City of Winnipeg
Water and Waste Department

# Red and Assiniboine Ammonia Criteria Study

# FINAL TECHNICAL REPORT


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Prepared by:

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In Association With:

**North / South Consultants**

## ACKNOWLEDGEMENTS

The study team acknowledges the assistance of the City of Winnipeg Project Management Committee, and the City of Winnipeg Laboratory Services Branch.

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# PREAMBLE

This Technical Report summarizes the findings of a series of investigations conducted on behalf of the City of Winnipeg, Water and Waste Department as part of the ammonia-criteria study.

A series of Technical Memoranda were provided for purposes of internal discussion and scientific review. These provide supporting documentation for this technical report and comprise the following:

- Toxicity Technical Memorandum #T1.0
  - Ammonia Toxicity Testing in 1999 and 2000
- River Conditions Technical Memorandum #RC2.0
- Fish Habitat Technical Memoranda #FH 01, FH 02, FH 03
  - Physical data to characterize fish habitat in the Red and Assiniboine Rivers
  - Benthic invertebrate and sediment data to characterize fish habitat in the Red and Assiniboine Rivers
  - Water chemistry data to characterize fish habitat in the Red and Assiniboine Rivers
- Fish Population Technical Memoranda #FP 01, FP 02, FP 03
  - The occurrence of external deformities, erosion, lesions, and tumours (DELTS) on fish from the Red and Assiniboine Rivers, 1999
  - Species composition, abundance, and distribution of fish in the Red and Assiniboine Rivers within the City of Winnipeg ammonia criteria study area, 1999
  - Abundance, composition and distribution of benthic invertebrates in the Red and Assiniboine Rivers within the City of Winnipeg, 1999
- Fish Behaviour Technical Memoranda #FB 01, FB 02, FB 03, FB 04
  - Biological and environmental data from experimental gillnetting in the vicinity of the NEWPCC outfall, March 1999
  - Biological and environmental data from experimental netting in the vicinity of the NEWPCC outfall, October 1999
  - Movements of fish tagged with acoustic transmitters in the vicinity of the City of Winnipeg's water pollution control centers, 1999-2000
  - Movements of 10 northern pike tagged with acoustic transmitters in the Red River in the vicinity of the NEWPCC effluent plume, February-March 2000
- Other Stressors: Resource Harvesting Technical Memorandum #RH2.0
  - Resource harvesting program report for 1999
- Other stressors: Physical Constraints Memorandum #OSPC 01

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# 1. INTRODUCTION

## 1.1 BACKGROUND

The Red and Assiniboine rivers are an important natural resource for the City of Winnipeg. The rivers provide scenic waterways, support a wide-range of water-based recreation, as well as an international-valued sports fishery. They have also been important to the City to receive and assimilate land drainage and wastewater.

Since the 1930s, the City has had an ongoing program of pollution control for the discharges to the Red and Assiniboine rivers. This program has resulted in continued upgrades of Winnipeg's Water Pollution Control Centres (WPCCs) to meet both a growing population and increased environmental standards. Until 1988, the responsibility for protecting the water quality of the Red and Assiniboine rivers in the Winnipeg area was delegated to the City by the Province of Manitoba through Order-in-Council. The City developed its own pollution-control program in accordance with broad guidelines accepted by both jurisdictions. Within this context, the individual Winnipeg Pollution Control Centres did not require effluent-discharge licences from the province. With the promulgation of *The Environment Act* on March 31, 1988, all projects in the province with discharges to the environment that have potential to create environmental impacts must possess a licence to operate. In accordance with the *Act* and a request from the Minister of Environment on November 4, 1989, the City of Winnipeg submitted proposals to the province for the three Water Pollution Control Centres in early February 1990. The province subsequently indicated that final licences for the WPPCs would be issued after consideration of broader surface water-quality objectives through a public hearing process for both the Red and Assiniboine rivers within and downstream of the City of Winnipeg.

The province had established guidelines for surface water objectives to protect a range of categories of uses of the surface water in the province. The province mandated the Clean Environment Commission (CEC) to convene a hearing in 1991/92 to deliberate, with public input, on the types of river uses that are appropriate for protection and the associated water-quality objectives that should be adopted and applied to the rivers to protect these uses. The City of Winnipeg participated in these hearings. The hearings focussed primarily on discussing proposed fecal coliform objectives for protection of public using river for designated water uses, and proposed ammonia objectives for protection of aquatic life within the rivers. The City acknowledged the need to protect the designated water uses, but questioned both the scientific information base supporting the proposed protective guidelines for ammonia and the extent of risk from river recreation which would necessitate the proposed guideline for coliform bacteria. Pure ammonia is a strong-smelling, colourless gas manufactured from nitrogen and hydrogen or is produced from coal gas. Ammonia is also produced naturally as a decomposition product from urea and protein. Human and animal waste contain organic nitrogen that breaks down to ammonia, so it is found in domestic wastewater. Aquatic life and fish also contribute to ammonia levels in a stream.

Ammonia is rich in nitrogen so it makes an excellent fertilizer. Like nitrates, ammonia may accelerate the process of eutrophication in waterways. Ammonia does not accumulate in the food chain and has no affect on the safety of easting fish.

The formula for ammonia, $NH_3$, consists of one atom of nitrogen and three atoms of hydrogen. $NH_3$, also known as un-ionized ammonia, is the principal form of toxic ammonia. It has been reported toxic to fresh water organisms at concentrations ranging from 0.53 to 22.8 mg/L. Toxic levels of ammonia are both pH and temperature dependent. Toxicity increases as pH increases and as temperature increases. Generally, plants are more tolerant of ammonia than animals, and invertebrates are more tolerant than fish. Excessive levels of ammonia can affect hatching and growth rates of fish. In fish development, sufficient exposure to ammonia can cause changes in tissues of gills, liver, and kidneys. Different species of fish are more sensitive to ammonia than others. Ammonia-sensitive fish such as trout and salmon can begin to die at ammonia levels of 0.2 mg/L, while ammonia tolerant fish such as carp, can begin to die at ammonia levels near 2.0 mg/L. For the Red and Assiniboine rivers, the concern regarding ammonia is primarily related to potential chronic effects such as growth rate reduction and tissue damage. Historically, ammonia levels in the Red and the Assiniboine rivers have not been thought to be high enough to result in fish kills. Following the hearings, the CEC made multiple recommendations in its 1992 report to the Minister of Environment (CEC 1992). In Recommendation No. 6 of the Clean Environment Commission report, the CEC concurred with the City's position on ammonia:

> "*Detailed site-specific studies should be undertaken to determine both the acute toxic and chronic effects of un-ionized ammonia from wastewater effluent on the*

> *cool-water aquatic life of the rivers. Members of the scientific community within Manitoba should be invited to collaborate in the study design. Recommendations should be available before July 1997 as to the program required to deal with un-ionized ammonia in wastewater at the water pollution control sites along the river system being considered.*"

Following the CEC report, the City also initiated an assessment of the impacts of combined sewer overflows on the Red and Assiniboine rivers. This study was initiated in 1994, and is being completed in parallel with the Ammonia-Criteria Study.

