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DRAFT 2009 UPDATE AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA FOR AMMONIA - FRESHWATER

Supersedes 1999 Update

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Draft 2009 Update Aquatic Life Ambient Water Quality Criteria For Ammonia – Freshwater

December 2009

Supersedes 1999 Update

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, DC

NOTICES

This update provides guidance to States and Tribes authorized to establish water quality standards under the Clean Water Act (CWA), to protect aquatic life from acute and chronic effects of ammonia. Under the CWA, States and Tribes are to establish water quality criteria to protect designated uses. State and tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance when appropriate. While this update constitutes EPA's scientific recommendations regarding ambient concentrations of ammonia that protect freshwater aquatic life, this update does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, States, Tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. EPA may change this guidance in the future. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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This update is a modification of the 1999 Update of Ambient Water Quality Criteria for Ammonia. The 2009 modifications were prepared by Lisa Huff (EPA Work Assignment Manager), Charles Delos, and Charles Stephan with the majority of written and technical support provided by EPA Contractors: Tyler Linton, Christopher Tarr and Keith Taulbee of Great Lakes Environmental Center, Inc. Portions of the 1999 Update carried into the 2009 Update, were written by Russell Erickson, Charles Stephan, and Charles Delos. EPA received substantial input from James (Russ) Hockett of the EPA's NHEERL Mid-Continent Ecology Division, Duluth, MN.; and Cindy Roberts, EPA Headquarters. Please submit comments or questions to: Lisa Huff, U.S. EPA, Mail Code 4304, Washington, DC 20460 (e-mail: huff.lisa@epa.gov).

EXECUTIVE SUMMARY

Following the directives established under the Clean Water Act (CWA) to periodically review and revise 304(a) Ambient Water Quality Criteria (AWQC) as necessary to ensure the criteria are adequately protective based on the latest science, EPA reviewed and updated the freshwater ammonia aquatic life AWQC. The process of updating the freshwater ammonia criteria was initiated to include all new acute and chronic data published since the criteria document in 1984/1985, including any new toxicity data published for several freshwater mussel species in the family Unionidae. Based upon the literature, it appears that many states in the continental USA have freshwater mussel fauna in at least some of their waters (Abell et al. 2000, Williams et al. 1993, Williams and Neves 1995). Moreover, approximately one-quarter of freshwater unionid mussel species and subspecies in the United States are Federally-listed as endangered, threatened or are of special concern. While declining mussel populations may be due to many factors, the newly published ecotoxicological data indicate that freshwater mussels are more sensitive to ammonia when compared to other freshwater aquatic organisms. Given the wide distribution of freshwater mussels, including unionid mussels, it is important that this criteria update consider ammonia toxicity information specific to freshwater mussels. Because ammonia is particularly toxic to freshwater unionids, EPA updated the numeric freshwater acute and chronic aquatic life criteria for ammonia to ensure they are protective of unionids.

Several literature searches dating back to 1985 were conducted to locate results of laboratory toxicity tests compiled that quantify the adverse effects of ammonia on freshwater aquatic life, with particular attention given to tests conducted with freshwater mussels and snails since such data were not available for many of these species at that time. Acceptable values for these and other test species were used to re-calculate the freshwater ammonia acute and chronic aquatic life criteria.

Acute and chronic toxicity data acceptable for criteria derivation were identified and selected following EPA's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (Stephan et al. 1985). During the evaluation of the new toxicity data, including new data on other threatened and endangered species, EPA identified several technical issues about the interpretation and use of toxicity data for studies with glochidia of freshwater mussels, juvenile mussels, and with the freshwater amphipod species, *Hyalella azteca.* In this document, EPA presents its scientific analysis, approach, and rationale for addressing these issues. The rationale on the technical issues and the draft criteria document were externally peer reviewed and the final draft reflects consideration of those reviewer's comments.

The criteria contained herein account for the influence of pH and temperature on toxicity, the greater sensitivity of freshwater invertebrates (particularly freshwater mussels) to acute and chronic ammonia toxicity, and the greater sensitivity of fish early life stages than juvenile and adult stages to chronic toxicity of ammonia. The pH and temperature relationships used to account for the influence of these two abiotic factors on ammonia toxicity were the same as those established in the 1999 AWQC document.

This ammonia criteria update document recommends an acute criterion of 2.9 or 5.0 mg N/L (at pH 8 and 25^{o}C) depending on whether freshwater mussels are present or absent, and a chronic criterion of either 0.26 or 1.8 mg N/L depending on the same (at pH 8 and 25^{o}C and whether freshwater mussels present or absent). For this document, the use of the EC20 for deriving the CCC was retained as in the 1999 document. Additionally, the 30 day averaging period was retained with the restriction that the highest 4-day average within the 30 days is no greater than 2.5 times the CCC (or 0.65 or 4.5 mg N/L freshwater mussels present or absent, respectively).

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INTRODUCTION

National Ambient Water Quality Criteria (AWQC) are established by the United States Environmental Protection Agency (EPA) following directives set forth in the Clean Water Act (CWA). Periodically EPA will review and revise 304(a) AWQC as necessary to ensure the criteria are adequately protective based on the latest science. The section 304(a) aquatic life criteria serve as recommendations to states and tribes in defining water column concentrations that should protect against adverse ecological effects to aquatic life resulting from exposure to a single pollutant found in the water column from direct contact or ingestion. Aquatic life criteria address the Clean Water Act 101(a)(2) & (3) goals and policy of attaining "water quality which provides for the protection and propagation of fish, shellfish, and wildlife," and are the basis for deriving permit limits, which prevent the discharge of toxic pollutants in toxic amounts.

EPA published a Federal Register Notice in July 2004 notifying the public of EPA's intent to re-evaluate the ammonia aquatic life AWQC. At that time, EPA requested all new information particularly related to ammonia toxicity to freshwater mussel species. Based upon the literature, it appears that many states in the continental USA have freshwater mussel fauna in at least some of their waters (Abell et al. 2000, Williams et al. 1993, Williams and Neves 1995). Moreover, approximately one-quarter of freshwater unionid mussel species and subspecies in the United States are Federally-listed as endangered, threatened or are of special concern. While the number of species is less and the distribution is sparse in the dry western states, even New Mexico and Arizona have at least one native mussel species (Williams et al 1993). Given the wide distribution of freshwater mussels, including unionid mussels, it is important that this criteria update consider ammonia toxicity information specific to freshwater mussels**.** Because ammonia is particularly toxic to freshwater unionids, EPA is re-assessing the numeric freshwater acute and chronic aquatic life criteria for ammonia to ensure they are protective of unionids.

Several literature searches dating back to 1985 have been conducted to locate results of laboratory toxicity tests compiled that quantify the adverse effects of ammonia on freshwater aquatic life, with particular attention given to tests conducted with freshwater mussels since such data were not available for many of these species at that time. Acceptable values for these and other test species were used in reviewing the 1999 freshwater ammonia acute and chronic aquatic life criteria (U.S. EPA 1999) and developing the recommended acute and chronic values presented in this notice .

EPA’s national numeric aquatic life criteria recommendations are calculated to protect aquatic organisms from unacceptable toxicity during acute (short) and chronic (long) exposures in the water column of a water body. EPA’s acute criterion recommendation is called the Criterion Maximum Concentration (CMC). The CMC is derived from a set of LC50s or EC50s for a variety of aquatic species. An LC50 represents the lethal concentration of a chemical that causes 50% mortality. An EC50 represents the 50% effect concentration when organisms are killed or effectively dead (e.g., immobilized). To provide aquatic organisms a reasonable level of protection, the CMC is set to one-half of the fifth percentile of the Genus Mean Acute Values (GMAVs) for the various species tested. To make exceeding this level of toxicity a rare event, EPA’s “*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*” (Stephan et al. 1985), hereafter referred to as the Guidelines, recommends that the one-hour average exposure concentrations should not exceed the CMC more than once every three years. Following this guidance, a new CMC for ammonia was calculated.

EPA’s chronic criterion recommendation is called the Criterion Continuous Concentration (CCC). Under the Agency's 1985 Guidelines, the CCC is normally derived from a set of chronic values (CVs), which have been defined as the geometric mean of the highest no observed effect concentrations (NOECs) and lowest observed effect concentrations (LOECs) for survival, growth, or reproduction in chronic tests. However, in the case of the Criterion Continuous Concentration for the Agency's 1999 ammonia recommended ammonia criteria, this procedure resulted in significant variation between the magnitudes of the effects corresponding to the individual CVs due to variation in the power of the statistical tests used, the selected dilution series and number of concentrations tested, and the size and variability of the samples used to calculate the no and low effect thresholds (Stephan and Rogers 1985). To make CVs reflect a more uniform level of effect, logistic regression analysis was used to calculate the 20 percent effect concentration (EC20) for each chronic test to derive the 1999 freshwater CCC for ammonia (U.S. EPA 1999). Then by direct calculation, the CCC was set to an estimated fifth percentile of CVs. In order to make exceeding the level of toxicity associated with the CCC a rare event, EPA's Technical Support Document (U.S. EPA 1991) recommends that four-day average exposure concentrations should not exceed the CCC more frequently than once every three years. For the 1999 ammonia criteria, however, this recommendation was extended such that the 30-day average exposure concentration should not exceed the CCC more frequently than once every three years based on duration of exposure needed to elicit chronic effects. The use of the EC20 (or an equivalent 20 percent inhibition concentration or IC20) for deriving the CCC has been maintained in this update of the 1999 AWQC freshwater CCC, as appropriate, as has the 30 day averaging period with the restriction that the highest 4-day average within the 30 days is no greater than 2.5 times the CCC (see U.S. EPA 1999, page 81).

The 1999 criteria are expressed on the basis of total ammonia nitrogen (TAN) as a function of pH (fish) or pH and temperature (invertebrates) (see U.S. EPA 1999 for specific calculations). In the 1999 freshwater AWQC document, the CMC differs based on the presence or absence of salmonids, and the CCC differs based on the presence or absence of fish early life stages.

BACKGROUND INFORMATION ON AMMONIA

Ammonia is considered one of the most important pollutants in the aquatic environment not only because of its highly toxic nature and ubiquity in surface water systems (Russo 1985), but also because many effluents have to be treated extensively in order to keep the concentrations of ammonia in surface waters from being unacceptably high. Ammonia can enter the aquatic environment via direct means such as municipal effluent discharges, and indirect means such as nitrogen fixation and the excretion of nitrogenous wastes from animals. While much of the early information regarding lethal concentrations of ammonia was driven by the consequences of ammonia buildup in aquaculture systems (i.e., fish culture ponds, hatchery raceways, and fish holding and transporting tanks), the introduction of large amounts of ammonia into surface water systems from industrial processes, agricultural run-off, and sewage effluents has also received considerable attention since the 1980s (Alabaster and Lloyd 1980, U.S. EPA 1985).

The chemical form of ammonia in water consists of two species, the more abundant of which is the ammonium ion (NH_4^+) and the less abundant of which is the non-dissociated or un-ionized ammonia (NH_3) molecule; the ratio of these species in a given aqueous solution is dependent upon both pH and temperature (Emerson et al. 1975, Erickson 1985, Thurston 1988, Wood 1993). In general, the ratio of un-ionized ammonia to ammonium ion in fresh water increases by 10-fold for each rise of a single pH unit, and by approximately 2-fold for each $10^{O}C$ rise in temperature from $0\text{-}30^{O}C$ (Erickson 1985).

Chemically, ammonia in an aqueous medium behaves as a moderately strong base with pK values ranging from approximately 9 to slightly above 10 as a function of temperature and ionic strength (Emerson et al. 1975, Whitfield 1974). The total ammonia in solution will consist of the gas NH_3 and the cation NH_4^+, the sum of which is most commonly expressed as total ammonia-nitrogen (TAN) (Thurston et al. 1984a). Each separate fraction of TAN can be calculated in freshwater (note: this relationship changes with salinity, see Hampson 1977 and Whitfield 1974) from the Henderson-Hasselbach equation if the pH and appropriate pK are known:

NH_4^+ = Total ammonia/(1+ antilog (pH-pK)) = Total ammonia – NH_3 (Wood 1993)

and,

$pK = 0.09018 + (2729.92/(273.2 + T))$ (Emerson et al. 1975)

where T is temperature in ^{O}C. In keeping with the recommendations made in the 1999 AWQC document, the concentrations of ammonia affecting freshwater animals in this criteria update are expressed on the basis of TAN (mg N/L), and normalized to pH=8 (fishes) or to pH=8 and 25^{O}C (invertebrates).

DATA COLLECTION

The acute and chronic ammonia toxicity data used here to update the 1999 AWQC acute and chronic criteria were collected from a literature search of EPA's ECOTOX database, EPA's Ambient Aquatic Life Water Quality Criteria for Ammonia (U.S. EPA 1985, 1998, 1999), data provided by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service (collectively known as the Services), and EPA regional and field offices. Relevant papers were identified, by title and abstract, and their data selected according to recommendations described in the Guidelines. The primary focus of this update was on tests with freshwater mussels (and secondarily snails); however, acute and chronic toxicity values published since 1985[1] for other aquatic animals were incorporated into the appropriate ammonia AWQC tables and used to recalculate the CMC and the CCC, following the methods briefly described above and outlined in complete detail in the Guidelines. The most recent literature search was conducted in February 2009.

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[1] Note: Although the freshwater criteria for ammonia were updated in 1999, the 1999 Update presented an overview of ammonia toxicology in order to provide the background needed to explain the revisions of the freshwater ammonia criterion made in 1998. Then the equations used in the older documents to address the temperature- and pH-dependence of ammonia toxicity in fresh water were revised to take into account newer data, better models, and improved statistical methods. For both the 1998 and 1999 updates, the CMC (acute criterion) was derived from the acute toxicity data in the 1984/1985 criteria document, pH-normalized using the new equations. Some new and old chronic toxicity data were evaluated and used to derive a CCC (chronic criterion). In the 1999 Update, the chronic averaging period was also addressed.

This 2009 Update differs from the preceding Updates in that this document incorporates a comprehensive literature search while utilizing the same temperature- and pH-dependence equations to normalize and calculate the new criteria for ammonia.

RESULTS

All acceptable acute and chronic values for freshwater aquatic animal species, including those from the 1999 AWQC document, are presented in Tables 1 (acute) and 5 (chronic). Because data on the acute and chronic toxicity of ammonia to freshwater mussels have recently become available, it is prudent to discuss these data and their inclusion in the AWQC calculations. There are concerns that have been raised about the appropriateness of using data obtained from tests conducted with the parasitic bivalve glochidia life-stage of freshwater mussels (for more detail, see Appendix A). Since glochidia of different species have different life history strategies for finding an appropriate fish host, glochidia may be free living in the water column (and potentially exposed to pollutants) for a duration ranging from seconds to days, depending on the particular species. In order for the toxicity test results with glochidia to be ecologically relevant, the duration of the test must be comparable to the duration of the free-living proportion of the glochidia on a species-by-species basis. For glochidia that become juveniles, there appears that little or no useful information is available concerning the average duration of the free-living portion of the glochidia life stage of any species of freshwater mussel. Therefore, as discussed in more detail in Appendix A, results of acute toxicity tests with glochidia that lack this information are not used in the derivation of water quality criteria for aquatic life. For this update, only acceptable acute toxicity data from the juvenile life-stages of these species have been included; these are provided in Table 1. Other acute toxicity data from the glochidia life stage, while excluded from calculation of the acute criterion, are provided in Table 2 (acute data from several unused tests/studies are also included in Table 9).

Criterion Maximum Concentration (CMC)

Data considered acceptable for inclusion in Table 1, according to the Guidelines, now includes 46 species of fish, 48 species of invertebrates and 4 species of amphibians. There are now 67 genera represented in the freshwater acute toxicity dataset for ammonia, as opposed to only 34 genera in the 1999 AWQC document. Of the 67 genera represented in Table 1 and listed according to sensitivity in Table 3, approximately half are invertebrates. Freshwater bivalve mollusks and snails are the predominant group of genera ranked in the lowest quartile, and the four most sensitive genera are all bivalves (see text Table A). Overall, invertebrates represent the eight most sensitive genera, and six of these are bivalves (see Table 3). This is in contrast to the four lowest ranked GMAVs in the 1999 AWQC document where all taxa were fish (text Table A). Note that in this update of the 1999 AWQC document, the SMAVs and GMAVs for invertebrates were not only normalized to pH=8, but to a temperature of 25^{O}C as well; this temperature normalization accounts for some of the difference observed in GMAVs between the two documents. The GMAVs ranked according to sensitivity, the 1999 AWQC CMC values, and the CMC values re-calculated in this update of the acute criterion for ammonia in freshwater are shown in Figure 1. The GMAVs represent LC50s or EC50s, whereas the CMC values represent concentrations that are lethal to a minimal percentage of the individuals in either the fifth percentile genus or a sensitive commercially or recreationally important species.

Table A. Comparison of the four taxa used to calculate the FAV and CMC between this update of the acute criterion and the current (1999) acute criterion[2].

Update of the Acute Criterion		Current (1999) Acute Criterion	
SPECIES [2]	**GMAV (mg N/L)**	**SPECIES [2]**	**GMAV (mg N/L)**
Oyster mussel, *Epioblasma capsaeformis*	6.037	*Oncorhynchus* sp. (salmonids), includes: *O. aquabonita*, *O. clarki*, *O. gorbuscha*, *O. kisutch*, *O. mykiss*, and *O. tshawytscha*	21.95
Asiatic clam, *Corbicula fluminea*	6.018	Orangethroat darter, *Etheostoma spectabile*	17.96
Lampsilis sp.(Unionidae), includes: *L. abrupta*, *L. cardium*, *L. fasciola*, *L. higginsii*, *L. rafinesqueana*, and *L. siliquoidea*	5.919	Golden shiner, *Notemigonus crysoleucas*	14.67
Rainbow mussel, *Villosa iris*	5.036	Mountain whitefish, *Prosopium williamsoni*	12.09
FAV	5.734	FAV[3]	11.23
CMC	2.9	CMC	5.6

As previously mentioned, freshwater mussels are among some of the most sensitive genera in the dataset, and therefore, significantly influence the FAV calculation. Since freshwater mussels may not be present in all waters, we are recommending two acute criteria, one to be applied, as appropriate, to waters where mussels are present and another criterion to be applied where mussels are absent. With the freshwater mussel data removed from the dataset for the mussels

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[2] Note, as per the Guidelines, whenever there are 59 or greater GMAVs in the acute criteria dataset, the FAV is calculated using the four GMAVs which have cumulative probabilities closest to 0.05. For example, in this 2009 draft update, the four GMAVs shown above with cumulative probabilities closest to 0.05 are sensivity rank 2-5, the most sensitive species Lasmigon subviridus is not included. If there are less than 59 GMAVs, the four lowest GMAVs are used to calculate the FAV regardless of cumulative probabilities.

[3] The FAV in the 1999 AWQC document was lowered to 11.23 mg N/L in order to protect large rainbow trout which were shown in Thurston and Russo (1983) to be measurably more sensitive than other life stages. The FAV prior to adjusting it to protect the commercially and recreationally important adult rainbow trout was calculated to be 14.32 mg N/L (CMC = 7.2 mg N/L).

absent criteria derivation, three of the five most sensitive genera are invertebrates (snails and Asiatic clam) in the Phylum Mollusca (see text Table B).

Table B. Comparison of the four taxa used to calculate the FAV and CMC in this update with and without freshwater bivalve data from the Family Unionidae.

Including All Data		**Excluding Freshwater Mussel Data**	
SPECIES [2]	**GMAV (mg N/L)**	**SPECIES [2]**	**GMAV (mg N/L)**
Oyster mussel, *Epioblasma capsaeformis*	6.037	Lost River sucker *Deltistes luxatus*	13.18
Asiatic clam, *Corbicula fluminea*	6.018	Mountain whitefish, *Prosopium williamsoni*	12.09
Lampsilis sp.(Unionidae), includes: *L. abrupta, L. L. cardium, L. fasciola, L. higginsii, L. rafinesqueana*, and *L. siliquoidea*	5.919	Snail (adult), *Pleurocera uncial*	10.54
Rainbow mussel, *Villosa iris*	5.035	Snail, *Potamopyrgus antipodarum*	7.605
FAV	5.734	FAV	9.935
CMC	2.9	CMC	5.0

Justification for Exclusion of *Hyalella azteca* Data from Acute and Chronic Ammonia Criteria Development

For this update of the 1999 freshwater ammonia AWQC, the SMAV and SMCV for *H. azteca* were not used to calculate the CMC or CCC. For a full description of EPA's rationale for this decision, see Appendix B. Briefly, data were not included because several laboratories have recently reported regular or intermittent difficulty obtaining consistent results and acceptable survival and growth of *H. azteca* during testing and culturing. At this time, the water quality conditions that promote optimal health are not known. However, laboratory evidence suggests that chloride (and possibly bromide) is an important water quality parameter for improving *H. azteca* health. The importance of chloride to *H. azteca* health has been suggested by the results of the following studies:

a. Smith et al. (1997) reformulated moderately hard water with 34 mg Cl/L and saw improved *H. azteca* control survival of >80% during 96-hr tests. Survival during prior tests, which used moderately hard water with 2 mg/L chloride, was never >70%.
b. Soucek (2007) demonstrated that increasing chloride from 5 to 25 mg/L in acute toxicity tests of *H. azteca* exposed to sulfate significantly increased the LC50 value (decreased acute toxicity).
c. Borgmann (1996) raised the water concentration of chloride for *H. azteca* laboratory cultures from 0 to 21.3 mg Cl/L and observed a large improvement in organism survival.

From these and other observations, it appears that *H. azteca* are healthier when the range of chloride concentration is between 25 and 100 mg Cl/L.

The uncertain health status of *H. azteca* used in the laboratory-based toxicity tests with ammonia may be an important contributing factor in the extreme variability of LC50s (between 1.70 and 83.9 mg N/L) observed for this species (see Table 4). Seven studies report results of ammonia toxicity to *H. azteca*. The following paragraphs provide a brief summary of those studies and the test conditions reported in each.

Sarda (1994) reported conducting 96 h tests with *H. azteca*, but only presents survival data after 48 h. The tests were assumed to be static as no information was provided to indicate otherwise. The test material was ammonium chloride. During testing, the author states pH was altered, but no details were provided describing how pH was altered, and no results were provided for *H. azteca* at the various levels of pH. Temperature was measured daily, whereas pH was measured at the beginning and end of the tests. Total ammonia was measured using an electrode, but no information was provided on when the measurements were made. Tests were performed in two waters (a reconstituted water and creek water) that differed with respect to pH and hardness. Hardness, alkalinity, and pH changed substantially during the tests. Although control survival was acceptable, the concentration of chloride in the creek water is not known. One of the ingredients of the reconstituted water was mineral water. According to the company that produces the mineral water, the concentration of chloride in the water was likely 26 mg Cl/L, but because the test material was ammonium chloride, the concentration of chloride differed between treatments. The results of these tests were not considered for use in the derivation of aquatic life criteria because, among other things, hardness, alkalinity, and pH changed substantially during the tests and the concentration of chloride changed from one treatment to another.

Borgmann (1994) performed a variety of toxicity tests, two of which were 10-week water-only life-cycle tests in which the test solutions were renewed weekly. Ammonia was measured at the beginning and end of each renewal. The measured concentrations were close to nominal and the ratio of final to initial measured ammonia concentration averaged 1.09. The pH of the test solutions was measured three times per week. Ten-week control survival averaged 66.3 percent. The test material was ammonium chloride and the dilution water was dechlorinated tap water that contained 26 mg Cl/L. On the basis of the nominal concentrations of total ammonia, increased chloride concentration due to the added ammonium chloride at the lowest tested concentration of ammonia was 3.5 mg Cl/L, whereas the increase at the highest tested concentration of ammonia was 64 mg Cl/L. Thus the concentration of chloride in the treatments ranged from about 30 mg Cl/L to about 90 mg Cl/L.

Ankley et al. (1995) performed 96-hr water-only toxicity tests in which the test solutions were renewed daily. The test organisms were cultured in hardened, unaltered Lake Superior water, and tests were performed at three levels of pH in each of three waters (soft water = Lake Superior water; moderately-hard water = hardened Lake Superior water; ASTM hard water = salts added to Millipore water[4]). The test material was ammonium chloride and hydrochloric acid was used to acidify some test solutions. The chloride concentration of Lake Superior water has been reported as 1.2 and 1.4 mg/L by Biesinger and Christensen (1972) and Tiffany et al. (1969), respectively. The concentration of chloride in the hardened Lake Superior water was about 19 mg/L, based on information provided for culturing *H. azteca* at the USEPA Laboratory in Duluth, Minnesota. The concentration of chloride in the ASTM hard water used in these tests was probably near 4 mg Cl/L. The increase in the concentration of chloride due to acidification is not known. On the basis of the nominal concentrations of total ammonia, the increase in chloride at the lowest and highest reported LC50s was 44 mg Cl/L and 516 mg Cl/L, but the range within any one test would not be nearly this large.

Whiteman et al. (1996) compared the toxicity of ammonia in a spiked-sediment exposure versus a water-only exposure. The water-only toxicity test was a flow-through 96-hr test and the test material was ammonium chloride. The dilution water was dechlorinated tap water from Superior, WI, which was drawn from a well in a sandy area near Lake Superior. The concentration of chloride in this water was probably less than 2 mg/L (see above). Ammonia, temperature, and pH were measured sufficiently often. The increase in the concentration of chloride due to the test material at the 96-hr LC50 was 23 mg Cl/L; thus the total chloride concentration would be less than 25 Cl/L in treatments below the LC50, but greater than 25 mg Cl/L in treatments above the LC50. The results of these tests were not considered for use in the derivation of water quality criteria because of the low concentration of chloride in Lake Superior water.

Borgmann and Borgmann (1997) performed water-only toxicity tests in which the test solutions were renewed weekly. The test material was ammonium chloride, and hydrochloric acid was

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[4] per American Society for Testing and Materials. 2007. Standard guide for conducting acute toxicity tests on test materials with fishes, macroinvertebrates, and amphibians. Standard E 729-96 in Vol. 11.06 of the Annual Book of ASTM Standards. American Society for Testing and Materials, West Conshohocken, PA. 218 pp.

used to acidify some solutions. The authors reported that both sodium and potassium affected the toxicity of ammonia to *H. azteca*, and that the effect of pH on the toxicity of ammonia to *H. azteca* depends on hardness and on the concentrations of sodium and potassium. On the basis of some dilution tests, they concluded that calcium, magnesium and anions did not affect the toxicity of ammonia, but they did not explicitly study the effect of a series of closely-spaced concentrations of calcium, magnesium, or any anion on the toxicity of ammonia.

Besser et al. (1998) performed 96-hr static acute toxicity tests on two sediments spiked with a solution prepared by adding ammonium chloride to a 50-50 mixture of well water and deionized water. One sediment was from Little Dixie Lake and the other was a formulated sediment. The concentrations of chloride and bromide in the dilution water were not reported; it is possible that one or both of the sediments increased or decreased the concentrations of chloride and/or bromide in the test solutions. The results of these tests were not considered for use in the derivation of water quality criteria because the concentration of ammonia in the pore water was not determined.

Wang et al. (2008) performed 48-h toxicity tests on ammonia at pH = 6.5, 7.5, 8.0, 8.5, and 9.0 using a combination of ammonium chloride and ammonium hydroxide. The pH of some solutions was adjusted using hydrochloric acid. The dilution water was reconstituted hard water that contained 7.9 mg Cl/L. At only two of the pH levels tested was the concentration of ammonia sufficiently high to kill more than 20 percent of the *H. azteca* in any of the treatments. In both of these tests, there was an unusual concentration response where percent survival was higher at higher test concentrations. Moreover, the LC50s and confidence limits at pH = 9.0 do not agree with the data at elevated pH for *H. azteca*. These LC50s should not be used in the derivation of an aquatic life criterion for ammonia for the reasons given.

Data reported by Besser et al. (1998), Sarda (1994), and Wang (2008) concerning the sensitivity of *H. azteca* to ammonia were not considered for use in the derivation of an aquatic life criterion for ammonia for the reasons specified. Data from the other publications are deemed questionable because of concerns regarding:

- the importance of chloride (and possibly bromide and/or other ions) to *H. azteca*;

- the possible effect of chloride and/or bromide on the toxicity of ammonia to *H. azteca*;
- the use of ammonium chloride as the test material;
- the use of hydrochloric acid to acidify some test solutions;
- the use of dilution waters that contained low concentrations of chloride in some of the tests; and
- other aspects of the methodology used in some of the tests.

At this time it is not known how much of the wide range of ammonia LC50s obtained with *H. azteca* is due to water quality, the methodology used in some of the tests, and/or the health of the organisms. It appears that some of the lowest acute values were obtained using dilution waters that contained low concentrations of chloride.

Criterion Continuous Concentration (CCC)

Review and Analysis of Chronic Data

The freshwater final chronic value, or CCC, was updated using newly acquired chronic data for three freshwater mussel species and three fish species (Table 5). Each chronic dataset was reviewed following the three-step review process described in the 1999 AWQC document. Briefly, the first step was to determine whether the test methodology was acceptable. A test was considered acceptable if the dilution water, control mortality, experimental design, organism loading, etc., were consistent with ASTM Standards for tests with fish and invertebrates, i.e., E1193, E1241, and E1295 (ASTM 2004, 2005, and 2006b, respectively), and specifically for freshwater mussels via E2455-06 (ASTM 2006a). The concentration of dissolved oxygen was also reviewed to determine acceptability based on the general limits specified in the 1999 AWQC document.

If the test methodology was acceptable, the second step of the review process was to determine whether the test satisfied one of the definitions provided in the Guidelines for a life-cycle, partial life-cycle, and early life-stage test. In general, if the test did not satisfy one of the definitions given in the Guidelines for a life-cycle, partial life-cycle, or early life-stage test, a third step was necessary to determine whether the toxicant used in the test caused an unacceptable reduction in (a) survival, reproduction, and/or hatchability over any period of at least seven days, or (b) growth (if the duration of the test is judged sufficiently long to capture growth reductions that are not temporary - as determined on a species-specific basis). If it caused either kind of unacceptable reduction, the test could provide an upper limit on a CV or it might lower a CV from an early life-stage test. If it did not cause either kind of unacceptable reduction, the test cannot provide a CV or an upper or lower limit on a CV, but the test might provide other useful information.

Consistent with the rationale above, and in accordance with the Guidelines, 28-d survival and growth tests using juvenile and adult freshwater snails and juvenile freshwater mussels do not qualify as chronic toxicity tests for use in the derivation of aquatic life criteria (because the 28-d survival and growth test using juvenile or adult animals is neither a life-cycle test nor a partial life-cycle test, and early life-stage tests are used as predictors of life-cycle tests for fishes only[5]). Nevertheless, a concentration that causes a reduction in survival of 20% or more can usually be used as an upper limit on a Species Mean Chronic Value (SMCV). Reduction in growth cannot be similarly used at this time because of uncertainties concerning these data[6]. Growth data from 28-day tests with juvenile and adult snails and mussels will be included in a criteria document as "other data" (Table 6) and might influence a criterion by means of sections X and XII.B of the Guidelines. For a full description of EPA's rationale for this decision, see Appendix C.

As indicated in the 1999 AWQC document, it was not necessary, nor appropriate, to consider CVs based on histopathological effects as in the 1984/1985 ammonia criteria document.

Calculation of Chronic Values

To help achieve consistency among studies, regression analysis was used, both to demonstrate that a concentration-effect relationship was present, and to estimate CVs with a consistent level

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[5] The basis for and use of early-life stage toxicity tests with fish as an acceptable surrogate for life-cycle tests with fish was established by McKim (1977).

[6] See Appendix C this document for more explanation and additional detail.

of effect. Use of regression analysis is discussed on page 39 of the Guidelines (Stephan et al. 1985). Precise estimates of effect concentrations can generally be made for a 50 percent reduction (EC50); however, such a major reduction is not necessarily consistent with chronic criteria. In contrast, a concentration that caused a low level of reduction, such as an EC5 or EC10, is rarely significantly different from the control treatment based on conventional statistical analysis. As a suitable compromise, the EC20 (or equivalent IC20) values are used to estimate a low level of effect observed in chronic datasets that are available for ammonia (U.S. EPA 1999).

With only a few exceptions (indicated in the text as such), regression analysis was performed on a chronic dataset only if the dataset met the general conditions specified in the 1999 AWQC document:
(1) it contained a control treatment to anchor the curve at the low end,
(2) it contained at least four concentrations of ammonia to provide at least two error degrees of freedom when the three-parameter equation is fit to a set of data,
(3) the highest tested concentration of ammonia caused >50 percent reduction relative to the control treatment to anchor the curve at the high end, and
(4) at least one tested concentration of ammonia caused <20 percent reduction relative to the control treatment to ensure that the EC20 was bracketed by tested concentrations of ammonia.

For life-cycle and partial life-cycle tests, the toxicological variables used in these regression analyses were survival, embryo production, and embryo hatchability. For early life-stage tests, the variables used were embryo hatchability, fry/larval survival, and fry/larval growth; if ammonia reduced both survival and growth, the product of these variables (biomass) was analyzed (when possible), rather than analyzing them separately. For other acceptable chronic tests, the toxicological variable analyzed was survival, reproduction, hatchability, and/or growth as appropriate, based on the requirements stated above concerning acceptability of chronic tests. When applicable, the regression analysis was performed using EPA’s Toxicity Relationship Analysis Program (TRAP, Version 1.00, 11/29/02) if possible, or via A Linear Interpolation Method for Sublethal Toxicity: The Inhibition Concentration Approach (ICpin, Version 2.0, 06/03).

Evaluation of the Chronic Data Available for Each New Species

The following presents a species-by-species discussion of each new freshwater chronic dataset evaluated for this update of the 1999 AWQC for ammonia. Also presented are the results of regression analysis of each dataset from an acceptable chronic test that met the data requirements to perform such regression analysis. For each such dataset, Appendix F contains a figure of the data and fitted regression line, a table with the regression parameters, and effect concentration estimates (e.g., EC20 values). All analyses were conducted in terms of total ammonia nitrogen, either as reported by the authors or as converted from the reported values for un-ionized ammonia, pH, and temperature using the speciation relationship applied in the 1999 AWQC document (i.e., Emerson et al. 1975). When an EC20 could be determined, it was first reported as calculated by regression analysis of the data at the pH and temperature of the test. Then, to facilitate comparisons of sensitivities within and between species, each EC20 was adjusted to pH=8 using Equation 12 in the 1999 AWQC document, and for invertebrates, adjusted to a temperature of 25^{O}C using Equation 5 with a slope of -0.028, per the discussions of the temperature and pH dependency sections in the 1999 AWQC document. SMCVs were derived when justified by the data, and Genus Mean Chronic Values (GMCVs) were calculated when justified by the SMCVs. All of the EC20 values, SMCVs, and GMCVs derived are tabulated and included with the existing values from the 1999 AWQC document in Table 5. Note that for some of the new chronic data for species presented below, authors reported EC20 values (or an equivalent IC20 value) on the basis of total ammonia nitrogen. In such cases these reported CVs were normalized to pH 8 and 25^{O}C (temperature normalization for invertebrates only), as per the 1999 AWQC document, and utilized for the analysis.

Lampsilis fasciola (wavy-rayed lampmussel)

Wang et al. (2007a) recently published their results of the effect of ammonia on survival and growth of 2-month old juvenile freshwater mussels whose length averaged 0.66 mm. The test was part of a series of studies designed to refine the methods for conducting acute and chronic toxicity tests with early life stages of freshwater mussels. Dissolved oxygen was maintained above 7.0 mg/L during the 28-day test. Survival in the control treatment and lowest ammonia concentration (0.13 mg N/L) were 100 and 83%, respectively. Survival decreased to 30% at 1.02 mg N/L, and zero at 1.98 mg N/L. Shell length sampled as a measure of growth was no different from controls up to the 0.44 mg N/L exposure. The reported IC25 values based on survival and shell length were 0.39 and 0.57 mg N/L, respectively, at 20^{O}C and pH=8.2. The corresponding IC10 values were <0.13 and 0.48 mg N/L. The survival IC25 for this freshwater mussel species is 0.38 mg N/L when adjusted to pH=8 and 25^{O}C. The survival IC20 for this freshwater mussel species, calculated using EPA's ICpin program, is 0.23 mg N/L when adjusted to pH=8 and 25^{O}C. Using EPA's TRAP (piecewise linear regression model with full convergence), the adjusted IC20 value is 0.39 mg N/L (see Appendix F).

Lampsilis siliquoidea (fatmucket)

As part of the same study summarized above, Wang et al. (2007a) also determined the effect of ammonia on survival and growth of 2-month old juvenile fatmucket whose length averaged 0.62 mm. The 28 day test was conducted following the same methods (see ASTM 2006a). Survival in the control treatment and lowest ammonia concentration (0.13 mg N/L) were 98 and 83%, respectively. Survival decreased to 18% at 0.49 mg N/L, 45% at 1.00 mg N/L, and 13% at 1.99 mg N/L, respectively. Shell length sampled as a measure of growth was no different from controls up to the 0.28 mg N/L exposure. The reported IC25 values based on survival and shell length were 0.32 and 0.44 mg N/L, respectively, at 20^{O}C and pH=8.2. The corresponding IC10 values were <0.13 and 0.32 mg N/L, while the survival IC25 for juvenile fatmucket is 0.31 mg N/L when adjusted to pH=8 and 25^{O}C. The survival IC20 for this freshwater mussel species, calculated using EPA's ICpin program, is 0.30 mg N/L when adjusted to pH=8 and 25^{O}C (Table 5). Note: Using EPA's TRAP the adjusted value is 0.17 mg N/L, but the piecewise linear regression indicated a large standard error for steepness and for Y0, and therefore, the adjusted IC20 value of 0.30 mg N/L was retained for the test (results of TRAP analysis not included in Appendix F).

Villosa iris (rainbow mussel)

The effect of ammonia on survival and growth of a third freshwater mussel species was also reported in the study by Wang et al. (2007a). Juvenile (2 month old) rainbow mussels whose length averaged 0.90 mm were tested under similar conditions as described above. Survival was ≥ 98% up to the 0.81 mg N/L exposure, but fell to 15% at 1.67 mg N/L. In contrast, shell length was reduced by approximately 13% at 0.40 mg N/L compared to controls, and by 28% when exposed to 0.81 mg N/L. The reported IC25 values based on survival and shell length were 1.0 and 0.73 mg N/L, respectively, at 20^{O}C and pH=8.2. The corresponding IC10 values were 0.89 and <0.40 mg N/L. The survival IC25 for this freshwater mussel species is <0.98 mg N/L when adjusted to pH=8 and 25^{O}C. The survival IC20 for this freshwater mussel species, calculated using EPA's ICpin program, is also 0.98 mg N/L when adjusted to pH=8 and 25^{O}C. Note: EPA's TRAP could not be used to generate a corresponding EC20 value for this species based on survival.

Considering the above, and with the exception of the rainbow mussel, juvenile mussel survival was the more sensitive endpoint in the 28-day tests. The calculated EC20 value using TRAP for *L. fasciola* and IC20 values using ICpin for *L. siliquoidea* and *V. iris* were deemed sufficiently representative of the mussel's sensitivity to be included in Table 5. For all three freshwater mussel species, and as per the text presented earlier in this document, the EC20 and IC20 values presented in Table 5 are considered an upper limit CV for the species because the values are based on survival of juveniles, which might not be as sensitive to ammonia toxicity as other chronic test endpoints, such as reproduction. Thus, the SMCVs for all three freshwater mussel species have been ascribed a less than sign. Note: Equivalent IC25 values based on growth for the three mussel species are included in Table 6 (refer to Appendix C for further explanation regarding this decision).

Cyprinus carpio (common carp)

Mallet and Sims (1994) conducted a 28-day early life-stage test starting with eggs approximately 6 hours post-fertilization. The measured DO concentrations reported for the test ranged from 79 to 94% of saturation. Ammonia had no effect on hatching success at the highest concentration tested (19.6 mg N/L); although survival of the post-hatch stages was significantly reduced at this level compared to controls (average fry survival in the control treatment was 86%). Growth of fry was the most sensitive endpoint, and mean fry wet weights were inhibited at concentrations ≥10.4 mg N/L. Even though the number of larvae in each replicate vessel was not made uniform on hatching, at least one vessel per concentration contained an equivalent stocking density (23 to 29 carp), so the mean wet weight of carp in the one selected replicate per concentration was analyzed using regression analysis. The resulting EC20 value was 8.36 mg N/L at 23^{O}C and pH=7.85 (see Appendix F), which was calculated to be 6.82 mg N/L at pH=8.

Oncorhynchus clarki (cutthroat trout)

Table 6 in the 1999 AWQC document contains the value of <19.7 mg N/L for cutthroat trout estimated from a 29-day lethality study with fish whose average weights were 3.3 and 3.4 g, respectively (see Thurston et al. 1978). Because EC20 values could not be calculated and the test was not conducted with an early life stage, the true SMCV is assumed lower than 19.7 mg N/L. Thus, this value was not used in the calculation of a SMCV for the species (see U.S. EPA 1999).

Koch et al. (1980) exposed Lahontan cutthroat trout (*Oncorhynchus clarki* Henshawi) for 103 days in an early-life stage test. The measured dissolved oxygen concentrations for the entire study ranged from 7.0 mg/L to 8.9 mg/L, with an overall average of 7.88 mg/L. Survival of embryos in the control treatment was 80%, with approximately 95% surviving through the fry stage, and 80% surviving as fingerlings up to day 94 of the test. There were no successful hatches at exposure levels of 148 mg N/L or higher, and no significant mortality at exposure levels below 32.9 mg N/L. Regression analysis of the survival data using an arcsine transformation resulted in a calculated EC20 value of 20.80 mg N/L at 13.7 ^{O}C and pH=7.57 (see Appendix F). The EC20 value is 12.38 mg N/L when adjusted to pH=8.

As noted in the 1999 AWQC document, five other studies have reported results of chronic tests conducted with ammonia and other salmonids including *Oncorhynchus mykiss* and *Oncorhynchus nerka*. There is a lack of consistency among the chronic values obtained from these tests, and several tests produced "greater than" and "less than" values (Table 5). Consequently, in keeping with the decision made in the 1999 AWQC document, a GMCV is not derived for *Oncorhynchus*. Instead, the results of the chronic tests were used to assess the appropriateness of the CCC.

Esox lucius (northern pike)

Harrahy et al. (2004) conducted a 52-day early life-stage test starting with newly-fertilized northern pike embryos. The mean dissolved oxygen concentration in test water ranged from 8.7 to 9.1 mg/L during the test. There was no effect of ammonia on hatching success up to 62.7 mg N/L, and larval survival of control fish was 100%. A significant reduction in larval survival and growth was observed at concentrations of total ammonia ≥30.4 and 15.1 mg N/L, respectively, at pH=7.6 and 8.7^{O}C. The estimated EC20 value reported for biomass was 13.44 mg N/L, which was calculated by the authors to be 8.40 mg N/L at pH=8. Thus, the CV of 8.40 mg N/L reported for biomass in the study was retained for northern pike in Table 5 of this document.

Other Chronic Toxicity Data

There were several other freshwater invertebrate and fish studies that were excluded from Table 5 and subsequent SMCV and GMCV calculation because the tests did not include the appropriate life stage for the test, or did not meet other general Guidelines requirements for use in calculating the CCC. These tests are summarized below and in Table 6.

Invertebrates:

Besser et al. (2009), in a USGS study report recently completed for EPA[7], conducted 28-day flow-through survival and growth tests with five species of snails. All tests were conducted in ASTM hard water (mean hardness and alkalinity of 169 and 121 mg/L as $CaCO_3$, respectively) as the dilution water which had a pH range of 8.20-8.29 and a temperature range of 19-21^{O}C during testing. Total ammonia (mg N/L) concentrations in tests were measured weekly with the percent of nominal concentrations ranging from 83 to 101 (most test concentrations averaged ≥ 90 percent of nominal except two concentrations in one of the tests – test designated as #5 in the report). Test results were based upon the mean of the measured concentrations. For all snail exposures, the effect of ammonia on growth was not determined for test species that were of mixed ages at test initiation (as explained further below); growth, however, was not as sensitive of an endpoint as survival for the two snail species where both growth and survival were measured (see summaries of the *Lymnaea stagnalis* and *Pyrgulopsis idahoensis* tests below).

Normalized chronic values reported for the five snail species are provided in Table 6. A summary of the Besser study results for each snail species is as follows:

Fluminicola sp. (Pebblesnail)

For the survival tests with *Fluminicola sp.*, mixed-aged adult and young-adult organisms (from 6 to 12 months) were used because the acclimation cultures produced only approximately 200 neonates for testing that were collected over a period of about four months. *Fluminicola sp.* did not show statistically significant mortality at any of the test concentrations compared to the controls because of the extreme variation between replicates at the highest test concentrations. Because of this extreme variability among treatment replicates, the NOEC and LOEC for survival were reported as 7.9 mg N/L and >7.9 mg N/L, respectively. It is worth noting, however, that snails in the control treatment exhibited 100% survival, while snails exposed to the highest ammonia concentration (7.9 mg N/L) exhibited 0% survival, but because of the extreme variability between replicate groups of snails in the 1.7 and 3.6 mg N/L treatments (all alive

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[7] Available via EPA Public Comment Docket #OW-2009-0921.

versus all dead), the ANOVA for the test was not significant (p=0.339). The lack of a statistically significant ANOVA for snail survival in the test precluded post hoc comparison of means testing. Based on the reported mean survivals for *Fluminicola sp.*, the reported EC20 for *Fluminicola sp.* was estimated to be 1.02 mg N/L, or 1.19 mg N/L when adjusted to pH 8 and 25 ^{O}C (see Table 6). The EC20 calculated for the test is not considered reliable, however, due to the extreme variability in survival among replicates in the 1.7 and 3.6 mg N/L test concentrations (i.e., the all-or-none response in the replicates of these two treatments, which, when averaged and analyzed as means instead of analyzing the replicates separately in the regression, allows estimation of an EC20 that would otherwise be incalculable because of the extreme variability between treatment replicates). Thus, the upper limit chronic value for the test is uncertain. The value clearly is some concentration below 7.9 mg N/L, but exactly where that point lies cannot be determined at this time.

