the pH and temperature corrected pH acute data.

(b) The acute data are from the 1976 paper.

(c) The chronic data are from the 1978 paper.

Table 15. INDIVIDUAL ACUTE:CHRONIC RATIOS (ACRs) & SPECIES MEAN ACRS USED TO CALCULATE A FINAL ACR FOR ALL SURFACE WATER CLASSIFICATIONS

Species	Chronic Value	Corrected Acute Value	ACR	Species Mean ACR
Daphnia magna	0.6 0.43 0.52	2.94 2.26* 0.578*	4.9 5.26 1.11	3.06
Micropterus dolomieu	0.036 0.122 0.493 0.504	0.611 0.897 1.08 1.47	17.0 7.35 2.19 2.92	5.32
Pimephales promelas	0.21 0.22 0.18	1.59 2.27* 1.49*	7.57 10.3 8.28	8.64
Ictalurus punctatus	0.15 0.22	1.20* 2.75*	8.00 12.5	10.0
Lepomis cyanellus	0.27	1.45	5.37	5.37
Lepomis macrochirus	0.076	1.00	13.2	13.2
Menidia beryllina	0.050	0.84*	16.8	16.8

* The value presented is the geometric mean of the pH and temperature corrected pH acute data.

Table 16. RECOMMENDED CRITERION MAXIMUM CONCENTRATIONS (CMC) FOR NEW JERSEY SURFACE WATER CLASSIFICATIONS

CLASSIFICATION	CRITERIA	pH
FW2-TP & FW2-TM	CMC (mg NH_3-N/L) = $0.179 * 10^{0.026(Temp-20) + 0.41 (pH-7.80)}$ CMC (mg NH_3-N/L) = $0.179 * 10^{0.026(Temp-20) + 0.20}$	pH < 8.30 pH $\geq$ 8.30
FW2-NT (Summer[1])	CMC (mg NH_3-N/L) = $0.201 * 10^{0.026(Temp-20) + 0.41 (pH-7.80)}$ CMC (mg NH_3-N/L) = $0.201 * 10^{0.026(Temp-20) + 0.20}$	pH < 8.30 pH $\geq$ 8.30
FW2-NT (Winter[2])	CMC (mg NH_3-N/L) = $0.232 * 10^{0.026(Temp-20) + 0.41 (pH-7.80)}$ CMC (mg NH_3-N/L) = $0.232 * 10^{0.026(Temp-20) + 0.20}$	pH < 8.30 pH $\geq$ 8.30
PL	CMC (mg NH_3-N/L) = $0.238 * 10^{0.026(Temp-20) + 0.41 (pH-7.80)}$ CMC (mg NH_3-N/L) = $0.238 * 10^{0.026(Temp-20) + 0.20}$	pH < 8.30 pH $\geq$ 8.30
SE1, SE2 & SE3	CMC (mg NH_3-N/L) = 0.115	
SC	CMC (mg NH_3-N/L) = 0.094	

1. Summer is defined as the spawning period from March 1 through October 31.

2. Winter is defined as the non-spawning period from November 1 through February 28/29.
Interim values subject to change based on evaluation of ammonia toxicity database without early life stage tests.
Note: pH and temperature corrected un-ionized and total ammonia criteria are presented in Appendix A.

Table 17. RECOMMENDED CRITERION CONTINUOUS CONCENTRATIONS (CCC) FOR NEW JERSEY SURFACE WATER CLASSIFICATIONS

CLASSIFICATION	CRITERIA	pH
FW2-TP & FW2-TM	CCC (mg NH_3-N/L) = 0.046 * $10^{0.026(Temp-20) + 0.41 (pH-7.80)}$ CCC (mg NH_3-N/L) = 0.046 * $10^{0.026(Temp-20) + 0.20}$	pH < 8.30 pH $\geq$ 8.30
FW2-NT (Summer[1])	CCC (mg NH_3-N/L) = 0.054 * $10^{0.026(Temp-20) + 0.41 (pH-7.80)}$ CCC (mg NH_3-N/L) = 0.054 * $10^{0.026(Temp-20) + 0.20}$	pH < 8.30 pH $\geq$ 8.30
FW2-NT (Winter[2])	CCC (mg NH_3-N/L) = 0.060 * $10^{0.026(Temp-20) + 0.41 (pH-7.80)}$ CCC (mg NH_3-N/L) = 0.060 * $10^{0.026(Temp-20) + 0.20}$	pH < 8.30 pH $\geq$ 8.30
PL	CCC (mg NH_3-N/L) = 0.061 * $10^{0.026(Temp-20) + 0.41 (pH-7.80)}$ CCC (mg NH_3-N/L) = 0.061 * $10^{0.026(Temp-20) + 0.20}$	pH < 8.30 pH $\geq$ 8.30
SE1, SE2 & SE3	CCC (mg NH_3-N/L) = 0.030	
SC	CCC (mg NH_3-N/L) = 0.024	

1. Summer is defined as the spawning period from March 1 through October 31.
2. Winter is defined as the non-spawning period from November 1 through February 28/29.

Note: pH and temperature corrected un-ionized and total ammonia criteria are presented in Appendix.

Table 18. STATIONS CONTAINED IN THE WATER QUALITY DATA BASE THAT HAD AT LEAST ONE OBSERVATION DURING 1980 TO 1994 THAT EXCEEDED THE PROPOSED CCC AND HAVE BEEN SAMPLED IN THE LAST FIVE YEARS

Station #	Waterbody	# Obs. > CCC	# Obs. Within Factor of Five	Total # Obs.	Water Classification
01381200	Rockaway River, Pine Brook	9	21	86	FW2-NT
01391500	Saddle River, Lodi	10	53	86	FW2-NT/SE1
01381500	Whippany River, Morristown	1	8	84	FW2-NT
01381800	Whippany River, Pine Brook	1	35	85	FW2-NT
01467081	S.B. Pennsauken Creek, Cherry Hill	10	49	84	FW2-NT
01409416	Hammonton Creek, Westcoatville	3	26	87	PL
01463500	Delaware River, Trenton	1	2	123	FW2-NT
01398000	Neshanic River, Reaville	1	16	85	FW2-NT
6947133201	Barnegat Bay, Main Pt.	1	1	26	SE1

Table 19. STATIONS CONTAINED IN THE WATER QUALITY DATA BASE THAT HAD AT LEAST ONE OBSERVATION DURING 1980 TO 1994 THAT EXCEEDED THE PROPOSED CMC

Station #	Waterbody	# Obs. > CMC	# Obs. Within Factor of Two	Total # Obs.	Water Classification
013090610	Weequahic Lake	2	2	21	FW2-NT
01467130	Cooper River, Kirkwood	2	5	19	FW2-NT
01467190	Cooper River, Camden	2	5	25	FW2-NT
01391200	Saddle River, Fair Lawn	2	8	73	FW2-NT
3670400285	Lower Overpeck Lake	2	2	4	FW2-NT
3670400375	Upper Overpeck Lake	1	1	4	FW2-NT
6520000060	Sunset Lake/ Loper Lake	1	1	8	FW2-NT
7296001330	Kirkwood Lake Dam	1	1	4	FW2-NT
7296000076	Cooper River, Haddonfield	1	1	70	FW2-NT

Table 20. STATIONS WITH AT LEAST ONE UIA CONCENTRATION OVER THE PAST FIFTEEN YEARS (1980-94) GREATER THAN THE CURRENT CRITERIA THAT WERE NOT GREATER THAN THE PROPOSED CMC AND CCC CRITERIA

Station #	Waterbody	Classification
0090303610	Lily Lake/Lower Area	FW2-NT
0130909610	Weequahic Lake/Central Area	FW2-NT
01381200	Rockawy River, Pine Brook	FW2-NT
01381800	Whippany River, Pine Brook	FW2-NT
3136000090	Whippany River, Stimic Road	FW2-NT
3136000750	Whippany River, Parsippany Road	FW2-NT
3136000890	Whippany River, Morristown	FW2-NT
01391200	Saddle River, Fair Lawn	FW2-NT/SE1
01391500	Saddle River, Lodi	FW2-NT
01398000	Neshanic River, Reaville	Fw2-NT
01461300	Wickecheoke Creek, Stockton	FW2-NT
0170202610	North Hudson Park Lake	FW2-NT
2864000009	Pequannock River, Hamburg	FW2-NT
01462500	Delaware River, Washington Crossing	Zone 1
01462500	Delaware River, Trenton	Zone 1
332049	Delaware River, Marcus Hook	Zone 3
01467081	S.B. Pennsaken Creek, Cherry Hill	FW2-NT
01467130	Cooper River, Kirkwood	FW2-NT
01467140	Cooper River, Lawnside	FW2-NT
01467190	Cooper River, Camden	FW2-NT
7296000076	Cooper Run, Haddonfield	FW2-NT
7296001440	Kirkwood Lake, Cooper River	FW2-NT
105	Loantaka Brook	FW2-NT
6404002150	Sunset Lake	FW2-NT
6512800058	Shaw Branch, Sunset Lake	FW2-NT
6522400020	Beebe Run, Sunset Lake	FW2-NT
3140800040	Troy Brook, Stimis Road	FW2-NT
3670400230	Lower Overpeck Lake	FW2-NT
3670400345	Overpeck Creek	FW2-NT
4137604890	Great Egg Harbor, below 691	FW2-NT
4137605030	Great Egg Harbor, Albion	FW2-NT
4137605060	Great Egg Harbor, below 691	FW2-NT
5586400015	Debois Creek, Srickland Rd	FW2-NT
6493600050	Mary Elmer Lake	FW2-NT
6493600129	Barret Run, Mary Elmer Lake	FW2-NT
L6947233621	Barnegat Bay, Cedar Creek	SE1
RSH-7	Sandy Hook Bay, Leonardo	SE3

Table 21. STATIONS WITH AT LEAST ONE UIA CONCENTRATION OVER THE PAST FIFTEEN YEARS (1980-94) GREATER THAN THE PROPOSED CCC THAT DID NOT EXCEED THE CURRENT CRITERIA

Station #	Waterbody	Classification
01381200	Rockaway River, Pine Brook	FW2-NT
01381500	Whippany River, Morristown	FW2-NT
01381800	Whippany River, Pine Brook	FW2-NT
01391200	Saddle River, Fair Lawn	FW2-NT
01391500	Saddle River, Lodi	FW2-NT/SE1
01409416	Lamington River, Ironia	FW2-NT
01462500	Delaware River, Washington Crossing	Zone 1
01467081	S.B. Pennsauken Creek, Cherry Hill	FW2-NT
01467130	Cooper River, Kirkwood	FW2-NT
01467140	Cooper River, Lawnside	FW2-NT
01467190	Cooper River, Camden	FW2-NT
01399200	Lamington River, Ironia	FW2-NT
0170101800	Lincoln Park Lake	FW2-NT
105	Loantaka Brook	FW2-NT
110	Loantaka Brook, Morris County	FW2-NT
180	Great Brook, GSNWR Property	FW2-NT
1935202370	Lamington River, Power Line	FW2-NT
2588000479	Passaic River, Eagle Rock	FW2-NT
3136000890	Whippany River, Morristown	FW2-NT
3670400090	Overpeck Lake, Hendricks Rd	FW2-NT
5511200380	Manasquan River, Rte 70	FW2-NT
5586400190	Debois Creek, Strickland	FW2-NT
7296001340	Kirkwood Lake	FW2-NT
7296001370	Kirkwood Lake	FW2-NT
7296001402	Kirkwood Lake, Farm Ponds	FW2-NT
7296001440	Kirkwood Lake, Cooper River	FW2-NT
L6947133201	Barnegat Bay, Main Point	SE1
L6948634572	Barnegat Bay, Mantoloking Bridge	SE1
NB-12	Newark Bay, N. End	SE3

Table 22. SUMMARY OF CORRELATION RESULTS OF TOTAL AMMONIA WITH OTHER MEASURED PARAMETERS IN NEW JERSEY'S WATER QUALITY DATA BASE FOR STATIONS CONTAINING AMMONIA DATA THAT EXCEEDED THE PROPOSED CRITERIA

Water Quality Parameter	Inadequate Data	Non-Significant Correlations	Significant Correlations	
			Positive	Negative
Acidity	10	0	0	0
Alkalinity	1	3	6	0
Dissolved Oxygen	1	5	0	4
Hardness	1	4	5	0
Nitrate	2	5	3	0
pH	0	7	1	2
Salinity	10	0	0	0
Conductivity	0	1	9	0
Total Dissolved Solids	10	0	0	0
Temperature	0	7	1	2
Tidal Stage	10	0	0	0
Total Nitrogen	1	2	7	0
Total Organic Nitrogen	1	8	1	0

Table 23. SUMMARY OF CORRELATION RESULTS OF UIA WITH OTHER MEASURED PARAMETERS IN NEW JERSEY'S WATER QUALITY DATA BASE FOR STATIONS CONTAINING AMMONIA DATA THAT EXCEEDED THE PROPOSED CRITERIA

Water Quality Parameter	Inadequate Data	Nonsignificant Correlations	Significant Correlations	
			Positive	Negative
Acidity	10	0	0	0
Alkalinity	1	4	5	0
Dissolved oxygen	1	2	0	7
Hardness	1	5	4	0
Nitrate	2	6	2	0
pH	0	1	9	0
Salinity	10	0	0	0
Conductivity	0	4	6	0
Total Dissolved Solids	10	0	0	0
Temperature	0	6	4	0
Tidal Stage	10	0	0	0
Total Nitrogen	1	5	4	0
Total Organic Nitrogen	1	6	2	0

Table 24. CORRELATION COEFFICIENTS FOR STATIONS FOUND TO BE SIGNIFICANT ($p < 0.05$) FOR TOTAL AMMONIA AND CONDUCTIVITY

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	59	0.43	0.009	0.0001
01381800	Whippany River	60	0.62	0.004*	0.0215
01391200	Saddle River, Fair Lawn	64	0.63	0.015	0.0001
01399200	Lamington River	57	0.34	0.003*	0.164
01407997	Marsh Bog Brook	61	0.66	0.008	0.0042
01467081	S.B. Pennsauken Creek	61	0.43	0.008	0.0004
01467140	Cooper River, Lawnside	61	0.87	0.037*	<0.0001
7296000076	Cooper River, Haddonfield	62	0.44	0.010*	0.0001

Table 25. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT ($p<0.05$) FOR UIA AND CONDUCTIVITY

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	59	0.44	0.00003	0.343
01381800	Whippany River	60	0.38	0.0004	0.212
01391200	Saddle River, Fair Lawn	64	0.30	0.00016*	0.0001
01399200	Lamington River	57	0.30	0.00002	0.534
01407997	Marsh Bog Brook	61	0.52	0.00008	0.117
01467140	Cooper River, Lawnside	61	0.51	0.00013	0.002

* Slope of regression significantly different from one or more of the other regressions.

Table 26. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT p<0.05) FOR TOTAL AMMONIA AND ALKALINITY

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	17	0.65	0.029	0.013
01381800	Whippany River	17	0.67	0.020	0.044
01391200	Saddle River, Fair Lawn	18	0.80	0.064*	0.0001
01391500	Saddle River, Lodi	18	0.53	0.025	0.016
01467081	S.B. Pennsauken Creek	19	0.55	0.043	0.005
01467140	Cooper River, Lawnside	16	0.68	0.091*	0.0001

Table 27. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT (p<0.05) FOR TOTAL AMMONIA AND HARDNESS

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	24	0.60	0.027	0.005
01381800	Whippany River	22	0.64	0.018	0.037
01391200	Saddle River, Fair Lawn	25	0.45	0.035	0.0001
01391500	Saddle River, Lodi	25	0.44	0.017	0.024
01467140	Cooper River, Lawnside	24	0.55	0.227*	0.0001

Table 28. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT (p<0.05) FOR UIA AND ALKALINITY

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	17	0.68	0.0002	0.605
01381800	Whippany River	17	0.75	0.0003	0.306
01391200	Saddle River, Fair Lawn	18	0.57	0.0005	0.043
01467081	S.B. Pennsauken Creek	19	0.64	0.0005	0.315
01467140	Cooper River, Lawnside	16	0.56	0.0008	0.093

* Slope of regressions are significantly different from one or more of the other regressions.

Table 29. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT ($p<0.05$) FOR UIA AND HARDNESS

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	24	0.64	0.0002	0.393
01381800	Whippany River	22	0.56	0.0002	0.340
01391500	Saddle River, Lodi	25	0.41	0.0002	0.311
01407997	Marsh Bog Brook	25	0.70	0.001	0.889

Table 30. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT ($p < 0.05$) FOR UIA AND DISSOLVED OXYGEN

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	59	-0.51	-0.0012	0.277
01391200	Saddle River, Fair Lawn	64	-0.30	-0.0087	0.0001
01391500	Saddle River, Lodi	62	-0.33	-0.0019	0.153
01399200	Lamington River	58	-0.33	-0.0009	0.488
01407997	Marsh Bog Brook	61	-0.23	-0.0010	0.481
01467081	S.B. Pennsauken Creek	60	-0.49	-0.0037	0.079
01467140	Cooper River, Lawnside	60	-0.50	-0.0040	0.0029

Table 31. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT ($p<0.05$) FOR TOTAL AMMONIA AND DISSOLVED OXYGEN

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	59	-0.35	-0.210	0.0035
01407997	Marsh Bog Brook	61	-0.31	-0.103	0.249
01467081	S.B. Pennsauken Creek	60	-0.37	-0.228	0.011
01467140	Cooper River, Lawnside	60	-0.48	-0.647*	0.0001

* Significantly different correlation.

Table 32. **CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT (p<0.05) FOR TOTAL AMMONIA AND TOTAL NITROGEN**

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	15	0.79	0.641	0.0012
01381800	Whippany River	17	0.83	0.432	0.065
01391200	Saddle River, Fair Lawn	22	0.55	0.353	0.0001
01391500	Saddle River, Lodi	22	0.56	0.349	0.0041
01399200	Lamington River	18	0.59	0.114	0.505
01407997	Marsh Bog Brook	18	0.69	0.543	0.147
01467081	S.B. Pennsauken Creek	18	0.59	0.413	0.0064
01467140	Cooper River, Lawnside	15	0.49	0.582	0.0009

Table 33. **CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT (p<0.05) FOR UIA AND TOTAL NITROGEN**

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	15	0.70	0.004	0.489
01381800	Whippany River	17	0.67	0.005	0.459
01391200	Saddle River, Fair Lawn	22	0.53	0.004	0.040
01407997	Marsh Bog Brook	18	0.79	0.001	0.895

Table 34. **CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT (p<0.05) FOR TOTAL AMMONIA AND TEMPERATURE**

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01391200	Saddle River, Fair Lawn	64	-0.27	-0.103	0.005
01391500	Saddle River, Lodi	63	-0.41	-0.096	0.006
01467081	S.B. Pennsauken Creek	61	0.25	0.056*	0.108

* Slope of regression is significantly different from other regressions.

Table 35. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT ($p<0.05$) FOR UIA AND TEMPERATURE

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381800	Whippany River	61	0.26	0.0004	0.388
01467081	S.B. Pennsauken Creek	61	0.45	0.0012	0.015
01467140	Cooper River, Lawnside	61	0.31	0.0010	0.054
7296000076	Cooper River, Haddonfield	63	0.35	0.0012	0.013

Table 36. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT ($p < 0.05$) FOR UIA AND pH

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381800	Whippany River	61	0.64	0.022	0.026
01391200	Saddle River, Fair Lawn	64	0.35	0.056	0.0001
01391500	Saddle River, Lodi	63	0.43	0.018	0.046
01399200	Lamington River	58	0.28	0.008*	0.53
01407997	Marsh Bog Brook	62	0.33	0.005*	0.29
01467081	S.B. Pennsauken Creek	61	0.68	0.037	0.001
01467140	Cooper River, Lawnside	61	0.46	0.029	0.0028
7296000076	Cooper River, Haddonfield	63	0.56	0.043*	0.0001
01398000	Neshanic River	61	0.35	0.026	0.0001

Table 37. CORRELATION COEFFICIENTS FOR STATIONS SIGNIFICANT ($p<0.05$) FOR TOTAL AMMONIA AND pH

Station #	Waterbody	# of Obs.	Correlation Coefficient	Slope of Regression	p Value of Slope
01381200	Rockaway River	59	-0.46	-2.75	0.0005
01391500	Saddle River, Lodi	63	-0.40	-1.89	0.007
01407997	Marsh Bog Brook	62	0.27	0.34*	0.368

* Slope of regression is significantly different from one or more of the other stations.

Table 38. **UNIT ANNUALIZED COSTS ($/1000 GAL.) FOR THE SELECTED AMMONIA REMOVAL TECHNOLOGIES AND WASTEWATER TREATMENT TYPES - IN 1999 DOLLARS.**

Type of Wastewater Treatment	Treatment Capacity or Discharge Flow (MGD)				
	1.0	2.0	5.0	10.0	20.0
Separate Stage Nitrification	2.14	1.61	1.13	0.99	0.86
Ammonia (Air) Stripping	0.86	0.70	0.54	0.38	0.35
Secondary Wastewater Treatment	8.04	5.36	4.02	2.68	2.41
Advanced Wastewater Treatment	10.72	8.04	6.03	4.69	4.02

Table 39. **TEMPERATURE CORRECTION MODELS FOR THE EQUILIBRIUM CONSTANT pK_T^0.**

Temperature (°C)	pK_T^0 ESTIMATES		
	Theoretical Model	Emerson Model	Whitfield Model
0	0.837	0.839	0.820
5	0.658	0.660	0.658
10	0.485	0.486	0.496
15	0.317	0.319	0.334
20	0.156	0.158	0.172
25	0	0.001	0.010
30	-0.151	-0.150	-0.152
35	-0.299	-0.296	-0.314
40	-0.438	-0.437	-0.476

Table 40. **ESTIMATES OF AMMONIUM ACTIVITY COEFFICIENT (γNH_4^+) AT 25°C AND pH 7.0 FOR A VARIETY OF PREDICTIVE MODELS.**

IONIC STRENGTH	SALINITY (ppt)	PITZER EQUATION	DEBYE-HUECKEL THEORY	GUNTELBERG APPROXIMATION	DAVIES EQUATION
0.02	1	0.868	0.868	0.864	0.847
0.10	5	0.763	0.771	0.753	0.689
0.20	10	0.708	0.727	0.694	0.590
0.41	20	0.650	0.696	0.632	0.470
0.62	30	0.616	0.689	0.596	0.395
0.72	35	0.604	0.690	0.582	0.368

Table 41. **MODELS FOUND IN THE LITERATURE THAT CAN BE USED TO ESTIMATE IONIC STRENGTH (I) FROM COMMONLY MEASURED WATER QUALITY PARAMETERS.**

MODEL	SOURCE
I = [19.93 × Salinity (ppt)] × [1000 -1.005 × Salinity(ppt)]	Whitfield 1974
I = 4 × [Calcium(Molar) + Magnesium (Molar)] - 1/2 × [Alkalinity μeq/L)]	Messer et al 1984
I = (2.5×10^{-5}) × Total Dissolved Solids (mg/L)	Langelier 1936
I = (1.675×10^{-5}) × Conductivity (μmhos/cm at 20°C)	Kemp 1974

A - APPENDIX

Table 1A Calculated un-ionized ammonia CMC values (mg/L as N) for New Jersey trout waters (FW2-TP and FW2-TM).

Freshwater Criteria = 0.179

Temperature (°C)	pH 5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0	0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.031	0.037	0.045	0.054	0.065	0.079	0.086	0.086	0.086	0.086
2	0.008	0.009	0.011	0.013	0.016	0.020	0.024	0.029	0.035	0.042	0.050	0.061	0.074	0.089	0.097	0.097	0.097	0.097
4	0.009	0.010	0.013	0.015	0.018	0.022	0.027	0.032	0.039	0.047	0.057	0.069	0.083	0.100	0.109	0.109	0.109	0.109
6	0.010	0.012	0.014	0.017	0.021	0.025	0.030	0.036	0.044	0.053	0.064	0.077	0.094	0.113	0.123	0.123	0.123	0.123
8	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.041	0.050	0.060	0.072	0.087	0.105	0.127	0.138	0.138	0.138	0.138
10	0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.046	0.056	0.067	0.081	0.098	0.119	0.144	0.156	0.156	0.156	0.156
12	0.014	0.017	0.020	0.024	0.030	0.036	0.043	0.052	0.063	0.076	0.092	0.111	0.134	0.162	0.176	0.176	0.176	0.176
14	0.016	0.019	0.023	0.028	0.033	0.040	0.049	0.059	0.071	0.086	0.103	0.125	0.151	0.182	0.198	0.198	0.198	0.198
16	0.018	0.021	0.026	0.031	0.038	0.045	0.055	0.066	0.080	0.097	0.117	0.141	0.170	0.206	0.223	0.223	0.223	0.223
18	0.020	0.024	0.029	0.035	0.042	0.051	0.062	0.075	0.090	0.109	0.131	0.159	0.192	0.232	0.252	0.252	0.252	0.252
20	0.022	0.027	0.033	0.040	0.048	0.058	0.070	0.084	0.102	0.123	0.148	0.179	0.216	0.261	0.284	0.284	0.284	0.284
22	0.025	0.031	0.037	0.045	0.054	0.065	0.078	0.095	0.115	0.138	0.167	0.202	0.244	0.294	0.320	0.320	0.320	0.320
24	0.029	0.034	0.042	0.050	0.061	0.073	0.088	0.107	0.129	0.156	0.188	0.227	0.275	0.332	0.360	0.360	0.360	0.360
26	0.032	0.039	0.047	0.057	0.068	0.083	0.100	0.120	0.145	0.176	0.212	0.256	0.310	0.374	0.406	0.406	0.406	0.406

Table 1A-1 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey trout waters (FW2-TP and FW2-TM).

