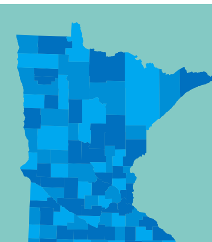
Ammonia

July 2022

Aquatic Life Water Quality Standards for Ammonia: Draft Technical Support Document

Amendments to Class 2 water quality standards in Minn. R. chs. 7050 and 7052

MINNESOTA POLLUTION CONTROL AGENCY



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Contributors/acknowledgements

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Acronyms, abbreviations, and units of measurement

Acronym	Meaning
CCC	Criterion continuous concentration
CMC	Criterion maximum concentration
CS	Chronic standard
DNR	Minnesota Department of Natural Resources
EPA	U.S. Environmental Protection Agency
FAV	Final acute value
FCV	Final chronic value
GMAV	Genus mean acute value
GMCV	Genus mean chronic value
Minn. R.	Minnesota Rules
MPCA	Minnesota Pollution Control Agency
MS	Maximum standard
SMAV	Species mean acute value
SMCV	Species mean chronic value
TAN	Total ammonia nitrogen
WQS	Water quality standards
mg/L	Milligrams per liter
µg/L	Micrograms per liter

Definitions

Beneficial uses: Surface water uses by people, aquatic communities, and wildlife that are recognized in Minnesota's water quality standards at Minn. R. 7050.0140, including:

Class 1: Domestic consumption

Class 2: Aquatic life and recreation

Class 3: Industrial consumption

Class 4: Agriculture and wildlife

Class 5: Aesthetics and navigation

Class 6: Other uses

Class 7: Limited Resource Value Water (LRVW)

Multiple beneficial use classes are designated for each surface water body, or segment thereof, as described in Minn. R. 7050.0400 to Minn. R. 7050.0470.

Chronic standard (CS): An estimate of the highest toxicant concentration in ambient water to which aquatic life can be exposed indefinitely without chronic toxicity (mortality, reduced growth, reproductive impairment, harmful changes in behavior, or other adverse effects). The CS is an element of Minnesota's water quality standards and is analogous to the EPA-defined CCC.

Criterion maximum concentration (CMC): An estimate provided by EPA of the highest toxicant concentration in ambient water to which an aquatic community can be briefly exposed without unacceptable adverse effects on growth, reproduction, or survival. Equivalent to the FAV divided by two, the CMC is also referred to as the "acute criterion".

Criterion continuous concentration (CCC): An estimate provided by EPA of the highest toxicant concentration in ambient water to which an aquatic community can be exposed indefinitely without unacceptable adverse effects on growth, reproduction, or survival. Equivalent to the FCV divided by two, the CCC is also referred to as the "chronic criterion".

Final acute value (FAV): The toxicant concentration corresponding to the 5^{th} percentile of the acute toxicity value distribution for the genera on which acute toxicity tests have been conducted (i.e., 5^{th} percentile of the GMAV distribution).

Final chronic value (FCV): The toxicant concentration corresponding to the 5^{th} percentile of the chronic toxicity value distribution for the genera on which chronic toxicity tests have been conducted (i.e., 5^{th} percentile of the GMCV distribution).

Genus mean acute value (GMAV): The geometric mean of all species mean acute values (SMAVs) available within a genus.

Genus mean chronic value (GMCV): The geometric mean of all species mean chronic values (SMCVs) available within a genus.

Maximum standard (MS): An estimate of the highest toxicant concentration in ambient water to which aquatic life can be exposed briefly with zero to slight mortality. Also referred to as the "acute standard", the MS is an element of Minnesota's water quality standards and is analogous to the EPA-defined CMC. It equals the FAV divided by two.

Species mean acute value (SMAV): The geometric mean of all available and acceptable measures of acute toxicity effects for a species.

Species mean chronic value (SMCV): The geometric mean of all available and acceptable measures of chronic toxicity effects for a species.

Total ammonia nitrogen (TAN): The sum of nitrogen present in the forms of un-ionized ammonia (NH_3) and ionized ammonium (NH_4^+), expressed as a concentration (e.g., mg/L TAN).

National recommended water quality criteria (or 304(a) Criteria): National recommendations established by EPA, as required under Section 304(a) of the Clean Water Act, regarding the quality of water sufficient to ensure adequate protection of designated uses. The criteria generally assume the form of numeric concentrations or qualitative measures of pollutants.

Water quality standards (WQS): The fundamental regulatory and policy foundation established to preserve and restore the quality of all waters of the state, consisting of three elements:

1. Designated beneficial use classes.
2. Narrative and numeric descriptions[1] of pollutant levels that should not be exceeded.
3. Antidegradation policies to maintain existing uses, protect high quality waters, and preserve waters of outstanding value.