Fontigens aldrichi (Ozark springsnail)

As part of the same study summarized above, Besser et al. (2009) also determined the effect of ammonia on survival of *F. aldrichi*. Because *F. aldrichi* did not reproduce during culturing and acclimation, field-collected organisms of "older" (adult) mixed-ages were used for ammonia exposures. *F. aldrichi* exposed to ammonia in the 28-day test exhibited a NOEC based on survival of 0.45 mg N/L and a LOEC of 0.83 mg N/L. Similar to the adult pebblesnail study, the replicates associated with the LOEC (0.83 mg N/L) in this study were characterized by high variability. In addition, field-collected *F. aldrichi* did not reproduce in captivity and animals in the control group did not grow during testing. The reported EC20 for *F. aldrichi* survival was 0.61 mg N/L, or 0.71 mg N/L when adjusted to pH 8.0 and 25 ^{O}C (Table 6).

Lymnaea stagnalis (pulmonate pondsnail)

The effect of ammonia on survival and growth of a third freshwater snail species, *L. stagnalis,* was also reported in Besser et al. (2009). *L. stagnalis* tests used organisms that were <1 week post-hatch due to the abundance of young produced during culturing. *L. stagnalis* exposed to ammonia in a 28-day flow-through chronic test exhibited a survival NOEC and LOEC of 8.0 and

>8.0 mg N/L, and a growth NOEC and LOEC of 1.0 and 1.8 mg N/L (Note: an EC20 could not be calculated using the growth endpoint because the magnitude of the growth reduction was so small, i.e., 6% at 1.8 mg N/L and only 16% at 8 mg N/L). Because of the apparent negligible effect of ammonia on growth, the EC20 value for both survival and growth were reported as >7.9 mg N/L, or >8.5 mg N/L when adjusted to pH 8 and 25 ^{O}C. Note: For the purposes of this document, the EC20 based on survival for this test species is included in Table 6 because of the uncertainty of this value (> 8.5 mg N/L) as an upper limit SMCV for the species.

Besser et al. (2009) also determined the effect of ammonia on survival and growth on two snail species that were listed under the Endangered Species Act at the time of testing. One of these snail species, *P. idahoensis*, has since been de-listed.

Pyrgulopsis idahoensis (Idaho springsnail)

Two separate 28-day tests with one of the two listed species at the time of testing, *P. idahoensis*, included exposing juvenile organisms that were 7-9 and 11-13 weeks post-hatch (organisms in each cohort tested as separate replicates in the same test; test identified as test #3 in the report), as well as a cohort of mixed-age adults for all subsequent tests (test identified as test #5 in the report). The older life stages were chosen for testing because of the high control mortality demonstrated in preliminary tests using 2-3 week post-hatch *P. idahoensis.*

For *P. idahoensis* juveniles (both the 7-9 and 11-13 week post-hatch juveniles), the survival NOEC and LOEC were 1.8 and 3.6 mg N/L respectively, while the EC20 for survival was <0.48 mg N/L, or <0.52 when adjusted to pH 8 and 25 ^{O}C. It is important to note that juvenile snails in four of the test concentrations in this test exhibited ≤44.4 percent survival and were considered significantly less than the control survival of 100 percent, except for those snails in the middle tests concentration of 1.8 mg N/L, which demonstrated 62.5 percent survival and was not considered significantly different from the control. Thus, the NOEC and LOEC values for juvenile survival were viewed with skepticism due to the poor concentration-response relationship, and therefore, are not included with the other chronic toxicity data found in Table 6.

The NOEC, LOEC and EC20 for *P. idahoensis* growth was 8.0, >8.0 and >8.0 mg N/L respectively. When adjusted to pH 8 and 25 ^{O}C, the EC20 value is >8.62 mg N/L (see Table 6).

The chronic tests initiated with mixed-aged adult *P. idahoensis* (4 to 8 months of age) exhibited a survival NOEC, LOEC and EC20 of 3.6, 7.9 and 3.24 mg N/L, respectively. The EC20 adjusted to pH 8 and 25 ^{O}C is 3.77 mg N/L (Table 6). Comparison of the juvenile and adult *P. idahoensis* survival results indicates that juveniles are possibly the more sensitive of the two life stages; however, due to unreliability of the juvenile data, specifically the survival concentration-response relationship, such an assertion is uncertain at this time.

Taylorconcha serpenticola (Bliss Rapids snail)

The second snail species listed under the Endangered Species Act, *Taylorconcha serpenticola*, was exposed to ammonia by Besser et al. (2009) in 28-day flow-through chronic tests. Because *T. serpenticola* did not reproduce or grow well during culturing and acclimation, field-collected organisms of “older” (adult) mixed-ages were used. The EC20 for survival of *T. serpenticola* was 3.42 mg N/L, or 3.98 mg N/L at pH 8.0 and 25 ^{O}C (Table 6). The reported EC20 (3.42 mg N/L) was double the LOEC value of 1.7 mg N/L, where 15 percent mortality (or 85 percent survival) was observed compared to the control survival of 100 percent. The next highest concentration tested (3.6 mg N/L) exhibited 80 percent survival.

Fish:

Table 6 includes data for several fish species in addition to the other chronic invertebrate data described above. The chronic results from these several studies are summarized in brief as follows:

1. Sadler (1981) reported that the growth rate of juvenile European eel (*Anguilla anguilla*) weighing approximately 2.8 g was inhibited after 77 days of exposure to a concentration of 15.2 mg N/L at 23^{O}C and pH=7.53; when adjusted to pH=8, the LOEC value was 8.54 mg N/L.

2. In a 35-day study of the effects of sublethal ammonia on juvenile Nile tilapia (*Oreochromis niloticus*; 6 g – a non-indigenous species located in the southern United States), the concentration of total ammonia that resulted in an approximate 20% reduction in weight gain was approximately 7 mg N/L at 28^{O}C and pH=7.8 (Abdalla and McNabb 1999). At pH=8, this results in a value of 5.41 mg N/L. No mortalities were observed in the control fish or fish exposed to any of the ammonia concentrations tested up to 22.5 mg N/L.
3. Similarly, juvenile Nile tilapia weighing 20 g and exposed to total ammonia concentrations of 5.3 mg N/L or greater experienced a reduction in specific growth rate over 75 days at pH=7.45 (El-Shafai et al. 2004). The temperature during the exposure ranged from 26 to 34^{O}C, and the measured dissolved oxygen concentration was 7.7 mg/L. The LOEC of 5.3 mg N/L for the study corresponds to a value of 2.84 mg N/L at pH=8.
4. Beamish and Tandler (1990) exposed juvenile lake trout (*Salvelinus namaycush*) for 60 days on two different diets and observed a significant reduction in rate of weight gain when total ammonia was 6.44 mg N/L at pH 8.02 and temperature was 11.6^{O}C. Food intake by fish was initially decreased at this concentration of total ammonia, but was no different from controls by the end of the test. The growth LOEC for the study, when adjusted to pH=8, was calculated to be 6.63 mg N/L.

A final chronic study for a freshwater vertebrate worth mentioning here is Jofre and Karasov (1999), in which pre-metamorphic (Gosner stage 24-26) green frog (*Rana clamitans*) tadpoles were exposed to ammonia for 103 days under renewal conditions. Tadpoles were evaluated in two different experiments conducted in successive years. In the 1997 experiment, survival and growth were not significantly different from controls at the highest concentration tested, or 2.2 mg N/L at pH=8.7 and 24^{O}C, although only approximately 50% of the frogs survived at this concentration compared to the controls (98% survival). Note: survival was reduced to approximately 78% at 0.94 mg N/L at test temperature and pH. Growth, measured as total length, was no different between treatments. The frogs grew from an average total length of approximately 7.5 mm at test initiation to approximately 50 mm in all treatments. The NOEC for growth of green frog tadpoles in the study (which does not represent an early life-stage or partial life-cycle study) is >6.90 mg N/L at pH=8.

In addition to the several "other" chronic studies identified above, three studies provide useful information with which to assess the appropriateness of the CCC on its protectiveness to threatened and endangered fish species (data included in Table 6 for convenience).

In order to determine if whole effluent toxicity testing is protective of threatened and endangered fish species, Dwyer et al. (2005) conducted 7-day chronic toxicity tests with *Ceriodaphnia dubia* (neonates, <24 h old) and fathead minnow larvae (*Pimephales promelas*, <24 h) in addition to the following six threatened and endangered fish species: boneytail chub (*Gila elegans*), spotfin chub (*Cyprinella monocha*), Cape Fear shiner (*Notropis mekistocholas*), gila topminnow (*Poeciliopsis occidentalis*), Colorado pike minnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*). The age of the six threatened and endangered fish species used during the 7-day ammonia exposures ranged from <1 to 7 days. The mean temperature during the tests was 25^{O}C and the pH of the ASTM hard water used in tests was in the range of 7.8 to 8.0. Actual test concentrations were not measured in the tests, although test solutions were renewed daily. Results were based on nominal total ammonia nitrogen (mg N/L). The combined effect on test species survival and growth were determined as IC25 values. Tests were repeated anywhere from one to six times for each species, and the reported IC25 values are the geometric mean of replicate IC25 values when applicable. The reported IC25 values for *C. dubia* and fathead minnow are 1.3 and 7.2 mg N/L, or 1.08 and 5.97 mg N/L when adjusted to a pH of 8.0 and 25 ^{O}C (*C. dubia* only). The six endangered species, presented in the same order as they are listed above, have reported IC25 values of: 11.0, 15.8, 8.8, 24.1, 8.9 and 13.4 mg N/L, or 9.12, 13.10, 7.30, 19.99, 7.38 and 11.11 mg N/L when adjusted to a pH of 8.0. Based on the results, the two species typically used for whole effluent toxicity testing (*C. dubia and P. promelas)* were more sensitive to ammonia and are protective of the six listed fish species when used as surrogate test species.

Meyer and Hansen (2002) conducted a 30-day toxicity test with late-stage larvae (0.059 g) of Lost River suckers (*Deltistes luxatus*) at pH=9.5. The exposure duration and pH were chosen to represent the period of combined elevated un-ionized ammonia concentrations and elevated pH that occur during cyanobacterial blooms in surface waters of Upper Klamath Lake, which have been shown to last for several weeks to a month. Mean measured temperature during the study was 22.3^{O}C and dissolved oxygen was 6.2 mg/L. Survival decreased significantly at 1.23 and 2.27 mg N/L, whereas the highest NOEC for all endpoints (survival, growth, body ions, and swimming performance) was 0.64 mg N/L. Most deaths in the 2.27 mg N/L exposure occurred during the first three days of the test, while mortality of larvae in the 1.23 mg N/L treatment occurred gradually from days 2 to 24. The 29% average mortality in the 0.64 mg N/L treatment was all due to an unexplained complete loss of one replicate between days 5 and 7 of the exposure. Control survival was > 90%. The calculated LOEC of 1.23 mg N/L total ammonia normalized to pH=8 corresponds to a value of 10.43 mg N/L.

Fairchild et al. (2005) conducted 28-day toxicity tests with early life-stages of Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*), and compared the results of those tests with a test using a surrogate fish species, the fathead minnow (*Pimephales promelas*). Tests were initiated 2 days after swim-up when the larvae were feeding exogenously (or at 8-d post hatch for Colorado pikeminnow, 9-d post hatch for razorback sucker, and 4-d post-hatch for fathead minnow). Temperature, pH and dissolved oxygen over the 28-day test period averaged 19.9^{O}C, 8.24, and 7.4 mg/L (80% saturation) over the course of the three studies. Control mortality was 7% (fathead minnows and Colorado pikeminnow) or less (3%, razorback sucker) on day 28. Effect concentrations based on the survival and growth endpoints of the fathead minnow and razorback sucker tests were not different; however, growth was the more sensitive endpoint for the Colorado pikeminnow test. The 28-d growth LOEC for the Colorado pikeminnow was 8.60 mg N/L, or 12.26 mg N/L at pH=8. The 28-d survival LOEC for the razorback sucker was 13.25 mg N/L, or 19.20 mg N/L at pH=8. Both endangered fish species exhibited similar sensitivity to ammonia as the fathead minnow (LOEC of 13.48 mg N/L at pH=8; see Table 6). The same can be said for the Lost River sucker, which indicates that these particular endangered fish species will be protected by the CCC value calculated in this update and provided below.

Update of the CCC

Twelve GMCVs are presented in Table 5. Although Table 5 contains additional SMCVs for two species within the genus *Oncorhynchus*, no GMCV was derived for this genus because of the large range in EC20 values; the 1999 AWQC document has evaluated whether the CCC poses a risk to this genus, and concluded that it does not.

As was the case in the 1999 AWQC chronic dataset, Table 5 still does not contain data for an insect genus. However, available information for a stonefly (Thurston et al. 1984b) indicates that at least one aquatic insect species is relatively insensitive to ammonia (U.S. EPA 1999). Therefore, calculation of the fifth percentile directly from the GMCVs in Table 5 should be protective of insects and should adequately reflect the intent of the Guidelines.

For the calculation of the CCC in this update of the 1999 recommendation, the number of tested genera is considered to be 13 because the GMCV for *H. azteca* was not used (see previous discussion), and a GMCV for an insect is assumed to be greater than the four lowest GMCVs[8]. The fifth percentile value calculated by this procedure could be considered to be a “less than” value because three of the four lowest GMCVs are “less than” values. The relevant relationships for formulating a seasonal, pH- and temperature-dependent chronic criterion remain as specified in the 1999 AWQC document, and are as follows:

- The acute pH dependence is not applied to chronic toxicity because the measured acute-chronic ratios change substantially with pH. Equation 12, presented in the 1999 AWQC document, describes the shape of chronic pH dependence.
- This criteria formulation assumes no temperature dependence for fish endpoints.
- The temperature dependence for invertebrate chronic endpoints is set to the chronic slope of -0.028 above 7^{O}C; the slope is then set to zero below 7^{O}C. Thus, invertebrate chronic endpoints are temperature normalized in Table 5.

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[8] For this reassessment of the 1999 chronic criterion concentration, the addition of a thirteenth genus representative of an aquatic insect species increases the number of GMAVs to 13, which is the number used in the calculation of the fifth percentile value or Final Chronic Value, as per the calculation provided in the Guidelines.

Similar to the 1999 AWQC approach, this update of the CCC also begins with a baseline chronic criterion calculated at 25^{O}C. This reference temperature was selected because: a) it is the same temperature used to normalize the chronic invertebrate toxicity data in the 1999 AWQC document, and b) it is close to the temperature for the chronic test with the four most sensitive genera (*Lampsilis*, *Villosa*, *Musculium* and *Lepomis*; 20-20.8^{O}C). Consequently, temperature extrapolation uncertainties are minimized. Table 5 presents the GMCVs normalized to 25^{O}C. The GMCVs for the four most sensitive species are thus as follows:

< 0.3443 mg N/L for *Lampsilis*
< 0.9805 mg N/L for *Villosa*
< 2.260 mg N/L for *Musculium*
2.852 mg N/L for *Lepomis*

With N=13 (i.e., the 12 GMCVs provided in Table 5 plus the hypothetical GMCV for insects), this results in a CCC of 0.26 mg N/L at 25^{O}C and pH=8. Figure 2 shows the ranked GMCVs all at pH=8 and 25^{O}C.

If all data from the Family Unionidae were removed from the dataset, the total number of genera is reduced from 13 to 11 (10 GMCVs provided in Table 5 plus the hypothetical GMCV for insects). With the freshwater mussel (Unionidae) data removed from the dataset, one of the four most sensitive genera is an invertebrate (long fingernail clam) in the Phylum Mollusca, while the other three are fish species (see text Table C). The removal of the Unionidae data results in a CCC seven times greater than the CCC of 0.26 mg N/L calculated with the two freshwater mussel genera, or 1.8 mg N/L at 25^{O}C and pH=8.

Table C. Comparison of the four taxa used to calculate the CCC in this update with and without freshwater bivalve data from the Family Unionidae.

Including All Data		Excluding Freshwater Mussel Data (Family Unionidae)	
SPECIES	**GMCV (mg N/L)**	**SPECIES**	**GMCV (mg N/L)**
Bluegill *Lepomis macrochirus*	2.852	Smallmouth bass, *Micropterus dolomieui*	4.562
Long fingernail clam *Musculium transversum*	<2.260	Fathead minnow, *Pimephales promelas*	3.093
Rainbow mussel, *Villosa iris*	<0.9805	Bluegill *Lepomis macrochirus*	2.852
Lampsilis sp.(Unionidae), includes: *L. fasciola* and *L. siliquoidea*	<0.3443	Long fingernail clam *Musculium transversum*	<2.260
CCC	0.26	CCC	1.8

At 25^{O}C and pH 8, this 2009 update of the current CCC (with freshwater mussels present) is approximately 4.8 times lower than that listed in the 1999 document (CCC=1.2 mg N/L), due to the addition of the two freshwater mussels. The updated CCC of 0.26 mg N/L in this document is 26 percent lower than the lowest GMCV (0.34 mg N/L for *Lampsilis*). As discussed in the 1999 AWQC document, the alternative of calculating the CCC directly from new sets of GMCVs for each pH and temperature combination results in different degrees of extrapolation that would not be reasonable here.

The most important difference between the calculation of the CCC in this update and the 1999 AWQC document is that the GMCVs for bivalve mollusks, particularly the two new GMCVs for freshwater mussels, control the value of the criterion.

Although the CCC was calculated directly from CVs using the fifth percentile procedure as it was in the 1999 AWQC document (U.S. EPA 1999), it is prudent to consider how this new CCC compares a CCC calculated using acute-chronic ratios (ACRs). Consistent with the approach in the 1999 AWQC document, ACRs were determined for most of the EC20s in Table 5 that are used in the derivation of a GMCV and for which comparable acute values were found. All relevant acute and chronic values were adjusted to pH=8 and are expressed in terms of mg N/L, where N is total ammonia nitrogen. (Note that for this comparison, the acute and chronic values for invertebrates were not adjusted to 25^{O}C.) The resulting ACRs are provided in Table 7, along with the resulting Genus Mean Acute-Chronic Ratios (GMACRs).

Three new ACRs were added to the 1999 AWQC dataset. Two of the ACRs were for freshwater mussels in the genus *Lampsilis* (Table 7). The ACRs within the genus were in good agreement. A third ACR was added for the freshwater mussel species *Villosa iris*. The ACR for this sensitive species was roughly half that of *Lampsilis* (Table 7), but very close to the median ACR (6.3) of the other freshwater and invertebrate species for which information is available.

Two additional ACRs for endangered fish species, though not included in Table 7 because they were not from studies using true early life-stage fish, are worth noting here. ACRs of 2.772 and 2.135 were estimated for the Colorado pikeminnow (*P. lucius*) and razorback sucker (*X. texanus*), respectively. These ACRs are lower than most other freshwater fish species owing to their relatively high tolerance to chronic ammonia exposure (see Table 6).

Table 8 provides the GMACRs beside the ranked GMAVs to demonstrate whether there is a trend, because ACRs for some chemicals are higher for resistant species than for sensitive species (U.S. EPA 1985). No trend is obvious and the range of the GMACRs is 1.8 to 18. The findings are similar to those reported in the 1999 AWQC document.

The problem with using the ACR procedure for calculating a CCC for ammonia in the 1999 AWQC document was that ACRs were not available for the most sensitive species. For the current document GMACRs are available for the two most sensitive genera: *Lampsilis* (GMACR = >18.27) and *Villosa* (GMACR = >6.129). At pH=8 and 25^{O}C, the hypothetical FACR at the new CCC corresponds to (5.734 mg N/L)/(0.26 mg N/L) or 22.05 using the calculated FAV when freshwater mussels are present. The hypothetical FACR is reasonable under this scenario (i.e., 17% higher than the SMACR of 18.27 for *Lampsilis*), and thus, direct calculation of the

CCC using the fifth percentile calculation appears to be an acceptable, appropriately conservative procedure. In addition, the CCC obtained using the fifth percentile procedure agrees well with the available chronic data (i.e., at pH 8 and 25^{O}C, the CCC is 24 percent lower than the lowest GMCV).

Temperature and pH-Dependent Criteria Calculation

As indicated in the 1999 AWQC document, part of a criterion derivation is the estimation of the CMC or CCC based on the set of toxicity values available for different genera. The CMC or CCC estimate is intended to be what would be obtained by simple inspection if many genera had been tested. Generally, this CMC or CCC is below the lowest value. For small datasets (<19) it is assumed that the lowest toxicity value is below the fifth percentile (i.e., if many more genera were tested, the fifth percentile would likely be more sensitive than any value in the small dataset). Because the CMC is one half of the fifth percentile (i.e., FAV/2), it is typically lower than the lowest GMAV even in large datasets. Because the extrapolation procedure used to calculate the CMC or CCC is based on the slope of the four most sensitive genera, if the genera vary widely in sensitivity, the extrapolated criterion value is further below the lowest value than if the criteria were tightly grouped. This is statistically appropriate because when variance is high (i.e., values are widely spaced), the fifth percentile of the distribution would be expected to lie further below the lowest value of a small dataset than if the variance was low.

However, this extrapolation procedure, while appropriate for criteria derivations across chemicals with different variances for genus sensitivities, is not necessarily appropriate when the genera are following different temperature or life stage dependencies. Sensitivities change with temperature or life stage, and as a result, the spread of the four lowest GMAVs or GMCVs, and the resulting degree of extrapolation to the fifth percentile of sensitivity also changes. Rather than develop separate sets of GMAVs and GMCVs for each temperature and computing the CMC or CCC from the four most sensitive GMAVs or GMCVs at each temperature-pH combination, the extrapolation approach described below will be used.

This issue of extrapolation to different temperatures and pHs with regard to chronic toxicity was addressed in the 1999 AWQC document for ammonia by first calculating the ratio of the CCC to the lowest GMCV, and then applying that ratio to subsequent criteria calculations for all possible pH and temperature combinations. The rationale of this approach was that it offered a degree of extrapolation that was modest and reasonable given the relatively low number of tested genera, and that it was a preferable approach to the alternative procedure of calculating CCCs directly from new sets of GMCVs for each pH-temperature combination, as each combination could result in different degrees of extrapolation, some of which could be more than 50% below the lowest GMCV. Because fish GMCVs are not affected by temperature, and because the most sensitive fish species was an early life stage (ELS) of *Lepomis*, this analysis was conducted separately for the scenarios of when fish ELS were included or not included in the calculation of the CCC. The reason for this is because even though the lowest GMCV at 25°C was for an invertebrate, as temperature decreases, invertebrates, but not fish, become less sensitive to ammonia, and below a particular temperature threshold, fish become the most sensitive genera. This consequence was described in detail in the 1999 AWQC document, and will be described further below.

Finally, in the 1999 Update, the most sensitive GMAVs were fish, and because their sensitivities to ammonia did not vary with temperature, no temperature extrapolation was performed. In contrast, the lowest GMAVs in this document are for invertebrates, and as a consequence, the temperature extrapolation procedure will be similarly applied to the CMC as well as the CCC.

Temperature Extrapolation of Acute Toxicity

When freshwater mussels are present, the lowest GMAV is 3.539 mg N/L for *Lasmigona subviridus* (Table 3). The resulting CMC when mussels are present of 2.87 mg N/L is 18.9% lower than the lowest GMAV. When freshwater mussels are absent, the lowest GMAV is 6.018 mg N/L for *Corbicula fluminea* (Table 3). The resulting CMC when mussels are absent of 4.97 mg N/L is 17.4% lower than the lowest GMAV. In both cases, the most sensitive fish species is the salmonid *Prosopium williamsoni*, with a GMAV of 12.09 mg N/L (Table 3). Because the most sensitive genera are invertebrates, regardless of whether freshwater mussels are included or excluded, the criterion will vary with temperature according to the invertebrate acute temperature relationship, but cannot exceed the extrapolated ratio multiplied by the lowest (most sensitive) fish GMAV.

When freshwater mussels are present, at pH=8, the CMC would be expressed as:

$$CMC = 0.811 * MIN\left(12.09, 3.539 * 10^{0.036*(25-T)}\right)$$

This function increases steadily with decreasing temperature (T), until it reaches a maximum (0.811 * 12.09 = 9.805 mg N/L) at 10.2°C, below which it remains constant (Figure 3).

When freshwater mussels are absent, at pH=8, the CMC would be expressed as:

$$CMC = 0.826 * MIN\left(12.09, 6.018 * 10^{0.036*(25-T)}\right)$$

This function increases steadily with decreasing temperature (T), until it reaches a maximum (0.826 * 12.09 = 9.99 mg N/L) at 16.6°C, below which it remains constant (Figure 3). The slightly higher maximum concentration is the result of the higher CMC/lowest GMAV ratio calculated when freshwater mussels are present (0.826) versus when freshwater mussels are absent (0.811).

Temperature Extrapolation of Chronic Toxicity

When freshwater mussels are present, the lowest GMCV is <0.3443 mg N/L for *Lampsilis* sp. (Table 5). The resulting CCC when mussels are present of 0.256 mg N/L is 25.6% lower than the lowest GMCV, as noted above. When freshwater mussels are absent, the lowest GMCV is <2.260 mg N/L for *Musculium transversum* (Table C). The resulting CCC when mussels are absent of 1.84 mg N/L is 18.6% lower than the lowest GMCV. In both cases, the most sensitive fish species is the early life stage of *Lepomis macrochirus* with a GMCV of 2.852 mg N/L (Table C). Because the most sensitive genera are invertebrates, regardless of whether freshwater mussels are included or excluded, the criterion will vary with temperature according to the invertebrate chronic temperature relationship, but cannot exceed the extrapolated ratio multiplied by the lowest fish GMCV.

When freshwater mussels are present, at pH=8, the CCC would be expressed as:

$$CCC = 0.744 * \left(0.3443 * 10^{0.028*(25-MAX(T,7))} \right)$$

This function increases steadily with decreasing temperature (T), until it reaches a maximum at 7°C, below which it remains constant (Figure 4). The rationale for the 7°C plateau in extrapolated invertebrate sensitivities was described in detail in the 1999 AWQC document. In summary, the assumption of invertebrate insensitivity to temperatures of 7°C and below is based on an interpretation of the empirical relationship between acute ammonia toxicity of invertebrates and temperature, first described by Arthur et al (1987), and reproduced in the 1999 document as Figure 6. Because the highest possible extrapolated CCC (0.817 mg N/L at 0-7°C and pH=8) is lower than the extrapolated value for the early life stage of the most sensitive fish species (0.744*2.852=2.12 mg N/L at pH=8), fish are not considered in the CCC temperature extrapolations when freshwater mussels are present (Figure 4).

When freshwater mussels are absent and fish ELS are absent, at pH=8, the CCC would be expressed as:

$$CCC = 0.814 * \left(2.260 * 10^{0.028*(25-MAX(T,7))}\right)$$

This function increases steadily with decreasing temperature (T), until it reaches a maximum at 7°C, below which it remains constant (Figure 4), following the same rationale for the 7°C plateau as described in the case with mussels present. As described in the 1999 document, when early life stages are absent, the ELS GMCV of 2.852 mg N/L for *Lepomis* would have been replaced by the 8.78 mg N/L GMCV for juvenile and adult *Lepomis*. Because the highest extrapolated CCC (5.87 mg N/L at 0-7°C and pH=8) is lower than the extrapolated value for the most sensitive juvenile or adult fish species (0.814*8.78=7.15 mg N/L at pH=8), juvenile and adult fish are not considered in the CCC temperature extrapolations when freshwater mussels are absent (Figure 4).

When freshwater mussels are absent and fish ELS are present, at pH=8, the CCC would be expressed as:

$$CCC = 0.814 * MIN\left(2.852, 2.260 * 10^{0.028*(25-T)}\right)$$

This function is analogous to the functions described in the two acute scenarios, and increases steadily with decreasing temperature (T), until it reaches a maximum (0.814 * 2.852 = 2.32 mg N/L) at 21.3°C, below which it remains constant (Figure 4).

THE NATIONAL CRITERIA FOR AMMONIA IN FRESH WATER

The available data for ammonia, evaluated using the procedures described in the Guidelines, indicate that, except possibly where an unusually sensitive species is important at a site, freshwater aquatic life should be protected if both of the following conditions are satisfied for the temperature, T, and pH of the waterbody:

1. The one-hour average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once every three years on the average, the CMC calculated using the following equations:

Where freshwater mussels are present:

$$CMC = 0.811 * \left(\frac{0.0489}{1 + 10^{7.204-pH}} + \frac{6.95}{1 + 10^{pH-7.204}}\right) * MIN\left(12.09, 3.539 * 10^{0.036*(25-T)}\right)$$

Or where freshwater mussels are absent:

$$CMC = 0.826 * \left(\frac{0.0489}{1 + 10^{7.204-pH}} + \frac{6.95}{1 + 10^{pH-7.204}}\right) * MIN\left(12.09, 6.018 * 10^{0.036*(25-T)}\right)$$

2A. The thirty-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once every three years on the average, the CCC (chronic criterion) calculated using the following equations:

Where freshwater mussels are present and fish early life stages are present or absent:

$$CCC = 0.744 * \left(\frac{0.0676}{1 + 10^{7.688 - pH}} + \frac{2.912}{1 + 10^{pH - 7.688}}\right) * \left(0.3443 * 10^{0.028 * (25 - MAX(T,7))}\right)$$

Or where freshwater mussels are absent and fish early lifte stages are absent:

$$CCC = 0.814 * \left(\frac{0.0676}{1 + 10^{7.688 - pH}} + \frac{2.912}{1 + 10^{pH - 7.688}}\right) * \left(2.260 * 10^{0.028 * (25 - MAX(T,7))}\right)$$

2B. The thirty-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once every three years on the average, the CCC (chronic criterion) calculated using the following equation.

When freshwater mussels are absent and fish early life stages are present:

$$CCC = 0.814 * \left(\frac{0.0676}{1 + 10^{7.688 - pH}} + \frac{2.912}{1 + 10^{pH - 7.688}}\right) * MIN\left(2.852, 2.260 * 10^{0.028 * (25 - T)}\right)$$

2C. In addition, the highest four-day average within the 30-day exceedence period should not exceed 2.5 times the CCC.

Several points should be noted concerning the updated acute and chronic criteria:

Acute:

1. Unlike in the 1999 AQWC document, the lowest GMAV when freshwater mussels are present or absent in this update is an invertebrate species; thus, the CMCs under both conditions are pH- **and** temperature-dependent.
2. Because the most sensitive genera are invertebrates, the criterion will vary with temperature according to the invertebrate acute temperature relationship, but cannot exceed 81.1% of the lowest fish GMAV (mussels present) or 82.6% of the lowest fish GMAV (mussels absent). The lowest seasonal GMAV for fish is 12.09 mg N/L for the salmonid *Prosopium williamsoni*, the mountain whitefish. Therefore, the CMC equals 81.1% (or 82.6%) times the lower of (a) the temperature adjusted lowest invertebrate GMAV, or (b) the lowest fish GMAV (Figure 3).
3. When a threatened or endangered species occurs at a site and sufficient data indicate that it is sensitive at concentrations below the CMC, it is appropriate to consider deriving a site-specific criterion.

Chronic:

1. The four lowest GMCVs are all “less than” values. The CCC might be lower if early life stages of the two freshwater mussel genera (*Lampsilis* and *Villosa*) are more sensitive than the juvenile life stages tested. The CCC might also be lower if a point estimate (e.g. EC20), rather than a “less than” value, could have been derived from the studies with the fingernail clam.
2. The laboratory data for some of the snail species, particularly non-pulmonates, which might be considered to have special ecological importance at some sites, indicate that these species could be affected at concentrations below the CCC when freshwater mussels are absent, but not when freshwater mussels are present. Other data indicate that these species might not be affected by such concentrations. At most sites the intermittency of exposures would probably reduce risk.
4. Likewise, some of the laboratory and field data for the fingernail clam also indicate that this species could be affected at concentrations below the CCC when freshwater mussels are absent, but not when freshwater mussels are present. Other data indicate that it would not be affected by such concentrations. Again, at most sites the intermittency of exposures would probably reduce risk.
5. The central tendency of the available chronic EC20s for salmonids (5.4 mg /L), even though not used directly in the calculation of the CCC, indicates that these species will be protected by

the CCC when freshwater mussels are present, and will probably be protected when freshwater mussels are absent, although the data suggest there might be important differences between strains of rainbow trout, and some tests indicated effects at concentrations slightly below the CCC.

6. All new chronic data added to this update of the 1999 AWQC for fish is from early life stage tests of the species (see new data for *Oncorhynchus clarki* Henshawi, *Esox lucius*, and *Cyprinus carpio* in Table 5); thus, the justification for the derivation of a CCC for fish early stages present and absent established in the 1999 AWQC document also applies in this document.
8. As above, when a threatened or endangered species occurs at a site and sufficient data indicate that it is sensitive at concentrations below the CCC, it is appropriate to consider deriving a site-specific criterion.
9. And, as previously explained in the 1999 AWQC document, the CCC is based on a 20 percent reduction in survival, growth, and/or reproduction, which is a risk management decision by EPA also retained for this document.

In addition to the above, the following general points also hold true for this document:

1. The Recalculation Procedure, the WER Procedure, and the Resident Species Procedure may be used to derive site-specific criteria for ammonia, but most WERs that have been determined for ammonia are close to 1.
2. The CMC, CCC, and chronic averaging period presented above supersede those presented in previous guidance on the aquatic life criterion for ammonia in fresh water. The 1998, 1999 and this update do not address or alter the past recommendation of a one-hour averaging period for the CMC or the past recommendation of a once-in-three years on the average allowable frequency for exceeding the CMC or CCC. Many issues concerning the implementation of aquatic life criteria are discussed in the "Technical Support Document for Water Quality based Toxics Control" (U.S. EPA 1991).
3. If concentrations in 95 percent of grab or 24-hour composite samples do not exceed the CCC, then the 30-day average concentrations are unlikely to exceed the CCC more than once in three years (Delos 1999). This assumes that concentrations are log normally distributed, with first-order log serial correlation coefficient between 24-hour composite samples approximately 0.86 - 0.94 (or less), and a log standard deviation of 0.5 - 0.8 (or less).

4. Finally, because the ammonia criteria are a function of both pH and temperature, calculation of the appropriate weighted average temperature or pH is complicated. For some purposes, calculation of an average pH and temperature can be avoided. For example, if samples are obtained from a receiving water over a period of time during which pH and/or temperature was not constant, the pH, temperature, and the concentration of total ammonia in each sample should be determined. For each sample, the criterion should be determined at the pH and temperature of the sample, and then the concentration of total ammonia nitrogen in the sample should be divided by the criterion to determine a quotient. The criterion is attained if the mean of the quotients is less than 1 over the duration of the averaging period.

The temperature and pH-dependent values for the CMC and CCC are provided in the tables below for a given scenario, i.e., freshwater mussels present or absent, fish early life stages present or absent. The same values are presented graphically for ease of understanding in Figures 3 (temperature- and pH-dependence of the CMC) and 4 (temperature- and pH-dependence of the CCC).

Available data indicate that freshwater mussels exhibit the same general response to ammonia at higher pH such that total ammonia EC50s decrease with increasing pH similar to the average relationship for other taxa as established in the 1999 AWQC document (Wang et al. 2008). For this update of the freshwater ammonia AWQC the relationship between the acute and chronic toxicity of ammonia to freshwater mussels and temperature is assumed to be similar to other invertebrate species, i.e., sensitivity to ammonia decreases at lower ambient water temperatures.

Temperature and pH-Dependent Values of the CMC (Acute Criterion): Mussels Present

CMC: Mussels Present, mg N/L

pH	Temperature, C									
	0	14	16	18	20	22	24	26	28	30
6.5	57.0	41.5	35.2	29.8	25.2	21.4	18.1	15.4	13.0	11.0
6.6	54.7	39.8	33.7	28.6	24.2	20.5	17.4	14.7	12.5	10.6
6.7	52.0	37.9	32.1	27.2	23.0	19.5	16.5	14.0	11.9	10.1
6.8	49.0	35.7	30.2	25.6	21.7	18.4	15.6	13.2	11.2	9.48
6.9	45.7	33.3	28.2	23.9	20.2	17.2	14.5	12.3	10.4	8.84
7.0	42.1	30.7	26.0	22.0	18.7	15.8	13.4	11.3	9.61	8.15
7.1	38.3	27.9	23.7	20.1	17.0	14.4	12.2	10.3	8.75	7.42
7.2	34.5	25.1	21.3	18.0	15.3	12.9	11.0	9.29	7.87	6.67
7.3	30.6	22.3	18.9	16.0	13.6	11.5	9.73	8.24	6.98	5.92
7.4	26.8	19.5	16.5	14.0	11.9	10.1	8.52	7.22	6.12	5.18
7.5	23.2	16.9	14.3	12.1	10.3	8.71	7.38	6.25	5.30	4.49
7.6	19.9	14.5	12.3	10.4	8.81	7.46	6.32	5.35	4.54	3.84
7.7	16.9	12.3	10.4	8.81	7.47	6.33	5.36	4.54	3.85	3.26
7.8	14.2	10.3	8.74	7.41	6.28	5.32	4.50	3.82	3.23	2.74
7.9	11.8	8.61	7.30	6.18	5.24	4.44	3.76	3.19	2.70	2.29
8.0	9.81	7.15	6.06	5.13	4.35	3.68	3.12	2.64	2.24	1.90
8.1	8.11	5.91	5.00	4.24	3.59	3.04	2.58	2.18	1.85	1.57
8.2	6.68	4.87	4.12	3.49	2.96	2.51	2.13	1.80	1.53	1.29
8.3	5.50	4.01	3.40	2.88	2.44	2.07	1.75	1.48	1.26	1.06
8.4	4.53	3.30	2.80	2.37	2.01	1.70	1.44	1.22	1.03	0.876
8.5	3.74	2.72	2.31	1.95	1.66	1.40	1.19	1.01	0.853	0.723
8.6	3.09	2.25	1.91	1.62	1.37	1.16	0.984	0.833	0.706	0.598
8.7	2.57	1.87	1.59	1.35	1.14	0.966	0.818	0.693	0.587	0.497
8.8	2.15	1.57	1.33	1.13	0.954	0.808	0.685	0.580	0.491	0.416
8.9	1.82	1.32	1.12	0.949	0.804	0.681	0.577	0.489	0.414	0.351
9.0	1.54	1.13	0.953	0.808	0.684	0.580	0.491	0.416	0.353	0.299

Temperature and pH-Dependent Values of the CMC (Acute Criterion): Mussels Absent

CMC: Mussels Absent, mg N/L										
pH	Temperature, C									
	0	14	16	18	20	22	24	26	28	30
6.5	58.0	58.0	58.0	58.0	43.7	37.0	31.4	26.6	22.5	19.1
6.6	55.7	55.7	55.7	55.7	41.9	35.5	30.1	25.5	21.6	18.3
6.7	53.0	53.0	53.0	53.0	39.9	33.8	28.6	24.3	20.6	17.4
6.8	49.9	49.9	49.9	49.9	37.6	31.9	27.0	22.9	19.4	16.4
6.9	46.5	46.5	46.5	46.5	35.1	29.7	25.2	21.3	18.1	15.3
7.0	42.9	42.9	42.9	42.9	32.3	27.4	23.2	19.7	16.7	14.1
7.1	39.1	39.1	39.1	39.1	29.4	24.9	21.1	17.9	15.2	12.8
7.2	35.1	35.1	35.1	35.1	26.4	22.4	19.0	16.1	13.6	11.5
7.3	31.2	31.2	31.2	31.2	23.5	19.9	16.8	14.3	12.1	10.2
7.4	27.3	27.3	27.3	27.3	20.6	17.4	14.8	12.5	10.6	8.98
7.5	23.6	23.6	23.6	23.6	17.8	15.1	12.8	10.8	9.18	7.77
7.6	20.2	20.2	20.2	20.2	15.3	12.9	10.9	9.27	7.86	6.66
7.7	17.2	17.2	17.2	17.2	12.9	11.0	9.28	7.86	6.66	5.64
7.8	14.4	14.4	14.4	14.4	10.9	9.21	7.80	6.61	5.60	4.74
7.9	12.0	12.0	12.0	12.0	9.07	7.69	6.51	5.52	4.67	3.96
8.0	9.99	9.99	9.99	9.99	7.53	6.38	5.40	4.58	3.88	3.29
8.1	8.26	8.26	8.26	8.26	6.22	5.27	4.47	3.78	3.21	2.72
8.2	6.81	6.81	6.81	6.81	5.13	4.34	3.68	3.12	2.64	2.24
8.3	5.60	5.60	5.60	5.60	4.22	3.58	3.03	2.57	2.18	1.84
8.4	4.61	4.61	4.61	4.61	3.48	2.95	2.50	2.11	1.79	1.52
8.5	3.81	3.81	3.81	3.81	2.87	2.43	2.06	1.74	1.48	1.25
8.6	3.15	3.15	3.15	3.15	2.37	2.01	1.70	1.44	1.22	1.04
8.7	2.62	2.62	2.62	2.62	1.97	1.67	1.42	1.20	1.02	0.862
8.8	2.19	2.19	2.19	2.19	1.65	1.40	1.19	1.00	0.851	0.721
8.9	1.85	1.85	1.85	1.85	1.39	1.18	1.00	0.847	0.718	0.608
9.0	1.57	1.57	1.57	1.57	1.19	1.00	0.851	0.721	0.611	0.517

Temperature and pH-Dependent Values of the CCC (Chronic Criterion): Mussels Present

CCC: Mussels Present, mg N/L										
pH	Temperature, C									
	0	14	16	18	20	22	24	26	28	30
6.5	2.24	1.43	1.25	1.10	0.968	0.851	0.748	0.658	0.578	0.508
6.6	2.21	1.40	1.23	1.09	0.954	0.838	0.737	0.648	0.569	0.501
6.7	2.16	1.38	1.21	1.06	0.936	0.823	0.723	0.636	0.559	0.491
6.8	2.11	1.35	1.18	1.04	0.914	0.804	0.707	0.621	0.546	0.480
6.9	2.05	1.31	1.15	1.01	0.889	0.781	0.687	0.604	0.531	0.466
7.0	1.98	1.26	1.11	0.977	0.858	0.755	0.663	0.583	0.513	0.451
7.1	1.90	1.21	1.07	0.937	0.823	0.724	0.636	0.559	0.492	0.432
7.2	1.81	1.15	1.01	0.891	0.783	0.688	0.605	0.532	0.467	0.411
7.3	1.71	1.09	0.955	0.839	0.738	0.648	0.570	0.501	0.440	0.387
7.4	1.59	1.01	0.890	0.782	0.688	0.604	0.531	0.467	0.411	0.361
7.5	1.47	0.933	0.820	0.721	0.634	0.557	0.490	0.431	0.379	0.333
7.6	1.34	0.850	0.747	0.657	0.578	0.508	0.446	0.392	0.345	0.303
7.7	1.20	0.765	0.673	0.591	0.520	0.457	0.402	0.353	0.310	0.273
7.8	1.07	0.681	0.598	0.526	0.462	0.406	0.357	0.314	0.276	0.243
7.9	0.940	0.598	0.526	0.462	0.406	0.357	0.314	0.276	0.243	0.213
8.0	0.817	0.521	0.458	0.402	0.354	0.311	0.273	0.240	0.211	0.186
8.1	0.704	0.449	0.394	0.347	0.305	0.268	0.235	0.207	0.182	0.160
8.2	0.602	0.384	0.337	0.296	0.261	0.229	0.201	0.177	0.156	0.137
8.3	0.512	0.326	0.287	0.252	0.221	0.195	0.171	0.150	0.132	0.116
8.4	0.433	0.276	0.243	0.213	0.187	0.165	0.145	0.127	0.112	0.0983
8.5	0.366	0.233	0.205	0.180	0.158	0.139	0.122	0.107	0.0945	0.0831
8.6	0.309	0.197	0.173	0.152	0.134	0.117	0.103	0.0908	0.0798	0.0701
8.7	0.261	0.166	0.146	0.129	0.113	0.0994	0.0874	0.0768	0.0675	0.0593
8.8	0.222	0.141	0.124	0.109	0.0960	0.0844	0.0742	0.0652	0.0573	0.0504
8.9	0.190	0.121	0.106	0.0934	0.0821	0.0721	0.0634	0.0557	0.0490	0.0431
9.0	0.163	0.104	0.0914	0.0804	0.0707	0.0621	0.0546	0.0480	0.0422	0.0371

Temperature and pH-Dependent Values of the CCC (Chronic Criterion): Mussels Absent and Fish Early Life Stages Absent