Conductivity (umhos) = 100

Ionic Strength = 0.002

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		215	164	125	95.2	72.5	55.3	42.1	32.1	24.5	18.7	14.2	10.9	8.31	6.36	4.39	2.80	1.80	1.17
2		205	156	119	90.8	69.2	52.7	40.2	30.6	23.4	17.8	13.6	10.4	7.94	6.08	4.21	2.69	1.73	1.13
4		196	149	114	86.8	66.1	50.4	38.4	29.3	22.3	17.0	13.0	9.94	7.61	5.83	4.04	2.59	1.67	1.10
6		188	143	109	83.2	63.4	48.3	36.8	28.1	21.4	16.3	12.5	9.54	7.30	5.61	3.89	2.50	1.62	1.07
8		181	138	105	79.9	60.9	46.4	35.4	27.0	20.6	15.7	12.0	9.18	7.03	5.41	3.76	2.42	1.58	1.05
10		174	132	101	76.9	58.6	44.7	34.1	26.0	19.8	15.1	11.6	8.85	6.79	5.23	3.64	2.35	1.54	1.03
12		168	128	97.4	74.3	56.6	43.1	32.9	25.1	19.1	14.6	11.2	8.56	6.57	5.07	3.54	2.30	1.51	1.02
14		162	124	94.2	71.8	54.7	41.7	31.8	24.3	18.5	14.1	10.8	8.29	6.37	4.93	3.45	2.25	1.49	1.01
16		157	120	91.3	69.6	53.1	40.4	30.8	23.5	18.0	13.7	10.5	8.06	6.20	4.80	3.37	2.21	1.48	1.01
18		153	116	88.7	67.6	51.5	39.3	30.0	22.9	17.5	13.3	10.2	7.84	6.05	4.70	3.31	2.18	1.47	1.02
20		149	113	86.3	65.8	50.1	38.2	29.2	22.3	17.0	13.0	9.96	7.66	5.92	4.60	3.26	2.16	1.47	1.03
22		145	110	84.2	64.1	48.9	37.3	28.5	21.7	16.6	12.7	9.74	7.49	5.80	4.53	3.22	2.15	1.48	1.05
24		142	108	82.2	62.7	47.8	36.4	27.8	21.2	16.2	12.4	9.54	7.35	5.70	4.47	3.20	2.15	1.49	1.07
26		139	106	80.5	61.4	46.8	35.7	27.2	20.8	15.9	12.2	9.36	7.23	5.62	4.42	3.18	2.16	1.51	1.10

Table 1A-2 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey trout waters (FW2-TP and FW2-TM).

Conductivity (umhos) = 500

Ionic Strength = 0.008

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		226	172	131	100	76.3	58.2	44.3	33.8	25.8	19.6	15.0	11.4	8.74	6.69	4.62	2.95	1.89	1.22
2		216	164	125	95.5	72.8	55.5	42.3	32.2	24.6	18.7	14.3	10.9	8.35	6.40	4.42	2.83	1.82	1.18
4		206	157	120	91.3	69.6	53.1	40.4	30.8	23.5	17.9	13.7	10.5	8.00	6.13	4.25	2.72	1.76	1.15
6		198	151	115	87.6	66.7	50.9	38.8	29.6	22.5	17.2	13.1	10.0	7.68	5.90	4.09	2.62	1.70	1.12
8		190	145	110	84.1	64.1	48.9	37.3	28.4	21.7	16.5	12.6	9.66	7.40	5.68	3.95	2.54	1.65	1.10
10		183	139	106	81.0	61.8	47.1	35.9	27.4	20.9	15.9	12.2	9.31	7.14	5.50	3.82	2.47	1.62	1.08
12		177	135	103	78.2	59.6	45.4	34.6	26.4	20.2	15.4	11.8	9.00	6.91	5.33	3.72	2.41	1.59	1.07
14		171	130	99.2	75.6	57.7	44.0	33.5	25.6	19.5	14.9	11.4	8.73	6.71	5.18	3.62	2.36	1.56	1.06
16		166	126	96.2	73.3	55.9	42.6	32.5	24.8	18.9	14.5	11.1	8.48	6.52	5.05	3.54	2.32	1.54	1.06
18		161	123	93.4	71.2	54.3	41.4	31.6	24.1	18.4	14.1	10.8	8.26	6.36	4.93	3.48	2.29	1.54	1.06
20		157	119	90.9	69.3	52.8	40.3	30.7	23.5	17.9	13.7	10.5	8.06	6.22	4.84	3.42	2.26	1.53	1.07
22		153	116	88.7	67.6	51.5	39.3	30.0	22.9	17.5	13.4	10.3	7.89	6.10	4.76	3.38	2.25	1.54	1.09
24		149	114	86.7	66.1	50.4	38.4	29.3	22.4	17.1	13.1	10.0	7.74	6.00	4.69	3.35	2.25	1.55	1.11
26		146	111	84.9	64.7	49.3	37.6	28.7	21.9	16.8	12.8	9.86	7.61	5.91	4.64	3.33	2.25	1.57	1.14

Table 1B Calculated un-ionized ammonia CCC values (mg/L as N) for New Jersey trout waters (FW2-TP and FW2-TM).

Freshwater Criteria = 0.046

Temperature (°C)	pH 5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0	0.002	0.002	0.003	0.003	0.004	0.004	0.005	0.007	0.008	0.010	0.012	0.014	0.017	0.020	0.022	0.022	0.022	0.022
2	0.002	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.011	0.013	0.016	0.019	0.023	0.025	0.025	0.025	0.025
4	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.018	0.021	0.026	0.028	0.028	0.028	0.028
6	0.002	0.003	0.004	0.004	0.005	0.006	0.008	0.009	0.011	0.014	0.016	0.020	0.024	0.029	0.032	0.032	0.032	0.032
8	0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.011	0.013	0.015	0.019	0.022	0.027	0.033	0.036	0.036	0.036	0.036
10	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.031	0.037	0.040	0.040	0.040	0.040
12	0.004	0.004	0.005	0.006	0.008	0.009	0.011	0.013	0.016	0.020	0.024	0.028	0.034	0.042	0.045	0.045	0.045	0.045
14	0.004	0.005	0.006	0.007	0.009	0.010	0.012	0.015	0.018	0.022	0.027	0.032	0.039	0.047	0.051	0.051	0.051	0.051
16	0.005	0.005	0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.030	0.036	0.044	0.053	0.057	0.057	0.057	0.057
18	0.005	0.006	0.007	0.009	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.041	0.049	0.060	0.065	0.065	0.065	0.065
20	0.006	0.007	0.008	0.010	0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.046	0.056	0.067	0.073	0.073	0.073	0.073
22	0.006	0.008	0.009	0.011	0.014	0.017	0.020	0.024	0.029	0.036	0.043	0.052	0.063	0.076	0.082	0.082	0.082	0.082
24	0.007	0.009	0.011	0.013	0.016	0.019	0.023	0.027	0.033	0.040	0.048	0.058	0.071	0.085	0.093	0.093	0.093	0.093
26	0.008	0.010	0.012	0.015	0.018	0.021	0.026	0.031	0.037	0.045	0.055	0.066	0.080	0.096	0.104	0.104	0.104	0.104

Table 1B-1 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey trout waters (FW2-TP and FW2-TM).

Conductivity (umhos) = 100

Ionic Strength = 0.002

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		55.2	42.1	32.1	24.5	18.6	14.2	10.8	8.25	6.29	4.80	3.66	2.80	2.14	1.64	1.13	0.72	0.46	0.30
2		52.7	40.2	30.6	23.3	17.8	13.5	10.3	7.87	6.00	4.58	3.49	2.67	2.04	1.56	1.08	0.69	0.45	0.29
4		50.4	38.4	29.3	22.3	17.0	13.0	9.88	7.53	5.74	4.38	3.34	2.55	1.95	1.50	1.04	0.67	0.43	0.28
6		48.3	36.8	28.0	21.4	16.3	12.4	9.47	7.22	5.50	4.20	3.21	2.45	1.88	1.44	1.00	0.64	0.42	0.27
8		46.4	35.4	26.9	20.5	15.7	11.9	9.10	6.94	5.29	4.04	3.08	2.36	1.81	1.39	0.97	0.62	0.41	0.27
10		44.7	34.0	25.9	19.8	15.1	11.5	8.76	6.68	5.10	3.89	2.97	2.27	1.74	1.34	0.94	0.60	0.40	0.26
12		43.1	32.9	25.0	19.1	14.5	11.1	8.45	6.45	4.92	3.76	2.87	2.20	1.69	1.30	0.91	0.59	0.39	0.26
14		41.7	31.8	24.2	18.5	14.1	10.7	8.18	6.24	4.76	3.64	2.78	2.13	1.64	1.27	0.89	0.58	0.38	0.26
16		40.4	30.8	23.5	17.9	13.6	10.4	7.93	6.05	4.62	3.53	2.70	2.07	1.59	1.23	0.87	0.57	0.38	0.26
18		39.2	29.9	22.8	17.4	13.2	10.1	7.70	5.88	4.49	3.43	2.63	2.02	1.55	1.21	0.85	0.56	0.38	0.26
20		38.2	29.1	22.2	16.9	12.9	9.83	7.50	5.72	4.37	3.34	2.56	1.97	1.52	1.18	0.84	0.56	0.38	0.27
22		37.2	28.4	21.6	16.5	12.6	9.58	7.31	5.58	4.26	3.26	2.50	1.93	1.49	1.16	0.83	0.55	0.38	0.27
24		36.4	27.7	21.1	16.1	12.3	9.37	7.15	5.46	4.17	3.19	2.45	1.89	1.47	1.15	0.82	0.55	0.38	0.28
26		35.6	27.1	20.7	15.8	12.0	9.17	7.00	5.34	4.09	3.13	2.41	1.86	1.45	1.14	0.82	0.55	0.39	0.28

Table 1B-2 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey trout waters (FW2-TP and FW2-TM).

Conductivity (umhos) = 500

Ionic Strength = 0.008

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		58.1	44.3	33.8	25.7	19.6	14.9	11.4	8.68	6.62	5.05	3.85	2.94	2.25	1.72	1.19	0.76	0.49	0.31
2		55.5	42.3	32.2	24.5	18.7	14.3	10.9	8.29	6.32	4.82	3.68	2.81	2.15	1.64	1.14	0.73	0.47	0.30
4		53.0	40.4	30.8	23.5	17.9	13.6	10.4	7.92	6.04	4.61	3.52	2.69	2.06	1.58	1.09	0.70	0.45	0.29
6		50.8	38.7	29.5	22.5	17.2	13.1	10.0	7.60	5.79	4.42	3.37	2.58	1.97	1.52	1.05	0.67	0.44	0.29
8		48.8	37.2	28.4	21.6	16.5	12.6	9.58	7.30	5.57	4.25	3.25	2.48	1.90	1.46	1.01	0.65	0.43	0.28
10		47.0	35.8	27.3	20.8	15.9	12.1	9.22	7.03	5.36	4.09	3.13	2.39	1.84	1.41	0.98	0.63	0.42	0.28
12		45.4	34.6	26.4	20.1	15.3	11.7	8.90	6.79	5.18	3.95	3.02	2.31	1.78	1.37	0.95	0.62	0.41	0.27
14		43.9	33.5	25.5	19.4	14.8	11.3	8.61	6.57	5.01	3.83	2.93	2.24	1.72	1.33	0.93	0.61	0.40	0.27
16		42.6	32.4	24.7	18.8	14.4	10.9	8.35	6.37	4.86	3.71	2.84	2.18	1.68	1.30	0.91	0.60	0.40	0.27
18		41.3	31.5	24.0	18.3	14.0	10.6	8.11	6.19	4.73	3.61	2.76	2.12	1.64	1.27	0.89	0.59	0.39	0.27
20		40.2	30.7	23.4	17.8	13.6	10.4	7.90	6.03	4.60	3.52	2.70	2.07	1.60	1.24	0.88	0.58	0.39	0.28
22		39.2	29.9	22.8	17.4	13.2	10.1	7.71	5.88	4.49	3.44	2.63	2.03	1.57	1.22	0.87	0.58	0.40	0.28
24		38.3	29.2	22.3	17.0	12.9	9.87	7.53	5.75	4.39	3.36	2.58	1.99	1.54	1.21	0.86	0.58	0.40	0.29
26		37.5	28.6	21.8	16.6	12.7	9.67	7.38	5.63	4.31	3.30	2.53	1.96	1.52	1.19	0.86	0.58	0.40	0.29

Table 2A Calculated un-ionized ammonia CMC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during summer spawning period (March 1 through October 31).

Freshwater Criteria =- 0.201

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.008	0.009	0.011	0.013	0.016	0.020	0.024	0.029	0.034	0.042	0.050	0.061	0.073	0.089	0.096	0.096	0.096	0.096
2		0.009	0.010	0.013	0.015	0.018	0.022	0.027	0.032	0.039	0.047	0.057	0.068	0.083	0.100	0.108	0.108	0.108	0.108
4		0.010	0.012	0.014	0.017	0.021	0.025	0.030	0.036	0.044	0.053	0.064	0.077	0.093	0.113	0.122	0.122	0.122	0.122
6		0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.041	0.049	0.060	0.072	0.087	0.105	0.127	0.138	0.138	0.138	0.138
8		0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.046	0.056	0.067	0.081	0.098	0.118	0.143	0.155	0.155	0.155	0.155
10		0.014	0.017	0.020	0.024	0.029	0.036	0.043	0.052	0.063	0.076	0.091	0.110	0.133	0.161	0.175	0.175	0.175	0.175
12		0.016	0.019	0.023	0.027	0.033	0.040	0.048	0.059	0.071	0.085	0.103	0.125	0.150	0.182	0.197	0.197	0.197	0.197
14		0.018	0.021	0.026	0.031	0.037	0.045	0.055	0.066	0.080	0.096	0.116	0.140	0.170	0.205	0.222	0.222	0.222	0.222
16		0.020	0.024	0.029	0.035	0.042	0.051	0.062	0.074	0.090	0.108	0.131	0.158	0.191	0.231	0.251	0.251	0.251	0.251
18		0.022	0.027	0.033	0.039	0.048	0.057	0.069	0.084	0.101	0.122	0.148	0.178	0.215	0.260	0.283	0.283	0.283	0.283
20		0.025	0.030	0.037	0.044	0.054	0.065	0.078	0.094	0.114	0.138	0.166	0.201	0.243	0.293	0.319	0.319	0.319	0.319
22		0.028	0.034	0.041	0.050	0.060	0.073	0.088	0.106	0.129	0.155	0.188	0.227	0.274	0.331	0.359	0.359	0.359	0.359
24		0.032	0.039	0.047	0.056	0.068	0.082	0.099	0.120	0.145	0.175	0.211	0.255	0.308	0.373	0.405	0.405	0.405	0.405
26		0.036	0.044	0.053	0.064	0.077	0.093	0.112	0.135	0.163	0.197	0.238	0.288	0.348	0.420	0.456	0.456	0.456	0.456
28		0.041	0.049	0.059	0.072	0.087	0.105	0.126	0.152	0.184	0.222	0.269	0.324	0.392	0.473	0.514	0.514	0.514	0.514
30		0.046	0.055	0.067	0.081	0.098	0.118	0.142	0.172	0.208	0.251	0.303	0.366	0.442	0.534	0.580	0.580	0.580	0.580

Table 2A-1 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during summer spawning period (March 1 through October 31).

Conductivity (umhos) = 100

Ionic Strength = 0.002

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		241	184	140	107	81.4	62.1	47.3	36.1	27.5	21.0	16.0	12.2	9.34	7.15	4.93	3.15	2.02	1.31
2		230	175	134	102	77.7	59.2	45.1	34.4	26.2	20.0	15.3	11.7	8.92	6.83	4.72	3.02	1.95	1.27
4		220	168	128	97.5	74.3	56.6	43.2	32.9	25.1	19.1	14.6	11.2	8.54	6.55	4.54	2.91	1.88	1.23
6		211	161	123	93.4	71.2	54.3	41.4	31.5	24.1	18.4	14.0	10.7	8.20	6.30	4.37	2.81	1.82	1.20
8		203	154	118	89.7	68.4	52.1	39.7	30.3	23.1	17.6	13.5	10.3	7.90	6.07	4.22	2.72	1.77	1.18
10		195	149	113	86.4	65.9	50.2	38.3	29.2	22.3	17.0	13.0	9.94	7.62	5.87	4.09	2.64	1.73	1.16
12		188	144	109	83.4	63.6	48.4	36.9	28.2	21.5	16.4	12.5	9.61	7.38	5.69	3.97	2.58	1.70	1.15
14		182	139	106	80.6	61.5	46.9	35.7	27.3	20.8	15.9	12.1	9.31	7.16	5.53	3.87	2.53	1.68	1.14
16		177	135	103	78.2	59.6	45.4	34.6	26.4	20.2	15.4	11.8	9.05	6.96	5.39	3.79	2.48	1.66	1.14
18		171	131	99.6	75.9	57.9	44.1	33.6	25.7	19.6	15.0	11.5	8.81	6.79	5.27	3.72	2.45	1.65	1.15
20		167	127	96.9	73.9	56.3	42.9	32.8	25.0	19.1	14.6	11.2	8.60	6.64	5.17	3.66	2.43	1.65	1.16
22		163	124	94.5	72.0	54.9	41.9	31.9	24.4	18.6	14.3	10.9	8.42	6.51	5.09	3.62	2.42	1.66	1.18
24		159	121	92.3	70.4	53.7	40.9	31.2	23.8	18.2	14.0	10.7	8.26	6.41	5.02	3.59	2.41	1.67	1.20
26		156	119	90.4	68.9	52.5	40.1	30.6	23.4	17.9	13.7	10.5	8.12	6.32	4.97	3.57	2.42	1.70	1.24
28		153	116	88.6	67.6	51.5	39.3	30.0	22.9	17.5	13.4	10.3	8.00	6.24	4.93	3.57	2.44	1.73	1.28
30		150	114	87.1	66.4	50.6	38.6	29.5	22.5	17.3	13.2	10.2	7.91	6.19	4.92	3.58	2.48	1.78	1.33

Table 2A-2 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during summer spawning period (March 1 through October 31).

Conductivity (umhos) = 500

Ionic Strength = 0.008

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		254	194	148	112	85.7	65.3	49.8	37.9	28.9	22.1	16.8	12.8	9.82	7.52	5.19	3.31	2.12	1.38
2		242	185	141	107	81.7	62.3	47.5	36.2	27.6	21.1	16.1	12.3	9.38	7.19	4.97	3.17	2.04	1.33
4		232	177	135	103	78.2	59.6	45.4	34.6	26.4	20.1	15.4	11.7	8.98	6.89	4.77	3.05	1.97	1.29
6		222	169	129	98.3	74.9	57.1	43.5	33.2	25.3	19.3	14.7	11.3	8.63	6.62	4.59	2.95	1.91	1.26
8		213	163	124	94.5	72.0	54.9	41.8	31.9	24.3	18.6	14.2	10.8	8.31	6.38	4.43	2.85	1.86	1.23
10		206	157	119	91.0	69.3	52.9	40.3	30.7	23.4	17.9	13.7	10.5	8.02	6.17	4.29	2.77	1.81	1.21
12		198	151	115	87.8	66.9	51.0	38.9	29.7	22.6	17.3	13.2	10.1	7.76	5.98	4.17	2.71	1.78	1.20
14		192	146	111	84.9	64.7	49.4	37.6	28.7	21.9	16.7	12.8	9.80	7.53	5.81	4.07	2.65	1.75	1.19
16		186	142	108	82.3	62.8	47.8	36.5	27.8	21.2	16.2	12.4	9.52	7.33	5.67	3.98	2.60	1.73	1.19
18		181	138	105	80.0	61.0	46.5	35.4	27.0	20.6	15.8	12.1	9.27	7.15	5.54	3.90	2.57	1.72	1.19
20		176	134	102	77.8	59.3	45.2	34.5	26.3	20.1	15.4	11.8	9.05	6.99	5.43	3.84	2.54	1.72	1.20
22		171	131	99.6	75.9	57.9	44.1	33.7	25.7	19.6	15.0	11.5	8.86	6.85	5.34	3.80	2.53	1.73	1.22
24		168	128	97.3	74.2	56.6	43.1	32.9	25.1	19.2	14.7	11.3	8.69	6.74	5.27	3.76	2.52	1.74	1.25
26		164	125	95.3	72.6	55.4	42.2	32.2	24.6	18.8	14.4	11.1	8.55	6.64	5.22	3.74	2.53	1.76	1.28
28		161	123	93	71.3	54.3	41.5	31.6	24.2	18.5	14.2	10.9	8.42	6.56	5.18	3.74	2.55	1.80	1.32
30		158	121	91.9	70.0	53.4	40.8	31.1	23.8	18.2	14.0	10.7	8.33	6.51	5.16	3.75	2.58	1.84	1.38

Table 2B Calculated un-ionized ammonia CCC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during summer spawning period (March 1 through October 31).

Freshwater Criteria =- 0.054

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.002	0.002	0.003	0.004	0.004	0.005	0.006	0.008	0.009	0.011	0.014	0.016	0.020	0.024	0.026	0.026	0.026	0.026
2		0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.010	0.013	0.015	0.018	0.022	0.027	0.029	0.029	0.029	0.029
4		0.003	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.030	0.033	0.033	0.033	0.033
6		0.003	0.004	0.004	0.005	0.006	0.008	0.009	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.037	0.037	0.037	0.037
8		0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.042	0.042	0.042	0.042
10		0.004	0.004	0.005	0.007	0.008	0.010	0.012	0.014	0.017	0.020	0.025	0.030	0.036	0.043	0.047	0.047	0.047	0.047
12		0.004	0.005	0.006	0.007	0.009	0.011	0.013	0.016	0.019	0.023	0.028	0.033	0.040	0.049	0.053	0.053	0.053	0.053
14		0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.018	0.021	0.026	0.031	0.038	0.046	0.055	0.060	0.060	0.060	0.060
16		0.005	0.006	0.008	0.009	0.011	0.014	0.017	0.020	0.024	0.029	0.035	0.043	0.051	0.062	0.067	0.067	0.067	0.067
18		0.006	0.007	0.009	0.011	0.013	0.015	0.019	0.023	0.027	0.033	0.040	0.048	0.058	0.070	0.076	0.076	0.076	0.076
20		0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.031	0.037	0.045	0.054	0.065	0.079	0.086	0.086	0.086	0.086
22		0.008	0.009	0.011	0.013	0.016	0.020	0.024	0.029	0.035	0.042	0.050	0.061	0.074	0.089	0.096	0.096	0.096	0.096
24		0.009	0.010	0.013	0.015	0.018	0.022	0.027	0.032	0.039	0.047	0.057	0.069	0.083	0.100	0.109	0.109	0.109	0.109
26		0.010	0.012	0.014	0.017	0.021	0.025	0.030	0.036	0.044	0.053	0.064	0.077	0.093	0.113	0.123	0.123	0.123	0.123
28		0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.041	0.049	0.060	0.072	0.087	0.105	0.127	0.138	0.138	0.138	0.138
30		0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.046	0.056	0.067	0.081	0.098	0.119	0.143	0.156	0.156	0.156	0.156

Table 2B-1 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during summer spawning period (March 1 through October 31).

Conductivity (umhos) = 100

Ionic Strength = 0.002

Temperature (°C)	pH 5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0	64.9	49.4	37.7	28.7	21.9	16.7	12.7	9.69	7.39	5.63	4.30	3.28	2.51	1.92	1.33	0.85	0.54	0.35
2	61.9	47.1	35.9	27.4	20.9	15.9	12.1	9.24	7.05	5.38	4.10	3.13	2.40	1.84	1.27	0.81	0.52	0.34
4	59.1	45.1	34.4	26.2	20.0	15.2	11.6	8.84	6.74	5.14	3.92	3.00	2.29	1.76	1.22	0.78	0.50	0.33
6	56.7	43.2	32.9	25.1	19.1	14.6	11.1	8.47	6.46	4.93	3.76	2.88	2.20	1.69	1.17	0.75	0.49	0.32
8	54.5	41.5	31.6	24.1	18.4	14.0	10.7	8.14	6.21	4.74	3.62	2.77	2.12	1.63	1.13	0.73	0.48	0.32
10	52.4	40.0	30.5	23.2	17.7	13.5	10.3	7.84	5.98	4.57	3.49	2.67	2.05	1.58	1.10	0.71	0.47	0.31
12	50.6	38.6	29.4	22.4	17.1	13.0	9.92	7.57	5.77	4.41	3.37	2.58	1.98	1.53	1.07	0.69	0.46	0.31
14	48.9	37.3	28.4	21.7	16.5	12.6	9.60	7.32	5.59	4.27	3.26	2.50	1.92	1.49	1.04	0.68	0.45	0.31
16	47.4	36.1	27.5	21.0	16.0	12.2	9.31	7.10	5.42	4.14	3.17	2.43	1.87	1.45	1.02	0.67	0.45	0.31
18	46.1	35.1	26.8	20.4	15.5	11.9	9.04	6.90	5.27	4.03	3.08	2.37	1.82	1.42	1.00	0.66	0.44	0.31
20	44.8	34.2	26.0	19.8	15.1	11.5	8.80	6.71	5.13	3.92	3.01	2.31	1.78	1.39	0.98	0.65	0.44	0.31
22	43.7	33.3	25.4	19.4	14.8	11.3	8.58	6.55	5.01	3.83	2.94	2.26	1.75	1.37	0.97	0.65	0.45	0.32
24	42.7	32.5	24.8	18.9	14.4	11.0	8.39	6.40	4.90	3.75	2.88	2.22	1.72	1.35	0.96	0.65	0.45	0.32
26	41.8	31.9	24.3	18.5	14.1	10.8	8.22	6.27	4.80	3.68	2.82	2.18	1.70	1.33	0.96	0.65	0.46	0.33
28	41.0	31.2	23.8	18.2	13.8	10.6	8.06	6.16	4.71	3.61	2.78	2.15	1.68	1.33	0.96	0.66	0.47	0.34
30	40.3	30.7	23.4	17.8	13.6	10.4	7.92	6.06	4.64	3.56	2.74	2.13	1.66	1.32	0.96	0.66	0.48	0.36

Table 2B-2 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during summer spawning period (March 1 through October 31).

