



Canadian Water Quality Guidelines for the Protection of Aquatic Life

AMMONIA

Ammonia (CAS # 7664-41-7, atomic mass 17.03) is a colourless alkaline gas which has a pungent suffocating odour at ambient temperature and pressure (WHO 1986; CCREM 1987). It freezes at -77.8°C and boils at -33.35°C , and is often stored or shipped in liquified form (Gedah 1985).

Ammonia is an important component of the nitrogen cycle and because it is oxidized in the environment by microorganisms (i.e., nitrification), it is a large source of available nitrogen in the environment (Raven & Johnson 1989). The complexity of the nitrogen cycle, various rate determining environmental conditions for nitrification (e.g., pH, temperature), and the physical behaviour of ammonia (e.g., volatilization, adsorption) make determining the fate of ammonia in the environment extremely complex. Ammonia can form explosive mixtures with air at concentrations between 16 and 27% by volume, but is generally regarded as non-flammable (WHO 1986; Gedah 1980). Ionized ammonium salts form when ammonia dissolves in dilute acids. Some of these salts are found in nature (water, soil, atmosphere) (WHO 1986).

Ammonia is highly soluble in water and its speciation is affected by a wide variety of environmental parameters including pH, temperature, and ionic strength. In aqueous solutions, an equilibrium exists between un-ionized (NH_3) and ionized (NH_4^+) ammonia species. Un-ionized ammonia refers to all forms of ammonia in water with the exception of the ammonium ion (NH_4^+) (Environment Canada 1997; CCREM 1987). Ionized ammonia refers to the ammonium ion. The term 'total ammonia' is used to describe the sum of ammonia (NH_3) and ammonium (NH_4^+) concentrations and may also be expressed as 'total ammonia-nitrogen', due to the slightly different relative molecular masses (Environment Canada 1997; CCREM 1987; WHO 1986).

In Canada, the Haber-Bosch process is the key commercial method of ammonia production. In this process, a catalyst is used to speed up the reaction between hydrogen and nitrogen (in a 3-to-1 ratio) combined under high pressure and high temperature (approximately 600°C) to produce ammonia (Harding 1959; Gedah 1985; Environment Canada 1997).

Total domestic demand for ammonia in Canada in 1996 and 1997 was approximately 3508 kt and 3535 kt, respectively. 1277 kt and 1226 kt of ammonia were exported in 1996 and 1997, respectively (CPI 1998). Ammonia is used in numerous applications in the refrigeration, pulp and paper, mining, food processing, refining, and animal husbandry sectors (Environment Canada 1997; Environment Canada 1992). The principal use of ammonia is the production of nitrogenous fertilizers (ammonium nitrate, ammonium phosphate, urea, and ammonium sulphate). In the agriculture industry, anhydrous ammonia is directly

Table 1. Water quality guidelines for un-ionized ammonia for the protection of aquatic life.

Aquatic life	Guideline value (mg·L)
Freshwater	0.019
Marine	NRG ¹

¹No recommended guideline

Table 2. Water quality guidelines for total ammonia for the protection of aquatic life ($\text{mg}\cdot\text{L}^{-1}\text{NH}_3$).

Temp (°C)	pH							
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	10
0	231	73.0	23.1	7.32	2.33	0.749	0.250	0.042
5	153	48.3	15.3	4.84	1.54	0.502	0.172	0.034
10	102	32.4	10.3	3.26	1.04	0.343	0.121	0.029
15	69.7	22.0	6.98	2.22	0.715	0.239	0.089	0.026
20	48.0	15.2	4.82	1.54	0.499	0.171	0.067	0.024
25	33.5	10.6	3.37	1.08	0.354	0.125	0.053	0.022
30	23.7	7.50	2.39	0.767	0.256	0.094	0.043	0.021

* The guideline values and all reported total ammonia concentrations in this factsheet are reported in mg/L NH_3 ; measurements of total ammonia in the aquatic environment are often also expressed as $\text{mg/L total ammonia-N}$. The present guideline values (mg/L NH_3) can be converted to $\text{mg/L total ammonia-N}$ by multiplying the corresponding guideline value by 0.8224.