[1] *Note that EPA and most states refer to these descriptions as "criteria", while in Minnesota they are generally referred to as "standards".*

Purpose

The suite of water quality standards (WQS) for the State of Minnesota is designed to protect multiple beneficial uses of aquatic resources, including domestic and industrial consumption, recreational activity, aesthetic character, navigability, and maintenance of a healthy community of aquatic life. Development of WQS entails the classification of waters based on potential beneficial uses, derivation of numeric or narrative conditions to protect those uses, and establishment of antidegradation policies to maintain existing uses as well as to protect high-quality waters and preserve waters of outstanding value (Minn. R. ch. 7050). Each standard requires specification of the beneficial use to be protected as well as provision of scientific support for the stated protective conditions.

This technical support document describes the formulation of numeric WQS for ammonia in Class 2 waters for the purpose of protecting the propagation and maintenance of aquatic life. To ensure adequate protection of aquatic life from both acute and chronic ammonia toxicity, the MPCA proposes to update its existing WQS by adopting the national recommended ambient water quality criteria for ammonia provided by the U.S. Environmental Protection Agency (EPA, 2013). The adopted criteria would serve as the new numeric thresholds for judgments of water quality impairment due to ammonia, and they would guide the MPCA's determination of ammonia discharge limits from regulated facilities. Proposed updates to Minnesota WQS include the addition of new acute standards and revision of the current 4-day chronic standard, supplemented by a new 30-day chronic standard.

Background

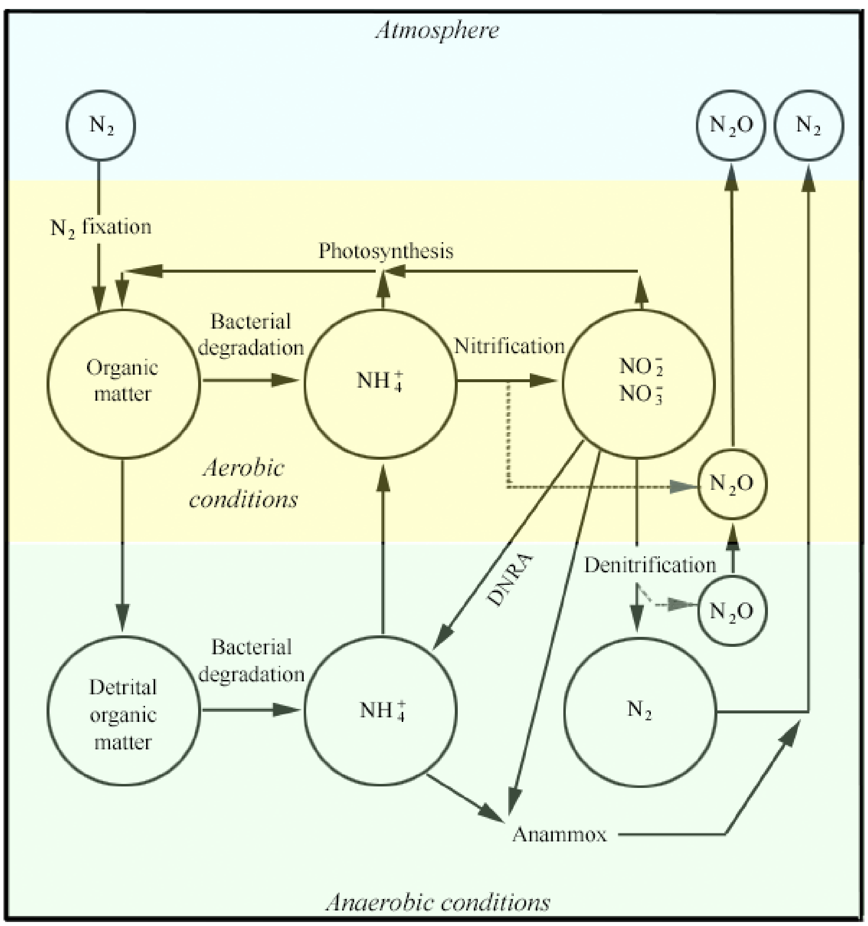
Ammonia in the aquatic environment exists in un-ionized (NH_3) and ionized (ammonium, NH_4^+) forms, the balance of which is strongly influenced by local pH and temperature (Emerson et al., 1975). Measurements of ammonia in water samples are typically reported as total ammonia nitrogen (TAN), defined as the sum of nitrogen present in both chemical forms. The toxicity of ammonia to aquatic life is primarily attributed to the un-ionized form (Chipman, 1934; Thurston et al., 1981); lethality to aquatic organisms and/or impairment of their biologic functions depends not only on the prevalence of un-ionized ammonia in the environment but also the organism's degree of sensitivity to it, which may additionally vary along a gradient of pH and temperature conditions (EPA, 1985a; EPA, 2013).

Urban stormwater conveyances and wastewater treatment facility discharges are important anthropogenic sources of ammonia to aquatic environments, as are overland flow and subsurface drainage from agricultural lands on which artificial fertilizers and/or manure are applied. Certain types of industrial discharges may also contain significant quantities of ammonia, such as those generated by food processers (including sugar beet factories), canneries, meat packers, tanneries, dairies, rendering plants, oil refineries, chemical processers, metal finishers, and pharmaceutical producers (MPCA, 1981; EPA, 2013). Natural sources of ammonia include decomposing organic matter, animal excretions, and atmospheric deposition (at levels that are anthropogenically enhanced; Lehmann et al., 2007; Behera et al., 2013).

