To: **Washington Citizens**

From: **Megan White, P.E., Manager**
Water Quality Program
Department of Ecology

Subject: **Proposed Ammonia Criteria**
Decision Process for Ecology's Proposed Rule

This memorandum constitutes the decision-making process that resulted in the Washington Department of Ecology's (Ecology) proposed changes to the freshwater ammonia criteria.

Proposed Alternative

Ecology's proposed alternative is to retain the existing chronic criterion to waters used as salmonid habitat and to apply the new EPA recommended chronic criteria to other freshwaters. The new EPA recommended acute criteria would be applied to all freshwaters. This application scenario is outlined in the table below.

Criterion	Area of application
1999 update acute criterion	All freshwaters
1999 update chronic criterion for "fish early life stages absent"	Freshwaters with no early life stages present and not designated as salmonid habitat
1999 update chronic criterion for "fish early life stages present"	Freshwaters with early life stages of non-salmonid fish species present and not designated as salmonid habitat
Existing chronic criterion for "salmonids present"	All freshwaters with salmonid habitat as a designated use

Background

Ecology administers the state's surface water quality standards regulations (Chapter 173-201A WAC). These regulations establish minimum requirements for the quality of water that must be maintained in lakes, rivers, streams, and marine waters. This is done to ensure that all beneficial uses associated with these waterbodies are protected.

The water quality standards currently contain criteria for ammonia that have been approved by EPA and are protective of aquatic life. In 1999, the EPA released revised ammonia criteria for freshwater. The new criteria are less stringent than the existing criteria and a small set of data indicated that salmonids might not be fully protected by the chronic criteria. Ecology reviewed both the EPA criteria document and the published literature on effects of ammonia to early-life stage salmonids to determine whether adopting the less stringent criteria would still ensure protection of salmonids in Washington.

Basis for Proposed Alternative

Ecology's proposed alternative for ammonia criteria is based upon a review of the technical literature and in consideration of the species and environmental conditions existing in the state of Washington. Consideration was also given to the ability to implement the criteria in a feasible and reasonable manner. Available scientific and technical literature were assessed to establish ammonia recommendations that will maintain healthy and productive populations of the state's aquatic species, and not hinder efforts to recover populations of fish species that are threatened with extinction.

Recommendations Suggested from Literature Review

Only four papers were found in the published literature that document the effects of long-term ammonia exposure on early-life stage salmonids. Those papers document four tests done with rainbow trout, a salmonid that is frequently used in toxicity testing. The results of the four tests showed 20 percent lethality at concentrations ranging from 1.34 to 22.0 milligrams of nitrogen per liter (mg N/L). The EPA recommended criteria for these types of effects is 2.43 mg N/L, while the existing criterion values representing the test conditions range from 1.29 to 1.36 mg N/L.

Ecology does not think there is a reliable way to determine a specific "safe" level for early-life stages of salmonids that will give a predicted level of effects, nor does Ecology think that we can reliably evaluate whether the EPA criteria are protective of Washington salmon species and wild or hatchery populations based on the available studies. Ecology does not believe there were enough studies done that examined the effects of ammonia on early-life stages of salmonids, and the few studies available had a broad range of effect levels and only one species of salmonid used (which might or might not represent the sensitivity of local Washington salmonids) to generate the test data. We simply do not have enough information which leads to a level of uncertainty regarding the protectiveness of the EPA recommended criterion. This does not mean that the EPA criterion is not fully protective but simply that we do not have enough information to evaluate whether it is fully protective.

Given this uncertainty, Ecology has chosen to recommend a partial adoption of the EPA criteria as discussed above. In recommending that we retain the existing chronic criterion in freshwaters used as salmon habitat, Ecology has made a very precautionary risk management decision to stay with a criterion that we feel confident will be protective of salmonids. If more data from chronic long-term tests becomes available on the effects of ammonia on early life stage salmonids, Ecology would be very interested in reviewing the data.

Also of importance when making the risk management decision described above were comments Ecology received earlier in the process of reviewing the criteria, when the basic approach of using precaution to deal with uncertainty was being made. EPA staff evaluated the approach used by Ecology and did not agree with it for several reasons.

One of the most important reasons was Ecology's method of comparing test results from individual studies to the recommended criteria levels instead of averaging all the test results for a species and then comparing the average effects level to the recommended criterion level. The EPA felt that this practice incorporated too much variability into the comparison. However, because published data are so limited (four papers, as described above), because they show such a wide range of effects levels, and because the tests were conducted with rainbow trout (which might be more or less sensitive than the many different species of wild and hatchery salmonids that use Washington waters), Ecology made the decision to use individual test data to compare with the recommended criteria and to use this comparison in developing a preferred alternative. We hope to receive public input during the comment period that will address the approaches outlined above.

Although the proposed adoption of the other EPA recommended criteria for ammonia (as outlined above in the table) will result in less stringent criteria for permitting and water body assessment, this is unlikely to have any material effect on costs of compliance. Because almost all freshwaters in Washington are used by salmonids and because the existing chronic criteria for salmon waters is the most restrictive criterion we have for ammonia, this stringent criteria will still remain the driver for most permitting and waterbody assessment decisions. In effect, the cost of complying with the criteria will remain unchanged. If the EPA recommended criteria were to be adopted in its entirety, it is likely that costs for municipal treatment plants and waterbodies addressing TMDLs would be reduced.

Accompanying Documents & Information

This decision memo is accompanied by a discussion document and literature summary entitled "Review of USEPA's 1999 Ammonia Criteria for Freshwaters."

Draft language for ammonia in freshwater can be found in the proposed rule at WAC 173-201A-240(3).

A discussion of alternatives for ammonia criteria in freshwater can be found in the draft Environmental Impact Statement for the proposed rule on page 76.

Additional questions on the proposed revisions to the ammonia criteria can be directed to Cheryl Niemi in the Water Quality Program at (360) 407-6440.

Additional information on proposed revisions to the rule, including draft Administrative Procedures Act (APA) materials and the draft Implementation Plan, can be found by visiting our Web site at www.ecy.wa.gov/programs/wq/swqs.

Review of USEPA's 1999 Ammonia Criteria for Freshwaters

Draft Discussion Paper and Literature Summary

Water Quality Program
Washington State Department of Ecology
Watershed Management Section
Olympia, Washington 98504

December 2002
Publication Number 02-10-064

Review of USEPA's 1999 Ammonia Criteria for Freshwaters

Draft Discussion Paper and Literature Summary

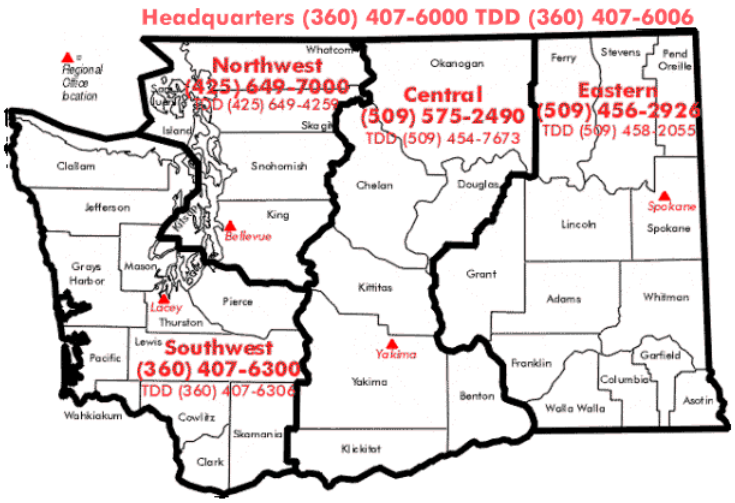
Water Quality Program
Washington State Department of Ecology
Watershed Management Section
Olympia, Washington 98504

December 2002
Publication Number 02-10-0XX

For additional copies of this document contact:

Department of Ecology
Publications Distribution Center
P.O. Box 47600
Olympia, WA 98504-7600

Telephone: (360) 407-7472



If you have special accommodation needs or require this document in an alternative format, please call Cheryl Niemi at 360-407-6440. The TTY number is 711 or 1-800-833-6388

Table of Contents

Summary

On December 22, 1999 the United States Environmental Protection Agency (USEPA) published the *1999 Update of Ambient Water Quality Criteria for Ammonia* (U.S. Environmental Protection Agency, 1999) (hereinafter referred to as the 1999 Update). The new 1999 criteria are higher than the existing criteria values (WAC 173-201A-040) and, because of the emphasis placed on salmonids in regulatory decisions made in the Pacific Northwest, the 1999 Update criteria were evaluated to determine whether the increased criteria values posed any risk to salmonids. The evaluation was done within the context of a larger and more long-term process to revise the surface water standards for the state of Washington (WAC 173-201A).