CCC: Mussels Absent and Fish Early Life Stages Absent, mg N/L

pH	Temperature, C									
	0	14	16	18	20	22	24	26	28	30
6.5	16.1	10.2	9.00	7.91	6.96	6.11	5.37	4.72	4.15	3.65
6.6	15.8	10.1	8.87	7.79	6.85	6.02	5.29	4.65	4.09	3.60
6.7	15.5	9.90	8.70	7.65	6.72	5.91	5.19	4.57	4.01	3.53
6.8	15.2	9.67	8.50	7.47	6.57	5.77	5.08	4.46	3.92	3.45
6.9	14.8	9.40	8.26	7.26	6.38	5.61	4.93	4.34	3.81	3.35
7.0	14.3	9.08	7.98	7.02	6.17	5.42	4.76	4.19	3.68	3.24
7.1	13.7	8.71	7.65	6.73	5.91	5.20	4.57	4.02	3.53	3.10
7.2	13.0	8.28	7.28	6.40	5.62	4.94	4.35	3.82	3.36	2.95
7.3	12.2	7.80	6.86	6.03	5.30	4.66	4.09	3.60	3.16	2.78
7.4	11.4	7.27	6.39	5.62	4.94	4.34	3.82	3.36	2.95	2.59
7.5	10.5	6.70	5.89	5.18	4.55	4.00	3.52	3.09	2.72	2.39
7.6	9.59	6.11	5.37	4.72	4.15	3.65	3.21	2.82	2.48	2.18
7.7	8.63	5.50	4.83	4.25	3.73	3.28	2.89	2.54	2.23	1.96
7.8	7.68	4.89	4.30	3.78	3.32	2.92	2.57	2.26	1.98	1.74
7.9	6.75	4.30	3.78	3.32	2.92	2.57	2.26	1.98	1.74	1.53
8.0	5.87	3.74	3.29	2.89	2.54	2.23	1.96	1.72	1.52	1.33
8.1	5.06	3.22	2.83	2.49	2.19	1.92	1.69	1.49	1.31	1.15
8.2	4.33	2.76	2.42	2.13	1.87	1.64	1.45	1.27	1.12	0.982
8.3	3.68	2.34	2.06	1.81	1.59	1.40	1.23	1.08	0.949	0.835
8.4	3.11	1.98	1.74	1.53	1.35	1.18	1.04	0.914	0.804	0.706
8.5	2.63	1.67	1.47	1.29	1.14	0.999	0.878	0.772	0.679	0.597
8.6	2.22	1.41	1.24	1.09	0.960	0.844	0.742	0.652	0.573	0.504
8.7	1.88	1.20	1.05	0.924	0.812	0.714	0.628	0.552	0.485	0.426
8.8	1.60	1.02	0.893	0.785	0.690	0.606	0.533	0.469	0.412	0.362
8.9	1.36	0.868	0.763	0.671	0.589	0.518	0.455	0.400	0.352	0.309
9.0	1.17	0.747	0.657	0.577	0.508	0.446	0.392	0.345	0.303	0.266

Temperature and pH-Dependent Values of the CCC (Chronic Criterion): Mussels Absent and Fish Early Life Stages Present

CCC: Mussels Absent and Fish Early Life Stages Present, mg N/L										
pH	Temperature, C									
	0	14	16	18	20	22	24	26	28	30
6.5	6.36	6.36	6.36	6.36	6.36	6.11	5.37	4.72	4.15	3.65
6.6	6.26	6.26	6.26	6.26	6.26	6.02	5.29	4.65	4.09	3.60
6.7	6.15	6.15	6.15	6.15	6.15	5.91	5.19	4.57	4.01	3.53
6.8	6.00	6.00	6.00	6.00	6.00	5.77	5.08	4.46	3.92	3.45
6.9	5.84	5.84	5.84	5.84	5.84	5.61	4.93	4.34	3.81	3.35
7.0	5.64	5.64	5.64	5.64	5.64	5.42	4.76	4.19	3.68	3.24
7.1	5.41	5.41	5.41	5.41	5.41	5.20	4.57	4.02	3.53	3.10
7.2	5.14	5.14	5.14	5.14	5.14	4.94	4.35	3.82	3.36	2.95
7.3	4.84	4.84	4.84	4.84	4.84	4.66	4.09	3.60	3.16	2.78
7.4	4.52	4.52	4.52	4.52	4.52	4.34	3.82	3.36	2.95	2.59
7.5	4.16	4.16	4.16	4.16	4.16	4.00	3.52	3.09	2.72	2.39
7.6	3.79	3.79	3.79	3.79	3.79	3.65	3.21	2.82	2.48	2.18
7.7	3.41	3.41	3.41	3.41	3.41	3.28	2.89	2.54	2.23	1.96
7.8	3.04	3.04	3.04	3.04	3.04	2.92	2.57	2.26	1.98	1.74
7.9	2.67	2.67	2.67	2.67	2.67	2.57	2.26	1.98	1.74	1.53
8.0	2.32	2.32	2.32	2.32	2.32	2.23	1.96	1.72	1.52	1.33
8.1	2.00	2.00	2.00	2.00	2.00	1.92	1.69	1.49	1.31	1.15
8.2	1.71	1.71	1.71	1.71	1.71	1.64	1.45	1.27	1.12	0.982
8.3	1.45	1.45	1.45	1.45	1.45	1.40	1.23	1.08	0.949	0.835
8.4	1.23	1.23	1.23	1.23	1.23	1.18	1.04	0.914	0.804	0.706
8.5	1.04	1.04	1.04	1.04	1.04	0.999	0.878	0.772	0.679	0.597
8.6	0.878	0.878	0.878	0.878	0.878	0.844	0.742	0.652	0.573	0.504
8.7	0.742	0.742	0.742	0.742	0.742	0.714	0.628	0.552	0.485	0.426
8.8	0.631	0.631	0.631	0.631	0.631	0.606	0.533	0.469	0.412	0.362
8.9	0.539	0.539	0.539	0.539	0.539	0.518	0.455	0.400	0.352	0.309
9.0	0.464	0.464	0.464	0.464	0.464	0.446	0.392	0.345	0.303	0.266

UNUSED DATA

For this criteria update document, EPA considered those data referenced in the document that met the test quality requirements described in the Guidelines (see Stephan et al. 1985). Some of the data referenced in the document, however, did not meet these basic QA/QC requirements. In such cases, EPA further scrutinized those studies where either: (1) the study included tests with a species associated with one of the four most sensitive GMAVs or GMCVs used to derive the criterion; (2) the study included test with a freshwater mussel species that could have been used to derive the criterion, i.e., was a test with a freshwater mussel species with a pH and temperature normalized EC50 less than 6.018 mg N/L or a normalized CV less than 2.852 mg N/L; or (3) the study included tests with a species associated with a GMAV or GMCV within a factor of approximately three of the fourth ranked most sensitive GMAV or GMCV. For example, all studies with species associated with genera in the acute dataset with freshwater mussels present that were within three times the GMAV of 6.018 mg N/L for *Corbicula fluminea*, or 18 mg N/L (rounded to 20 mg N/L), were further scrutinized: thus including all species within the range of the GMAVs for the genera *Lasmigona* through *Micropterus* in Table 3. EPA undertook this additional review of the tests in those cases where the outcome of the review could actually lead to a different decision regarding the protectiveness of the criteria. For each study that was potentially influential, but did not pass the additional review, the study was not used in the determination and the rationale for its exclusion is detailed in Tables 9 (acute studies) and 10 (chronic studies). A list of all other studies considered but “screened out” from consideration or use in deriving the criteria is provided in Appendix G with a code (and in some cases comments) indicating the reason for exclusion.

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Figure 1. Ranked Freshwater Genus Mean Acute Values (GMAVs) with Criterion Maximum Concentrations (CMCs).

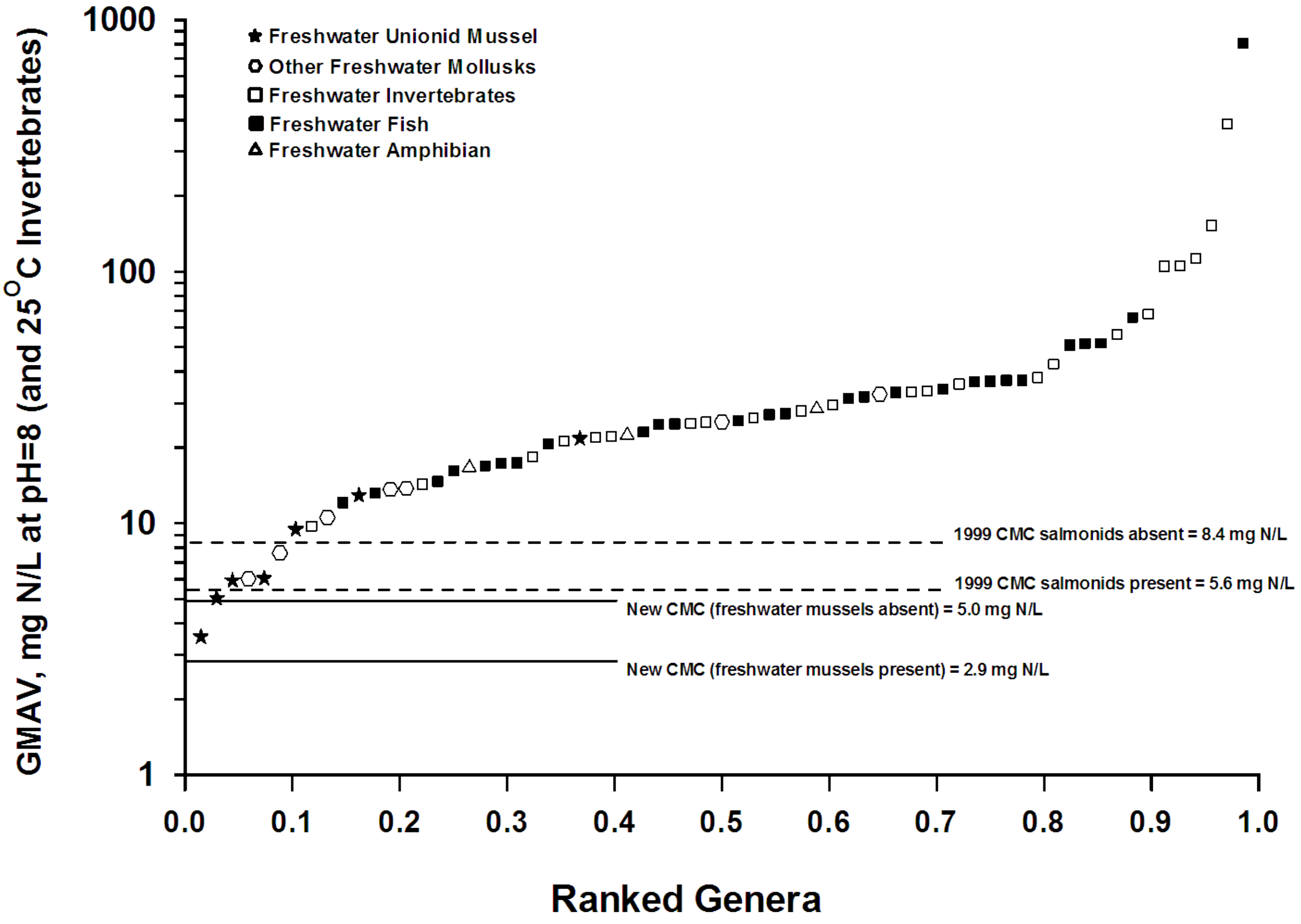


Figure 2. Ranked Freshwater Genus Mean Chronic Values (GMCVs) with Criterion Continuous Concentrations (CCCs).

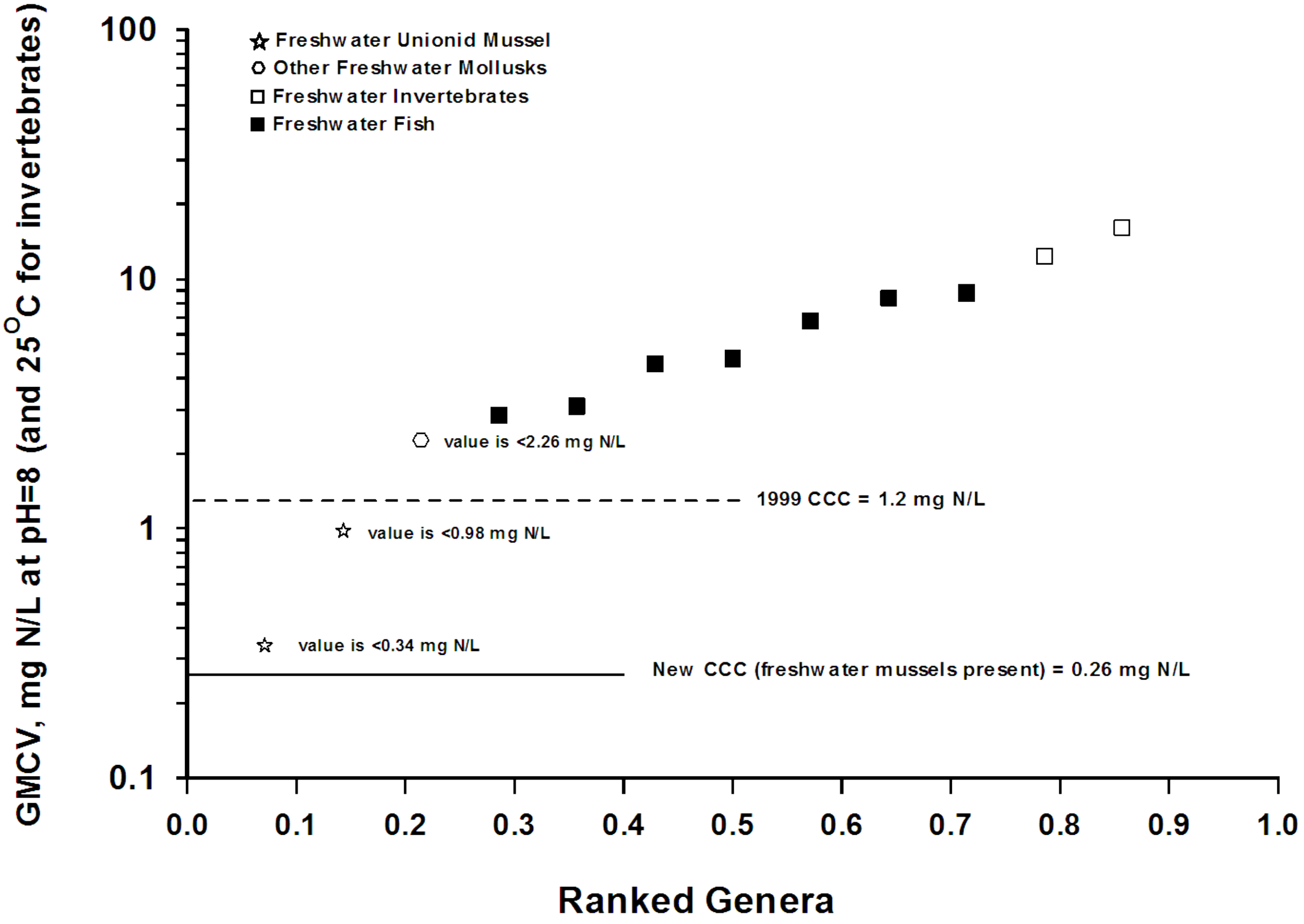
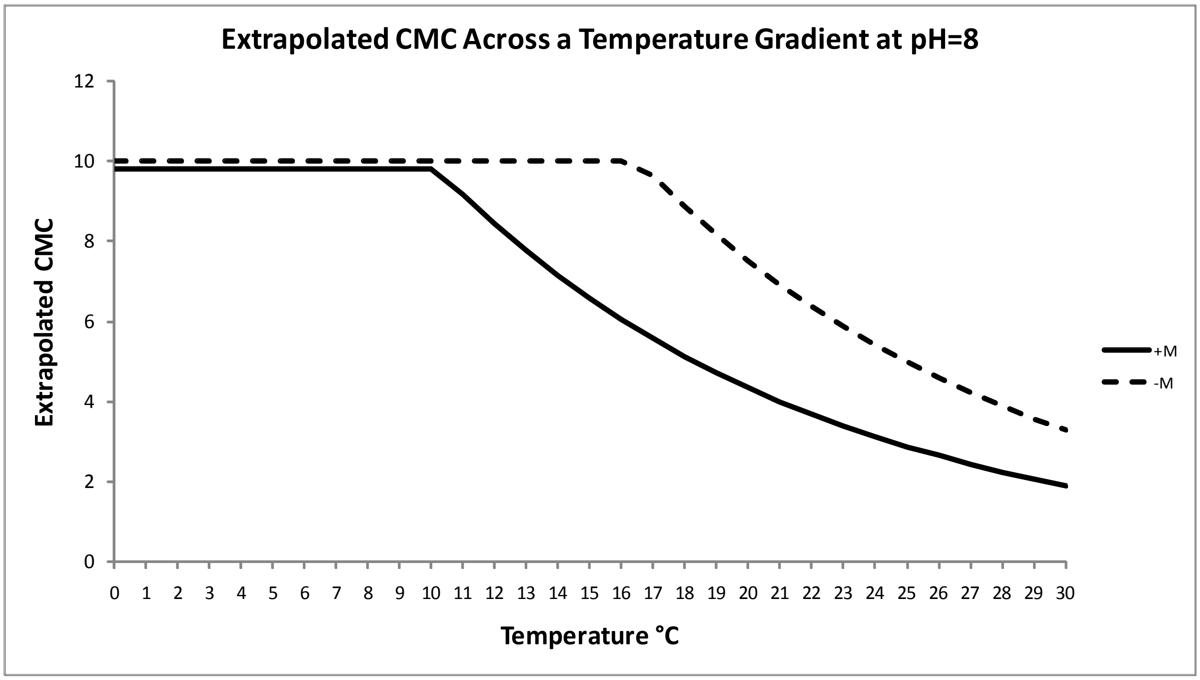
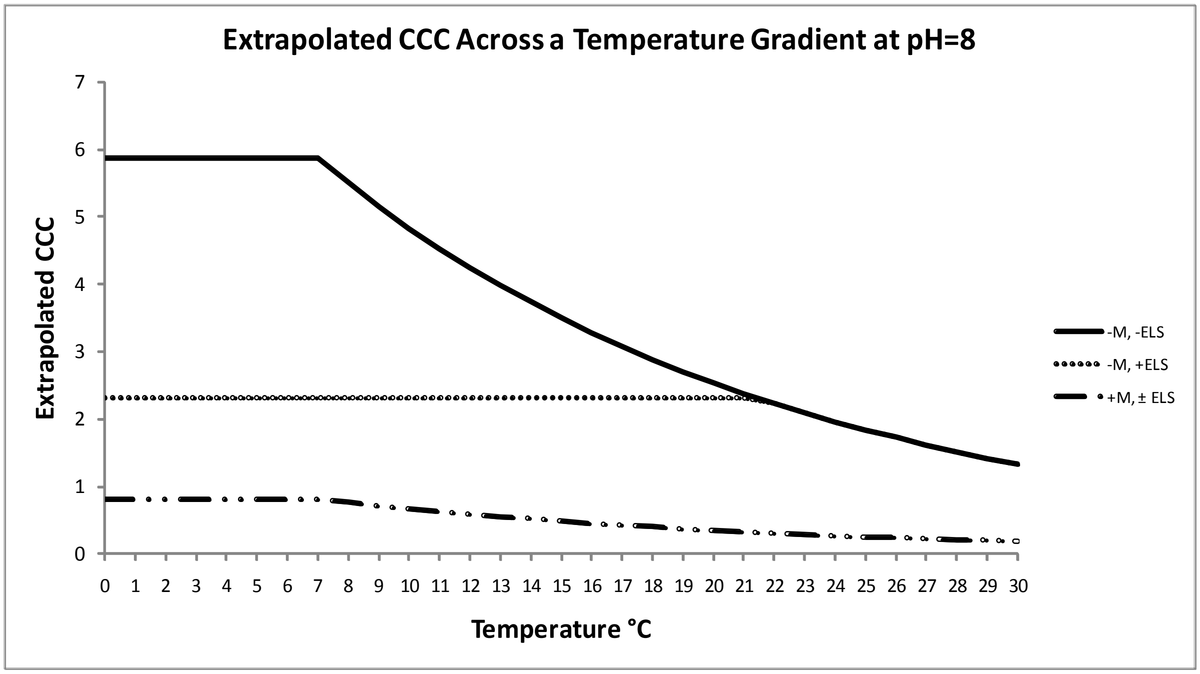


Figure 3. CMC Extrapolated Across a Temperature Gradient at pH=8.



† +M = Mussels Present, -M = Mussels Absent

Figure 4. CCC Extrapolated Across a Temperature Gradient at pH=8.



† -M, -ELS = Mussels Absent, Fish ELS Absent; -M, +ELS = Mussels Absent, Fish ELS Present; +M, ±ELS = Mussels Present, Fish ELS Present or Absent

Table 1. Acute Toxicity of Ammonia to Aquatic Invertebrates and Vertebrates

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Freshwater Invertebrates										
Flatworm, *Dendrocoelum lacteum*	Ammonium chloride	4 d	S,U	8.2	18	22.37	**18.37**	18.37	18.37	Stammer 1953
Oligochaete, worm, *Lumbriculus variegatus*		4 d	S,M	7.56	23	286.0	112.21			Besser et al. 1998
Oligochaete, worm, *Lumbriculus variegatus*		4 d	S,M	6.69	23	302.0	47.86			Besser et al. 1998
Oligochaete, worm (10-25 mm), *Lumbriculus variegatus*	Ammonium chloride	4 d	R,M	8.2	15	13.66	8.75			Hickey and Vickers 1994
Oligochaete, worm (adult), *Lumbriculus variegatus*		4 d	F,M	6.5	25	100.0	**17.21**			Schubauer-Berigan et al. 1995
Oligochaete, worm (adult), *Lumbriculus variegatus*		4 d	F,M	6.5	25	200.0	**34.42**			Schubauer-Berigan et al. 1995
Oligochaete, worm (adult), *Lumbriculus variegatus*		4 d	F,M	8.1	25	34.00	**41.12**			Schubauer-Berigan et al. 1995
Oligochaete, worm (adult), *Lumbriculus variegatus*		4 d	F,M	8.1	25	43.50	**52.61**	33.64	33.64	Schubauer-Berigan et al. 1995
Tubificid worm (30-40 mm), *Limnodrilus hoffmeisteri*		4 d	F,M	7.9	11.5	96.62	**26.17**	26.17	26.17	Williams et al. 1986
Tubificid worm, Oligochaete, *Tubifex tubifex*	Ammonium chloride	4 d	S,U	8.2	12	66.67	**33.30**	33.30	33.30	Stammer 1953
Snail (3.6 mm), *Potamopyrgus antipodarum*	Ammonium chloride	4 d	R,U	8.3	20.4	26.77	**32.59**			Alonso and Camargo 2003
Snail (2-3 mm), *Potamopyrgus antipodarum*	Ammonium chloride	4 d	R,M	7.6	15	23.67	**5.098**			Hickey and Vickers 1994
Snail (2-3 mm), *Potamopyrgus antipodarum*	Ammonium chloride	4 d	R,M	8.2	20	4.727	**4.583**			Hickey and Vickers 1994
Snail (2-3 mm), *Potamopyrgus antipodarum*	Ammonium chloride	4 d	R,M	8.2	25	4.081	**5.988**			Hickey and Vickers 1994
Snail (2-3 mm), *Potamopyrgus antipodarum*	Ammonium chloride	4 d	R,M	8.2	15	8.711	**5.579**	7.605	7.605	Hickey and Vickers 1994

Table 1. (continued)

Species	**Chemical Name**	**Duration**	**Methods**	**pH**	**Temp (˚C)**	**Total Ammonia (mg N/L)**	**Total Ammonia[a] (mg N/L) at pH=8 and 25°C**	**SMAV (mg N/L)**	**GMAV (mg N/L)**	**Reference**
Snail (adult), *Pleurocera unciale*	Ammonium chloride	4 d	R,M	8.1	22	11.18	**10.54**	10.54	10.54	Goudreau et al. 1993
Great pond snail (25-30 mm), *Lymnaea stagnalis*		4 d	F,M	7.9	11.5	50.33	**13.63**	13.63	13.63	Williams et al. 1986
Ramshorn snail, *Helisoma trivolvis*	Ammonium chloride	4 d	F,M	7.9	22	47.73	**30.87**			Arthur et al. 1987
Ramshorn snail, *Helisoma trivolvis*	Ammonium chloride	4 d	F,M	8.2	12.9	63.73	**34.30**	32.54	32.54	Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8	4	114.9	**20.15**			Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8.2	5.5	85.13	**24.81**			Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8.1	12.1	76.29	**31.67**			Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8.2	12.8	50.25	**26.82**			Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8	13.3	62.39	**23.64**			Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8	24.9	26.33	**26.10**	25.29	25.29	Arthur et al. 1987
Pleasantshell (juvenile), *Actinonaias pectorosa*	Ammonium chloride	4 d	S,M	7.90	25	14.06	**11.66**			Keller 2000
Pleasantshell (juvenile), *Actinonaias pectorosa*	Ammonium chloride	4 d	S,M	7.95	25	14.08	**12.81**	12.22	12.22	Keller 2000
Oyster mussel, *Epioblasma capsaeformis*	Ammonium chloride	4 d	S,M	8.3	20	5.700	**6.712**			Ingersoll 2004
Oyster mussel (Newly-transformed juveniles), *Epioblasma capsaeformis*	Ammonium chloride	4 d	R,M	8.3	20	4.610	**5.430**	6.037	6.037	Wang et al. 2007b
Pink mucket (2 mo old juveniles), *Lampsilis abrupta*	Ammonium chloride	4 d	R,M	8.3	20	1.860	**2.191**	2.191		Wang et al. 2007b

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia^a (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Plain pocketbook (juvenile), *Lampsilis cardium*	Ammonium chloride	4 d	S,M	8.2	20.5	23.50	23.75			Newton et al. 2003
Plain pocketbook (juvenile), *Lampsilis cardium*	Ammonium chloride	4 d	S,M	8.2	21.2	23.70	25.38			Newton et al. 2003
Plain pocketbook (1-2 d old juvenile), *Lampsilis cardium*	Ammonium chloride	4 d	F,M	7.6	21.2	23.10	**8.101**			Newton and Bartsch 2007
Plain pocketbook (1-2 d old juvenile), *Lampsilis cardium*	Ammonium chloride	4 d	F,M	7.1	21.2	38.90	**7.298**	7.689		Newton and Bartsch 2007
Wavy-rayed lampmussel (6-d juvenile), *Lampsilis fasciola*	Ammonium chloride	4 d	S,M	8.3	20	7.400	**8.714**			Ingersoll 2004
Wavy-rayed lampmussel (juvenile), *Lampsilis fasciola*	Ammonium chloride	4 d	R,M	7.83	12.6	14.90	**3.893**			Mummert et al. 2003
Wavy-rayed lampmussel (Newly-transformed juveniles), *Lampsilis fasciola*	Ammonium chloride	4 d	R,M	8.3	20	5.987	**7.049**	6.207		Wang et al. 2007b
Higgin's eye (1-2 d old juvenile), *Lampsilis higginsii*	Ammonium chloride	4 d	F,M	7.6	21.2	19.50	**6.860**			Newton and Bartsch 2007
Higgin's eye (1-2 d old juvenile), *Lampsilis higginsii*	Ammonium chloride	4 d	F,M	7.1	21.2	31.70	**5.692**	6.249		Newton and Bartsch 2007
Neosho mucket (4-d juvenile), *Lampsilis rafinesqueana*	Ammonium chloride	4 d	S,M	8.3	20	11.00	**12.95**			Ingersoll 2004
Neosho mucket (Newly-transformed juveniles), *Lampsilis rafinesqueana*	Ammonium chloride	4 d	R,M	8.3	20	8.900	**10.48**	11.65		Wang et al. 2007b
Fatmucket (Newly-transformed juveniles), *Lampsilis siliquoidea*	Ammonium chloride	4 d	R,M	8.3	20	8.090	9.526			Wang et al. 2007b

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Fatmucket (juvenile), *Lampsilis siliquoidea*	Ammonium chloride	4 d	S,M	8.3	24	1.275	2.092			Myers-Kinzie 1998
Fatmucket (2 mo old juveniles), *Lampsilis siliquoidea*	Ammonium chloride	4 d	R,M	8.3	20	3.964	4.668			Wang et al. 2007b
Fatmucket (10 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	7.6	20	11.00	**3.586**			Wang et al. 2008
Fatmucket (10 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	8.1	20	5.200	**4.155**			Wang et al. 2008
Fatmucket (10 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	8.5	20	3.400	**5.893**			Wang et al. 2008
Fatmucket (10 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	9	20	0.9600	**4.026**			Wang et al. 2008
Fatmucket (10 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	6.6	20	88.00	**10.43**			Wang et al. 2008
Fatmucket (10 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	8.1	20	11.00	**8.789**	5.646	5.919	Wang et al. 2008
Green floater (juvenile), *Lasmigona subviridus*	Ammonium chloride	4 d	R,M	7.73	24	6.613	**3.728**			Black 2001
Green floater (juvenile), *Lasmigona subviridus*	Ammonium chloride	4 d	R,M	7.92	24.8	3.969	**3.360**	3.539	3.539	Black 2001
Giant floater mussel (adult), *Pyganodon grandis*	Ammonium chloride	4 d	S,M	8	25	18.84	**18.84**			Scheller 1997
Giant floater mussel (adult), *Pyganodon grandis*	Ammonium chloride	4 d	S,M	8	25	25.13	**25.13**	21.76	21.76	Scheller 1997
Pondshell mussel (8-day old juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	7.8	24	14.29	**9.104**			Wade et al. 1992
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	8.16	25	5.254	**7.134**			Black 2001
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	8.17	25	5.781	**8.003**			Black 2001

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	8.29	25	8.845	**15.46**			Black 2001
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	8	25.1	2.734	**2.755**			Black 2001
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	S,M	7.9	24	8.235	**6.287**			Keller 2000
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	S,M	8.35	25	3.269	**6.422**			Keller2000
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	S,M	7.9	25	9.355	**7.760**	7.164	7.164	Keller2000
Rainbow mussel (Newly-transformed juveniles), *Villosa iris*	Ammonium chloride	4 d	R,M	7.3	12.5	20.60	**2.343**			Mummert et al. 2003
Rainbow mussel (Newly-transformed juveniles), *Villosa iris*	Ammonium chloride	4 d	R,M	8.3	20	5.100	**6.002**			Wang et al. 2007b
Rainbow mussel (juvenile), *Villosa iris*	Ammonium chloride	4 d	S,M	8.3	20	3.000	**3.533**			Ingersoll 2004
Rainbow mussel (juvenile), *Villosa iris*	Ammonium chloride	4 d	S,M	8	25	7.070	**7.070**			Scheller 1997
Rainbow mussel (juvenile), *Villosa iris*	Ammonium chloride	4 d	S,M	8	25	7.810	**7.810**			Scheller 1997
Rainbow mussel (2 mo old juveniles), *Villosa iris*	Ammonium chloride	4 d	R,M	8.3	20	2.427	**2.858**			Wang et al. 2007b
Rainbow mussel (2 mo old juveniles), *Villosa iris*	Ammonium chloride	4 d	R,M	8.3	20	8.899	**10.48**	5.036	5.036	Wang et al. 2007b
Asian clam (juv., 1wk), *Corbicula fluminea*	Ammonium chloride	4 d	S,M	8	25	1.000	1.000			Scheller 1997
Asian clam (juv., 1wk), *Corbicula fluminea*	Ammonium chloride	4 d	S,M	8	25	1.780	1.780			Scheller 1997

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Asian clam (juv., <48 h), *Corbicula fluminea*	Ammonium chloride	4 d	S,M	8	25	2.250	2.250			Scheller 1997
Asiatic clam (12.0-25.0 mm SL), *Corbicula fluminea*	Ammonium chloride	4.1 d	F,M	8.05	29.4	6.316	**9.996**			Belanger et al. 1991
Asiatic clam (5.0-8.5 mm SL), *Corbicula fluminea*	Ammonium chloride	4.2 d	F,M	8.05	30.3	2.125	**3.623**	6.018	6.018	Belanger et al. 1991
Long fingernail clam, *Musculium transversum*	Ammonium chloride	4 d	F,M	8.1	14.6	32.83	**16.76**			Arthur et al. 1987
Long fingernail clam, *Musculium transversum*	Ammonium chloride	4 d	F,M	8.2	5.4	38.18	**11.03**			Arthur et al. 1987
Long fingernail clam, *Musculium transversum*	Ammonium chloride	4 d	F,M	8.6	20.5	6.429	**14.03**	13.74	13.74	Arthur et al. 1987
Water flea, *Ceriodaphnia acanthina*	Ammonium chloride	2 d	F,M	7.06	24	104.8	**23.73**	23.73		Mount 1982
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.08	24.75	15.60	**17.61**			Andersen and Buckley 1998
Water flea, *Ceriodaphnia dubia*	Ammonium hydroxide	2 d	R,M	8.4	26.4	7.412	**18.01**			Cowgill and Milazzo 1991
Water flea, *Ceriodaphnia dubia*	Ammonium sulfate	2 d	R,NR	7.4	23	48.59	**15.06**			Manning et al. 1996
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	R,M	7.8	25	33.98	**23.52**			Nimmo et al. 1989
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	R,M	8.2	7	16.65	**5.494**			Nimmo et al. 1989
Water flea (<24hrs), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.02	24.8	21.265	**21.71**			Andersen and Buckley 1998
Water flea (<24hrs), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	7.5	25	47.05	**19.88**			Bailey et al. 2001
Water flea (<24hrs), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	7.5	25	56.84	**24.01**			Bailey et al. 2001
Water flea (<24hrs), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.16	22	24.77	**26.23**			Black 2001

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Water flea (<24hrs), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.4	23	28.06	**51.45**			Black 2001
Water flea (<24hrs), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.4	23	32.63	**59.83**			Black 2001
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	7.85	23	28.65	**18.38**			Sarda 1994
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	7.85	23	28.77	**18.45**			Sarda 1994
Water flea (<24hrs), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8	25	14.52	**14.52**	20.64	22.13	Scheller 1997
Water flea (<24 hrs), *Chydorus sphaericus*	Ammonium chloride	4 d	S,M	8	20	37.88	**25.01**	25.01	25.01	Dekker et al. 2006
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.5	20	26.34	**45.66**			Gersich and Hopkins 1986
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.92	21	9.463	**5.792**			Gulyas and Fleit 1990
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.2	25.0	20.71	**30.38**			Parkhurst et al. 1979,1981
Water flea, *Daphnia magna*	Ammonium chloride	2 d	R,U	8.34	19.7	51.92	**64.46**			Reinbold and Pescitelli 1982a
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.07	19.6	51.09	**37.28**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.51	20.1	48.32	**13.80**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.53	20.1	55.41	**16.32**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.50	20.3	43.52	**12.46**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.40	20.6	42.31	**10.75**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.09	20.9	41.51	**35.06**			Russo et al. 1985

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.95	22	51.30	**36.40**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.15	22	37.44	**38.88**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.04	22.8	38.70	**34.77**	24.25		Russo et al. 1985
Water flea, *Daphnia pulicaria*	Ammonium chloride	2 d	F,M	8.05	14	34.50	**15.23**	15.23	19.22	DeGraeve et al. 1980
Water flea (adult), *Simocephalus vetulus*	Ammonium chloride	2 d	F,M	8.3	17	31.58	**29.00**			Arthur et al. 1987
Water flea (adult), *Simocephalus vetulus*	Ammonium chloride	2 d	F,M	8.1	20.4	21.36	**17.64**			Arthur et al. 1987
Water flea, *Simocephalus vetulus*	Ammonium chloride	2 d	F,M	7.25	24.5	83.51	**24.15**			Mount 1982
Water flea, *Simocephalus vetulus*	Ammonium chloride	2 d	F,M	7.06	24	83.51	**18.90**	21.98	21.98	Mount 1982
Aquatic sowbug, *Asellus racovitzai*	Ammonium chloride	4 d	F,M	7.8	22	148.8	**80.34**			Arthur et al. 1987
Aquatic sowbug (adult), *Asellus racovitzai*	Ammonium chloride	4 d	F,M	8	4	357.8	**62.72**			Arthur et al. 1987
Aquatic sowbug, *Asellus racovitzai*	Ammonium chloride	d	F,M			176.0	**41.87**	59.53	59.53	Thurston et al. 1983
Amphipod (4-6 mm), *Crangonyx pseudogracilis*	Ammonium chloride	4 d	S,U	7.5	12	43.36	6.24			Prenter et al. 2004
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8	4	199.5	**34.97**			Arthur et al. 1987
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8	12.1	216.0	**74.09**			Arthur et al. 1987
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8	13.3	115.3	**43.70**			Arthur et al. 1987
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8	24.9	25.10	**24.88**			Arthur et al. 1987

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8.2	13	81.60	**44.28**	41.61		Arthur et al. 1987
Amphipod (13 d), *Crangonyx sp.*	Ammonium chloride	4 d	F,M	8	12	79.23	**26.96**			Diamond et al. 1993
Amphipod (8-42 d), *Crangonyx sp.*	Ammonium chloride	4 d	F,M	8	20	19.83	**13.09**	18.79	27.96	Diamond et al. 1993
Crayfish, *Orconectes immunis*	Ammonium chloride	4 d	F,M	7.9	17.1	488.1	**210.3**			Arthur et al. 1987
Crayfish (adult), *Orconectes immunis*	Ammonium chloride	4 d	F,M	8.2	4.6	999.4	**270.3**	238.4		Arthur et al. 1987
Crayfish (2.78 cm), *Orconectes nais*	Ammonium chloride	4 d	F,M	8.3	26.5	23.15	**46.73**	46.73	105.6	Evans 1979
Crayfish (Adult Intermoult), *Pacifastacus leniusculus*	Ammonium chloride	2 d	F,M	8.2	15	88.20	**56.49**	56.49	56.49	Harris et al. 2001
Red swamp crayfish (2.1 cm), *Procambarus clarkii*	Ammonium chloride	4 d	F,M	8	20	26.08	**17.22**			Diamond et al. 1993
Red swamp crayfish (<2.5 cm), *Procambarus clarkii*	Ammonium chloride	4 d	F,M	8	12	76.92	**26.17**	21.23	21.23	Diamond et al. 1993
Chinese mitten crab (juvenile), *Eriocheir sinensis*	Ammonium chloride	4 d	R,M	7.81	22	31.60	**14.30**	14.30	14.30	Zhao et al. 1997
Mayfly, *Callibaetis skokianus*	Ammonium chloride	4 d	F,M	7.7	10.8	263.6	**47.26**			Arthur et al. 1987
Mayfly, *Callibaetis skokianus*	Ammonium chloride	4 d	F,M	7.9	13.3	211.7	**66.56**	56.09		Arthur et al. 1987
Mayfly (middle to late instar), *Callibaetis sp.*	Ammonium chloride	4 d	F,M	7.81	11.9	107.8	**25.64**	25.64	37.92	Thurston et al. 1984b
Mayfly (middle to late instar), *Drunella grandis*	Ammonium chloride	4 d	F,M	7.84	12.8	259.1	**70.07**			Thurston et al. 1984b
Mayfly (middle to late instar), *Drunella grandis*	Ammonium chloride	4 d	F,M	7.84	13.2	195.6	**54.69**			Thurston et al. 1984b
Mayfly (middle to late instar), *Drunella grandis*	Ammonium chloride	4 d	F,M	7.85	12	319.0	**82.22**	68.05	68.05	Thurston et al. 1984b

Table 1. (continued)

Species	**Chemical Name**	**Duration**	**Methods**	**pH**	**Temp (˚C)**	**Total Ammonia (mg N/L)**	**Total Ammonia[a] (mg N/L) at pH=8 and 25°C**	**SMAV (mg N/L)**	**GMAV (mg N/L)**	**Reference**
Dragonfly (< 233 d), *Pachydiplax longipennis*	Ammonium chloride	4 d	F,M	8	12	76.92	**26.17**			Diamond et al. 1993
Dragonfly (<140 d), *Pachydiplax longipennis*	Ammonium chloride	4 d	F,M	8	20	74.37	**49.11**	35.85	35.85	Diamond et al. 1993
Damselfly (8-10 mm), *Enallagma sp.*	Ammonia	4 d	F,M	7.9	11.5	93.10	**25.22**	25.22	25.22	Williams et al. 1986
Insect (8th-10th instar), *Erythromma najas*	Ammonium chloride	4 d	R,U	7.5	25	589.0	**248.8**			Beketov 2002
Insect (8th-10th instar), *Erythromma najas*	Ammonium chloride	4 d	R,U	8.7	25	168.0	**640.4**			Beketov 2002
Insect (8th-10th instar), *Erythromma najas*	Ammonium chloride	4 d	R,U	9.1	25	49.20	**363.1**	386.8	386.8	Beketov 2002
Stonefly, Little golden stonefly (middle to late instar), *Skwala americana*	Ammonium chloride	4 d	F,M	7.81	13.1	109.3	**28.72**			Thurston et al. 1984b
Stonefly, Little golden stonefly (middle to late instar), *Skwala americana*	Ammonium chloride	4 d	F,M	7.76	13.8	119.6	**30.50**	29.60	29.60	Thurston et al. 1984b
Beetle, *Stenelmis sexlineata*	Ammonium chloride	4 d	F,M	8.7	25	29.70	**113.2**	113.2	113.2	Hazel et al. 1979
Caddisfly, *Philarctus quaeris*	Ammonium chloride	4 d	F,M	7.8	21.9	296.5	**158.7**			Arthur et al. 1987
Caddisfly, *Philarctus quaeris*	Ammonium chloride	4 d	F,M	7.8	13.3	561.7	**147.4**	153.0	153.0	Arthur et al. 1987
Midge (10-d (2-3 instar)), *Chironomus riparius*	Ammonium chloride	4 d	R,M	7.7	21.7	357.7	**158.3**	158.3		Monda et al. 1995
Midge, *Chironomus tentans*	Ammonia	4 d	S,M	6.69	23	430.0	68.14			Besser et al. 1998
Midge, *Chironomus tentans*	Ammonia	4 d	S,M	7.56	23	564.0	221.3			Besser et al. 1998
Midge (2nd instar), *Chironomus tentans*	Ammonium chloride	4 d	F,M	6.5	25	371.0	**63.85**			Schubauer-Berigan et al. 1995

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Midge (2nd instar), *Chironomus tentans*	Ammonium chloride	4 d	F,M	8.1	25	78.10	**94.45**			Schubauer-Berigan et al. 1995
Midge (2nd instar), *Chironomus tentans*	Ammonium chloride	4 d	F,M	6.5	25	368.0	**63.33**			Schubauer-Berigan et al. 1995
Midge (2nd instar), *Chironomus tentans*	Ammonium chloride	4 d	F,M	8.1	25	50.50	**61.07**	69.49	104.9	Schubauer-Berigan et al. 1995

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Freshwater Vertebrates										
Common eel (0.20 g), *Anguilla anguilla*	Ammonium chloride	4 d	F,M	7.5	23	110.6	**46.73**[c]			Sadler 1981
Common eel (2.8 g), *Anguilla anguilla*	Ammonium chloride	4 d	F,M	7.5	23	136.6	**57.73**[c]	51.94	51.94	Sadler 1981
Swamp eel (200-250g), *Monopterus albus*		4 d	R,M	7	28	3478	**809.6**	809.6	809.6	Ip et al. 2004
Golden trout (0.09 g, 24 cm), *Oncorhynchus aguabonita*	Ammonium chloride	4 d	F,M	8.06	13.2	23.30	**26.10**	26.10		Thurston and Russo 1981
Cutthroat trout (3.6 g), *Oncorhynchus clarki*	Ammonium chloride	4 d	F,M	7.7	10	17.30	**10.07**			Thurston et al 1981a
Cutthroat trout (3.6 g), *Oncorhynchus clarki*	Ammonium chloride	4 d	F,M	7.7	10	29.10	**16.93**			Thurston et al 1981a
Cutthroat trout (4.1 g), *Oncorhynchus clarki*	Ammonium chloride	4 d	F,M	7.7	10	19.30	**11.23**			Thurston et al 1981a
Cutthroat trout (4.1 g), *Oncorhynchus clarki*	Ammonium chloride	4 d	F,M	7.7	10	26.30	**15.30**			Thurston et al 1981a

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Cutthroat trout (3.4 g), *Oncorhynchus clarki*	Ammonium chloride	4 d	F,M	7.78	12.2	32.57	**21.76**			Thurston et al 1978
Cutthroat trout (3.3 g), *Oncorhynchus clarki*	Ammonium chloride	4 d	F,M	7.8	12.4	36.55	**25.30**			Thurston et al 1978
Cutthroat trout (1.0 g), *Oncorhynchus clarki*	Ammonium chloride	4 d	F,M	7.8	12.8	37.75	**26.13**			Thurston et al 1978
Cutthroat trout (1.0 g), *Oncorhynchus clarki*	Ammonium chloride	4 d	F,M	7.81	13.1	43.72	**30.81**	18.37		Thurston et al 1978
Pink salmon (late alevins), *Oncorhynchus gorbuscha*	Ammonium sulfate	4 d	S,M	6.4	4.3	230.5	**38.33**			Rice and Bailey 1980
Pink salmon (fry), *Oncorhynchus gorbuscha*	Ammonium sulfate	4 d	S,M	6.4	4.3	277.7	**46.18**	42.07		Rice and Bailey 1980
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,U	7	15	81.96	19.08			Wilson. 1974
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,U	7	15	84.43	19.66			Wilson. 1974
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,U	7.5	15	50.68	21.41			Wilson. 1974
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,U	7.5	15	52.80	22.30			Wilson. 1974
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,U	8	15	21.64	21.64			Wilson. 1974
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,U	8	15	21.98	21.98			Wilson. 1974
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,U	8.5	15	9.090	23.85			Wilson. 1974
Coho salmon (6 g), *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	8.1	17.2	11.59	**14.02**			Buckley 1978
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	7	15	82.02	**19.10**			Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	7	15	84.43	**19.66**			Robinson-Wilson and Seim 1975