Metabolism of nitrogen-containing compounds by aquatic organisms results in the internal production of ammonia waste that must be excreted from the body, generally accomplished via passive diffusion from internal organs into the surrounding water (Smith, 1929; Randall & Wright, 1987). Outward diffusion of ammonia relies upon a positive concentration gradient between internal tissues (higher concentration) and the water (lower concentration). High ambient concentrations of ammonia caused by pollution discharge may lessen or even reverse the diffusive gradient, resulting in the accumulation of ammonia in tissues and blood. The toxic effects of un-ionized ammonia accumulation in aquatic organisms can include damage to gill tissues, reduction in the oxygen-carrying capacity of blood, oxidative stress, depletion of adenosine triphosphate (ATP) energy reserves in the brain, disruption of osmoregulation and circulation, and impairment of liver and kidney function (EPA, 2013; EPA, 2022). Fish can additionally experience loss of equilibrium, hyperexcitability, slowed growth and morphological development, and reduced hatching success (EPA, 1985a). Excessive ammonia levels can cause convulsions, coma, and death. In freshwater mussels, toxic effects include a variety of negative physiological responses – impaired secretion of anchoring threads, reduction in valve opening for respiration and feeding, metabolic alterations due to depletion of energy stores – that inhibit growth, reproduction, and survivorship (EPA, 2013). Ammonia concentrations in anoxic sediment porewaters – especially within highly-organic, nutrient-rich sediments – frequently exceed concentrations in overlying surface water and therefore can impose additional stress on mussels and other benthic aquatic organisms (Frazier et al., 1996; Kinsman-Costello et al., 2015).

Because nitrogen readily cycles between multiple forms in nature, following various microbial transformation pathways (Figure 1), ammonia in the aquatic environment may not have originally entered as such. It may be produced via bacterial degradation of organic matter, released from dead microbial tissue, or converted from nitrate or nitrite under anaerobic conditions in a process called dissimilatory nitrate reduction to ammonium (DNRA). Ammonia in its ionic form (ammonium) is consumed via incorporation into plant and microbial biomass, anaerobic oxidation (anammox) to nitrogen or nitrogen dioxide gases, or conversion to nitrate (nitrification) under aerobic conditions. The connectedness of ammonia, nitrate, and other forms of nitrogen warrants consideration of holistic approaches to reduce pollutant nitrogen entering the aquatic environment. The State of Minnesota has a long-standing nutrient reduction strategy that focuses on lessening nitrogen and phosphorus loads in state waters as well as those downstream (MPCA, 2014). Despite this effort, nitrogen levels are increasing in both surface water and groundwater throughout the state (MPCA, 2013).

Figure 1. Biological transformations of nitrogen in aerobic and anaerobic environments, based on Wollast (1981) and the modifications of Schlesinger and Bernhardt (2013).



Minnesota is a water-rich state containing more than 4,500 square miles of lake area and over 92,000 miles of streams and rivers. It is home to a considerable diversity of aquatic life that includes approximately 50 species of mussels – 28 of which are listed as extirpated, endangered, threatened, or of special concern (Minnesota Department of Natural

Resources (DNR), 2022b and 2022c) – and over 150 species of fish (Hatch, 2015) – 34 of which are similarly listed (DNR, 2022c). Aquatic snails, although broadly distributed and prevalent in general, include 9 rare species (DNR, 2022c). Recognized by various conservation organizations as the most imperiled group of animals in North America, freshwater mussels declined in both abundance and diversity over the past century due to dam construction, stream channel modification, sedimentation, chemical pollutants, overharvesting, and invasive fauna (DNR, 2022b). Their biological importance as ecosystem engineers (DNR, 2022a; Gutiérrez et al., 2003; Vaughn, 2017), precarious conservation status, and sensitivity to ammonia pollution provide strong rationales for adopting water quality protections that account for updated science on the acute and chronic toxicity of ammonia to aquatic invertebrates.

Aquatic life criteria for ammonia

Development of EPA recommendations

National recommended water quality criteria are developed by EPA in accordance with Section 304(a)(1) of the Clean Water Act and with the objective to protect the vast majority (approximately 95%) of animal species in an aquatic community from unacceptable adverse effects on growth, reproduction, or survival. Established procedures for derivation of national criteria (EPA, 1985b) are predicated on the assumption that laboratory-based determinations of toxicity in cultured and collected aquatic organisms apply in outdoor settings with similar toxicant concentrations and key environmental conditions (e.g., pH and temperature). EPA conducts a thorough review of available toxicological information in the scientific literature, screens findings of toxicant effect thresholds according to specific data quality requirements, and assembles a dataset spanning a variety of taxonomic and functional groups that collectively represent the North American assemblage of aquatic organisms. From this dataset, EPA then calculates a criterion maximum concentration (CMC) for short-term (acute) exposures and a criterion continuous concentration (CCC) for long-term (chronic) exposures. The CMC and CCC are analogous to Minnesota's maximum standard (MS) and chronic standard (CS), respectively, which are used under Minnesota Rules chapter 7050 as numeric expressions of state-level WQS. Derivations of numeric criteria by EPA and MPCA are based solely upon toxicological data and best professional scientific judgments regarding toxicological effects.