** Values falling outside of shaded area should be used with caution.

*** No recommended guideline for marine waters.

applied to fields and ammonia is injected into animal feed to increase its nutrient value (Environment Canada 1997; Environment Canada 1992).

In the textile industry, ammonia is used in the fabrication of synthetic fibres (such as nylon and rayon), and as a curing agent in leather making (Environment Canada 1997). The health care industry uses ammonia in the manufacture of pharmaceuticals, vitamins, amino acids, lotions, and cosmetics. The household chemical industry uses ammonia for the manufacturing of cleansing agents and detergents (Environment Canada 1999). In addition, ammonia is used in the production of many goods including explosives, rocket fuel, beer, plastics, rubber, nitrogen oxides required for manufacturing sulphuric acid, in sugar purification, and in the treatment and transformation of metals (Chemical and Engineering News 1980, as cited in WHO 1986; Environment Canada 1997).

Ammonia commonly enters the environment as a result of municipal, industrial, agricultural, and natural processes. Natural sources of ammonia include the decomposition or breakdown of organic waste matter, gas exchange with the atmosphere, forest fires, animal waste, human breath, the discharge of ammonia by biota, and nitrogen fixation processes (Environment Canada 1997; Geadah 1985).

Point sources of ammonia include emissions and effluents from a wide variety of industrial plants such as iron and steel mills, fertilizer plants, oil refineries, and meat processing plants (Environment Canada 1997; CCREM 1987; WHO 1986). The manufacturing of explosives and the use of explosives in mining and construction can also be significant point sources of ammonia (Pommen 1983, as cited in CCREM 1987). The largest non-industrial point sources are sewage treatment plants (Environment Canada 1999). Accidental ammonia spills are a major anthropogenic source of ammonia entering the Canadian environment (Environment Canada 1992). An ammonia spill can occur during the production, processing, storage, application, or disposal stage of the chemical's life cycle (Environment Canada 1992). Environment Canada ranked ammonia as the top priority on the Environment Canada 1990 Canadian Chemical Spill Priority List. Additionally, the Major Industrial Accidents Council of Canada (MIACC) has identified ammonia as a priority substance (Environment Canada 1992). From 1974 to 1984, there were 107 reported spills of anhydrous ammonia (a total of 46 t), which accounted for 5.5% of all chemical spills in Canada during that time. From 1985 to 1990 there were 92

reported ammonia spills. The number of spills may be higher, as spill reports to the National Analysis of Trends in Emergencies System (NATES) are voluntary (Environment Canada 1992).

Non-point sources of ammonia include agricultural, residential, municipal, and atmospheric releases. Major agricultural sources include areas with intensive farming, accidental releases or spills of ammonia-rich fertilizer, and the decomposition of livestock wastes (Environment Canada 1992; WHO 1986). Residential and municipal sources of ammonia include the use and disposal of cleansing agents that contain ammonia, improper disposal or accidental spills of ammonia products, and urban runoff (Environment Canada 1997; WHO 1986). Combustion processes such as the burning of municipal waste, emissions from sewage treatment plants, domestic heating, the decay of vegetation, and the production and use of chemical fertilizers increase atmospheric concentrations of ammonia. Mobile sources of ammonia to the atmosphere arise from all forms of transportation (Environment Canada 1997).

The National Pollutant Release Inventory (NPRI 1996) states that, in 1996, 32 037 metric tonnes of ammonia were released into the Canadian environment from reporting industries. Of all the substances reported, ammonia was ranked second in total amount released. Approximately 56% of the ammonia was released to air, 24% released underground, 18% to water, and 2% to land. Due to the reporting requirements of the NPRI, some large anthropogenic sources (municipal sewage treatment plants, transportation systems, and animal husbandry systems) are excluded from these totals.