## 1.2 STUDY OBJECTIVES

Understanding the need for detailed, site-specific knowledge of effects of ammonia on aquatic life of rivers, the objectives of the Red and Assiniboine Ammonia-Criteria Study were as follows:

- study the presence of ammonia in the Red and Assiniboine rivers under variable conditions;
- test toxicity of ammonia to selected indigenous aquatic species;
- assess the characteristics of the local aquatic ecosystem;
- develop alternative and site-specific criteria for consideration by Manitoba Conservation and the City of Winnipeg that would provide appropriate protection to aquatic life in the Red and Assiniboine rivers;
- consider the requirements for additional ammonia reduction at Winnipeg's Water Pollution Control Centres (WPCCs) to meet the protective criteria; and
- provide the information base for the City of Winnipeg and Manitoba Conservation to develop the appropriate mutually-acceptable ammonia reduction programs.

## 1.3 OVERVIEW OF THE RED AND ASSINIBOINE RIVERS

### 1.3.1 The River Basins

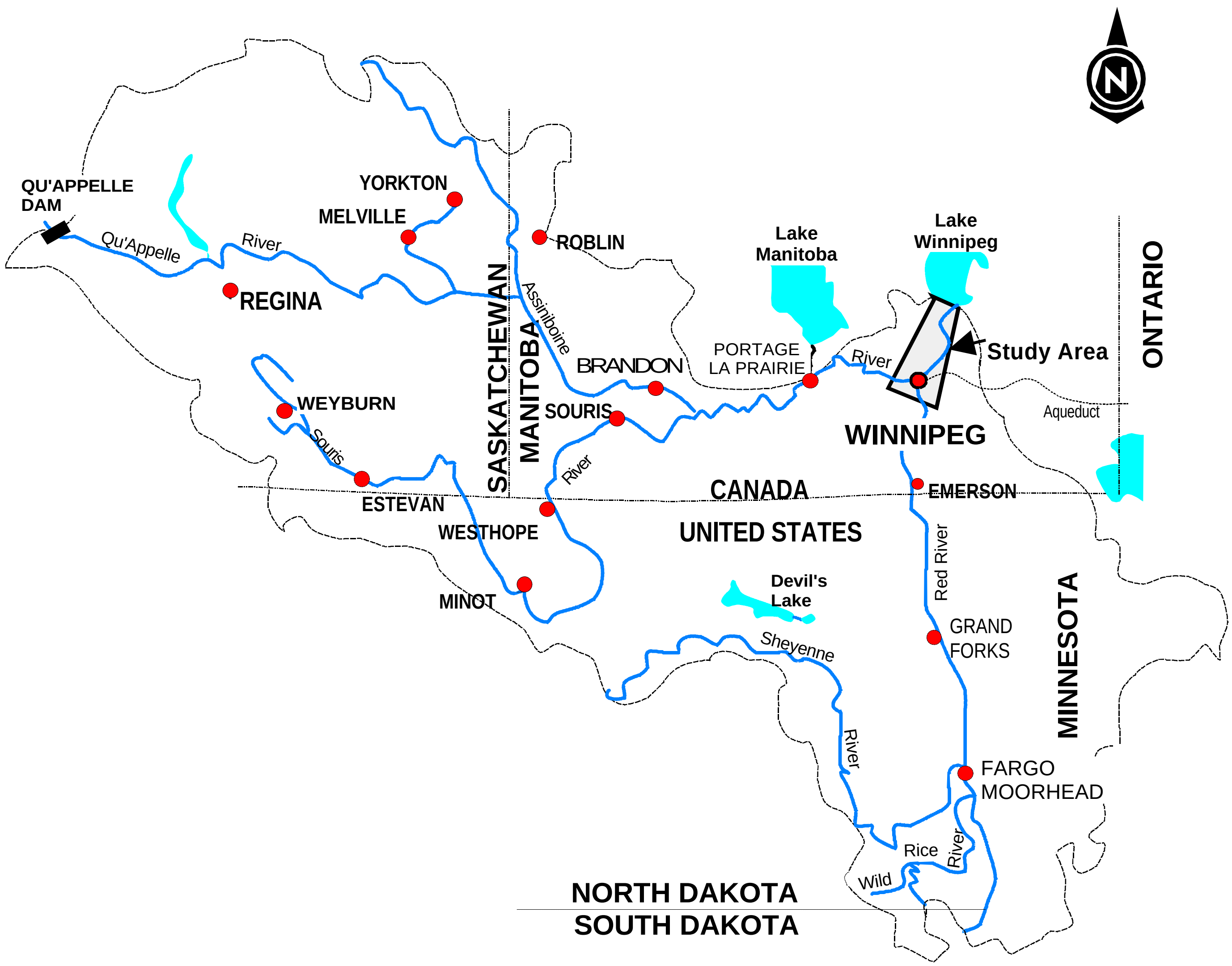
The study area comprises a small fraction of the river basins for the two rivers (Figure 1-1 and 1-2). The Red and Assiniboine rivers drain the prairie regions of southern Manitoba, southeastern Saskatchewan, North Dakota, northern South Dakota, and northwestern Minnesota. The basin is almost entirely underlain by limestone bedrock. The bedrock is covered with a thick deposit of clay. Soils in the region are black and fine textured. The Red River Valley plain is virtually level while the Assiniboine River passes through the Manitoba escarpment in the western portion of the province.

The main tributaries of the Red and Assiniboine rivers include the Ottertail, Cheyenne, Red Lake, Pembina, Roseau and Souris rivers, plus numerous small rivers and streams (see Figure 1-1). The total drainage area exceeds 270,000 $km^2$ (MacLaren 1986). Much of the tributary lowlands have been extensively drained.