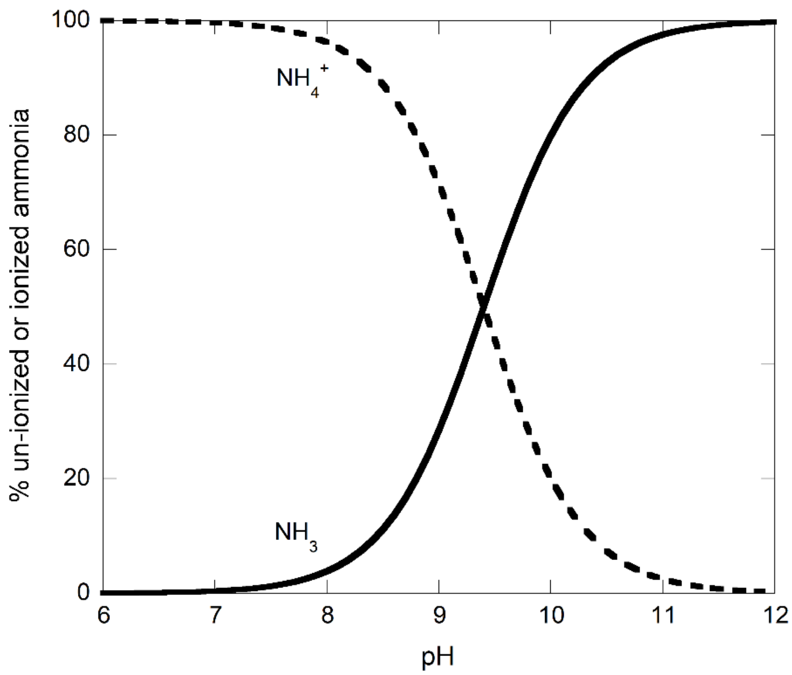
Current Class 2 ammonia standards for Minnesota, last updated in 1981, are based on an assessment of acute and chronic toxicity data for a limited number of resident fish species (MPCA, 1981). Separate chronic standards (4-day average concentration values) apply to Subclasses 2A and 2B, which are protected for the propagation and maintenance of coldwater aquatic biota (2A) and cool or warmwater aquatic biota (2B). The numeric value assigned to Subclass 2B also applies to Subclass 2Bd, which is additionally protected for use as drinking water, as well as to Subclass 2D (wetlands). These standards do not take into account the often-greater sensitivity of freshwater mussels (Augspurger et al., 2003), gill-bearing snails (Besser et al., 2009), and other aquatic fauna to ammonia, as determined in toxicological studies published over subsequent decades. The dataset compiled by EPA for its determination of national ammonia criteria includes important additions and updates for these groups of organisms (EPA, 2013).

The most recent national recommended ambient ammonia criteria for the protection of aquatic life are derived from a dataset composed of acute toxicity test results from 100 freshwater aquatic species across 69 genera and chronic toxicity test results from 21 freshwater aquatic species across 16 genera (EPA, 2013). Multiple families of coldwater and warmwater fish are represented in the acute toxicity data, as are planktonic and benthic crustaceans, mollusks (including sensitive gill-breathing snails and freshwater mussels in Family Unionidae that had not previously been tested), insects, and amphibians.

Biological collections information contained in the Minnesota Biodiversity Atlas (Bell Museum, 2022), explored in conjunction with readily accessible species range descriptions, indicate that at least 55 of the 100 species represented in the acute toxicity tests (and at least 54 of the 69 genera) reside in Minnesota. Many of the nonresident species provide useful surrogate representation of untested yet functionally- or taxonomically-related resident species. Freshwater phytoplankton and vascular plants are not represented in either the acute or chronic toxicity studies, but prior analysis of available data for these groups indicated that aquatic vegetation is far less sensitive to ammonia than aquatic animals (EPA, 1985a). EPA therefore assumes that any ammonia criteria derived for the protection of aquatic animals will also be protective of aquatic vegetation.