The review of the 1999 Update raised two issues of concern in the calculation of the criteria. The first is the formulation of the relationship between chronic ammonia toxicity and temperature. An incorrect or inappropriate formulation could result in criteria set at higher or lower concentrations. The second is that the small amount of long-term toxicity test data available for early life stages of rainbow trout show chronic effects over a wide range of concentrations. In some tests effects were observed at concentrations below the lower temperature chronic criteria in the 1999 Update. The chronic criteria in the 1999 Update address waters with "fish early life stages absent" and with "fish early life stages present." The "fish early life stages present" criterion is the focus of this evaluation.

Based on the two concerns described above, the Washington Department of Ecology (WDOE), aided by USEPA Region X, began a review of the new 1999 Update in early February. This paper summarizes the findings of that review process. The process included several review components, including:

- Literature search: Literature searches by USEPA Region X, Idaho Department of Environmental Quality, and WDOE for papers published within the last ten years that address salmonids and chronic ammonia toxicity to early life stages
- Relationship between temperature and chronic ammonia toxicity: USEPA headquarters staff provided an explicit explanation of the development of the relationship between temperature and chronic invertebrate toxicity
- **C**hronic criterion and salmonid toxicity: Available data were examined to determine whether existing and 1999 Update chronic criteria appear to be protective of early life stages of salmonids.
- A short discussion of the margin of safety a criterion should provide for regionally important species, including some discussion of areas needing further guidance when developing criteria for regionally important species.
- Preparation of four alternatives for adoption of the new criteria, and a recommended alternative.
- A discussion of the recommended adoption and implementation of the 1999 Update criteria.

The review process concludes that:

- Data are not available to determine the relationship between temperature and ammonia toxicity for salmonids.
- A paucity of data on effects of ammonia to early life stages of salmonids makes an assessment of the protectiveness of the new "fish early life stage present" chronic criterion difficult to quantify. Because of insufficient data to quantify safe levels, effects levels from each paper were used separately to evaluate the 1999 criterion instead of relying on a species mean (or other measure of central tendency) effects level to represent the effects level for rainbow trout.
- Data from one paper on the biochemical effects of exposure of rainbow trout to ammonia suggest that the existing chronic criteria may not be adequately protective of salmonids; however, the biological relevance of the effects appears speculative.

A recommended approach including adoption of the 1999 Update chronic criteria for all freshwaters where salmonid habitat is not a beneficial use is presented and discussed. This approach includes adoption of the new 1999 Update acute criteria for both salmonid and nonsalmonid waters.

Background

Water Quality Criteria and Protection of Uses

Water quality criteria are discrete numeric or narrative statements that provide specific levels of protection for designated uses such as aquatic life, fishing, recreation, and wildlife protection (CFR 131.11(a)). Aquatic life-based water quality criteria are designed to provide a reasonable level of protection to all but a small fraction of taxa present in a waterbody unless a commercially or recreationally important species is very sensitive (U.S. Environmental Protection Agency, 1985b). In the Pacific Northwest, salmonids have both recreational and commercial importance, are culturally important to many Native American tribes, and many are listed as threatened or endangered. In Washington the designated use that applies directly to salmonids is "salmonid migration, rearing, spawning, and harvesting" (Washington Administrative Code 193-301A). In the following discussion these specific aquatic uses are lumped into the category "salmonid habitat."

Water quality criteria for the protection of beneficial uses serve many purposes, including:

- The basis for water quality-based effluent limits in NPDES permits.
- Waterbody assessment. In this case the criterion serves as a discrete numeric that can be used to compare to concentrations measured in waterbodies, and used to determine whether waterbodies are in compliance with water quality standards (whether beneficial uses are being maintained).
- A target for recovery efforts in impaired waterbodies.

The application of the criteria to these purposes is briefly discussed below.

Criteria are the basis for calculating water quality-based effluent limits. Point-source discharges to surface waters are permitted through the NPDES system. Permits are required to contain effluent limits that will protect against exceedances of water quality criteria.

Criteria are the basis for waterbody assessment. Water quality criteria are used to assess whether conditions suitable to protection of designated beneficial uses are maintained in a waterbody (Clean Water Act (CWA) 303(d) listing process). Fourteen waterbodies in Washington are currently listed as impaired because of exceedances of the ammonia criteria. If a criterion does not reflect a level of protection both accurate and appropriate for a designated use, accurate assessment of whether uses are protected cannot be easily measured. In this case, if the criterion concentration is higher than the level needed to maintain beneficial uses, a problematic concentration level may occur yet remain undetected because the "comparison tool" is flawed.

Criteria are the basis for planning recovery efforts. When a waterbody is listed as impaired because of exceedances of water quality criteria, the CWA requires that the waste sources and assimilative capacity of the waterbody be determined and quantified and that a plan for recovery of the waterbody uses be developed. This requirement is encapsulated in processes within the total maximum daily load (TMDL) process. TMDLs are in most cases resource intensive and complex. In order to develop an effective TMDL that will restore beneficial uses, the criteria used to determine exceedances and as a target for recovery efforts must be reasonably accurate.

Water Quality Criteria for Ammonia

On December 22, 1999, the USEPA published the *1999 Update of Ambient Water Quality Criteria for Ammonia* (U.S. Environmental Protection Agency, 1999) (hereinafter referred to as the 1999 Update). This document supercedes the previously released *1998 Update of Ambient Water Quality Criteria for Ammonia* (U.S. Environmental Protection Agency, 1998) (hereinafter referred to as the 1998 Update). The existing Washington surface water quality criteria for ammonia are based on the 1984 EPA criteria document (U.S. Environmental Protection Agency, 1985a), with updates to portions of the criterion equation as developed by EPA. The new 1999 Update ammonia criteria are higher than the existing ammonia criteria values and, because of the emphasis placed on salmonids in many regulatory decisions made in the Pacific Northwest, the 1999 Update criteria were evaluated to determine whether their use posed an acceptable or unacceptable risk to salmonids based on regional concerns. The review focuses on salmonids due to their economic ans cultural importance in the Pacific Northwest, as well as several threatened and endangered (T&E) listings under the Endangered Species Act (ESA). Many Clean Water Act (CWA) related regulatory decisions now require consultation under the ESA. Any proposal to raise the existing water quality criteria for ammonia will likely result in CWA-ESA consultation to ensure that salmonids are adequately protected. The evaluation was also done within the context of a larger and more long term process to revise the surface water standards for the state of Washington (WAC 173-201A).

This review is not focused on the 1999 Update *acute* criteria or the fish early-life-stage-*absent* chronic criterion. The 1999 Update acute ammonia criterion for "salmonids present" appears to

be protective of acute effects to salmonids and is based on protection of rainbow trout. These criteria are expected to provide protection from acute effects of ammonia to salmonids in the freshwaters they are applied to. The fish early-life-stage-*absent* chronic criterion is not addressed here, as comparison of the criterion with data used to generate the criterion does not indicate any likelihood of lack of protection for salmonids that have developed beyond early life stages.

This review focuses on the "fish early-life-stage present" chronic ammonia criteria in the 1999 Update and raises two issues of concern in the calculation of the chronic criteria. The first is the formulation of the relationship between chronic ammonia toxicity and temperature. An incorrect or inappropriate formulation could result in criteria set at higher or lower concentrations than justifiable. The second concern is that the small amount of long-term toxicity test data available for early life stages of rainbow trout show chronic effects over a wide range of concentrations. In some tests effects were observed at concentrations below the lower temperature chronic criteria in the 1999 Update.

Approach

The Washington Department of Ecology (WDOE), aided by USEPA Region X, began a review of the new 1999 Update in early February 2000. This paper summarizes the findings of that review process. The process included several review components, including:

- Literature search: Literature searches by USEPA Region X, Idaho Department of Environmental Quality, and WDOE for papers published within the last 10 years that address salmonids and chronic ammonia toxicity to early life stages.
- Relationship between temperature and chronic ammonia toxicity: USEPA headquarters staff provided an explicit explanation of the development of the relationship between temperature and chronic invertebrate toxicity used in the 1999 Update.
- **C**hronic criterion and salmonid toxicity: Available data were examined to determine whether existing and 1999 Update chronic criteria appear to be protective of early life stages of salmonids.
- Criteria modification: A discussion of site-specific "fish early life-stages present" (ELSP) criterion development for chronic ammonia effects on salmonids. In this case the term "site-specific" could apply to individual states, the geographic area covered by USEPA Region X, or some other area representative of the Pacific Northwest.
- Preparation of four alternatives for adoption of the new criteria, and a recommended alternative.
- A discussion of the recommended adoption and implementation of the 1999 Update criteria.