#### 1.3.1.1 Hydrology

The flow in the rivers is dominated by spring runoff. Snowmelt, in combination with the spring rains, has been responsible for major floods. Flows usually decrease steadily in the summer. The minimum annual flow month often occurs in January or February. Annual average flows on the Red River upstream of Winnipeg (Ste. Agathe) are 162 $m^3/s$ (1962-1997 data). Flows at Lockport, which include the contribution from the Assiniboine River, average 225 $m^3/s$ annually. The average annual flows of the Assiniboine River at Headingley upstream of Winnipeg are 41 $m^3/s$.

River flows and levels are regulated throughout the drainage basin, with over 15 control structures (Wardrop/Tetr*ES* 1990). On the Assiniboine River system, important control structures include the Shellmouth Dam and the Portage Diversion. The river's reservoir is located on a tributary of the Assiniboine, and five small structures control flows on the Qu'Appelle River in Saskatchewan, which is a tributary of the Assiniboine River. The Souris River is also regulated within Saskatchewan. The Winnipeg Floodway and the St. Andrews

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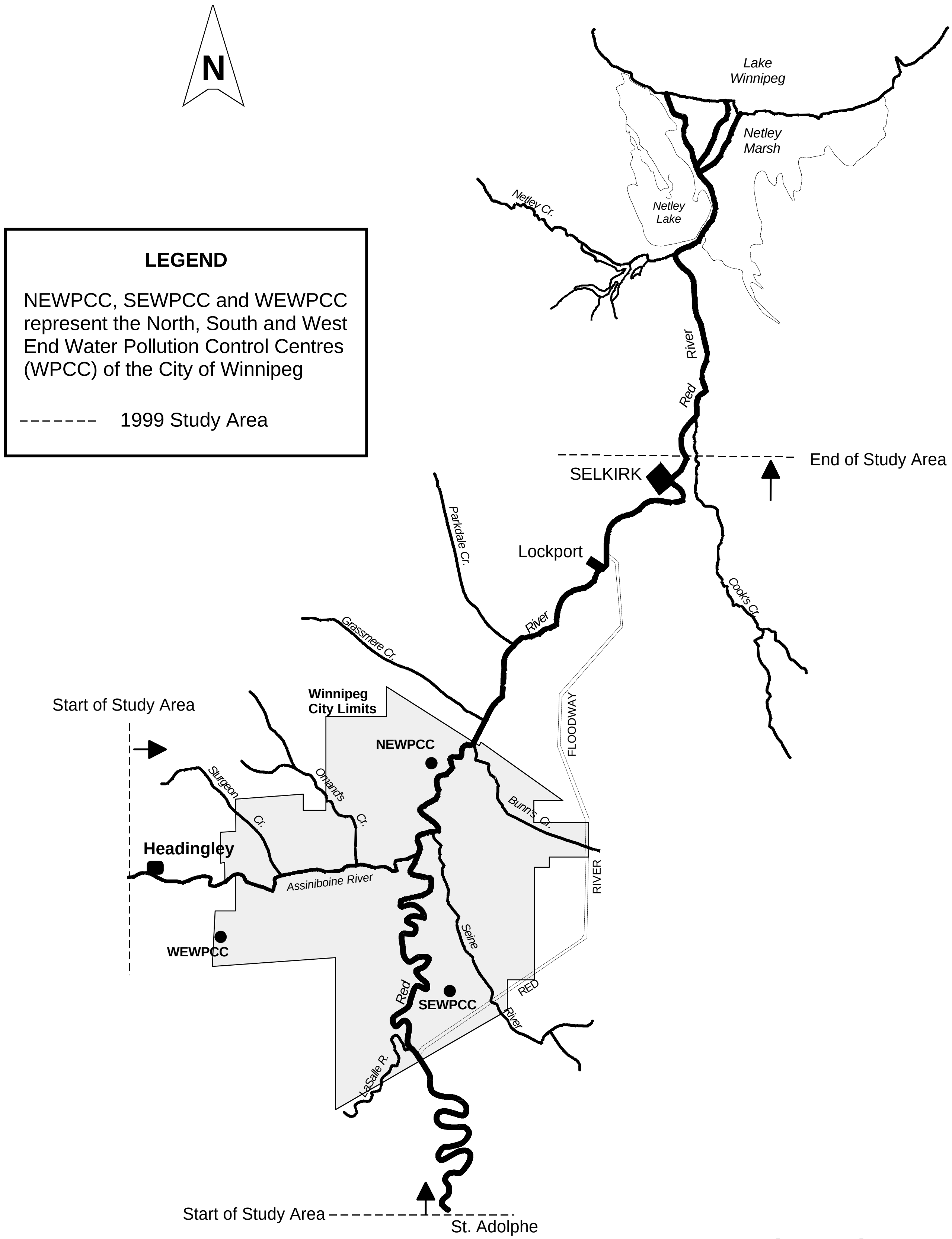
# The Red and Assiniboine Rivers Watershed

Figure 1-1




## Ammonia Study Area
Figure 1-2

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Lock are the major hydraulic structures on the Red River in Manitoba although many smaller ones have been built on tributaries such as the La Salle River. In the U.S.A., five major reservoirs are located on tributaries of the Red River: the Red Rock Reservoir on the Red Rock River; Orwell on the Otter Tail River; Bald Hill on the Sheyenne River; and Homme Dam on the Park River and Lake Traverse.

Additional regulation of the Red and Assiniboine rivers and their drainage basins may occur in the future. Current proposals include a control structure on the Red, an intermittent diversion of the Pembina River into Pelican Lake and diversions of water from the Assiniboine River to southwestern Manitoba. Proposed diversion of waters between watersheds in North Dakota could contribute flows of Missouri River waters into the two subject watersheds.

### 1.3.2 <u>Regional Land Use</u>

Land use in the drainage basins is principally agricultural, but numerous cities and towns are located on the riverbanks. The principal urban centres are: Fargo, Moorhead, Grand Forks, Winnipeg and Selkirk on the Red River and Minot, Brandon and Portage la Prairie on the Assiniboine River. Agriculture use affects the water quality of runoff (e.g., nutrients, pesticides and sediments). Towns and cities and residential areas discharge domestic and industrial sewage which has received varying levels of treatment. Sections of the riverbank still remain in their natural state and support a variety of birds and mammals, while many aquatic species are present within the rivers. Waterfowl conservation projects in the region are a major water user in the Red River basin.

# 2. STUDY APPROACH

## 2.1 OVERVIEW

Ammonia in water is comprised of two constituents, namely dissolved ammonia in the ionic form ($NH^{+}_{4}$) and undissolved un-ionized ammonia ($NH_3$). Ammonia is an essential nutrient used in the development of amino acids and eventually proteins. It is a natural substance found in water and is excreted by aquatic life such as fish.