Table 1. (continued)

Species	**Chemical Name**	**Duration**	**Methods**	**pH**	**Temp(˚C)**	**Total Ammonia (mg N/L)**	**Total Ammonia[b] (mg N/L) at pH=8**	**SMAV (mg N/L)**	**GMAV (mg N/L)**	**Reference**
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	7.5	15	50.65	**21.40**			Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	7.5	15	52.76	**22.29**			Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	8	15	21.63	**21.63**			Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	8	15	22.00	**22.00**			Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	8.5	15	9.093	**23.86**	20.27		Robinson-Wilson and Seim 1975
Rainbow trout (0.5-3.0 g), *Oncorhynchus mykiss*	Ammonium sulfate	4 d	S,U	7.95	15	51.06	46.46			Qureshi et al. 1982
Rainbow trout (McConaughy strain, 251 mg), *Oncorhynchus mykiss*	Ammonium chloride	4 d	S,M	6.84	12	112.0	23.02			Buhl and Hamilton 2000
Rainbow trout (0.80 g), *Oncorhynchus mykiss*		4 d	S,M	6.95	14.7	163.6	36.52			Environment Canada 2004
Rainbow trout (0.60 g), *Oncorhynchus mykiss*		4 d	S,M	6.97	14.5	144.0	32.67			Environment Canada 2004
Rainbow trout (0.63 g), *Oncorhynchus mykiss*		4 d	S,M	7.02	15.4	146.7	34.77			Environment Canada 2004
Rainbow trout (0.80 g), *Oncorhynchus mykiss*		4 d	S,M	7.02	14.6	159.0	37.68			Environment Canada 2004
Rainbow trout (0.80 g), *Oncorhynchus mykiss*		4 d	S,M	7.03	15.1	156.6	37.45			Environment Canada 2004
Rainbow trout (0.90 g), *Oncorhynchus mykiss*		4 d	S,M	7.18	15.1	141.6	39.39			Environment Canada 2004
Rainbow trout (2.01 g), *Oncorhynchus mykiss*		4 d	S,M	7.45	15.1	104.4	40.99			Environment Canada 2004
Rainbow trout (1.30 g), *Oncorhynchus mykiss*		4 d	S,M	7.47	14.7	72.65	29.36			Environment Canada 2004

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (0.78 g), *Oncorhynchus mykiss*		4 d	S,M	7.47	14.5	79.67	32.20			Environment Canada 2004
Rainbow trout (0.40 g), *Oncorhynchus mykiss*		4 d	S,M	7.51	14.2	73.71	31.61			Environment Canada 2004
Rainbow trout (1.64 g), *Oncorhynchus mykiss*		4 d	S,M	7.54	14.6	75.30	33.81			Environment Canada 2004
Rainbow trout, *Oncorhynchus mykiss*	Ammonium chloride	4 d	S,M	7.55	15	34.23	15.61			Craig and Beggs 1979
Rainbow trout (1.13 g), *Oncorhynchus mykiss*		4 d	S,M	7.59	13.9	59.40	28.84			Environment Canada 2004
Rainbow trout (1.50 g), *Oncorhynchus mykiss*		4 d	S,M	7.87	15.1	42.90	33.68			Environment Canada 2004
Rainbow trout (1.38 g), *Oncorhynchus mykiss*		4 d	S,M	7.93	15.2	41.15	36.08			Environment Canada 2004
Rainbow trout (0.90 g), *Oncorhynchus mykiss*		4 d	S,M	7.97	15.2	36.17	33.85			Environment Canada 2004
Rainbow trout (1.00 g), *Oncorhynchus mykiss*		4 d	S,M	7.98	15.1	35.29	33.97			Environment Canada 2004
Rainbow trout (1.30 g), *Oncorhynchus mykiss*		4 d	S,M	8.03	14.9	23.03	24.36			Environment Canada 2004
Rainbow trout (1.26 g), *Oncorhynchus mykiss*		4 d	S,M	8.04	14.3	25.84	27.86			Environment Canada 2004
Rainbow trout (1.60 g), *Oncorhynchus mykiss*		4 d	S,M	8.34	15.3	19.15	36.89			Environment Canada 2004
Rainbow trout (1.30 g), *Oncorhynchus mykiss*		4 d	S,M	8.39	15.3	12.05	25.58			Environment Canada 2004
Rainbow trout (1.11 g), *Oncorhynchus mykiss*		4 d	S,M	8.4	14.9	12.84	27.79			Environment Canada 2004
Rainbow trout (1.40 g), *Oncorhynchus mykiss*		4 d	S,M	8.44	14.7	14.41	33.69			Environment Canada 2004
Rainbow trout (0.90 g), *Oncorhynchus mykiss*		4 d	S,M	8.46	14.5	11.82	28.72			Environment Canada 2004

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (1.26 g), *Oncorhynchus mykiss*		4 d	S,M	8.47	14.3	17.20	42.60			Environment Canada 2004
Rainbow trout (1.01 g), *Oncorhynchus mykiss*		4 d	S,M	8.93	14.2	4.800	27.24			Environment Canada 2004
Rainbow trout (1.44 g), *Oncorhynchus mykiss*		4 d	S,M	8.93	15	5.400	30.65			Environment Canada 2004
Rainbow trout (1.42 g), *Oncorhynchus mykiss*		4 d	S,M	9.46	14.6	1.600	18.40			Environment Canada 2004
Rainbow trout, *Oncorhynchus mykiss*		4 d	S,M	7.5	15.0	38.37	16.21			Holt and Malcolm 1979
Rainbow trout (129 mm), *Oncorhynchus mykiss*	Phosphoric acid, Diammonium salt	4 d	F,U	7	15	207.5	48.32			Blahm 1978
Rainbow trout (1.7-1.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,U	7.4	14.5	20.03	7.33			Calamari et al. 1981
Rainbow trout, *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,U	7.4	14.5	46.31	16.94			Calamari et al. 1981
Rainbow trout (Stage 11, 8-10 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,U	7.4	14.5	55.07	20.15			Calamari et al. 1981
Rainbow trout (129 mm), *Oncorhynchus mykiss*	Phosphoric acid, Diammonium salt	4 d	F,U	8	15	70.00	70.00			Blahm 1978
Rainbow trout (10.9 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.7	3.6	38.52	**22.41**			Arthur et al. 1987
Rainbow trout (14.0 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.7	9.8	55.15	**32.09**			Arthur et al. 1987
Rainbow trout (22.4 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	16.2	15.23	**12.63**			Arthur et al. 1987
Rainbow trout (10.3 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	11.3	30.15	**25.01**			Arthur et al. 1987
Rainbow trout (3.3 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.3	18.7	12.75	**22.72**			Arthur et al. 1987

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (53 mm, 1.48 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.95	10	35.14	**31.97**			Broderius and Smith Jr. 1979
Rainbow trout (Stage 8), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.4	14.4	40.99	**14.99**			Calamari et al. 1977
Rainbow trout, *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.05	14	22.90	**25.17**			DeGraeve et al. 1980
Rainbow trout (45(35-55) mm, 0.86(0.32-1.75) g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.16	14.2	23.39	**31.76**			Reinbold and Pescitelli 1982b
Rainbow trout (119(95-145) mm, 20.6(10.0-32.6) g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.28	12.8	15.40	**26.40**			Reinbold and Pescitelli 1982b
Rainbow trout (115(103-134) mm, 18.1(10.0-32.6) g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.34	5	17.32	**33.37**			Reinbold and Pescitelli 1982b
Rainbow trout (42(32-50) mm, 0.61(0.23-1.03) g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.43	3	11.86	**27.20**			Reinbold and Pescitelli 1982b
Rainbow trout (52(33-51) mm, 1.47(0.26-1.31) g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.5	14.9	10.09	**26.47**			Reinbold and Pescitelli 1982b
Rainbow trout (44(37-65) mm, 0.76(0.41-3.07) g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.6	3.3	15.27	**48.40**			Reinbold and Pescitelli 1982b
Rainbow trout (6.3 g, 8.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.44	12.8	32.49	**12.57**			Thurston and Russo 1983
Rainbow trout (8.0 g, 8.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.5	14.5	24.20	**10.22**			Thurston and Russo 1983
Rainbow trout (29.8 g, 13.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.59	12.7	32.62	**15.84**			Thurston and Russo 1983
Rainbow trout (28.0 g, 13.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.6	13	23.80	**11.74**			Thurston and Russo 1983

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (24.5 g, 12.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.6	12.9	25.14	**12.40**			Thurston and Russo 1983
Rainbow trout (2596 g, 57.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.62	7.9	20.53	**10.46**			Thurston and Russo 1983
Rainbow trout (15.1 g, 10.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.62	14.4	28.62	**14.58**			Thurston and Russo 1983
Rainbow trout (29.6 g, 13.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.63	12.9	25.65	**13.28**			Thurston and Russo 1983
Rainbow trout (1496 g, 48.5 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.64	9.8	25.82	**13.59**			Thurston and Russo 1983
Rainbow trout (18.9 g, 11.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.64	13.1	29.28	**15.41**			Thurston and Russo 1983
Rainbow trout (558 g, 37.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.64	10	31.85	**16.77**			Thurston and Russo 1983
Rainbow trout (1698 g, 50.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.65	9.8	19.46	**10.41**			Thurston and Russo 1983
Rainbow trout (22.8 g, 12.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.65	13.2	28.64	**15.33**			Thurston and Russo 1983
Rainbow trout (12.3 g, 10.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.65	14.3	29.02	**15.53**			Thurston and Russo 1983
Rainbow trout (513 g, 35.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.66	9.8	25.95	**14.12**			Thurston and Russo 1983
Rainbow trout (22.6 g, 12.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.66	13.6	28.27	**15.38**			Thurston and Russo 1983
Rainbow trout (26.0 g, 13.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.66	12.8	33.97	**18.48**			Thurston and Russo 1983
Rainbow trout (14.8 g, 10.5 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.67	14	27.30	**15.10**			Thurston and Russo 1983
Rainbow trout (38.0 g, 14.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.68	13	33.15	**18.65**			Thurston and Russo 1983

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (1122 g, 45.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.69	10.4	17.75	**10.16**			Thurston and Russo 1983
Rainbow trout (1140 g, 46.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.69	10.7	20.18	**11.55**			Thurston and Russo 1983
Rainbow trout (152 g, 23.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.69	10.7	25.62	**14.66**			Thurston and Russo 1983
Rainbow trout (23.6 g, 13.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.69	13.4	27.51	**15.74**			Thurston and Russo 1983
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	12.7	20.03	**16.61**			Thurston and Russo 1983
Rainbow trout (4.3 g, 7.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.71	11.5	30.22	**17.89**			Thurston and Russo 1983
Rainbow trout (4.0 g, 7.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.71	11.4	32.02	**18.95**			Thurston and Russo 1983
Rainbow trout (248 g, 25.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.74	10.4	25.76	**16.05**			Thurston and Russo 1983
Rainbow trout (25.8 g, 13.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.75	11.8	31.53	**19.99**			Thurston and Russo 1983
Rainbow trout (8.1 g, 9.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.75	12.3	33.94	**21.52**			Thurston and Russo 1983
Rainbow trout (380 g, 32.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.76	10	22.44	**14.48**			Thurston and Russo 1983
Rainbow trout (42.0 g, 16.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.77	13.6	31.81	**20.89**			Thurston and Russo 1983
Rainbow trout (1.7 g, 5.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.79	12.4	41.97	**28.54**			Thurston and Russo 1983
Rainbow trout (11.2 g, 10.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.8	9.7	23.65	**16.37**			Thurston and Russo 1983
Rainbow trout (5.7 g, 8.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.8	13.3	42.02	**29.09**			Thurston and Russo 1983

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (2.3 g, 6.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.8	12.4	47.87	**33.14**			Thurston and Russo 1983
Rainbow trout (8.0 g, 9.5 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.82	13.2	33.67	**24.15**			Thurston and Russo 1983
Rainbow trout (4.6 g, 7.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.83	13.5	33.55	**24.50**			Thurston and Russo 1983
Rainbow trout (6.7 g, 8.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.84	12.2	24.54	**18.25**			Thurston and Russo 1983
Rainbow trout (9.0 g, 9.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.84	12.9	32.30	**24.02**			Thurston and Russo 1983
Rainbow trout (1.8 g, 5.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.84	13.8	33.09	**24.61**			Thurston and Russo 1983
Rainbow trout (4.3 g, 7.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.84	13	38.69	**28.77**			Thurston and Russo 1983
Rainbow trout (0.47 g, 4.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	12.5	29.77	**22.54**			Thurston and Russo 1983
Rainbow trout (2.5 g, 6.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	13.1	31.55	**23.89**			Thurston and Russo 1983
Rainbow trout (0.61 g, 4.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	13.1	33.59	**25.43**			Thurston and Russo 1983
Rainbow trout (1.02 g, 4.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	12.3	33.99	**25.73**			Thurston and Russo 1983
Rainbow trout (9.4 g, 9.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	16.1	34.17	**25.87**			Thurston and Russo 1983
Rainbow trout (0.33 g, 3.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	13	20.70	**15.96**			Thurston and Russo 1983
Rainbow trout (0.33 g, 3.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	13.4	23.71	**18.28**			Thurston and Russo 1983
Rainbow trout (0.47 g, 4.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	12.7	28.77	**22.18**			Thurston and Russo 1983
Rainbow trout (1.7 g, 5.8 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	14.1	34.95	**26.95**			Thurston and Russo 1983

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (48.6 g, 15.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	10.2	35.31	**27.22**			Thurston and Russo 1983
Rainbow trout (0.15 g, 2.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	12.9	16.81	**13.20**			Thurston and Russo 1983
Rainbow trout (0.18 g, 2.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	12.9	18.99	**14.91**			Thurston and Russo 1983
Rainbow trout (0.23 g, 3.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	13.1	19.08	**14.98**			Thurston and Russo 1983
Rainbow trout (7.0 g, 8.8 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	12.2	20.02	**15.72**			Thurston and Russo 1983
Rainbow trout (0.18 g, 2.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	13	21.15	**16.61**			Thurston and Russo 1983
Rainbow trout (2.6 g, 6.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	12.1	31.80	**24.97**			Thurston and Russo 1983
Rainbow trout (11.1 g, 9.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	13	34.32	**26.95**			Thurston and Russo 1983
Rainbow trout (0.12 g, 2.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.88	12.8	11.07	**8.85**			Thurston and Russo 1983
Rainbow trout (0.14 g, 2.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.88	12.9	15.91	**12.72**			Thurston and Russo 1983
Rainbow trout (0.23 g, 3.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.88	13.4	19.43	**15.54**			Thurston and Russo 1983
Rainbow trout (52.1 g, 15.5 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.88	10	28.60	**22.87**			Thurston and Russo 1983
Rainbow trout (1.8 g, 5.9 cm), *Oncorhynchus mykiss*	Ammonium sulfate	4 d	F,M	7.89	12.4	36.73	**29.91**			Thurston and Russo 1983
Rainbow trout (0.06 g, 1.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	13.4	19.44	**16.12**			Thurston and Russo 1983
Rainbow trout (0.06 g, 1.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.7	13.9	28.54	**16.61**			Thurston and Russo 1983
Rainbow trout (7.9 g, 9.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	11.9	22.65	**18.79**			Thurston and Russo 1983

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (9.7 g, 9.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	13	35.75	**29.65**			Thurston and Russo 1983
Rainbow trout (9.3 g, 9.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	13	37.41	**31.03**			Thurston and Russo 1983
Rainbow trout (0.08 g, 2.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.91	13.1	12.68	**10.71**			Thurston and Russo 1983
Rainbow trout (0.06 g, 1.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.91	13	20.99	**17.73**			Thurston and Russo 1983
Rainbow trout (7.1 g, 8.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.91	19	25.36	**21.43**			Thurston and Russo 1983
Rainbow trout (10.1 g, 9.8 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.91	19.1	26.44	**22.34**			Thurston and Russo 1983
Rainbow trout (1.7 g, 5.8 cm), *Oncorhynchus mykiss*	Phosphoric acid, Diammonium salt	4 d	F,M	7.94	12.8	26.49	**23.66**			Thurston and Russo 1983
Rainbow trout (2.1 g, 6.2 cm), *Oncorhynchus mykiss*	Ammonium sulfate	4 d	F,M	7.94	12.5	39.25	**35.06**			Thurston and Russo 1983
Rainbow trout (0.15 g, 2.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.95	12.5	19.75	**17.97**			Thurston and Russo 1983
Rainbow trout (8.6 g, 8.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.96	19.2	23.21	**21.52**			Thurston and Russo 1983
Rainbow trout (2.1 g, 6.2 cm), *Oncorhynchus mykiss*	Phosphoric acid, Diammonium salt	4 d	F,M	7.98	12.5	27.02	**26.01**			Thurston and Russo 1983
Rainbow trout (1.01 g, 4.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.06	13.2	33.64	**37.68**			Thurston and Russo 1983
Rainbow trout (0.36 g, 3.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.08	12.8	23.05	**26.83**			Thurston and Russo 1983
Rainbow trout (1.7 g, 5.9 cm), *Oncorhynchus mykiss*	Ammonium bicarbonate	4 d	F,M	8.1	13.9	18.14	**21.94**			Thurston and Russo 1983
Rainbow trout (1.8 g, 5.8 cm), *Oncorhynchus mykiss*	Ammonium bicarbonate	4 d	F,M	8.12	13.6	17.34	**21.79**			Thurston and Russo 1983
Rainbow trout (2596 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.62	7.9	21.60	**11.01**			Thurston et al. 1981a

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (2080 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.67	7.7	17.00	**9.405**			Thurston et al. 1981a
Rainbow trout (293 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.71	8.5	20.70	**12.25**			Thurston et al. 1981a
Rainbow trout (230 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.72	8.2	10.50	**6.322**			Thurston et al. 1981a
Rainbow trout (244 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.72	8.1	19.80	**11.92**			Thurston et al. 1981a
Rainbow trout (230 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.74	8.3	22.30	**13.90**			Thurston et al. 1981a
Rainbow trout (247 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.74	8.1	28.00	**17.45**			Thurston et al. 1981a
Rainbow trout (18 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	9.6	19.30	**14.88**			Thurston et al. 1981a
Rainbow trout (21 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	9.7	31.60	**24.36**			Thurston et al. 1981a
Rainbow trout (4.6 g, 7.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.75	12.7	32.09	**20.35**			Thurston et al. 1981b
Rainbow trout (5.7 g, 8.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.75	12.5	36.97	**23.44**			Thurston et al. 1981b
Rainbow trout (5.0 g, 7.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.76	12.5	39.08	**25.21**			Thurston et al. 1981b
Rainbow trout (5.7 g, 8.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.79	12.9	40.88	**27.80**			Thurston et al. 1981b
Rainbow trout (4.0 g, 7.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.83	12.8	36.49	**26.65**			Thurston et al. 1981b
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	6.51	14.1	157.4	**27.18**			Thurston et al. 1981c
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	6.8	14.1	94.05	**18.82**			Thurston et al. 1981c
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.3	14	74.20	**23.78**			Thurston et al. 1981c

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.29	14.1	13.85	**24.21**			Thurston et al. 1981c
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.82	13.9	3.950	**18.63**			Thurston et al. 1981c
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	9.01	14.5	2.510	**16.18**			Thurston et al. 1981c
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.2	10	174.0	**49.50**			Wicks and Randall 2002
Rainbow trout (40.0 g; swimming fish), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	6.97	16.6	32.38	**7.347**			Wicks et al. 2002
Rainbow trout (40.0 g; resting fish), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	6.97	16.6	207.0	**46.97**	19.30		Wicks et al. 2002
Chinook salmon (1.0-7 g), *Oncorhynchus tshawytscha*	Ammonia	4 d	S,M	7.96	7	28.03	**25.98**			Servizi and Gordon 1990
Chinook salmon (14.4 g, 11.9 cm), *Oncorhynchus tshawytscha*	Ammonium chloride	4 d	F,U	7.87	13.5	18.47	**14.50**			Thurston and Meyn 1984
Chinook salmon (15.3 g, 12.1 cm), *Oncorhynchus tshawytscha*	Ammonium chloride	4 d	F,U	7.82	12.2	27.23	**19.53**			Thurston and Meyn 1984
Chinook salmon (18.1 g, 12.7 cm), *Oncorhynchus tshawytscha*	Ammonium chloride	4 d	F,U	7.84	12.3	24.74	**18.40**	19.18	23.09	Thurston and Meyn 1984
Mountain whitefish (177 g, 27.0 cm), *Prosopium williamsoni*	Ammonium chloride	4 d	F,U	7.68	12.1	11.30	**6.357**			Thurston and Meyn 1984
Mountain whitefish (56.9 g, 19.1 cm), *Prosopium williamsoni*	Ammonium chloride	4 d	F,U	7.84	12.4	25.47	**18.94**			Thurston and Meyn 1984

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Mountain whitefish (63.0 g, 20.4 cm), *Prosopium williamsoni*	Ammonium chloride	4 d	F,U	7.8	12.3	21.20	**14.68**	12.09	12.09	Thurston and Meyn 1984
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.4	1.8	123.0	**20.45**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.4	1.8	133.9	**22.27**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6	2.1	297.2	**45.42**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6	2.1	341.1	**52.12**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	2.5	400.0	**61.56**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	2.5	491.7	**75.67**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6	7.3	581.5	**88.86**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6	7.3	587.6	**89.79**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.45	7.4	171.3	**28.95**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.45	7.4	214.4	**36.24**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.45	12.5	230.6	**38.98**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.45	12.5	248.3	**41.97**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	12.5	403.5	**62.10**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	12.5	451.5	**69.49**			Knoph 1992

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	17.1	356.1	**54.80**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	17.1	373.0	**57.41**			Knoph 1992
Atlantic salmon (1.5 g), *Salmo salar*	Ammonium chloride	4 d	S,M	7.45	8.5	60.29	**23.67**			Soderberg and Meade 1992
Atlantic salmon (1.5 g), *Salmo salar*	Ammonium chloride	4 d	S,M	7.45	8.5	35.74	**14.03**			Soderberg and Meade 1992
Atlantic salmon (36 g), *Salmo salar*	Ammonium chloride	4 d	S,M	7.45	8.5	118.2	**46.40**			Soderberg and Meade 1992
Atlantic salmon (36 g), *Salmo salar*	Ammonium chloride	4 d	S,M	7.45	8.5	70.62	**27.72**	42.66		Soderberg and Meade 1992
Brown trout (1.20 g, 5.4 cm), *Salmo trutta*	Ammonium chloride	4 d	F,U	7.85	13.2	29.58	**22.40**			Thurston and Meyn 1984
Brown trout (1.17 g, 5.3 cm), *Salmo trutta*	Ammonium chloride	4 d.	F,U	7.86	13.8	32.46	**25.03**			Thurston and Meyn 1984
Brown trout (0.91 g, 4.9 cm), *Salmo trutta*	Ammonium chloride	4 d	F,U	7.82	14.2	33.30	**23.89**	23.75	31.83	Thurston and Meyn 1984
Brook trout (3.12 g, 7.2 cm), *Salvelinus fontinalis*	Ammonium chloride	4 d	F,U	7.86	13.6	45.21	**34.86**			Thurston and Meyn 1984
Brook trout (3.40 g, 7.4 cm), *Salvelinus fontinalis*	Ammonium chloride	4 d	F,U	7.83	13.8	52.03	**38.00**	36.39		Thurston and Meyn 1984
Lake trout, siscowet (0.9 g), *Salvelinus namaycush*	Ammonium chloride	4 d	S,M	7.45	8.5	90.43	**35.50**			Soderberg and Meade 1992
Lake trout, siscowet (0.9 g), *Salvelinus namaycush*	Ammonium chloride	4 d	S,M	7.45	8.5	110.2	**43.27**			Soderberg and Meade 1992
Lake trout, siscowet (8 g), *Salvelinus namaycush*	Ammonium chloride	4 d	S,M	7.45	8.5	96.25	**37.78**			Soderberg and Meade 1992
Lake trout, siscowet (8 g), *Salvelinus namaycush*	Ammonium chloride	4 d	S,M	7.45	8.5	83.11	**32.62**	37.10	36.74	Soderberg and Meade 1992

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Central stoneroller (2.1 g), *Campostoma anomalum*	Ammonium chloride	4 d	F,M	7.8	25.7	38.97	**26.97**	26.97	26.97	Swigert and Spacie 1983
Rainbow dace, *Cyprinella lutrensis*	Ammonium chloride	4 d	F,M	8.3	24	24.37	**43.43**			Hazel et al. 1979
Rainbow dace, *Cyprinella lutrensis*	Ammonium chloride	4 d	F,M	9.1	24	6.502	**47.99**	45.65		Hazel et al. 1979
Spotfin shiner (31-85 mm), *Cyprinella spiloptera*	Ammonium chloride	4 d	F,M	7.95	26.5	18.52	**16.85**			Rosage et al. 1979
Spotfin shiner (41-78 mm), *Cyprinella spiloptera*	Ammonium chloride	4 d	F,M	8.15	26.5	16.27	**21.67**			Rosage et al. 1979
Spotfin shiner (0.5 g), *Cyprinella spiloptera*	Ammonium chloride	4 d	F,M	7.9	25.7	24.52	**20.34**	19.51		Swigert and Spacie 1983
Steelcolor shiner (0.5 g), *Cyprinella whipplei*	Ammonium chloride	4 d	F,M	7.9	25.7	22.71	**18.83**	18.83	25.60	Swigert and Spacie 1983
Common carp (206 mg), *Cyprinus carpio*	Ammonium chloride	4 d	R,M	7.72	28	51.78	**31.18**			Hasan and MacIntosh 1986
Common carp (299 mg), *Cyprinus carpio*	Ammonium chloride	4 d	R,M	7.72	28	48.97	**29.48**			Hasan and MacIntosh 1986
Common carp (4-5 cm), *Cyprinus carpio*	Ammonium chloride	4 d	R,M	7.4	28	45.05	**16.48**	24.74	24.74	Rao et al. 1975
Rio Grande silvery minnow (3-5 days old), *Hybognathus amarus*	Ammonium chloride	4 d	R,M	8	25	16.90	**16.90**	16.90	16.90	Buhl 2002
Golden shiner, *Notemigonus crysoleucas*	Ammonium chloride	4 d	S,M	7.5	19.6	89.61	37.86			EA Engineering 1985
Golden shiner, *Notemigonus crysoleucas*	Ammonium chloride	4 d	S,M	7.55	19.5	73.85	33.67			EA Engineering 1985
Golden shiner (8.7 g), *Notemigonus crysoleucas*	Ammonium chloride	4 d	F,M	7.5	24.5	34.73	**14.67**	14.67	14.67	Swigert and Spacie 1983
Fathead minnow (Larva, 14 d), *Pimephales promelas*		4 d	S,U	7.6	20	37.56	18.53			Markle et al. 2000

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.52	20.25	36.73	15.87			EA Engineering 1985
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.48	19.85	40.93	16.79			EA Engineering 1985
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.52	20.25	37.49	16.20			EA Engineering 1985
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.48	19.85	41.79	17.14			EA Engineering 1985
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.48	19.85	43.49	17.84			EA Engineering 1985
Fathead minnow (4-6 days old), *Pimephales promelas*	Ammonium chloride	4 d	R,M	8.01	25	14.40	14.67			Buhl 2002
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	R,M	8	20	5.389	5.389			Diamond et al. 1993
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	R,M	8	20	6.100	6.100			Diamond et al. 1993
Fathead minnow (1.9 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.9	3.4	229.7	**190.5**			Arthur et al. 1987
Fathead minnow (1.8 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	12.1	56.07	**67.81**			Arthur et al. 1987
Fathead minnow (1.6 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8	17.1	52.22	**52.22**			Arthur et al. 1987
Fathead minnow (1.7 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	26.1	29.23	**35.35**			Arthur et al. 1987
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.05	14	47.29	**51.97**			DeGraeve et al. 1980
Fathead minnow (4-5 mo. old), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.46	6	97.27	**38.74**			DeGraeve et al. 1987
Fathead minnow (4-5 mo. old), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.46	10	101.7	**40.50**			DeGraeve et al. 1987
Fathead minnow (4-5 mo. old), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.41	15	76.58	**28.40**			DeGraeve et al. 1987

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Fathead minnow (4-5 mo. old), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.41	20	78.22	**29.01**			DeGraeve et al. 1987
Fathead minnow (4-5 mo. old), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.45	20	66.94	**26.28**			DeGraeve et al. 1987
Fathead minnow (4-5 mo. old), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.4	25	81.81	**29.93**			DeGraeve et al. 1987
Fathead minnow (4-5 mo. old), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.41	25	91.40	**33.90**			DeGraeve et al. 1987
Fathead minnow (4-5 mo. old), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.44	30	64.12	**24.81**			DeGraeve et al. 1987
Fathead minnow (0.28 g, 26.6 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.14	22	25.16	**32.86**			Mayes et al. 1986
Fathead minnow (10 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.9	20.6	28.90	**23.97**			Nimmo et al. 1989
Fathead minnow (10 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.2	6.2	7.320	**10.74**			Nimmo et al. 1989
Fathead minnow (10 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.8	20.1	18.73	**12.96**			Nimmo et al. 1989
Fathead minnow (10 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.8	19.8	32.12	**22.23**			Nimmo et al. 1989
Fathead minnow (25 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	19.6	24.89	**30.10**			Nimmo et al. 1989
Fathead minnow (25 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.2	6.2	11.56	**16.96**			Nimmo et al. 1989

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Fathead minnow (25 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	5.8	19.94	**24.12**			Nimmo et al. 1989
Fathead minnow (25 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	5.8	21.44	**25.93**			Nimmo et al. 1989
Fathead minnow (25 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.7	20.1	32.25	**18.77**			Nimmo et al. 1989
Fathead minnow (15(9-24) mm, 0.0301(0.0009-0.1195)), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.46	4.1	18.54	**45.05**			Reinbold and Pescitelli 1982b
Fathead minnow (16(9-25) mm, 0.0315(0.0076-0.1107)), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.02	23.9	19.55	**20.29**			Reinbold and Pescitelli 1982b
Fathead minnow (19(14-34) mm, 0.0629(0.0102-0.3467)), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.26	4.6	30.57	**50.40**			Reinbold and Pescitelli 1982b
Fathead minnow (21(16-28) mm, 0.0662(0.0322-0.1597)), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.16	25.2	17.65	**23.96**			Reinbold and Pescitelli 1982b
Fathead minnow (5.2 (4.6-5.5) cm, 1.1 (0.6-1.6) g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.7	21.65	63.02	**36.67**			Sparks 1975
Fathead minnow (0.2 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.78	25.9	40.85	**27.30**			Swigert and Spacie 1983
Fathead minnow (0.5 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.8	25.6	42.65	**29.53**			Swigert and Spacie 1983
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.83	11.8	45.71	**33.38**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.82	12	62.72	**44.99**			Thurston et al. 1981c

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	6.51	13	260.0	**44.91**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	9.03	13.2	5.940	**39.49**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.51	13.5	18.88	**50.49**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.01	13.8	145.9	**34.27**			Thurston et al. 1981c
Fathead minnow (0.09 g, 2.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.91	16.3	51.55	**43.55**			Thurston et al. 1983
Fathead minnow (0.09 g, 2.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.89	13.1	50.20	**40.88**			Thurston et al. 1983
Fathead minnow (0.13 g, 2.3 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.64	13.6	58.40	**30.74**			Thurston et al. 1983
Fathead minnow (0.19 g, 2.6 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.68	13.5	64.70	**36.40**			Thurston et al. 1983
Fathead minnow (0.22 g, 2.7 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.03	22.1	47.60	**50.36**			Thurston et al. 1983
Fathead minnow (0.22 g, 2.9 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.06	22	42.60	**47.72**			Thurston et al. 1983
Fathead minnow (0.26 g, 3.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.67	13.9	58.80	**32.53**			Thurston et al. 1983
Fathead minnow (0.31 g, 3.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.05	13	74.65	**82.04**			Thurston et al. 1983

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Fathead minnow (0.31 g, 3.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.05	13.6	66.48	**73.06**			Thurston et al. 1983
Fathead minnow (0.35 g, 3.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.94	19.1	42.30	**37.78**			Thurston et al. 1983
Fathead minnow (0.42 g, 3.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.76	19	50.28	**32.44**			Thurston et al. 1983
Fathead minnow (0.42 g, 3.6 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.66	13.4	58.20	**31.67**			Thurston et al. 1983
Fathead minnow (0.47 g, 3.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.87	15.8	58.91	**46.25**			Thurston et al. 1983
Fathead minnow (0.47 g, 3.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.83	22	50.60	**36.95**			Thurston et al. 1983
Fathead minnow (0.5 g, 3.8 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.91	18.9	49.30	**41.65**			Thurston et al. 1983
Fathead minnow (0.8 g, 4.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.77	14.3	66.70	**43.79**			Thurston et al. 1983
Fathead minnow (1.0 g, 4.6 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.77	14.1	72.71	**47.74**			Thurston et al. 1983
Fathead minnow (1.4 g, 4.9 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.04	22.4	36.59	**39.45**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.08	21.4	44.80	**52.14**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.16	21.4	47.39	**64.34**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.88	21.7	50.90	**40.70**			Thurston et al. 1983

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Fathead minnow (1.4 g, 5.4 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.68	12.9	91.80	**51.65**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.5 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.63	13.2	89.85	**46.53**			Thurston et al. 1983
Fathead minnow (1.5 g, 5.6 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.76	12.9	107.5	**69.38**			Thurston et al. 1983
Fathead minnow (1.7 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.84	21.7	55.43	**41.22**			Thurston et al. 1983
Fathead minnow (2.1 g, 6.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.76	13.1	66.73	**43.05**			Thurston et al. 1983
Fathead minnow (2.2 g, 6.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.74	12.8	52.20	**32.53**			Thurston et al. 1983
Fathead minnow (2.3 g, 6.3 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.91	15.9	47.43	**40.07**	37.07	37.07	Thurston et al. 1983
White sucker (5.6 g), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	7.8	3.6	89.57	**62.00**			Arthur et al. 1987
White sucker (5.2 g), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	8.1	11.3	60.86	**73.60**			Arthur et al. 1987
White sucker (12.6 g), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	8.2	12.6	40.85	**59.94**			Arthur et al. 1987
White sucker (9.6 g), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	8.2	15.3	43.01	**63.10**			Arthur et al. 1987
White sucker (110 mm length), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	7.8	20.2	31.21	**21.61**			Nimmo et al. 1989
White sucker (110 mm length), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	7.8	20.2	18.93	**13.10**			Nimmo et al. 1989
White sucker (92(71-119) mm, 6.3(2.6-13.2) g), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	8.16	15	30.28	**41.11**			Reinbold and Pescitelli 1982c
White sucker (92(71-119) mm, 6.3(2.6-13.2) g), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	8.14	15.4	29.65	**38.73**			Reinbold and Pescitelli 1982c

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
White sucker (11.4 g), *Catostomus commersoni*	Ammonium chloride	4 d	F,M	7.8	22.5	22.30	**15.44**	36.68		Swigert and Spacie 1983
Mountain sucker (63.3 g, 18.2 cm), *Catostomus platyrhynchus*	Ammonium chloride	4 d	F,U	7.67	12	66.91	**37.02**			Thurston and Meyn 1984
Mountain sucker (45.3 g, 16.2 cm), *Catostomus platyrhynchus*	Ammonium chloride	4 d	F,U	7.69	13.2	47.59	**27.23**			Thurston and Meyn 1984
Mountain sucker (47.8 g, 15.9 cm), *Catostomus platyrhynchus*	Ammonium chloride	4 d	F,U	7.73	11.7	51.62	**31.62**	31.70	34.10	Thurston and Meyn 1984
Shortnose sucker (0.53-2.00 g), *Chasmistes brevirostris*	Ammonium chloride	4 d	F,M	8	20	11.42	**11.42**			Saiki et al. 1999
Shortnose sucker, *Chasmistes brevirostris*	Ammonium chloride	4 d	F,M	8	20	22.85	**22.85**	16.15	16.15	Saiki et al. 1999
Lost River sucker (0.49-0.80 g), *Deltistes luxatus*	Ammonium chloride	4 d	F,M	8	20	16.81	**16.81**			Saiki et al. 1999
Lost River sucker (larvae), *Deltistes luxatus*	Ammonium chloride	4 d	F,M	8	20	10.35	**10.35**	13.19	13.19	Saiki et al. 1999
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,U	8.7	26	10.56	40.26			Colt and Tchobanoglous 1976
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,U	8.7	22	10.19	38.85			Colt and Tchobanoglous 1976
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,U	8.7	30	10.88	41.47			Colt and Tchobanoglous 1976
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,M	7.49	19.7	131.5	54.72			EA Engineering 1985
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,M	7.53	19.75	99.67	44.06			EA Engineering 1985
Channel catfish (larvae (1 d)), *Ictalurus punctatus*	Ammonium chloride	4 d	R,M	8.2	23.8	13.03	19.11			Bader and Grizzle 1992

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Channel catfish (juvenile (7 d)), *Ictalurus punctatus*	Ammonium chloride	4 d	R,M	8.2	23.9	17.22	25.27			Bader and Grizzle 1992
Channel catfish (3.5 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.8	19.6	44.71	**30.95**			Arthur et al. 1987
Channel catfish (5.8 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8	3.5	37.64	**37.61**			Arthur et al. 1987
Channel catfish (6.4 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.1	14.6	24.94	**30.16**			Arthur et al. 1987
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.4	28	10.71	**23.19**			Colt and Tchobanoglous 1978
Channel catfish (3-11 mo. old), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.46	10	124.8	**49.70**			DeGraeve et al. 1987
Channel catfish (3-11 mo. old), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.41	15	113.1	**41.95**			DeGraeve et al. 1987
Channel catfish (3-11 mo. old), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.41	20	89.63	**33.24**			DeGraeve et al. 1987
Channel catfish (3-11 mo. old), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.45	20	72.15	**28.32**			DeGraeve et al. 1987
Channel catfish (3-11 mo. old), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.4	25	89.41	**32.70**			DeGraeve et al. 1987
Channel catfish (3-11 mo. old), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.41	25	85.69	**31.78**			DeGraeve et al. 1987
Channel catfish (3-11 mo. old), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.44	30	65.25	**25.25**			DeGraeve et al. 1987
Channel catfish (<110 d), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8	20	15.09	**15.09**			Diamond et al. 1993
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.94	23.8	33.10	**29.57**			Reinbold and Pescitelli 1982d
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.98	23.8	30.49	**29.35**			Reinbold and Pescitelli 1982d
Channel catfish (4.5-10.8 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.08	28	44.44	**51.72**			Roseboom and Richey 1977

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Channel catfish (7.1-12.7 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.09	22	32.33	**38.36**			Roseboom and Richey 1977
Channel catfish (14.3(13.0-15.7)cm, 19.0(14.9-25.7)g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.93	20	74.35	**64.58**			Sparks 1975
Channel catfish (0.5 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.8	25.7	32.85	**22.74**			Swigert and Spacie 1983
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8	26	32.34	**32.34**			West 1985
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.1	17	40.83	**49.38**	33.14	33.14	West 1985
Western mosquitofish, *Gambusia affinis*		4 d	S,U	7.75	19	129.6	**82.17**			Wallen et al. 1957
Western mosquitofish, *Gambusia affinis*		4 d	S,U	8.2	19.5	34.54	**50.68**			Wallen et al. 1957
Western mosquitofish, *Gambusia affinis*		4 d	S,U	8.5	23	14.64	**38.41**			Wallen et al. 1957
Western mosquitofish, *Gambusia affinis*		4 d	S,U	8	24	42.53	**42.53**	51.07	51.07	Wallen et al. 1957
Guppy (0.13 g, 2.03 cm), *Poecilia reticulata*	Ammonium chloride	4 d	S,U	7.5	27.55	5.929	**2.505**			Kumar and Krishnamoorthi 1983
Guppy (8.0(7.1-11.0) mm), *Poecilia reticulata*	Ammonia	4 d	S,U	7.22	25	129.4	**37.66**			Rubin and Elmaraghy 1976
Guppy (8.25(6.3-11.0) mm), *Poecilia reticulata*	Ammonia	4 d	S,U	7.45	25	75.65	**29.70**			Rubin and Elmaraghy 1976
Guppy (8.70(6.8-10.6) mm), *Poecilia reticulata*	Ammonia	4 d	S,U	7.45	25	82.95	**32.56**	17.38	17.38	Rubin and Elmaraghy 1976
Threespine stickleback (juv.-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.1	23.3	198.1	**50.40**			Hazel et al. 1971

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Threespine stickleback (juv.-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.15	15	577.0	**155.4**			Hazel et al. 1971
Threespine stickleback (juv.-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.25	23.3	203.8	**61.46**			Hazel et al. 1971
Threespine stickleback (juv.-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.5	15	143.9	**60.78**			Hazel et al. 1971
Threespine stickleback (juv.-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.5	23.3	78.70	**33.25**			Hazel et al. 1971
Threespine stickleback (juv.-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.5	23.3	115.4	**48.76**			Hazel et al. 1971
Threespine stickleback (juv.-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.5	15	259.0	**109.4**	65.53	65.53	Hazel et al. 1971
White perch (76 mm), *Morone americana*	Ammonium chloride	4 d	S,M	8	16	14.93	**14.93**			Stevenson 1977
White perch (76 mm), *Morone americana*	Ammonium chloride	4 d	S,M	6	16	418.4	**63.94**	30.90		Stevenson 1977
White bass (4.4 g), *Morone chrysops*	Ammonium chloride	4 d	S,M	7.09	19.7	132.4	**33.52**	33.52		Ashe et al. 1996
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.4	23.3	92.17	**33.72**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.5	23.3	73.45	**31.03**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.35	15	259.8	**88.22**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.5	15	182.2	**76.99**			Hazel et al. 1971

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.93	23.3	48.03	**42.10**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.5	23.3	125.9	**53.20**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.84	15	165.7	**122.1**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.5	15	354.9	**149.9**			Hazel et al. 1971
Striped bass (126.6 (35.0-313.4) g), *Morone saxatilis*	Ammonium chloride	4 d	S,M	8.3	21	12.86	**22.92**	57.32		Oppenborn and Goudie 1993
Sunshine bass (larvae (12 h)), *Morone saxatilis chrysops*	Ammonium chloride	4 d	S,M	8.5	18.7	3.903	**10.24**			Harcke and Daniels 1999
Sunshine bass (367.2 (62.1-928.7) g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	8.3	21	8.147	**14.52**			Oppenborn and Goudie 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	63.62	**14.81**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	83.06	**19.34**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	56.55	**13.17**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	65.39	**15.22**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	60.09	**13.99**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	64.51	**15.02**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	79.53	**18.52**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	86.60	**20.16**			Weirich et al. 1993

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	95.43	**22.22**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	105.2	**24.48**	16.35	31.39	Weirich et al. 1993
Green sunfish (larvae, 9 d swim up fry), *Lepomis cyanellus*	Ammonium chloride	4 d	F,U	8.28	26.2	8.430	14.45			Reinbold and Pescitelli 1982a
Green sunfish, *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	7.84	12.3	33.09	**24.61**			Jude 1973
Green sunfish (62.5 mg), *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	7.2	22.4	142.8	**40.64**			McCormick et al. 1984
Green sunfish (62.5 mg), *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	6.61	22.4	254.5	**45.86**			McCormick et al. 1984
Green sunfish (62.5 mg), *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	7.72	22.4	55.79	**33.59**			McCormick et al. 1984
Green sunfish (62.5 mg), *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	8.69	22.4	9.240	**34.59**	35.10		McCormick et al. 1984
Pumpkinseed (4.13-9.22 g), *Lepomis gibbosus*	Ammonium chloride	4 d	F,M	7.77	12	9.110	**5.981**			Jude 1973
Pumpkinseed, *Lepomis gibbosus*	Ammonium chloride	4 d	F,M	7.77	14	48.09	**31.58**			Thurston 1981
Pumpkinseed, *Lepomis gibbosus*	Ammonium chloride	4 d	F,M	7.77	14.5	42.02	**27.59**			Thurston 1981
Pumpkinseed, *Lepomis gibbosus*	Ammonium chloride	4 d	F,M	7.71	15.7	34.43	**20.38**	18.05		Thurston 1981
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.51	20.35	40.41	17.20			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.51	20.35	41.96	17.86			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.52	20.65	41.90	18.24			EA Engineering 1985

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.51	20.35	44.30	18.85			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.52	20.65	42.63	18.56			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.52	20.65	44.10	19.20			EA Engineering 1985
Bluegill (1.7 cm), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8	20	21.56	**21.56**			Diamond et al. 1993
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8	12	25.12	**25.12**			Diamond et al. 1993
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.11	18.5	16.73	**20.62**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.24	18.5	42.01	**66.62**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.75	18.5	12.70	**52.95**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	9.05	18.5	6.581	**45.11**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	9.19	18.5	3.755	**31.44**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	9.62	18.5	0.7859	**10.44**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	9.85	18.5	1.346	**20.88**			Emery and Welch 1969