The main factors that influence the equilibrium between un-ionized and ionized ammonia are pH and temperature (Environment Canada 1999; Jofre and Karasov 1999; EPA 1998). Raising pH by one unit can cause the un-ionized ammonia concentration to increase nearly tenfold, while a 5°C temperature increase can cause an increase of 40-50% (Environment Canada 1999). Emerson et al. (1975) examined data on ammonia-water equilibrium systems and prepared calculations for pKa at different temperatures and percent NH₃ in ammonia solutions as a function of pH and temperature. Two equations were developed:

EQUATION 1.

$$pK_a = 0.0901821 + 2729.92 / T$$

Where,

T = Temperature in K; Absolute zero = - 273.15 °C

$$T \text{ (in K)} = T \text{ (in } ^\circ\text{C)} + 273.15$$

EQUATION 2.

$$f = 1 / [10^{(pK_a - pH)} + 1]$$

Where,

f = fraction of total ammonia that is un-ionized

pK_a = dissociation constant from equation 1

Using the equations above, a table describing the percent of NH_3 in low ionic strength water for temperatures (0–30°C) and pH (pH= 6–10) is presented (Table 3). The ionic strength of the water is also an important influence on the un-ionized ammonia concentration. As the ionic strength increases in hard or marine waters, there is a decrease in the un-ionized NH_3 concentration (Environment Canada 1997; Emerson et al. 1975). Freshwater systems with up to 200–300 $\text{mg}\cdot\text{L}^{-1}$ total dissolved solids may have a negligible reduction in percent NH_3 . The effect of ionic strength is much smaller than the effects of temperature and pH (Soderberg and Meade 1991).

Table 3. Percent un-ionized aqueous ammonia solutions for 0-30°C and pH 6-10 (Emerson et al. 1975)

Temp (°C)	pH								
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10
0	0.008	0.026	0.082	0.261	0.820	2.55	7.64	20.7	45.3
5	0.012	0.039	0.125	0.394	1.23	3.80	11.1	28.3	55.6
10	0.018	0.058	0.186	0.586	1.83	5.56	15.7	37.1	65.1
15	0.027	0.086	0.273	0.859	2.67	7.97	21.5	46.4	73.3
20	0.039	0.125	0.396	1.24	3.82	11.2	28.4	55.7	79.9
25	0.056	0.180	0.566	1.77	5.38	15.3	36.3	64.3	85.1
30	0.080	0.254	0.799	2.48	7.46	20.3	44.6	71.8	89.0

In surface waters, both nitrification and volatilization are important competitive fate processes for ammonia (Environment Canada 1999). Volatilization increases with increasing wind speed, temperature, and pH. In addition, the partial pressure of ammonia in solution increases with increasing pH, and in aqueous solutions, ammonia may form complexes with a number of metal ions. It may be sorbed onto suspended and bed sediments and to colloidal particles. Ammonia may

also be exchanged between sediments and overlying water. Ammonia concentrations in water vary seasonally and regionally. In natural waters, concentrations of total ammonia are generally less than 0.1 $\text{mg}\cdot\text{L}^{-1}$. Higher levels of ammonia are generally indicative of organic pollution (McNeely et al. 1979 as cited in WQB 1989).

The data on Canadian environmental concentrations presented below have been selected from a database prepared by Environment Canada in support of the Second Canadian Environmental Protection Act Priority Substances List (CEPA PSL II) assessment for ammonia (Environment Canada 1998). Detection limits were often not reported in the database.

From 1993 to 1996, concentrations of dissolved ammonia in twenty rivers sampled in the Northwest Territories ranged from 0.0002 to 0.294 $\text{mg}\cdot\text{L}^{-1}$ (n=521), with an average concentration of 0.0148 $\text{mg}\cdot\text{L}^{-1}$. Total ammonia sampled from two rivers in the Northwest Territories waters ranged from 0.002 to 0.19 $\text{mg}\cdot\text{L}^{-1}$ (n=4) (Environment Canada 1998).