The Water and Waste Department of the City of Winnipeg engaged a consulting team lead by Tetr*ES* Consultants Inc., in association with North/South Consultants Inc. and supported by a number of Specialist Advisors, to carry out the Ammonia-Criteria Study. The goal of this study is to create and provide information to assist in the development of locally appropriate ammonia criteria for protection of aquatic life in the urban reaches of the Red and Assiniboine rivers.

The City initiated the Ammonia-Criteria Study on September 14, 1998. Initial ("pre-Study") work focused on organizing a Workshop involving selected representatives of the scientific community in Manitoba, and subsequently developing a comprehensive Workplan outlining the expected scope of activities and budgets required to carry out this study. The Workshop was held on September 24, 1998, with the participation of the City, their consultants, and members of the local scientific community. A second Workshop was held February 18 and 19, 1999.

The major activities of the study relate to:

- understanding the water-quality regime for a wide and dynamic range of river conditions both under existing and potential future ammonia-control scenarios;
- understanding the scientific rationale behind existing and evolving ammonia regulations in various jurisdictions and determining their applicability to the local reaches of the 2 rivers;
- understanding the abundance, distribution, behaviour, and health of aquatic life within the study area;
- determining the toxicity of ammonia to selected indigenous aquatic species; and

- integration of the results to assist in the identification of candidate criteria protective of indigenous aquatic life and to support consideration of the implications of conformance with these alternative protective criteria.

Work has proceeded on these activities since February 1999. Details regarding execution of the work are documented in separate Technical Memoranda. Integration of all relevant information created in these workstreams is described in this Report.

## 2.2 WATERSHED CLASSIFICATION

*Provincial*

Manitoba adopted a Watershed Classification Process over a decade ago to assist the protection of the quality of surface waters. The process can lay the foundation for and contribute to the development of long-term water-quality management programs. The watershed-classification process identifies river or basin-specific water uses and the Surface Water Quality Objectives (SWQOs) proposed to protect these water uses (Williamson 1990). A wide variety of "beneficial" uses has been identified through this process for selected Manitoba rivers and lakes, including domestic and agricultural consumption, aquatic life and wildlife habitat, recreation and industrial use (including effluent assimilation).

The Watershed Classification Process involves four important steps:

- technical evaluation of watershed water quality;
- public review (often including public hearings conducted by the Clean Environment Commission (CEC), which provides recommendations to the Minister);
- classification of the watershed by the Minister, including specification of protective SWQOs; and
- implementation of a long-term, feasible, water-quality management strategy, according to the Objectives set out in the Watershed Classification.

The process recognizes the need for further environmental reviews for licensing of individual projects or facilities, as part of the comprehensive management approach to achieving the Objectives established through watershed classification.

The current process requires a variety of 'site-specific investigations' to create the information necessary for developing locally appropriate water-quality protection programs and Objectives. These investigations involve assessments of existing conditions, identification of existing and potential future water uses, and determination of whether or not water quality may be a limiting factor in attaining the present or future uses. If water quality is not a limiting factor, then water quality Objectives (and an appropriate level of protection) are recommended to protect identified uses. If the existing water quality is presently impaired, thus affecting either present or future water uses, evaluation is necessary to answer key questions (Williamson 1990):

- *Which water uses are being impaired*?
- *What are the water quality variables causing the impaired use*?
- *To what extent do human activities contributed to the impairment*?
- *What level of control is required to ameliorate the water quality exceedences*?
- *Do control technologies actually exist in order to achieve the level of reclamation necessary*?
- *Does the cost of achieving the water quality improvement bear a reasonable relationship to the benefits associated with attaining the water use*?

Depending upon the result of this evaluation, Objectives could be recommended for the site under consideration such that the existing (i.e., "impaired") water quality could be accepted.

Surface Water Quality Objectives developed through the Watershed Classification Process can be modified to better reflect the unique circumstances within areas under consideration. Modifications can be undertaken, for instance, to account for the lower or greater sensitivity of resident aquatic species, the altered availability or toxicity of a pollutant (due to chemical or physical properties of the receiving water) or other reasons, if reasonable scientific evidence, professional judgement, or other evidence was available to support such modifications.

Draft objectives for ammonia which consider the potential for site-specific or regional-specific objectives are under public review (Williamson 2001).

*Federal*

The federal approach to aquatic use protection, expressed most clearly in the 1991 publication by the Canadian Council of Ministers of the Environment (CCME), is similarly based on site-specific investigations to identify factors influencing use attainment and to develop a practical basis for developing feasible and effective protective criteria. The CCME approach calls for a logical examination of all factors relevant to the protection of a given water use. Documentation describing the approach acknowledges need for a science-based and locally-appropriate foundation for the setting of protective water-quality criteria. The CCME approach is highly congruent with the approach advanced by Manitoba Environment (now Manitoba Conservation). These processes are outlined in Figure 2-1.