Literature Search Results

New literature addressing the chronic toxicity of ammonia to salmonids was sparse. One paper by Arillo *et al*. (1981a), which had not been considered in the 1985 ammonia criteria document

or in the 1998 or 1999 Updates, was provided by EPA Reg. X . This paper is included in the discussion below.

Relationship between Temperature and Chronic Ammonia Toxicity

Ammonia toxicity is dependent on several factors, among them pH, temperature, and dissolved oxygen. The form of ammonia most toxic to aquatic life is the unionized form (NH3). The relative proportions of unionized and ionized ($NH4^{+}$) ammonia in solution are dependent on temperature and pH.

The relationship between temperature and ammonia toxicity is difficult to ascertain, largely due to variability and inconsistency in the toxicity data sets. The 1984 ammonia criteria document based the relationship between temperature and ammonia toxicity on the concentrations of *unionized ammonia* in solution. An average temperature relationship for fish was used to adjust fish acute toxicity data to a common temperature, and this relationship was then used to extrapolate the acute criterion to other temperatures. This resulted in a higher acute criterion at higher temperatures. The unionized ammonia acute criterion was capped at a value near the upper end of the temperature range of the acute toxicity data for fishes. A similar cap, developed from the chronic toxicity database for fishes, was incorporated in the chronic criterion. These caps were added to reduce the uncertainty of extrapolation to higher temperatures beyond the extent of the original data sets.

The 1999 Update develops the relationship between temperature and ammonia toxicity based on total ammonia nitrogen concentrations. The analysis includes data from Arthur *et al*. (1987). These data were not used in the 1998 EPA update because EPA expressed concern that factors in this mesocosm experiment other than temperature might have confounded their data set. In the 1999 Update, EPA's reanalysis of the data found the following:

Fish Acute Data

The fish acute data set shows considerable variability in the relationship between temperature and toxicity, with both positive and negative slopes present. A pooled regression analysis including data from Arthur *et al*. (1987) showed a statistically significant trend between toxicity and temperature. USEPA found that two data points, one of which was inconsistent with other test results and a second that was part of a test that used fish from three different sources, heavily influenced this significant slope. When these data points were removed, the regression resulted in a lower slope that was not statistically significant. An analysis of fathead minnow data showed significant nonzero slopes, but this species is not sensitive enough to affect the acute criterion values. Analysis of the relationship between rainbow trout toxicity and temperature data was statistically insignificant but suggested weak trends similar to the pooled analyses over all data sets. The 1999 Update concludes that a temperature correction for acute toxicity for fish data would be inappropriate due to the lack of any statistical trend over all the data sets.

Invertebrate Acute Data

Based on data from outdoor experimental stream studies (Arthur *et al*. 1987), the 1999 Update concluded that invertebrate sensitivity to acute ammonia toxicity decreases with decreasing

temperature. These were seasonal tests where water quality characteristics other than temperature were not held constant. Due to the large magnitude of the changes in toxicity associated with temperature, EPA found that temperature was likely the major cause for the toxicity changes. Because invertebrates are not among the most sensitive taxa to ammonia, this relationship does not influence the acute criterion. However, EPA used the temperature relationship developed from a pooled regression analysis of these data in the formulation of the invertebrate chronic temperature slope, which affects the chronic criterion values.

Fish Chronic Data

Only one fish study containing adequate information on the relationship between temperature and chronic toxicity (DeGraeve *et al*. 1987, as cited in U.S. Environmental Protection Agency 1999) was available for review in the 1999 Update. This fathead minnow study includes both chronic and acute toxicity data**.** When the chronic toxicity data were analyzed, taking into account the effects of pH on the relationship, the effect levels show a nonsignificant upward trend with temperature (different from that for acute toxicity). EPA examined the difference between acute and chronic toxicity relationships and concluded that acute to chronic ratios (ACRs) are higher at low temperatures. EPA discussed the possible reason for this ACR relationship with temperature as being due to slowed reaction time (thus delayed toxicity) based on lower temperatures, and the overall impact on the ACRs and LC50s would be dependent on the test duration and speed of action of acute toxicity in the species of concern. Chronic salmonid data were not available to determine whether the fathead-minnow data appropriately characterized the relationship between ammonia toxicity and temperature for salmonids. Because the fathead-minnow data showed no relationship between chronic ammonia toxicity and temperature (slope close to zero), the sensitive fish data used in the chronic criterion calculation were not adjusted for such a relationship.

Invertebrate Chronic Data and Projections

No data were available to directly determine the relationship between chronic ammonia toxicity and temperature for invertebrates. In this case, EPA relied on the slope of the ACRs developed from the chronic fathead minnow data described above to calculate the relationship between chronic ammonia toxicity and temperature for invertebrates. The assumption used here was that the kinetics of toxicity as demonstrated by the fish ACR (discussed above: lower temperature results in delayed toxicity) would hold true for invertebrates as well as fish. Invertebrate data are not available to test this assumption, but EPA is presently contracting toxicity test work to test this hypothesis (Charles Delos, pers. comm). EPA subtracted the slope of the fathead minnow ACR (adjusted to pH = 8) from the pooled invertebrate acute slope to calculate a chronic invertebrate slope. This calculation is explained further in Appendix A. The calculated chronic relationship was applied only to the sensitive invertebrate data when the chronic criterion was calculated.

The temperature relationship developed by EPA is difficult to evaluate with regard to salmonids. A literature search found no new literature on salmonids and ammonia toxicity that would be relevant to a determination of the relationship between temperature and chronic ammonia toxicity. The relationship included in the 1999 Update is driven by ACRs for one species of fish (fathead minnow), and the extrapolation of this relationship to invertebrate test data. The premise supporting this is that the kinetics of ammonia toxicity are similar across taxa. Ongoing

toxicity testing using an invertebrate will help determine whether a kinetics-based approach is accurate. Because of the many suppositions involved with this approach and the lack of data on salmonids, the inverse relationship between temperature and chronic toxicity incorporated in the 1999 Update cannot be evaluated with regard to its applicability to salmonids.

1999 Update Chronic Criterion (fish early life stages present) and Salmonid Toxicity

There are few published studies that examine the chronic effects of ammonia on early life stages of salmonids. The studies that are available show effects occurring over a wide range of concentrations (Table 1). The 1999 Update points this out and states that "the data suggest there might be important differences between strains of rainbow trout." In the 1999 Update criterion calculation, salmonids were not included in the data set because of concerns with the variability of the data set. Instead, salmonid data were compared to the criteria to determine whether the criteria are protective of salmonids. Some of the data examined in the 1999 Update show effects to early life stages of rainbow trout at concentrations less than the criterion (Table 1).

The 1999 Update expresses the criteria as total ammonia nitrogen while the existing criteria is expressed as unionized ammonia. The discussion below uses **total ammonia nitrogen values (at pH=8)** in order to be consistent with the new criteria.

Table 1. Comparison of literature toxicity values, 1999 Update, and existing freshwater ammonia chronic criteria values at pH =8 and the temperature conditions reported in the indicated study. The first four tests listed are early life-stage tests.