Concentrations of dissolved ammonia collected from 165 rivers and lakes across British Columbia between 1990 and 1996 ranged from ND (not detected) to 180 $\text{mg}\cdot\text{L}^{-1}$ (n=5135), with an average concentration of 0.689 $\text{mg}\cdot\text{L}^{-1}$. The maximum concentration was detected in the Fraser River at a hydro station south of Mission City in 1993. Total ammonia levels from 32 water bodies in British Columbia ranged from ND to 8.4 $\text{mg}\cdot\text{L}^{-1}$ (n=2129), with an average concentration of 0.0858 $\text{mg}\cdot\text{L}^{-1}$ (Environment Canada 1998). Similarly, concentrations of total ammonia sampled from 232 waterbodies in the province of Alberta between 1990 and 1996 ranged between ND and 10.2 $\text{mg}\cdot\text{L}^{-1}$ (n=2599), with an average concentration of 0.183 $\text{mg}\cdot\text{L}^{-1}$ (Environment Canada 1998). Dissolved ammonia concentrations from 414 rivers and lakes in Alberta ranged between ND and 8.8 $\text{mg}\cdot\text{L}^{-1}$ (n=1929), with an average concentration of 0.110 $\text{mg}\cdot\text{L}^{-1}$ (Environment Canada 1998).

In 1987, total ammonia concentrations in the South Saskatchewan River, 140 m below the outfall diffuser of Saskatoon's sewage treatment plant outfall, reached a maximum of 4.26 $\text{mg}\cdot\text{L}^{-1}$ (WQB 1989). For five kilometres downstream of the sewage treatment plant outfall, a few of the transects had mean total ammonia concentrations within the effluent plume that surpassed the Saskatchewan Surface Water Quality Objective for total ammonia for the protection of aquatic life of 0.44 $\text{mg}\cdot\text{L}^{-1}$ (WQB 1989).

Total ammonia concentrations in Ontario between 1994 and 1996 ranged from 0.001 mg·L⁻¹ at several locations to 16.5 mg·L⁻¹ at Hayward Creek downstream from Molson and Lim Lakes, with an average concentration of 0.144 mg·L⁻¹, and an average pH of 7.92 (Environment Canada 1998). Concentrations of total ammonia ranged between 0.375 and 0.938 mg·L⁻¹ in stormwaters monitored in Ontario between 1985 and 1986 (Marsalek and Ng 1989). In 1987-88, distributions of ammonia, nitrite, and total dissolved nitrogen were measured in Hamilton Harbour, Lake Ontario. In the spring and summer seasons, levels of un-ionized ammonia in Hamilton Harbour surpassed the International Joint Commission (IJC) objective of 20 µg·L⁻¹ at all sampling sites (NWRI 1990). Loadings of total ammonia from multiple sources in Hamilton Harbour were estimated to be 7500 kg/day (DOE-MOE 1989, as cited in NWRI 1990). Approximately 70% (5300 kg/day) of the total loading in 1987 was released by the Hamilton sewage treatment plant. Other sources of ammonia to Hamilton Harbour include steel industries and combined sewer overflows (NWRI 1990). Since the late 1970s and early 1980s, total quantities of ammonia in Hamilton Harbour have been greatly reduced. For example, reductions in the total ammonia loading from steel industries, alone, decreased from 24000 kg/day in 1967 to 857 kg/day by 1987. However, the reductions from the municipal sewage treatment plants were less noticeable.