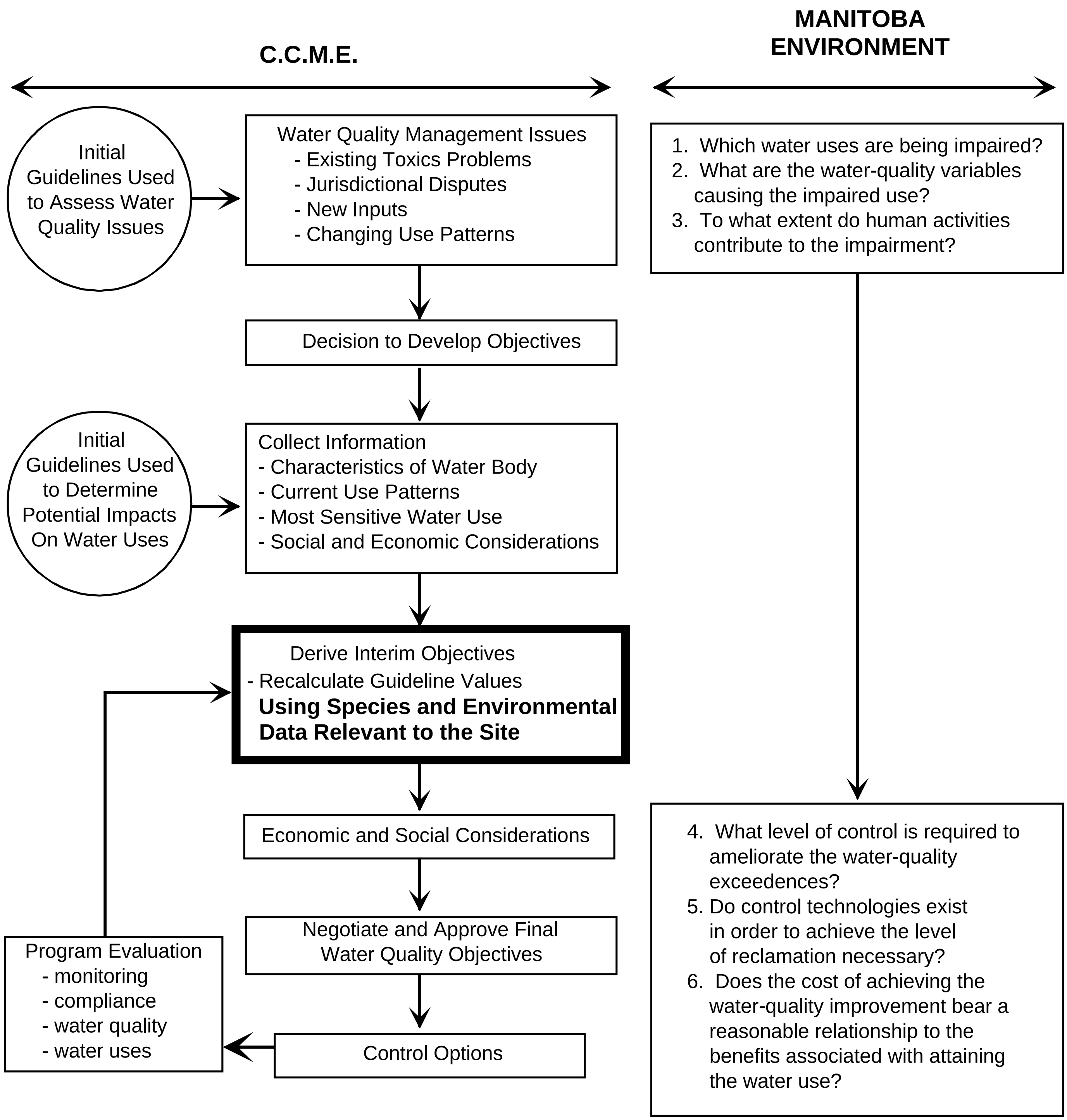
Other agencies (U.S. EPA, British Columbia) have developed approaches to developing site-specific criteria, as discussed in Section 5.

## 2.3 THE ROLE OF PROTECTIVE CRITERIA

Water-quality criteria are guidelines developed to assist in the protection of water quality. They are also often used to develop prescriptive limits in treatment plant licences for discharges to the surface waters in receiving environments. Clauses in such licences thus prescribe performance objectives for the effluent discharged from a treatment plant which, in turn, assist the treatment plant designers and operators in the development of a treatment system designed and operated to limit the impact on the aquatic life in the receiving stream. If the treatment system operates within prescribed licence terms and conditions, it can be expected that there will be only limited (or no) significant impacts to the aquatic ecosystems and in the event of an impact, that it will persist only for short durations, at infrequent intervals. If impacts are of short enough duration and do not occur frequently, then it can be expected that the ecosystem as a whole will not be significantly affected over the long term.

In specific terms, a particular constituent (such as ammonia) is often given a chronic criterion concentration value in an effluent-discharge license under the expectation that it will be exceeded for a 30-day duration only once in three years, on average. Even if this chronic concentration value is exceeded, 95% of the species should remain unaffected. Of the 5% of

# RELATIONSHIP OF C.C.M.E. AND MANITOBA APPROACHES TO DERIVATION OF WATER QUALITY GUIDELINES




*Sources: CCME 1999; Chapter 4, Fig.2*
*Williamson, 1990*

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Figure 2-1

the species within the local species assemblage which may be affected, only a limited percentage of the individuals within that species (20% or $EC_{20}$) should show sufficient effects of exposure as to be measurable (EPA 1999). Because it is difficult to measure subtle effects such as tissue damage or changes in growth in adult members of these species, early life-cycle stages are generally tested and their mortality becomes a surrogate for determining the potential for more subtle effects for ammonia. The intent of this study was therefore to provide credible new scientific data to assist in the development of numerically based protective criteria by outlining:

- locally appropriate chronic and acute concentration values capable of serving as protective criteria;
- the duration of an averaging period for which these criteria should be applied; and
- the frequency for which the criteria concentration should be applied.

Since protective criteria are generally applied within a region, more specific guidance on how to apply a specific criterion to a specific waterbody is usually addressed at the licencing application stage. However, because this document is intended to give guidance on the development of site-specific criteria, a more direct assessment of how to apply a criterion, specifically in the development of effluent limits for each of the treatment plants in the study area, is included. In this way, specific guidance can be developed for decisions on:

- the period of river-flow record to use in the development of protective criteria; and
- how to assess the variability of ammonia concentrations expected in the effluent of each treatment plant.

Resolution of these uncertainties should ensure that the wastewater-treatment systems ultimately developed will meet the intended goal of the criteria, which is to preclude significant long-term damage to the aquatic ecosystem.

## 2.4 OUTLINE OF REPORT

The organization of this document is as follows:

- **Section 3** reviews the history of regulatory criteria for ammonia over the last two decades;
- **Section 4** is an overview of the various workstreams and the technical memoranda produced for those workstreams. The workstreams are assessed in terms of their response to a number of key questions that were used as a test for the various activities in the individual workstreams to confirm their relevance to the main objective and their relative value in contributing to these objectives;
- **Section 5** is the review of various guidance given to develop site-specific criteria as well as a case history of site-specific criteria development on the Red River;
- **Section 6** provides the rationale for development of potential criteria on the Red and Assiniboine rivers;
- **Section 7** describes the application of the site-specific criteria to the Winnipeg situation including potential treatment process requirements;
- **Section 8** is an integrated risk assessment which utilizes information collected directly for the study and development of a risk for specific key and sensitive species found in the Red and Assiniboine rivers;
- **Section 9** reviews other information which can be used to assist in decision-making for the protection of aquatic life in the Red and Assiniboine rivers;
- **Section 10** reviews potential costs of meeting alternative criteria;
- **Section 11** is a discussion of the conservative assumptions used in the development and application of criteria on the Red and Assiniboine rivers; and
- **Section 12** is the Conclusions and Recommendations for the study.