Study	Study test temperature	Study test result at pH = 8	1999 Update criterion at pH = 8 and average test temperature	Existing criterion for "salmonids present" at pH = 8 and test temperature
Thurston *et al*. (1984)	7.5 to 10° C	EC20 < 5.4 mg N/L	2.43 mg N/L	1.328 - 1.363 mg N/L
Burkhalter and Kaya (1977)	9.5 to 12.5° C	LC20 < 22.0 or 18.7 mg N/L	2.43 mg N/L	1.310 - 1.339 mg N/L
Solbe and Shurben (1989)	14.9°C (range from 11.5 - 17°C)	LC20 < 1.44 mg N/L	Approx. 2.3 mg N/L	1.293 mg N/L (1.117 - 1.293 mg N/L)
Calamari *et al*. (1977,1981)	14.5°C	LC20 = 1.34 mg N/L	Approx. 2.35 mg N/L	1.296 mg N/L
Arillo *et al.* (1981a)	11°C	EC? = 1.012 mg N/L	2.43 mg N/L	1.323 mg N/L (*)

Two early life stage salmonid studies discussed in the 1999 Update indicate that early life stages of salmonids would be protected by the new criteria. These studies include Thurston *et al*. (1984), who conducted a continuous exposure five-year study of three generations of rainbow trout to total ammonia concentrations of 0.77 - 5.4 mg/L. Severe effects were not seen at any tested concentration, thus the EC20 for the test is unlikely to be much lower than the highest tested concentration. The EC20 could not be directly measured because data variability at each life stage was so great. Burkhalter and Kaya (1977) tested embryos and sac fry, beginning the tests within 24 hours of fertilization and continuing to the beginning of feeding. Reduced growth was found in very young fish. LC50s for the tests were 18.7 or 22.0 mg/L, depending on whether control mortality was adjusted for. The LC20s for this test would have been less than the LC50s.

Calamari *et al*. (1977,1981) and Solbe and Shurben (1989) (both reviewed in the 1999 Update) showed effects levels at concentrations less than the 1999 criteria. These tests began within 24 hours of fertilization and lasted for up to 73 days. EPA reviewed data in Calamari *et al.* (1977, 1981), and developed an LC20 of 1.34 mg N/L at 14 - 15°C using semilog interpolation. The EPA review of Solbe and Shurben (1989) found 67% reduced survival at 1.44 mg N/L at 14.9°C average temperature (11.5-17°C temperature range). The study showed that when exposure began within 24 hours of fertilization, lethality was much enhanced over tests where exposure began 24 days after fertilization.

The four early-life stage studies for rainbow trout indicate wide variability in effects concentrations. Interesting to note are the temperatures at which the tests were conducted (Table 1). Thurston *et al*. (1984) tested at 7.5 - 10.5°C, Burkhalter (1975), and Burkhalter and Kaya (1977) tests were run at 9.5 - 12.5°C. These tests all show toxic effects at relatively high

concentrations. Calamari *et al*. (1977, 1981) tests were run at 14 - 15°C, and Solbe and Shurben (1989) ran tests with temperatures ranging from 11.5 - 17°C. These tests showed toxic effects at relatively low concentrations. Ongoing work at the WDOE to develop temperature criteria for protection of aquatic life indicate that early life stages of rainbow trout are sensitive to higher temperatures and may have optimal survival at 9-10°C, and that temperatures from 14°C and above could result in increased mortality (Mark Hicks, pers. comm). Control mortality data were not presented in Solbe and Shurben (1989), but data in Calamari *et al*. (1977, 1981) indicate that temperature was not a confounding factor in their test design.

Data from Calamari *et al*. (1977, 1981) and Solbe and Shurben (1989) indicate that effects on rainbow trout early life stages might occur at concentrations lower than the "fish early life stage present" ammonia criteria in the 1999 update (Table 1). The small number of tests on early life stage salmonids, and the high variability of the effects levels from these tests, leave us with a high degree of uncertainty regarding the protectiveness of the 1999 Update ELSP chronic criterion for salmonids.

Existing Chronic Criterion and the Level of Protection Desired for Regionally Important Species

In the Pacific Northwest, salmonids are viewed as a *regionally important species* for many reasons: they are a cultural icon of many native American tribes, they are recreationally and commercially important, and several species and runs are listed as threatened or endangered under the ESA. Water quality criteria are designed to provide a reasonable level of protection to all but a small fraction of taxa present in a waterbody unless a commercially or recreationally important species is very sensitive (U.S. Environmental Protection Agency, 1985b). Although the focus of this review has been to determine whether the 1999 Update recommended chronic criteria would provide appropriate protection for salmonids in Washington, an important component of the review is to determine an appropriate alternative criterion choice if the 1999 Update criteria are not used in Washington. In this, case the alternative criterion evaluated for protection of salmonids was the existing freshwater aquatic life chronic criterion for “salmonids present” (WAC 173-201A-040). The emphasis of this review was to develop an overall recommendation likely to:

- Provide the most reasonable criteria for use in effluent limit development and facility planning for the regulated community.
- Provide full protection for salmonids in Washington.

In Washington, the designated use that applies directly to salmonids is “salmonid migration, rearing, spawning, and harvesting” (Washington Administrative Code 193-301A). In the following discussion these specific uses are lumped into the category “salmonid habitat.”

Regulatory agencies address the appropriate levels of protection provided by water quality criteria when the criteria are applied to regionally important species. One way of measuring the protectiveness of a criterion to a specific species is to calculate a “margin of safety.” In this

discussion, the margin of safety (MOS) of the *existing* "salmonids present" chronic criterion for ammonia is a *percentage value* calculated as follows:

$$\frac{((\text{salmonid EC20 or LC20}) - \text{criterion})) \times 100}{\text{criterion}} = \text{Margin of Safety}$$

The MOS approach, as used here, includes three major assumptions:

- An effects concentration of 20% (EC20 or LC20) is an effects level that adequately represents protection for regionally important species.
- Effects levels developed in laboratory tests mirror effects levels that would be seen in the field.
- Rainbow trout is an appropriate toxicity test surrogate for regionally important salmonid species in Washington.

Because the four early life stage studies discussed above show considerable variability in effects levels and because only five studies were found for review, the MOS approach presented here uses a comparison with effects levels from *individual studies* instead of a comparison with the geometric mean effects levels for a species that would normally form the basis for criteria development (U.S. Environmental Protection Agency, 1985b). Using the margin of safety approach, the results of the four early life stage studies discussed above indicate that the existing chronic ammonia criteria would be protective of early life stages of salmonids (i.e., margin of safety). Calamari *et al*. (1977, 1981) and Solbe and Shurben (1989) indicate that the MOS of this criterion may be very small (Table 2).

Arillo *et al*. (1981a) (not reviewed in the 1999 Update) used rainbow trout 14 cm. in length to test ammonia effects on stress-induced biochemical markers and found test responses at levels lower than the four early life stage studies discussed above. The temperature and pH test conditions for this study were 11°C and 7.5, respectively (Arillo *et al.* 1981b, 1981c). The authors point out that concentrations of unionized ammonia less than 20 ug/L (1.012 mg N/L at pH=8) cause changes in biochemical parameters related to brain, kidney, and liver metabolism. An effects level of 1.012 mg N/L is also lower than the existing chronic criteria of 1.323 mg N/L at 11°C and pH=8. Arillo *et al.* offer the opinion that the effects are probably the expression of physiological damage caused by a failure in maintenance of biochemical homeostasis. The authors speculate that chronic stresses that cause these types of effects may influence important aspects of growth, reproduction, immunologic response, and ability to successfully compete with other species. The biological significance of the Arillo *et al*. (1981a) data are uncertain and although rarely used in criteria development, the types of subtle effects measured may be of significance to salmonids in the Pacific Northwest. The MOS for Arillo *et al*. (1981a) is (-)23.28% (Table 2).

Table 2. Comparison of literature toxicity values and existing freshwater ammonia chronic criteria values at pH =8 and the temperature conditions reported in the indicated study. The MOS of the existing chronic criterion is expressed as a percentage, as explained in the text.

Study	Study test temperature	Study test result at pH = 8	Existing chronic criterion for "salmonids present" at pH = 8 and test temperature	Margin of safety of existing chronic criterion for "salmonids present"
Thurston *et al*. (1984)	7.5 to 10° C	EC20 < 5.4 mg N/L	1.328 - 1.363 mg N/L	<296.2% to <306.6%
Burkhalter and Kaya (1977)	9.5 to 12.5° C	LC20 < 22.0 or 18.7 mg N/L	1.310 - 1.339 mg N/L	Mean values of <1561% or <1312.1%
Solbe and Shurben (1989)	14.9°C (range from 11.5 - 17°C)	LC20 < 1.44 mg N/L	1.293 mg N/L (1.117 - 1.293 mg N/L)	Mean value of <11.7%
Calamari *et al*. (1977,1981)	14.5°C	LC20 = 1.34 mg N/L	1.296 mg N/L	3.4%
Arillo *et al.* (1981a)	11°C	EC? = 1.012 mg N/L	1.323 mg N/L	-23.28%

Ideally, the desired MOS for regionally important species would be dependent on several variables, including the seasonality of the variable being considered, the sensitivity of the life stages present during certain seasons, and the magnitude of the concentrations being considered in relation to natural conditions and the scale of changes likely to occur. Additionally, the importance of the effect being considered when compared to other parameters (e.g., temperature and dissolved oxygen) affecting salmonid population health is a key consideration when determining how resources are allocated to address competing priorities.