Water samples from 206 river sampling stations in Quebec indicated that total ammonia concentrations ranged from ND to 15.9 mg·L⁻¹ (n=2035), with an average concentration of 0.103 mg·L⁻¹. Samples of total ammonia collected from 62 lake sampling stations in Quebec ranged from 0.01 to 0.82 mg·L⁻¹, with an average concentration of 0.082 mg·L⁻¹ (Environment Canada 1998). No dates were reported for the samples collected in Quebec. Between 1981 and 1985, the average concentration of total ammonia sampled from 276 lakes in Nova Scotia was 0.09 mg·L⁻¹. Ammonia levels ranged from <0.01 mg·L⁻¹ to a maximum level of 0.3 mg·L⁻¹ (Environment Canada 1998).

Concentrations of ammonia in the atmosphere in urban areas typically vary from 5 – 25 µg·m⁻³ and in rural areas between 2-6 µg·m⁻³. Agricultural areas with a high use or production of manure may release ammonia concentrations between 100 - 200 µg·m⁻³. Particulate ammonium concentrations have been detected above oceans at levels ranging from 0.01-0.1 µg·m⁻³ (WHO 1986).

Water Quality Guideline Derivation

The Canadian water quality guidelines for un-ionized and total ammonia for the protection of aquatic life (Tables 1 and 2) were developed using the CCME protocol (CCME 1991) and the community ecological risk criteria from Environment Canada (1999). It should be noted that due to the paucity of ammonia toxicity data on marine organisms; currently, there is insufficient information to adequately derive a full or interim guideline for the protection of marine life. As a result, no marine guideline is recommended.

Freshwater Life

There are several factors that are known to affect the toxicity of ammonia in freshwater. These factors may have an effect on the concentrations of un-ionized ammonia in water or impact directly on the organism making it more or less susceptible to ammonia (Environment Canada 1999). Factors shown to affect ammonia toxicity include pH, temperature, dissolved oxygen concentration, ionic strength, salinity, previous acclimatization to ammonia, fluctuating or intermittent exposure, and the presence of other toxic substances (Environment Canada 1997). Of these, pH is thought to be the most important factor influencing ammonia toxicity.

The speciation of ammonia is very important to understanding ammonia toxicity. As un-ionized ammonia is known to be more toxic than the ammonium ion, the influence of pH and temperature, on the relative proportion of ionized and un-ionized ammonia, in particular is important. It is thought that un-ionized ammonia is more toxic to aquatic organisms because it is a neutral molecule and is therefore able to diffuse across biological membranes more readily than other forms (EPA 1998).

There is a substantial body of data available on the toxicity of ammonia to aquatic organisms, in particular acute, chronic, and sub-lethal effects of ammonia in fish. Less information is available on the toxicity of ammonia to invertebrates and benthic organisms. Mean 48- and 96-hr LC₅₀ values reported for freshwater invertebrates and fish ranged from 1.10 to 22.8 mg·L⁻¹ for invertebrates and from 0.56 to 2.37 mg·L⁻¹ for fish species (Environment Canada 1999). Several authors have suggested that the ammonium ion may contribute to the toxicity of total ammonia especially at low pH (Borgmann 1994; Thurston et al. 1981; Armstrong et al. 1978). However, the weight-of-evidence suggests that the un-ionized fraction is the best indicator of ammonia toxicity

(Environment Canada 1999; Frias-Espericueta et al. 1999; EPA 1998).

Ochromonas sociabilis, a freshwater alga, was exposed to ammonia concentrations to observe the effect of ammonia on growth and mortality (Bretthauer 1978). Un-ionized ammonia concentrations ranging from 0.06 to 0.15 mg·L⁻¹ had an insignificant effect on growth. Concentrations of 0.015 to 0.03 mg·L⁻¹ were found to enhance alga growth. Development was reduced at 0.3 mg·L⁻¹ of NH₃ and mortality was observed at 0.6 mg·L⁻¹. Nimmo et al. (1989) conducted a 7-day life-cycle test on water fleas (*Ceriodaphnia dubia*). Test conditions included water from the St. Vrain River, Colorado at 25°C and pH 7.8. An EC₂₀ (# of neonates per original female) of 15.2 mg·L⁻¹ total ammonia was calculated using regression analysis and square root transformation (EPA 1998). The total ammonia concentration can be converted to un-ionized ammonia using the equations (EQ 1 & 2) from Emerson et al. (1975). Using this approach, the EC₂₀ is 0.525 mg·L⁻¹ for un-ionized ammonia.