Conductivity (umhos) = 500

Ionic Strength = 0.008

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		68.2	52.0	39.6	30.2	23.0	17.5	13.4	10.2	7.77	5.93	4.52	3.45	2.64	2.02	1.39	0.89	0.57	0.37
2		65.1	49.6	37.8	28.8	22.0	16.7	12.8	9.73	7.42	5.66	4.32	3.30	2.52	1.93	1.33	0.85	0.55	0.36
4		62.3	47.4	36.2	27.6	21.0	16.0	12.2	9.30	7.09	5.41	4.13	3.16	2.41	1.85	1.28	0.82	0.53	0.35
6		59.7	45.5	34.7	26.4	20.1	15.3	11.7	8.92	6.80	5.19	3.96	3.03	2.32	1.78	1.23	0.79	0.51	0.34
8		57.3	43.7	33.3	25.4	19.3	14.7	11.2	8.57	6.54	4.99	3.81	2.91	2.23	1.71	1.19	0.77	0.50	0.33
10		55.2	42.1	32.1	24.4	18.6	14.2	10.8	8.26	6.30	4.81	3.67	2.81	2.15	1.66	1.15	0.75	0.49	0.33
12		53.3	40.6	31.0	23.6	18.0	13.7	10.5	7.97	6.08	4.64	3.55	2.72	2.08	1.61	1.12	0.73	0.48	0.32
14		51.5	39.3	29.9	22.8	17.4	13.3	10.1	7.71	5.88	4.49	3.44	2.63	2.02	1.56	1.09	0.71	0.47	0.32
16		50.0	38.1	29.0	22.1	16.9	12.9	9.80	7.48	5.71	4.36	3.34	2.56	1.97	1.52	1.07	0.70	0.47	0.32
18		48.5	37.0	28.2	21.5	16.4	12.5	9.52	7.27	5.55	4.24	3.25	2.49	1.92	1.49	1.05	0.69	0.46	0.32
20		47.2	36.0	27.4	20.9	15.9	12.2	9.27	7.08	5.40	4.13	3.16	2.43	1.88	1.46	1.03	0.68	0.46	0.32
22		46.1	35.1	26.8	20.4	15.6	11.9	9.05	6.90	5.27	4.03	3.09	2.38	1.84	1.44	1.02	0.68	0.46	0.33
24		45.0	34.3	26.1	19.9	15.2	11.6	8.84	6.75	5.16	3.95	3.03	2.33	1.81	1.42	1.01	0.68	0.47	0.34
26		44.1	33.6	25.6	19.5	14.9	11.3	8.66	6.61	5.06	3.87	2.98	2.30	1.78	1.40	1.01	0.68	0.47	0.34
28		43.2	32.9	25.1	19.1	14.6	11.1	8.50	6.49	4.97	3.81	2.93	2.26	1.76	1.39	1.00	0.68	0.48	0.36
30		42.5	32.4	24.7	18.8	14.4	10.9	8.36	6.39	4.89	3.75	2.89	2.24	1.75	1.39	1.01	0.69	0.49	0.37

Table 2C Calculated un-ionized ammonia CMC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during winter non-spawning period (November 1 through February 28/29).

Freshwater Criteria = 0.232

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.009	0.011	0.013	0.015	0.019	0.023	0.027	0.033	0.040	0.048	0.058	0.070	0.085	0.102	0.111	0.111	0.111	0.111
2		0.010	0.012	0.014	0.017	0.021	0.025	0.031	0.037	0.045	0.054	0.065	0.079	0.095	0.115	0.125	0.125	0.125	0.125
4		0.011	0.013	0.016	0.020	0.024	0.029	0.035	0.042	0.051	0.061	0.074	0.089	0.108	0.130	0.141	0.141	0.141	0.141
6		0.013	0.015	0.018	0.022	0.027	0.032	0.039	0.047	0.057	0.069	0.083	0.100	0.121	0.146	0.159	0.159	0.159	0.159
8		0.014	0.017	0.021	0.025	0.030	0.036	0.044	0.053	0.064	0.078	0.094	0.113	0.137	0.165	0.179	0.179	0.179	0.179
10		0.016	0.019	0.023	0.028	0.034	0.041	0.050	0.060	0.072	0.087	0.106	0.127	0.154	0.186	0.202	0.202	0.202	0.202
12		0.018	0.022	0.026	0.032	0.038	0.046	0.056	0.068	0.082	0.099	0.119	0.144	0.174	0.210	0.228	0.228	0.228	0.228
14		0.020	0.025	0.030	0.036	0.043	0.052	0.063	0.076	0.092	0.111	0.134	0.162	0.196	0.236	0.257	0.257	0.257	0.257
16		0.023	0.028	0.033	0.040	0.049	0.059	0.071	0.086	0.104	0.125	0.151	0.183	0.221	0.266	0.289	0.289	0.289	0.289
18		0.026	0.031	0.038	0.045	0.055	0.066	0.080	0.097	0.117	0.141	0.170	0.206	0.249	0.300	0.326	0.326	0.326	0.326
20		0.029	0.035	0.042	0.051	0.062	0.075	0.090	0.109	0.132	0.159	0.192	0.232	0.280	0.338	0.368	0.368	0.368	0.368
22		0.033	0.040	0.048	0.058	0.070	0.084	0.102	0.123	0.148	0.179	0.217	0.262	0.316	0.381	0.414	0.414	0.414	0.414
24		0.037	0.045	0.054	0.065	0.079	0.095	0.115	0.139	0.167	0.202	0.244	0.295	0.356	0.430	0.467	0.467	0.467	0.467
26		0.042	0.050	0.061	0.073	0.089	0.107	0.129	0.156	0.189	0.228	0.275	0.332	0.401	0.485	0.527	0.527	0.527	0.527
28		0.047	0.057	0.068	0.083	0.100	0.121	0.146	0.176	0.213	0.257	0.310	0.375	0.452	0.546	0.594	0.594	0.594	0.594
30		0.053	0.064	0.077	0.093	0.113	0.136	0.164	0.198	0.240	0.289	0.350	0.422	0.510	0.616	0.669	0.669	0.669	0.669

Table 2C-1 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during winter non-spawning period (November 1 through February 28/29).

Conductivity (umhos) = 100

Ionic Strength = 0.002

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		279	212	162	123	94.0	71.6	54.6	41.6	31.7	24.2	18.5	14.1	10.8	8.25	5.70	3.63	2.33	1.51
2		266	203	154	118	89.7	68.3	52.1	39.7	30.3	23.1	17.6	13.5	10.3	7.89	5.45	3.49	2.25	1.46
4		254	194	148	112	85.7	65.3	49.8	38.0	29.0	22.1	16.9	12.9	9.86	7.56	5.23	3.35	2.17	1.42
6		244	186	141	108	82.2	62.6	47.7	36.4	27.8	21.2	16.2	12.4	9.47	7.27	5.04	3.24	2.10	1.39
8		234	178	136	104	78.9	60.2	45.9	35.0	26.7	20.4	15.6	11.9	9.11	7.01	4.87	3.14	2.05	1.36
10		225	172	131	99.7	76.0	57.9	44.2	33.7	25.7	19.6	15.0	11.5	8.80	6.77	4.72	3.05	2.00	1.34
12		217	166	126	96.2	73.4	55.9	42.6	32.5	24.8	18.9	14.5	11.1	8.51	6.57	4.58	2.98	1.96	1.32
14		210	160	122	93.1	70.9	54.1	41.2	31.5	24.0	18.3	14.0	10.7	8.26	6.38	4.47	2.92	1.93	1.32
16		204	155	118	90.2	68.8	52.4	40.0	30.5	23.3	17.8	13.6	10.4	8.04	6.22	4.37	2.87	1.92	1.32
18		198	151	115	87.6	66.8	50.9	38.8	29.6	22.6	17.3	13.2	10.17	7.84	6.09	4.29	2.83	1.90	1.32
20		193	147	112	85.3	65.0	49.6	37.8	28.8	22.0	16.9	12.9	9.93	7.67	5.97	4.23	2.80	1.90	1.34
22		188	143	109	83.1	63.4	48.3	36.9	28.1	21.5	16.5	12.6	9.71	7.52	5.87	4.18	2.79	1.91	1.36
24		183	140	107	81.2	61.9	47.2	36.0	27.5	21.0	16.1	12.4	9.53	7.39	5.79	4.14	2.79	1.93	1.39
26		180	137	104	79.5	60.6	46.3	35.3	27.0	20.6	15.8	12.1	9.37	7.29	5.73	4.13	2.80	1.96	1.43
28		176	134	102	78.0	59.5	45.4	34.6	26.5	20.2	15.5	11.9	9.24	7.21	5.69	4.12	2.82	2.00	1.48
30		173	132	101	76.6	58.5	44.6	34.0	26.0	19.9	15.3	11.8	9.13	7.15	5.67	4.14	2.86	2.05	1.54

Table 2C-2 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during winter non-spawning period (November 1 through February 28/29).

Conductivity (umhos) = 500

Ionic Strength = 0.008

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		293	223	170	130	98.9	75.4	57.5	43.8	33.4	25.5	19.4	14.8	11.3	8.67	5.99	3.82	2.45	1.59
2		280	213	162	124	94.4	71.9	54.8	41.8	31.9	24.3	18.5	14.2	10.8	8.29	5.73	3.66	2.36	1.53
4		267	204	155	118	90.2	68.8	52.4	40.0	30.5	23.2	17.7	13.6	10.4	7.95	5.50	3.52	2.28	1.49
6		256	195	149	113	86.5	65.9	50.3	38.3	29.2	22.3	17.0	13.0	9.96	7.64	5.30	3.40	2.20	1.45
8		246	188	143	109	83.1	63.3	48.3	36.8	28.1	21.4	16.4	12.5	9.59	7.37	5.12	3.29	2.14	1.42
10		237	181	138	105	80.0	61.0	46.5	35.5	27.1	20.7	15.8	12.1	9.26	7.12	4.96	3.20	2.09	1.40
12		229	174	133	101.4	77.3	58.9	44.9	34.2	26.1	19.9	15.2	11.7	8.96	6.90	4.82	3.12	2.05	1.38
14		221	169	129	98.0	74.7	57.0	43.4	33.1	25.3	19.3	14.8	11.3	8.69	6.71	4.70	3.06	2.02	1.37
16		215	164	125	95.0	72.4	55.2	42.1	32.1	24.5	18.7	14.3	11.0	8.46	6.54	4.59	3.00	2.00	1.37
18		208	159	121	92.3	70.4	53.6	40.9	31.2	23.8	18.2	13.9	10.7	8.25	6.40	4.50	2.96	1.99	1.38
20		203	155	118	89.8	68.5	52.2	39.8	30.4	23.2	17.7	13.6	10.4	8.07	6.27	4.43	2.93	1.99	1.39
22		198	151	115	87.6	66.8	50.9	38.9	29.7	22.7	17.3	13.3	10.22	7.91	6.17	4.38	2.92	1.99	1.41
24		193	147	112	85.6	65.3	49.8	38.0	29.0	22.2	17.0	13.0	10.03	7.77	6.08	4.34	2.91	2.01	1.44
26		189	144	110	83.9	63.9	48.8	37.2	28.4	21.7	16.6	12.8	9.86	7.66	6.02	4.32	2.92	2.04	1.48
28		186	142	108	82.3	62.7	47.8	36.5	27.9	21.3	16.4	12.6	9.7	7.58	5.98	4.32	2.94	2.08	1.53
30		183	139	106	80.8	61.7	47.0	35.9	27.4	21.0	16.1	12.4	9.61	7.51	5.95	4.33	2.98	2.13	1.59

Table 2D Calculated un-ionized ammonia CCC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during winter non-spawning period (November 1 through February 28/29).

Freshwater Criteria = 0.060

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.010	0.012	0.015	0.018	0.022	0.026	0.029	0.029	0.029	0.029
2		0.003	0.003	0.004	0.005	0.005	0.007	0.008	0.010	0.012	0.014	0.017	0.020	0.025	0.030	0.032	0.032	0.032	0.032
4		0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.036	0.036	0.036	0.036
6		0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.018	0.021	0.026	0.031	0.038	0.041	0.041	0.041	0.041
8		0.004	0.004	0.005	0.006	0.008	0.009	0.011	0.014	0.017	0.020	0.024	0.029	0.035	0.043	0.046	0.046	0.046	0.046
10		0.004	0.005	0.006	0.007	0.009	0.011	0.013	0.015	0.019	0.023	0.027	0.033	0.040	0.048	0.052	0.052	0.052	0.052
12		0.005	0.006	0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.031	0.037	0.045	0.054	0.059	0.059	0.059	0.059
14		0.005	0.006	0.008	0.009	0.011	0.013	0.016	0.020	0.024	0.029	0.035	0.042	0.051	0.061	0.066	0.066	0.066	0.066
16		0.006	0.007	0.009	0.010	0.013	0.015	0.018	0.022	0.027	0.032	0.039	0.047	0.057	0.069	0.075	0.075	0.075	0.075
18		0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.030	0.036	0.044	0.053	0.064	0.078	0.084	0.084	0.084	0.084
20		0.008	0.009	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.041	0.050	0.060	0.072	0.088	0.095	0.095	0.095	0.095
22		0.008	0.010	0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.046	0.056	0.068	0.082	0.099	0.107	0.107	0.107	0.107
24		0.010	0.012	0.014	0.017	0.020	0.025	0.030	0.036	0.043	0.052	0.063	0.076	0.092	0.111	0.121	0.121	0.121	0.121
26		0.011	0.013	0.016	0.019	0.023	0.028	0.033	0.040	0.049	0.059	0.071	0.086	0.104	0.125	0.136	0.136	0.136	0.136
28		0.012	0.015	0.018	0.021	0.026	0.031	0.038	0.046	0.055	0.066	0.080	0.097	0.117	0.141	0.154	0.154	0.154	0.154
30		0.014	0.017	0.020	0.024	0.029	0.035	0.042	0.051	0.062	0.075	0.090	0.109	0.132	0.159	0.173	0.173	0.173	0.173

Table 2D-1 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during winter non-spawning period (November 1 through February 28/29).

Conductivity (umhos) = 100

Ionic Strength = 0.002

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		72.1	54.9	41.9	31.9	24.3	18.5	14.1	10.8	8.21	6.26	4.78	3.65	2.79	2.13	1.47	0.94	0.60	0.39
2		68.7	52.4	39.9	30.4	23.2	17.7	13.5	10.27	7.83	5.97	4.56	3.48	2.66	2.04	1.41	0.90	0.58	0.38
4		65.7	50.1	38.2	29.1	22.2	16.9	12.9	9.82	7.49	5.71	4.36	3.33	2.55	1.96	1.35	0.87	0.56	0.37
6		63.0	48.0	36.6	27.9	21.3	16.2	12.3	9.41	7.18	5.48	4.18	3.20	2.45	1.88	1.30	0.84	0.54	0.36
8		60.5	46.1	35.1	26.8	20.4	15.6	11.9	9.05	6.90	5.27	4.02	3.08	2.36	1.81	1.26	0.81	0.53	0.35
10		58.3	44.4	33.8	25.8	19.7	15.0	11.4	8.71	6.65	5.07	3.88	2.97	2.28	1.75	1.22	0.79	0.52	0.35
12		56.2	42.8	32.7	24.9	19.0	14.5	11.0	8.41	6.42	4.90	3.75	2.87	2.20	1.70	1.19	0.77	0.51	0.34
14		54.4	41.4	31.6	24.1	18.3	14.0	10.7	8.14	6.21	4.74	3.63	2.78	2.14	1.65	1.16	0.75	0.50	0.34
16		52.7	40.2	30.6	23.3	17.8	13.6	10.34	7.89	6.02	4.60	3.52	2.70	2.08	1.61	1.13	0.74	0.50	0.34
18		51.2	39.0	29.7	22.7	17.3	13.2	10.04	7.66	5.85	4.47	3.42	2.63	2.03	1.57	1.11	0.73	0.49	0.34
20		49.8	38.0	28.9	22.1	16.8	12.8	9.78	7.46	5.70	4.36	3.34	2.57	1.98	1.54	1.09	0.72	0.49	0.35
22		48.6	37.0	28.2	21.5	16.4	12.5	9.54	7.28	5.56	4.26	3.26	2.51	1.94	1.52	1.08	0.72	0.49	0.35
24		47.4	36.2	27.6	21.0	16.0	12.2	9.32	7.12	5.44	4.16	3.20	2.46	1.91	1.50	1.07	0.72	0.50	0.36
26		46.4	35.4	27.0	20.6	15.7	12.0	9.13	6.97	5.33	4.08	3.14	2.42	1.89	1.48	1.07	0.72	0.51	0.37
28		45.5	34.7	26.5	20.2	15.4	11.7	8.96	6.84	5.23	4.01	3.09	2.39	1.86	1.47	1.07	0.73	0.52	0.38
30		44.7	34.1	26.0	19.8	15.1	11.5	8.81	6.73	5.15	3.95	3.05	2.36	1.85	1.47	1.07	0.74	0.53	0.40

Table 2D-2 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey non-trout waters (FW2-NT) during winter non-spawning period (November 1 through February 28/29

Conductivity (umhos) = 500

Ionic Strength = 0.008

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		75.8	57.8	44.0	33.6	25.6	19.5	14.9	11.3	8.64	6.59	5.02	3.84	2.93	2.24	1.55	0.99	0.63	0.41
2		72.3	55.1	42.0	32.0	24.4	18.6	14.2	10.8	8.24	6.28	4.80	3.66	2.80	2.14	1.48	0.95	0.61	0.40
4		69.2	52.7	40.2	30.6	23.3	17.8	13.6	10.34	7.88	6.01	4.59	3.51	2.68	2.06	1.42	0.91	0.59	0.38
6		66.3	50.5	38.5	29.4	22.4	17.1	13.0	9.91	7.56	5.77	4.40	3.36	2.58	1.98	1.37	0.88	0.57	0.37
8		63.7	48.6	37.0	28.2	21.5	16.4	12.5	9.52	7.26	5.54	4.23	3.24	2.48	1.91	1.32	0.85	0.55	0.37
10		61.3	46.8	35.6	27.2	20.7	15.8	12.0	9.17	7.00	5.34	4.08	3.12	2.39	1.84	1.28	0.83	0.54	0.36
12		59.2	45.1	34.4	26.2	20.0	15.2	11.6	8.86	6.76	5.16	3.94	3.02	2.32	1.79	1.25	0.81	0.53	0.36
14		57.3	43.6	33.3	25.4	19.3	14.7	11.2	8.57	6.54	4.99	3.82	2.93	2.25	1.74	1.21	0.79	0.52	0.35
16		55.5	42.3	32.2	24.6	18.7	14.3	10.9	8.31	6.34	4.84	3.71	2.84	2.19	1.69	1.19	0.78	0.52	0.35
18		53.9	41.1	31.3	23.9	18.2	13.9	10.6	8.07	6.16	4.71	3.61	2.77	2.13	1.65	1.17	0.77	0.51	0.36
20		52.5	40.0	30.5	23.2	17.7	13.5	10.30	7.86	6.00	4.59	3.52	2.70	2.09	1.62	1.15	0.76	0.51	0.36
22		51.2	39.0	29.7	22.7	17.3	13.2	10.05	7.67	5.86	4.48	3.44	2.64	2.05	1.60	1.13	0.75	0.52	0.36
24		50.0	38.1	29.1	22.1	16.9	12.9	9.82	7.50	5.73	4.39	3.37	2.59	2.01	1.57	1.12	0.75	0.52	0.37
26		49.0	37.3	28.4	21.7	16.5	12.6	9.62	7.35	5.62	4.30	3.31	2.55	1.98	1.56	1.12	0.76	0.53	0.38
28		48.0	36.6	27.9	21.3	16.2	12.4	9.44	7.21	5.52	4.23	3.25	2.51	1.96	1.55	1.12	0.76	0.54	0.40
30		47.2	36.0	27.4	20.9	15.9	12.2	9.29	7.10	5.43	4.17	3.21	2.49	1.94	1.54	1.12	0.77	0.55	0.41

Table 3A Calculated un-ionized ammonia CMC values (mg/L as N) for New Jersey Pineland waters (PL).

Freshwater Criteria = 0.238

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.009	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.041	0.049	0.060	0.072	0.087	0.105	0.114	0.114	0.114	0.114
2		0.010	0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.046	0.056	0.067	0.081	0.098	0.118	0.128	0.128	0.128	0.128
4		0.011	0.014	0.017	0.020	0.024	0.029	0.036	0.043	0.052	0.063	0.076	0.091	0.110	0.133	0.145	0.145	0.145	0.145
6		0.013	0.016	0.019	0.023	0.027	0.033	0.040	0.048	0.058	0.071	0.085	0.103	0.124	0.150	0.163	0.163	0.163	0.163
8		0.015	0.018	0.021	0.026	0.031	0.037	0.045	0.055	0.066	0.080	0.096	0.116	0.140	0.169	0.184	0.184	0.184	0.184
10		0.016	0.020	0.024	0.029	0.035	0.042	0.051	0.061	0.074	0.090	0.108	0.131	0.158	0.191	0.207	0.207	0.207	0.207
12		0.018	0.022	0.027	0.033	0.039	0.047	0.057	0.069	0.084	0.101	0.122	0.147	0.178	0.215	0.234	0.234	0.234	0.234
14		0.021	0.025	0.030	0.037	0.044	0.054	0.065	0.078	0.094	0.114	0.138	0.166	0.201	0.242	0.263	0.263	0.263	0.263
16		0.023	0.028	0.034	0.041	0.050	0.060	0.073	0.088	0.106	0.128	0.155	0.187	0.226	0.273	0.297	0.297	0.297	0.297
18		0.026	0.032	0.039	0.047	0.056	0.068	0.082	0.099	0.120	0.145	0.175	0.211	0.255	0.308	0.335	0.335	0.335	0.335
20		0.030	0.036	0.044	0.053	0.063	0.077	0.093	0.112	0.135	0.163	0.197	0.238	0.287	0.347	0.377	0.377	0.377	0.377
22		0.034	0.041	0.049	0.059	0.072	0.086	0.104	0.126	0.152	0.184	0.222	0.268	0.324	0.391	0.425	0.425	0.425	0.425
24		0.038	0.046	0.055	0.067	0.081	0.097	0.118	0.142	0.172	0.207	0.250	0.302	0.365	0.441	0.479	0.479	0.479	0.479
26		0.043	0.052	0.062	0.075	0.091	0.110	0.133	0.160	0.193	0.234	0.282	0.341	0.412	0.497	0.540	0.540	0.540	0.540
28		0.048	0.058	0.070	0.085	0.102	0.124	0.149	0.181	0.218	0.263	0.318	0.384	0.464	0.561	0.609	0.609	0.609	0.609
30		0.054	0.066	0.079	0.096	0.115	0.140	0.168	0.204	0.246	0.297	0.359	0.433	0.523	0.632	0.686	0.686	0.686	0.686

Table 3A-1 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey Pineland waters (PL).

Conductivity (umhos) = 100

Ionic Strength = 0.002

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		286	218	166	127	96.4	73.5	56.0	42.7	32.6	24.8	18.9	14.5	11.1	8.46	5.84	3.73	2.39	1.55
2		273	208	158	121	92.0	70.1	53.4	40.7	31.1	23.7	18.1	13.8	10.6	8.09	5.59	3.58	2.30	1.50
4		261	199	151	115	88.0	67.0	51.1	39.0	29.7	22.7	17.3	13.2	10.1	7.76	5.37	3.44	2.22	1.46
6		250	190	145	111	84.3	64.3	49.0	37.3	28.5	21.7	16.6	12.7	9.71	7.46	5.17	3.32	2.16	1.42
8		240	183	139	106	81.0	61.7	47.1	35.9	27.4	20.9	16.0	12.2	9.35	7.19	4.99	3.22	2.10	1.39
10		231	176	134	102	78.0	59.4	45.3	34.6	26.4	20.1	15.4	11.8	9.03	6.95	4.84	3.13	2.05	1.37
12		223	170	130	98.7	75.3	57.4	43.7	33.4	25.5	19.4	14.9	11.4	8.73	6.74	4.70	3.05	2.01	1.36
14		216	164	125	95.5	72.8	55.5	42.3	32.3	24.6	18.8	14.4	11.0	8.48	6.55	4.59	2.99	1.98	1.35
16		209	159	121	92.5	70.5	53.8	41.0	31.3	23.9	18.2	14.0	10.7	8.25	6.38	4.49	2.94	1.96	1.35
18		203	155	118	89.9	68.5	52.2	39.8	30.4	23.2	17.7	13.6	10.4	8.04	6.24	4.40	2.90	1.95	1.36
20		198	151	115	87.5	66.7	50.8	38.8	29.6	22.6	17.3	13.2	10.2	7.87	6.12	4.34	2.88	1.95	1.37
22		193	147	112	85.3	65.0	49.6	37.8	28.9	22.1	16.9	12.9	9.96	7.71	6.02	4.29	2.86	1.96	1.39
24		188	143	109	83.3	63.5	48.5	37.0	28.2	21.6	16.5	12.7	9.78	7.58	5.94	4.25	2.86	1.98	1.43
26		184	140	107	81.6	62.2	47.4	36.2	27.7	21.1	16.2	12.4	9.61	7.48	5.88	4.23	2.87	2.01	1.47
28		181	138	105	80.0	61.0	46.5	35.5	27.1	20.8	15.9	12.3	9.48	7.39	5.84	4.23	2.89	2.05	1.52
30		178	135	103	78.6	60.0	45.8	34.9	26.7	20.4	15.7	12.1	9.37	7.33	5.82	4.24	2.93	2.10	1.58

Table 3A-2 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey Pineland waters (PL).

Conductivity (umhos) = 500

Ionic Strength = 0.008

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		301	229	175	133	101.5	77.3	58.9	44.9	34.3	26.1	19.9	15.2	11.6	8.90	6.14	3.92	2.51	1.63
2		287	219	167	127	96.8	73.8	56.2	42.9	32.7	24.9	19.0	14.5	11.1	8.51	5.88	3.76	2.42	1.57
4		274	209	159	121	92.6	70.6	53.8	41.0	31.3	23.8	18.2	13.9	10.6	8.16	5.64	3.61	2.33	1.53
6		263	200	153	116	88.7	67.6	51.6	39.3	30.0	22.9	17.5	13.3	10.2	7.84	5.43	3.49	2.26	1.49
8		253	193	147	112	85.3	65.0	49.5	37.8	28.8	22.0	16.8	12.8	9.84	7.56	5.25	3.38	2.20	1.46
10		243	185	141	108	82.1	62.6	47.7	36.4	27.8	21.2	16.2	12.4	9.49	7.31	5.08	3.28	2.15	1.43
12		235	179	136	104	79.2	60.4	46.1	35.1	26.8	20.5	15.6	12.0	9.19	7.08	4.94	3.20	2.11	1.42
14		227	173	132	100.6	76.7	58.4	44.6	34.0	25.9	19.8	15.1	11.6	8.92	6.88	4.82	3.14	2.08	1.41
16		220	168	128	97.5	74.3	56.7	43.2	33.0	25.2	19.2	14.7	11.3	8.67	6.71	4.71	3.08	2.05	1.41
18		214	163	124	94.7	72.2	55.0	42.0	32.0	24.4	18.7	14.3	11.0	8.46	6.56	4.62	3.04	2.04	1.41
20		208	159	121	92.2	70.3	53.6	40.9	31.2	23.8	18.2	13.9	10.7	8.27	6.43	4.55	3.01	2.04	1.43
22		203	155	118	89.9	68.5	52.3	39.9	30.4	23.2	17.8	13.6	10.5	8.11	6.33	4.49	2.99	2.04	1.45
24		198	151	115	87.9	67.0	51.1	39.0	29.8	22.7	17.4	13.4	10.3	7.98	6.24	4.46	2.99	2.06	1.48
26		194	148	113	86.0	65.6	50.0	38.2	29.1	22.3	17.1	13.1	10.1	7.86	6.18	4.43	3.00	2.09	1.52
28		191	145	111	84.4	64.3	49.1	37.5	28.6	21.9	16.8	12.9	9.97	7.77	6.13	4.43	3.02	2.13	1.57
30		187	143	109	82.9	63.2	48.3	36.8	28.1	21.5	16.5	12.7	9.86	7.71	6.11	4.44	3.05	2.18	1.63

Table 3B Calculated un-ionized ammonia CCC values (mg/L as N) for New Jersey Pineland waters (PL).