Toxicity data from rainbow trout early life stage tests indicate that the existing criteria for ammonia (salmonids present) would provide full protection for regionally important salmonids (MOS ranges from 306.6 to 3.4). The data from Arillo *et al*. (1981a) present a challenge because they suggest subtle effects at levels lower than the existing criteria (MOS = -23.28%), which might be relevant to some salmonids. However, in the absence of any other criterion value or additional toxicity testing data that could be used to develop a criterion concentration focused on protection of regionally important species, **the existing chronic criterion for "salmonids-present" is the most reasonable criterion to use to protect regionally important salmonids.**

Alternative Approaches to Criteria Adoption

Four alternative approaches to address the acute and chronic criteria for freshwaters where salmonid habitat is a beneficial use are presented here. Proposed adoption of the acute criterion is part of all alternatives to modify the ammonia criteria, since these criteria appear to be at levels that data indicate would be protective of salmonids. . Additionally, adoption of the early-life-stage-absent (ELSA) chronic criterion for nonsalmonid waters is part of the first three alternatives. This new criterion appears to be protective of organisms that have developed beyond early life stages. The first three alternatives include proposed adoption of the new 1999 Update ELSP chronic criteria, but the three alternatives differ greatly in the areas of application of the chronic criteria. The first and second alternatives include the recommendation to retain the existing "salmonids present" chronic criterion in waters providing salmonid habitat. The alternatives are:

1. Propose adoption of the new 1999 Update acute criteria for all freshwaters and the new 1999 Update ELSP and ELSA chronic criteria for *all freshwaters where salmonids do not occur*. Retain the existing "salmonids present" chronic criterion in waters where salmonids are found.

2. Propose adoption of the new 1999 Update acute criteria for all freshwaters and the new 1999 Update ELSP and ELSA chronic criteria for *all freshwaters where salmonid spawning does not occur*. Retain the existing "salmonids present" chronic criterion in waters where salmonids spawn.

3. Propose adoption of the new 1999 Update criteria for *all freshwaters.*

4. No action.

The main objectives used in choosing an alternative are:

- To provide the most reasonable criteria for use in effluent limit development and facility planning for the regulated community.
- To provide full protection for salmonids in Washington.

<u>Alternative 1. Propose adoption of the new 1999 Update acute criteria for all freshwaters and the new 1999 Update chronic criteria for all waters where salmonids do not occur.</u>

- Proposed adoption of the acute criterion would allow higher ammonia concentrations in Washington freshwaters. These criteria would result in fewer and less restrictive ammonia limits (based on acute effects) in NPDES permits.
- Proposed adoption of the chronic criteria would allow higher ammonia concentrations in Washington freshwaters, and limited toxicity data indicate these concentrations might not be protective of salmonids. Restricting the area of application of the new criteria to waters where salmonids do not occur is a reasonable approach to address the uncertainties in the

toxicity data. Early life stage data discussed above indicate the existing chronic criteria for "salmonids present" would be protective of early life stages of salmonids (Calamari *et al*. (1977, 1981); Solbe and Shurben (1989); Thurston *et al*. (1984); Burkhalter and Kaya (1977)). These same data indicate the 1999 Update ELSP chronic criterion might not be protective of all early life stage salmonids. The data in Arillo *et al*. (1981a) indicate that even the existing criterion might not be adequately protective of larger salmonids, depending on whether the type of effects measured are of concern and the MOS is appropriate for regionally important species. In this alternative, uncertainty in the significance of the effects measured by Arillo *et al*. (1981a) are addressed in a precautionary manner, and the existing criterion (the most protective criterion reviewed) is recommended for all freshwaters used by salmonids. This will ensure, as much as reasonably possible, that salmonids at any life stage are not affected by ammonia. These criteria would result in fewer and less restrictive ammonia limits (based on chronic effects) in NPDES permits in waters where salmonid habitat is not a beneficial use and no change to the current permitting strategy in areas where salmonid habitat is a beneficial use.

Alternative 2. Propose adoption of the new 1999 Update acute criteria for all freshwaters and the new 1999 Update ELSP and ELSA chronic criteria for all freshwaters where salmonid spawning does **not** occur.

- Proposed adoption of the acute criterion would allow higher ammonia concentrations in Washington freshwaters. These criteria would result in fewer and less restrictive ammonia limits (based on acute effects) in NPDES permits.
- In this alternative, the proposed adoption of the chronic criteria would allow higher ammonia concentrations in any Washington freshwater where salmonid spawning is **not** a use. Restricting the area of application of the new criteria to waters where salmonid spawning does not occur is one approach we have to address the uncertainties in the toxicity data. Early life stage data discussed above indicate the existing chronic criteria for "salmonids present" would be protective of early life stages of salmonids (Calamari *et al*. (1977, 1981); Solbe and Shurben (1989); Thurston *et al*. (1984); Burkhalter and Kaya (1977)). These same data indicate the 1999 Update ELSP chronic criterion might not be protective of all early life stage salmonids.The data in Arillo *et al*. (1981a) indicate that the existing criterion might not be adequately protective of larger salmonids, depending on whether the type of effects measured are of concern and the MOS appropriate for regionally important species. In this alternative, the existing criteria are retained only in salmonid spawning waters, in effect reflecting doubt about the biological significance of the effects measured by Arillo *et al*. (1981). The new 1999 Update criteria would be applied to all freshwaters where salmonid spawning is not a use. These criteria would result in fewer and less restrictive ammonia limits (based on chronic effects) in NPDES permits in waters where salmonid spawning is not a beneficial use and no change to the current permitting strategy in areas where salmonid spawning is a beneficial use.

Alternative 3. Propose adoption of the new 1999 Update criteria for all freshwaters.

- Proposed adoption of the acute criterion would allow higher ammonia concentrations in Washington freshwaters. These criteria would result in fewer and less restrictive ammonia limits (based on acute effects) in NPDES permits.
- Proposed adoption of the chronic criteria would allow higher ammonia concentrations in Washington freshwaters, and limited toxicity data indicate these concentrations might not be protective of early life stages of salmonids. Applying the 1999 Update chronic criteria to all freshwaters might result in toxic effects to early life stages of salmonids in areas where ammonia concentrations are below or at criteria concentrations. These criteria would result in fewer and less restrictive ammonia limits (based on chronic effects) in NPDES permits in freshwaters.

Alternative 4. No action.

This alternative would defer proposed modification of the acute and chronic ammonia criteria until broader stakeholder and service participation resulted in a more definitive determination of the level of protection from effects of ammonia desired for salmonids in Washington. This approach would result in no changes to the current effluent limit calculations in freshwaters.

Recommended Alternative: Alternative 1.

Alternative 1 is the recommended approach. Alternative 1 addresses uncertainties in the application of toxicity data to Washington salmonids by erring on the side of protection for salmonids. This alternative provides a reasonable approach to adoption of recommended criteria for regionally important species and is likely to provide full protection for Washington salmonids. Ancillary benefits of this approach over Alternatives 2 and 3 are: (1) It is unlikely to result in an immediate and large agency resource focus toward ESA consultation-related issues and (2) Taken in the context of the larger rule making that this criteria revision is part of, this recommendation is unlikely to cause large delays in finalizing the ESA Section 7 consultation over the revised standards.

Adoption and Implementation: Alternative 1

The discussion above contains the recommendation to propose adoption and implementation of the 1999 Update criteria for ammonia in freshwaters, as discussed in **Alternative 1**. Specifically, this includes:

- Propose adoption of the 1999 Update acute criteria for both nonsalmonid and salmonid waters. These criteria (criteria maximum concentrations, CMCs) are:

$$CMC_{(\text{salmonids present})} = \frac{0.275}{1 + 10^{7.204-pH}} + \frac{39.0}{1 + 10^{pH-7.205}}$$

$$CMC_{(\text{salmonids absent}} = \frac{0.411}{1 + 10^{7.204\text{-pH}}} + \frac{58.4}{1 + 10^{\text{pH-7.205}}}$$

Applied as a one-hour average concentration of total ammonia nitrogen (in mg N/L) not to be exceeded more than once every three years on the average.