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.6	24	5.509	**17.46**			Hazel et al. 1979
Bluegill (5.2(3.7-6.7) cm,), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.9	24.25	33.06	**27.42**			Lubinski et al. 1974
Bluegill (0.38 g, 26.3 mm), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.1	22	19.39	**23.45**			Mayes et al. 1986
Bluegill (19(15-25) mm, 0.0781(0.0417-0.1940)), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.4	4	14.64	**31.68**			Reinbold and Pescitelli 1982b
Bluegill (22(17-27) mm, 0.1106(0.0500-0.2384)), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.12	25	23.37	**29.37**			Reinbold and Pescitelli 1982b
Bluegill (28(21-36) mm, 0.250(0.123-0.555) g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.16	4.5	12.55	**17.04**			Reinbold and Pescitelli 1982b
Bluegill (30(23-40) mm, 0.267(0.152-0.698) g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.09	24.8	17.22	**20.43**			Reinbold and Pescitelli 1982b
Bluegill (217 mg), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8	22	12.75	**12.75**			Roseboom and Richey 1977
Bluegill (342 mg), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.2	28	14.81	**21.72**			Roseboom and Richey 1977
Bluegill (646 mg), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.93	22	24.08	**21.11**			Roseboom and Richey 1977
Bluegill (72 mg), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.07	22	8.846	**10.10**			Roseboom and Richey 1977
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.6	21.7	44.03	**21.72**			Smith et al. 1984
Bluegill (4.8 (4.6-5.2) cm, 1.1 (0.9-1.3) g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.85	22.05	59.93	**45.38**			Sparks 1975

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Bluegill (0.9 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.8	24.2	33.88	**23.45**			Swigert and Spacie 1983
Bluegill (0.9 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.6	26.5	58.69	**28.95**			Swigert and Spacie 1983
Bluegill (1.2 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.8	26.6	37.52	**25.97**	24.34	24.89	Swigert and Spacie 1983
Smallmouth bass (26-29 mm, 264-267 mg), *Micropterus dolomieui*	Ammonium chloride	4 d	F,M	7.16	22.3	123.4	**33.59**			Broderius et al. 1985
Smallmouth bass (26-29 mm, 264-267 mg), *Micropterus dolomieui*	Ammonium chloride	4 d	F,M	6.53	22.3	359.9	**62.67**			Broderius et al. 1985
Smallmouth bass (26-29 mm, 264-267 mg), *Micropterus dolomieui*	Ammonium chloride	4 d	F,M	7.74	22.3	39.30	**24.49**			Broderius et al. 1985
Smallmouth bass (26-29 mm, 264-267 mg), *Micropterus dolomieui*	Ammonium chloride	4 d	F,M	8.71	22.3	7.560	**29.34**	35.07		Broderius et al. 1985
Largemouth bass (0.086-0.322 g), *Micropterus salmoides*	Ammonium chloride	4 d	F,M	8.04	28	19.59	**21.12**			Roseboom and Richey 1977
Largemouth bass (2.018-6.286 g), *Micropterus salmoides*	Ammonium chloride	4 d	F,M	7.96	22	20.48	**18.99**	20.03		Roseboom and Richey 1977
Guadalupe bass (6.5 g), *Micropterus treculi*	Ammonium chloride	4 d	S,M/	8	22	12.70	**12.70**	12.70	20.74	Tomasso and Carmichael 1986
Johnny darter (38 mm length), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	7.9	20.6	28.90	**23.97**			Nimmo et al. 1989
Johnny darter (38 mm length), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8	20.1	24.61	**24.61**			Nimmo et al. 1989
Johnny darter (38 mm length), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8.2	6.2	6.937	**10.18**			Nimmo et al. 1989

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Johnny darter (38 mm length), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8.1	5.8	11.47	**13.87**			Nimmo et al. 1989
Johnny darter (38 mm length), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8.1	5.8	13.46	**16.28**			Nimmo et al. 1989
Johnny darter (38 mm length), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8	20.1	15.63	**15.63**	16.64		Nimmo et al. 1989
Orangethroat darter, *Etheostoma spectabile*	Ammonium chloride	4 d	F,M	8.1	22	16.12	**19.49**			Hazel et al. 1979
Orangethroat darter, *Etheostoma spectabile*	Ammonium chloride	4 d	F,M	8.4	21	7.650	**16.56**	17.97	17.29	Hazel et al. 1979
Walleye, *Sander vitreus*	Ammonium chloride	4 d	F,U	8.08	18.2	17.43	20.29			Reinbold and Pescitelli 1982a
Walleye (22.6 g), *Sander vitreus*	Ammonium chloride	4 d	F,M	7.9	3.7	48.37	**40.12**			Arthur et al. 1987
Walleye (19.4 g), *Sander vitreus*	Ammonium chloride	4 d	F,M	7.7	11.1	89.93	**52.33**			Arthur et al. 1987
Walleye (13.4 g), *Sander vitreus*	Ammonium chloride	4 d	F,M	8.3	19	6.123	**10.91**			Arthur et al. 1987
Walleye (3.0 g, 65.6 mm), *Sander vitreus*	Ammonium chloride	4 d	F,M	8.06	21.5	21.49	**24.07**	27.25	27.25	Mayes et al. 1986
Mozambique tilapia (juvenile), *Oreochromis mossambicus*	Ammonium chloride	4 d	R,U	7.2	28	151.5	**43.11**	43.11		Rani et al. 1998
Nile Tilapia (adults 3 g), *Oreochromis niloticus*		4 d	F,M	8.1	28	16.75	**20.25**			Abdalla and McNabb 1999
Nile Tilapia (adults 45 g), *Oreochromis niloticus*		4 d	F,M	8	28	40.40	**40.40**			Abdalla and McNabb 1999
Nile Tilapia (adults 11 g), *Oreochromis niloticus*		4 d	F,M	8.2	23	31.01	**45.50**			Abdalla and McNabb 1999
Nile Tilapia (adults 11 g), *Oreochromis niloticus*		4 d	F,M	8.2	33	18.55	**27.22**	31.73	36.98	Abdalla and McNabb 1999
Mottled sculpin (1.8 g, 5.4 cm), *Cottus bairdi*	Ammonium chloride	4 d	F,M	8.02	12.4	49.83	**51.72**	51.72	51.72	Thurston and Russo 1981

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Shortnose sturgeon (fingerling), *Acipenser brevirostrum*	Ammonium chloride	4 d	S,M	7.05	18	149.8	**36.49**	36.49	36.49	Fontenot et al. 1998
Leopard frog (fertilized eggs), *Rana pipiens*	Ammonium chloride	4 d	F,M	8	20	31.04	**31.04**			Diamond et al. 1993
Leopard frog (8 day), *Rana pipiens*	Ammonium chloride	4 d	F,M	8	12	16.23	**16.23**	22.43	22.43	Diamond et al. 1993
Spring peeper (fertilized), *Pseudacris crucifer*	Ammonium chloride	4 d	F,U	8	12	17.78	**17.78**			Diamond et al. 1993
Spring peeper, *Pseudacris crucifer*	Ammonium chloride	4 d	F,U	8	20	11.42	**11.42**	14.24		Diamond et al. 1993
Pacific tree frog (embryo), *Pseudacris regilla*	Ammonium nitrate	4 d	R,M	6.7	22	41.19	**7.77**			Schuytema and Nebeker 1999a
Pacific tree frog (embryo), *Pseudacris regilla*	Ammonium chloride	4 d	R,M	6.7	22	60.44	**11.40**			Schuytema and Nebeker 1999a
Pacific tree frog (embryo), *Pseudacris regilla*	Ammonium sulfate	4 d	R,M	6.7	22	103.1	**19.45**			Schuytema and Nebeker 1999a
Pacific tree frog (90 mg, GOSNER STAGE 26-27), *Pseudacris regilla*	Nitric acid ammonium salt	4 d	R,M	7.3	22	136.6	**43.80**			Schuytema and Nebeker 1999b
Pacific tree frog (60 mg, GOSNER STAGE 26-27), *Pseudacris regilla*	Ammonium sulfate	4 d	R,M	7.3	22	116.4	**37.30**	19.49	16.66	Schuytema and Nebeker 1999b
Clawed toad (embryo), *Xenopus laevis*	Ammonium sulfate	4 d	R,M	7.2	22	33.20	**9.524**			Schuytema and Nebeker 1999a
Clawed toad (embryo), *Xenopus laevis*	Ammonium sulfate	4 d	R,M	7.2	22	102.9	**29.52**			Schuytema and Nebeker 1999a
Clawed toad (embryo), *Xenopus laevis*	Ammonium nitrate	4 d	R,M	7.2	24	32.37	**9.208**			Schuytema and Nebeker 1999a
Clawed toad (embryo), *Xenopus laevis*	Ammonium sulfate	4 d	R,M	7.2	24	60.71	**17.27**			Schuytema and Nebeker 1999a

Table 1. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp(˚C)	Total Ammonia (mg N/L)	Total Ammonia[b] (mg N/L) at pH=8	SMAV (mg N/L)	GMAV (mg N/L)	Reference
Clawed toad (17 mg, Gosner Stage 26-27), *Xenopus laevis*	Nitric acid ammonium salt	4 d	R,M	7.15	22	101.4	**27.29**			Schuytema and Nebeker 1999b
Clawed toad (17 mg, Gosner Stage 26-27), *Xenopus laevis*	Ammonium sulfate	4 d	R,M	7.15	22	135.9	**36.59**			Schuytema and Nebeker 1999b
Clawed toad (21 mg, Gosner Stage 26-27), *Xenopus laevis*	Ammonium chloride	4 d	R,M	7.15	22	128.3	**34.56**			Schuytema and Nebeker 1999b
Clawed toad (embryo), *Xenopus laevis*	Ammonium phosphate	4 d	R,M	8.43	25	37.30	**85.55**			Tietge et al. 2000
Clawed toad (embryo), *Xenopus laevis*	Ammonium phosphate	4 d	R,M	8.62	25	28.70	**94.43**	28.51	28.51	Tietge et al. 2000

[a] Acute values are normalized to pH 8 and temperature 25°C as per the equations provided in the 1999 criterion document (see Appendix D for an example calculation).

[b] Acute values (LC50 or EC50, except where noted otherwise) are normalized to pH 8 as per the equations provided in the 1999 criterion document (see Appendix D for an example calculation).

[c] Value reported is the concentration associated with the lethal time to 50% mortality, or LT50. The LT50 was reached at 4-d, and therefore, is appropriate for inclusion in Table 1.

Note: Each SMAV was calculated from the associated bold-face number(s) in the preceding column.

Table 2. Other Acute Ammonia Toxicity for Glochidia Life Stage of Freshwater Mussels.

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	Reference
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	2 d	S,M	8.3	20	3.99	4.70	Wang et al., 2007c
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	2 d	S,M	8.3	20	3.18	3.74	Wang et al., 2007c
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	2 d	S,M	8.3	20	2.30	2.71	Wang et al., 2007c
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	2 d	S,M	8.3	20	5.14	6.05	Wang et al., 2007c
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	2 d	S,M	8.45	20	3.99	6.28	Wang et al., 2007b
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	2 d	S,M	8.45	20	2.30	3.62	Wang et al., 2007b
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	2 d	S,M	8.45	20	5.14	8.09	Wang et al., 2007b
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	2 d	S,M	8.45	20	3.18	5.00	Wang et al., 2007b
Dwarf wedgemussel (glochidia), *Alasmidonta heterodon*	Ammonium chloride	2 d	S,M	8.3	20	10.14	11.94	Wang et al., 2007c
Wavy-rayed lampmussel (glochidia), *Lampsilis fasciola*	Ammonium chloride	2 d	S,M	8.3	20	4.26	5.01	Wang et al., 2007c
Wavy-rayed lampmussel (glochidia), *Lampsilis fasciola*	Ammonium chloride	2 d	S,M	8.3	20	2.91	3.42	Wang et al., 2007c
Neosho mucket (glochidia), *Lampsilis rafinesqueana*	Ammonium chloride	2 d	S,M	8.3	20	3.85	4.54	Wang et al., 2007c

Table 2. (continued)

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	Reference
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.3	20	10.00	11.78	Ingersoll 2004
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.3	20	6.15	7.24	Wang et al., 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.3	20	8.11	9.55	Wang et al., 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.3	20	8.79	10.35	Wang et al., 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.3	20	3.52	4.14	Wang et al., 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.3	20	5.41	6.37	Wang et al., 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.35	20	6.15	7.98	Wang et al., 2007c
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.35	20	8.11	10.53	Wang et al., 2007c
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.35	20	5.41	7.02	Wang et al., 2007c
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.35	20	8.79	11.40	Wang et al., 2007c
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	2 d	S,M	8.35	20	3.52	4.56	Wang et al., 2007c
Pink papershell (glochidia), *Potamilus ohiensis*	Ammonium chloride	2 d	S,M	8.30	20	4.93	5.81	Wang et al., 2007b
Ellipse (glochidia), *Venustaconcha ellipsiformis*	Ammonium chloride	2 d	S,M	8.3	20	1.83	2.15	Wang et al., 2007b
Rainbow mussel (glochidia), *Villosa iris*	Ammonium chloride	2 d	S,M	8.3	20	6.22	7.32	Wang et al., 2007b
Rainbow mussel (glochidia), *Villosa iris*	Ammonium chloride	4 d	S,M	8	20	3.29	2.17	Scheller 1997

[a] Acute values are normalized to pH 8 and temperature 25°C as per the equations provided in the 1999 criterion document (see Appendix D for an example calculation).

Table 3. Ranked Genus Mean Acute Values – Freshwater Mussels Present.

Rank	GMAV (mg N/L)	Species	SMAV (mg N/L)
67	809.6	Swamp eel, *Monopterus albus*	809.6
66	386.8	Insect, *Erythromma najas*	386.8
65	153.0	Caddisfly, *Philarctus quaeris*	153.0
64	113.2	Beetle, *Stenelmis sexlineata*	113.2
63	105.6	Crayfish, *Orconectes nais*	46.73
		Crayfish, *Orconectes immunis*	238.4
62	104.9	Midge, *Chironomus tentans*	69.49
		Midge, *Chironomus riparius*	158.3
61	68.05	Mayfly, *Drunella grandis*	68.05
60	65.53	Threespine stickleback, *Gasterosteus aculeatus*	65.53
59	59.53	Aquatic sowbug, *Asellus racovitzai*	59.53
58	56.49	Crayfish, *Pacifastacus leniusculus*	56.49
57	51.94	Common eel, *Anguilla anguilla*	51.94
56	51.72	Mottled sculpin, *Cottus bairdi*	51.72
55	51.07	Western mosquitofish, *Gambusia affinis*	51.07
54	37.92	Mayfly, *Callibaetis sp.*	25.64
		Mayfly, *Callibaetis skokianus*	56.09
53	37.07	Fathead minnow, *Pimephales promelas*	37.07
52	36.98	Nile Tilapia, *Oreochromis niloticus*	31.73
		Mozambique tilapia, *Oreochromis mossambicus*	43.11
51	36.74	Lake trout, siscowet, *Salvelinus namaycush*	37.10
		Brook trout, *Salvelinus fontinalis*	36.39
50	36.49	Shortnose sturgeon, *Acipenser brevirostrum*	36.49

Table 3. (continued)

Rank	GMAV (mg N/L)	Species	SMAV (mg N/L)
49	35.85	Dragonfly, *Pachydiplax longipennis*	35.85
48	34.10	Mountain sucker, *Catostomus platyrhynchus*	31.70
		White sucker, *Catostomus commersoni*	36.68
47	33.64	Oligochaete, worm, *Lumbriculus variegatus*	33.64
46	33.30	Tubificid worm, Oligochaete, *Tubifex tubifex*	33.30
45	33.14	Channel catfish, *Ictalurus punctatus*	33.14
44	32.54	Ramshorn snail, *Helisoma trivolvis*	32.54
43	31.83	Brown trout, *Salmo trutta*	23.75
		Atlantic salmon, *Salmo salar*	42.66
42	31.39	Sunshine bass, *Morone saxatilis x chrysops*	16.35
		Striped bass, *Morone saxatilis*	57.32
		White bass, *Morone chrysops*	33.52
		White perch, *Morone americana*	30.90
41	29.60	Stonefly, Little golden stonefly, *Skwala americana*	29.60
40	28.51	Clawed toad, *Xenopus laevis*	28.51
39	27.96	Amphipod, *Crangonyx sp.*	18.79
		Amphipod, *Crangonyx pseudogracilis*	41.61
38	27.25	Walleye, *Sander vitreus*	27.25
37	26.97	Central stoneroller, *Campostoma anomalum*	26.97
36	26.17	Tubificid worm, *Limnodrilus hoffmeisteri*	26.17

Table 3. (continued)

Rank	GMAV (mg N/L)	Species	SMAV (mg N/L)
35	25.60	Steelcolor shiner, *Cyprinella whipplei*	18.83
		Spotfin shiner, *Cyprinella spiloptera*	19.51
		Rainbow dace, *Cyprinella lutrensis*	45.65
34	25.29	Pouch snail, *Physa gyrina*	25.29
33	25.22	Damselfly, *Enallagma sp.*	25.22
32	25.01	Water flea, *Chydorus sphaericus*	25.01
31	24.89	Bluegill, *Lepomis macrochirus*	24.34
		Pumpkinseed, *Lepomis gibbosus*	18.05
		Green sunfish, *Lepomis cyanellus*	35.10
30	24.74	Common carp, *Cyprinus carpio*	24.74
29	23.09	Chinook salmon, *Oncorhynchus tshawytscha*	19.18
		Rainbow trout, *Oncorhynchus mykiss*	19.30
		Coho salmon, *Oncorhynchus kisutch*	20.27
		Pink salmon, *Oncorhynchus gorbuscha*	42.07
		Cutthroat trout, *Oncorhynchus clarki*	18.37
		Golden trout, *Oncorhynchus aguabonita*	26.10
28	22.43	Leopard frog, *Rana pipiens*	22.43
27	22.13	Water flea, *Ceriodaphnia dubia*	20.64
		Water flea, *Ceriodaphnia acanthina*	23.73
26	21.98	Water flea, *Simocephalus vetulus*	21.98
25	21.76	Giant floater mussel, *Pyganodon grandis*	21.76

Table 3. (continued)

Rank	GMAV (mg N/L)	Species	SMAV (mg N/L)
24	21.23	Red swamp crayfish, *Procambarus clarkii*	21.23
23	20.74	Guadalupe bass, *Micropterus treculi*	12.70
		Largemouth bass, *Micropterus salmoides*	20.03
		Smallmouth bass, *Micropterus dolomieui*	35.07
22	19.22	Water flea, *Daphnia pulicaria*	15.23
		Water flea, *Daphnia magna*	24.25
21	18.37	flatworm, *Dendrocoelum lacteum*	18.37
20	17.38	Guppy, *Poecilia reticulata*	17.38
19	17.29	Orangethroat darter, *Etheostoma spectabile*	17.97
		Johnny darter, *Etheostoma nigrum*	16.64
18	16.90	Rio Grande Silvery Minnow, *Hybognathus amarus*	16.90
17	16.66	Pacific tree frog, *Pseudacris regilla*	19.49
		Spring peeper, *Pseudacris crucifer*	14.24
16	16.15	Shortnose sucker, *Chasmistes brevirostris*	16.15
15	14.67	Golden shiner, *Notemigonus crysoleucas*	14.67
14	14.30	Chinese mitten crab, *Eriocheir sinensis*	14.30
13	13.74	Long fingernail clam, *Musculium transversum*	13.74
12	13.63	Great pond snail, *Lymnaea stagnalis*	13.63
11	13.19	Lost River sucker, *Deltistes luxatus*	13.19
10	12.22	Pleasantshell, *Actinonaias pectorosa*	12.22
9	12.09	Mountain whitefish, *Prosopium williamsoni*	12.09

Table 3. (continued)

Rank	GMAV (mg N/L)	Species	SMAV (mg N/L)
8	10.54	Snail, *Pleurocera unciale*	10.54
7	7.605	Snail, *Potamopyrgus antipodarum*	7.605
6	7.164	Pondshell mussel, *Utterbackia imbecillis*	7.164
5	6.037	Oyster mussel, *Epioblasma capsaeformis*	6.037
4	6.018	Asiatic clam, *Corbicula fluminea*	6.018
3	5.919	Fatmucket, *Lampsilis siliquoidea*	5.646
		Neosho mucket, *Lampsilis rafinesqueana*	11.65
		Higgin's eye, *Lampsilis higginsii*	6.249
		Wavy-rayed lampmussel, *Lampsilis fasciola*	6.207
		Plain pocketbook, *Lampsilis cardium*	7.689
		Pink mucket, *Lampsilis abrupta*	2.191
2	5.036	Rainbow mussel, *Villosa iris*	5.036
1	3.539	Green floater, *Lasmigona subviridus*	3.539
FAV = 5.734			
CMC = 2.9			

Table 4. Other Acute Ammonia Toxicity for *Hyalella azteca*.

Species	Chemical Name	Duration	Methods	pH	Temp (˚C)	Estimated Cl mg/L	Total Ammonia (mg N/L)	Total Ammonia[a] (mg N/L) at pH=8 and 25°C	Reference
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	7.49	25	44 - 516 Note: Values represent the range of Cl concentrations at the respective LC50s within the study	17.50	7.28	Ankley et al. 1995
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	6.5	25		22.80	3.92	Ankley et al. 1995
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	8.21	25		24.00	35.90	Ankley et al. 1995
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	8.45	25		35.20	83.90	Ankley et al. 1995
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	8.3	25		39.80	70.93	Ankley et al. 1995
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	7.31	25		64.00	20.78	Ankley et al. 1995
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	6.43	25		105.00	17.63	Ankley et al. 1995
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	7.41	25		140.00	51.93	Ankley et al. 1995
Scud (7-14 D), *Hyalella azteca*	Ammonium chloride	4 d	R,M	6.55	25		204.00	35.81	Ankley et al. 1995
Scud, *Hyalella azteca*	Ammonia	4 d	S,M	6.69	23	-[a]	117.00	18.54	Besser et al. 1998
Scud, *Hyalella azteca*	Ammonia	4 d	S,M	7.56	23	-[a]	126.00	49.43	Besser et al. 1998
Scud (juvenile, <7 d old), *Hyalella azteca*	Ammonium chloride	4 d	S,M	7.85	23	Min of 26 + contribution from NH_4Cl	60.32	38.69	Sarda 1994
Scud (juvenile, <7 d old), *Hyalella azteca*	Ammonium chloride	4 d	S,M	7.85	23	Min of 26 + contribution from NH_4Cl	63.00	40.41	Sarda 1994
Scud, *Hyalella azteca*	Ammonium chloride	4 d	R,M	6.85	23	Approx. 25 Overlying water	9.70	1.70	Whiteman et al. 1996
Scud, *Hyalella azteca*	Ammonium chloride	4 d	R,M	6.28	23	-[a] Pore water	82.0	11.18	Whiteman et al. 1996
Scud (14-21 d), *Hyalella azteca*	Ammonium chloride	4 d	F,M	6.82	23	Approx. 25 Water-only	9.20	1.58	Whiteman et al. 1996

[a] Could not be estimated.

Table 5. Chronic Toxicity of Ammonia to Aquatic Animals.

Species	Test and Effect	pH	Temp (˚C)	Total Ammonia (mg N/L)	Chronic value[a] Adjusted to pH 8 (all *organisms) and 25°C (invertebrates)* (mg N/L)	SMCV (mg N/L)	GMCV (mg N/L)	Reference
Freshwater Invertebrates								
Wavy-rayed lamp mussel (2 mo old juveniles), *Lampsilis fasciola*	28-d Juv Survival	8.2	20	0.3981	<0.3917	<0.3917		Wang et al. 2007a
Fatmucket (2 mo old juveniles), *Lampsilis siliquoidea*	28-d Juv Survival	8.2	20	0.3076	<0.3027 (IC20)	<0.3027	<0.3443	Wang et al. 2007a
Rainbow mussel (2 mo old juveniles), *Villosa iris*	28-d Juv Survival	8.2	20	0.9965	<0.9805 (IC20)	<0.9805	<0.9805	Wang et al. 2007a
Long fingernail clam, *Musculium transversum*	42-d Juv Survival	8.15	23.5	5.820	6.630			Anderson et al. 1978
Long fingernail clam, *Musculium transversum*	42-d Juv Survival	7.8	21.8	1.230	0.7659	<2.260	<2.260	Sparks and Sandusky 1981
Water flea, *Ceriodaphnia acanthina*	7-d LC Reproduction	7.15	24.5	44.90	19.14	19.14		Mount 1982
Water flea, *Ceriodaphnia dubia*	7-d LC Reproduction	7.8	25	15.20	11.63			Nimmo et al. 1989
Water flea, *Ceriodaphnia dubia*	7-d LC Reproduction	7.8	25	15.20	11.63			Nimmo et al. 1989
Water flea, *Ceriodaphnia dubia*	7-d LC Reproduction	8.57	26	5.80	15.57	13.46	16.05	Willingham 1987
Water flea, *Daphnia magna*	21-d LC Reproduction	8.45	19.8	7.370	10.83			Gerisch et al. 1985
Water flea, *Daphnia magna*	21-d LC Reproduction	7.92	20.1	21.70	14.15	12.38	12.38	Reinbold and Pescitelli 1982a

Table 5. (continued)

Species	Test and Effect	pH	Temp (˚C)	Total Ammonia (mg N/L)	Chronic value[a] Adjusted to pH 8 (all *organisms) and 25°C (invertebrates)* (mg N/L)	SMCV (mg N/L)	GMCV (mg N/L)	Reference
Freshwater Vertebrates								
Cutthroat trout (juvenile; 3.3-3.4 g), *Oncorhynchus clarki*	29-d Juv Survival	8.0	12.2-13.1		<19.70[b]			Thurston et al. 1978
Lahontan Cutthroat Trout (fertilized), *Oncorhynchus clarki henshawi*	103-d ELS Survival	7.57	13.7	20.80	12.38	12.38[c]		Koch et al. 1980
Rainbow trout (fertilized), *Oncorhynchus mykiss*	42-d ELS Survival	7.5	10	33.60	<18.75[b]			Burkhalter and Kaya 1977
Rainbow trout, *Oncorhynchus mykiss*	72-d ELS Survival	7.4	14.5	2.600	1.336[b]			Calamari et al. 1977,1981
Rainbow trout (fertilized), *Oncorhynchus mykiss*	73-d ELS Survival	7.52	14.9	2.550	<1.449[b]			Solbe and Shurben 1989
Rainbow trout, *Oncorhynchus mykiss*	5-year LC	7.7	7.5-10.5	8.000	≥5.445[b]			Thurston et al. 1984b
Sockeye salmon, *Oncorhynchus nerka*	62-d Embryos Hatchability	8.42	10	2.130	<4.160	<4.160[c]		Rankin 1979
Northern pike (eggs, larvae), *Esox lucius*	52-d ELS Biomass	7.62	8.7	13.44	8.401	8.401	8.401	Harrahy et al. 2004
Common carp (larvae), *Cyprinus carpio*	28-d ELS Weight	7.85	23	8.360	6.815	6.815	6.815	Mallet and Sims 1994
Fathead minnow (embryo-larvae), *Pimephales promelas*	28-d ELS Survival	8	24.8	5.120	5.124			Mayes et al. 1986
Fathead minnow, *Pimephales promelas*	30-d ELS Biomass	7.82	25.1	3.730	2.927			Swigert and Spacie 1983
Fathead minnow, *Pimephales promelas*	LC Hatchability	8	24.2	1.970	1.972	3.093	3.093	Thurston et al. 1986

Table 5. (continued)

Species	Test and Effect	pH	Temp (˚C)	Total Ammonia (mg N/L)	Chronic value[a] Adjusted to pH 8 (all *organisms) and 25°C (invertebrates)* (mg N/L)	SMCV (mg N/L)	GMCV (mg N/L)	Reference
White sucker (3 d old embryos), *Catostomus commersoni*	30-d ELS Biomass	8.32	18.6	2.900	4.790	>4.790	>4.790	Reinbold and Pescitelli 1982a
Channel catfish, *Ictalurus punctatus*	30-d ELS Weight	7.8	25.8	12.20	9.338			Reinbold and Pescitelli 1982a
Channel catfish, *Ictalurus punctatus*	30-d Juv Survival	8.35	27.9	5.020	8.717			Colt and Tchobanoglous 1978
Channel catfish, *Ictalurus punctatus*	30-d ELS Biomass	7.76	26.9	11.50	8.386	8.805	8.805	Swigert and Spacie 1983
Green sunfish, *Lepomis cyanellus*	30-d ELS Biomass	7.9	22	5.610	4.884			McCormick et al. 1984
Green sunfish, *Lepomis cyanellus*	30-d ELS Survival	8.16	25.4	5.840	7.444	6.030		Reinbold and Pescitelli 1982a
Bluegill, *Lepomis macrochirus*	30-d ELS Biomass	7.76	22.5	1.850	1.349	1.349	2.852	Smith et al. 1984
Smallmouth bass, *Micropterus dolomieui*	32-d ELS Biomass	6.6	22.3	9.610	3.565			Broderius et al. 1985
Smallmouth bass, *Micropterus dolomieui*	32-d ELS Biomass	7.25	22.3	8.620	4.009			Broderius et al. 1985
Smallmouth bass, *Micropterus dolomieui*	32-d ELS Biomass	7.83	22.3	8.180	6.500			Broderius et al. 1985
Smallmouth bass, *Micropterus dolomieui*	32-d ELS Biomass	8.68	22.3	1.540	4.662	4.562	4.562	Broderius et al. 1985

[a] The chronic value is an EC20 value calculated using EPA’s TRAP (Versions 1.0 and 2.1), or, where indicated, an IC20 value calculated using EPA’s ICpin (Version 2.0). Note: all chronic values were normalized to pH 8 (all organisms) and 25^{O}C (invertebrates) as per the equations provided in the 1999 criterion document (see Appendix E for an example calculation).

[b] Not used in the calculation of the SMCV because of the uncertainty of the chronic value, and because of the profound differences in chronic values for tests with rainbow trout (see Text in Evaluation of the Chronic Data Available for Each New Species).

[c] Not used in the calculation of the GMCV for Oncorhynchus because of the profound differences in chronic values for other species within the genus (also see Text in Evaluation of the Chronic Data Available for Each New Species).

Table 6. Other Chronic Ammonia Toxicity Data.

Species	Test and Effect	Method	pH	Temp (˚C)	Total Ammonia (mg N/L)	Chronic value Adjusted to pH 8 (all *organisms) and 25°C (invertebrates)* (mg N/L)	Reference
Freshwater Invertebrates							
Pulmonate pondsnail (<1 week post-hatch) *Lymnaea stagnalis*	28-d Juv NOEC - Survival	F,M	8.25	20.1	>7.90	>8.51	Besser et al. 2009
Pulmonate Pondsnail (<1 week post hatch), *Lymnaea stagnalis*	28-d NOEC - Growth	F,M	8.25	20.1	>7.90	>8.51	Besser et al. 2009
Idaho springsnail (mixed aged, adults) *Pyrgulopsis idahoensis*	28-d Juv EC20 - Survival	F,M	8.26	20.8	3.24	<3.77	Besser et al. 2009
Idaho Springsnail (7-9 and 11-13 week post hatch juveniles), *Pyrgulopsis idahoensis*	28-d NOEC - Growth	F,M	8.25	20.1	>8.00	>8.62	Besser et al. 2009
Pebblesnail (mixed aged, field collected) *Fluminicola sp.*	28-d Juv EC20 - Survival	F,M	8.26	20.8	1.02	<1.19	Besser et al. 2009
Ozark springsnail (mixed age, field collected) *Fontigens aldrichi*	28-d Juv EC20 - Survival	F,M	8.26	20.8	0.61	<0.71	Besser et al. 2009
Bliss Rapids snail (mixed age, field collected) *Taylorconcha serpenticola*	28-d Juv EC20 - Survival	F,M	8.26	20.8	3.42	<3.98	Besser et al. 2009
Wavy-rayed lamp mussel (2 mo old juveniles), *Lampsilis fasciola*	28-d IC25 - Growth	F,M	8.2	20.1	0.57	0.56	Wang et al. 2007a
Fatmucket (2 mo old juveniles), *Lampsilis siliquoidea*	28-d IC25 - Growth	F,M	8.2	20.1	0.44	0.43	Wang et al. 2007a
Rainbow mussel (2 mo old juveniles), *Villosa iris*	28-d IC25 - Growth	F,M	8.2	20.1	0.73	0.72	Wang et al. 2007a
Water flea, (<24hrs), *Ceriodaphnia dubia*	3 broods in control IC25 Reproduction	R,M	7.9	25.0	1.3	1.08	Dwyer et al. 2005

Table 6. Continued

Species	Test and Effect	Method	pH	Temp (˚C)	Total Ammonia (mg N/L)	Chronic value Adjusted to pH 8 (all *organisms)* *and 25°C (invertebrates)* (mg N/L)	Reference
Bonytail chub (2 and 7-d post hatch), *Gila Elegans*	7-d IC25 - Growth	R,M	7.9	25.0	11.0	9.12	Dwyer et al. 2005
Spotfin chub (<24hrs), *Cyprinella monocha*	7-d IC25 - Growth	R,M	7.9	25.0	15.8	13.10	Dwyer et al. 2005
Cape Fear shiner (<24hrs), *Notropis mekistocholas*	7-d IC25 - Growth	R,M	7.9	25.0	8.8	7.30	Dwyer et al. 2005
Gila topminnow (<24, 48 and 72hrs), *Poeciliopsis occidentalis*	7-d IC25 - Growth	R,M	7.9	25.0	24.1	19.99	Dwyer et al. 2005
European eel (2.8 g), *Anguilla anguilla*	77-d Juv LOEC- Growth Rate	F,M	7.53	23.0	15.2	8.54	Sadler 1981
Fathead minnow (24hrs), *Pimephales promelas*	7-d IC25 - Growth	R,M	7.9	25.0	7.2	5.97	Dwyer et al. 2005
Fathead minnow (4-d post hatch), *Pimephales promelas*	28-d Juv LOEC- Survival	R,M	8.34	19.9	7.9	13.48	Fairchild et al. 2005
Colorado pike minnow (5 and 6-d post hatch), *Ptychocheilus lucius*	7-d IC25 - Growth	R,M	7.9	25.0	8.9	7.38	Dwyer et al. 2005
Colorado pikeminnow (juvenile, 8-d), *Ptychocheilus lucius*	28-d Juv LOEC- Growth	R,M	8.23	19.9	8.6	12.26	Fairchild et al. 2005
Razorback sucker (7-d post hatch), *Xyrauchen texanus*	7-d IC25 - Growth	R,M	7.9	25.0	13.4	11.11	Dwyer et al. 2005
Razorback sucker (9-d), *Xyrauchen texanus*	28-d Juv LOEC- Survival	R,M	8.25	19.9	13.25	19.20	Fairchild et al. 2005
Lost River sucker (Late-stage larva), *Deltistes luxatus*	30-d Juv LOEC-Survival	F,M	9.5	22.3	1.23	10.43	Meyer and Hansen 2002
Lake trout, siscowet, *Salvelinus namaycush*	60-d Juv LOEC- Weight gain	F,M	8.02	11.6	6.44	6.63	Beamish and Tandler 1990
Tilapia (Juvenile), *Oreochromis niloticus*	75-d Juv LOEC- Specific growth weight	F,M	7.45	30	5.30	2.84	El-Shafai et al. 2004

Table 6. Continued

Species	**Test and Effect**	**Method**	**pH**	**Temp (˚C)**	**Total Ammonia (mg N/L)**	**Chronic value Adjusted to pH 8 (all *organisms) and 25°C (invertebrates)* (mg N/L)**	**Reference**
Nile Tilapia (6 g), *Oreochromis niloticus*	35-d Juv LOEC- Weight gain	F,M	7.8	28	7.07	5.41	Abdalla and McNabb 1999
Green frog (STAGE 24-26), *Rana clamitans*	103-d Juv NOEC- Growth	R,M	8.7	24	2.20	>6.90	Jofre and Karasov 1999

Table 7. Genus Mean Acute-Chronic Ratios

Species	Acute and Chronic Test Endpoint	pH	Temp (oC)	Concentration Normalized to pH 8 (all organisms) and 25°C (invertebrates) (mg N/l)	Reference(s)	ACR	SMACR	GMACR
V. iris	LC50	8.3	20	8.293[a]	Wang et al. 2007b	>6.129	>6.129	>6.129
	EC20	8.2	20	<1.353	Wang et al. 2007a			
L. fasciola	LC50	8.3	20	10.67	Wang et al. 2007b	>19.73	>19.73	>18.27
	EC20	8.2	20	<0.5407	Wang et al. 2007a			
L. siliquoidea	LC50	8.3	20	7.065	Wang et al. 2007b	>16.91	>16.91	
	EC20	8.2	20	<0.4178	Wang et al. 2007a			
C. acanthina	LC50	7.06	24	25.78	Mount 1982	1.304	1.304	1.832
	EC20	7.15	24.5	19.77				
C. dubia	LC50	7.8	25	23.52	Nimmo et al. 1989	2.022	2.573	
	EC20	7.8	25	11.63				
	LC50	8.61	26	47.80	Willingham 1987	3.274		
	EC20	8.57	26	14.60				
D. magna	LC50	8.5	20	69.12	Gersich et al. 1985	4.565	4.850	4.850
	EC20	8.45	19.8	15.14				
	LC50	8.34	19.7	100.0	Reinbold and Pescitelli 1982a	5.152		
	EC20	7.92	20.1	19.41				
C. commersoni	LC50	8.16	15	39.89[a]	Reinbold and Pescitelli 1982c	<8.330	<8.330	<8.330
	EC20	8.32	18.6	>4.790				
I. punctatus	LC50	7.8	25.7	22.74	Swigert and Spacie 1983	2.712	2.712	2.712
	EC20	7.76	26.9	8.386				

Table 7. (continued)

Species	Acute and Chronic Test Endpoint	pH	Temp (oC)	Concentration Normalized to pH 8 (all organisms) and 25°C (invertebrates) (mg N/l)	Reference(s)	ACR	SMACR	GMACR
L. cyanellus	LC50	7.72	22.4	33.59	McCormick et al. 1984	6.878	3.654	7.671
	EC20	7.9	22	4.884				
	LC50	8.28	26.2	14.5	Reinbold and Pescitelli 1982d	1.941		
L. macrochirus	LC50	7.6	21.7	21.73	Smith et al. 1984	16.11	16.11	
	EC20	7.76	22.5	1.349				
M. dolomieui	LC50	6.53	22.3	62.67	Broderius et al. 1985 at pH 6.5	17.58	7.688	7.688
	EC20	6.6	22.3	3.565				
	LC50	7.16	22.3	33.60	Broderius et al. 1985 at pH 7.0	8.380		
	EC20	7.25	22.3	4.009				
	LC50	7.74	22.3	24.49	Broderius et al. 1985 at pH 7.5	3.768		
	EC20	7.83	22.3	6.500				
	LC50	8.71	22.3	29.35	Broderius et al. 1985 at pH 8.5	6.295		
	EC20	8.68	22.3	4.662				
P. promelas	LC50	7.76	19	40.68[b]	Thurston et al. 1983	20.63	10.86	10.86
	EC20	8	24.2	1.972				
	LC50	8.14	22	32.86	Mayes et al. 1986	6.413		
	EC20	8	24.8	5.124				
	LC50	7.78	25.9	28.39[a]	Swigert and Spacie 1983	9.700		
	EC20	7.82	25.1	2.927				

Table 8. Ordered Genus Mean Acute-Chronic Ratios

Rank	Genus	GMAV Adjusted to pH=8 (all organisms) and 25^{O}C (invertebrates only)	GMACR
67	Monopterus	809.6	
66	Erythromma	386.8	
65	Philarctus	153.0	
64	Stenelmis	113.2	
63	Orconectes	105.6	
62	Chironomus	104.9	
61	Drunella	68.05	
60	Gasterosteus	65.53	
59	Asellus	59.53	
58	Pacifastacus	56.49	
57	Anguilla	51.94	
56	Cottus	51.72	
55	Gambusia	51.07	
54	Callibaetis	37.92	
53	Pimephales	37.07	10.86
52	Oreochromis	36.98	
51	Salvelinus	36.74	
50	Acipenser	36.49	
49	Pachydiplax	35.85	
48	Catostomus	34.10	<8.330
47	Lumbriculus	33.64	
46	Tubifex	33.30	
45	Ictalurus	33.14	2.712
44	Helisoma	32.54	
43	Salmo	31.83	
42	Morone	31.39	
41	Skwala	29.60	
40	Xenopus	28.51	
39	Crangonyx	27.96	
38	Sander	27.25	
37	Campostoma	26.97	
36	Limnodrilus	26.17	
35	Cyprinella	25.60	
34	Physa	25.29	
33	Enallagma	25.22	
32	Chydorus	25.01	
31	Lepomis	24.89	7.671
30	Cyprinus	24.74	
29	Oncorhynchus	23.09	
28	Rana	22.43	

Table 8. (continued)

Rank	Genus	GMAV Adjusted to pH=8 (all organisms) and 25^{O}C (invertebrates only)	GMACR
27	Ceriodaphnia	22.13	1.832
26	Simocephalus	21.98	
25	Pyganodon	21.76	
24	Procambarus	21.23	
23	Micropterus	20.74	7.688
22	Daphnia	19.22	4.850
21	Dendrocoelum	18.37	
20	Poecilia	17.38	
19	Etheostoma	17.29	
18	Hybognathus	16.90	
17	Pseudacris	16.66	
16	Chasmistes	16.15	
15	Notemigonus	14.67	
14	Eriocheir	14.30	
13	Musculium	13.74	
12	Lymnaea	13.63	
11	Deltistes	13.19	
10	Actinonaias	12.22	
9	Prosopium	12.09	
8	Pleurocera	10.54	
7	Potamopyrgus	7.605	
6	Utterbackia	7.164	
5	Epioblasma	6.037	
4	Corbicula	6.018	
3	Lampsilis	5.919	>18.27
2	Villosa	5.036	>6.129
1	Lasmigona	3.539	

Table 9. Unused Acute Studies Potentially Influential for Freshwater Ammonia Criteria Development.

Reference:	Organism:	Reported or Normalized Acute Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, where applicable	Rationale for Omission:
Anderson, B.G. 1948. The Apparent thresholds of toxicity to *Daphnia magna* for chlorides of various metals when added to Lake Erie water. Trans. Am. Fish. Soc. 78:96-113.	*Daphnia magna*	Normalized EC50 = 133.6	LC50 based on a non-standard (64 h) test duration for species.
Babu, T.R., P. Surendranath and K.V. Ramana Rao. 1987. Comparative evaluation of DDT and fenvalerate toxicity on *Penaeus indicus* (H. Milne Edwards). Mahasagar 20(4):249-253.	*Daphnia magna*	Reported LC50s: 60 (25 h), 32 (50 h), 20 (100 h)	pH not reported – LC50s could not be normalized.
Black, M. 2001.Water quality standards for North Carolina's endangered mussels. Department of Environmental Health Science, Athens, GA.	*Fusconaia masoni*	Normalized LC50 = 2.49	Other data for other species from this study was used in Table 1. LC50 based on a 24 h (non-standard) test duration.
Diamond, J.M., D.G. Mackler, W.J. Rasnake and D. Gruber. 1993. Derivation of site-specific ammonia criteria for an effluent-dominated headwater stream. Environ. Toxicol. Chem. 12:649-658.	*Daphnia magna*	Normalized LC50s = 16.68, 33.56	Test duration not reported.
Dowden, B.F. 1961. Cumulative toxicities of some inorganic salts to *Daphnia magna* as determined by median tolerance limits. Proc. La. Acad. Sci. 23:77-85.	*Daphnia magna*	Reported LC50s: 161 (48 h), 206 (24 h)	pH not reported – LC50s could not be normalized.

Reference:	Organism:	Reported or Normalized Acute Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, where applicable	Rationale for Omission:
Dowden, B.F. and H.J. Bennett. 1965. Toxicity of selected chemicals to certain animals. J. Water Pollut. Control Fed. 37(9):1308-1316.	*Daphnia magna*	Reported LC50s: 202 (24 h), 423 (25 h), 161 (48 h), 433 (50 h), 67 (72 h), 50 (96 h), 202, 139 (100 h)	pH not reported – LC50s could not be normalized.
	Lymnaea sp.	Reported LC50s: 241 (24 h), 173 (48 h), 73 (72 h), 70 (96 h)	pH not reported – LC50s could not be normalized.
Ewell, W.S., J.W. Gorsuch, R.O. Kringle, K.A. Robillard and R.C. Spiegel. 1986. Simultaneous evaluation of the acute effects of chemicals on seven aquatic species. Environ. Toxicol. Chem. 5(9):831-840.	*Daphnia magna*	Reported LC50 in paper = >100; Reported LC50 in ECOTOX = >20	Insufficient controls. pH that varied from 6.5-8.5 during the exposure. LC50 based on a 96 h (non-standard) test duration.
Goudreau, S.E., R.J. Neves, and R.J. Sheehan. 1993. Effects of wastewater treatment plant effluents on freshwater mollusks in the upper Clinch River, Virginia, USA. Hydrobiologia 252(3): 211-230.	*Villosa iris*	Normalized LC50 = 4.03	LC50 based on a 24 h (non-standard) test duration.
Hazel, R.H., C.E. Burkhead and D.G. Huggins. 1982. Development of water quality criteria for ammonia and total residual chlorine	*Etheostoma spectabile*	Normalized LC50s = 19.49, 16.56	Same data as in Hazel (1979) – see *E. spectabile* in Table 1.