Freshwater Criteria =- 0.061

Temperature (°C)	pH 5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.010	0.013	0.015	0.018	0.022	0.027	0.029	0.029	0.029	0.029
2	0.003	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.030	0.033	0.033	0.033	0.033
4	0.003	0.004	0.004	0.005	0.006	0.008	0.009	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.037	0.037	0.037	0.037
6	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.042	0.042	0.042	0.042
8	0.004	0.005	0.005	0.007	0.008	0.010	0.012	0.014	0.017	0.020	0.025	0.030	0.036	0.043	0.047	0.047	0.047	0.047
10	0.004	0.005	0.006	0.007	0.009	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.040	0.049	0.053	0.053	0.053	0.053
12	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.018	0.021	0.026	0.031	0.038	0.046	0.055	0.060	0.060	0.060	0.060
14	0.005	0.006	0.008	0.009	0.011	0.014	0.017	0.020	0.024	0.029	0.035	0.043	0.051	0.062	0.068	0.068	0.068	0.068
16	0.006	0.007	0.009	0.011	0.013	0.015	0.019	0.023	0.027	0.033	0.040	0.048	0.058	0.070	0.076	0.076	0.076	0.076
18	0.007	0.008	0.010	0.012	0.014	0.017	0.021	0.025	0.031	0.037	0.045	0.054	0.065	0.079	0.086	0.086	0.086	0.086
20	0.008	0.009	0.011	0.013	0.016	0.020	0.024	0.029	0.035	0.042	0.051	0.061	0.074	0.089	0.097	0.097	0.097	0.097
22	0.009	0.010	0.013	0.015	0.018	0.022	0.027	0.032	0.039	0.047	0.057	0.069	0.083	0.100	0.109	0.109	0.109	0.109
24	0.010	0.012	0.014	0.017	0.021	0.025	0.030	0.036	0.044	0.053	0.064	0.078	0.094	0.113	0.123	0.123	0.123	0.123
26	0.011	0.013	0.016	0.019	0.023	0.028	0.034	0.041	0.050	0.060	0.072	0.087	0.106	0.127	0.138	0.138	0.138	0.138
28	0.012	0.015	0.018	0.022	0.026	0.032	0.038	0.046	0.056	0.068	0.082	0.098	0.119	0.144	0.156	0.156	0.156	0.156
30	0.014	0.017	0.020	0.025	0.030	0.036	0.043	0.052	0.063	0.076	0.092	0.111	0.134	0.162	0.176	0.176	0.176	0.176

Table 3B-1 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey Pinelans waters (PL).

Conductivity (umhos) = 100

Ionic Strength = 0.002

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		73.3	55.8	42.5	32.4	24.7	18.8	14.4	10.9	8.34	6.36	4.86	3.71	2.83	2.17	1.50	0.96	0.61	0.40
2		69.9	53.3	40.6	30.9	23.6	18.0	13.7	10.4	7.96	6.07	4.63	3.54	2.71	2.07	1.43	0.92	0.59	0.38
4		66.8	50.9	38.8	29.6	22.5	17.2	13.1	9.99	7.61	5.81	4.43	3.39	2.59	1.99	1.38	0.88	0.57	0.37
6		64.0	48.8	37.2	28.3	21.6	16.5	12.6	9.57	7.30	5.57	4.25	3.25	2.49	1.91	1.33	0.85	0.55	0.36
8		61.5	46.9	35.7	27.2	20.8	15.8	12.1	9.20	7.02	5.35	4.09	3.13	2.40	1.84	1.28	0.83	0.54	0.36
10		59.2	45.1	34.4	26.2	20.0	15.2	11.6	8.86	6.76	5.16	3.94	3.02	2.31	1.78	1.24	0.80	0.53	0.35
12		57.2	43.6	33.2	25.3	19.3	14.7	11.2	8.55	6.52	4.98	3.81	2.92	2.24	1.73	1.21	0.78	0.52	0.35
14		55.3	42.1	32.1	24.5	18.7	14.2	10.8	8.27	6.31	4.82	3.69	2.83	2.17	1.68	1.18	0.77	0.51	0.35
16		53.6	40.8	31.1	23.7	18.1	13.8	10.5	8.02	6.12	4.68	3.58	2.75	2.11	1.64	1.15	0.75	0.50	0.35
18		52.0	39.7	30.2	23.0	17.6	13.4	10.2	7.79	5.95	4.55	3.48	2.67	2.06	1.60	1.13	0.74	0.50	0.35
20		50.6	38.6	29.4	22.4	17.1	13.0	9.94	7.59	5.79	4.43	3.39	2.61	2.02	1.57	1.11	0.74	0.50	0.35
22		49.4	37.6	28.7	21.9	16.7	12.7	9.70	7.40	5.65	4.33	3.32	2.55	1.98	1.54	1.10	0.73	0.50	0.36
24		48.2	36.8	28.0	21.4	16.3	12.4	9.48	7.23	5.53	4.23	3.25	2.51	1.94	1.52	1.09	0.73	0.51	0.37
26		47.2	36.0	27.4	20.9	15.9	12.2	9.28	7.09	5.42	4.15	3.19	2.46	1.92	1.51	1.08	0.74	0.52	0.38
28		46.3	35.3	26.9	20.5	15.6	11.9	9.11	6.96	5.32	4.08	3.14	2.43	1.90	1.50	1.08	0.74	0.53	0.39
30		45.5	34.7	26.4	20.2	15.4	11.7	8.95	6.84	5.24	4.02	3.10	2.40	1.88	1.49	1.09	0.75	0.54	0.40

Table 3B-2 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey Pineland waters (PL).

Conductivity (umhos) = 500

Ionic Strength = 0.008

Temperature (°C)	pH 5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0	77.1	58.7	44.8	34.1	26.0	19.8	15.1	11.5	8.78	6.70	5.11	3.90	2.98	2.28	1.57	1.00	0.64	0.42
2	73.5	56.0	42.7	32.5	24.8	18.9	14.4	11.0	8.38	6.39	4.88	3.72	2.85	2.18	1.51	0.96	0.62	0.40
4	70.3	53.6	40.8	31.1	23.7	18.1	13.8	10.5	8.01	6.11	4.67	3.56	2.73	2.09	1.45	0.93	0.60	0.39
6	67.4	51.4	39.2	29.8	22.7	17.3	13.2	10.1	7.68	5.86	4.48	3.42	2.62	2.01	1.39	0.89	0.58	0.38
8	64.8	49.4	37.6	28.7	21.9	16.7	12.7	9.68	7.38	5.64	4.30	3.29	2.52	1.94	1.35	0.87	0.56	0.37
10	62.4	47.5	36.2	27.6	21.0	16.0	12.2	9.33	7.11	5.43	4.15	3.17	2.43	1.87	1.30	0.84	0.55	0.37
12	60.2	45.9	35.0	26.6	20.3	15.5	11.8	9.00	6.87	5.24	4.01	3.07	2.36	1.82	1.27	0.82	0.54	0.36
14	58.2	44.4	33.8	25.8	19.6	15.0	11.4	8.71	6.65	5.08	3.88	2.97	2.29	1.76	1.23	0.80	0.53	0.36
16	56.4	43.0	32.8	25.0	19.0	14.5	11.1	8.45	6.45	4.93	3.77	2.89	2.22	1.72	1.21	0.79	0.53	0.36
18	54.8	41.8	31.8	24.3	18.5	14.1	10.8	8.21	6.27	4.79	3.67	2.81	2.17	1.68	1.18	0.78	0.52	0.36
20	53.4	40.7	31.0	23.6	18.0	13.7	10.5	7.99	6.10	4.67	3.58	2.75	2.12	1.65	1.17	0.77	0.52	0.37
22	52.0	39.7	30.2	23.0	17.6	13.4	10.2	7.80	5.96	4.56	3.49	2.69	2.08	1.62	1.15	0.77	0.52	0.37
24	50.8	38.8	29.5	22.5	17.2	13.1	9.99	7.63	5.83	4.46	3.42	2.64	2.04	1.60	1.14	0.77	0.53	0.38
26	49.8	37.9	28.9	22.0	16.8	12.8	9.78	7.47	5.71	4.37	3.36	2.59	2.02	1.58	1.14	0.77	0.54	0.39
28	48.8	37.2	28.4	21.6	16.5	12.6	9.60	7.33	5.61	4.30	3.31	2.56	1.99	1.57	1.13	0.77	0.55	0.40
30	48.0	36.6	27.9	21.3	16.2	12.4	9.44	7.21	5.52	4.24	3.26	2.53	1.97	1.56	1.14	0.78	0.56	0.42

Table 4A Calculated un-ionized ammonia CMC values (mg/L as N) for New Jersey saline estuary waters (SE1, SE2, SE3).

Saltwater Criteria = 0.115

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
2		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
4		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
6		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
8		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
10		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
12		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
14		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
16		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
18		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
20		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
22		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
24		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
26		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
28		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
30		0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115

Table 4A-1 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey saline estuary waters (SE1, SE2, SE3).

Salinity (ppt) = 10

Ionic Strength = 0.201

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		5023	3169	2000	1262	796	502	317	200	126	79.7	50.3	31.8	20.1	12.7	8.08	5.14	3.28	2.11
2		4254	2684	1694	1069	674	425	269	169	107	67.5	42.7	27.0	17.0	10.8	6.86	4.37	2.80	1.81
4		3612	2279	1438	907	573	361	228	144	90.8	57.4	36.2	22.9	14.5	9.19	5.84	3.73	2.39	1.55
6		3074	1939	1224	772	487	307	194	122	77.3	48.8	30.9	19.5	12.4	7.84	4.99	3.19	2.05	1.34
8		2622	1654	1044	659	416	262	166	104	66.0	41.7	26.3	16.7	10.6	6.70	4.27	2.74	1.77	1.16
10		2242	1414	893	563	355	224	142	89.4	56.4	35.6	22.5	14.3	9.04	5.75	3.67	2.36	1.53	1.01
12		1921	1212	765	483	305	192	121	76.6	48.4	30.6	19.3	12.2	7.76	4.94	3.16	2.04	1.33	0.88
14		1650	1041	657	414	262	165	104	65.8	41.6	26.3	16.6	10.5	6.68	4.26	2.73	1.76	1.16	0.77
16		1420	896	565	357	225	142	89.7	56.6	35.8	22.6	14.3	9.07	5.77	3.68	2.37	1.53	1.01	0.68
18		1225	773	488	308	194	123	77.4	48.9	30.9	19.5	12.4	7.84	4.99	3.19	2.06	1.34	0.89	0.60
20		1058	668	421	266	168	106	66.9	42.2	26.7	16.9	10.7	6.79	4.33	2.77	1.79	1.17	0.78	0.54
22		917	578	365	230	145	91.8	57.9	36.6	23.1	14.6	9.28	5.90	3.76	2.42	1.57	1.03	0.69	0.48
24		795	502	317	200	126	79.6	50.3	31.8	20.1	12.7	8.07	5.13	3.28	2.11	1.38	0.91	0.62	0.43
26		691	436	275	174	110	69.2	43.7	27.6	17.5	11.1	7.03	4.48	2.87	1.85	1.21	0.81	0.55	0.39
28		602	380	240	151	95.5	60.3	38.1	24.1	15.2	9.66	6.14	3.91	2.51	1.63	1.07	0.72	0.49	0.35
30		526	332	209	132	83.4	52.7	33.3	21.0	13.3	8.44	5.37	3.43	2.21	1.43	0.95	0.64	0.45	0.32

Table 4A-2 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey saline estuary waters (SE1, SE2, SE3).

Salinity (ppt) = 30

Ionic Strength = 0.616

Temperature (°C)	pH 5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0	5981	3774	2381	1502	948	598	377	238	150	94.9	59.9	37.9	23.9	15.1	9.59	6.10	3.89	2.50
2	5068	3198	2018	1273	803	507	320	202	127	80.4	50.8	32.1	20.3	12.8	8.15	5.18	3.31	2.13
4	4304	2716	1714	1081	682	431	272	171	108	68.3	43.2	27.3	17.3	10.9	6.94	4.42	2.83	1.83
6	3665	2312	1459	921	581	367	231	146	92.2	58.2	36.8	23.2	14.7	9.32	5.92	3.78	2.43	1.57
8	3128	1973	1245	786	496	313	197	125	78.7	49.7	31.4	19.8	12.6	7.97	5.07	3.24	2.09	1.36
10	2675	1688	1065	672	424	268	169	107	67.3	42.5	26.9	17.0	10.8	6.83	4.35	2.79	1.80	1.18
12	2294	1447	913	576	364	229	145	91.4	57.7	36.5	23.0	14.6	9.25	5.88	3.75	2.41	1.56	1.03
14	1971	1243	785	495	312	197	124	78.6	49.6	31.3	19.8	12.5	7.96	5.06	3.24	2.09	1.36	0.90
16	1697	1071	676	426	269	170	107	67.7	42.7	27.0	17.1	10.8	6.87	4.38	2.80	1.81	1.19	0.79
18	1464	924	583	368	232	147	92.5	58.4	36.9	23.3	14.8	9.35	5.94	3.79	2.44	1.58	1.04	0.70
20	1266	799	504	318	201	127	80.0	50.5	31.9	20.2	12.8	8.10	5.16	3.30	2.12	1.38	0.91	0.62
22	1097	692	437	276	174	110	69.3	43.8	27.7	17.5	11.1	7.04	4.48	2.87	1.85	1.21	0.81	0.55
24	952	601	379	239	151	95	60.2	38.0	24.0	15.2	9.64	6.12	3.91	2.51	1.62	1.07	0.72	0.49
26	828	523	330	208	131	83.0	52.4	33.1	20.9	13.2	8.40	5.34	3.41	2.20	1.43	0.94	0.64	0.44
28	722	456	288	181	115	72.3	45.7	28.9	18.2	11.6	7.33	4.67	2.99	1.93	1.26	0.84	0.57	0.40
30	631	398	251	158	100	63.2	39.9	25.2	15.9	10.1	6.42	4.09	2.62	1.70	1.11	0.75	0.51	0.37

Table 4B Calculated un-ionized ammonia CCC values (mg/L as N) for New Jersey saline estuary waters (SE1, SE2, SE3).

Saltwater Criteria = 0.030

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
2		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
4		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
6		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
8		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
10		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
12		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
14		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
16		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
18		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
20		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
22		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
24		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
26		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
28		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
30		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030

Table 4B-1 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey saline estuary waters (SE1, SE2, SE3).

Salinity (ppt) = 10

Ionic Strength = 0.201

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		1310	827	522	329	208	131	82.7	52.2	32.9	20.8	13.1	8.30	5.25	3.32	2.11	1.34	0.86	0.55
2		1110	700	442	279	176	111	70.0	44.2	27.9	17.6	11.1	7.03	4.45	2.82	1.79	1.14	0.73	0.47
4		942	594	375	237	149	94.2	59.5	37.5	23.7	15.0	9.45	5.97	3.78	2.40	1.52	0.97	0.62	0.41
6		802	506	319	201	127	80.2	50.6	32.0	20.2	12.7	8.05	5.09	3.22	2.04	1.30	0.83	0.54	0.35
8		684	432	272	172	108	68.4	43.2	27.3	17.2	10.9	6.87	4.35	2.75	1.75	1.11	0.71	0.46	0.30
10		585	369	233	147	92.7	58.5	36.9	23.3	14.7	9.30	5.88	3.72	2.36	1.50	0.96	0.61	0.40	0.26
12		501	316	200	126	79.4	50.1	31.6	20.0	12.6	7.97	5.04	3.19	2.02	1.29	0.82	0.53	0.35	0.23
14		430	272	171	108	68.2	43.1	27.2	17.2	10.8	6.85	4.33	2.75	1.74	1.11	0.71	0.46	0.30	0.20
16		370	234	147	93.1	58.7	37.1	23.4	14.8	9.33	5.90	3.73	2.37	1.50	0.96	0.62	0.40	0.26	0.18
18		319	202	127	80.3	50.7	32.0	20.2	12.7	8.05	5.09	3.22	2.05	1.30	0.83	0.54	0.35	0.23	0.16
20		276	174	110	69.4	43.8	27.6	17.4	11.0	6.96	4.41	2.79	1.77	1.13	0.72	0.47	0.31	0.20	0.14
22		239	151	95.2	60.1	37.9	23.9	15.1	9.55	6.03	3.82	2.42	1.54	0.98	0.63	0.41	0.27	0.18	0.13
24		207	131	82.6	52.1	32.9	20.8	13.1	8.29	5.24	3.32	2.10	1.34	0.86	0.55	0.36	0.24	0.16	0.11
26		180	114	71.8	45.3	28.6	18.1	11.4	7.21	4.56	2.89	1.83	1.17	0.75	0.48	0.32	0.21	0.14	0.10
28		157	99.1	62.6	39.5	24.9	15.7	9.94	6.28	3.98	2.52	1.60	1.02	0.66	0.42	0.28	0.19	0.13	0.09
30		137	86.5	54.6	34.5	21.8	13.7	8.68	5.49	3.47	2.20	1.40	0.89	0.58	0.37	0.25	0.17	0.12	0.08

Table 4B-2 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey saline estuary waters (SE1, SE2, SE3).

Salinity (ppt) = 30

Ionic Strength = 0.616

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		1560	985	621	392	247	156	98.5	62.1	39.2	24.8	15.6	9.87	6.24	3.95	2.50	1.59	1.01	0.65
2		1322	834	526	332	210	132	83.4	52.7	33.2	21.0	13.3	8.37	5.29	3.35	2.13	1.35	0.86	0.56
4		1123	709	447	282	178	112	70.9	44.7	28.2	17.8	11.3	7.11	4.50	2.85	1.81	1.15	0.74	0.48
6		956	603	381	240	152	95.6	60.4	38.1	24.0	15.2	9.59	6.06	3.84	2.43	1.55	0.99	0.63	0.41
8		816	515	325	205	129	81.6	51.5	32.5	20.5	13.0	8.19	5.18	3.28	2.08	1.32	0.85	0.54	0.35
10		698	440	278	175	111	69.8	44.1	27.8	17.6	11.1	7.01	4.43	2.81	1.78	1.14	0.73	0.47	0.31
12		598	378	238	150	94.9	59.9	37.8	23.8	15.1	9.51	6.01	3.80	2.41	1.53	0.98	0.63	0.41	0.27
14		514	324	205	129	81.5	51.4	32.5	20.5	12.9	8.18	5.17	3.27	2.08	1.32	0.84	0.54	0.35	0.23
16		443	279	176	111	70.2	44.3	28.0	17.7	11.1	7.05	4.46	2.82	1.79	1.14	0.73	0.47	0.31	0.21
18		382	241	152	96.0	60.6	38.2	24.1	15.2	9.62	6.08	3.85	2.44	1.55	0.99	0.64	0.41	0.27	0.18
20		330	208	132	83.0	52.4	33.1	20.9	13.2	8.33	5.26	3.33	2.11	1.34	0.86	0.55	0.36	0.24	0.16
22		286	181	114	71.9	45.4	28.6	18.1	11.4	7.22	4.57	2.89	1.84	1.17	0.75	0.48	0.32	0.21	0.14
24		248	157	98.9	62.4	39.4	24.9	15.7	9.92	6.27	3.97	2.51	1.60	1.02	0.65	0.42	0.28	0.19	0.13
26		216	136	86.1	54.3	34.3	21.6	13.7	8.63	5.46	3.45	2.19	1.39	0.89	0.57	0.37	0.25	0.17	0.12
28		188	119	75.0	47.3	29.9	18.9	11.9	7.53	4.76	3.01	1.91	1.22	0.78	0.50	0.33	0.22	0.15	0.10
30		164	104	65.5	41.3	26.1	16.5	10.4	6.58	4.16	2.64	1.67	1.07	0.68	0.44	0.29	0.19	0.13	0.10

Table 5A Calculated un-ionized ammonia CMC values (mg/L as N) for New Jersey saline coastal waters (SC).

Saltwater Criteria = 0.094

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
2		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
4		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
6		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
8		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
10		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
12		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
14		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
16		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
18		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
20		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
22		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
24		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
26		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
28		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
30		0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094

Table 5A-1 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey saline coastal waters (SC).

Salinity (ppt) = 10

Ionic Strength = 0.201

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		4106	2590	1634	1031	651	411	259	164	103	65.2	41.1	26.0	16.4	10.4	6.60	4.20	2.68	1.73
2		3477	2194	1384	873	551	348	219	139	87.4	55.2	34.9	22.0	13.9	8.83	5.60	3.57	2.29	1.48
4		2952	1863	1175	742	468	295	186	118	74.2	46.9	29.6	18.7	11.8	7.51	4.77	3.05	1.96	1.27
6		2512	1585	1000	631	398	251	159	100	63.2	39.9	25.2	15.9	10.1	6.40	4.08	2.61	1.68	1.09
8		2143	1352	853	538	340	214	135	85.4	53.9	34.1	21.5	13.6	8.63	5.48	3.49	2.24	1.45	0.95
10		1832	1156	730	460	290	183	116	73.0	46.1	29.1	18.4	11.7	7.39	4.70	3.00	1.93	1.25	0.82
12		1570	991	625	394	249	157	99.2	62.6	39.5	25.0	15.8	10.0	6.34	4.04	2.58	1.66	1.08	0.72
14		1348	851	537	339	214	135	85.2	53.8	34.0	21.5	13.6	8.60	5.46	3.48	2.23	1.44	0.94	0.63
16		1161	732	462	292	184	116	73.3	46.3	29.2	18.5	11.7	7.42	4.71	3.01	1.93	1.25	0.83	0.56
18		1001	632	399	251	159	100	63.2	39.9	25.2	16.0	10.1	6.41	4.08	2.61	1.68	1.09	0.73	0.49
20		865	546	344	217	137	86.6	54.7	34.5	21.8	13.8	8.74	5.55	3.54	2.27	1.46	0.96	0.64	0.44
22		749	473	298	188	119	75.0	47.4	29.9	18.9	12.0	7.58	4.82	3.08	1.98	1.28	0.84	0.57	0.39
24		650	410	259	163	103	65.1	41.1	26.0	16.4	10.4	6.59	4.19	2.68	1.73	1.12	0.74	0.50	0.35
26		565	357	225	142	89.6	56.6	35.7	22.6	14.3	9.05	5.74	3.66	2.34	1.51	0.99	0.66	0.45	0.32
28		492	311	196	124	78.1	49.3	31.1	19.7	12.5	7.89	5.02	3.20	2.05	1.33	0.87	0.59	0.40	0.29
30		430	271	171	108	68.2	43.0	27.2	17.2	10.9	6.90	4.39	2.80	1.80	1.17	0.77	0.52	0.37	0.26

Table 5A-2 Calculated total ammonia values from UIA CMC values (mg/L as N) for New Jersey saline coastal waters (SC).

Salinity (ppt) = 30

Ionic Strength = 0.616

Temperature (°C)	pH 5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0	4889	3085	1946	1228	775	489	309	195	123	77.6	49.0	30.9	19.6	12.4	7.84	4.98	3.18	2.04
2	4142	2614	1649	1041	657	414	261	165	104	65.7	41.5	26.2	16.6	10.5	6.66	4.24	2.71	1.74
4	3518	2220	1401	884	558	352	222	140	88.5	55.9	35.3	22.3	14.1	8.93	5.67	3.61	2.31	1.49
6	2996	1890	1193	753	475	300	189	119	75.3	47.6	30.0	19.0	12.0	7.62	4.84	3.09	1.98	1.29
8	2556	1613	1018	642	405	256	161	102	64.3	40.6	25.7	16.2	10.3	6.52	4.15	2.65	1.71	1.11
10	2187	1380	871	549	347	219	138	87.1	55.0	34.8	22.0	13.9	8.80	5.59	3.56	2.28	1.47	0.96
12	1875	1183	746	471	297	188	118	74.7	47.2	29.8	18.8	11.9	7.56	4.80	3.07	1.97	1.28	0.84
14	1611	1016	641	405	255	161	102	64.2	40.6	25.6	16.2	10.3	6.51	4.14	2.65	1.70	1.11	0.74
16	1387	875	552	348	220	139	87.6	55.3	34.9	22.1	14.0	8.84	5.62	3.58	2.29	1.48	0.97	0.65
18	1197	755	477	301	190	120	75.6	47.7	30.2	19.1	12.1	7.65	4.86	3.10	1.99	1.29	0.85	0.57
20	1035	653	412	260	164	104	65.4	41.3	26.1	16.5	10.4	6.62	4.21	2.69	1.73	1.13	0.75	0.51
22	897	566	357	225	142	89.8	56.7	35.8	22.6	14.3	9.06	5.75	3.66	2.35	1.52	0.99	0.66	0.45
24	778	491	310	196	123	77.9	49.2	31.1	19.6	12.4	7.88	5.01	3.19	2.05	1.33	0.87	0.59	0.40
26	677	427	270	170	107	67.8	42.8	27.1	17.1	10.8	6.87	4.37	2.79	1.79	1.17	0.77	0.52	0.36
28	590	372	235	148	93.6	59.1	37.3	23.6	14.9	9.45	6.00	3.82	2.44	1.58	1.03	0.68	0.47	0.33
30	515	325	205	130	81.8	51.6	32.6	20.6	13.0	8.26	5.25	3.35	2.15	1.39	0.91	0.61	0.42	0.30

Table 5B-Calculated un-ionized ammonia CCC values (mg/L as N) for New Jersey saline coastal waters (SC).