- Propose adoption of the 1999 Update "fish early life stages absent" chronic criterion for all non-salmonid freshwaters. This criterion (Criterion Chronic Concentration or CCC) is:

$$(CCC) = \frac{0.0557}{1+10^{7.688\text{-pH}}} + \frac{2.487}{1+10^{\text{pH-7.688}}} \times 1.45 \times 10^{0.028(25 - \text{MAX}(T,7))}$$

Applied as a 30-day average concentration of total ammonia nitrogen (in mg N/L) not to be exceeded more than once every three years on the average. The highest four-day average within the 30-day period should not exceed 2.5 times the CCC.

- Propose adoption of the 1999 Update "fish early life stages present" chronic criterion (for all non-salmonid freshwaters. This criterion (Criterion Chronic Concentration or CCC) is:

$$(CCC) = \frac{0.0557}{1+10^{7.688\text{-pH}}} + \frac{2.487}{1+10^{\text{pH-7.688}}} \times \text{MIN}(2.85, 1.45 \times 10^{0.028 \times (25-T)})$$

Applied as a 30-day average concentration of total ammonia nitrogen (in mg N/L) not to be exceeded more than once every three years on the average. The highest four-day average within the 30-day period should not exceed 2.5 times the CCC.

- Retain existing chronic criteria for "salmonids present" (temperature cap set at 15°C) for waters where salmonids are found. This criterion (Criterion Chronic Concentration or CCC) is:

CCC for "salmonids present" = 0.80 ÷(FT)(FPH)(Ratio), where:

$FT = 10^{[0.03(20-TCAP)]}$
$FPH = 1$, where $8 \leq pH \leq 9$
$FPH = (1+10^{(7.4-pH)}) \div 1.25$, where $6.5 \leq pH \leq 8.0$
Ratio = 13.5, at $7.7 \leq pH \leq 9$
$Ratio = (20.25 \times 10^{(7.7-pH)}) \div (1+10^{(7.4-pH)})$, at $7.7 \leq pH \leq 9$
TCAP = 15°C where salmonids are present

Applied as a 4-day average of unionized ammonia (NH3) not to be exceeded more than once every three years on the average.

If adopted as recommended above, criteria would be applied as summarized in Table 3.

Table 3. Recommended freshwater ammonia criteria and areas of application.

Criterion	Area of application
1999 update acute criterion	All freshwaters
1999 update chronic criterion for "fish early life stages absent"	Freshwaters with no early life stages present and not designated as salmonid habitat
1999 Update chronic criteria for “fish early life stages present”	Freshwaters with early life stages of non-salmonid fish species present and not designated as salmonid habitat
Existing chronic criterion for "salmonids present"	All freshwaters with salmonid habitat as a designated use

References

Arillo, A., C. Margiocco, F. Melodia, P. Mensi, G. Schenone. 1981. Biochemical aspects of water quality criteria: the case of ammonia pollution. Environmental Technology Letters. V.2, pp. 285-292.

Arillo, A., C. Margiocco, F. Melodia, P. Mensi, G. Schenone. 1981. Ammonia toxicity mechanism in fish: studies on rainbow trout trout (*Salmo gairdneri* Rich.). Ecotoxicology and Environmental Safety. 5:316-328.

Arillo, A., B. Uva, and M. Vallarino. 1981. Renin activity in rainbow trout (*Salmo gairdneri* Rich.) and effects of environmental ammonia. Comp. Biochem. Physiol. 68A:307-311.

Arthur, J.W., C.W. West, K.N. Allen, and S.F. Hedtke. 1987. Seasonal toxicity of ammonia to five fish and nine invertebrate species. Bull. Environ. Contam. Toxicol. 38:324-331.

Burkhalter, D.E. 1975. *Effects of prolonged exposure to ammonia on rainbow trout (Salmo gairdneri) eggs and sac fry*. Masters thesis. Montana State University, Bozeman, Montana. 67 pp.

Burkhalter, D.E. and C.M. Kaya. 1975. Effects of prolonged exposure to ammonia on fertilized eggs and sac fry of rainbow trout (Salmo gairdneri). Trans. Am. Fish. Soc. 106 (5):470-475

Calamari, D.R., R. Marchetti, and G. Vailati. 1981. Effects of long-term exposure to ammonia on the developmental stages of rainbow trout (*Salmo gairdneri* Richardson). Rapp. P.-v. Reun. Cons. Int. Explor. Mer. 178:81-86

Calamari, D.R., R. Marchetti, and G. Vailati. 1977. Effects of prolonged treatments with ammonia on the developmental stages of rainbow trout (*Salmo gairdneri*). Nuovi Ann. Ig. Microbiol.. 28:333-345. (English translation from Italian text used.)

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 unionized ammonia to fathead minnows and channel catfish. Final report to U.S.EPA by Battelle, Columbus, Ohio. 39 p.

Solbe, J.F. De L.G. and D.G. Shurben. 1989. Toxicity of ammonia to early life stages of rainbow trout (Salmo gairdneri). Water Research. 23:127-129.

Thurston, R.V., R.C. Russo, R.J. Luedtke, C.E. Smith, E.L. Meyn, C. Chakoumakos, K.C. Wang, and C.J.D. Brown. 1984. Chronic toxicity of ammonia to rainbow trout. Trans. Amer. Fish. Soc. 113:56-73.1984

U.S.Environmental Protection Agency. 1999. *1999 Update of Ambient Water Quality Criteria for Ammonia.* Office of Water, Washington, D.C. 147 p.

U.S.Environmental Protection Agency. 1998. *1998 Update of Ambient Water Quality Criteria for Ammonia.* EPA 822-R-98-008. Office of Water, Washington, D.C. 148 p.

U.S.Environmental Protection Agency. 1985a. *Ambient Water Quality Criteria for Ammonia – 1984*. EPA 440/5-85-001. Office of Water, Washington D.C. 217 p.

U.S.Environmental Protection Agency. 1985b. *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses*. PB85-227049. National technical Information Service, Springfield, Virginia. 98 p.

Appendix A

February 29, 2000, memo from Charles Delos (USEPA) to Cheryl Niemi (Department of Ecology) containing additional explanation of the algebraic calculations used to formulate the final temperature relationship for invertebrates.

(Note: This file was imported into a Microsoft Word file from a PDF file, and original formatting and letterhead was lost. File was reformatted to match the original.)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF WATER

February 29, 2000

MEMORANDUM

SUBJECT: Ammonia Chronic Criterion Temperature Relationship

FROM: Charles Delos, Health and Ecological Criteria Division

TO: Cheryl Niemi, State of Washington Department of Ecology

You have asked for a clear answer for the following question: Why is it appropriate to obtain the chronic temperature slope by subtracting the ACR (acute-chronic ratio) temperature slope from the acute temperature slope?

The situation we are dealing with involves a graph, such as Figure 6 or Figure 7 of the 1999 Ammonia Update. We plot temperature on the x-axis, and log A, log C, and log *(A/*C) on the y-axis, where *A* represents the acute value, *C* the chronic value, and *A/C* the acute-chronic ratio. The plot defines the temperature dependencies for these parameters.

Using a formula for the definition of slope, we can write the following:

$$Slope\ A = \frac{\log A_2 - \log A_1}{T_2 - T_1} \quad (1)$$

$$Slope\ C = \frac{\log C_2 - \log C_1}{T_2 - T_1} \quad (2)$$

$$Slope\ A/C = \frac{\log (A_2/C_2) - \log (A_1/C_1)}{T_2 - T_1} \quad (3)$$

We question whether the following mathematical statement is true:

$$Slope\ A - Slope\ A/C = Slope\ C \quad (4)$$

If we substitute our defining equations for slope, Equations 1 to 3, into Equation 4, will we end up with an identity? Substitution yields:

$$\frac{\log A_2 \,\&\, \log A_1}{T_2 - T_1} - \frac{\log (A_2/C_2) - \log (A_1/C_1)}{T_2 - T_1} = \frac{\log C_2 - \log C_1}{T_2 - T_1} \quad (5)$$

We may now cancel the denominators. Furthermore, we may note the following rule for the log of a quotient:

$$\log (A/C) = \log A - \log C \quad (6)$$

Substituting Equation 6 into Equation 5 sans denominators, we obtain:

$$\log A_2 - \log A_1 - (\log A_2 - \log C_2) - (\log A_1 - \log C_1) = \log C_2 - \log C_1 \quad (7)$$