Reference:	Organism:	Reported or Normalized Acute Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, where applicable	Rationale for Omission:
for the protection of aquatic life in two Johnson County, Kansas Streams. In: J.G. Pearson, R.B. Foster, and W.E. Bishop (Eds.), Proc. Annu. Symp. Aq. Tox., ASTM STP 766, Philadelphia, PA: 381-388.			
Hecnar, S.J. 1995. Acute and chronic toxicity of ammonium nitrate fertilizer to amphibians from Southern Ontario. Environ. Toxicol. Chem. 14(12):2131-2137.	*Pseudacris triseriata triseria*	Reported values: 100-d NOEC = 2.5, 100-d LOEC = 10 4-d LC50 = 17 4-d NOEC = 5, 4-d LOEC = 45	pH was not reported – normalized effect concentrations could not be calculated.
Hong, M., L. Chen, X. Sun, S. Gu, L. Zhang and Y. Chen. 2007. Metabolic and immune responses in Chinese mitten-handed crab (*Eriocheir sinesnsis*) juveniles exposed to elevated ambient ammonia. Comp. Biochem. Phys. C. 145:363-369	*Eriocheir sinesnsis*	Normalized LC50s: 65.27 (24 h), 56.44 (48 h), 40.47 (72 h), 31.04 (96 h)	Used municipal water as test water with no chemical description of sourcewater quality. No water quality information provided for crab farm where animals were obtained. No control to calculate LC50s.
Horne, F.R. and S. McIntosh. 1979. Factors influencing distribution of mussels in the Blanco River of Central Texas. Nautilus 94(4):119-133.	*Cyrtonaias tampicoensis*	Normalized LC50 = 4.12	LC50 based on a 7 d (non-standard) test duration.
	Toxolasma texasensis	Normalized LC50 = 4.12	LC50 based on a 7 d (non-standard) test duration.
	Corbicula manilensis	Normalized LC50 = 4.12	LC50 based on a 7 d (non-standard) test duration.
Kaniewska-Prus, M. 1982. The Effect of ammonia, chlorine, and chloramine toxicity on the mortality	*Daphnia magna*	Normalized LC50 = 0.30	LC50 based on a 24 h (non-standard) test duration.

Reference:	Organism:	Reported or Normalized Acute Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, where applicable	Rationale for Omission:
of *Daphnia magna* Straus. Pol. Arch. Hydrobiol. 29(3/4):607-624.			
Khatami, S.H., D. Pascoe and M.A. Learner. 1998. The acute toxicity of phenol and unionized ammonia, separately and together, to the ephemeropteran *Baetis rhodani* (Pictet). Environ. Pollut. 99: 379-387.	*Baetis rhodani*	Normalized 24-hr LC50 = 103.6	Species not resident in North America. LC50 based on a 24 h (non-standard) test duration.
Lee, D.R. 1976. Development of an invertebrate bioassay to screen petroleum refinery effluents discharged into freshwater. Ph.D. Thesis, VA Polytech. Inst. 108 pp.	*Daphnia pulex*	Normalized LC50s: 71, 22, 35, 66, 85 (24 h); 68, 18, 28, 35, 66 (48 h); 13, 14, 29 (96 h)	*D. pulex* used in the tests were 5-6 days old (instead of <24 h old).
Mangas-Ramirez, E. S.S.S. Sarma and S. Nandini. 2001. Acute and chronic toxicity of ammonium chloride to the cladoceran *Daphnia pulex* Leydig in relation to algal food density. Bull. Environ. Contam. Toxicol. 67:834-840.	*Daphnia pulex*	Normalized LC50s = 32.36, 35.57, 36.28	LC50 based on a 24 h (non-standard) test duration.
Meyer, J.S. and J.A. Hansen. 2002. Subchronic toxicity of low dissolved oxygen concentrations, elevated pH, and elevated ammonia concentrations to Lost River suckers. Trans. Amer. Fish. Soc. 131: 656-666.	*Deltistes luxatus*	Normalized LC50s = 15.81, 10.21, 18.41	LC50 based on a 48 h (non-standard) test duration.
Morgan, W.S.G. 1979. Fish Locomotor Behavior Patterns as a	*Micropterus salmonides*	Normalized EC50 = 1.17	Acute toxicity evaluated electronically based on activity. Exposure was only 24 h (non-standard)

Reference:	Organism:	Reported or Normalized Acute Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, where applicable	Rationale for Omission:
Monitoring Tool. J. Water Pollut. Control. Fed. 51(3):580-589.			in test duration. Concentrations were nominal.
Morgan, W.S.G. 1976. Fishing for toxicity: Biological automonitor for continuous water quality control. Effl. Water Treat. J. 16(9):471-475.	*Micropterus salmonides*	Normalized EC50 = 1.17	Added nominal concentrations equivalent to 48 h LC50 from previous literature values, then monitored opercular rhythm activity for 24 h.
Morgan, W.S.G., and P.C. Kuhn. 1974. A method to monitor the effects of toxicants upon breathing rate of largemouth bass (*Micropterus salmoides* Lacepede). Water Res. 8(1):67-77	*Micropterus salmonides* Lacepede	Normalized EC50s: 25.68 (11 h), 7.29 (22 h), 25.68 (23 h), 0.36 (44 h)	Similar to Morgan (1976). This is not an actual toxicity test. Rather, it is a test of a monitoring system that relates nominal LC50 concentrations (based on literature values), to breathing rate monitored over 24 h.
Morgan, W.S.G. 1978. The use of fish as a biol. sensor for tox. comp. in potable water. Prog. Water Tech. 10:395-398.	*Micropterus salmonides*	Normalized LC50 = 2.12	Similar to other Morgan studies listed in this table. Nominal ammonia concentrations based on literature LC50 concentrations are added to tanks, and breathing rate and activity level are monitored electronically for 24 h.
Passell, H.D., C.N. Dahm and E.J. Bedrick. 2007. Ammonia modeling for assessing potential toxicity to fish species in the Rio Grande, 1989-2002. Ecol. Appl. 17(7):2087-2099.	*Hybognathus amarus*	Secondary data; reported LC50 from Buhl 2002 = 1.01 mg/L NH3-N	In this study the frequency of acute ammonia exceedences were modeled by relating discharge, pH, temperature, and stream ammonia concentrations to literature LC50 values.
Rubin, A.J. and G.A. Elmaraghy. 1977. Studies on the toxicity of ammonia, nitrate and their mixtures to guppy fry. Water Res. 11(10):927-935.	*Poecilia reticulata*	Normalized LC50s = 37.7, 29.7, 32.6	Same 96 h LC50s as reported in Rubin and Elmaraghy (1976) – see Table 1.
Tabata, K. 1962. Toxicity of ammonia to aquatic animals with	*Poecilia reticulata*	Normalized LC50s = 28.76, 23.05	LC50s based on a 24 h (non-standard) test duration.

Reference:	Organism:	Reported or Normalized Acute Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, where applicable	Rationale for Omission:
reference to the effect of pH and carbonic acid. Bull. Tokai. Reg. Fish. Res. Lab. 34:67-74.			
Tonapi, G.T. and G. Varghese. 1987. Cardio-Physiological Responses of Some Selected Cladocerans to Three Common Pollutants. Arch. Hydrobiol. 110(1):59-65.	*Daphnia carinata*	Reported value = 0.5%	pH and temperature were not reported. Value based on a physiological endpoint obtained from a 15 minute exposure.
Watton, A.J. and H.A. Hawkes. 1984. The acute toxicity of ammonia and copper to the gastropod *Potamopyrgus jenkinsi* (Smith). Environ. Pollut. Ser. A 36:17-29.	*Potamopyrgus jenkinsi*	Normalized EC50s: 6.47 (48 h), 4.18 (96 h)	Species not resident inNorth America.
Woltering, D.M., et al. 1978. Predator-prey interactions of fishes under the influence of ammonia. Trans. Am. Fish. Soc. 107(3):500-504.	*Micropterus salmonides*	Normalized value: LOEC = 7.12, 15.68	Alternative endpoint obtained from a 10 d exposure where pH and temperature were not reported.

Table 10. Unused Chronic Studies Potentially Influential for Freshwater Ammonia Criteria Development.

Reference:	Organism:	Reported or Normalized Chronic Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, Where Applicable	Rationale for Omission:
Biswas, J.K., D. Sarkar, P. Chakraborty, J.N. Bhakta and B.B. Jana. 2006. Density dependent ambient ammonia as the key factor for optimization of stocking density of common carp in small holding tanks. Aquacult. 261(3):952-959	*Cyprinus carpio*	N/A	Fry were stocked at different densities at a single initial ammonia concentration. Ammonia concentration was allowed to increase during the study as a function of excretion, which varied across densities, and all tanks received equivalent fertilizer amendments during the study.
Colt, J. and G. Tchobanoglous. 1978. Chronic exposures of channel catfish, *Ictalurus punctatus*, to ammonia: Effects on growth and survival. Aquaculture 15(4):353-372.	*Ictalurus punctatus*	Normalized NOEC = 8.72	One of the chronic tests with channel catfish was a 31-day test of juvenile growth and survival by Colt and Tchobanoglous (1976). These authors did not provide complete data on survival at each concentration, but the information provided indicated that (a) at 5.0 mg N/L (total ammonia) and below, mortality averaged about 2%, (b) at 5.7 mg N/L mortality was between 28 and 45% (based on a reported range of 11 to 62% mortality in three replicates), (c) at 6.8 mg N/L mortality was 83%, and (d) at 9.5 mg N/L and above mortality was 100%. This indicates that the LC20 was between 5.0 and 5.7 mg N/L (at pH=8.35 and T=28^{O}C), or between 8.7 and 9.9 mg N/L when adjusted to

Reference:	Organism:	Reported or Normalized Chronic Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, Where Applicable	Rationale for Omission:
			pH=8 based on the chronic pH relationship. While this test was not used in deriving the GMCV, it did indicate that juvenile channel catfish were as sensitive as early life stages and was included as support that the GMCV derived from the early life stage tests was reasonable. In fact, if the factor of 1.5 is applied to this number to make it more applicable to longer chronic exposures, the GMCV would be around 6.2 mg N/L -- below the GMCV (8.84 mg N/L) derived from the early life stage tests. Because the 1.5 adjustment factor has questionable applicability to channel catfish, the GMCV from Table 5 is the most appropriate number to use for both early-life-stage and juvenile sensitivity.
DeGraeve, G.M., W.D. Palmer, E.L. Moore, J.J. Coyle and P.L. Markham. 1987. The effect of temperature on the acute and chronic toxicity of un-ionized ammonia to fathead minnows and channel catfish. Battelle, Columbus, OH.	*Pimephales promelas*	Normalized EC20s = 9.45, 9.72, 19.35, 17.54	Study evaluated the effect of ammonia on 30-day survival of juvenile fathead minnows at several temperatures. The tests at 15 and 20^{o}C did not have ammonia concentrations sufficiently high to cause effects, but survival was significantly decreased at the higher concentrations of ammonia in the tests run at 6, 10, 25, and 30^{o}C. At 30^{o}C, the mean measured DO concentration

Reference:	Organism:	Reported or Normalized Chronic Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, Where Applicable	Rationale for Omission:
			in most of the treatments was below 5.5 mg/L, but it was above 60% of saturation in all treatments. EC20s based on survival were calculated to be 11.9, 13.8, 39, and 39 mg N/L at temperatures of 6.0, 10.0, 25.4, and 30.2^{o}C and pHs of 7.83, 7.73, 7.35, and 7.19, respectively. When adjusted to pH=8, the EC20s are 9.45, 9.72, 19.35, and 17.54 mg N/L, respectively. Although these EC20s were used to assess the effect of temperature on the chronic toxicity of ammonia, they were not used in the derivation of the SMCV in the 1999 ALC document because they indicate that 30-day survival of juveniles is not as sensitive to ammonia as the life-cycle and early life-stage tests available for the species from other studies.
	Ictalurus punctatus	Normalized NOEC = 0.23	According to the 1999 update, problems with the channel catfish chronic tests precluded effective use of those data.
Diamond, J.M., D.G. Mackler, W.J. Rasnake and D. Gruber. 1993. Derivation of site-specific ammonia criteria for an effluent-dominated headwater stream. Environ. Toxicol. Chem. 12:649-658.	*Crangonyx sp.*	Normalized NOEC = 5.16	The NOEC based on a 21-d (non-standard) chronic exposure. The dissolved oxygen level in this test was abnormally low.
	Procambarus clarkii	Normalized NOEC = 5.47	The NOEC based on a 21-d (non-standard) chronic exposure. The

Reference:	Organism:	Reported or Normalized Chronic Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, Where Applicable	Rationale for Omission:
			dissolved oxygen level in this test was abnormally low.
Diamond, J.M., S.J. Klaine and J.B. Butcher. 2006. Implications of pulsed chemical exposures for aquatic life criteria and wastewater permit limits. Envir. Sci. & Tech. 40(16):5132-5138.	*Daphnia magna*		Growth and survival endpoints assessed following intermittent exposures in static renewal systems at concentrations too closely spaced to construct a dose-response relationship.
	Pimephales promelas		Omitted for the same reasons as was *Daphnia magna*.
Flis, J. 1963. Anatomicohistopathological changes induced in carp (*Cyprinus carpio* L.) by ammonia water. Part 1. Effects of toxic concentrations. Acta Hydrobiol. 10(1/2):205-224.	*Cyprinus carpio*	Normalized results: 1-d NOEC = 23.98 1-d LOEC = 24.85 35-d LOEC = 3.62	Two static renewal tests of non-standard test durations (1 and 35 d).
Hermanutz, R.O., S.F. Hedtke, J.W. Arthur, R.W. Andrew and K.N. Allen. 1987. Ammonia effects on microinvertebrates and fish in outdoor experimental streams. Environ. Pollut. 47:249-283.	*Pimephales promelas*	Normalized NOEC = 3.92	Hermanutz et al. (1987) studied the survival, growth, and reproduction of fathead minnows in experimental streams. Two generations were each exposed for periods of approximately two months, during which pH averaged 7.5 to 7.7 and temperature averaged 19.6ºC. Deleterious effects on biomass were not apparent at or below the highest tested concentration of ammonia, which was 3.92 mg N/L when adjusted to pH=8. These results are not included because they are from a field study where ammonia concentrations were highly variable.

Reference:	**Organism:**	**Reported or Normalized Chronic Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, Where Applicable**	**Rationale for Omission:**
	Ictalurus punctatus	Normalized NOEC = 1.80	Omitted for the same reasons as was *Pimephales promelas*.
Hernandez, C., M. Martin, G. Bodega, I. Suarez, J. Perez and B. Fernandez. 1999. Response of carp central nervous system to hyperammonemic conditions: An immunocytochemical study of glutamine synthetase (GS), glial fibrillary acidic protein (GFAP) and 70 kDa heat-shock protein (HSP70). Aquat. Tox. 45(2/3):195-207.	*Cyprinus carpio*	Normalized values: 60-d LOEC = 26.01 48-hr 100% lethal conc. = 52.03	Alternative endpoints used to assess toxicity not defensible; effects based on nominal concentrations from a static renewal test. Chronic effects were observed at a nominal concentration of 4mM after a 60 d exposure. One hundred percent lethality was observed at a nominal concentration of 8mM after 48 h.
Manissery, J.K., and M.N. Madhyastha. 1993. Haematological and histopathological effect of ammonia at sublethal levels on fingerlings of common carp *Cyprinus carpio*. Sci. Tot. Envir. (Suppl.):913-920.	*Cyprinus carpio*	Normalized values: LOECs = 2.73 and 8.92	Effects of ammonia were based on nominal concentrations from a 45 d static renewal exposure.
Meador, M.R. and D.M. Carlisle. 2007. Quantifying tolerance indicator values for common stream fish species of the United States. Ecol. Indicators 7:329-338.	*Multiple species*	N/A	No toxicity tests were performed in this study. Rather, field surveys were conducted classifying species as tolerant or sensitive to a suite of abiotic stressors following statistical (PCA) analysis.
Ram, R.N. and A.G. Sathyanesan. 1986. Inclusion bodies: Formation and degeneration of the oocytes in the fish *Channa punctatus* (Bloch) in response to ammonium sulfate treatment. Ecotoxicol. Environ. Saf. 11(3):272-276.	*Channa punctatus*	N/A	Species is not resident to North America.
Sadler, K. 1981. The toxicity of ammonia	*Anguilla*	Normalized NOEC = 4.91	The first five weeks of this test had

Reference:	**Organism:**	**Reported or Normalized Chronic Value expressed as Total Ammonia (mg N/L) at pH=8 and 25°C, Where Applicable**	**Rationale for Omission:**
to the European eel (*Anguilla anguilla* L.). Aquaculture 26(1/2):173-181.	*anguilla*		high mortality rates, leaving some tanks with too few survivors to estimate growth
Smith, C.E. 1984. Hyperplastic lesions of the primary meninx of fathead min., *P. promelas*, induced by ammonia: Sp. pot. for carcin. test. In: K.L. Hoover (ed.), Use of small fish species in carcinogenicity testing, Monogr. Ser. Natl. Cancer Inst. No. 65, NIH Publ. No. 84-2653, U.S. Dept. Health Hum. Serv., Natl. Cancer Inst., Bethesda, MD, pp. 119-125.		Normalized chronic values: 18.26 (60 d) 32.97 (133 d)	60 d chronic value was based on histological endpoints. Chronic effects were based on nominal concentrations.
Suski, C.D., J.D. Kieffer, S.S. Killen and B.L. Tufts. 2007. Sub-lethal ammonia toxicity in largemouth bass. Comp. Biochem. Phys. A. 146:381-389.	*Micropterus salmonides*	Normalized LOEC = 11.43 (swimming and ventilation rates)	A variety of chronic endpoints were assessed via exposure to only two ammonia concentrations. Effects were primarily assessed as a function of a80 ctivity level of varying duration.
Zischke, J.A. and J.W. Arthur. 1987. Effects of elevated ammonia levels on the fingernail clam, *Musculium transversum*, in outdoor experimental streams. Arch. Environ. Contam. Toxicol. 16(2):225-231.	*Musculium transversum*	Normalized LOEC = 2.07 (survival)	This was a flow-through, measured mesocosm experiment performed in the field. The test concentrations varied during the length of the experiment.

Appendix A

EPA Final Draft Position Statement on: Acute Toxicity Tests using Freshwater Mussels

(dated 04-28-09)

Acute Toxicity Tests using Freshwater Mussels

Position statement:

When water quality criteria for aquatic life are derived, results of 96-hr acute toxicity tests using juveniles of freshwater mussels will be reviewed for acceptability in the same way that results of acute toxicity tests using other aquatic animals are reviewed for acceptability. Results of acute toxicity tests using glochidia of freshwater mussels will be reviewed for acceptability after USEPA's Aquatic Life Criteria Coordinating Committee decides that it is possible to derive defensible species-specific approximations of the duration of the free-living portion of the glochidia life stage of about 95% of the glochidia that attach to hosts.

Rationale:

For the purposes of deriving aquatic life criteria, acute toxicity tests should usually be performed with young organisms because (i) they are often more acutely sensitive than adults of the same species and (ii) the acute sensitivity of a species to a pollutant is most usefully determined using the most sensitive life stage of the species. There are two young life stages of freshwater mussels: glochidia and juveniles. The juvenile life stage of freshwater mussels lasts for at least several weeks and so 96-hr acute toxicity tests with juvenile freshwater mussels are ordinary acute toxicity tests and will be reviewed for acceptability in the same way that acute toxicity tests with other aquatic animals are reviewed for acceptability.

The situation is more complicated for the glochidia life stage because, after a glochidium becomes free-living in the water column, it must attach to a host fish in order to develop into an encysted parasite. For those glochidia that become encysted parasites, the glochidia life stage is free living in the water column only from the time when it enters the water column until the time when it attaches to a host; the average duration of the free-living portion of the glochidia life stage differs from one species of freshwater mussel to another. Unfortunately, an LC50 determined using glochidia sometimes decreases substantially as the duration of the test increases from, for example, 6 hr to 24 hr to 96 hr. The most defensible duration of the glochidia test is based on the species-specific duration of the free-living portion of the glochidia life stage of about 95% of the glochidia that attach to hosts. Such species-specific information is not available for any species of freshwater mussel. Until defensible species-specific approximations of the duration of the free-living portion of the glochidia life stage of about 95% of the glochidia that attach to hosts are obtained, results of acute toxicity tests with glochidia will not be used in the derivation of water quality criteria for aquatic life.

In order to facilitate use of results of acute toxicity tests with glochidia in the derivation of water quality criteria for aquatic life, the Aquatic Life Criteria Coordinating Committee wants to obtain defensible species-specific approximations of the duration of the free-living portion of the glochidia life stage of about 95% of the glochidia that attach to hosts. ASTM (2006) and Cope et al. (2008) have been cited as providing useful information concerning toxicity tests with glochidia. All of the relevant information given in ASTM Standard E 2455 - 06 (Standard Guide for Conducting Laboratory Toxicity Tests with Freshwater Mussels) concerning appropriate species-specific durations for toxicity tests with glochidia is contained in the following excerpts:

a. In Section 4.1.1 it says:

> For most species, the duration of a toxicity test conducted with glochidia should be up to 24 h with survival measured at 6 and 24 h. Control survival is typically >90 % at the end of 24-h toxicity tests conducted with glochidia. Longer duration toxicity tests with glochidia (for example, 48 h)

> can be conducted as long as control survival >90 % is achieved. For example, toxicity tests conducted for 48 h with glochidia might be used for species for which juvenile mussels are not readily available for testing or for species with a life history where glochidia are released into the water column and remain viable for days before attaching to a host (in contrast to species that release glochidia in mucus strands or in conglutinates).

b. In Section 10.1.4 it says:

> The successful transfer of mature glochidia to a suitable host constitutes a critical event in the life cycle of most freshwater mussels. Various adaptations have evolved to facilitate this process. High levels of mortality occur during the passage of glochidia from the female mussel to the host fish due to the low incidence of fish host contact. Once encysted in the gill, glochidia may be relatively protected from in situ exposure [to] contaminants in water (Jacobson et al 1997). The method of host infestation greatly varies among species. While some species simply broadcast glochidia into the surrounding water to haphazardly come into contact with the appropriate host, the process is more intricate and direct for other species. For example, females in the genus Lampsilis have an extension of the mantle tissue that resembles a small fish or invertebrate complete with eye spots and appendages. This lure is displayed outside the shell between the valves and is twitched repetitively to attract a predaceous fish host. The host is infested while attempting to eat the lure when the marsupial gills of the female are ruptured (Kramer 1970, Barnhart and Roberts 1997). Some species release conglutinates (small structures containing glochidia) freely into the water. In many conglutinate-producing species (for example, Elliptio, Fusconia, Pleurobema, Plethobasus, Cyprogenia, and Quadrula), conglutinates are released as cohesive masses made up of unfertilized eggs that hold together mature glochidia. Conglutinates of some species (for example, Ptychobranchus) are made up of gelatinous material that enclose large numbers of glochidia (Hartfield and Hartfield 1996). Conglutinates may resemble prey items of the host fish; the host fish are infested with glochidia when fish attempt to eat conglutinates (Chamberlain 1934, Barnhart and Roberts 1997, Jones et al 2004).

c. Section A1.2.2 is almost identical to Section 4.1.1.

d. In Section A1.2.5 it says:

> Toxicity tests with glochidia have been conducted for up to 144 h, but 24 and 48-h exposures are most often used (Table A1.1). The relatively short duration of toxicity tests with glochidia is based on the relatively short duration between release of glochidia into the water column and encystment on the host and is based on the relatively short survival times of glochidia after isolation from the female mussel (Table A1.2). If the life history of a particular species in not known (for example, the host required for encystment or how long glochidia released from a female mussel can remain in the water column before encysting on a host), it might be appropriate to conduct toxicity tests with glochidia for longer than 24 h as long as 90 % control survival can be achieved at the end of the test.

e. In Section A1.2.6 it says:

> The time between release of glochidia from the marsupium of the female mussel to attachment of these glochidia on a host may take only a few seconds for some species (10.1.4), but hours are required for the gill tissue of a fish to migrate to form a cyst around the glochidia. During that time, the glochidia may be exposed to water-borne toxicants. Many anodontinae species release glochidia into water column that remain viable for days before infesting a host fish. Therefore, a prolonged glochidia test would have ecological relevance for these species. Other species release glochidia in mucus strands that coat the bottom or remain suspended on vegetation, waiting for their hosts to swim by and still other species release glochidia packaged in conglutinates that serve as a lure to host fish. Hence, glochidia of these species may also be in water for extended periods of time; however, it is not known how exposure to water-borne contaminants would be influenced by the mucus or conglutinate surrounding the glochidia.

All of the relevant information given in Cope et al. (2008, Differential exposure, duration, and sensitivity of unionoidean bivalve life stages to environmental contaminants; J. N. Am. Benthol. Soc. 27(2):451-462) concerning appropriate species-specific durations for toxicity tests with glochidia is contained in the following excerpts:

a. "Toxicity tests with glochidia generally are conducted for 24 h (ASTM 2006). This test duration is based largely on the presumed length of time glochidia are in the water between release from the female and encystment onto a host fish and their survival time in water. A 24-h test duration ensures 90% survival in control treatments at the end of the test (required by ASTM protocols; ASTM 2006, Ingersoll et al. 2007). The actual longevity of glochidia after release from the female and before attachment onto a host fish varies with species and water temperature (Zimmerman and Neves 2002), but can range from several days to several weeks (ASTM 2006; Ingersoll et al. 2007)."
b. "For example, we measured survival of glochidia ... More than 90% of the species tested had viable glochidia for at least 24 h after release from female mussels (Fig 3A,B)."
c. "However, the duration of a toxicity tests with glochidia may be adjusted to longer or shorter than 24 h, based on the life history of the particular species of interest (ASTM 2006). A portion of the glochidia released from some species with mantle-flap lure display or other fish-attracting behaviors might attach to host fish within seconds to hours (Ingersoll et al. 2007)."
d. "Moreover, many species of mussels snare or lure host fish and increase the probability of infestation by releasing glochidia contained within mucus strands or conglutinate packets resembling prey items of fish (Watters 2007). Thus, glochidia of these species might remain in the water or on the sediment surface for extended periods of time. No studies are available on the toxicity of waterborne or sediment-associated contaminants to glochidia contained in these structures."
e. "Based on the available information for glochidia, the primary route of exposure for contaminants is through surface water, and occurrence of the exposure can be when the larvae are free in the water or packaged in mucus and conglutinates over the course of seconds to days."

USEPA's Aquatic Life Criteria Coordinating Committee has the following comments:

1. When water quality criteria for aquatic life are derived, USEPA does not automatically accept all toxicity tests that are performed according to an ASTM standard or according to "Standard Methods". USEPA reviews results of all aquatic toxicity tests for acceptability.
2. Aquatic species that are critical, keystone, threatened, endangered, of concern, unique, rare, and/or imperiled can receive special consideration in the derivation of site-specific water quality criteria for aquatic life, but not in the derivation of national water quality criteria for aquatic life.
3. There is no evidence that glochidia that are in mucus, in conglutinates, in lures, or attached to a host are exposed to water-borne pollutants; such exposure is hypothetical. Most uptake of pollutants by aquatic organisms occurs via gills and food.
4. Neither ASTM (2006) nor Cope et al. (2008) gives much defensible information concerning appropriate species-specific durations for toxicity tests with glochidia.
5. ASTM (2006) says that a 24-hr toxicity test should be performed with glochidia and survival should be measured at 6 and 24 hr, but it does not say how the 6-hr data and the 24-hr data should be used.
6. Figures 3A and 3B in Cope et al. (2008) show that glochidia of about five species had more than 10% mortality in less than 24 hr and a few more species had more than 10% mortality in less than 48 hr. It appears that glochidia of several species would have less than 90% survival in a 24-hr test.
7. Studies of the viability of free-living glochidia provide upper limits on the duration of the free-living portion of the glochidia life stage of glochidia that attach to hosts.
8. For glochidia that attach to hosts, there is a major difference between (i) glochidia that are in mucus, conglutinates, and lures and (ii) glochidia that are broadcast.

a. Glochidia are in mucus, conglutinates, and lures in order to facilitate rapid attachment to hosts; attachment apparently often begins within seconds after the glochidia become free-living. It is quite possible that the duration of the free-living portion of the glochidia life stage of about 95% of the glochidia in mucus, conglutinates, and lures is substantially less than 6 hours.
b. Other than the upper limits from laboratory studies of the viability of free-living glochidia, it is possible that, for species of freshwater mussels that broadcast glochidia, no defensible information is available concerning the duration of the free-living portion of the glochidia life stage of glochidia that attach to hosts.

Appendix B

EPA Final Draft Position Statement on:
Toxicity Tests on Ammonia using *Hyalella azteca*
(dated 04-28-09)

Toxicity Tests on Ammonia using *Hyalella azteca*

Position statement:

Neither a Species Mean Acute Value nor a Species Mean Chronic Value for H. azteca should be used in the derivation of a freshwater aquatic life criterion for ammonia at this time.

Rationale:

Several laboratories have reported regular or intermittent difficulty obtaining acceptable survival and growth of H. azteca during testing and culturing. Although some waters seem to be usually acceptable, it is not known why some of these waters work and others don't. Studies are currently being conducted in an attempt to develop waters and/or foods that will give improved survival, growth, and/or reproduction of this species, but much uncertainty remains. Although several water quality characteristics might be important, it seems reasonably certain that, at a minimum, chloride, and possibly bromide, are important to this species, as discussed in the following paragraphs.

Any consideration of toxicity tests using H. azteca should take into account the information that is now available concerning the possible importance of chloride to this species.

a. Smith et al. (1997) said that when they used KCl as a reference toxicant for acute toxicity tests using H. azteca, survival in the control treatments was never >70%, but survival in the lowest tested concentration of KCl was >80%. These tests used moderately hard reconstituted water, which contained 2 mg Cl/L. When they used a reformulated moderately hard reconstituted water that contained 34 mg Cl/L, it gave acceptable control survival in 96-hr tests. There is no indication that an attempt was made to determine the minimum acceptable concentration of chloride and/or the optimum concentration of chloride.

b. Soucek (2007) studied the effect of chloride on the toxicity of sulfate to H. azteca and Ceriodaphnia dubia. With H. azteca, as the concentration of chloride increased from 5 to 25 mg/L, the LC50 for sulfate increased substantially, but as the concentration of chloride increased from 100 to 500 mg/L, the LC50 for sulfate decreased substantially. With C. dubia, as the concentration of chloride increased from 5 to 25 mg/L, the LC50 for sulfate increased slightly, but as the concentration of chloride increased from 100 to 500 mg/L, the LC50 for sulfate decreased substantially. The LC50s for sulfate at 100 mg Cl/L were slightly higher than at 25 mg Cl/L for both species, but no tests were performed with either species at concentrations of chloride between 25 and 100 mg Cl/L. One possible interpretation of these results is that (i) the healthiness of H. azteca increased as the concentration of chloride increased from 5 to 25 mg/L and (ii) H. azteca was about as healthy at 100 mg Cl/L as at 25 mg Cl/L. It is interesting that the concentration of chloride in the Smith et al. (1997) reformulated moderately hard reconstituted water is between 25 and 100 mg/L.

c. On page 357 of Borgmann (1996) it says "Survival was substantially improved by the addition of NaCl, but was not improved further by the addition of KCl"; however, the NaCl addition raised the concentration of chloride from 0 to 21.3 mg Cl/L, whereas the further addition of KCl only raised the concentration of chloride from 21.3 mg Cl/L to 22.7 mg Cl/L. This is not a valid test of the possible usefulness of concentrations of chloride greater than 21.3 mg Cl/L.

d. The tap water that was successfully used by Borgmann (1996) contained 26 mg Cl/L and Borgmann's recommended SAM-5S water contains 73 mg Cl/L, both of which are between 25 and 100 mg/L. The higher concentration of chloride in SAM-5S water is due to the use of $CaCl_2$ as the source of calcium because it is more soluble than $CaSO_4$ and $CaCO_3$.

e. Lasier et al. (1997) reported that a toxicity test on sodium chloride using H. azteca produced a 96-hr LC50 of 3947 mg Cl/L in moderately hard reconstituted water.

It appears that (i) H. azteca is not healthy in waters having low concentrations of chloride, (ii) low concentrations of chloride increase the sensitivity of this species to sulfate, and (iii) the mitigating concentrations of chloride are much lower than concentrations that are acutely toxic to H. azteca.

Further, any consideration of toxicity tests using H. azteca should take into account the information that is now available concerning the possible importance of bromide to this species.

a. Borgmann (1996) said that H. azteca requires bromide and recommended 0.8 mg bromide/L. The concentration of bromide was not measured in the tap water that was successfully used by Borgmann, but the tap water is from Lake Ontario. Tiffany et al. (1969) reported that the concentration of bromide was 0.047 mg/L in Lake Ontario water and 0.013 mg/L in Lake Superior water. Borgmann's comparison of various concentrations of bromide used concentrations that differed by a factor of ten. The concentration of bromide in the waters used by Smith et al. (1997) and Soucek (2007) is not known.

b. Borgmann et al. (2005a) cultured H. azteca in dechlorinated Burlington City tap water and performed acute toxicity tests with H. azteca in dechlorinated Burlington City tap water and in a mixture of 10% dechlorinated tap water and 90% deionized water. Even though these two waters potentially contained 1/17 and 1/170 the concentration of bromide recommended by Borgmann (1996), Borgmann et al. (2005a) apparently were comfortable using them for culturing and testing H. azteca.

c. Soucek (personal communication to C. Stephan) said that when he transferred H. azteca from a culture in Smith et al. water to Borgmann water, the organisms did not do well. In contrast, when he slowly changed the water from Smith et al. water to Borgmann water, the organisms survived, grew, and reproduced.

d. Borgmann et al. (2005b) performed toxicity tests on copper using H. azteca in both artificial media and in dechlorinated Burlington City tap water. It was reported that "$CaBr_2$ was added to the artificial media to give a constant ratio of 0.01 mole Br^- per mole of Ca^{2+} because Br is essential to Hyalella and is required in combination with Ca". When Stephan asked Borgmann (via email) the justification for "0.01 mole Br per mole of Ca", he replied (via email):

> A 1:1000 ratio of Br to Ca is probably sufficient (see Fig. 2 in our 1996 paper), but we go with 1:100 just to be sure we have enough Br. We keep the Br to Ca ratio constant because Hyalella do well in both Lake Ontario water and in 10% Lake Ontario Water + 90% distilled water, however, they do not survive well in 10% Lake Ontario water if CaCl2 is added to bring the Ca back to it's original level (roughly 1 mM Ca, with Br estimated at 0.6/10 uM, for a Br to Ca ratio of about 0.6 to 10000). This suggests that either the Ca/Br ratio is critical, or that the Br/Cl ratio is important (i.e., Cl might interfere with Br's role). Since Ca is usually added as $CaCl_2$, we need to beef up the Br concentration whenever we add $CaCl_2$.

The information provided by Borgmann does not provide a valid basis for making a decision regarding the possible importance of bromide to H. azteca.

Another possible complication is the range of surface waters inhabited by H. azteca and the diversity that apparently exists within what is classified as "H. azteca" (Alcocer et al. 1998; Colburn 1988; France 1992; Galat et al. 1988; Thomas et al. 1997; Wellborn and Cothran 2004; Wellborn et al. 2005; Witt et al. 2006; Wollheim and Lovvorn 1995).

Seven documents report results of toxicity tests on ammonia using H. azteca:

1. Sarda (1991) says that the tests were 96 hr in the text, but pages 178 and 179 only give survival after 48 hr. There is nothing to imply that the tests were renewal or flow-through, so they were probably static. The test material was ammonium chloride. It is said that pH was altered but it does not say how and no results are given for H. azteca at various values of pH. Temperature was measured daily whereas pH was measured at the beginning and end of the tests. Total ammonia was measured using an electrode but it doesn't say when the measurements were made. Tests were performed in two waters (a reconstituted water and a creek water) that differed with respect to pH and hardness. Hardness, alkalinity, and pH changed substantially during the tests. Control survival was acceptable. The concentration of chloride in the creek water is not known. The formula for preparing the reconstituted water is given in Appendix A; one of the ingredients is Perrier water and www.usa.perrier.com says that the concentration of chloride in Perrier water is 26 mg/L. Because the test material was ammonium chloride, the concentration of chloride differed from one treatment to another. The results of these tests should not be used in the derivation of aquatic life criteria because, among other things, hardness, alkalinity, and pH changed substantially during the tests and the concentration of chloride changed from one treatment to another.
2. Borgmann (1994) performed a variety of toxicity tests, two of which were 10-week water-only life-cycle toxicity tests in which the test solutions were renewed weekly. Ammonia was measured at the beginning and end of each renewal; the measured concentrations were close to nominal and the final/initial measured ammonia concentrations averaged 1.09. pH was measured three times per week. Ten-week control survival averaged 66.3%. The test material was ammonium chloride and the dilution water was dechlorinated tap water that contained 26 mg Cl/L. On the basis of the nominal concentrations of total ammonia, the increase in the concentration of chloride at the lowest tested concentration of ammonia was 3.5 mg Cl/L whereas the increase at the highest tested concentration of ammonia was 64 mg Cl/L. Thus the concentration of chloride in the treatments ranged from about 30 mg Cl/L to about 90 mg Cl/L. This range is within the range of 25 to 100 mg Cl/L, but no data are available concerning the effect of chloride in the range from 25 to 100 mg/L on H. azteca or on its sensitivity to ammonia.
3. Ankley et al. (1995) performed 96-hr water-only toxicity tests in which the test solutions were renewed daily. The test organisms were cultured in hardened Lake Superior water and tests were performed at three values of pH in each of three waters (soft water = Lake Superior water; moderately-hard water = hardened Lake Superior water; hard water = salts added to Millipore water). The test material was ammonium chloride and HCl was used to acidify some test solutions. Biesinger and Christensen (1972) reported that the concentration of chloride in Lake Superior water was 1.2 mg/L and Tiffany et al. (1969) reported that the concentration of chloride in Lake Superior was 1.4 mg/L. The concentration of chloride in the hardened Lake Superior water is about 19 mg/L, based on information in an SOP for culturing H. azteca at MED. The concentration of chloride in the hard water used in these tests was probably near 4 mg Cl/L. The increase in the concentration of chloride due to acidification is not known. On the basis of the nominal concentrations of total ammonia, the increase in chloride at the lowest and highest reported LC50s was 44 mg Cl/L and 516 mg Cl/L, but the range within any one test would not be nearly this large. It is known that H. azteca does not do well in Lake Superior water. In addition, one investigator found that fathead minnows and C. dubia do not do well when a CO_2-enriched atmosphere is used to maintain pH, which means that this technique might adversely affect H. azteca.
4. Whiteman et al. (1996) compared the toxicity of ammonia in a spiked-sediment exposure versus a water-only exposure. The water-only toxicity test was a flow-through 96-hr test and the test material was ammonium chloride. The dilution water was dechlorinated tap water from Superior, WI, which is taken from a well in a sandy area near Lake Superior, and so the concentration of chloride in this water was probably less than 2 mg/L. Ammonia, temperature, and pH were measured sufficiently often. The increase in the concentration of chloride due to the test material at the 96-hr LC50 was 23 mg Cl/L;

thus the amount of increase in the concentration of chloride in some treatments would be less than 25 Cl/L in treatments below the LC50, but would be greater than 25 mg Cl/L in treatments above the LC50. The results of these tests should not be used in the derivation of water quality criteria because of the low concentration of chloride in Lake Superior water.

5. Borgmann and Borgmann (1997) performed water-only toxicity tests in which the test solutions were renewed weekly. The test material was ammonium chloride and HCl was used to acidify some solutions. They reported that sodium and potassium affected the toxicity of ammonia to H. azteca and that the effect of pH on the toxicity of ammonia to H. azteca depends on hardness and on the concentrations of sodium and potassium. On the basis of some dilution tests, they concluded that calcium, magnesium and anions did not affect the toxicity of ammonia, but they did not actually study the effect of a series of closely-spaced concentrations of calcium, magnesium, or any anion on the toxicity of ammonia.
6. Besser et al. (1998) performed 96-hr static toxicity tests on two sediments that were spiked with a solution that was prepared by adding ammonium chloride to a 50-50 mixture of well water and deionized water. One sediment was from Little Dixie Lake and the other was a formulated sediment. The dilution water contained about 11 mg Cl/L and 0.2 mg Br/L (C. Ingersoll, personal communication to C. Stephan on 4-28-09); it is possible that one or both of the sediments increased or decreased the concentrations of chloride and/or bromide in the test solutions. The methodology used for these tests makes the results unacceptable for use in the derivation of water quality criteria because the concentration of ammonia in the pore water is not known. Nevertheless, these results are interesting because “Ammonia toxicity to amphipods, expressed as either total ammonia or un-ionized ammonia, was similar to results of other 96-h tests at comparable pH and hardness [4],” where reference 4 is Ankley et al. (1995).
7. Wang et al. (2008) performed 48-h toxicity tests on ammonia at pH = 6.5, 7.5, 8.0, 8.5, and 9.0 using a combination of ammonium chloride and ammonium hydroxide. The pH of some solutions was adjusted using HCl. The dilution water was reconstituted hard water that contained 7.9 mg Cl/L. At only two of the pHs were the concentrations of ammonia sufficiently high to kill more than 20% of the H. azteca in any of the treatments, and in both of these tests the percent survival was higher at several concentrations of ammonia that were higher than the concentration at which the percent survival was lowest.

Data reported by Sarda (1991) and Besser et al. (1998) concerning the sensitivity of H. azteca to ammonia should not be used in the derivation of an aquatic life criterion for ammonia. Data from the other publications are very questionable because of concerns regarding the importance of chloride and bromide to H. azteca, the possible effect of chloride and/or bromide on the toxicity of ammonia to H. azteca, the use of ammonium chloride as the test material, the use of hydrochloric acid to acidify some test solutions, the use of dilution waters that contained low concentrations of chloride in some of the tests, and other aspects of the methodology used in some of the tests. Some of these issues are of much more concern in water-only tests with this species than in sediment tests. It is not known how much of the wide range of ammonia LC50s obtained with H. azteca is due to water quality, the methodology used in some of the tests, and/or the health of the organisms. It appears that some of the lowest acute values were obtained using dilution waters that contained low concentrations of chloride.

Studies are currently under way that might provide additional information concerning the importance of water quality to H. azteca. These studies might make it possible to perform one or more high quality toxicity tests on ammonia using H. azteca in the near future and might make it possible to identify one or more published results that are probably high quality in the near future.

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Appendix C

EPA Final Draft Position Statement on:
28-day Toxicity Tests using Juvenile Freshwater Mussels

(dated 04-28-09)

28-day Toxicity Tests using Juvenile Freshwater Mussels

Position statement:

In accordance with the 1985 Guidelines, 28-d survival and growth tests using juvenile freshwater mussels do not qualify as chronic toxicity tests for use in the derivation of aquatic life criteria. Nevertheless, a concentration that causes a reduction in survival of 20% or more can be used as an upper limit on a Species Mean Chronic Value if the test is otherwise acceptable. A concentration that causes a reduction in growth cannot be similarly used at this time because of uncertainties concerning these data. Therefore, growth data from 28-day toxicity tests with juvenile mussels should be included in a criteria document as "other data" if the tests are otherwise acceptable.

Rationale:

The 1985 Guidelines describe three kinds of toxicity tests that can be used in the derivation of a Species Mean Chronic Value: life-cycle tests, partial life-cycle tests, and early life-stage (ELS) tests with fishes. The 28-d survival and growth test using juvenile freshwater mussels is neither a life-cycle test nor a partial life-cycle test, and ELS tests are used as predictors of life-cycle tests only for fishes. Thus, as for any other similarly tested species that is not a fish, the 28-d survival and growth test with juvenile mussels is not an acceptable chronic toxicity test for use in the derivation of a Species Mean Chronic Value.

Because of the complexities in their life cycle, development of testing methods for freshwater mussels is very challenging. Although standard procedures have been adopted by ASTM, current literature shows that several aspects of juvenile mussel testing are still being evaluated; variables include the type and ration of food provided, and the water renewal and exposure apparatus that will sustain juvenile mussels in good health and provide a level of control growth reflective of an organism otherwise free of substantial background stress. These issues are further complicated by the comparatively limited data from which to establish minimum performance criteria for juvenile mussel tests across the diversity of mussel taxa, particularly for growth.

Toxicity tests with invertebrates that cover less than the full life cycle are not used in the derivation of Species Mean Chronic Values because of uncertainties regarding the relation of results of these shorter tests to results that would be obtained in full life-cycle tests. The above methodological issues notwithstanding, survival data from less than life-cycle tests can be used to establish an upper limit on a Species Mean Chronic Value because death is not reversible and so effects on survival are expected to translate directly to the outcome of a life-cycle chronic test if one were performed. Accordingly, reduction in survival in 28-d juvenile mussel tests can be used to set an upper limit on a Species Mean Chronic Value if the test is conducted in a manner consistent with the 1985 Guidelines, the control survival is adequate, and the organisms appear to be healthly. The resulting Species Mean Chronic Value would be an inequality indicating that the expected chronic value for that species is not more than the concentration of the pollutant that reduced survival by 20% or more in the 28-d juvenile test.