Saltwater Criteria = 0.024

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
2		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
4		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
6		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
8		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
10		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
12		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
14		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
16		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
18		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
20		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
22		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
24		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
26		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
28		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
30		0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024

Table 5B-1 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey saline coastal waters (SC).

Salinity (ppt) = 10

Ionic Strength = 0.201

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		1048	661	417	263	166	105	66.2	41.8	26.4	16.6	10.5	6.64	4.20	2.66	1.69	1.07	0.69	0.44
2		888	560	353	223	141	88.8	56.0	35.4	22.3	14.1	8.90	5.63	3.56	2.25	1.43	0.91	0.58	0.38
4		754	476	300	189	119	75.4	47.6	30.0	19.0	12.0	7.56	4.78	3.02	1.92	1.22	0.78	0.50	0.32
6		641	405	255	161	102	64.2	40.5	25.6	16.1	10.2	6.44	4.07	2.58	1.64	1.04	0.67	0.43	0.28
8		547	345	218	137	86.7	54.7	34.5	21.8	13.8	8.70	5.50	3.48	2.20	1.40	0.89	0.57	0.37	0.24
10		468	295	186	118	74.2	46.8	29.5	18.6	11.8	7.44	4.70	2.98	1.89	1.20	0.77	0.49	0.32	0.21
12		401	253	160	101	63.6	40.1	25.3	16.0	10.1	6.38	4.03	2.55	1.62	1.03	0.66	0.42	0.28	0.18
14		344	217	137	86.5	54.6	34.5	21.7	13.7	8.67	5.48	3.47	2.20	1.39	0.89	0.57	0.37	0.24	0.16
16		296	187	118	74.4	47.0	29.7	18.7	11.8	7.47	4.72	2.99	1.89	1.20	0.77	0.49	0.32	0.21	0.14
18		256	161	102	64.2	40.5	25.6	16.1	10.2	6.44	4.07	2.58	1.64	1.04	0.67	0.43	0.28	0.19	0.13
20		221	139	87.9	55.5	35.0	22.1	14.0	8.82	5.57	3.52	2.23	1.42	0.90	0.58	0.37	0.24	0.16	0.11
22		191	121	76.2	48.1	30.3	19.1	12.1	7.64	4.83	3.06	1.94	1.23	0.79	0.50	0.33	0.22	0.14	0.10
24		166	105	66.1	41.7	26.3	16.6	10.5	6.63	4.19	2.65	1.68	1.07	0.68	0.44	0.29	0.19	0.13	0.09
26		144	91.1	57.5	36.3	22.9	14.5	9.13	5.77	3.65	2.31	1.47	0.93	0.60	0.39	0.25	0.17	0.12	0.08
28		126	79.3	50.1	31.6	19.9	12.6	7.95	5.03	3.18	2.02	1.28	0.82	0.52	0.34	0.22	0.15	0.10	0.07
30		110	69.2	43.7	27.6	17.4	11.0	6.94	4.39	2.78	1.76	1.12	0.72	0.46	0.30	0.20	0.13	0.09	0.07

Table 5B-2 Calculated total ammonia values from UIA CCC values (mg/L as N) for New Jersey saline coastal waters (SC).

Salinity (ppt) = 30

Ionic Strength = 0.616

Temperature (°C)	pH	5.6	5.8	6	6.2	6.4	6.6	6.8	7	7.2	7.4	7.6	7.8	8	8.2	8.4	8.6	8.8	9
0		1248	788	497	314	198	125	78.8	49.7	31.4	19.8	12.5	7.90	4.99	3.16	2.00	1.27	0.81	0.52
2		1058	667	421	266	168	106	66.8	42.1	26.6	16.8	10.6	6.70	4.23	2.68	1.70	1.08	0.69	0.45
4		898	567	358	226	142	89.9	56.7	35.8	22.6	14.3	9.01	5.69	3.60	2.28	1.45	0.92	0.59	0.38
6		765	483	305	192	121	76.5	48.3	30.5	19.2	12.1	7.67	4.85	3.07	1.95	1.24	0.79	0.51	0.33
8		653	412	260	164	103	65.3	41.2	26.0	16.4	10.4	6.55	4.14	2.62	1.66	1.06	0.68	0.44	0.28
10		558	352	222	140	88.5	55.9	35.3	22.3	14.0	8.87	5.61	3.55	2.25	1.43	0.91	0.58	0.38	0.25
12		479	302	191	120	75.9	47.9	30.2	19.1	12.0	7.61	4.81	3.04	1.93	1.23	0.78	0.50	0.33	0.21
14		411	260	164	103	65.2	41.1	26.0	16.4	10.4	6.54	4.14	2.62	1.66	1.06	0.68	0.44	0.28	0.19
16		354	223	141	89.0	56.1	35.4	22.4	14.1	8.92	5.64	3.57	2.26	1.43	0.91	0.59	0.38	0.25	0.16
18		306	193	122	76.8	48.5	30.6	19.3	12.2	7.70	4.87	3.08	1.95	1.24	0.79	0.51	0.33	0.22	0.15
20		264	167	105	66.4	41.9	26.4	16.7	10.5	6.66	4.21	2.67	1.69	1.08	0.69	0.44	0.29	0.19	0.13
22		229	144	91.2	57.5	36.3	22.9	14.5	9.14	5.77	3.65	2.31	1.47	0.94	0.60	0.39	0.25	0.17	0.12
24		199	125	79.1	49.9	31.5	19.9	12.6	7.94	5.02	3.17	2.01	1.28	0.82	0.52	0.34	0.22	0.15	0.10
26		173	109	68.8	43.4	27.4	17.3	10.9	6.91	4.37	2.76	1.75	1.11	0.71	0.46	0.30	0.20	0.13	0.09
28		151	95.1	60.0	37.9	23.9	15.1	9.53	6.02	3.81	2.41	1.53	0.97	0.62	0.40	0.26	0.17	0.12	0.08
30		132	83.0	52.4	33.1	20.9	13.2	8.32	5.26	3.33	2.11	1.34	0.85	0.55	0.35	0.23	0.16	0.11	0.08

XIII. FIGURES

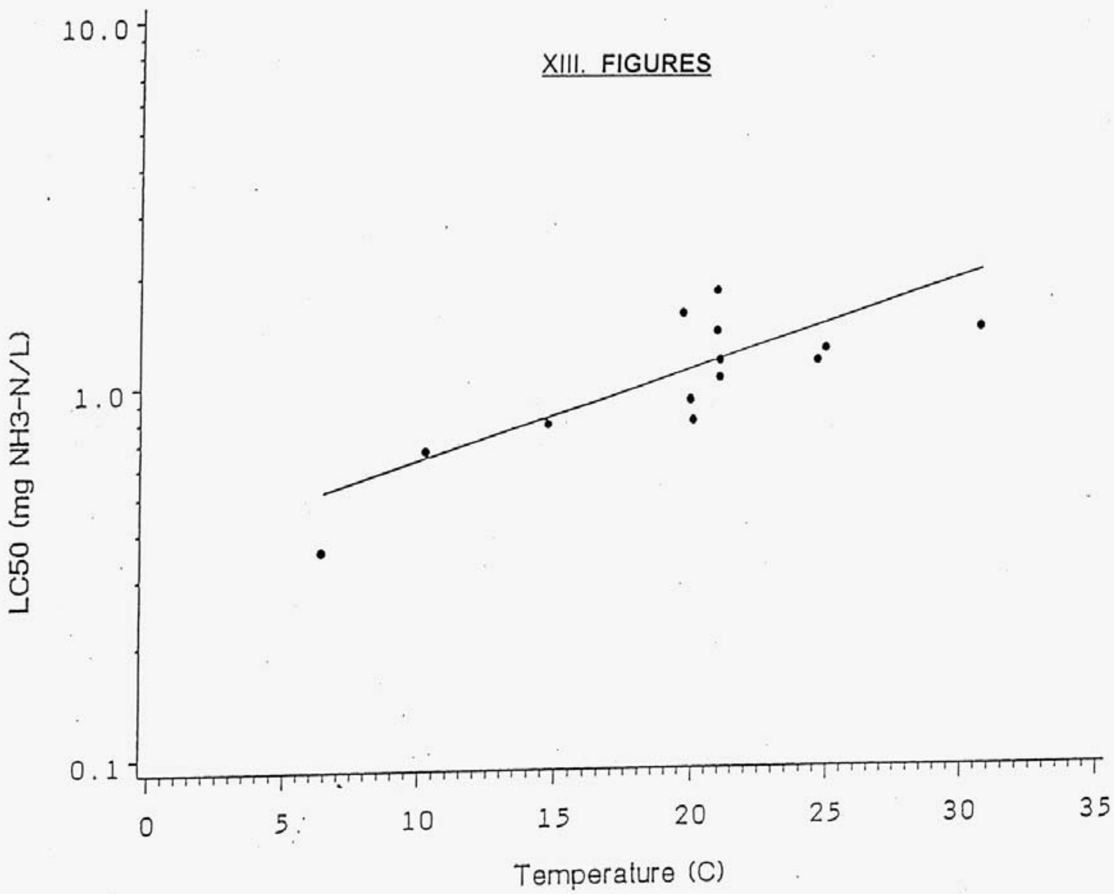

Figure 1 Linear regression of temperature-toxicity relationship for channel catfish for pH 7 ($p = 0.001$; $r^2 = 0.58$)

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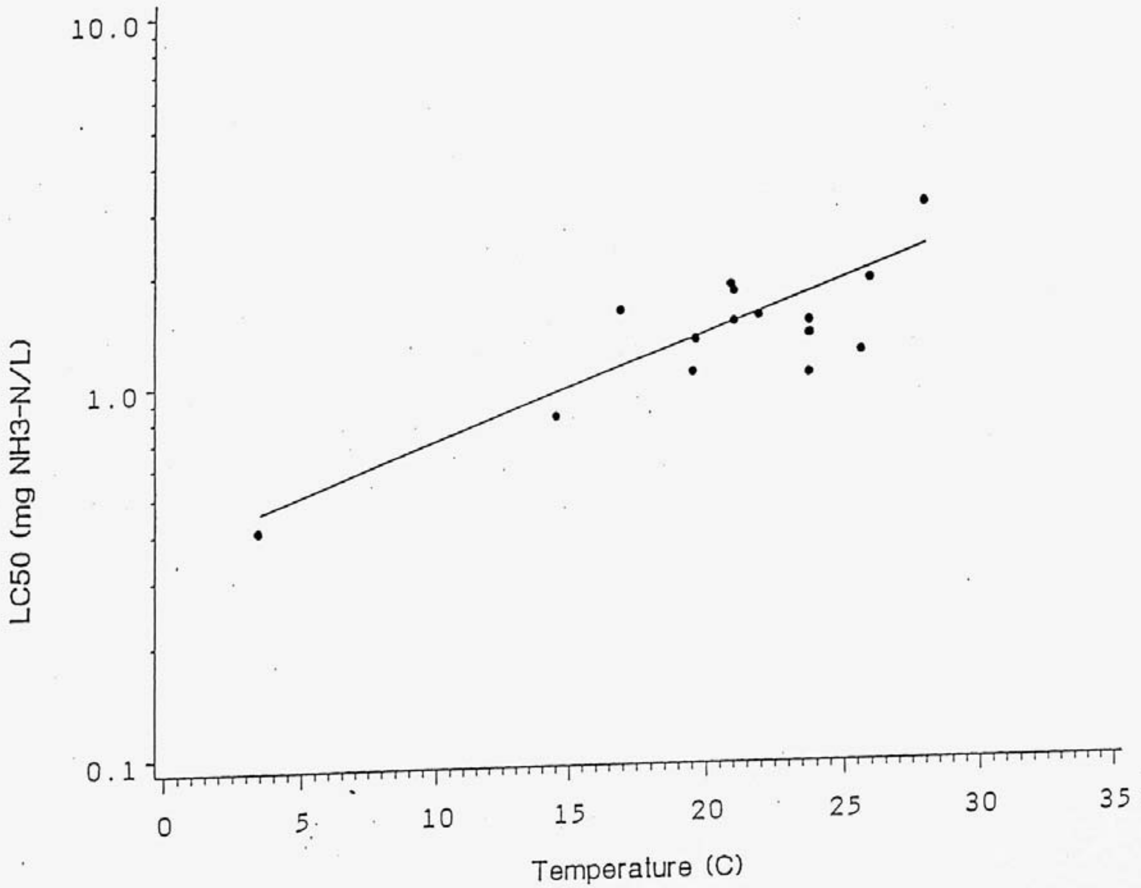

Figure 2 Linear regression of temperature-toxicity relationship for channel catfish for pH 8 ($p = 0.0001$; $r^2 = 0.64$)

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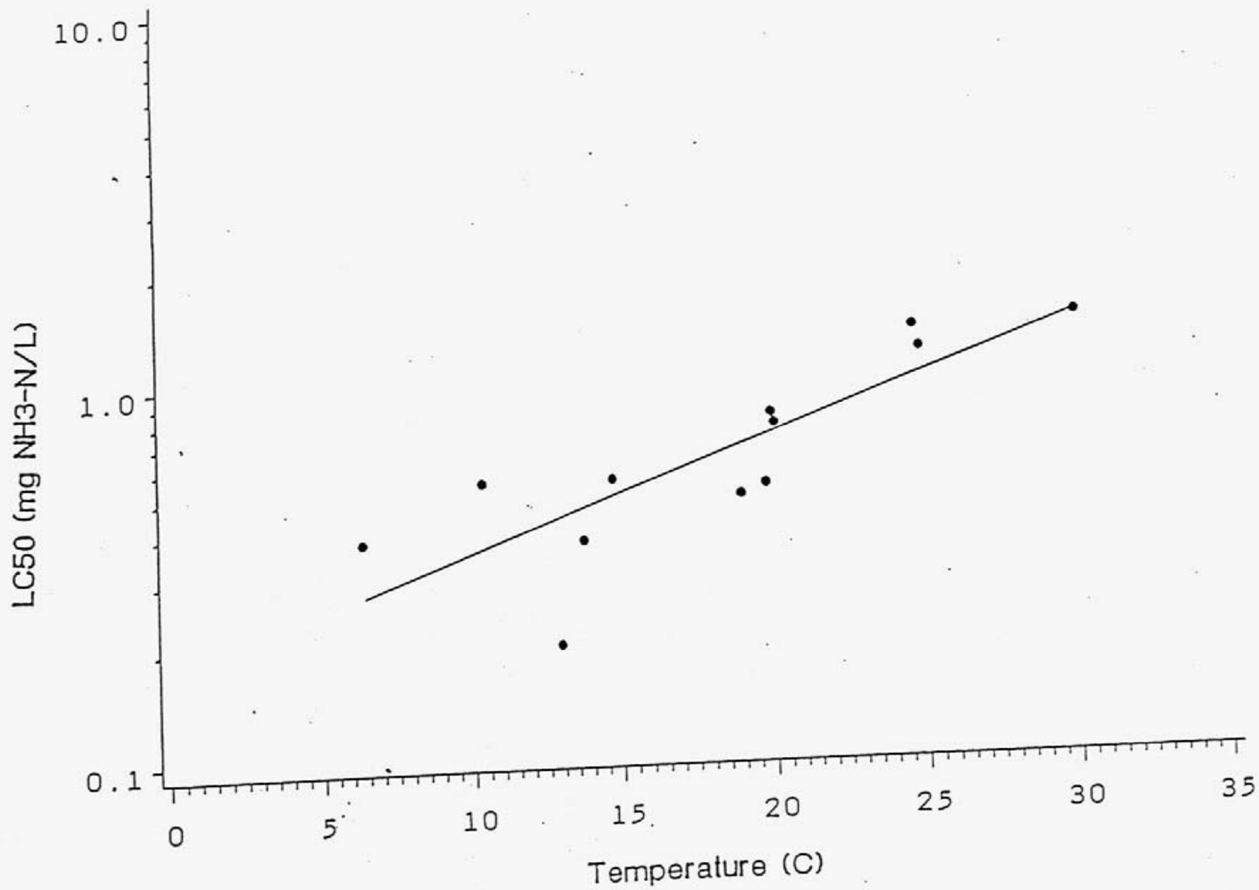

Figure 3 Linear regression of temperature-toxicity relationship for fathead minnow for pH 7 ($p = 0.0014$; $r^2 = 0.66$)

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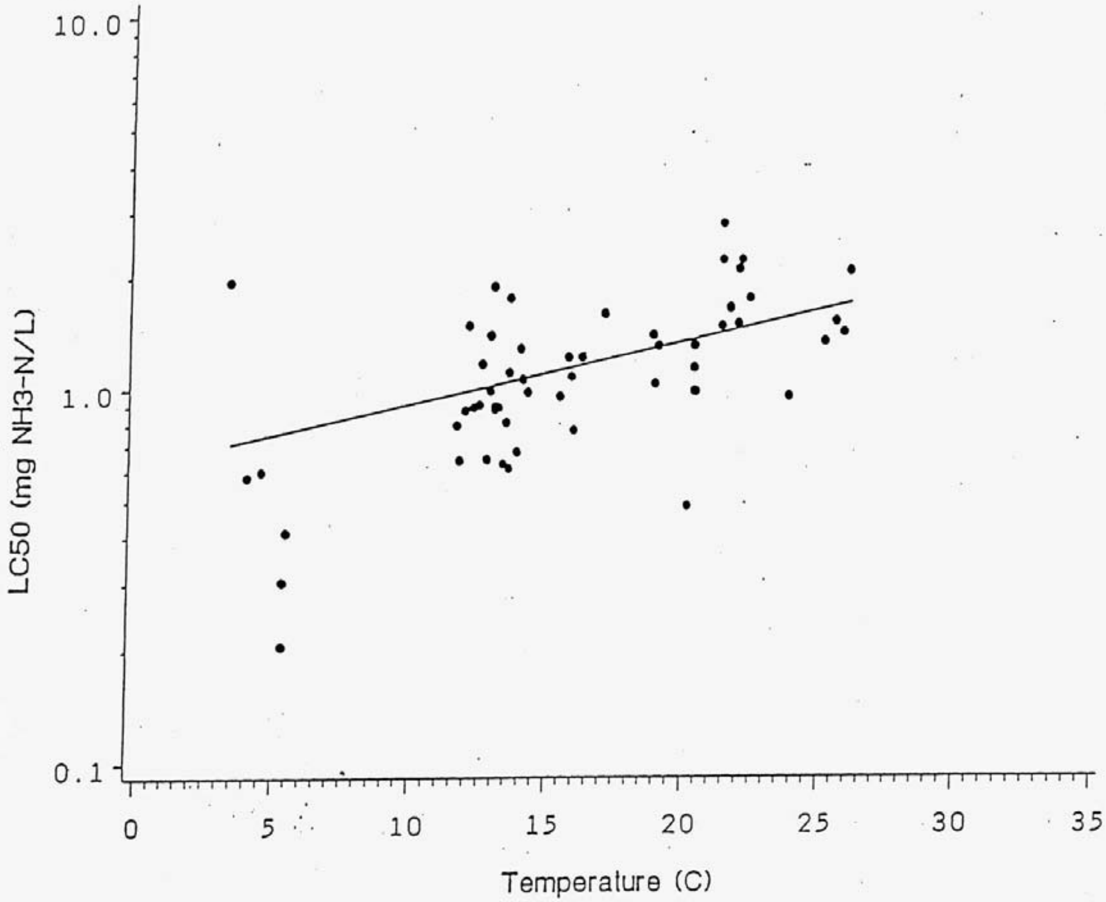

Figure 4 Linear regression of temperature-toxicity relationship for fathead minnow for pH 8 ($p = 0.0002$; $r^2 = 0.32$)

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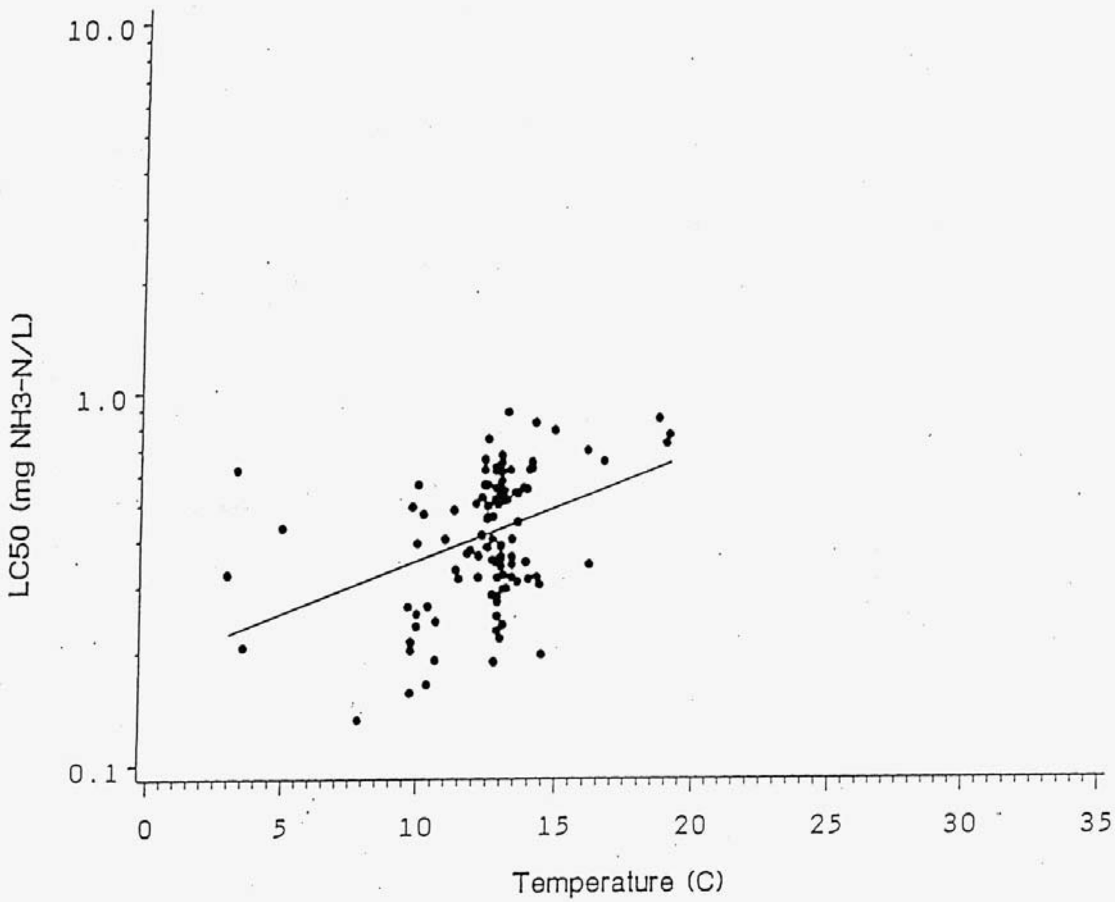

Figure 5 Linear regression of temperature-toxicity relationship for rainbow trout for pH 8 ($p = 0.0001$; $r^2 = 0.15$)

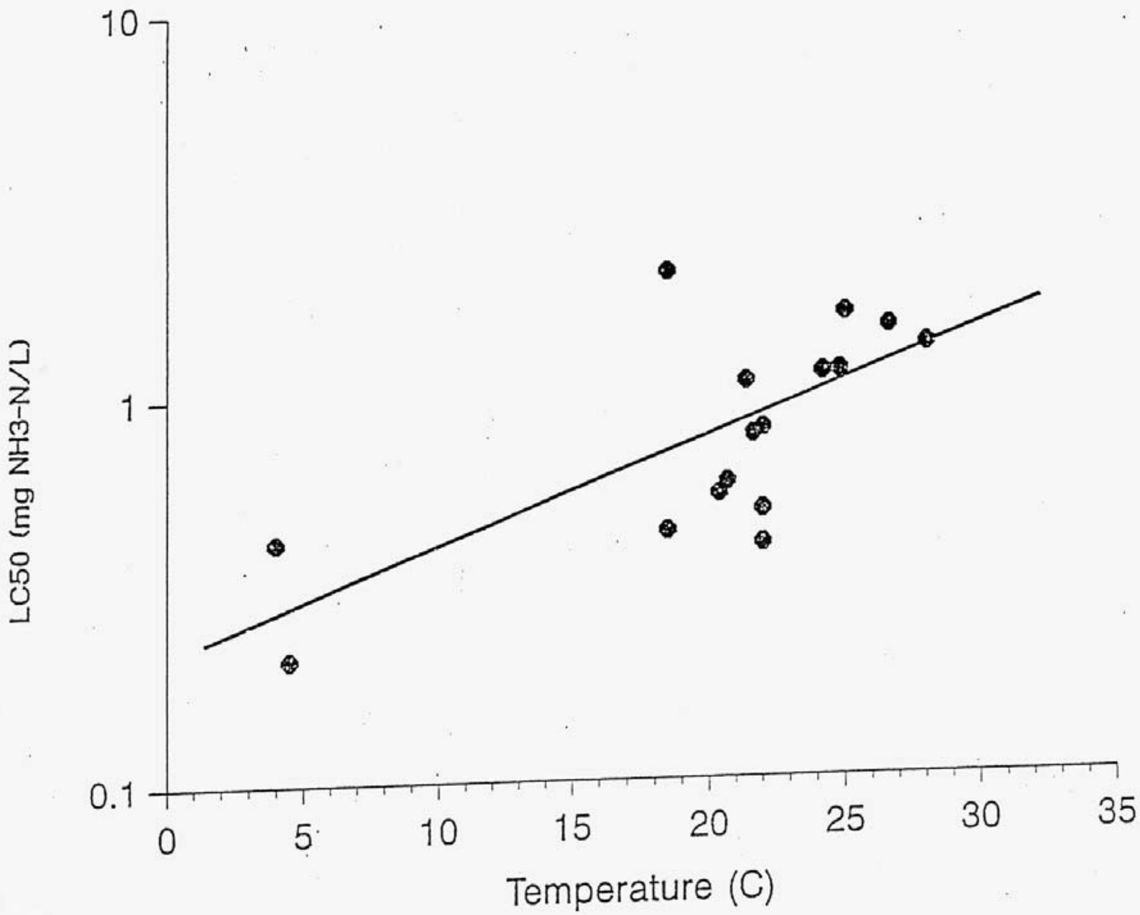

Figure 6 Linear regression of temperature-toxicity relationship for bluegill sunfish for pH 8 ($p = 0.0001$; $r^2 = 0.45$)