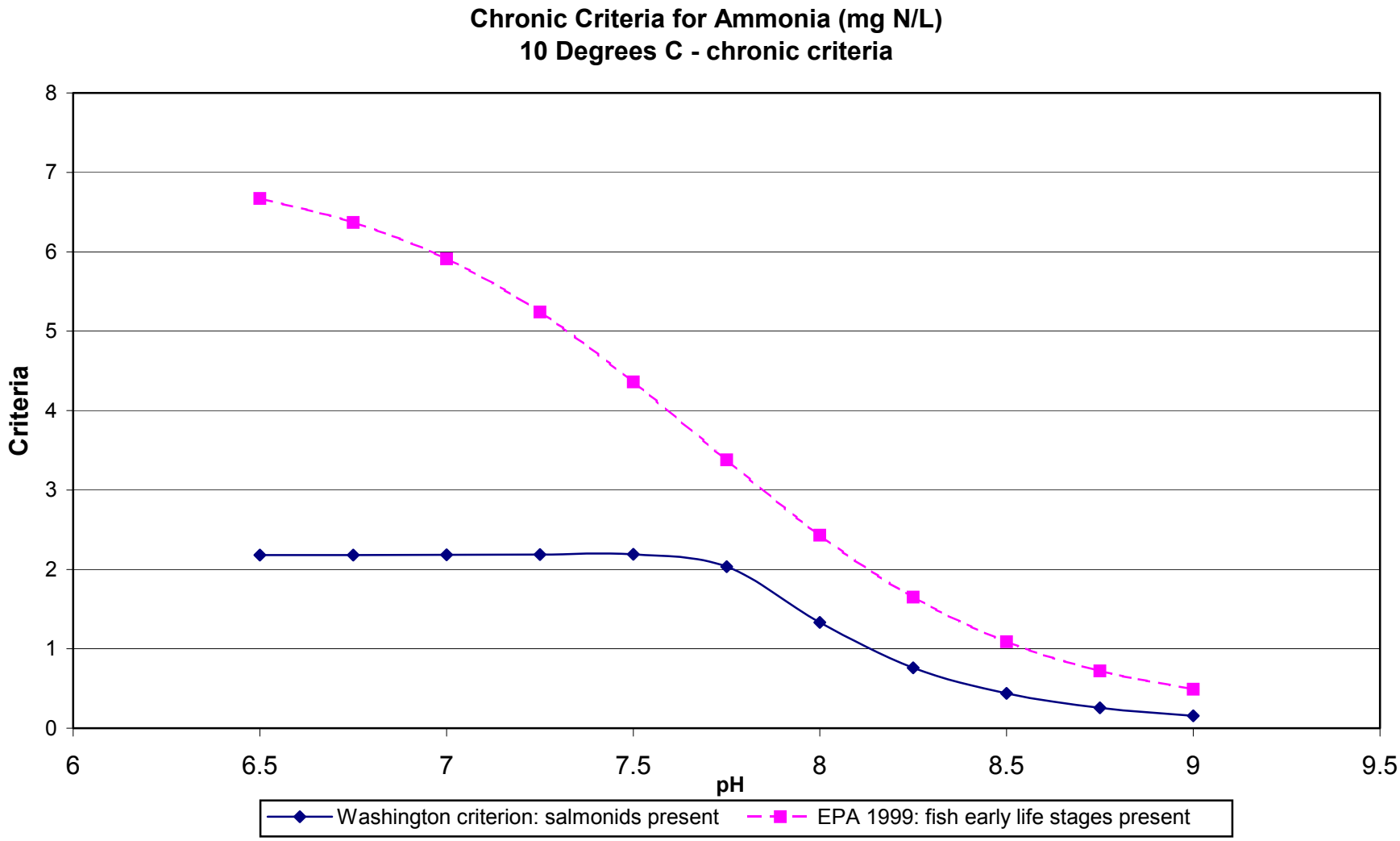
This yields an identity:

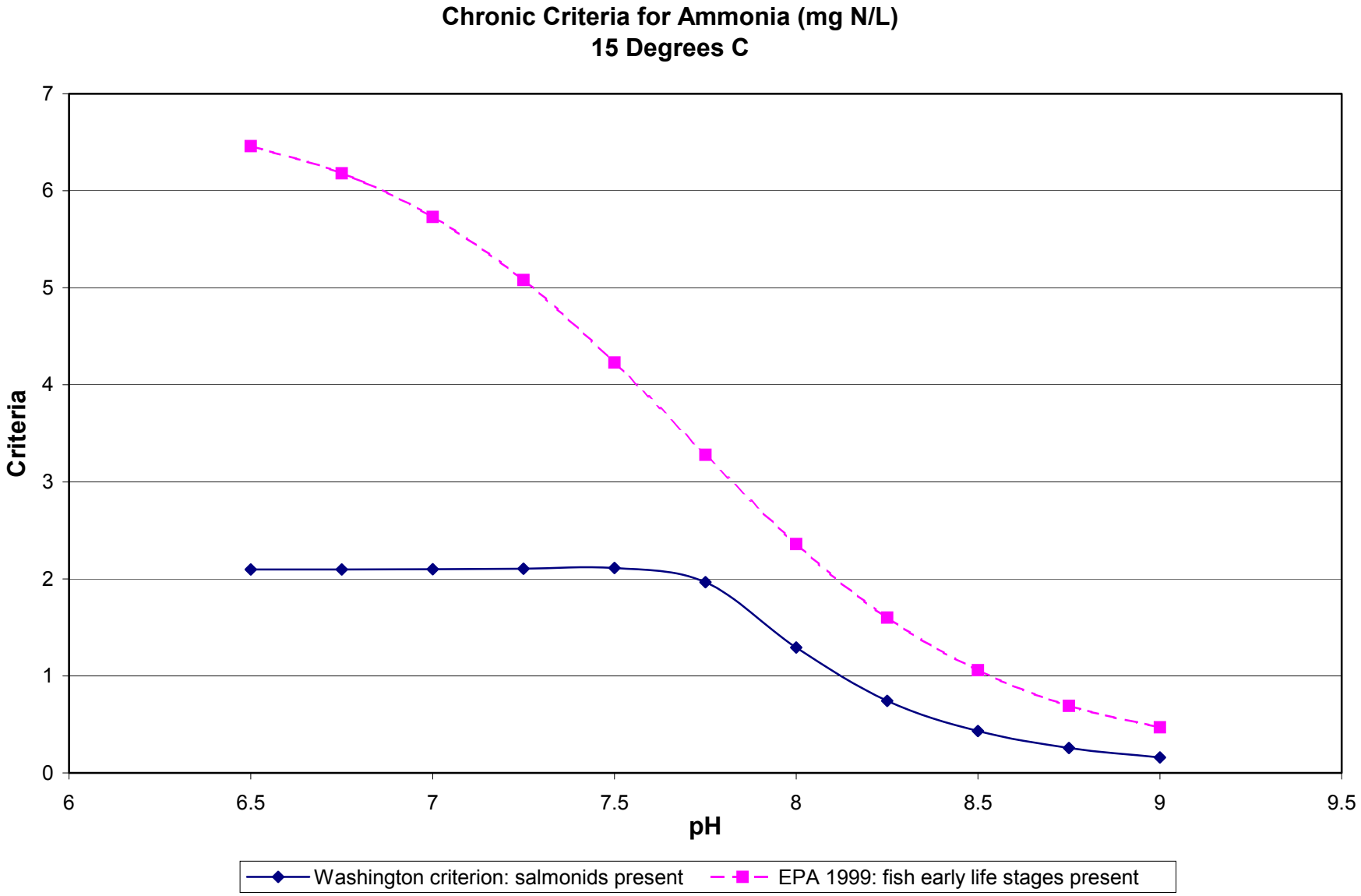
$$\log C_2 - \log C_1 = \log C_2 - \log C_1 \quad (8)$$