Toxicity tests used in the development of water quality criteria were performed with measured concentrations of ammonia (recorded as mg/L TAN, or converted to TAN if originally expressed in terms of un-ionized ammonia) in a controlled laboratory setting. For all test organisms, ammonia effect concentration values were then adjusted – statistically normalized – to a common pH of 7, following pH-TAN toxicity relationships established in an earlier version of the national recommended aquatic life criteria for ammonia (EPA, 1999), which EPA determined "still hold" and can be reasonably applied to newly-included organisms. The pH-dependence of ammonia toxicity, and therefore of ammonia criteria, may reflect the shifting chemical equilibrium between un-ionized ammonia and ionized ammonium. At higher pH values, the proportion of un-ionized ammonia increases (Figure 2), as does observed ammonia toxicity. For invertebrate test organisms, ammonia effect concentrations were further normalized to a temperature of 20°C, following temperature-TAN toxicity relationships outlined in the earlier national criteria document (EPA, 1999). Whereas vertebrate (fish) sensitivity to TAN does not meaningfully change with temperature, invertebrate sensitivity increases at higher temperatures.

Figure 2. The pH-dependent chemical speciation of ammonia at a temperature of 20°C, calculated from equilibrium relationships expressed in Emerson et al. (1975).



After any appropriate adjustments for pH and temperature, the reported ammonia effect concentrations resulting from toxicity tests on aquatic organisms were sorted by species to calculate species mean acute values (SMAVs) and species mean chronic values (SMCVs). These species-level values were then organized by genus to calculate genus mean acute values (GMAVs) and genus mean chronic values (GMCVs). Each calculation was performed using the geometric mean of all underlying data. Genus-level values, rank ordered to form a sensitivity distribution, were then used to determine, by regression analysis, a final acute value (FAV) and final chronic value (FCV), each equivalent to the 5th percentile of its corresponding distribution (EPA, 1985; EPA, 2013).

Acute criteria

At an example pH of 7 and temperature of 20°C, EPA recommends an acute criterion (CMC) of 17 mg/L TAN – a one-hour average concentration not to be exceeded more than once every 3 years on average. The range of acute criteria under varying pH and temperature conditions is defined by the following equation:

Equation 1

$$\mathrm{CMC} = MIN\left(\left(\frac{0.275}{1 + 10^{7.204-\mathrm{pH}}}\right) + \left(\frac{39.0}{1 + 10^{\mathrm{pH}-7.204}}\right), \left(0.7249 \times \left(\frac{0.0114}{1 + 10^{7.204-\mathrm{pH}}} + \frac{1.6181}{1 + 10^{\mathrm{pH}-7.204}}\right) \times \left(23.12 \times 10^{0.036 \times (20-\mathrm{T})}\right)\right)\right)$$

where: CMC = criterion maximum concentration in mg/L TAN
T = temperature in degrees Celsius

The equation incorporates a pH-TAN acute toxicity relationship determined by pooled regression analysis of data across multiples species as well as a temperature-based adjustment for aquatic invertebrates (EPA, 1999; EPA, 2013). The CMC returned by the above equation equals the minimum value produced by two mathematical expressions, separated by a comma. The first expression, which does not contain a temperature variable, is specific to rainbow trout (*Oncorhynchus mykiss*), which is regarded as a recreationally- and commercially-important fish species. Although not native to Minnesota, rainbow trout have been introduced to many coldwater habitats in the state and continue to be stocked by the Minnesota DNR. Additionally, the existing Class 2A chronic water quality standard for Minnesota is based on toxicity data for the species (MPCA, 1981). The second mathematical expression, which includes both temperature and pH variables, considers the full set of tested organisms and yields a value approximately equivalent to the 5th percentile of the GMAV sensitivity distribution.

Because the lowest GMAVs in the sensitivity distribution for acute ammonia toxicity are for aquatic invertebrates (specifically, freshwater Unionid mussels), the CMC is both pH- and temperature-dependent. However, because the sensitivity of these invertebrates to ammonia declines with decreasing temperature (EPA, 1999), temperature-invariant vertebrates (fish) emerge as the most sensitive organisms below a particular temperature threshold and therefore determine the calculated CMC under low-temperature conditions. Where *Oncorhynchus* species are present, this temperature threshold occurs at 15.7°C and Equation 1 applies. Where *Oncorhynchus* species are absent, the CMC equation is modified to:

Equation 2

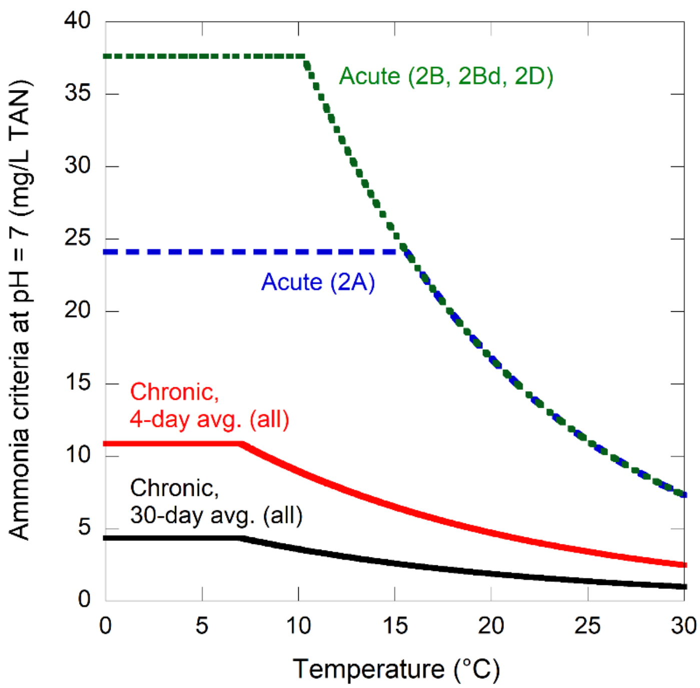
$$\mathrm{CMC} = 0.7249 \times \left(\frac{0.0114}{1 + 10^{7.204-\mathrm{pH}}} + \frac{1.6181}{1 + 10^{\mathrm{pH}-7.204}}\right) \times MIN\left(51.93, 23.12 \times 10^{0.036 \times (20-\mathrm{T})}\right)$$