# 3. HISTORY OF REGULATION OF AMMONIA IN SURFACE WATER

The regulation of ammonia in the U.S.A. and Canada with respect to surface water quality has been complex, dynamic, and is still evolving. This history provides an important background to this study.

Over the past two decades there have been six main positions for ammonia regulation proposed in Canada and the U.S.:

1) U.S. EPA 1985 – a statistically based goal to protect 95% of genera at criterion concentration. Criteria developed for both acute and chronic ammonia exposure.
2) Manitoba Surface Water Quality Objectives 1988 – based upon a blend of regulations – an acceptance of the EPA's chronic critierion only, adding an adjusted lower limit of un-ionized ammonia.
3) 1998 EPA Update – based upon newly developed equations using joint toxicity (both total and un-ionized ammonia). Acute toxicity data remained unchanged from 1985, however new chronic toxicity data was integrated.
4) 1999 EPA Update – following considerable comment regarding the EPA's 1998 Update, a need was identified for temperature adjustments for invertebrate-driven criteria. In this update, chronic toxicity data includes temperature adjustment, while acute toxicity data remains the same as in 1998.
5) Manitoba Standards, Objectives and Guideline's (SOG) [Draft 2001] – Manitoba adopted both EPA 1998 and 1999. Prescribed waters with temperatures below 5ºC as "early Life Stage Absent". Allowed for site-specific or regional criteria.
6) Environment Canada PSL-2 Process – embodied the same goals as EPA (protection of 95% of species at criterion concentration). Used a Canadian species list instead of an EPA list and applied different statistical methods than EPA methodology.

The nature of these evolving regulations reveal:

- a much improved understanding of ammonia toxicity since 1984, with largest improvements in understanding chronic toxicity;

- the historically limited nature of data and methods resulted I numerical criteria lower than what was actually required to achieve aquatic protection; and
- significant uncertainty exists in application of national criteria, requiring the application of site-specific criteria. Illustrative of this need is the fact that Canadian criterion are more stringent than U.S. criterion using the same data.

In addition to these observations derived from the evolution of the various ammonia regulations, the U.S. and Canada, as well as Manitoba Conservation, recommend developing site-specific criteria.

Additional detail regarding each major regulatory stance since 1985 is provided in the following sections.

## 3.1 UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA) POSITION IN 1985

### 3.1.1 Criteria Concentration Values

One of the earliest documents to address the development of ammonia criteria for surface water was the Ambient Water Quality Criteria for Ammonia – 1984 (U.S. EPA 1985). In this document, the U.S. EPA conducted a thorough review of the existing literature available on the toxicity of ammonia to aquatic life. The study focused on developing criteria for un-ionized ammonia and found correlations between ammonia concentrations, pH and temperature to the toxicity of various species. Criteria were developed for both acute (short-term) and chronic (long-term) ammonia exposure. The study used statistical methods with the goal of developing criteria which would protect 95% of the genera of aquatic life from measurable effects at the ambient water quality criteria concentration.

<u>Acute Criteria Concentration Values</u>

In development of the acute criteria, lethal concentrations, for which there was 50% mortality in the test group ( $LC_{50}$s), under ammonia exposure, were compiled for 34 different genera and 48 different species of fish (see Table 3-1). The acute values (AV) were adjusted to a reference pH

## Table 3-1

# US EPA 1984 Ranked Genus Mean Acute Values in Un-ionized Ammonia at pH=8

| Rank | Genus Mean Acute Value (mg NH3/L) | Common Name | Species Name | Species Mean Acute Value (mg NH3/ L in Un-ionized Ammonia) | Species Mean Acute-Chronic Ratio) |
|---|---|---|---|---|---|
| 34 | 11.40 | Caddisfly | *Philarctus quaeris* | 11.40 | |
| 33 | 8.48 | Crayfish | *Orconectes immunis* | 22.80 | |
| | | Crayfish | *Orconectes nais* | 3.15 | |
| 32 | 8.00 | Beetle | *stenelmis sexlineata* | 8.00 | |
| 31 | 5.25 | Mayfly | *Ephemerella grandis* | 5.25 | |
| 30 | 4.02 | Isopod | *Asellus racovitzai* | 5.02 | |
| 29 | 3.18 | Mayfly | *Callibaetis skokianus* | 5.07 | |
| | | Mayfly | *Callibaetis sp.* | 2.00 | |
| 28 | 3.12 | Amphipod | *Crangonyx pseudogracilis* | 3.12 | |
| 27 | 2.76 | Snail | *Helisoma trivolvis* | 2.76 | |
| 26 | 2.70 | Tubificid worm | *Tubifex tubifex* | 2.70 | |
| 25 | 2.48 | Mosquitofish | *Gambusia affinis* | 2.48 | |
| 24 | 2.35 | Mottled sculpin | *Cottus bairdi* | 2.35 | |
| 23 | 2.29 | Stonefly | *Arcynopteryx parallela* | 2.29 | |
| 22 | 2.07 | Fathead minnow | *Pimephales promelas* | 2.07 | 20 |
| 21 | 1.96 | Cladoceran | *Ceriodaphnia acanthina* | 1.96 | 3.5 |
| 20 | 1.95 | Snail | *Physa gyrina* | 1.95 | |
| 19 | 1.89 | Cladoceran | *Simocephalus vetulus* | 1.89 | |
| 18 | 1.79 | White sucker | *Catostomus commersoni* | 2.15 | 30 |
| | | Mountain sucker | *Catostomus platyrhynchus* | 1.49 | |
| 17 | 1.69 | Brook trout | *Salvelinus fontinalis* | 1.69 | |
| 16 | 1.68 | White perch | *Morone americana* | 1.68 | |
| 15 | 1.63 | Channel catfish | *Ictalurus punctatus* | 1.63 | 7.5 |
| 14 | 1.49 | Cladoceran | *Daphnia magna* | 1.91 | 3.1 |
| | | Cladoceran | *Daphnia pulicaria* | 1.16 | |
| 13 | 1.48 | Guppy | *Poecilia reticulata* | 1.48 | |
| 12 | 1.40 | Flatworm | *Dendrocoelum lacteum* | 1.40 | |
| 11 | 1.34 | Smallmouth bass | *Micropterus dolomieu* | 1.92 | 5.4 |
| | | Largemouth bass | *Micropterus salmoides* | 0.93 | |
| 10 | 1.30 | Stoneroller | *Campostoma anomalum* | 1.30 | |
| 9 | 1.24 | Pink salmon | *Oncorhynchus gorbuscha* | 2.37 | 43 |
| | | Coho salmon | *Oncorhynchus kisutch* | 1.02 | |
| | | Chinook salmon | *Oncorhynchus tshawytscha* | 0.80 | |
| 8 | 1.23 | Red shiner | *Notropis lutrensis* | 2.27 | |
| | | Spotfin shiner | *Notropis spilopterus* | 0.92 | |
| | | Steelcolor shiner | *Notropis whipplei* | 0.89 | |
| 7 | 1.16 | Green sunfish | *Lepomis cyanellus* | 1.57 | 6.3 |
| | | Pumpkinseed | *Lepomis gibbosus* | 0.85 | |
| | | Bluegill | *Lepomis macrochirus* | 1.16 | 12 |
| 6 | 1.10 | Clam | *Musculium transversum* | 1.10 | |
| 5 | 1.1 | Golden trout | *Salmo aguabonit** | 1.21 | |
| | | Cutthroat trout | *Salmo clarki** | 1.20 | |
| | | Rainbow trout | *Salmo gairder** | 0.93 | 14 |
| | | Brown trout | *Salmo trutta* | 1.10 | |
| 4 | 1.07 | Walleye | *Stizostedion vitreum* | 1.07 | |
| 3 | 0.88 | Orangethroat darter | *Etheostoma spectabile* | 0.88 | |
| 2 | 0.76 | Golden shiner | *Notemigonus crysoleucas* | 0.76 | |
| 1 | 0.56 | Mountain whitefish | *Prosopium williamsoni* | 0.56 | |