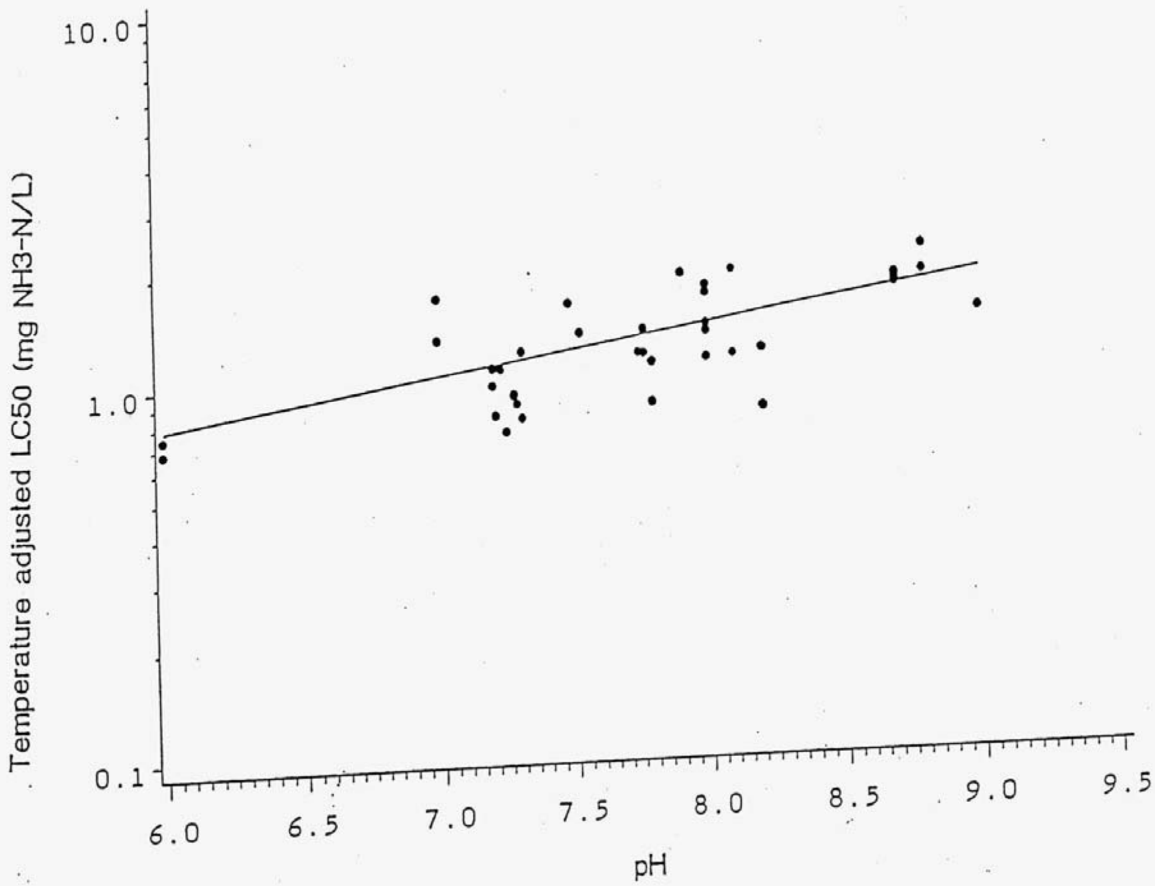

Figure 7 Linear regression of pH-toxicity relationship for channel catfish (all pH values) ($p = 0.0001$; $r^2 = 0.41$)

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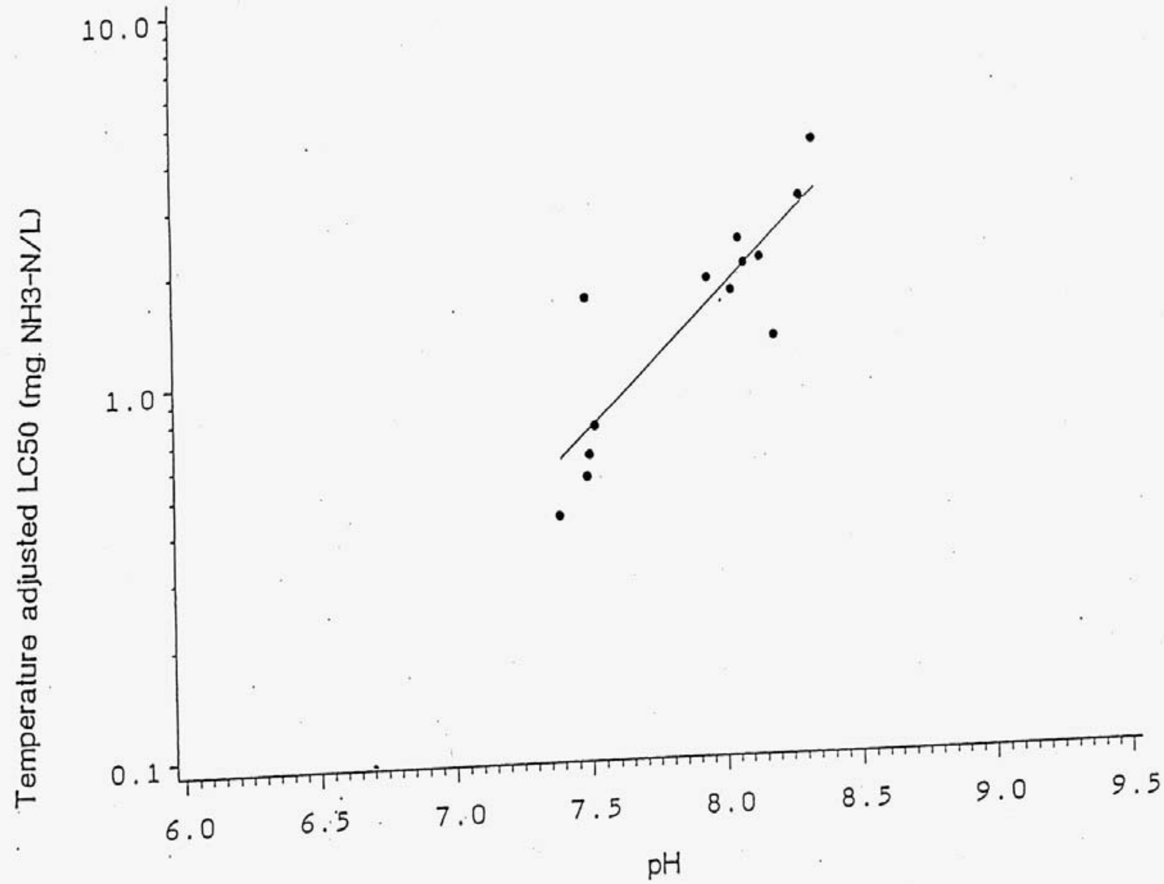

Figure 8 Linear regression of pH-toxicity relationship for Daphnia magna (all pH values) ($p = 0.0002$; $r^2 = 0.74$)

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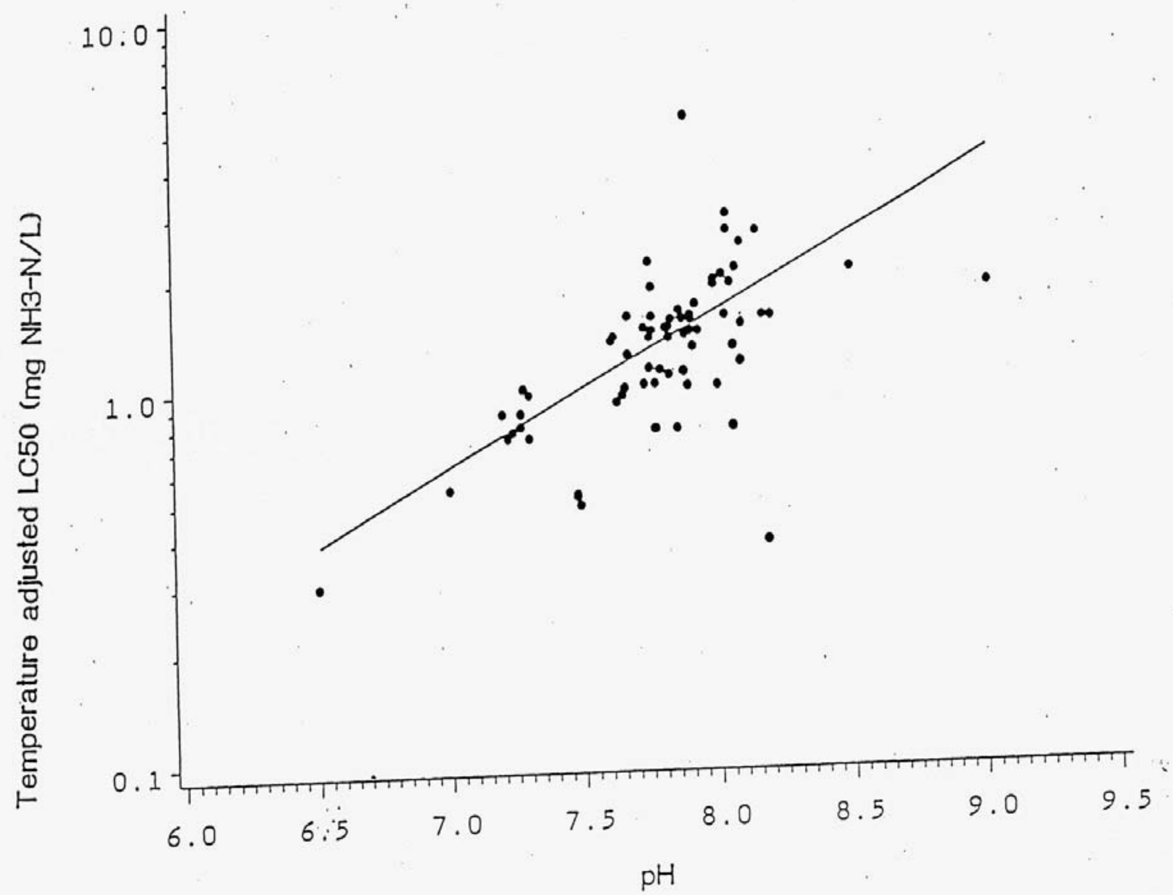

Figure 9 Linear regression of pH-toxicity relationship for fathead minnow (all pH values) ($p = 0.0001$; $r^2 = 0.36$)

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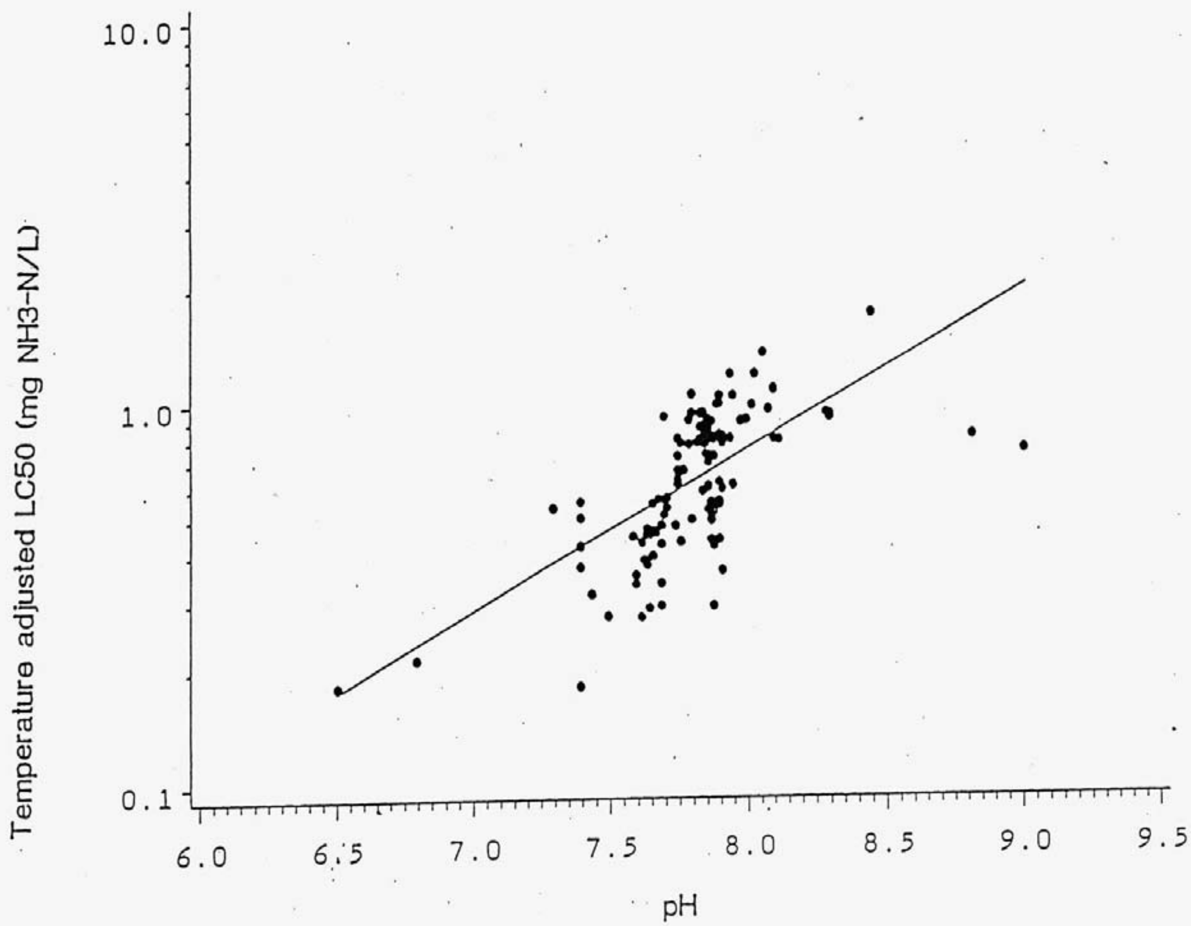

Figure 10 Linear regression of pH-toxicity relationship for rainbow trout (all pH values) ($p = 0.0001$; $r^2 = 0.41$)

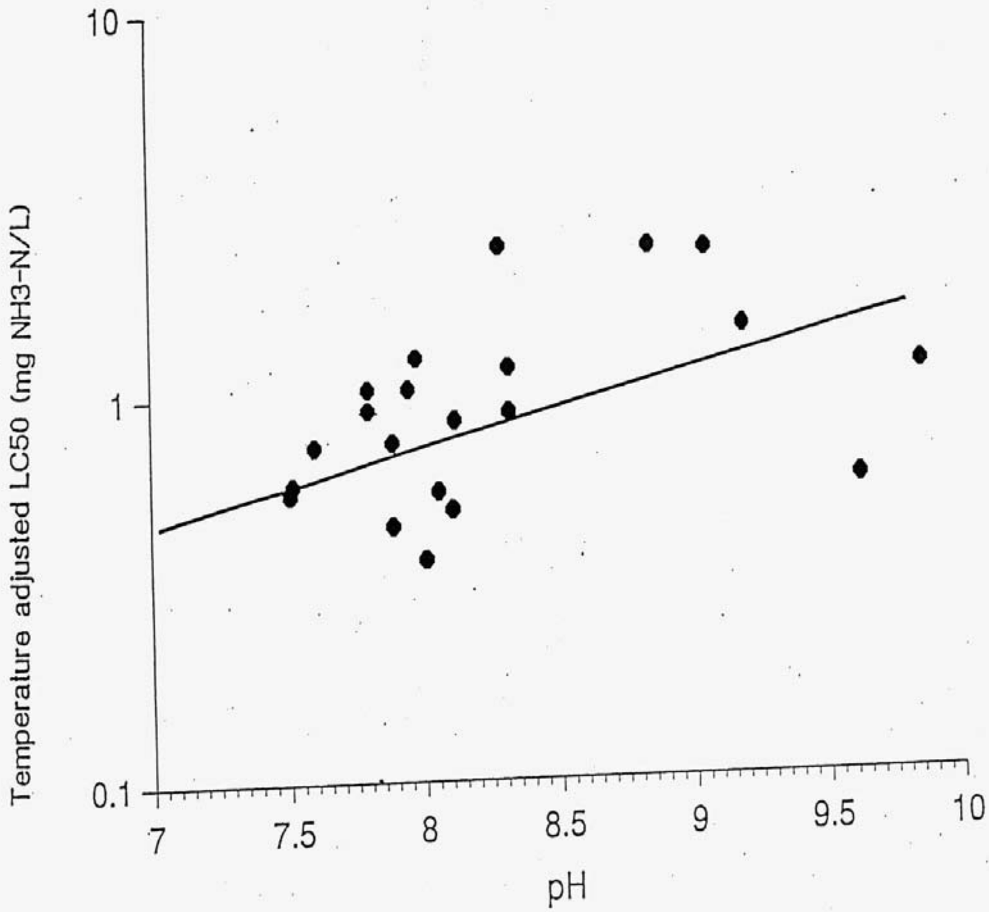

Figure 11 Linear regression of pH-toxicity relationship for bluegill sunfish (all pH values) ($p = 0.0001$; $r^2 = 0.41$)

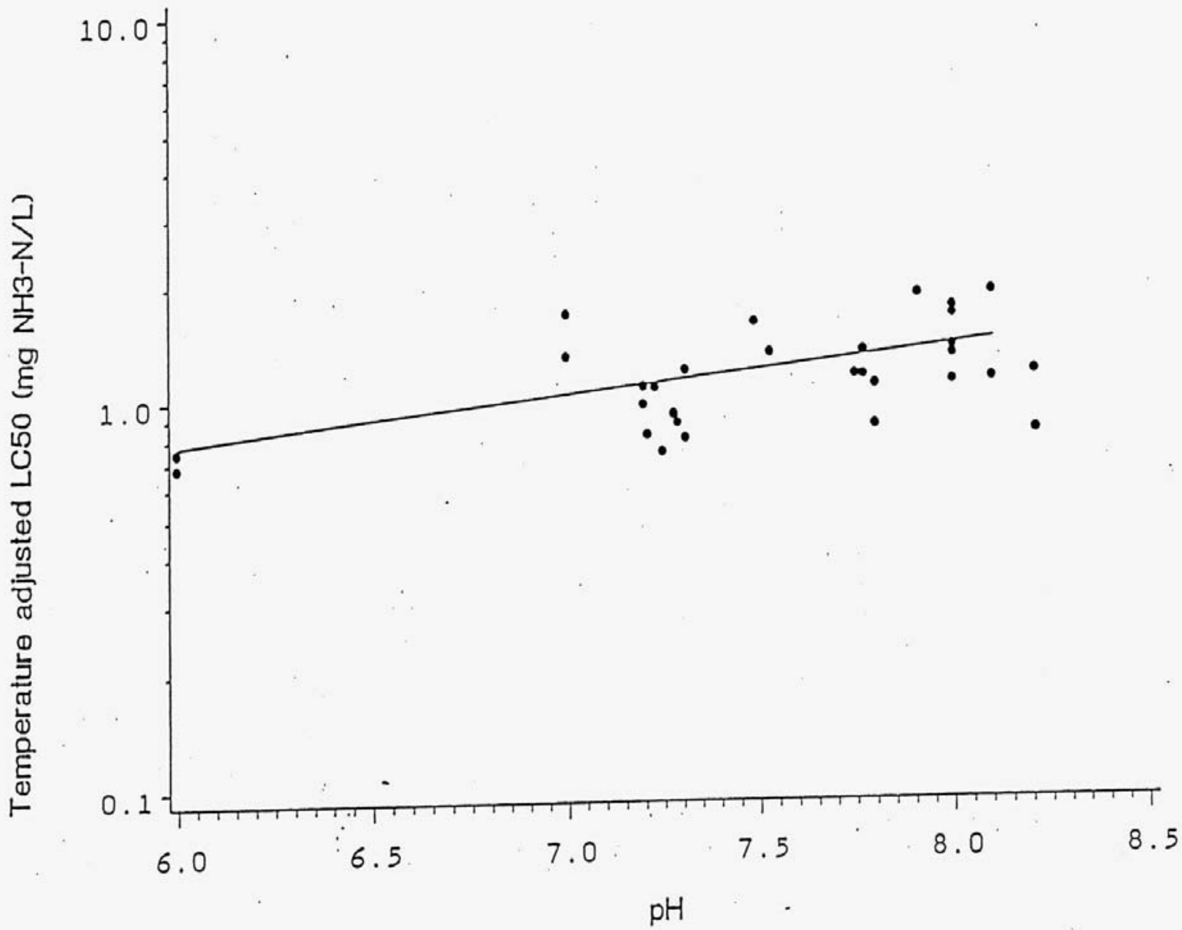

Figure 12 Linear regression of pH-toxicity relationship for channel catfish ($pH \leq 8.30$) ($p = 0.002$; $r^2 = 0.23$)

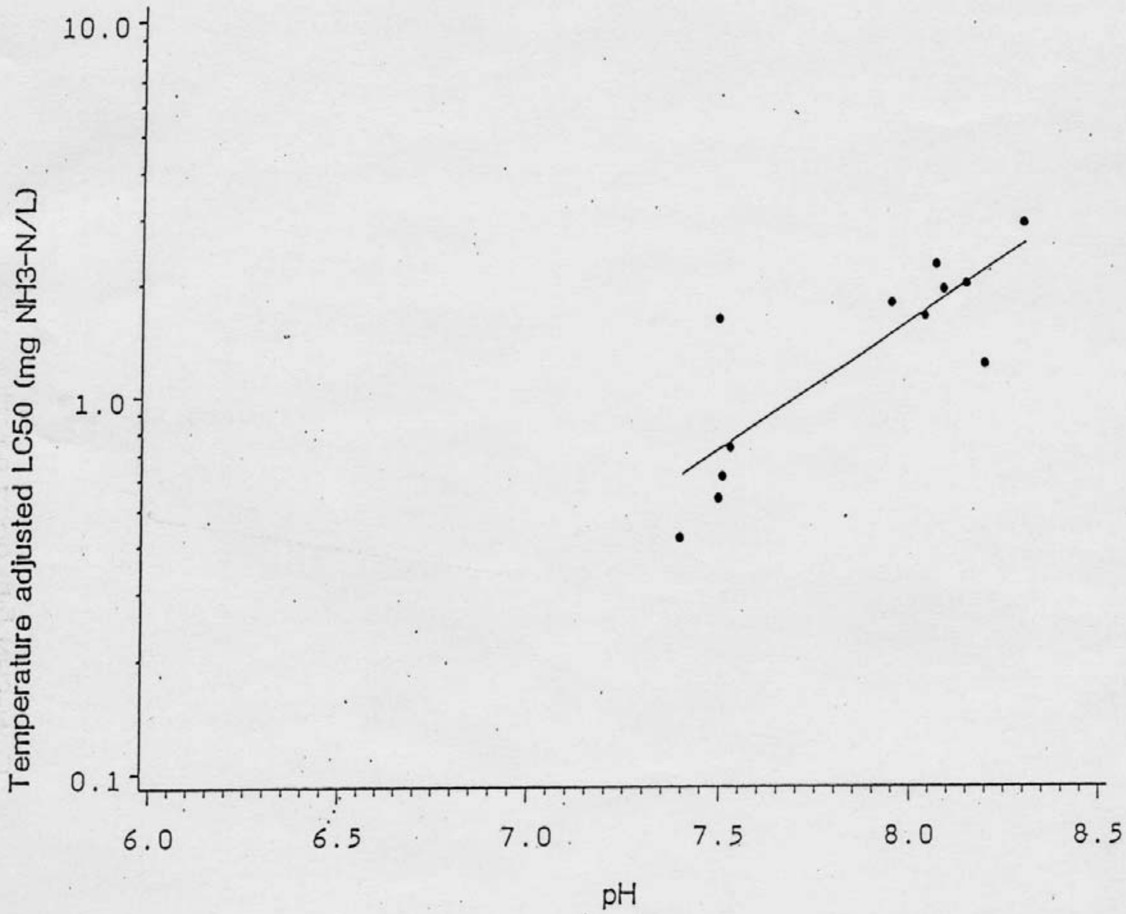

Figure 13 Linear regression of pH-toxicity relationship for Daphnia magna ($pH \leq 8.30$) ($p = 0.0008$; $r^2 = 0.69$)

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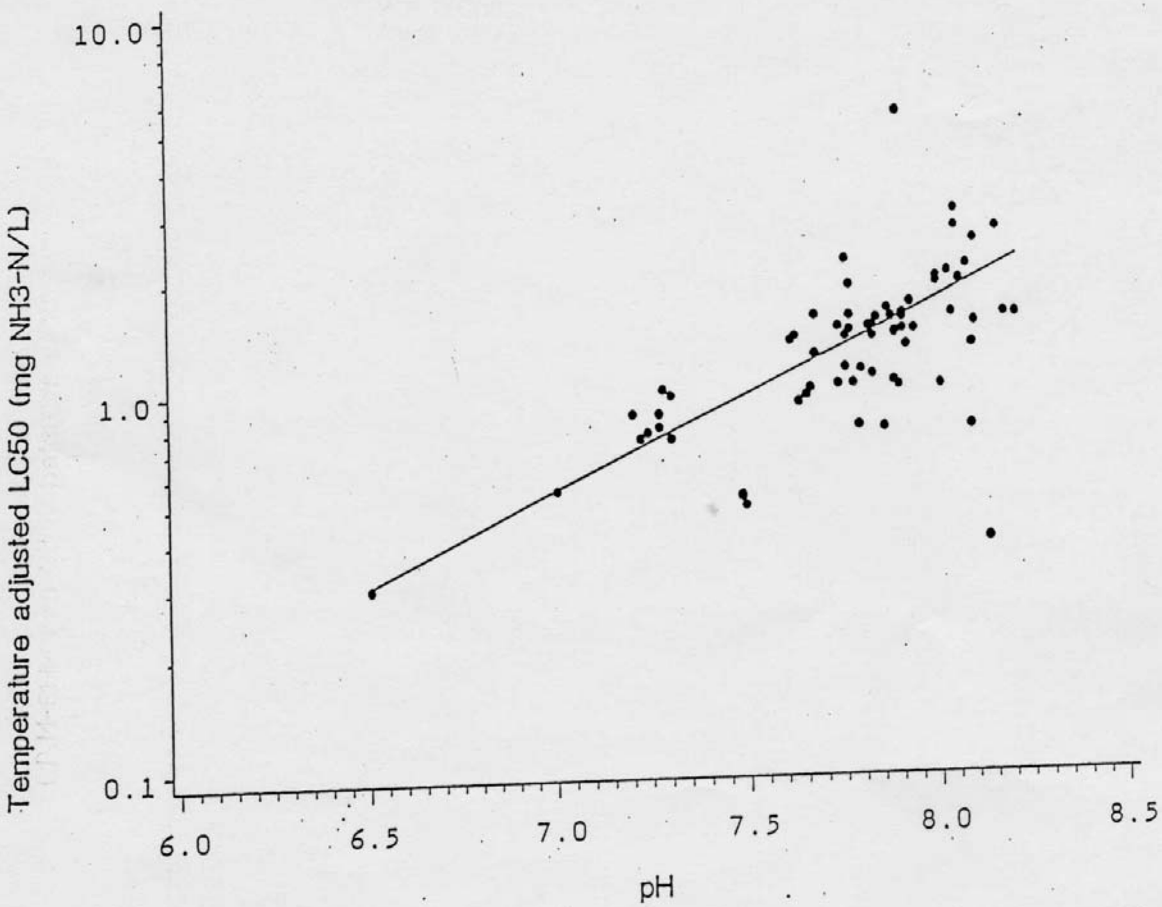