where: CMC = criterion maximum concentration in mg/L TAN
T = temperature in degrees Celsius

Equation 2 retains the same pH and temperature adjustments, excludes the separate expression for the commercially- and recreationally-important rainbow trout, and incorporates a new temperature sensitivity threshold based on the fish genus *Prosopium*. In the absence of *Oncorhynchus* species, the mountain whitefish (*Prosopium williamsoni*) becomes the most sensitive species at 10.2°C and below. This species does not reside in Minnesota, but it is regarded as an "appropriately sensitive surrogate species" for other fish in Class Actinopterygii (EPA, 2013).

Taken together, Equations 1 and 2 create a bifurcated acute criterion dependent on pH, temperature, and the presence or absence of fish in genus *Oncorhynchus* (see dashed lines in Figure 3). The CMC increases with decreasing temperature over a portion of the temperature range, as depicted in the curvature of the dashed lines, because aquatic invertebrates exhibit greater sensitivity to ammonia at higher temperatures (i.e., the invertebrates can tolerate higher concentrations of ammonia at lower temperatures). The sensitivity of vertebrate taxa (*Oncorhynchus* or other fish) to ammonia, in contrast, does not change appreciably with temperature. Consequently, at sufficiently low temperatures, vertebrate fish species become the organisms most sensitive to ammonia (i.e., the temperature-dependent sensitivity of invertebrates declines below the temperature-invariant sensitivity of vertebrates). If *Oncorhynchus* species are present, the CMC remains constant below a temperature of 15.7°C. If *Oncorhynchus* species are absent, the temperature threshold at which CMC values form a plateau changes to 10.2°C. Because *Oncorhynchus* species are coldwater fish, the MPCA proposes to apply the "*Oncorhynchus* present" acute criterion to Subclass 2A waters as the maximum standard, implemented as a one-day average in accordance with Minnesota Rules chapter 7050. The acute criterion developed for the "*Oncorhynchus* absent" scenario would then be applied to all other Class 2 waters (Subclasses 2B, 2Bd, and 2D) as the maximum standard, also implemented as a one-day average. Numeric values for the proposed standards, as defined by the above equations, are summarized for reference across a selected range of pH and temperature conditions in Tables 1 and 2.

Figure 3. Recommended ambient water quality criteria for the protection of aquatic life (EPA, 2013) and their translation to Class 2 waters in Minnesota. Numeric values are extrapolated across a temperature gradient at pH = 7.



Chronic criteria

At an example pH of 7 and temperature of 20°C, EPA recommends a chronic criterion (CCC) of 1.9 mg/L TAN as a 30-day rolling average, not to be exceeded more than once every 3 years on average. In addition, EPA stipulates that that the chronic criterion cannot exceed 2.5 times this value (4.8 mg/L TAN) as a 4-day average within the 30-day period. The range of chronic criteria across varying pH and temperature conditions is described by the following equations:

Equation 3

$$\mathrm{CCC}_{30} = 0.8876 \times \left(\frac{0.0278}{1+10^{7.688-\mathrm{pH}}} + \frac{1.1994}{1+10^{\mathrm{pH}-7.688}}\right) \times \left(2.126 \times 10^{0.028 \times (20 - MAX(\mathrm{T},7))}\right)$$

where: CCC_{30} = chronic standard (30-day rolling average) in mg/L TAN
T = temperature in degrees Celsius

Equation 4

$$\mathrm{CCC}_4 = \mathrm{CCC}_{30} \times 2.5$$

where: CCC_{30} = chronic standard (30-day rolling average) in mg/L TAN
CCC_4 = chronic standard (highest 4-day average) in mg/L TAN

Equation 3 incorporates a pH-TAN chronic toxicity relationship and a temperature-based adjustment for aquatic invertebrates (EPA, 1999; EPA, 2013). Because the lowest GMCVs in the sensitivity distribution for chronic toxicity are again for freshwater Unionid mussels, calculated CCC values are both pH- and temperature-dependent – except below a temperature threshold of 7.0°C, when the early life stages of temperature-invariant *Lepomis* fish (namely bluegill, *Lepomis macrochirus*) become most sensitive. The chronic criteria, expressed as both 30-day and 4-day average values (Figure 3), are not bifurcated based on the presence of a commercially- or recreationally-important taxon and do not distinguish between coldwater and warmwater species assemblages. The MPCA therefore proposes to apply the CCC_{30} and CCC_4 as chronic standards (CS) across all Class 2 waters (see Tables 3 and 4 for values across a selected range of pH and temperature conditions).