**Source EPA 1985**
* Species Re-classified in 1998 document

(8.0) and temperature (20ºC). Using statistical analysis, the fifth percentile final acute value (FAV) for the ammonia criteria was selected (protecting 95% of species at that value). However, the fifth percentile which was estimated as 0.70 mg-$NH_3$/L, was not used. The mature rainbow trout (>1.0 kg body weight) acute value was found to be more sensitive and the average value of these data was used (0.52 mg-$NH_3$/L) as the FAV. This average value was based on 5 of the roughly 110 rainbow trout tests used to calculate the average (0.93 mg $NH_3$/L) presented in Table 3-1. The EPA also gave guidance that this criterion concentration should be lower during periods of low pH (less than 7.7) and lower temperatures (less than 20°C). This lowering of the criterion concentration value during low temperatures and pH was to account for studies on some species which indicated a joint toxic effect between ammonium ($NH_4$+) and the un-ionized ammonia ($NH_3$). The fraction of total ammonia in the un-ionized ammonia form decreases for low temperature and pH, therefore the acute criteria value (in terms of $NH_3$) was decreased with pH and temperature to account for the increasing ammonium toxicity.

Chronic Criteria Concentration Values

In the development of a chronic toxicity criterion for ammonia, the EPA found there were limited chronic ammonia toxicity studies. Chronic response to ammonia included tissue damage and less growth which are difficult to monitor. The EPA reviewed studies on species which had both acute and chronic toxicity testing data. The ratio of the acute value divided by the chronic value was then determined for 10 species. On average, this acute chronic ratio (ACR) was about 16. To develop a chronic criterion, the EPA used the acute criterion and divided by the ACR. The value 0.8 mg/L was used as the "acute value base" for chronic criteria and is proposed by the EPA (1985). The explanation given by the EPA is as follows:

> "*To generate an FCV, an acute-chronic ratio must be applied to the appropriate FAV. The $FAV_{ref}$ used for the 1-hour average criteria (0.52) is not appropriate since it is based on a life stage that is more sensitive than those used in generating the acute-chronic ratios. Furthermore, the fifth percentile $FAV_{ref}$ computed earlier (0.70) is also not appropriate, since [sic] it is strongly influenced by the mountain whitefish data which is [sic] also for a sensitive life stage. To compensate for this problem, the mountain whitefish $SMAV_{ref}$ was increased by 40%, from 0.56 to 0.78, based on the difference between the acute sensitivities of rainbow trout of the size of the tested whitefish and the size used for*

*generating the acute-chronic ratio. The $FAV_{ref}$ was then recomputed to be 0.80, which will be used in subsequent calculations of the FCVs*."

This explanation is difficult to understand and was not verified. The extra effort of trying to verify these calculations did not seem appropriate because this 1985 criteria again was superseded by the 1998-1999 chronic criteria.

The un-ionized ammonia criterion varied with both temperature and pH. As with the acute values, the chronic criterion (as $NH_3$) also decreases with temperature and pH. The acute and chronic criteria concentrations for a range of pH and temperatures, for waters without salmonids or other cold water species, are shown on Table 3-2 (equations are shown in Appendix A). The EPA appear to use a "safety factor" by dividing by 2. No explanation of this safety factor is given. In addition, although the toxicity test was performed for 96 hours, the averaging period for which they are to be applied was for only 1 hour. This adds an additional "safety factor".

The EPA also gave guidance that the national criteria are subject to modification, if appropriate, to reflect local conditions. One method provided in the site-specific criteria guidelines (U.S. Environmental Protection Agency 1992) for such modification is to base certain calculations only on those species that occur in the waterbody of interest. They also indicated that there was a paucity of data available on chronic effects of ammonia on aquatic life and, recognizing that significant public works expenditures could result from applying the criteria, issued this cautionary note:

> *"There is limited data on the effect of temperature on chronic toxicity. EPA will be conducting additional research on the effects of temperature on ammonia toxicity in order to fill perceived data gaps. Because of this uncertainty, additional site-specific information should be developed before these criteria are used in waste allocation modelling. For example, the chronic criteria tabulated for sites lacking salmonids are less certain at temperatures much below 20ºC than those tabulated at temperatures near 20ºC. Where treatment levels need to meet these criteria, below 20ºC may be substantial, use of site-specific criteria is strongly suggested. Development of such criteria should be based on site-specific toxicity tests."* (U.S. EPA 1985)