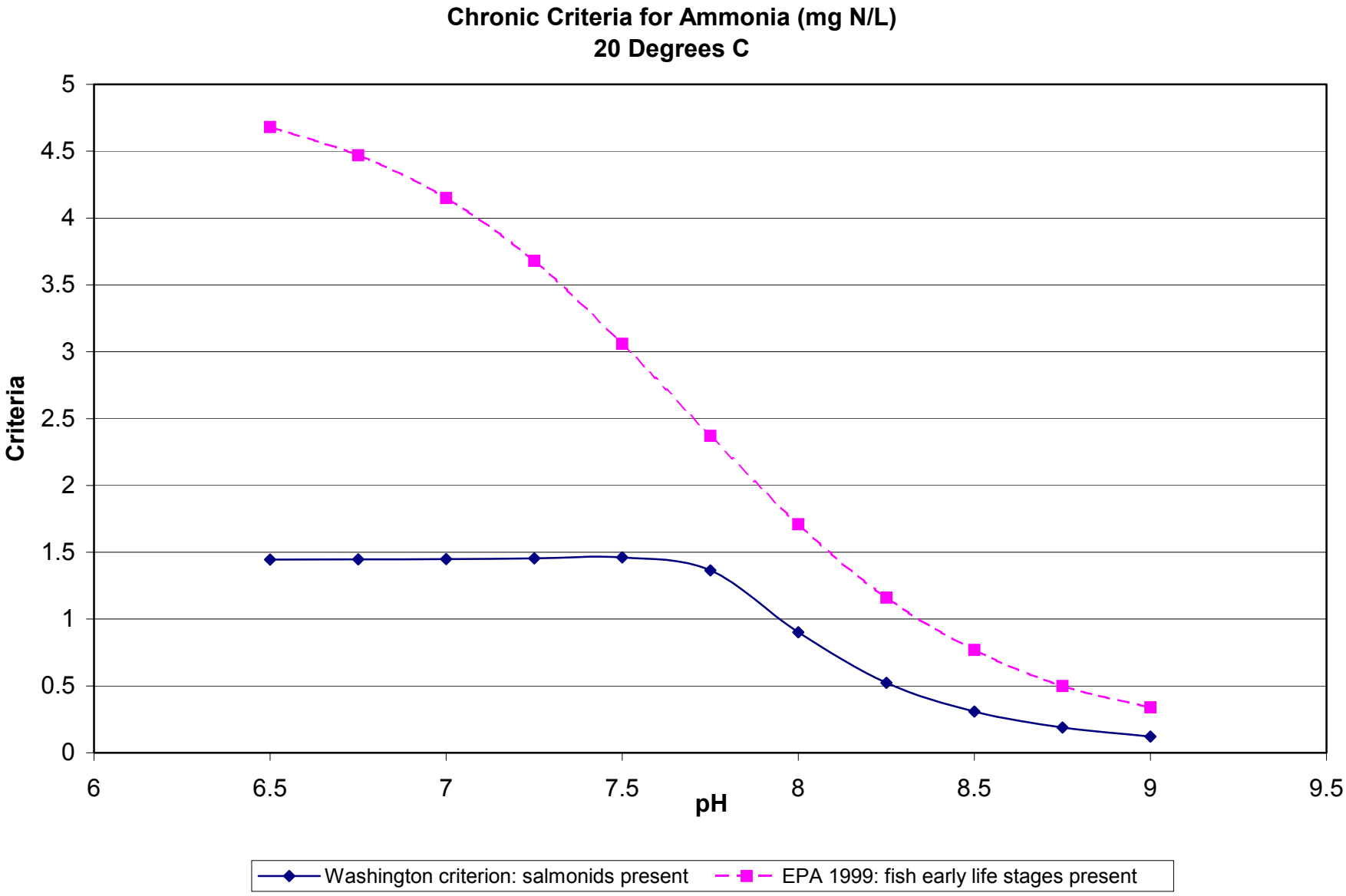
The original statement in question, Equation 4, must thus be true. The acute slope minus the ACR slope equals the chronic slope.

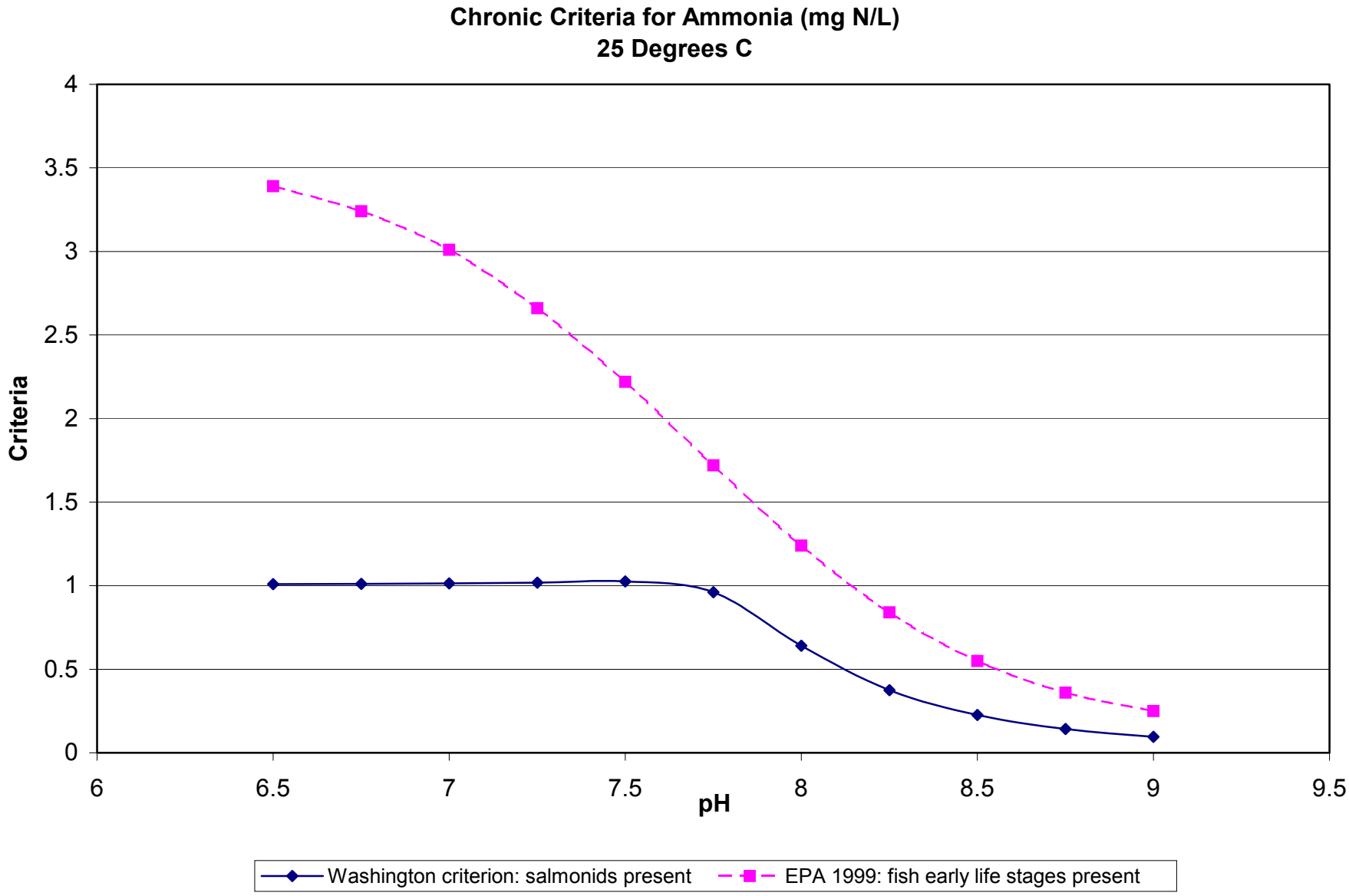
Appendix B

Washington chronic ammonia criterion for "salmonids present" and USEPA 1999 criterion for "fish early life stages present" at 10°C, 15°C, 20°C, and 25°C, for pH 's ranging from 6.5 to 9.


Chronic Criteria for Ammonia (mg N/L)
10 Degrees C - chronic criteria
Criteria
0
1
2
3
4
5
6
7
8
6
6.5
7
7.5
8
8.5
9
9.5
pH
Washington criterion: salmonids present
EPA 1999: fish early life stages present


Chronic Criteria for Ammonia (mg N/L)
15 Degrees C
Criteria
pH
0
1
2
3
4
5
6
7
6
6.5
7
7.5
8
8.5
9
9.5
Washington criterion: salmonids present
EPA 1999: fish early life stages present


Chronic Criteria for Ammonia (mg N/L)
20 Degrees C
Criteria
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
6
6.5
7
7.5
8
8.5
9
9.5
pH
Washington criterion: salmonids present
EPA 1999: fish early life stages present


Chronic Criteria for Ammonia (mg N/L)
25 Degrees C
Criteria
4
3.5
3
2.5
2
1.5
1
0.5
0
6
6.5
7
7.5
8
8.5
9
9.5
pH
Washington criterion: salmonids present
EPA 1999: fish early life stages present