Minnesota's existing chronic standards for ammonia are 16 µg/L and 40 µg/L, expressed as un-ionized NH_3 and implemented as 4-day averages, for Subclass 2A and Subclass 2B/2Bd/2D, respectively. The proposed new standards therefore include several changes: 1) numeric values are expressed in terms of TAN rather than un-ionized NH_3; 2) the same values are applied across all of Class 2 and no longer differ by subclass; and 3) the time-averaged basis for standards calculations includes a 30-day period as well as a 4-day period. New 4-day average values may be either more stringent or less stringent than existing values, depending on the subclass of water and the local pH (Table 5 provides a simple comparison of values at an example pH of 7 and temperature of 20°C).

Summary

The MPCA proposes to adopt the 2013 EPA national recommended water quality criteria for ammonia as its Class 2 ammonia water quality standards for the protection of aquatic life. Such adoption will bring Minnesota's standards into alignment with current scientific understanding on the sensitivity of freshwater mussels, snails, coldwater fish, and other organisms to ammonia in the aquatic environment. Adoption of EPA national criteria entails revising the existing 4-day chronic standard, adding a new 30-day chronic standard, and adding new acute standards – each with their own set of numeric values that vary across temperature and pH conditions. The temperature- and pH-dependent nature of the numeric standards reflects the shifting balance of un-ionized ammonia (more toxic) and ionized ammonium (less toxic), as well as known changes in the sensitivities of some aquatic species to ammonia, along these environmental gradients.

The proposed acute standard for Class 2 waters at an example pH of 7 and temperature of 20°C is 17 mg/L TAN. Because the recommended USEPA acute criterion bifurcates below a temperature of 15.7°C based on the presence or absence of coldwater trout and salmon in the genus *Oncorhynchus*, the MPCA will apply the “with *Oncorhynchus*” set of numeric values to Class 2A waters, which are regarded as favorable habitat for coldwater aquatic species, and the “without Oncorhynchus” set of numeric values to all other Class 2 waters (2B, 2Bd, 2D). The new acute water quality standard for Class 2A is defined by the set of numeric values in Table 1 and can be derived from Equation 1. The new acute water quality standard for Classes 2B, 2Bd, and 2D is defined by the set of numeric values in Table 2 and can be derived from Equation 2. At an example pH of 7 and temperature of 20°C, the proposed chronic standards for Class 2 waters are 1.9 mg/L TAN (30-day rolling average) and 4.8 mg/L TAN (highest 4-day average within a 30-day averaging period), applied uniformly across all subclasses. Chronic values at other temperature and pH conditions can be located in Tables 3 and 4 or calculated according to Equations 3 and 4.

Tables

Table 1. Temperature (°C) and pH-dependent values of the EPA acute* water quality criterion for ammonia (*Oncorhynchus* species present), in mg/L TAN

pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	31	31	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	30	30	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	28	28	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	26	26	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	24	24	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	22	22	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	20	20	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	18	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	15	15	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	11	11	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	9.6	9.6	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	8.1	8.1	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	6.8	6.8	6.6	6.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	5.6	5.6	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	4.6	4.6	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	3.8	3.8	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	3.1	3.1	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	2.6	2.6	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	2.1	2.1	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	1.5	1.5	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.73	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.2	1.2	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.0	1.0	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	0.88	0.88	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

*CMC values (EPA, 2013), to be applied to Class 2A waters in Minnesota as the maximum standard (MS)

Table 2. Temperature and pH-dependent values of the EPA acute* water quality criterion for ammonia (*Oncorhynchus* species absent), in mg/L TAN

pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	6.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7.0	6.4	5.9	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	6.0	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.2	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.73	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

*CMC values (EPA, 2013), to be applied to Class 2B, 2Bd, and 2D waters in Minnesota as the maximum standard (MS)

Table 3. Temperature (°C) and pH-dependent values of the EPA chronic* (30-day average) water quality criterion for ammonia, in mg/L TAN

pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1
6.6	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1
6.7	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
6.8	4.7	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
6.9	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0
7.0	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99
7.1	4.2	3.9	3.7	3.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95
7.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.96	0.90
7.3	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.85
7.4	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.96	0.90	0.85	0.79
7.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.83	0.78	0.73
7.6	2.9	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.0	0.98	0.92	0.86	0.81	0.76	0.71	0.67
7.7	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60
7.8	2.4	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53
7.9	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47
8.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.89	0.83	0.78	0.73	0.68	0.64	0.60	0.56	0.53	0.50	0.46	0.44	0.41
8.1	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99	0.93	0.87	0.81	0.76	0.72	0.67	0.63	0.59	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35
8.2	1.3	1.2	1.2	1.1	1.0	0.96	0.90	0.84	0.79	0.74	0.70	0.65	0.61	0.57	0.54	0.50	0.47	0.44	0.42	0.39	0.37	0.34	0.32	0.30
8.3	1.1	1.1	0.99	0.93	0.87	0.82	0.77	0.72	0.67	0.63	0.59	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.26
8.4	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47	0.44	0.41	0.39	0.36	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.22
8.5	0.81	0.75	0.71	0.66	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.24	0.22	0.21	0.19	0.18
8.6	0.68	0.64	0.60	0.56	0.53	0.49	0.46	0.43	0.41	0.38	0.36	0.33	0.31	0.29	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.16	0.15
8.7	0.58	0.54	0.51	0.47	0.44	0.42	0.39	0.37	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13
8.8	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.13	0.13	0.12	0.11
8.9	0.42	0.39	0.37	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10
9.0	0.36	0.34	0.32	0.30	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.09	0.09	0.08

*CCC values (EPA, 2013), to be applied to all Class 2 waters in Minnesota as a 30-day chronic standard (CS)

Table 4. Temperature (°C) and pH-dependent values of the EPA chronic* (4-day average) water quality criterion for ammonia in mg/L TAN

pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	12	12	11	10	9.5	8.9	8.4	7.8	7.4	6.9	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0	2.8
6.6	12	11	11	10	9.4	8.8	8.2	7.7	7.2	6.8	6.4	6.0	5.6	5.2	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8
6.7	12	11	10	9.8	9.2	8.6	8.1	7.6	7.1	6.7	6.2	5.9	5.5	5.2	4.8	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7
6.8	12	11	10	9.6	9.0	8.4	7.9	7.4	6.9	6.5	6.1	5.7	5.4	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0	2.8	2.6
6.9	11	11	9.9	9.3	8.7	8.2	7.7	7.2	6.8	6.3	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.6
7.0	11	10	9.6	9.0	8.4	7.9	7.4	7.0	6.5	6.1	5.7	5.4	5.0	4.7	4.4	4.2	3.9	3.7	3.4	3.2	3.0	2.8	2.6	2.5
7.1	10	9.8	9.2	8.6	8.1	7.6	7.1	6.7	6.3	5.9	5.5	5.2	4.8	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4
7.2	10	9.3	8.8	8.2	7.7	7.2	6.8	6.3	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.8	3.6	3.3	3.1	2.9	2.7	2.6	2.4	2.3
7.3	9.4	8.8	8.2	7.7	7.3	6.8	6.4	6.0	5.6	5.3	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1
7.4	8.7	8.2	7.7	7.2	6.8	6.3	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.3	2.1	2.0
7.5	8.1	7.6	7.1	6.6	6.2	5.8	5.5	5.1	4.8	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8
7.6	7.3	6.9	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0	2.8	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7
7.7	6.6	6.2	5.8	5.5	5.1	4.8	4.5	4.2	3.9	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	1.9	1.8	1.7	1.6	1.5
7.8	5.9	5.5	5.2	4.8	4.5	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3
7.9	5.2	4.8	4.5	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2
8.0	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0
8.1	3.9	3.6	3.4	3.2	3.0	2.8	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88
8.2	3.3	3.1	2.9	2.7	2.6	2.4	2.3	2.1	2.0	1.9	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.86	0.80	0.75
8.3	2.8	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64
8.4	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.85	0.80	0.75	0.70	0.66	0.62	0.58	0.54
8.5	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99	0.93	0.87	0.82	0.77	0.72	0.67	0.63	0.59	0.55	0.52	0.49	0.46
8.6	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.78	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47	0.44	0.41	0.39
8.7	1.4	1.3	1.3	1.2	1.1	1.0	0.98	0.92	0.86	0.81	0.75	0.71	0.66	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33
8.8	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60	0.56	0.53	0.50	0.46	0.44	0.41	0.38	0.36	0.34	0.32	0.30	0.28
8.9	1.0	0.98	0.92	0.86	0.81	0.76	0.71	0.66	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.24
9.0	0.90	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.54	0.50	0.47	0.44	0.41	0.39	0.36	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.22	0.20

*To be applied to all Class 2 waters in Minnesota as a 4-day chronic standard (CS). Each value equals 2.5 times the 30-day chronic value

Table 5. Comparison of existing water quality standards (MPCA) and recommended national criteria (EPA), as mg/L TAN (pH=7, T=20°C)*

Standard or criterion	Class 2A existing§	Class 2A recommended	Class 2B, 2Bd, 2D existing§	Class 2B, 2Bd, 2D recommended
FAV	--	33.5	--	33.5
MS	--	16.8	--	16.8
CS (4-day average)	4.1	4.8	10.1	4.8
CS (30-day average)	--	1.9	--	1.9

*FAV and MS values may differ across classes at lower temperatures

§ Existing values converted from µg/L un-ionized NH_3

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