Figure 14 Linear regression of pH-toxicity relationship for fathead minnow (pH ≤ 8.30) ($p = 0.002$; $r^2 = 0.38$)

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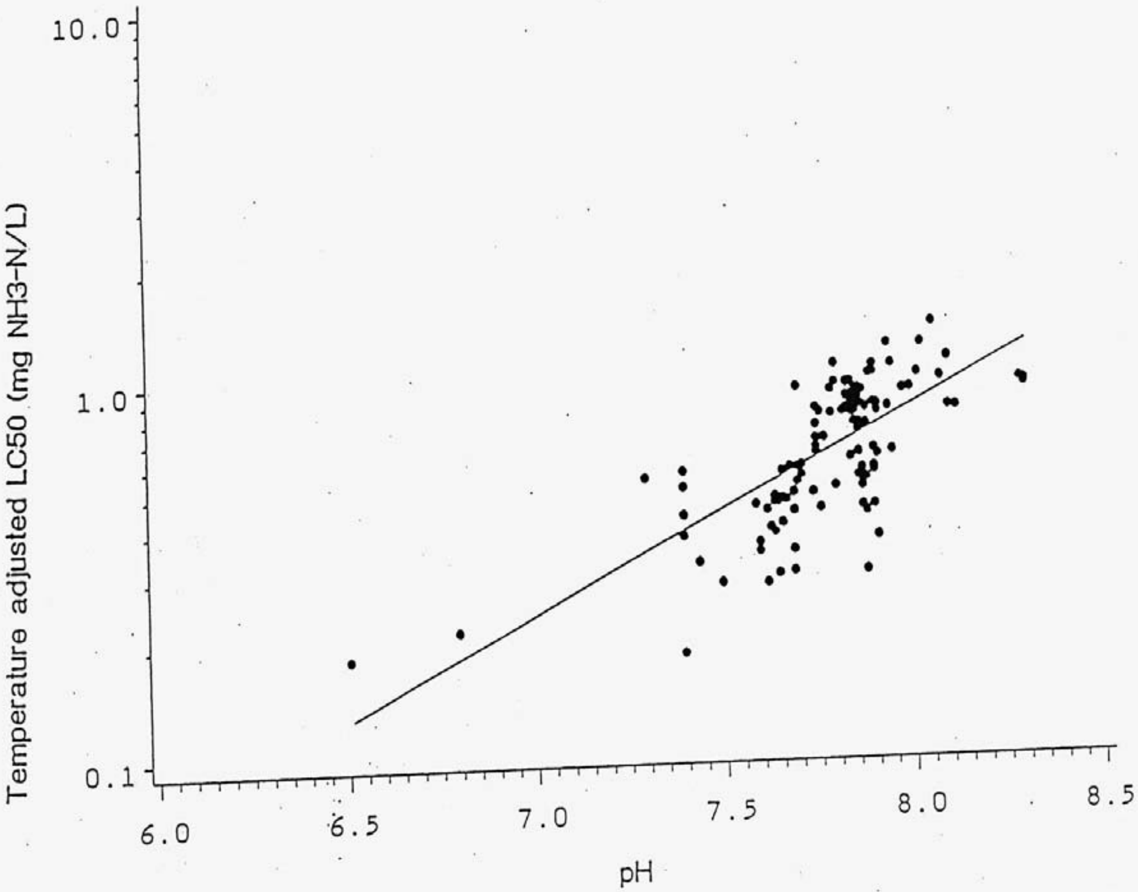

Figure 15 Linear regression of pH-toxicity relationship for rainbow trout (pH ≤ 8.30) (p = 0.0001; r^2 = 0.48)

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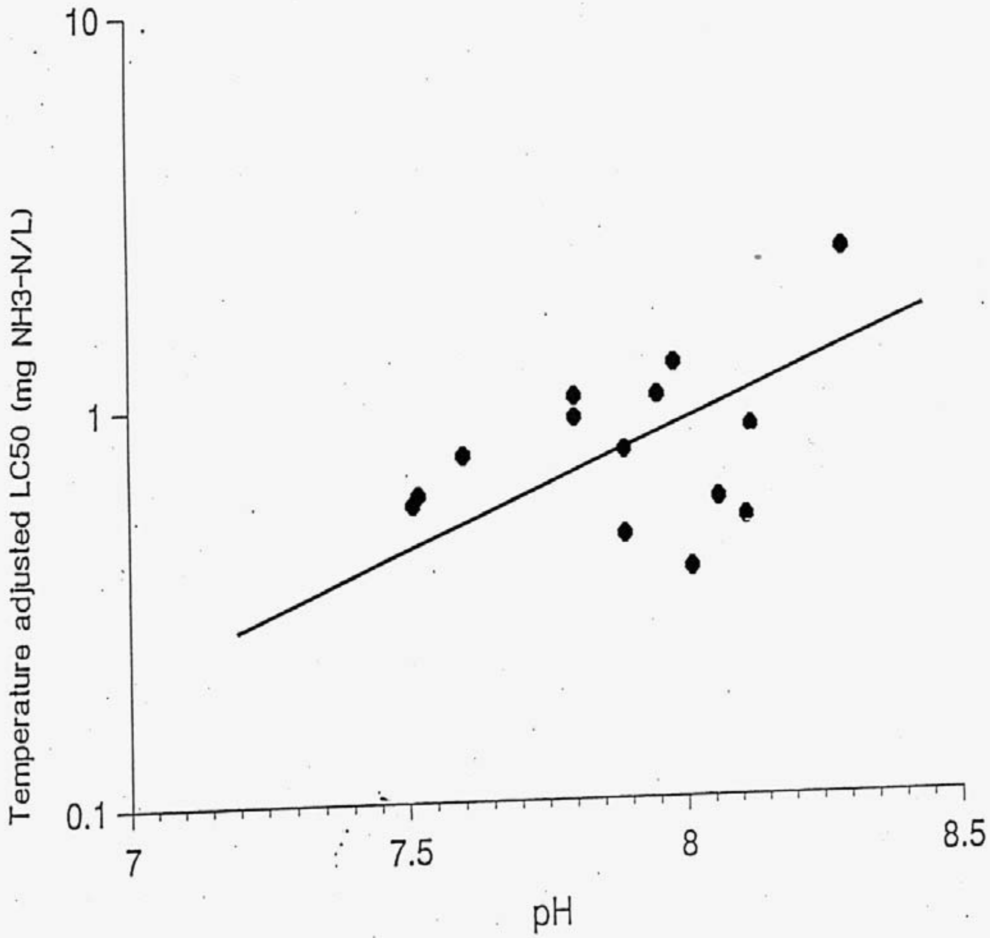

Figure 16 Linear regression of pH-toxicity relationship for bluegill sunfish ($pH \leq 8.30$) ($p = 0.0001$; $r^2 = 0.48$)

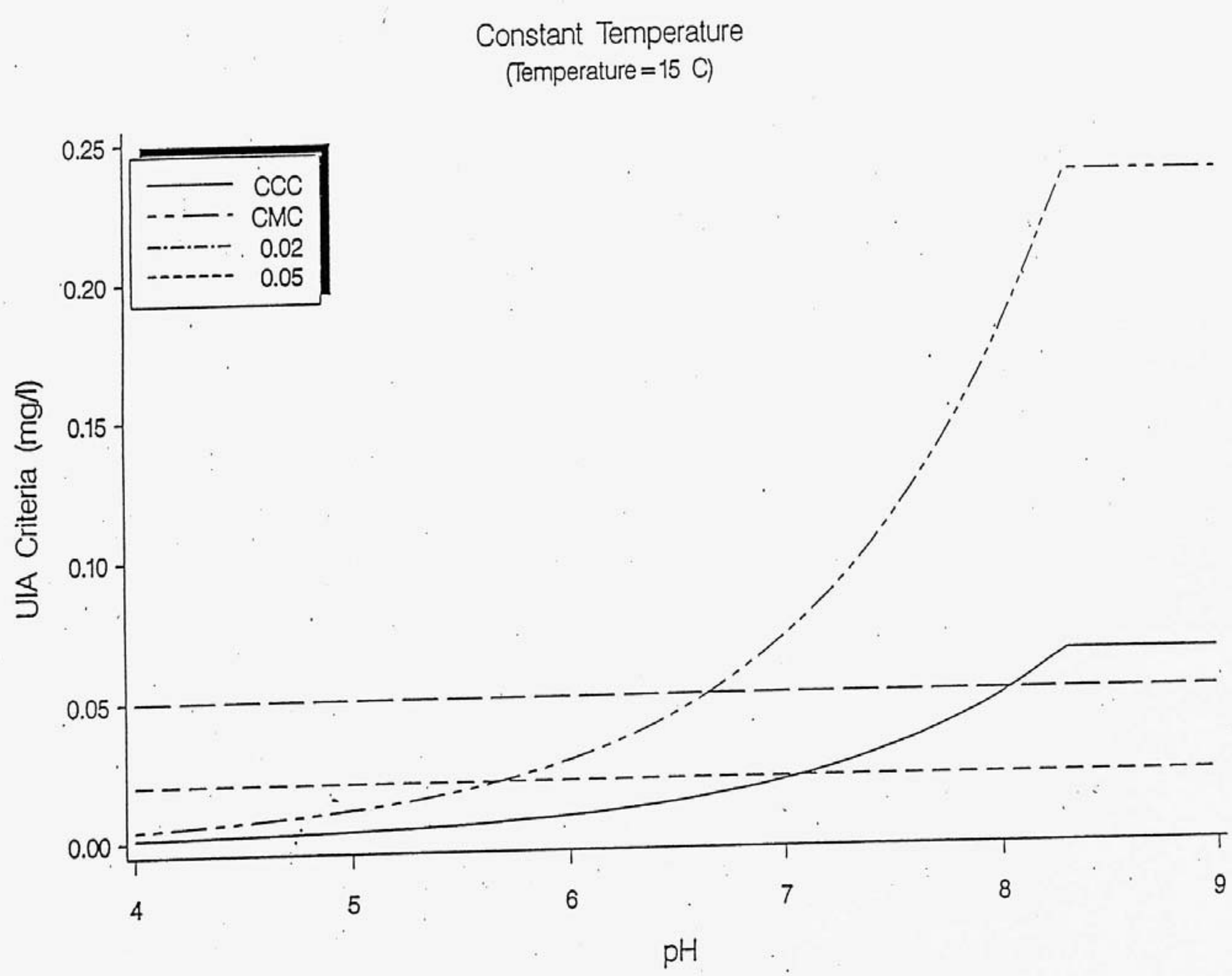

Figure 17 Affects of pH on the proposed CCC and CMC for FW2-NT and comparison with current criteria.

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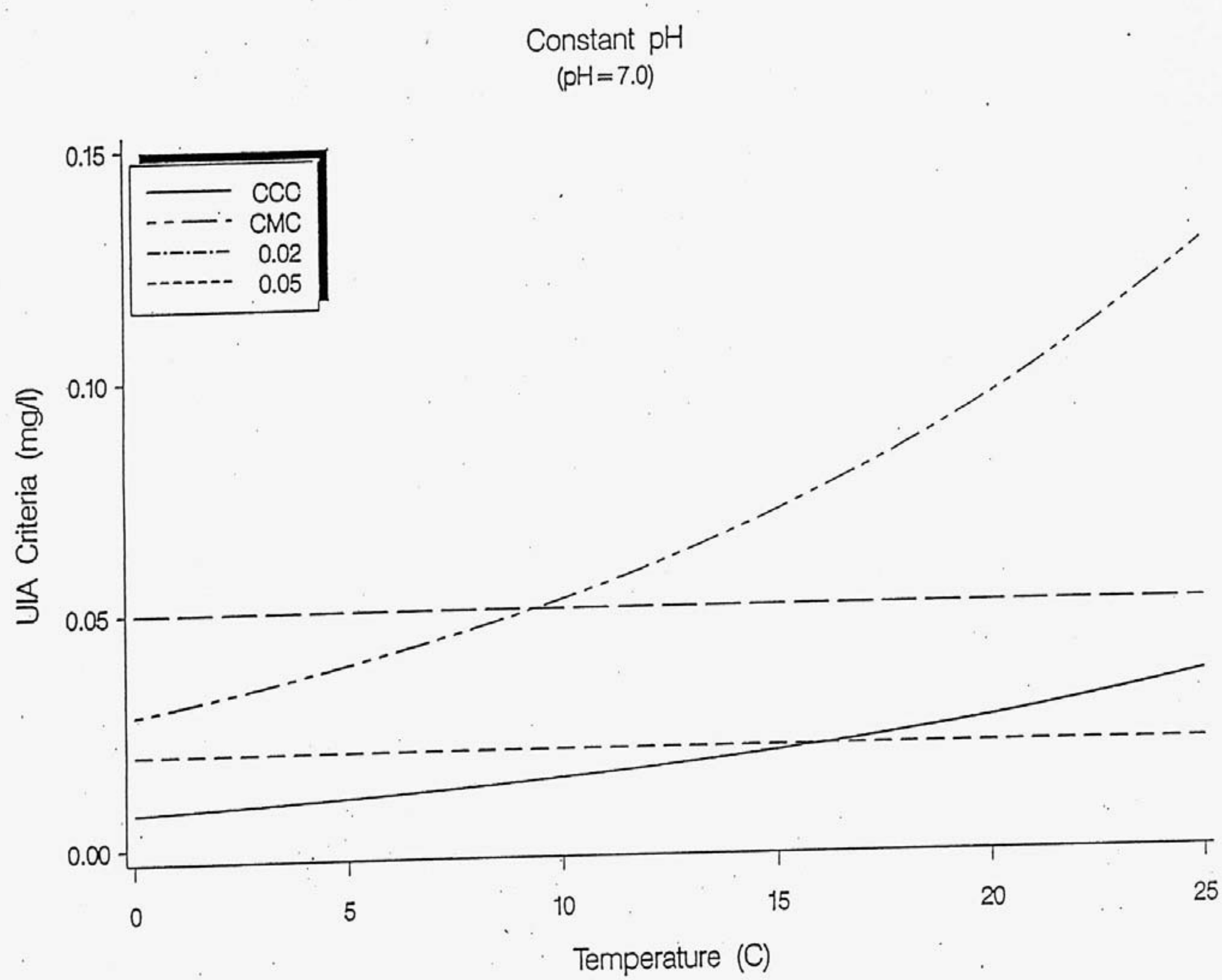

Figure 18 Affects of temperature on the proposed CCC and CMC for FW2-NT and comparison with current criteria.

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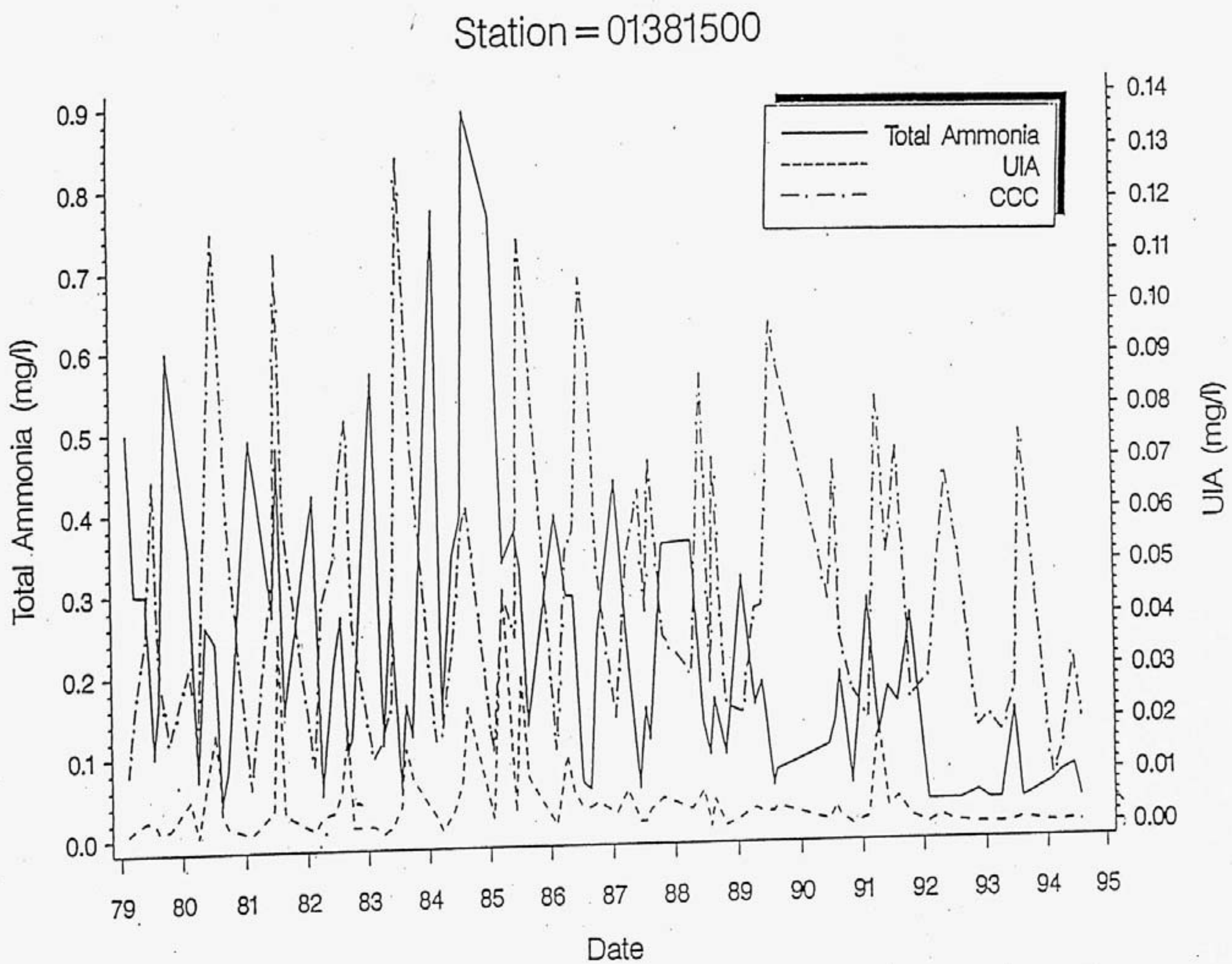

Figure 19 Historical trends of total ammonia and UIA at Station 01381500 on the Whippany River.

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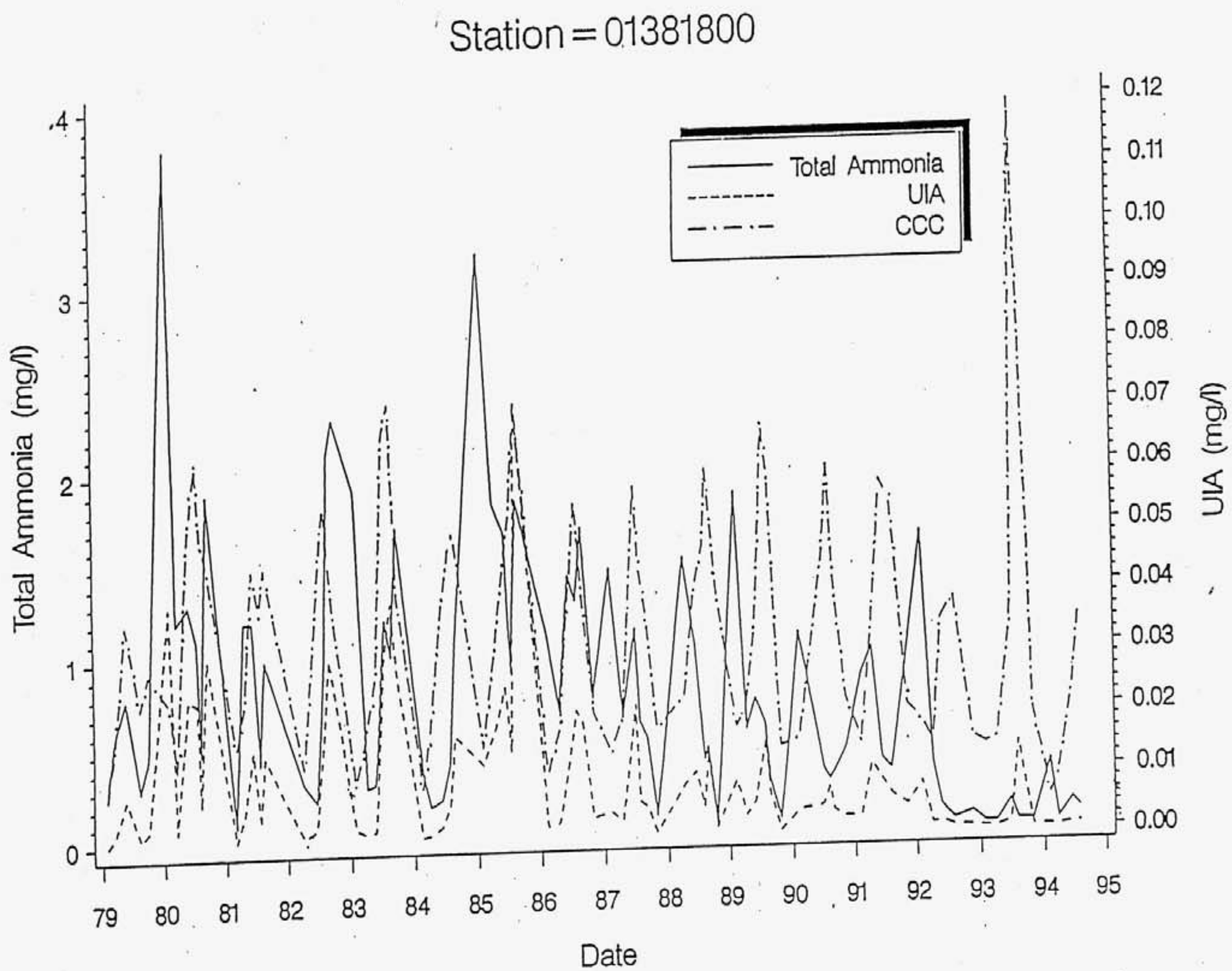

Figure 20 Historical trends of total ammonia and UIA at Station 01381800 on the Whippany River.

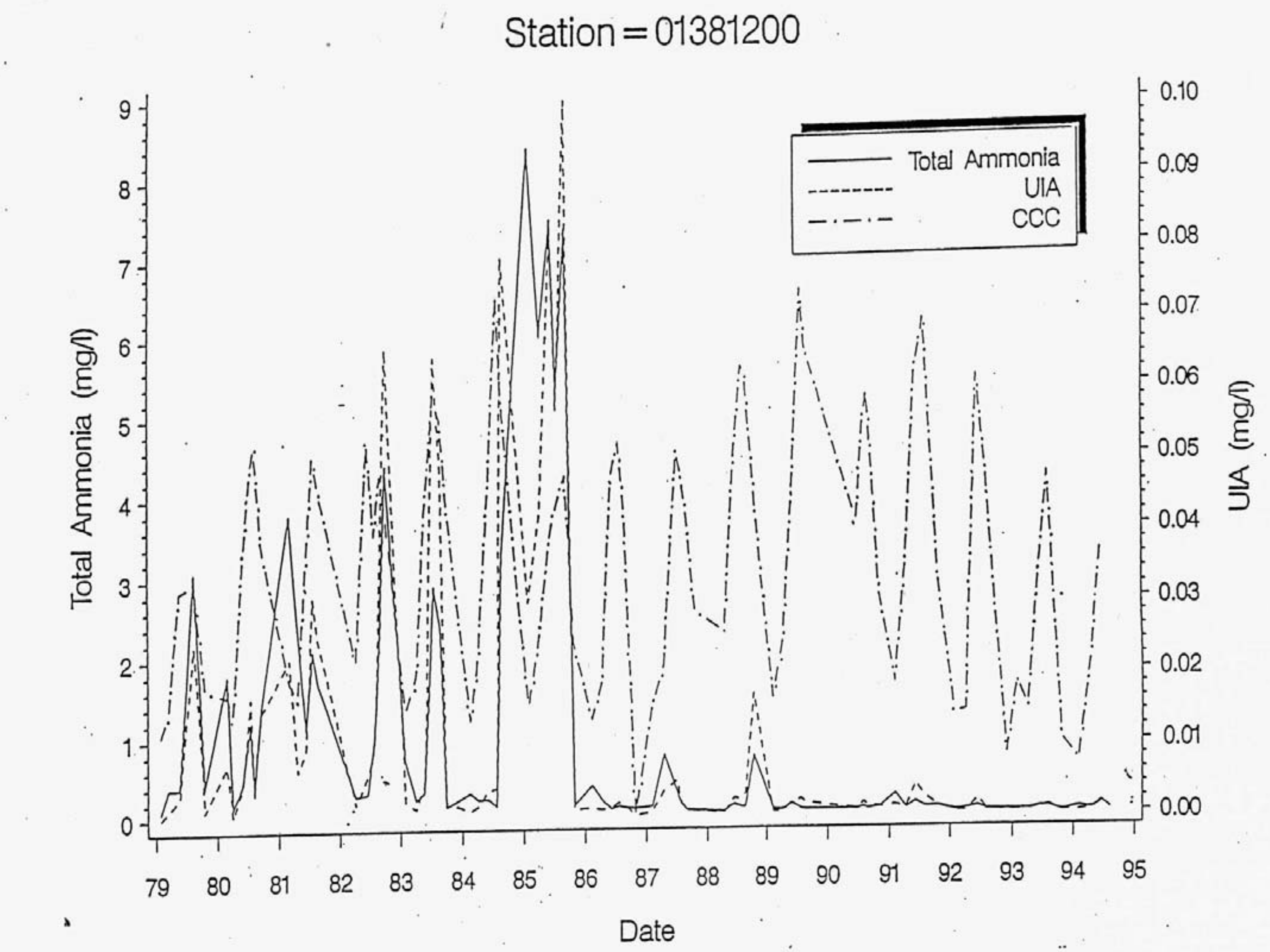

Figure 21 Historical trends of total ammonia and UIA at Station 01381200 on the Rockaway River.