In a previous criteria document, tests concerning growth of organisms in non-life-cycle tests with duration less than 90 days were not used in the derivation of a Species Mean Chronic Value (see page 45 in the 1999 ammonia criteria document). The reason for this is the lack of direct comparisons between these shorter tests and life-cycle tests (as exists for ELS tests with fish), and the accompanying uncertainties regarding the quantitative relationship between growth reductions observed over shorter exposures of only certain life stages and the expected effect on growth in a life-cycle test. In addition, some growth effects, particularly smaller reductions, might be transient during a longer exposure, and the 28-day exposure period represents a relatively small percentage of the overall duration of the juvenile life stage of mussels. As such, reduction in growth during a 28-d juvenile mussel test would be incorporated as “other data” (traditionally Table 6 of criteria documents), just as would be done with short-term growth data for any other species (if the test was otherwise acceptable), except for growth data that are used to determine the results of an ELS test. This placement is not because growth of juvenile mussels lacks biological importance, but because of the attendant uncertainties surrounding the methodologies used to generate the growth data and the uncertainties in relating any observed reductions to results of life-cycle toxicity tests.

As stated in the 1985 Guidelines, test results that do not otherwise qualify as acceptable acute or chronic toxicity data (typically compiled in Table 6) have the potential to influence an aquatic life criterion if the data indicate that the criterion is not consistent with sound scientific evidence (see Section XII.B of the 1985 Guidelines). It is likely that a concentration of a pollutant that causes a reduction in growth can be used as an upper limit on a Species Mean Chronic Value if, on a species-specific basis, the test is sufficiently long to indicate that the reduction is not transient (e.g., is not due to initial shock), if the percent reduction in growth is sufficiently great (i.e., the shorter the test, the larger a percent reduction must be in order to be considered unacceptable), and if the test is otherwise acceptable.

C. Ingersoll (personal communication to C. Stephan on 6-11-08) thinks that it might be possible to perform acceptable 90-d toxicity tests with juvenile freshwater mussels. If acceptable 90-d juvenile toxicity tests can be performed, it would be possible to determine whether the percent reductions in survival and growth in 90 days are greater than, less than, or the same as the percent reductions in survival and growth in 28 days. However, regardless of the relationship between 28-d and 90-d results, both the reduction in survival and the reduction in growth in a 90-d toxicity test with juvenile freshwater mussels can be used in the derivation of a SMCV, if the test is otherwise acceptable.

Appendix D

Conversion of Acute Results of Toxicity Tests

All of the ammonia acute values (LC50s and EC50s) in Table 1 of this document were converted to total ammonia nitrogen acute values using the reported temperatures and pHs, and using the pK relationship from Emerson et al. (1975). Conversions were dependent on the form of ammonia the acute values were expressed, e.g., un-ionized ammonia (UIA), un-ionized ammonia expressed as nitrogen (UIA-N), total ammonia (TA) and total ammonia nitrogen (TAN). Once all the acute values were converted to total ammonia nitrogen, these values were then adjusted to pH=8 using the pH relationship developed in the 1999 criterion document. After the adjustment to pH 8, the total ammonia nitrogen acute values were further normalized to a temperature of 25°C for invertebrates only, as per the recommendations in the 1999 criterion document. The conversion procedure is illustrated here using the data for the flatworm, *Dendrocoelum lacteum*, which is the first species in Table 1 in the 1984/1985 criteria document and was the species chosen to illustrate the conversion procedure in Appendix 3 of the 1999 criterion document:

Acute value (AV) = 1.40 mg un-ionized ammonia (UIA) or NH_3/L
pH = 8.20
Temperature = 18.0°C

Step 1.

Equation 3 in the 1999 criterion document is used to calculate the pK at 18 °C:
pK = 9.464905

Step 2.

Equation 2 in the 1999 criterion document and the definitions $pK = -\log_{10}K$ and $pH = -\log_{10}[H^+]$ are used to obtain the following:

$$\text{Total ammonia} = [NH_3] + [NH^+_4] = [NH_3] + [NH_3]/0.0543369$$

Step 3.

The AV in terms of total ammonia is calculated as:

$$[NH_3]/[NH^+_4] = 10^{(pH\text{-}pK)} = 0.0543369$$

= 27.1652 mg total ammonia/L

Step 4.

The AV in terms of total ammonia nitrogen (AV_t) is calculated as follows:

AV_t = (27.1652 mg total ammonia/L)(14/17)
= 22.3713 mg N/L.

Step 5.

The AV in terms of total ammonia nitrogen, or AV_t, is converted from pH=8.2 to pH=8 using Equation 11 in the 1999 criterion document:

$$AV_{t,8} = (AV_t)/(0.681546) = 32.8244 \text{ mg N/L}$$

Step 6. (temperature adjustment for invertebrates only)

The AV in terms of total ammonia nitrogen at pH=8, or $AV_{t,8}$, is converted from this concentration at test temperature to a standard test temperature of 25°C using Equation 5 in the 1999 criterion document with the invertebrate acute slope of -0.036:

$$\log(AV_{t,8,25}) = \log(AV_{t,8}) - [-0.036(18\,^\circ C - 25\,^\circ C)]$$

= 18.3737 mg N/L.

Because this is the only species in this genus for which data are in Table 1 in the 1984/1985 criteria document, 18.37 mg N/L is the GMAV given for the genus Dendrocoelum in Table 1 of this update document.

Appendix E

Conversion of Chronic Results of Toxicity Tests

As in the previous appendix with the acute results of toxicity tests, all of the ammonia chronic values (EC20s and IC20s) in Table 3 of this document were converted to total ammonia nitrogen chronic values using the reported temperatures and pHs, and using the pK relationship from Emerson et al. (1975). Conversions were dependent on the form of ammonia the acute values were expressed. Once all the chronic values were converted to total ammonia nitrogen, these values were then adjusted to pH=8 using the pH relationship developed in the 1999 criterion document. After the adjustment to pH 8, the total ammonia nitrogen chronic values were further normalized to a temperature of 25^{o}C for invertebrates only, as per the recommendations in the 1999 criterion document. The conversion procedure is illustrated here using the data for the wavy-rayed lamp mussel, *Lampsilis fasciola*, which is one of the several species in the genus Lampsilis ranked third in Table 3 in this update document and was the species chosen to illustrate the conversion procedure used in this document and the 1999 criterion document:

Chronic value (CV) = EC20 of <0.3981 mg total ammonia nitrogen (TAN)/L
pH = 8.20
Temperature = 20.0^{o}C

Step 1 through 4

(unnecessary in this case as CV is already expressed in terms of TAN, for more details regarding these steps, see Appendix C).

Step 5.

The CV in terms of total ammonia nitrogen, or CV_t, is converted from pH=8.2 to pH=8 using Equation 12 in the 1999 criterion document:

$$CV_{t,8} = (CV_t)/(0.736263) = <0.5407 \text{ mg N/L}$$

Step 6. (temperature adjustment for invertebrates only)

The CV in terms of total ammonia nitrogen at pH=8, or $CV_{t,8}$, is converted from this concentration at test temperature to a standard test temperature of 25^{o}C using Equation 5 in the 1999 criterion document with the invertebrate chronic slope of -0.028:

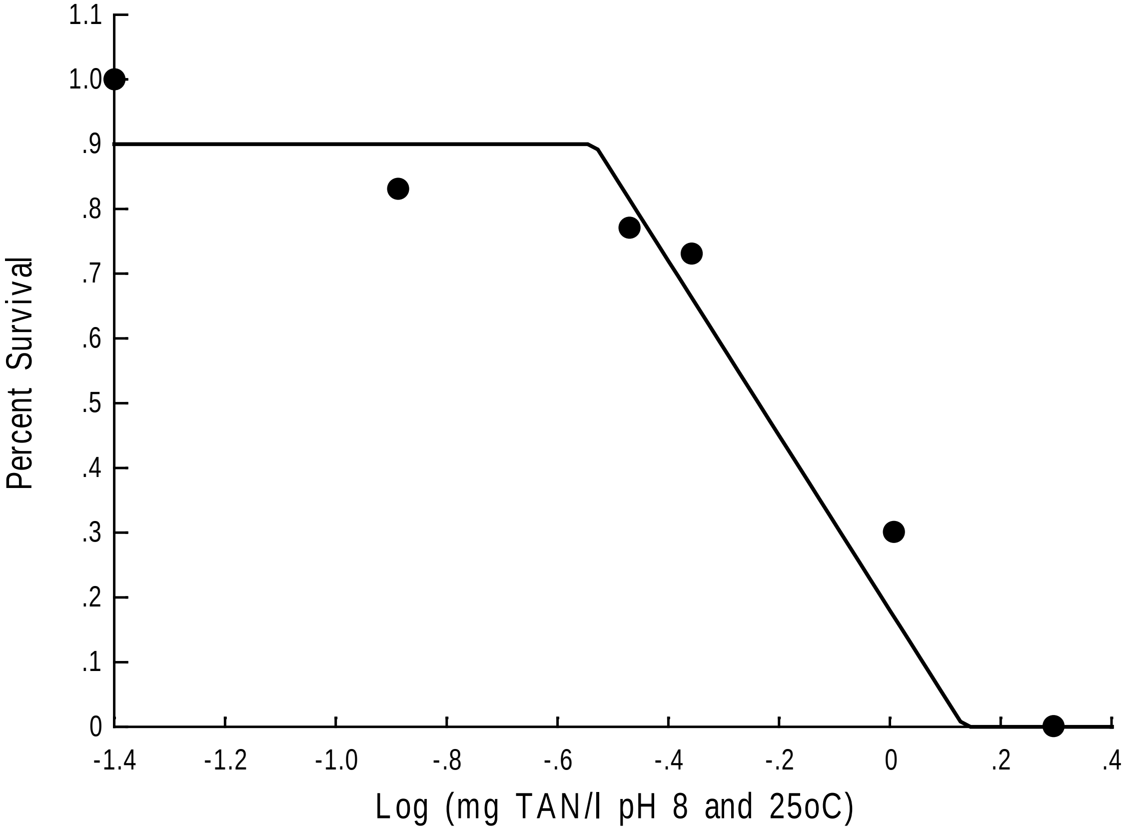
$$\log(CV_{t,8,25}) = \log(CV_{t,8}) - [-0.028(20^{o}C - 25^{o}C)]$$
$$= <0.3917 \text{ mg N/L}$$

Because this is one of two species in this genus for which data are in Table 3 of this document, the geometric mean of this value (<0.3917 mg N/L) and <0.3027 mg N/L for *Lampsilis siliquoidea* is the GMCV given for the genus Lampsilis (<0.34 mg N/L, rounded to two significant figures) in Table 3 of this update document.