Rainbow trout (*Oncorhynchus mykiss*) were tested for sensitivity to un-ionized ammonia (NH₃) concentrations ranging from 0.01 to 0.07 mg·L⁻¹ over a period of 5 years (Thurston et al. 1984). No correlation between ammonia concentration and number of eggs produced was observed in the parental generation. Pathological lesions in the gills and extensive tissue degradation in the kidneys were directly correlated with ammonia concentrations above 0.04 mg·L⁻¹, after 4 months of exposure.

Sockeye salmon (*Oncorhynchus nerka*) were exposed to total ammonia for 62 day from fertilization to hatching (Rankin 1979). Concentrations of un-ionized ammonia were calculated and ranged from 0.00097 - 4.92 mg NH₃ L⁻¹ at 10°C and pH 8.2 and hatchability was the measured endpoint. Hatchability was 63.3%, 49% and 0% in controls, at 0.12 mg·L⁻¹, and 0.46 mg·L⁻¹, respectively. An EC₂₀ was calculated for this study by Environment Canada (1999) with correction for control mortality. The reported EC₂₀ was 0.057 mg·L⁻¹ un-ionized ammonia. Bader and Grizzle (1992) exposed catfish (*Ictalurus punctatus*) fry to ammonia in a 7-day static renewal test. An IC₂₀ for fry growth was determined by Environment Canada (1999) at 0.162 mg·L⁻¹ un-ionized ammonia. There was no incremental mortality up to 0.490 mg·L⁻¹ exposure. Smith et al. (1984) conducted a 30-day early life-stage test on bluegill sunfish (*Lepomis macrochirus*). The test exposed 28-day old embryos and monitored them to the swim-up fry life stage. No significant reduction was found in percent of hatch up to a concentration of

37 mg·L⁻¹ un-ionized ammonia, however, larvae were deformed and generally died within 6 days. An IC₂₀ (survival and growth) of 0.060 mg·L⁻¹ was calculated (Environment Canada 1998) for this study.

Figure 1. Select freshwater chronic toxicity data for un-ionized ammonia.

Toxicity information		Species	Toxicity endpoint	pH	Temp (°C)	Un-ionized ammonia concentration (µg·L ⁻¹)
Chronic	Plants	<i>O. sociabilis</i>	LC ₅₀	6.5	30	•
		<i>C. dubia</i>	7-d IC ₂₀	8.57	26	•
	Invertebrates	<i>D. magna</i>	21-d LC	8.45	19.8	•
		<i>O. nerka</i>	62-d EC ₂₀	7.8	25	•
	Vertebrates	<i>O. mykiss</i>	LOEC	7.7	7.5 - 10	•
		<i>L. macrochirus</i>	30-d IC ₂₀	7.76	22.5	•
<i>I. punctatus</i>		7-d IC ₂₀			•	

Toxicity endpoints: ■ primary ■ secondary • critical value

10¹ 10² 10³ 10⁴

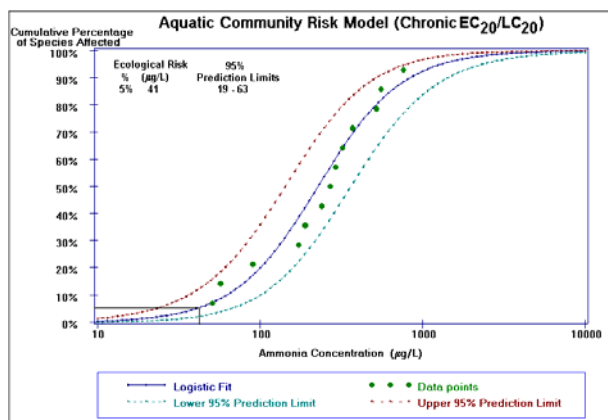
CWQG Un-ionized Ammonia CWQG Total Ammonia (pH=7.5 Temp=20°C)