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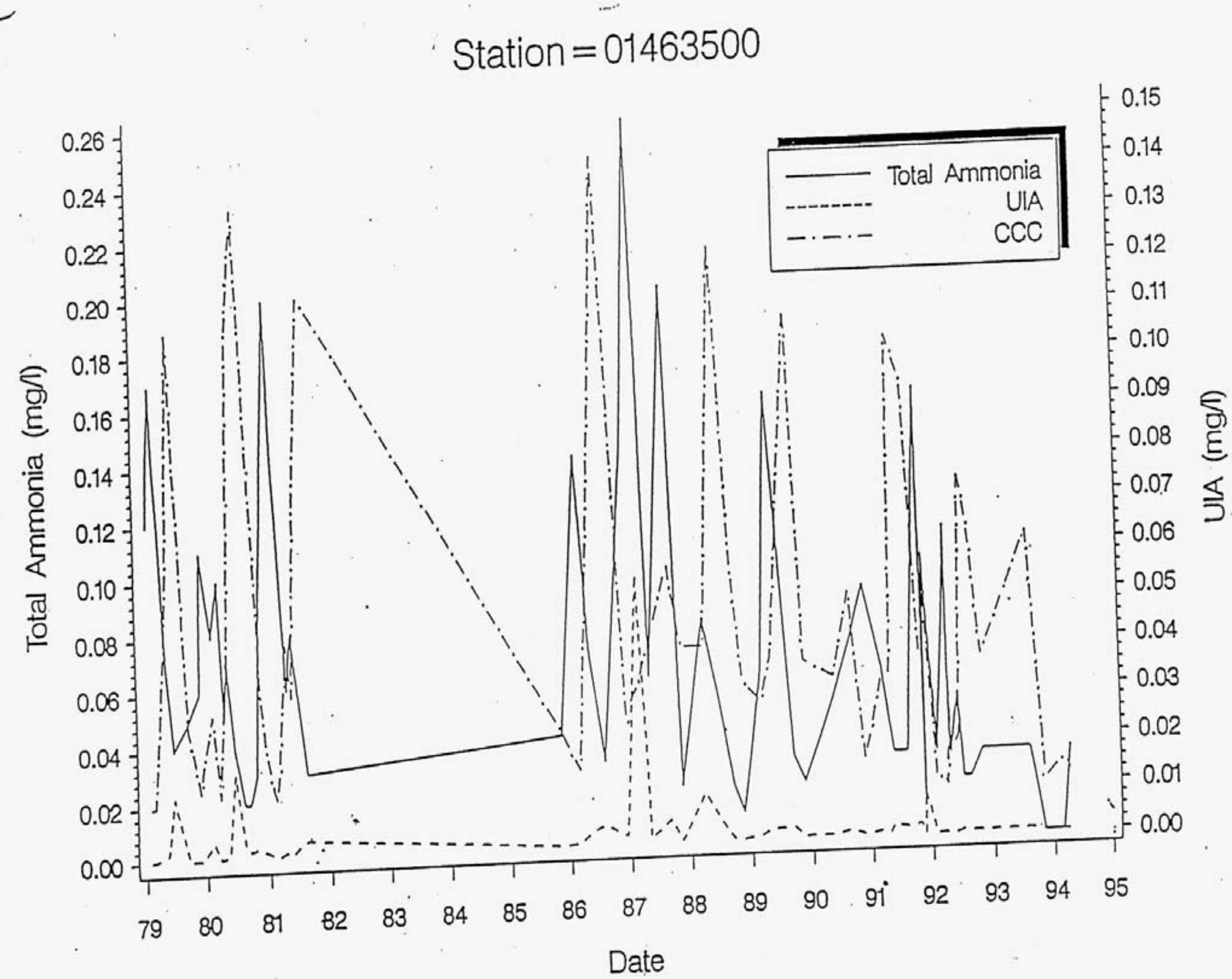

Figure 22 Historical trends of total ammonia and UIA at Station 01463500 on the Delaware River.

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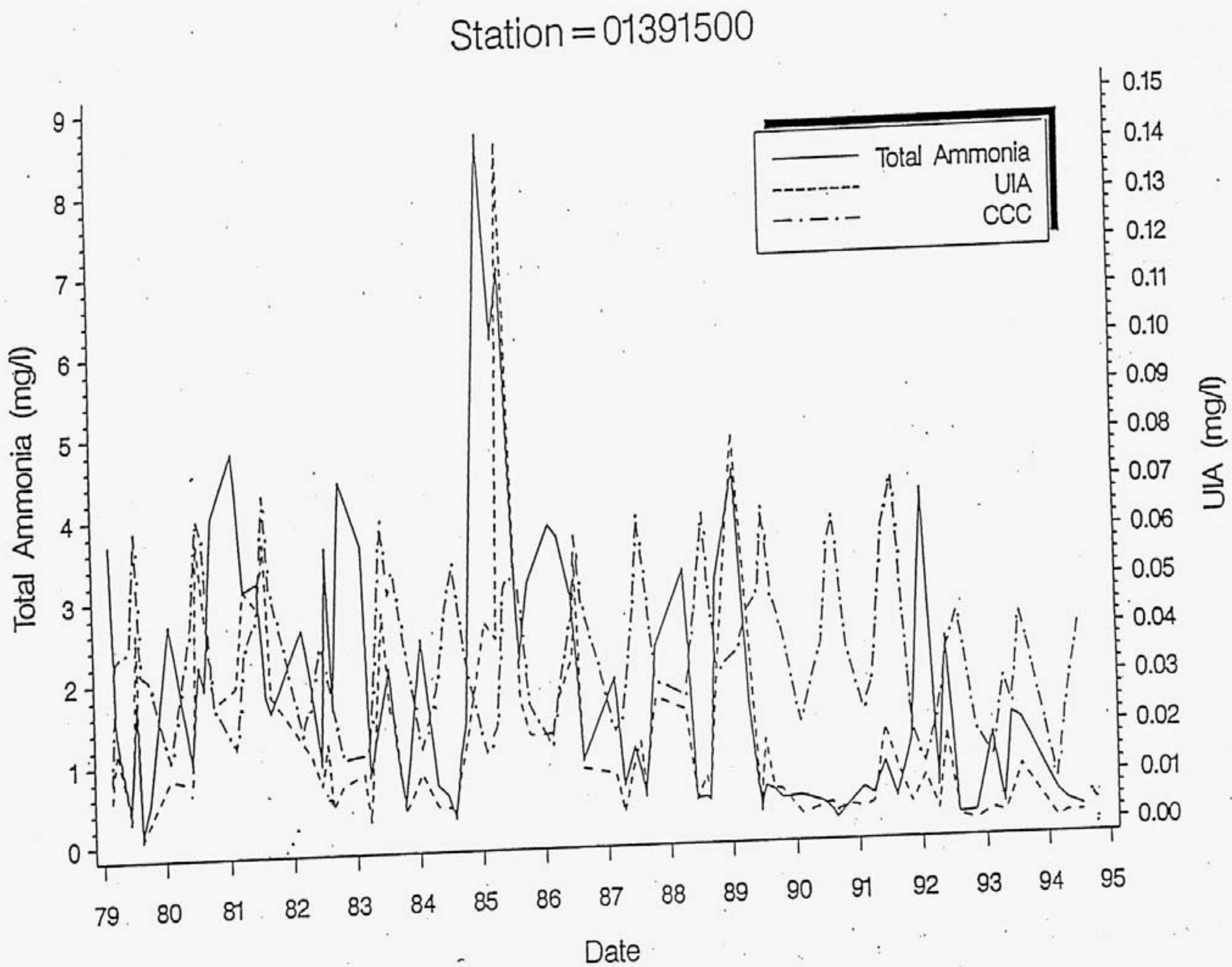

Figure 23. Historical trends of total ammonia and UIA at Station 01391500 on the Saddle River.

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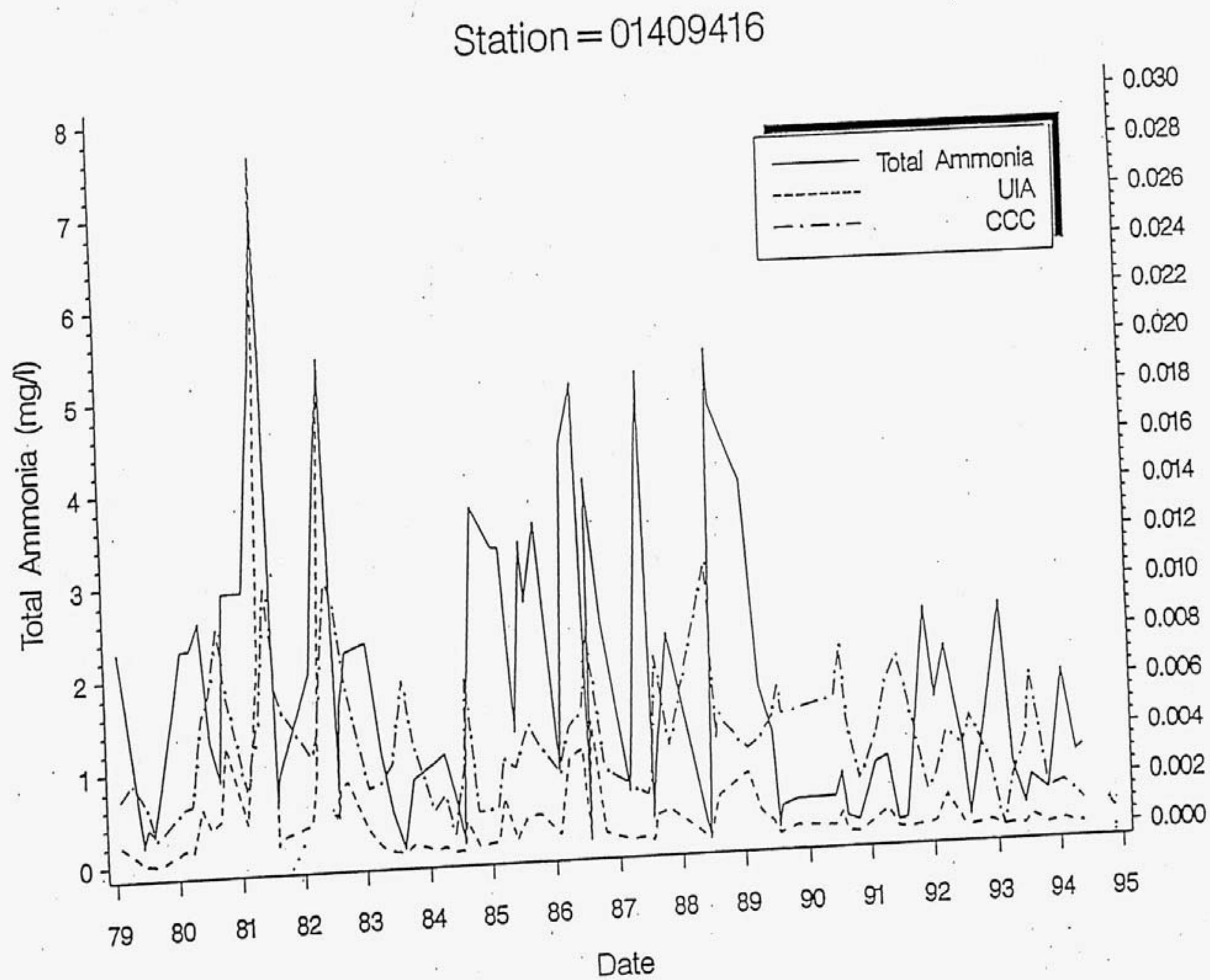

Figure 24 Historical trends of total ammonia and UIA at Station 01409416 on the Hammonton Creek.

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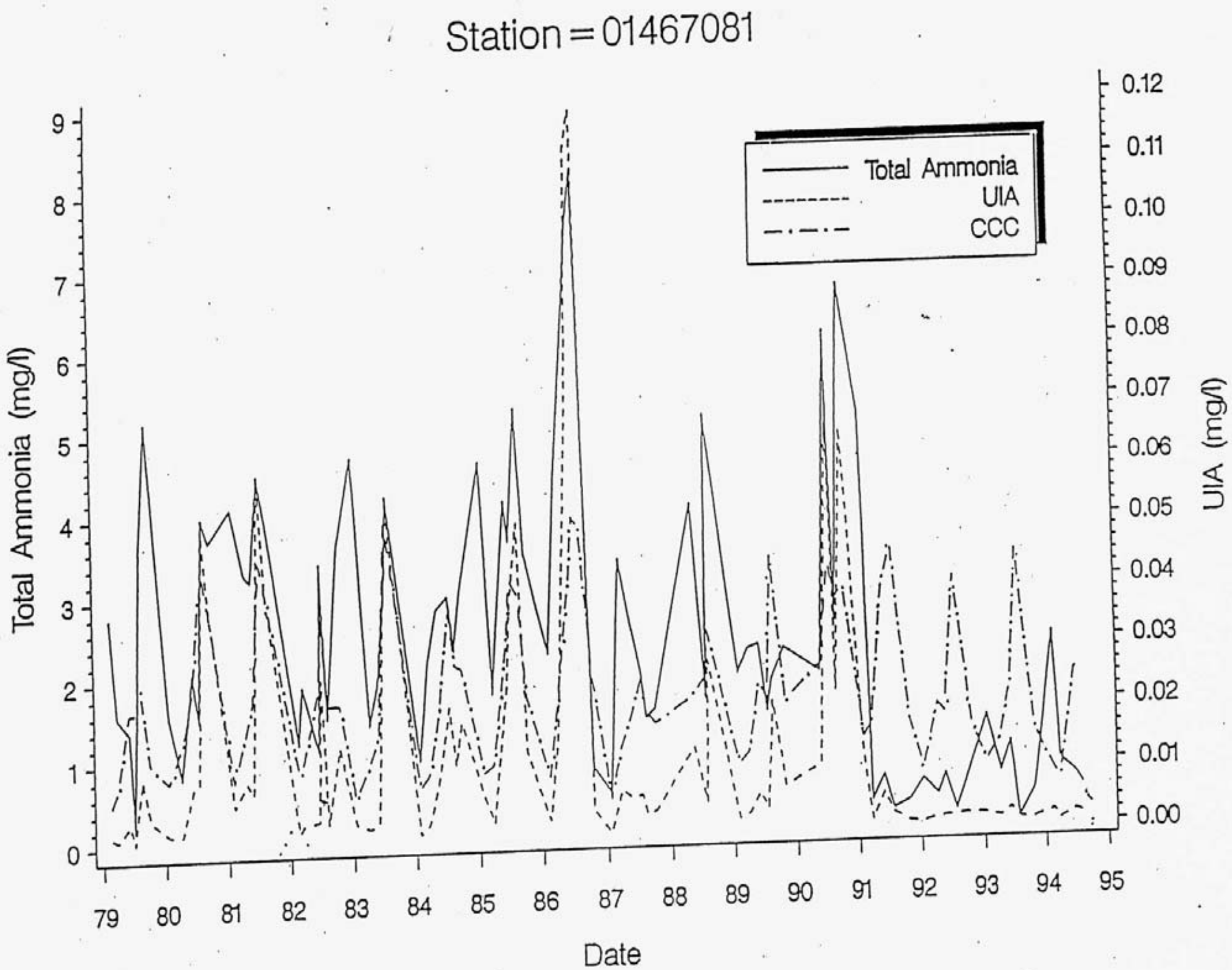

Figure 25 Historical trends of total ammonia and UIA at Station 01467081 on the South Branch Pennsauken Creek.

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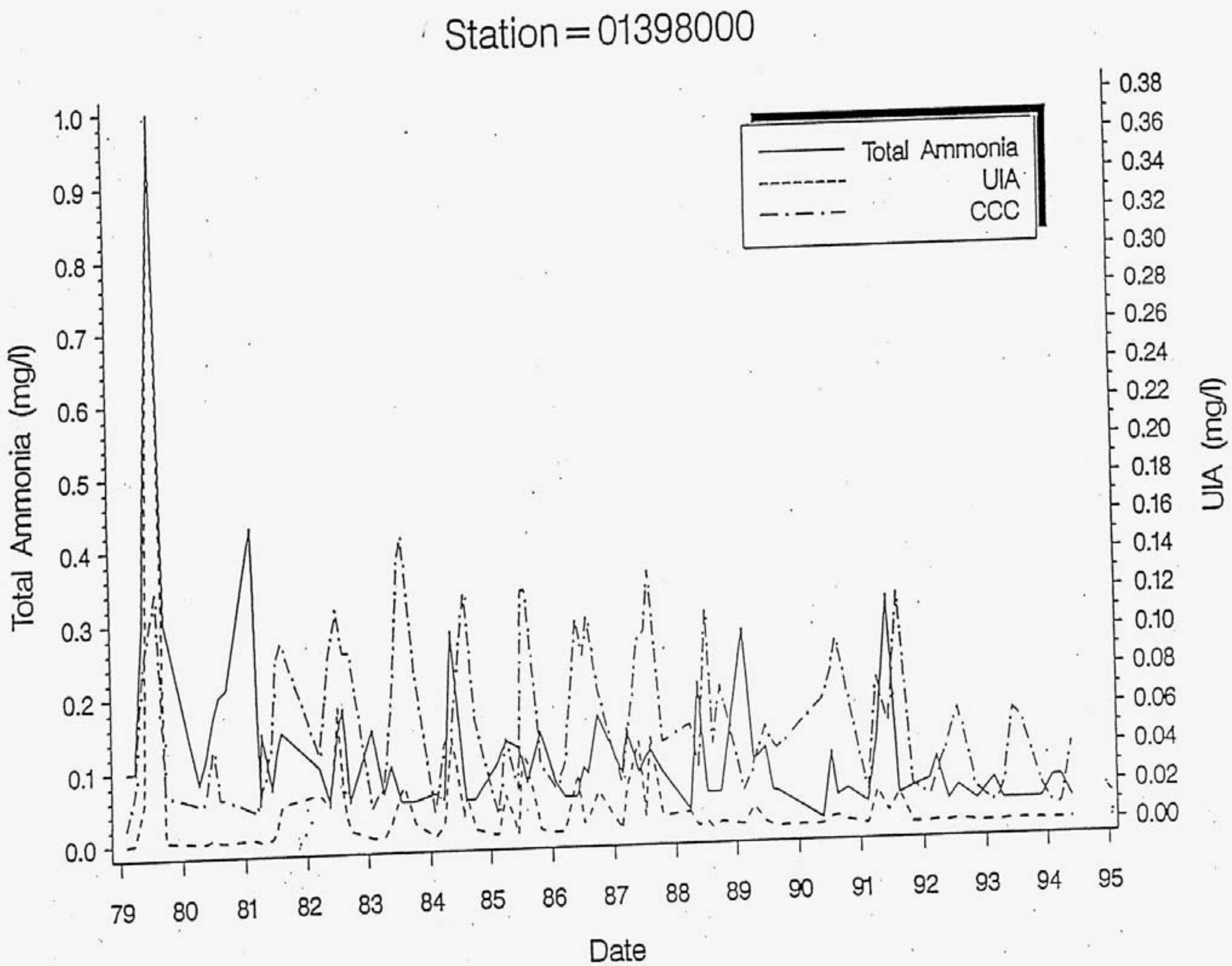

Figure 26 Historical trends of total ammonia and UIA at Station 01398000 on the Neshanic River.

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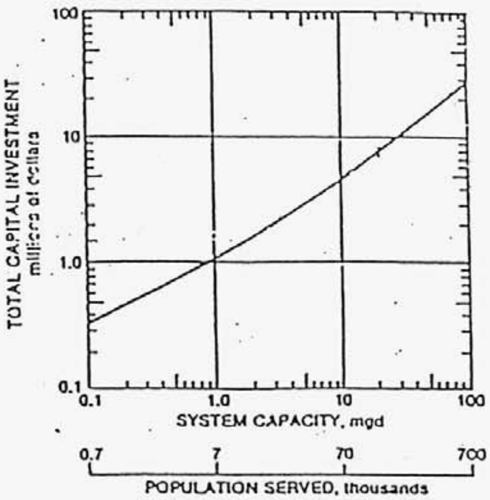

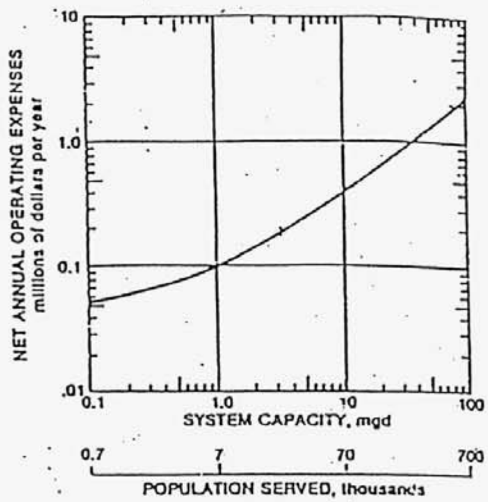

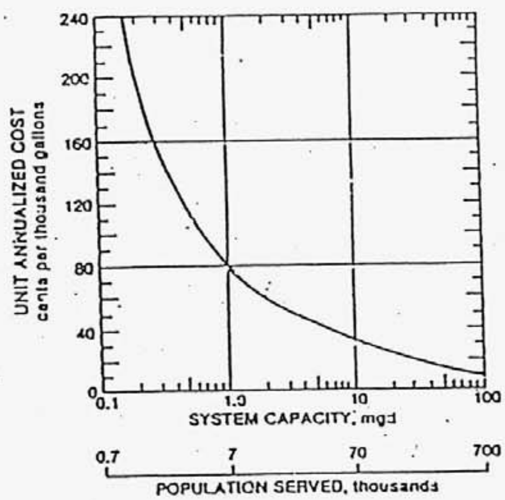

Figure 27. Costs of nitrification (separate-stage) for wastewater treatment in 1980 dollars (DeWolf *et al.* 1984)

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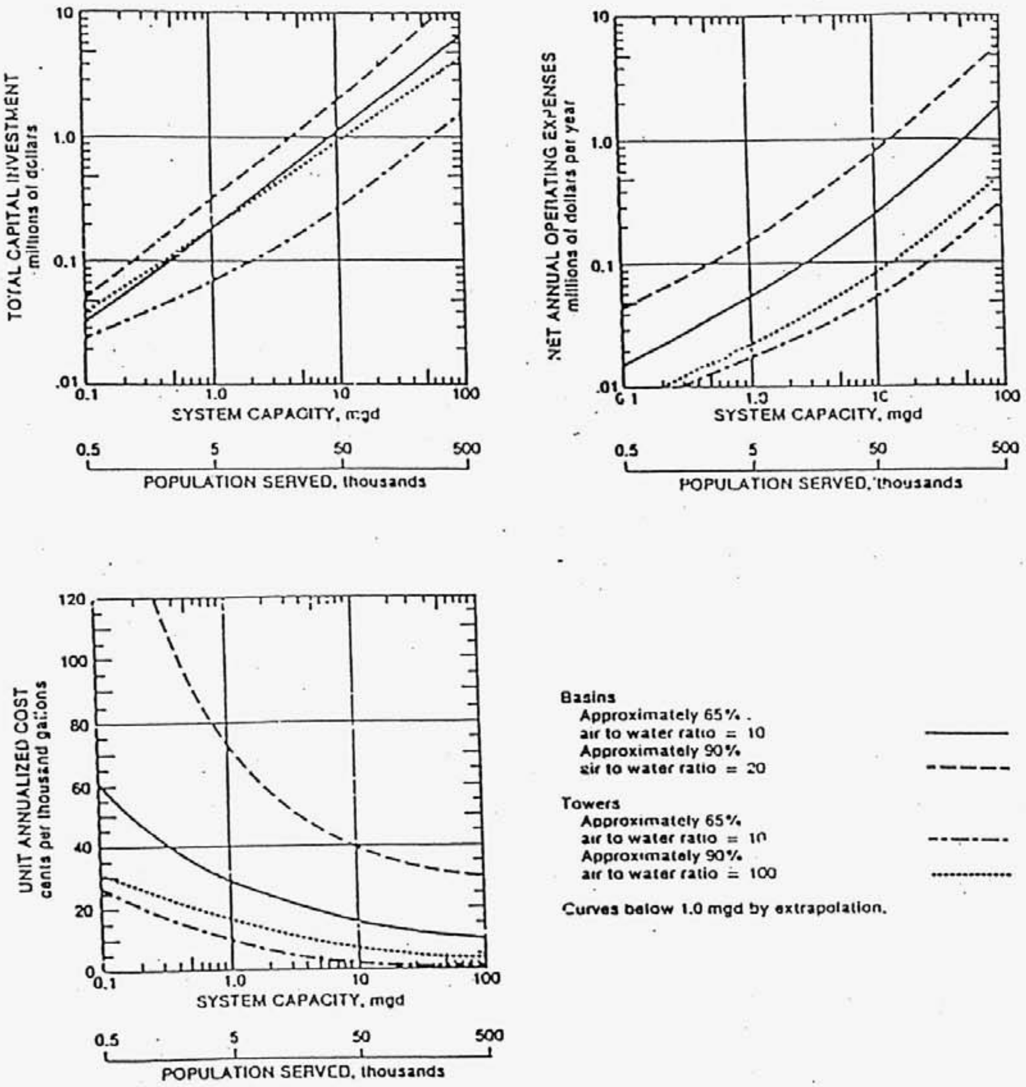

Figure 28. Costs of air stripping for wastewater treatment in 1980 dollars (DeWolf *et al.* 1984)