Appendix F

Results of the Regression Analyses of New Chronic Data

WAVY-RAYED LAMP MUSSEL, 28-D EXPOSURE OF JUVENILES, WANG et al. (2007a)



```
              Parameter Summary (Piecewise Linear Regression Analysis)
Parameter             Guess      FinalEst     StdError     95%LCL      95%UCL

LogX50             -0.20000      -0.20000      0.10810   -0.54402     0.14402

S                    1.5000        1.5000       0.6938    -0.7080      3.7080

Y0-Transformed       1.2490        1.2490       0.2432     0.4751      2.0230
  Untransformed      0.9000        0.9000         -        0.2093      0.8091
```

```
                         Effect Concentration Summary
      %Effect            Xp Est             95%LCL             95%UCL
        50.0             0.6310             0.2857             1.3932
        20.0             0.3981             0.1476             1.0737
        10.0             0.3415             0.1088             1.0714
         5.0             0.3162             0.0926             1.0795
```

```
                       Regression Analysis of Variance
Source          df          SS          MS             F          Alpha

Total            5      1.4081      0.2816

Regression       2      1.2804      0.6402          15.0         0.0273

Error            3      0.1277      0.0426
```

```
                               Data Summary
  Exposure     Obs Effects    Pred Effects       Residual         Weight
   -1.3979          0.9990          0.9000        -0.0990             1.
   -0.8861          0.8300          0.9000         0.0700             1.
   -0.4685          0.7700          0.8125         0.0425             1.
   -0.3565          0.7300          0.6613        -0.0687             1.
    0.0086          0.3000          0.1684        -0.1316             1.
    0.2967          0.0000          0.0000         0.0000             1.
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                               Error Summary
                                 No Errors
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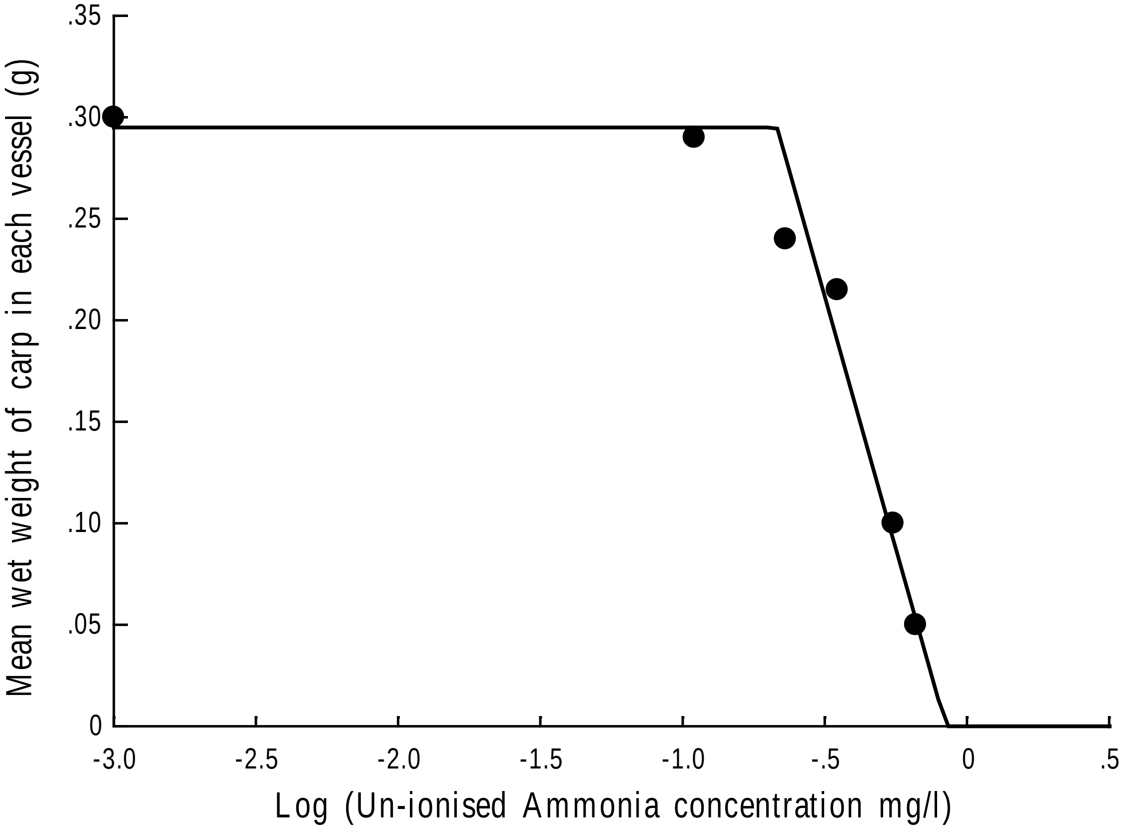
COMMON CARP, 28-D EXPOSURE OF LARVAE, MALLET AND SIMS (1994)



Parameter Summary (Piecewise Linear Regression Analysis)

Parameter	Guess	FinalEst	StdError	95%LCL	95%UCL
LogX50	-0.40000	-0.37111	0.06920	-0.59133	-0.15089
S	2.000	1.6850	0.5801	-0.1610	3.5311
Y0-Transformed	-0.52288	-0.53024	0.05838	-0.71603	-0.34445
Untransformed	0.3000	0.2950	-	0.1923	0.4524

Effect Concentration Summary

%Effect	Xp Est	95%LCL	95%UCL
50.0	0.4255	0.2563	0.7065
20.0	0.2824	0.1357	0.5878
10.0	0.2463	0.1054	0.5756
5.0	0.2301	0.0926	0.5718

Regression Analysis of Variance

Source	df	SS	MS	F	Alpha
Total	5	0.48289	0.09658		
Regression	2	0.47346	0.23673	75.3	0.0027
Error	3	0.00943	0.00314		

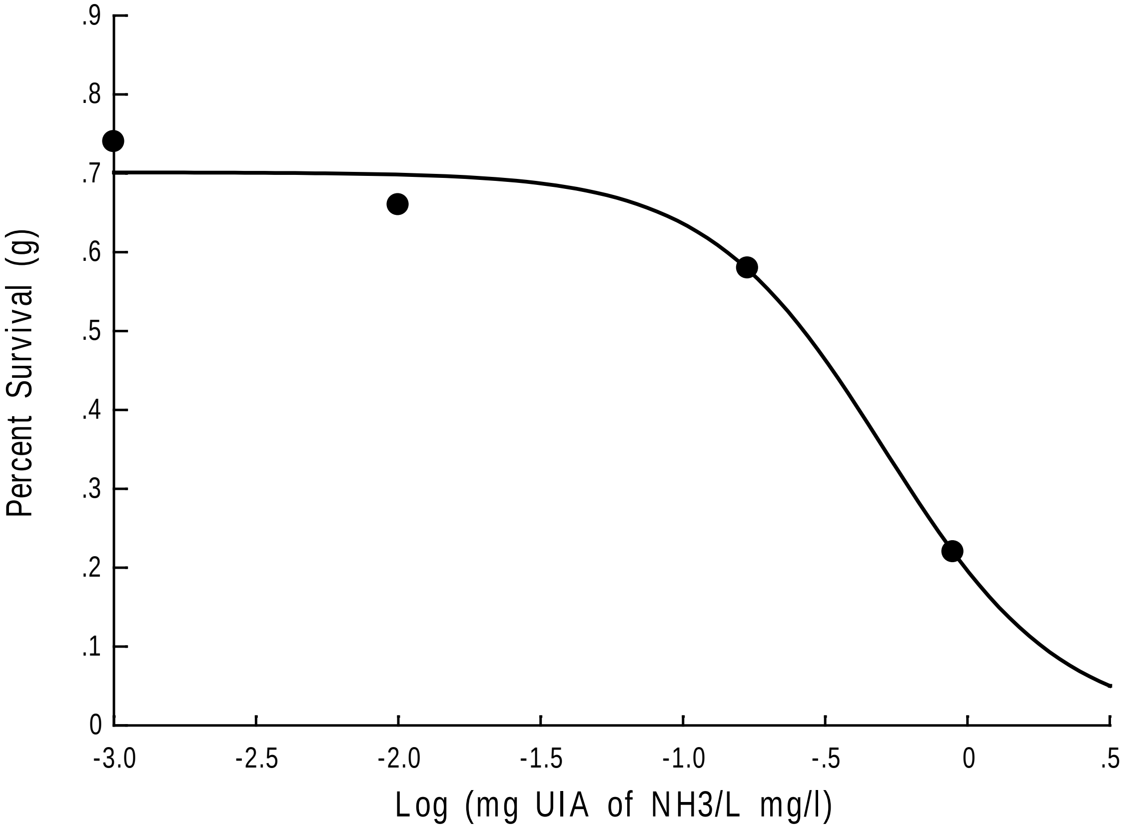
Data Summary

Exposure	Obs Effects	Pred Effects	Residual	Weight
-2.000	0.300	0.295	-0.005	1.
-0.959	0.290	0.295	0.005	1.
-0.638	0.240	0.280	0.040	1.
-0.456	0.215	0.190	-0.025	1.
-0.260	0.100	0.092	-0.008	1.
-0.180	0.050	0.053	0.003	1.

Error Summary

No Errors

ONCORHYNCHUS CLARKI HENSHAWI, 103-D EXPOSURE OF FERTILIZED EMBRYOS, KOCH et al. (1980)



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              Parameter Summary (Logistic Equation Regression Analysis)
Parameter             Guess      FinalEst    StdError     95%LCL      95%UCL
LogX50             -0.49795      -0.29623     0.11705   -1.78346     1.19099
S                     2.000        0.7945      0.2612    -2.5240      4.1131
Y0-Transformed       1.0357        0.9950      0.0478     0.3879      1.6022
  Untransformed      0.7400        0.7036        -        0.1430      0.9990
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                         Effect Concentration Summary
     %Effect             Xp Est            95%LCL            95%UCL
        50.0             0.5056            0.0165           15.5236
        20.0            0.18516           0.00047          73.42458
        10.0            0.10289           0.00003         351.30917
         5.0            0.05988           0.00000        1676.94336
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                         Regression Analysis of Variance
Source          df          SS            MS               F        Alpha
Total            3     0.17433       0.05811
Regression       2     0.17077       0.08538            24.0       0.1429
Error            1     0.00356       0.00356
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                                 Data Summary
  Exposure     Obs Effects     Pred Effects      Residual         Weight
    -3.000           0.740            0.703        -0.037             1.
    -2.000           0.660            0.700         0.040             1.
    -0.772           0.580            0.577        -0.003             1.
    -0.051           0.220            0.221         0.001             1.
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                                 Error Summary
                                   No Errors
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Appendix G

Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development – Screened Out Studies with Code List (appears separately at end of appendix)

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Academy of Natural Sciences. 1960. The Sensitivity of Aquatic Life to Certain Chemicals Commonly Found in Industrial Wastes. Final Report No.RG-3965(C2R1), U.S.Public Health Service Grant, Academy of Natural Sciences, Philadelphia, PA :89 p..	5683	AF	
Alabaster, J.S., D.G. Shurben, and G. Knowles. 1979. The Effect of Dissolved Oxygen and Salinity on the Toxicity of Ammonia to Smolts of Salmon, Salmo salar L. J.Fish Biol.15(6):705-712 (Personal Communication Used).	406	Dur - 1d	
Alabaster, J.S., D.G. Shurben, and M.J. Mallett. 1983. The Acute Lethal Toxicity of Mixtures of Cyanide and Ammonia to Smolts of Salmon, Salmo salar L. at Low Concentrations of Dissolved Oxygen. J.Fish Biol. 22:215-222.	10252	Dur - 1d	
Alam, M., Frankel, T. L., and Alam, M. Gill ATPase Activities of Silver Perch, Bidyanus bidyanus (Mitchell), and Golden Perch, Macquaria ambigua (Richardson): Effects of Environmental Salt and Ammonia. Aquaculture 251(1), 118-133. 2006.	84839	Non-NA	
Allan, I.R.H., D.W.M. Herbert, and J.S. Alabaster. 1958. A Field and Laboratory Investigation of Fish in a Sewage Effluent. Minist.Agric.Fish.Food, Fish.Invest.Ser.1 6(2):76.	10316	AF, Det	
Alonso, A. and Camargo, J. A. Ammonia Toxicity to the Freshwater Invertebrates Polycelis Felina (Planariidae, Turbellaria) and Echinogammarus echinosetosus (Gammaridae, Crustacea). Fresenius Environ.Bull. 15(12b), 1578-1583. 2006.		Non-NA	
Arillo, A., B. Uva, and M. Vallarino. 1981. Renin Activity in Rainbow Trout (Salmo gairdneri Rich.) and Effects of Environmental Ammonia. Comp.Biochem.Physiol.A 68(3):307-311.	5704	Dur - 2d	
Armstrong, D.A.. 1978. Toxicity and Metabolism of Nitrogen Compounds: Effects on Survival, Growth and Osmoregulation of the Prawn, Macrobrachium rosenbergii. Ph.D.Thesis, University of California, Davis, CA:92 p.(Personal Communication Used).	5620	Dur - 1d	
Babu, T.R., P. Surendranath, and K.V. Ramana Rao. 1987. Comparative Evaluation of DDT and Fenvalerate Toxicity on Penaeus indicus (H. Milne Edwards). Mahasagar 20(4):249-253.	15	AF, Dur	
Bailey, H.C., C. DiGiorgio, K. Kroll, J.L. Miller, D.E. Hinton, and G. Starrett. 1996. Development of Procedures for Identifying Pesticide Toxicity in Ambient Waters: Carbofuran, Diazinon, Chlorpyrifos. Environ.Toxicol.Chem. 15(6):837-845.	16844	AF	
Ball, I.R.. 1967. The Relative Susceptibilities of Some Species of Fresh-Water Fish to Poisons-I. Ammonia. Water Res. 1(11/12):767-775.	10000	Dur	
Banerjee, S., and S. Bhattacharya. 1994. Histopathology of Kidney of Channa punctatus Exposed to Chronic Nonlethal Level of Elsan, Mercury, and Ammonia. Ecotoxicol.Environ.Saf. 29(3):265-275.	13750	UEndp	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Banerjee, S., and S. Bhattacharya. 1995. Histopathological Changes Induced by Chronic Nonlethal Levels of Elsan, Mercury, and Ammonia in the Small Intestine of Channa punctatus (Bloch). Ecotoxicol.Environ.Saf. 31(1):62-68.	15256	UEndp	
Banerjee, S., and S. Bhattacharya. 1997. Histopathological Changes Induced by Chronic Nonlethal Levels of Elsan, Mercury and Ammonia in the Liver of Channa punctatus (Bloch). J.Environ.Biol. 18(2):141-148.	18229	UEndp	
Banerjee, T.K., and V.I. Paul. 1993. Estimation of Acute Toxicity of Ammonium Sulphate to the Fresh Water Catfish, Heteropneustes fossilis II. A Histopathological Analysis of the Epidermis. Biomed.Environ.Sci. 6(1):45-58.	13480	UEndp	
Baskaran, P., and S. Palanichamy. 1990. Impact of Agricultural Fertilizer (Ammonium Chloride) on Physiology and Biochemistry of the Freshwater Teleost Fish Oreochromis mossambicus. J.Ecobiol. 2(2):97-106.	11072	AF, UEndp	
Bergerhouse, D.L.. 1989. Lethal Effects of Elevated pH and Ammonia on Early Life Stages of Several Sportfish Species. Ph.D.Thesis, Southern Illinois University, Carbondale, IL :246 p..	3822	UEndp, Dur - 8h	
Bergerhouse, D.L.. 1992. Lethal Effects of Elevated pH and Ammonia on Early Life Stages of Walleye. N.Am.J.Fish.Manage. 12(2):356-366.	6903	UEndp, Dur - 8h	
Bergerhouse, D.L.. 1993. Lethal Effects of Elevated pH and Ammonia on Early Life Stages of Hybrid Striped Bass. J.Appl.Aquacult. 2(3/4):81-100.	4290	UEndp, Dur - 8h	
Besser, J. M., Brumbaugh, W. G., Allert, A. L., Poulton, B. C., Schmitt, C. J., and Ingersoll, C. G. Ecological Impacts of Lead Mining on Ozark Streams: Toxicity of Sediment and Pore Water. Ecotoxicology and Environmental Safety [Ecotoxicol. Environ. Saf.]. Vol. 72, no. 2, pp. 516-526. Feb 2009. 2009.		Mix	
Bhattacharya, T., S. Bhattacharya, A.K. Ray, and S. Dey. 1989. Influence of Industrial Pollutants on Thyroid Function in Channa punctatus (Bloch). Indian J.Exp.Biol. 27(1):65-68.	3106	AF, UEndp, Dur - 1d	
Bianchini, A., W. Wasielesky Jr., and K.C. Miranda Filho. 1996. Toxicity of Nitrogenous Compounds to Juveniles of Flatfish Paralichthys orbignyanus. Bull.Environ.Contam.Toxicol. 56(3):453-459.	16445	AF	
Biswas, J. K., Sarkar, D., Chakraborty, P., Bhakta, J. N., and Jana, B. B. Density dependent ambient ammonium as the key factor for optimization of stocking density of common carp in small holding tanks. Aquaculture 261(3), 952-959. 2006-.		No Dose, VarExp	Only 1 exposure concentration (naturally increased over time)
Blanco Saul, Romo Susana, Fernandez-Alaez Margarita, and Becares Eloy. Response of Epiphytic Algae to Nutrient Loading and Fish Density in a Shallow Lake: a Mesocosm Experiment. Hydrobiologia [Hydrobiologia]. Vol. 600, no. 1, pp. 65-76. Mar 2008. 2008.		Mix	Mesocosm; no ammonia

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Boone, M. D. , Semlitsch, R. D., Little, E. E., and Doyle, M. C. Multiple Stressors in Amphibian Communities: Effects of Chemical Contamination, Bullfrogs, and Fish. Ecol.Appl. 17(1), 291-301. 2007.		Mix	
Brun, F. G., Olive(acute), I., Malta, E. J., Vergara, J. J., Herna(acute)ndez, I., and Pe(acute)rez-Llore(acute)ns, J. L. Increased Vulnerability of Zostera Noltii to Stress Caused by Low Light and Elevated Ammonium Levels Under Phosphate Deficiency. Marine Ecology Progress Series, 365 (-) pp. 67-75, 2008 . 2008.		Mix	
Buikema, A.L.Jr., J. Cairns Jr., and G.W. Sullivan. 1974. Evaluation of Philodina acuticornis (Rotifera) as Bioassay Organisms for Heavy Metals. Water Resour.Bull. 10(4):648-661.	2019	Dur	
Burrows, R.E.. 1964. Effects of Accumulated Excretory Products on Hatchery-Reared Salmonids. U.S.Fish Wildl.Serv., Res.Rep.No.66, Washington, DC :12.	10002	Uenpd	
Byrne Maria, Oakes Diana J, Pollak John K, and Laginestra Edwina. Toxicity of Landfill Leachate to Sea Urchin Development With a Focus on Ammonia. Cell biology and toxicology, 2008 Dec, 24(6):503-12. Epub: 2008 Aug 21 . 2008.		Mix	
Cairns, J.Jr., and A. Scheier. 1959. The Relationship of Bluegill Sunfish Body Size to Tolerance for Some Common Chemicals. Proc.13th Ind.Waste Conf., Purdue Univ.Eng.Bull 96:243-252.	930	AF	
Cairns, J.Jr., B.R. Niederlehner, and J.R. Pratt. 1990. Evaluation of Joint Toxicity of Chlorine and Ammonia to Aquatic Communities. Aquat.Toxicol. 16(2):87-100.	3207	Ace; No Org	
Camargo, Julio A. and Alonso, lvaro. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International 32(6), 831-849. 2006.		Sec	
Cao, Te, Xie, Ping, Ni, Leyi, Zhang, Meng, and Xu, Jun. Carbon and nitrogen metabolism of an eutrophication tolerative macrophyte, Potamogeton crispus, under NH4+ stress and low light availability. Environmental and Experimental Botany In Press, Corrected Proof.		No Dose	Only 1 exposure concentration
Carr, R. S., Biedenbach, J. M., and Nipper, M. Influence of Potentially Confounding Factors on Sea Urchin Porewater Toxicity Tests. Archives of Environmental Contamination and Toxicology [Arch. Environ. Contam. Toxicol.]. Vol. 51, no. 4, pp. 573-579. Nov 2006. 2006.		Mix	
Centeno, M.D.F., G. Persoone, and M.P. Goyvaerts. 1995. Cyst-Based Toxicity Tests. IX. The Potential of Thamnocephalus platyurus as Test Species in Comparison with Streptocephalus proboscideus (Crustacea: Branchiopoda: Anostraca). Environ.Toxicol.Water Qual. 10(4):275-282.	14017	AF, Dur - 1d	
Chetty, A.N., and K. Indira. 1994. Alterations in the Tissue Lipid Profiles of Lamellidens marginalis Under Ambient Ammonia Stress. Bull.Environ.Contam.Toxicol. 53(5):693-698.	13744	Dur - 2d	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Colt, J.E.. 1978. The Effects of Ammonia on the Growth of Channel Catfish, Ictalurus punctatus. Ph.D.Thesis, Univ.of California, Davis, CA :185 p..	59792	AF	
Corpron, K.E., and D.A. Armstrong. 1983. Removal of Nitrogen by an Aquatic Plant, Elodea densa, in Recirculating Macrobrachium Culture Systems. Aquaculture 32(3/4):347-360.	15323	Uendp, Con	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Costa, Luiza Dy, Miranda-Filho, Kleber C., Severo, Marlon P., and Sampaio, Luis A. Tolerance of juvenile pompano Trachinotus marginatus to acute ammonia and nitrite exposure at different salinity levels. Aquaculture 285(1-4), 270-272. 2008-.		Non-NA	
Craig, G.R.. 1983. Interlaboratory Fish Toxicity Test Comparison-Ammonia. Environ.Protection Service, Quality Protection Section, Water Resour.Branch, Canada :7.	10259	AF	
Cucchiari, E., Guerrini, F., Penna, A., Totti, C., and Pistocchi, R. Effect of Salinity, Temperature, Organic and Inorganic Nutrients on Growth of Cultured Fibrocapsa Japonica (Raphidophyceae) From the Northern Adriatic Sea. Harmful Algae [Harmful Algae]. Vol. 7, no. 4, pp. 405-414. Jun 2008. 2008.		Mix	
Dabrowska, H., and H. Sikora. 1986. Acute Toxicity of Ammonia to Common Carp (Cyprinus carpio L.). Pol.Arch.Hydrobiol. 33(1):121-128.	12711	Dur - 2d	
Danecker, E.. 1964. The Jauche Poisoning of Fish - an Ammonia Poisoning. Osterreichs Fischerei.3/4:55-68 (ENG TRANSL).	10305	AF, UEndp, Dur	
Daoust, P.Y., and H.W. Ferguson. 1984. The Pathology of Chronic Ammonia Toxicity in Rainbow Trout, Salmo gairdneri Richardson. J.Fish Dis. 7:199-205.	10217	UEndp	
De Moor, I.J. 1984. The Toxic Concentration of Free Ammonia to Brachionus calyciflorus Pallas, a Rotifer Pest Species Found in High Rate Algal Ponds (HRAP'S). J.Limnol.Soc.South Afr. 10(2):33-36.	5433	UEndp	
Dendene, M.A., T. Rolland, M. Tremolieres, and R. Carbiener. 1993. Effect of Ammonium Ions on the Net Photosynthesis of Three Species of Elodea. Aquat.Bot. 46(3/4):301-315.	4268	Uendp, Plant	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Dey, S., and S. Bhattacharya. 1989. Ovarian Damage to Channa punctatus After Chronic Exposure to Low Concentrations of Elsan, Mercury, andAmmonia. Ecotoxicol.Environ.Saf. 17(2):247-257.	446	AF, Dur - 2d	
DeYoe Hudson R, Buskey Edward J, and Jochem Frank J. Physiological Responses of Aureoumbra Lagunensis and Synechococcus Sp. To Nitrogen Addition in a Mesocosm Experiment. Harmful Algae [Harmful Algae]. Vol. 6, no. 1, pp. 48-55. Jan 2007. 2007.		No Dose	Only one exposure concentration
Diamond, J. M., Klaine, S. J., and Butcher, J. B. Implications of Pulsed Chemical Exposures for Aquatic Life Criteria and Wastewater Permit Limits. Environ.Sci.Technol. 40(16), 5132-5138. 2006.	102216	No Dose, Dur, VarExp	Only 2 exposure concentrations
Dowden, B.F., and H.J. Bennett. 1965. Toxicity of Selected Chemicals to Certain Animals. J.Water Pollut.Control Fed. 37(9):1308-1316.	915	AF	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Dowden, B.F.. 1961. Cumulative Toxicities of Some Inorganic Salts to Daphnia magna as Determined by Median Tolerance Limits. Proc.La.Acad.Sci. 23:77-85.	2465	AF	
Drath, M., Kloft, N., Batschauer, A., Marin, K., Novak, J., and Forchhammer, K. Ammonia Triggers Photodamage of Photosystem Ii in the Cyanobacterium Synechocystis Sp. Strain Pcc 6803. Plant Physiology, 147 (1) pp. 206-215, 2008 . 2008.		No Dose	Only 1 or 2 exposure concentrations at a specific pH
D'Silva, C., and X.N. Verlencar. 1976. Relative Toxicity of Two Ammonium Compounds Found in the Waste of Fertilizer Plants. Mahasagar 9(1/2):41-44.	6084	Dur - 2d	
Egea-Serrano, A., Tejedo, M., and Torralva, M. Analysis of the Avoidance of Nitrogen Fertilizers in the Water Column by Juvenile Iberian Water Frog, Pelophylax perezi (Seoane, 1885), in Laboratory Conditions. Bull.Environ.Contam.Toxicol. 80(2), 178-183. 2008.	103070	Mix, No Dose	Only one exposure concentration
Ewell, W.S., J.W. Gorsuch, R.O. Kringle, K.A. Robillard, and R.C. Spiegel. 1986. Simultaneous Evaluation of the Acute Effects of Chemicals on Seven Aquatic Species. Environ.Toxicol.Chem. 5(9):831-840.	11951	Con; Uendp	Aside from insufficient controls, as determined by ECOTOX reviewers, the LC50s reported for the several aquatic organisms in this study were all greater than values, and more appropriate acute data are available for these species. pH was also varied between 6.5 and 8.5 during the exposure.
Fang, J. K. H., Wu, R. S. S., Chan, A. K. Y., Yip, C. K. M., and Shin, P. K. S. Influences of Ammonia-Nitrogen and Dissolved Oxygen on Lysosomal Integrity in Green-Lipped Mussel Perna Viridis: Laboratory Evaluation and Field Validation in Victoria Harbour, Hong Kong. Marine Pollution Bulletin [Mar. Pollut. Bull.]. Vol. 56, no. 12, pp. 2052-2058. Dec 2008. 2008.		No Dose	Only one exposure concentration
Fedorov, K.Y., and Z.V. Smirnova. 1978. Dynamics of Ammonia Accumulation and its Effect on the Development of the Pink Salmon, Oncorhynchus gorbuscha, in Closed Circuit Incubation Systems. Vopr.Ikhtiol. 19(2):320-328.	5478	UEndp	
Flagg, R.M., and L.W. Hinck. 1978. Influence of Ammonia on Aeromonad Susceptibility in Channel Catfish. Proc.Annu.Conf.Southeast.Assoc.Fish Wildl.Agencies 32:415-419.	10317	UEndp	
Flis, J.. 1963. Anatomicohistopathological Changes Induced in Carp (Cyprinus carpio L.) by Ammonia Water. Part 1. Effects of Toxic Concentrations. (Zmiany. Acta Hydrobiol. 10(1/2):205-224.	10005	UEndp, Dur - 1d	
Foss, Atle, Imsland, Albert K., Roth, Bjørn, Schram, Edward, and Stefansson, Sigurd O. Interactive effects of oxygen saturation and ammonia on growth and blood physiology in juvenile turbot. Aquaculture 271(1-4), 244-251. 2007-.		No Dose	Only 2 exposure concentrations

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Golding, C., Krassoi, R., and Baker, E. The Development and Application of a Marine Toxicity Identification Evaluation (TIE) Protocol for Use with an Australian Bivalve. Australas.J.Ecotoxicol. 12(1), 37-44. 2006.	108468	Mix, No Dose	Only one exposure concentration
Griffis-Kyle Kerry L and Ritchie Mark E. Amphibian Survival, Growth and Development in Response to Mineral Nitrogen Exposure and Predator Cues in the Field: an Experimental Approach. Oecologia, 2007 Jul, 152(4):633-42. Epub: 2007 Mar 10 . 2007.		Mix	
Gyore, K., and J. Olah. 1980. Ammonia Tolerance of Moina rectirostris Leydig (Cladocera). Aquacult.Hung.(Szarvas) 2:50-54.	5708	Dur - 1d	
Hanna, T.D.. 1992. The Effect of Oxygen Supplementation on the Toxicity of Ammonia (NH3) in Rainbow Trout Oncorhynchus mykiss (Richardson). M.S.Thesis, Montana State University, Bozeman, MT :51.	7823	UEndp, Dur	
Harader, R.R.J., and G.H. Allen. 1983. Ammonia Toxicity to Chinook Salmon Parr: Reduction in Saline Water. Trans.Am.Fish.Soc. 112(6):834-837.	10510	Dur - 1d	
Hazel, R.H., C.E. Burkhead, and D.G. Huggins. 1982. Development of Water Quality Criteria for Ammonia and Total Residual Chlorine for the Protection of Aquatic Life in Two Johnson County, Kansas Streams. In: J.G.Pearson, R.B.Foster, and W.E.Bishop (Eds.), Proc.5th Annu.Symp.Aquatic Toxicology, ASTM STP 766, Philadelphia, PA :381-388.	13785	AF	Data provided in earlier report
Healey, F.P.. 1977. Ammonium and Urea Uptake by Some Freshwater Algae. Can.J.Bot. 55(1):61-69.	7486	AF, Uendp	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Hecnar, S.J.. 1995. Acute and Chronic Toxicity of Ammonium Nitrate Fertilizer to Amphibians from Southern Ontario. Environ.Toxicol.Chem. 14(12):2131-2137.	16378	AF, UEndp	
Hedtke, J.L., and L.A. Norris. 1980. Effect of Ammonium Chloride on Predatory Consumption Rates of Brook Trout (Salvelinus fontinalis) on Juvenile Chinook Salmon (Oncorhynchus tshawytscha) i. Bull.Environ.Contam.Toxicol. 24(1):81-89.	6216	Uendp, Eff	
Hemens, J.. 1966. The Toxicity of Ammonia Solutions to the Mosquito Fish (Gambusia affinis Baird & Girard). J.Proc.Inst.Sewage Purif. 3:265-271.	10152	Dur - 17h	
Henderson, C., Q.H. Pickering, and A.E. Lemke. 1961. The Effect of Some Organic Cyanides (Nitriles) on Fish. Proc.15th Ind.Waste Conf., Eng.Bull.Purdue Univ., Ser.No.106, 65(2):120-130.	923	AF	
Herbert, D.W.M., and D.S. Shurben. 1963. A Preliminary Study of the Effect of Physical Activity on the Resistance of Rainbow Trout (Salmo gairdnerii Richardson) to Two Poisons. Ann.Appl.Biol. 52:321-326	8005	Dur - 1d	
Herbert, D.W.M., and D.S. Shurben. 1964. The Toxicity to Fish of Mixtures of Poisons I. Salts of Ammonia and Zinc. Ann.Appl.Biol. 53:33-41.	8006	Dur - 2d	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Herbert, D.W.M., and D.S. Shurben. 1965. The Susceptibility of Salmonid Fish to Poisons Under Estuarine Conditions-II Ammonium Chloride. Int.J.Air Water Pollut. 9(1/2):89-91.	10318	Dur - 1d	
Herbert, D.W.M., and J.M. Vandyke. 1964. The Toxicity to Fish of Mixtures of Poisons. II. Copper-Ammonia and Zinc-Phenol Mixtures. Ann.Appl.Biol. 53(3):415-421.	10193	Dur - 2d	
Hernandez, C., M. Martin, G. Bodega, I. Suarez, J. Perez, and B. Fernandez. 1999. Response of Carp Central Nervous System to Hyperammonemic Conditions: An Immunocytochemical Study of Glutamine Synthetase (GS), Glial Fibrillary Acidic Protein (GFAP) and 70 kDa Heat-Shock Protein (HSP70). Aquat.Toxicol. 45(2/3):195-207.	19920	UEndp	
Holland, G.A., J.E. Lasater, E.D. Neumann, and W.E. Eldridge. 1960. Toxic Effects of Organic and Inorganic Pollutants on Young Salmon and Trout. Res.Bull.No.5, State of Washington Dept.Fish., Seattle, WA :263 p..	14397	Dur - 3d	
Hong, M., Chen, L., Sun, X., Gu, S., Zhang, L., and Chen, Y. Metabolic and Immune Responses in Chinese Mitten-Handed Crab (Eriocheir sinensis) Juveniles Exposed to Elevated Ambient Ammonia. Comp.Biochem.Physiol.C 145(3), 363-369. 2007.		Det	Dilution water not described; Prior exposure?
Hued, A. C., Caruso, M. N., Wunderlin, D. A., and Bistoni, M. A. *. Field and in Vitro Evaluation of Ammonia Toxicity on Native Fish Species of the Central Region of Argentina. Bulletin of Environmental Contamination and Toxicology [Bull. Environ. Contam. Toxicol.]. Vol. 76, no. 6, pp. 984-991. Jun 2006. 2006.		Non-NA	
Hurlimann, J., and F. Schanz. 1993. The Effects of Artificial Ammonium Enhancement on Riverine Periphytic Diatom Communities. Aquat.Sci. 55(1):40-64.	4134	No Org	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Inman, R.C.. 1974. Acute Toxicity of Phos-Check (Trade Name) 202 and Diammonium Phosphate to Fathead Minnows. Environ.Health Lab., Kelly Air Force Base, TX :13 p.(U.S.NTIS AD/A-006122).	6010	Tox	
Ip, Y. K., Lee, S. M. L., Wong, W. P., and Chew, S. F. Mechanisms of and Defense Against Acute Ammonia Toxicity in the Aquatic Chinese Soft-Shelled Turtle, Pelodiscus Sinensis. Aquatic Toxicology [Aquat. Toxicol.]. Vol. 86, no. 2, pp. 185-196. 31 Jan 2008. 2008.		Exp	Injected
Ishio, S.. 1965. Behavior of Fish Exposed to Toxic Substances. In: O.Jaag (Ed.), Advances in Water Pollution Research, Pergamon Press, NY :19-40.	14092	AF, Dur - 6h, UEndp, No Org	
James, R., K. Sampath, and M. Narayanan. 1993. Effect of Sublethal Concentrations of Ammonia on Food Intake and Growth in Mystus vittatus. J.Environ.Biol. 14(3):243-248.	8994	AF, UEndp	
Jampeetong, Arunothai and Brix, Hans. Effects of NH4+ concentration on growth, morphology and NH4+ uptake kinetics of Salvinia natans. Ecological Engineering In Press, Corrected Proof.		VarExp	Concentration increased over time

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
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Jha, B.K., and B.S. Jha. 1995. Urea and Ammonium Sulfate Induced Changes in the Stomach of the Fish Heteropneustes fossilis. Environ.Ecol. 13(1):179-181.	17562	AF, UEndp	
Joy, K.P.. 1977. Ammonium Sulphate As a Thyroid Inhibitor in the Freshwater Teleost Clarias batrachus (L.). Curr.Sci. 46(19):671-673.	7513	AF, UEndp	
Kawabata, Z., T. Yoshida, and H. Nakagawa. 1997. Effect of Ammonia on the Survival of Zacco platypus (Temminck and Schlegel) at Each Developmental Stage. Environ.Pollut. 95(2):213-218.	17963	UEndp, Dur	
Khatami, S.H., D. Pascoe, and M.A. Learner. 1998. The Acute Toxicity of Phenol and Unionized Ammonia, Separately and Together, to the Ephemeropteran Baetis rhodani (Pictet). Environ.Pollut. 99:379-387.	19651	Dur - 1d	
Kim, J. K., Kraemer, G. P., Neefus, C. D., Chung, I. K., and Yarish, C. Effects of Temperature and Ammonium on Growth, Pigment Production and Nitrogen Uptake by Four Species of Porphyra (Bangiales, Rhodophyta) Native to the New England Coast. Journal of Applied Phycology, 19 (5) pp. 431-440, 2007 . 2007.		XNoec	
Kirk, R.S., and J.W. Lewis. 1993. An Evaluation of Pollutant Induced Changes in the Gills of Rainbow Trout Using Scanning Electron Microscopy. Environ.Technol. 14(6):577-585.	4931	UEndp, Dur	
Knepp, G.L., and G.F. Arkin. 1973. Ammonia Toxicity Levels and Nitrate Tolerance of Channel Catfish. Prog.Fish-Cult. 35(4):221-224.	8606	Dur - 7d, Form	
Krainara, T.. 1988. Effects of Ammonia on Walking Catfish, Clarias batrachus (Linnaeus). Abstracts of Master of Science Theses, Faculty of Fisheries, Kasetsart University, Bangkok, Thailand 13:6.	17533	AF	
Kulkarni, K.M., and S.V. Kamath. 1980. The Metabolic Response of Paratelphusa jacquemontii to Some Pollutants. Geobios 7(2):70-73 (Author Communication Used).	5036	AF, UEndp, Dur	
Lang, T., G. Peters, R. Hoffmann, and E. Meyer. 1987. Experimental Investigations on the Toxicity of Ammonia: Effects on Ventilation Frequency, Growth, Epidermal Mucous Cells, and Gill Structure of. Dis.Aquat.Org. 3:159-165.	4106	UEndp	
Larson James H, Frost Paul C, and Lamberti Gary A. Variable Toxicity of Ionic Liquid-Forming Chemicals to Lemna Minor and the Influence of Dissolved Organic Matter. Environmental Toxicology and Chemistry [Environ. Toxicol. Chem.]. Vol. 27, no. 3, pp. 676-681. Mar 2008. 2008.		Mix	Organic mixture
Lay, J.P., A. Peither, I. Juttner, and K. Weiss. 1993. In Situ Pond Mesocosms for Ecotoxicological Long-Term Studies. Chemosphere 26(6):1137-1150.	7048	AF, UEndp, No Org	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
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Lee, D.R.. 1976. Development of an Invertebrate Bioassay to Screen Petroleum Refinery Effluents Discharged into Freshwater. Ph.D.Thesis, Virginia Polytechnic Inst.and State University, Blacksburg, VA :108.	3402	Det	This thesis appears to provide appropriate 48 h LC50 data for *D. pulex*, but the paper should be secured to ensure acceptability. This reference was originally screened out based on title alone.
Lewis, J.W., A.N. Kay, and N.S. Hanna. 1995. Responses of Electric Fish (Family Mormyridae) to Inorganic Nutrients and Tributyltin Oxide. Chemosphere 31(7):3753-3769.	16156	UEndp, Dur	
LI, W. E. I., ZHANG ZHAO, and JEPPESEN ERIK. The Response of Vallisneria Spinulosa (Hydrocharitaceae) to Different Loadings of Ammonia and Nitrate at Moderate Phosphorus Concentration: a Mesocosm Approach. Freshwater Biology [Freshw. Biol.]. Vol. 53, no. 11, pp. 2321-2330. Nov 2008. 2008.		Mix	
Linton, T.K., I.J. Morgan, P.J. Walsh, and C.M. Wood. 1998. Chronic Exposure of Rainbow Trout (Oncorhynchus mykiss) to Simulated Climate Warming and Sublethal Ammonia: A Year-Long Study of Their Appetite. Can.J.Fish.Aquat.Sci. 55(3):576-586.	19144	UEndp, Dur	
Litav, M., and Y. Lehrer. 1978. The Effects of Ammonium in Water on Potamogeton lucens. Aquat.Bot. 5(2):127-138.	7093	AF, UEndp, Dur	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Lloyd, R., and D.W.M. Herbert. 1960. The Influence of Carbon Dioxide on the Toxicity of Un-Ionized Ammonia to Rainbow Trout (Salmo gairdnerii Richardson). Ann.Appl.Biol. 48(2):399-404.	10018	Dur - 8h	
Lloyd, R., and L.D. Orr. 1969. The Diuretic Response by Rainbow Trout to Sublethal Concentrations of Ammonia. Water Res. 3(5):335-344.	10019	UEndp, Dur - 1d	
Loong, A. M. , Tan, J. Y. L., Wong, W. P., Chew, S. F., and Ip, Y. K. Defense Against Environmental Ammonia Toxicity in the African Lungfish, Protopterus aethiopicus: Bimodal Breathing, Skin Ammonia Permeability and Urea Synthesis. Aquat.Toxicol. 85(1), 76-86. 2007.		Non-NA, No Dose	Only one exposure concentration
Loppes, R.. 1970. Growth Inhibition by NH4+ Ions in Arginine-Requiring Mutants of Chlamydomonas reinhardi. Mol.Gen.Genet. 109(3):233-240.	9619	AF, UEndp, Dur	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Losso, Chiara, Novelli, Alessandra Arizzi, Picone, Marco, Ghetti, Pier Francesco, and Ghirardini, Annamaria Volpi. Porewater as a matrix in toxicity bioassays with sea urchins and bivalves: Evaluation of applicability to the Venice lagoon (Italy). Environment International 35(1), 118-126. 2009.		Mix	
Ma, J., Wang, S., Wang, P., Ma, L., Chen, X., and Xu, R. Toxicity Assessment of 40 Herbicides to the Green Alga Raphidocelis Subcapitata. Ecotoxicology and Environmental Safety [Ecotoxicol. Environ. Saf.]. Vol. 63, no. 3, pp. 456-462. Mar 2006. 2006.		Unrel	No ammonia

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Magalhaes Bastos, J.A.. 1954. Importance of Ammonia As an Ichthyotoxic Substance. (Importancia Da Amonia Como Substacia Ictiotoxica.). No.159, Serv.Piscicultura, Publ.Ser.1-C, Dep.Nacl.Onbras Contra Secas, Ministerio Viacao E Onbras Publicas, Brazil :115-132.	10302	UEndp, Dur	
Magallon Barajas Francisco, Villegas Rosalia Servin, Clark Guillermo Portillo, Mosqueda Joaquin Garcia, and Moreno Berenice Lopez. Daily Variation in Short-Term Static Toxicity of Unionized Ammonia in Litopenaeus Vannamei (Boone) Postlarvae. Aquaculture Research [Aquacult. Res.]. Vol. 37, no. 14, pp. 1406-1412. Oct 2006. 2006.		Dur	
Magallon Barajas, F.J., R. S. Villegas, G.P. Clark and B.L. Moreno. 2006. *Litopenaeus vannamei* (Boone) post-larval survival related to age, temperature, pH and ammonium concentration. Aquacult. Res. 37: 492-499.		No Dose	Only 1 exposure concentration
Malacea, I.. 1966. Studies on the Acclimation of Fish to High Concentrations of Toxic Substances. Arch.Hydrobiol. 65(1):74-95 (GER) (ENG TRANSL) (1968).	10020	Dur	
Malham, Shelagh K., Cotter, Elizabeth, O'Keeffe, Selena, Lynch, Sharon, Culloty, Sarah C., King, Jonathan W., Latchford, John W., and Beaumont, Andy R. Summer mortality of the Pacific oyster, Crassostrea gigas, in the Irish Sea: The influence of temperature and nutrients on health and survival. Aquaculture 287(1-2), 128-138. 2009-.		Mix	
Manissery, J.K., and M.N. Madhyastha. 1993. Haematological and Histopathological Effect of Ammonia at Sublethal Levels on Fingerlings of Common Carp Cyprinus carpio. Sci.Total Environ.(Suppl .):913-920.	4314	UEndp	
McDonald, S.F., S.J. Hamilton, K.J. Buhl, and J.F. Heisinger. 1997. Acute Toxicity of Fire-Retardant and Foam-Suppressant Chemicals to Hyalella azteca (Saussure). Environ.Toxicol.Chem. 16(7):1370-1376.	18102	Tox	*Also, H. azteca* is sensitive to chloride concentration. EPA has decided to not use data for this species until additional tests are conducted.
McIntyre, M. , Davis, M., and Shawl, A. The Effects of Ammonia on the Development, Survival and Metamorphic Success of Strombus gigas veligers. 98th Annu.Meet.Natl.Shellfish.Assoc., Monterery, CA , (ABS). 2006-.		Det	Abstract only
Meador, Michael R. and Carlisle, Daren M. Quantifying tolerance indicator values for common stream fish species of the United States. Ecological Indicators 7(2), 329-338. 2007.		Mix	
Melching, C. S., Novotny, V., Schilling, J. B., Chen, J., and Beck, M. B. (eds). Probabilistic Evaluation of Ammonia Toxicity in Milwaukee's Outer Harbor. Alliance House 12 Caxton Street London SW1H 0QS UK . 2006. IWA Publishing.		Mix	
Merkens, J.C., and K.M. Downing. 1957. The Effect of Tension of Dissolved Oxygen on the Toxicity of Un-Ionized Ammonia to Several Species of Fish. Ann.Appl.Biol. 45(3):521-527.	10021	UEndp, Dur	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Merkens, J.C.. 1958. Studies on the Toxicity of Chlorine and Chloramines to the Rainbow Trout. Water Waste Treat.J. 7:150-151.	7404	UEndp, Dur	
Miron, Denise dos, Moraes, Bibiana, Becker, Alexssandro G., Crestani, Márcia, Spanevello, Rosélia, Loro, Vania L., and Baldisserotto, Bernardo. Ammonia and pH effects on some metabolic parameters and gill histology of silver catfish, Rhamdia quelen (Heptapteridae). Aquaculture 277(3-4), 192-196. 2008-.		Non-NA	
Mitchell, S.J.Jr.. 1983. Ammonia-Caused Gill Damage in Channel Catfish (Ictalurus punctatus): Confounding Effects of Residual Chlorine. Can.J.Fish.Aquat.Sci. 40(2):242-247.	10543	UEndp, Dur	
Morgan, W.S.G., and P.C. Kuhn. 1974. A Method to Monitor the Effects of Toxicants upon Breathing Rate of Largemouth Bass (Micropterus salmoides Lacepede). Water Res. 8(1):67-77 (Author Communication Used).	15362	UEndp, Dur	
Morgan, W.S.G.. 1976. Fishing for Toxicity: Biological Automonitor for Continuous Water Quality Control. Effluent Water Treat.J. 16(9):471-472, 474-475 (Author Communication Used).	5462	UEndp, Dur - 1d	
Morgan, W.S.G.. 1978. The Use of Fish as a Biological Sensor for Toxic Compounds in Potable Water. Prog.Water Technol. 10(1/2):395-398 (Author Communication Used).	11127	UEndp, Dur - 1d	
Morgan, W.S.G.. 1979. Fish Locomotor Behavior Patterns as a Monitoring Tool. J.Water Pollut.Control Fed. 51(3):580-589.	131	UEndp, Dur - 1d	
Morris, J. M., Snyder-Conn, E., Foott, J. S., Holt, R. A., Suedkamp, M. J., Lease, H. M., Clearwater, S. J., and Meyer, J. S. Survival of Lost River Suckers (Deltistes luxatus) Challenged with Flavobacterium columnare During Exposure to Sublethal Ammonia Concentrations at pH 9.5. Arch.Environ.Contam.Toxicol. 50(2), 256-263. 2006.	97379	Mix	
Mosier, A.R.. 1978. Inhibition of Photosynthesis and Nitrogen Fixation in Algae by Volatile Nitrogen Bases. J.Environ.Qual. 7(2):237-240.	15860	Dur	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Mugnier, Chantal, Zipper, Etienne, Goarant, Cyrille, and Lemonnier, Hugues. Combined effect of exposure to ammonia and hypoxia on the blue shrimp Litopenaeus stylirostris survival and physiological response in relation to molt stage. Aquaculture 274(2-4), 398-407. 2008-.		Non-NA	
Mukherjee, S., and S. Bhattacharya. 1974. Effects of Some Industrial Pollutants on Fish Brain Cholinesterase Activity. Environ.Physiol.Biochem. 4:226-231.	668	Dur - 2d	
Muturi Ephantus J, Jacob Benjamin G, Shililu Josephat, and Novak Robert. Laboratory Studies on the Effect of Inorganic Fertilizers on Survival and Development of Immature Culex Quinquefasciatus (Diptera: Culicidae). Journal of vector borne diseases, 2007 Dec, 44(4):259-65 . 2007.		Dilut	Deionized water

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Nimptsch, J. and Pflugmacher, S. Ammonia Triggers the Promotion of Oxidative Stress in the Aquatic Macrophyte Myriophyllum mattogrossense. Chemosphere 66(4), 708-714. 2007.	100651	Non-NA	
Obiekezie, A.I., and P.O. Ajah. 1994. Chemotherapy of Macrogyrodactylosis in the Culture of African Clariid Catfishes Clarias gariepinus and Heterobranchus longifiliis. J.Aquacult.Trop. 9(3):187-192.	16594	AF, UEndp, Dur	
Ohmori, M., K. Ohmori, and H. Strotmann. 1977. Inhibition of Nitrate Uptake by Ammonia in a Blue-Green Alga, Anabaena cylindrica. Arch.Microbiol. 114(3):225-229.	7605	UEndp, Dur	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Okelsrud, A. and Pearson, R. G. Acute and Postexposure Effects of Ammonia Toxicity on Juvenile Barramundi (Lates calcarifer). Arch.Environ.Contam.Toxicol. 53(4), 624-631. 2007.		Non-NA	
Olson, K.R., and P.O. Fromm. 1971. Excretion of Urea by Two Teleosts Exposed to Different Concentrations of Ambient Ammonia. Comp.Biochem.Physiol.A 40:999-1007.	10243	AF, UEndp, Dur - 1d	
Ortiz-Santaliestra, M. E., Marco, A., Fernandez, M. J., and Lizana, M. Influence of Developmental Stage on Sensitivity to Ammonium Nitrate of Aquatic Stages of Amphibians. Environ.Toxicol.Chem. 25(1), 105-111. 2006.		Non-NA	
Ortiz-Santaliestra, M. E., Marco, A., Fernandez-Beneitez, M. J., and Lizana, M. Effects of Ammonium Nitrate Exposure and Water Acidification on the Dwarf Newt: The Protective Effect of Oviposition Behaviour on Embryonic Survival. Aquat.Toxicol. 85(4), 251-257. 2007.		Non-NA	
Pagliarani, A., Bandiera, P., Ventrella, V., Trombetti, F., Manuzzi, M. P., Pirini, M., and Borgatti, A. R. Response of Na+-Dependent ATPase Activities to the Contaminant Ammonia Nitrogen in Tapes philippinarum: Possible ATPase Involvement in Ammonium Transport. Arch.Environ.Contam.Toxicol. 55(1), 49-56. 2008.		No Dose	Only 2 exposure concentrations
Palanichamy, S., S. Arunachalam, and M.P. Balasubramanian. 1985. Food Consumption of Sarotherodon mossambicus (Trewaves) Exposed to Sublethal Concentration of Diammonium Phosphate. Hydrobiologia 128(3):233-237.	11516	AF, UEndp, Dur	
Palanisamy, R., and G. Kalaiselvi. 1992. Acute Toxicity of Agricultural Fertilizers to Fish Labeo rohita. Environ.Ecol. 10(4):869-873.	8278	AF, Dur	
Paley, R.K., I.D. Twitchen, and F.B. Eddy. 1993. Ammonia, Na+, K+ and C1- Levels in Rainbow Trout Yolk-Sac Fry in Response to External Ammonia. y) :273-284.	7746	UEndp, Dur - 1d	
Passell, H. D., Dahm, C. N., and Bedrick, E. J. Ammonia Modeling for Assessing Potential Toxicity to Fish Species in the Rio Grande, 1989-2002. Ecological Applications [Ecol. Appl.]. Vol. 17, no. 7, pp. 2087-2099. Oct 2007. 2007.		Mix	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
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Paul, V.I., and T.K. Banerjee. 1995. Acute Toxicity of Ammonium Sulphate to the Air-Breathing Organ of the Live Fish Heteropneustes (Saccobranchus) fossilis (Bloch). Curr.Sci. 68(8):845-849.	19532	UEndp, Dur	
Penaz, M.. 1965. The Influence of Ammonia on the Eggs and Young of the Common Trout, Salmo trutta var. fario. Zool.Listy 14(1):47-54.	10307	UEndp, Dur	
Perez-Landa Victor, Belzunce Maria Jesus, and Franco Javier. The Effect of Seasonality and Body Size on the Sensitivity of Marine Amphipods to Toxicants. Bulletin of environmental contamination and toxicology, 2008 Dec, 81(6):548-52. Epub: 2008 Sep 13 . 2008.		Non-NA	
Phillips, B. M., Anderson, B. S., Hunt, J. W., Clark, S. L., Voorhees, J. P., Tjeerdema, R. S., Casteline, J., and Stewart, M. Evaluation of Phase Ii Toxicity Identification Evaluation Methods for Freshwater Whole Sediment and Interstitial Water. Chemosphere [Chemosphere]. Vol. 74, no. 5, pp. 648-653. Feb 2009. 2009.		Mix	
Puglis Holly J and Boone Michelle D. Effects of a Fertilizer, an Insecticide, and a Pathogenic Fungus on Hatching and Survival of Bullfrog (Rana Catesbeiana) Tadpoles. Environmental Toxicology and Chemistry [Environ. Toxicol. Chem.]. Vol. 26, no. 10, pp. 2198-2201. Oct 2007. 2007.		Mix	
Ram, R., and A.G. Sathyanesan. 1987. Effect of Chronic Exposure of Commercial Nitrogenous Fertilizer, Ammonium Sulfate, on Testicular Development of a Teleost Channa punctatus (Bloch). Indian J.Exp.Biol. 25(10):667-670.	24	Non Res, AF, UEndp, Dur	
Ram, R.N., and A.G. Sathyanesan. 1986. Ammonium Sulfate Induced Nuclear Changes in the Oocyte of the Fish, Channa punctatus (Bl.). Bull.Environ.Contam.Toxicol. 36(6):871-875.	11793	AF, UEndp, Dur	
Ram, R.N., and A.G. Sathyanesan. 1986. Inclusion Bodies: Formation and Degeneration of the Oocytes in the Fish Channa punctatus (Bloch) in Response to Ammonium Sulfate Treatment. Ecotoxicol.Environ.Saf. 11(3):272-276.	12428	AF, UEndp, Dur	
Ram, R.N., and A.G. Sathyanesan. 1987. Histopathological Changes in Liver and Thyroid of the Teleost Fish, Channa punctatus (Bloch), in Response to Ammonium Sulfate Fertilizer Treatment. Ecotoxicol.Environ.Saf. 13(2):185-190.	12684	AF, UEndp, Dur	
Ram, R.N., and S.K. Singh. 1988. Long-Term Effect of Ammonium Sulfate Fertilizer on Histophysiology of Adrenal in the Teleost, Channa punctatus (Bloch). Bull.Environ.Contam.Toxicol. 41(6):880-887.	2649	AF, UEndp, Dur	
Ramachandran, V.. 1960. Observations on the Use of Ammonia for the Eradication of Aquatic Vegetation. J.Sci.Ind.Res.19C:284-285; Chem.Abstr.55: (1961).	626	AF, UEndp, Dur	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Rani, E.F., M. Elumalal, and M.P. Balasubramanian. 1998. Toxic and Sublethal Effects of Ammonium Chloride on a Freshwater Fish Oreochromis mossambicus. Water Air Soil Pollut. 104(1/2):1-8.	19157	UChron	
Rao, V.N.R., and G. Ragothaman. 1978. Studies on Amphora coffeaeformis II. Inorganic and Organic Nitrogen and Phosphorus Sources for Growth. Acta Bot.Indica 6(Supp l):146-154.	5449	AF, UEndp, Dur	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Reddy-Lopata, K., Auerswald, L., and Cook, P. Ammonia Toxicity and Its Effect on the Growth of the South African Abalone Haliotis midae Linnaeus. Aquaculture 261(2), 678-687. 2006.	105390	Non-NA	
Redner, B.D., and R.R. Stickney. 1979. Acclimation to Ammonia by Tilapia aurea. Trans.Am.Fish.Soc. 108:383-388.	2561	Dur - 3d	
Redner, B.D., J.R. Tomasso, and B.A. Simco. 1980. Short Term Alleviation of Ammonia Toxicity by Environmental Sodium Chloride in Channel Catfish (Ictalurus punctatus). J.Tenn.Acad.Sci. 55:54.	407	Dur - 2d	
Reichenbach-Klinke, H.H.. 1967. Investigations on the Influence of the Ammonia Content on the Fish Organism. Arch.Fischereiwiss. 17(2):122-132 (GER) (ENG TRANSL).	10170	UEndp	Other data used from study
Remen, Mette, Imsland, Albert Kjartansson, Stefansson, Sigurd O., Jonassen, Thor Magne, and Foss, Atle. Interactive effects of ammonia and oxygen on growth and physiological status of juvenile Atlantic cod (Gadus morhua). Aquaculture 274(2-4), 292-299. 2008-.		No Dose	Only 2 exposure concentrations
Rice, S.D., and R.M. Stokes. 1975. Acute Toxicity of Ammonia to Several Developmental Stages of Rainbow Trout, Salmo gairdneri. Fish.Bull. 73(1):207-211 (Personal Communication Used).	667	Dur - 1d	
Rippon, G.D., and R.V. Hyne. 1992. Purple Spotted Gudgeon: Its Use as a Standard Toxicity Test Animal in Tropical Northern Australia. Bull.Environ.Contam.Toxicol. 49(3):471-476.	5770	AF, Dur	
Robinette, H.R.. 1976. Effects of Selected Sublethal Levels of Ammonia on the Growth of Channel Catfish (Ictalurus punctatus). Prog.Fish-Cult. 38(1):26-29.	524	Dur - 1d	
Rodríguez-Ramos, Tania, Espinosa, Georgina, Hernández-López, Jorge, Gollas-Galván, Teresa, Marrero, Jeannette, Borrell, Yaisel, Alonso, Maria E., Bécquer, Ubaldo, and Alonso, Maray. Effects of Echerichia coli lipopolysaccharides and dissolved ammonia on immune response in southern white shrimp Litopenaeus schmitti. Aquaculture 274(1), 118-125. 2008-.		Non-NA	
Romano, Nicholas and Zeng, Chaoshu. Ontogenetic changes in tolerance to acute ammonia exposure and associated gill histological alterations during early juvenile development of the blue swimmer crab, Portunus pelagicus. Aquaculture 266(1-4), 246-254. 2007-.		Non-NA	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Ronan Patrick J, Gaikowski Mark P, Hamilton Steven J, Buhl KevinJ. , and Summers Cliff H. Ammonia Causes Decreased Brain Monoamines in Fathead Minnows (Pimephales Promelas). Brain research, 2007 May 25, 1147:184-91. Epub: 2007 Feb 17 . 2007.		Det	
Rose, A., Carruthers, A. M., Stauber, J., Lim, R., and Blockwell, S. Development of an Acute Toxicity Test with the Marine Copepod Acartia sinjiensis. Australas.J.Ecotoxicol. 12(2), 73-81. 2006.		Non-NA	
Rubin, A.J., and G.A. Elmaraghy. 1977. Studies on the Toxicity of Ammonia, Nitrate and Their Mixtures to Guppy Fry. Water Res. 11(10):927-935.	7635	Dur - 3d	Other data used from study
Rushton, W.. 1921. Biological Notes. Salmon Trout Mag. 25:101-117.	11164	AF, UEndp, Dur	
Saha, N., and B.K. Ratha. 1994. Induction of Ornithine-Urea Cycle in a Freshwater Teleost, Heteropneustes fossilis, Exposed to High Concentrations of Ammonium Chloride. Comp.Biochem.Physiol.B 108(3):315-325.	16783	UEndp	
Salin, D., and P. Williot. 1991. Acute Toxicity of Ammonia to Siberian Sturgeon Acipenser baeri. In: P.Willot (Ed.), Proc.1st Symposium on Sturgeon, Bordeaux (Gironde, France), Oct.3-6, 1989 :153-167.	7491	Dur - 1d	
Samylin, A.F.. 1969. Effect of Ammonium Carbonate on Early Stages of Development of Salmon. Uch.Zap.Leningr.Gos.Pedagog.Inst.Im.A.I.Gertsena.422:47-62 (RUS) (ENG TRANSL).	2606	UEndp, Dur	
Sarkar, S.K., and S.K. Konar. 1988. Dynamics of Abiotic-Biotic Parameters of Water and Soil in Relation to Fish Growth Exposed to Ammonium Sulfate. Environ.Ecol. 6(3):730-733.	804	UEndp / No Org	
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Sarkar, S.K.. 1991. Dynamics of Aquatic Ecosystem in Relation to Fish Growth Exposed to Ammonium Sulphate. J.Environ.Biol. 12(1):37-43.	238	WatQual, UEndp / No Org	
Sarkar, S.K.. 1991. Toxicity Evaluation of Urea and Ammonium Sulphate to Oreochromis mossambicus (Peters). J.Ecobiol. 3(1):79-80.	7535	Con	
Sathyanesan, A.G., K.P. Joy, and R.S. Kulkarni. 1978. Endocrine Changes in Fishes in Response to Pollutants. Q.J.Surg.Sci. 14(1/2):67-77.	10173	AF, UEndp	
Schipper, C. A., Dubbeldam, M., Feist, S. W., Rietjens IMCM, and Murk, A. T. Cultivation of the Heart Urchin Echinocardium Cordatum and Validation of Its Use in Marine Toxicity Testing for Environmental Risk Assessment. Journal of Experimental Marine Biology and Ecology [J. Exp. Mar. Biol. Ecol.]. Vol. 364, no. 1, pp. 11-18. 12 Sep 2008. 2008.		Det	
Schubauer-Berigan, M.K., P.D. Monson, C.W. West, and G.T. Ankley. 1995. Influence of pH on the Toxicity of Ammonia to Chironomus tentans and Lumbriculus variegatus. Environ.Toxicol.Chem. 14(4):713-717.	15119	UEndp / Dur - 10d / AF	Other data used from study

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Schulze-Wiehenbrauck, H.. 1976. Effects of Sublethal Ammonia Concentrations on Metabolism in Juvenile Rainbow Trout (Salmo gairdneri Richardson). Ber.Dtsch.Wiss.Kommn.Meeresforsch. 24:234-250.	2616	UEndp, Dur	
Shedd, T.R., M.W. Widder, M.W. Toussaint, M.C. Sunkel, and E. Hull. 1999. Evaluation of the Annual Killifish Nothobranchius guentheri as a Tool for Rapid Acute Toxicity Screening. Environ.Toxicol.Chem. 18(10):2258-2261.	20487	Dur - 1d	
Sheehan, R.J., and W.M. Lewis. 1986. Influence of pH and Ammonia Salts on Ammonia Toxicity and Water Balance in Young Channel Catfish. Trans.Am.Fish.Soc. 115(6):891-899.	12194	Dur - 1d	
Singh, S.B., S.C. Banerjee, and P.C. Chakrabarti. 1967. Preliminary Observations on Response of Young Ones of Chinese Carps to Various Physico-Chemical Factors of Water. Proc.Nat.Acad.Sci., India 37(3B):320-324; Biol.Abstr.51:5159 (1970).	2629	UEndp, Dur	
Slabbert, J.L., and J.P. Maree. 1986. Evaluation of Interactive Toxic Effects of Chemicals in Water Using a Tetrahymena pyriformis Toxicity Screening Test. Water S.A. 12(2):57-62.	12836	AF, UEndp, Dur	
Slabbert, J.L., and W.S.G. Morgan. 1982. A Bioassay Technique Using Tetrahymena pyriformis for the Rapid Assessment of Toxicants in Water. Water Res. 16(5):517-523.	11048	AF, UEndp, Dur	
Smart, G.. 1976. The Effect of Ammonia Exposure on Gill Structure of the Rainbow Trout (Salmo gairdneri). J.Fish Biol. 8:471-475(Author Communication Used).	2631	UEndp / Dur	
Smith, C.E., and R.G. Piper. 1975. Lesions Associated with Chronic Exposure to Ammonia. In: W.E.Ribelin and G.Migaki (Eds.), The Pathology of Fishes, University of Wisconsin Press, Madison, WI :497-514.	2636	Uenpd, Dur	
Smith, C.E.. 1984. Hyperplastic Lesions of the Primitive Meninx of Fathead Minnows, Pimephales promelas, Induced by Ammonia: Species Potential for Carcinogen Testing. In: K.L.Hoover (Ed.), Use of Small Fish Species in Carcinogenicity Testing, Monogr.Ser.Natl.Cancer Inst.No.65, NIH Publ.No.84-2653, U.S.Dep.Health Human Serv., Natl.Cancer Inst., Bethesda, MD :119-125.	10254	UEndp	
Snell, T.W., B.D. Moffat, C. Janssen, and G. Persoone. 1991. Acute Toxicity Tests Using Rotifers IV. Effects of Cyst Age, Temperature, and Salinity on the Sensitivity of Brachionus calyciflorus. Ecotoxicol.Environ.Saf. 21(3):308-317 (OECDG Data File).	9385	AF, Dur - 1d	Data provided in earlier report
Soderberg, R.W., J.B. Flynn, and H.R. Schmittou. 1983. Effects of Ammonia on Growth and Survival of Rainbow Trout in Intensive Static-Water Culture. Trans.Am.Fish.Soc. 112(3):448-451.	15728	AF, UEndp, Dur	
Solomonson, L.P.. 1970. Effects of Ammonia and Some of its Derivatives on Photosynthesis in the Blue-Green Alga, Plectonema boryanum. Ph.D.Thesis, Univ.of Chicago, Chicago, I L:68.	5443	UEndp, Dur	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Speare, D., and S. Backman. 1988. Ammonia and Nitrite Waterborne Toxicity of Commercial Rainbow Trout. Can.Vet.J. 29:666.	2958	AF, UEndp, Dur - 2d	
Spencer, P., Pollock, R., and Dube, M. Effects of Un-Ionized Ammonia on Histological, Endocrine, and Whole Organism Endpoints in Slimy Sculpin (Cottus Cognatus). Aquatic Toxicology [Aquat. Toxicol.]. Vol. 90, no. 4, pp. 300-309. 11 Dec 2008. 2008.		Det	Dilution water not described
Stanley, R.A.. 1974. Toxicity of Heavy Metals and Salts to Eurasian Watermilfoil (Myriophyllum spicatum L.). Arch.Environ.Contam.Toxicol. 2(4):331-341.	2262	AF	Plants do not drive criteria, and therefore, are not included in CWA review and approval of OR WQS
Suski, C. D., Kieffer, J. D., Killen, S. S., and Tufts, B. L. Sub-Lethal Ammonia Toxicity in Largemouth Bass. Comparative Biochemistry and Physiology, Part A: Molecular & Integrative Physiology [Comp. Biochem. Physiol., A: Mol. Integr. Physiol.]. Vol. 146, no. 3, pp. 381-389. Mar 2007. 2007.		No Dose, Dur	Only 2 exposure concentrations
Tabata, K.. 1962. Toxicity of Ammonia to Aquatic Animals with Reference to the Effect of pH and Carbonic Acid. Bull.Tokai Reg.Fish.Res.Lab.(Tokai-ku Suisan Kenkyusho Kenkyu Hokoku) 34:67-74 (ENG TRANSL).	14284	Dur - 1d	
Tarazona, J.V., M. Munoz, J.A. Ortiz, M. Nunez, and J.A. Camargo. 1987. Fish Mortality due to Acute Ammonia Exposure. Aquacult.Fish.Manage. 18(2):167-172.	12807	UEndp, Dur - 1d	
Taylor, J.E.. 1973. Water Quality and Bioassay Study from Crawford National Fish Hatchery. Trans.Nebr.Acad.Sci. 2:176-181.	2531	UEndp, Dur - 2d	
Thomas, J.D., M. Powles, and R. Lodge. 1976. The Chemical Ecology of Biomphalaria glabrata: The Effects of Ammonia on the Growth Rate of Juvenile Snails. Biol.Bull. 151(2):386-397.	15962	UEndp, Dur	
Thomas, P.C., C. Turner, and D. Pascoe. 1991. An Assessment of Field and Laboratory Methods for Evaluating the Toxicity of Ammonia to Gammarus pulex L. - Effects of Water Velocity. In: D.W.Jeffrey and B.Madden (Eds.), Bioindic.Environ.Manage., 6th Symposium, Academic Press, London, UK :353-363.	6276	UEndp, Dur - 1d	
Thumann, M.E.. 1950. The Effect of Ammonium Salt Solutions on Rainbow and Brook Trout and Some Fish Nutrient Animals. (Uber Die Wirkung Von Ammoniumsalzlosungen Auf ...). Abh.Fischerei.Lieferung 2:327-348.	2528	UEndp, Dur	
Thurston, R.V., and R.C. Russo. 1981. Acute Toxicity of Ammonia to Golden Trout (Salmo aguabonita) and Mottled Sculpin (Cottus bairdi). Tech.Rep.No.81-1, Fisheries Bioassay Laboratory, Montana State University, Bozeman, MT :10.	10221	Dur	Other data used from study
Tilak, K. S. , Veeraiah, K., and Raju, J. M. P. Toxicity and Effects of Ammonia, Nitrite, Nitrate and Histopathological Changes in the Gill of Freshwater Fish Cyprinus carpio. J.Ecotoxicol.Environ.Monit. 16(6), 527-532. 2006	105937	Det, AF, Dur	Detail (no pH, temp, etc.)

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Tomasso, J.R., C.A. Goudie, B.A. Simco, and K.B. Davis. 1980. Effects of Environmental pH and Calcium on Ammonia Toxicity in Channel Catfish. Trans.Am.Fish.Soc. 109(2):229-234 (Personal Communication Used).	410	Dur - 1d	
Tonapi, G.T., and G. Varghese. 1984. Cardiophysiological Responses of the Crab, Berytelphusa cunnicularis (Westwood), to Three Common Pollutants. Indian J.Exp.Biol. 22(10):548-549.	12198	AF, UEndp, Dur	
Tonapi, G.T., and G. Varghese. 1987. Cardio-Physiological Responses of Some Selected Cladocerans to Three Common Pollutants. Arch.Hydrobiol. 110(1):59-65.	2075	AF, UEndp, Dur	
Tsai, C.F., and J.A. McKee. 1980. Acute Toxicity to Goldfish of Mixtures of Chloramines, Copper, and Linear Alkylate Sulfonate. Trans.Am.Fish.Soc. 109(1):132-141 (Personal Communication Used).	5619	AF, UEndp	
Twitchen, I.D., and F.B. Eddy. 1994. Effects of Ammonia on Sodium Balance in Juvenile Rainbow Trout Oncorhynchus mykiss Walbaum. Aquat.Toxicol. 30(1):27-45.	14071	UEndp	
Twitchen, I.D., and F.B. Eddy. 1994. Sublethal Effects of Ammonia on Freshwater Fish. In: R.Muller and R.Lloyd (Eds.), Sublethal and Chronic Effects of Pollutants on Freshwater Fish, Chapter 12, Fishing News Books, London :135-147.	18512	UEndp, Dur - 2d	
Van den Heuvel-Greve, M., Postma, J., Jol, J., Kooman, H., Dubbeldam, M., Schipper, C., and Kater, B. A Chronic Bioassay with the Estuarine Amphipod Corophium volutator: Test Method Description and Confounding Factors. Chemosphere 66(7), 1301-1309. 2007.		Exp	Sediment exposure
Van Der Heide, T., Smolders, A. J. P., Rijkens, B. G. A., Van Nes, E. H., VanKatwijk, M. M., and Roelofs, J. G. M. Toxicity of Reduced Nitrogen in Eelgrass (Zostera Marina) Is Highly Dependent on Shoot Density and Ph. Oecologia, 158 (3) pp. 411-419, 2008		VarExp	Substantial loss of ammonia; Plant
Van Vuren, J.H.J.. 1986. The Effects of Toxicants on the Haematology of Labeo umbratus (Teleostei: Cyprinidae). Comp.Biochem.Physiol.C 83(1):155-159.	11744	AF, UEndp, Dur	
Vedel, N.E., B. Korsgaard, and F.B. Jensen. 1998. Isolated and Combined Exposure to Ammonia and Nitrite in Rainbow Trout (Oncorhynchus mykiss): Effects on Electrolyte Status, Blood Respiratory. Aquat.Toxicol. 41(4):325-342.	19154	UEndp	
Vijayavel, K., Rani, E. F., Anbuselvam, C., and Balasubramanian, M. P. Interactive Effect of Monocrotophos and Ammonium Chloride on the Freshwater Fish Oreochromis mossambicus with Reference to Lactate/Pyruvate Ratio. Pestic.Biochem.Physiol. 86(3), 157-161. 2006.	108153	Det, AF	Detail (pH, temp, etc. not reported)
Wallen, I.E., W.C. Greer, and R. Lasater. 1957. Toxicity to Gambusia affinis of Certain Pure Chemicals in Turbid Waters. Sewage Ind.Wastes 29(6):695-711.	508	Dur, Con, Uendp	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Walsh, Patrick J., Veauvy, Clemence, and Weihrauch, Dirk. Comparison of the mechanisms of ammonia tolerance in ureotelic (toadfish) versus ammoniotelic (midshipman) fish. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology 148(4), 464-465. 2008.		Det	
Wang, C., Zhang, S. H., Wang, P. F., Hou, J., Li, W., and Zhang, W. J. Metabolic Adaptations to Ammonia-Induced Oxidative Stress in Leaves of the Submerged Macrophyte Vallisneria natans (Lour.) Hara. Aquat.Toxicol. 87(2), 88-98. 2008.		Non-NA	
Ward Sara, Augspurger, T. o. m., Dwyer FJames, Kane Cindy, and Ingersoll Christopher G. Risk Assessment of Water Quality in Three North Carolina, Usa, Streams Supporting Federally Endangered Freshwater Mussels (Unionidae). Environmental Toxicology and Chemistry [Environ. Toxicol. Chem.]. Vol. 26, no. 10, pp. 2075-2085. Oct 2007. 2007.		Mix	
Water Pollution Research Board. 1961. Effects of Pollution on Fish: Toxicity of Gas Liquors. In: Water Pollution Research 1960, Water Pollution Research Board, Dep.of Scientific and Industrial Research, H.M.Stationery Office, London, England :76-81.	2514	UEndp, Dur	
Water Pollution Research Board. 1968. Effects of Pollution on Fish: Chronic Toxicity of Ammonia to Rainbow Trout. In: Water Pollution Research 1967, Water Pollution Research Board, Dep.of Scientific and Industrial Research, H.M.Stationery Office, London :56-65.	10185	AF, Dur - 2d / UEndp	
Watt, P.J., and R.S. Oldham. 1995. The Effect of Ammonium Nitrate on the Feeding and Development of Larvae of the Smooth Newt, Triturus vulgaris (L.), and on the Behaviour of Its Food. Freshw.Biol. 33(2):319-324.	14883	UEndp	
Watton, A.J. and Hawkes, H.A. 1984. The acute toxicity of ammonia and copper to the gastropod *Potamopyrgus jenkinsi* (Smith). Environ. Pollut. (Series A) 36:17-29.		Non Res	
Wee, N. L. J., Tng, Y. Y. M., Cheng, H. T., Lee, S. M. L., Chew, S. F., and Ip, Y. K. Ammonia Toxicity and Tolerance in the Brain of the African Sharptooth Catfish, Clarias gariepinus. Aquat.Toxicol. 82(3), 204-213. 2007.		No Dose	Only 2 exposure concentrations
Wickins, J.F.. 1976. The Tolerance of Warm-Water Prawns to Recirculated Water. Aquaculture 9(1):19-37.	2320	AF, UEndp, Dur	
Woltering, D.M., J.L. Hedtke, and L.J. Weber. 1978. Predator-Prey Interactions of Fishes Under the Influence of Ammonia. Trans.Am.Fish.Soc. 107(3):500-504.	7218	UEndp, Dur	Other data used from study
Wu Jinfeng, Chen Suwen, Chen Lixiong, Mai Yangshan, Lu Yimin, and Gan Juli. Studies on Toxicity of Sulfide and Ammonia to Spat of Coelomactra Antiquata. Journal of tropical oceanograhy/Redai Haiyang Xuebao [J. Trop. Oceanogr./Redai Haiyang Xuebao]. Vol. 25, no. 1, pp. 42-46. 2006. 2006.		Det, Forgn	

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Xu, Q., and R.S. Oldham. 1997. Lethal and Sublethal Effects of Nitrogen Fertilizer Ammonium Nitrate on Common Toad (Bufo bufo) Tadpoles. Arch.Environ.Contam.Toxicol. 32(3):298-303.	17840	AF, UEndp, Dur	

Corresponding Code List

ABIOTIC FACTOR (AF)	Studies where an abiotic factor such as total water hardness, pH, or temperature are not reported for a criteria for which this information is necessary to derive a Species Mean Acute or Chronic Value, i.e., several freshwater metals, pentachlorophenol, ammonia.
ACELLULAR (Ace)	Studies of acellular organisms (protozoa) and yeast.
BACTERIA (Bact)	Studies describing only the results on bacteria.
BIOMARKER (Biom)	Studies reporting results for a biomarker having no reported association with a biologically significant adverse effect (survival, growth, or reproduction of an individual or population) and an exposure dose (or concentration).
CONTROL (Con)	Studies where control mortality is insufficient or unsatisfactory, i.e., where survival is less than 90% in acute tests or 80% in chronic tests; or where no control is used.
DETAIL (Det)	Insufficient detail regarding test methodology or statistical analysis.
DURATION (Dur)	Laboratory and field studies where duration of exposure is inappropriate (e.g., too short) for the type of test (i.e., acute or chronic), or was not reported or could not be easily estimated.
EFFLUENT (Efflu)	Studies reporting only effects of effluent, sewage, or polluted runoff where individual pollutants are not measured.
EFFECT (Eff)	Studies where the biologically significant adverse effect was not survival, growth, or reproduction of an individual or population.
ENDPOINT (UEndp)	Studies reported in ECOTOX where an endpoint (LC50, EC50, NOEC, LOEC, MATC, EC20, etc.) was not provided, where none of the concentrations tested in a chronic test were deleterious (no LOEC); or where all concentrations tested in a chronic test caused a statistically significant adverse effect (no NOEC).
FIELD (Field)	Chronic, long-term studies conducted in a field setting (stream segment, pond, etc.) where source/dilution water is not characterized for other possible contaminants.
FORMULATION (Form)	Studies where the chemical is a primary ingredient in a commercial formulation, e.g., biocide, fertilizer, etc.
IN VITRO (In Vit)	*In vitro* studies, including only exposure of the chemical to cell cultures and excised tissues and not related to whole organism toxicity.
LETHAL TIME (LT)	Laboratory studies reporting only lethal time to mortality, except under special conditions (no other applicable information is available for species pivotal in making a finding).
NO DOSE or CONC (No Dose or Conc)	Studies with too few concentrations to establish a dose-response, or no usable dose or concentration reported in either primary or sister article(s), except under special conditions (no other applicable information is available for species pivotal in making a finding).
NOMINAL (Nom)	Chronic studies where test concentrations were not measured.
NON-RESIDENT (NonRes)	Species that are not resident to North America, or where there is no reported evidence of their reproducing naturally in North America.
NO ORGANISM (No Org)	Laboratory and field studies where no one organism is studied (e.g., periphyton community) or where no scientific/common name is given in either a primary or sister article(s).
PURITY (Pur)	Studies where the chemical purity of the toxicant was less than 80% pure (active ingredient).
ROUTE OF EXPOSURE (RouExp)	Dietary or un-natural exposure routes for aquatic chemicals, e.g., injection, spray, inhalation.
TOXICANT (Tox)	Inappropriate form of toxicant used or none identified in a laboratory or field study. Note: Inappropriate form includes mixtures.

UNACCEPTABLE CHRONIC (UChron)	Chronic studies which were not based on flow-through exposures (exception for cladocerans and other small, planktonic organisms where test water is continuously renewed) and/or where test concentrations were not measured.
UNUSUAL DILUTION WATER (Dilut)	Laboratory or field studies where the dilution water contained unusual amounts or ratios of inorganic ions or was without addition of appropriate salts (i.e., distilled or de-ionized water).
VARIABLE EXPOSURE (VarExp)	Excessive variability in contaminant concentrations during the exposure period.
WATER QUALITY (WatQual)	Studies where the measured test pH is below 6 or greater than 9, where dissolved oxygen was less than 40% saturation for any length of time, or where total or dissolved organic carbon is greater than 5 mg/L.