Un-ionized Ammonia (NH₃)

The most sensitive freshwater study identified was for the rainbow trout (*O. mykiss*). The reported lowest observed effect concentration (LOEC) for un-ionized ammonia in a five year chronic study is 0.04 mg·L⁻¹, exposure to this and higher concentrations resulted in pathological lesions in the gills and tissue degradation in the kidneys (Thurston et al. 1984). Consistent with this study, Environment Canada's (1999) aquatic community ecological risk criteria on the impact of ammonia at the community level of both invertebrates and fish indicated that 5% of the species in an aquatic community would exhibit a 20% reduction in growth or reproduction at an un-ionized ammonia concentration of 0.041 mg·L⁻¹. Thus, an identical low toxic threshold of 0.4 mg·L⁻¹ was derived using two separate approaches namely the CCME Aquatic Life Protocol (CCME 1991) and a regression-based approach described in the ecological risk criteria for un-ionized ammonia (Environment Canada 1999). Following CCME protocol for the derivation of Water Quality Guidelines for the Protection of Aquatic Life (CCME 1991), the application of a safety factor to the designated low-threshold effects value should occur; however, the current protocol allows for deviation from the standard method of guideline development in cases where sufficient scientific weight of evidence permits. Such is the case for un-ionized ammonia. In the determination of the community ecological risk criteria (Figure 2), Environment Canada (1999) predicted 95% confidence intervals surrounding their sensitive ammonia data. The lower 95% prediction limit is 0.019 mg·L⁻¹ and the

upper 95% prediction limit is $0.063 \text{ mg}\cdot\text{L}^{-1}$ (Figure 2). Their analysis of the data using a two parameter logistic model produced an adequate model fit (i.e., $< 5\%$) according to the goodness-of-fit statistic (G test). Therefore, based on this weight of evidence that has made use of the complete data envelope for un-ionized ammonia a safety factor is not applied to the most sensitive study (Thurston et al. 1984), but rather, the lower 95% prediction limit ($0.019 \text{ mg}\cdot\text{L}^{-1}$) will be set as the guideline.

Figure 2. Aquatic Community Risk Model (Environment Canada 1999).



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Total Ammonia ($\text{NH}_3 + \text{NH}_4^+$)

In order to derive a Water Quality Guideline for the Protection of Aquatic Life for total ammonia, a series of calculations are required to convert un-ionized ammonia to total ammonia. Equations for these calculations are provided by Emerson et al. (1975) and EPA (1998). The variability of pH and temperature on a nation-wide basis is substantial. The impact of these factors on the speciation of ammonia is an important consideration when deriving a Water Quality Guideline for the Protection of Aquatic Life. As a result, the total ammonia guideline is not a specific value, but rather a range of values over various pHs and temperatures. Table 2 provides total ammonia guidelines over a range of pH (6.0-10.0) and temperature (0-30 °C) based upon the un-ionized ammonia guideline of $0.019 \text{ mg}\cdot\text{L}^{-1}$ and the equations presented in Emerson et al. (1975) and EPA (1998). It is recommended that the most conservative total ammonia guideline closest to the pH and temperature conditions of the waterbody be applied. Values falling outside of the pH and temperature ranges indicated in Table 2 should be used with caution because there was a lack of toxicity data to accurately determine the toxic effects at the low and high extremes

of the reported ranges. In addition, results of the toxicity data that were available outside of the reported ranges (pH 6-10; temp. 0-30°C) were often ambiguous and confounding. No safety factor is applied to these values based on the weight of evidence described above.

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