## TABLE 3-2
# EPA NATIONAL CRITERIA FOR AMMONIA -1985

### A) Acute Un-ionized Ammonia Criteria Concentrations in mg-NH3 /L

| | | Temperature in ºC | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 5 | 10 | 15 | 20 | 25 | 30 |
| pH | 6.50 | 0.0091 | 0.0129 | 0.0182 | 0.026 | 0.036 | 0.036 | 0.036 |
| | 6.75 | 0.0149 | 0.0211 | 0.0298 | 0.042 | 0.059 | 0.059 | 0.059 |
| | 7.00 | 0.023 | 0.033 | 0.046 | 0.066 | 0.093 | 0.093 | 0.093 |
| | 7.25 | 0.034 | 0.048 | 0.068 | 0.095 | 0.135 | 0.135 | 0.135 |
| | 7.50 | 0.045 | 0.064 | 0.091 | 0.128 | 0.181 | 0.181 | 0.181 |
| | 7.75 | 0.056 | 0.080 | 0.113 | 0.159 | 0.22 | 0.22 | 0.22 |
| | 8.00 | 0.065 | 0.092 | 0.130 | 0.184 | 0.26 | 0.26 | 0.26 |
| | 8.25 | 0.065 | 0.092 | 0.130 | 0.184 | 0.26 | 0.26 | 0.26 |
| | 8.50 | 0.065 | 0.092 | 0.130 | 0.184 | 0.26 | 0.26 | 0.26 |
| | 8.75 | 0.065 | 0.092 | 0.130 | 0.184 | 0.26 | 0.26 | 0.26 |
| | 9.00 | 0.065 | 0.092 | 0.130 | 0.184 | 0.26 | 0.26 | 0.26 |
| | 9.25 | 0.065 | 0.092 | 0.130 | 0.184 | 0.26 | 0.26 | 0.26 |

### B) Chronic Un-ionized Ammonia Criteria Concentrations in mg-NH3 /L

| | | Temperature in ºC | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 5 | 10 | 15 | 20 | 25 | 30 |
| pH | 6.50 | 0.0007 | 0.0009 | 0.0013 | 0.0019 | 0.0026 | 0.0026 | 0.0026 |
| | 6.75 | 0.0012 | 0.0017 | 0.0023 | 0.0033 | 0.0047 | 0.0047 | 0.0047 |
| | 7.00 | 0.0021 | 0.0029 | 0.0042 | 0.0059 | 0.0083 | 0.0083 | 0.0083 |
| | 7.25 | 0.0037 | 0.0052 | 0.0074 | 0.0105 | 0.0148 | 0.0148 | 0.0148 |
| | 7.50 | 0.0066 | 0.0093 | 0.0132 | 0.0186 | 0.026 | 0.026 | 0.026 |
| | 7.75 | 0.0109 | 0.0153 | 0.022 | 0.031 | 0.043 | 0.043 | 0.043 |
| | 8.00 | 0.0125 | 0.0177 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 8.25 | 0.0126 | 0.0177 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 8.50 | 0.0126 | 0.0177 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 8.75 | 0.0126 | 0.0177 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 9.00 | 0.0126 | 0.0177 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 9.25 | 0.0126 | 0.0177 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |

Source: US EPA 1985

### 3.1.2 Frequency of Exceedences

In 1985, the EPA recommended an allowable frequency of exceedence of once in three years on average (U.S. EPA 1985). This was based on the Agency's best scientific judgement on the average amount of time it would take an unstressed system to recover from a pollution event in which exposure to ammonia exceeds the criteria. (No specific studies were cited to support this judgement). However, they did state "*the resilience of ecosystems and their ability to recover differ greatly, however, a site-specific criteria may be established if adequate justification is provided*" (U.S. EPA 1985).

### 3.1.3 Duration of Exposure

In 1985, EPA recommended an averaging period for applying the criteria continuous concentration (CCC) as 4 days. (This is likely due to the fact that most testing had been done using 96 hr [4 day] exposures). However, the EPA acknowledged that the CCC averaging period may be longer when it can be demonstrated there is low effluent quality variability. They recommended that a 30-day averaging period would be acceptable if there was low effluent quality variability because the magnitude and duration of exceedences above the CCC would be sufficiently limited. (A definition of the level of variability which would be acceptable was not given.)

### 3.1.4 Application of Criteria

The EPA recommended that the use of the criteria in designing waste treatment facilities requires the selection of an appropriate waste load allocation (WLA) model. "*Dynamic models are preferred for the application of these criteria*" (U.S. EPA 1985). At that time dynamic models had limited applications and limited data for which to calibrate them. Therefore, the EPA gave guidance that one could use steady-state models. For the acute criteria, the EPA recommended the interim use of $1Q_5$ [1]or $1Q_{10}$ for criteria maximum concentration design flow to be used with the steady-state model to define the WLA. For application of the chronic criteria,

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[1] $1Q_5$ means the lowest one day average flow in 5 years.

they recommended the $7Q_5$ and $7Q_{10}$ for the design flow and steady-state models for unstressed and stressed system respectively (i.e., for a system which is not considered stressed, $7Q_5$ could be used, while a stressed system would require the use of a $7Q_{10}$).

## 3.2 MANITOBA SURFACE WATER QUALITY OBJECTIVES (MSWQO) - 1988

### 3.2.1 Chronic Criteria Concentrations

In 1988, Manitoba developed Water Quality Objectives for Surface Water (MSWQO) which included new criteria for ammonia (Williamson 1988). These criteria were adapted from the EPA's 1985 Ambient Water Quality Criteria for Ammonia, and were developed for chronic exposures only. Two modifications were made in order to better apply the adapted EPA criteria to Manitoba's situation. The first one was to simplify the criteria so that only one set would be needed for the whole province. (EPA had developed two criteria; (1) for salmonids and other cold water species present, and (2) for salmonids or other cold water species absent). The two criteria are only different above 15ºC in which the criterion without cold-water species was allowed to be higher. Manitoba believed that one broader range of criterion, 0.0007 to 0.050 mg/L un-ionized ammonia, would afford reasonable protection to Manitoba's cool and cold-water organisms. This assumption was predicated on the fact that temperature preference would limit distribution or range of these species within Manitoba to waters that generally remain below 15ºC. Therefore, they felt it would be administratively redundant to adopt a range of criteria to protect aquatic organisms from unacceptable adverse affects from exposure to un-ionized ammonia, when the actual water temperature would preclude these sensitive cold water species from inhabiting waters with such ambient temperature characteristics.

The second modification was done since it was felt that the extrapolation of the criteria by EPA to lower temperatures was done based on best scientific judgement with a limited chronic toxicity database at those low temperatures. Manitoba modified the EPA criteria by assessing 22 chronic-criteria tests and selecting the lower limit at the $5^{th}$ percentile of cumulative probability for data done on all tests (i.e., not species or genera). This modification raised the lower limit from 0.0007 to 0.0184 mg/L of un-ionized ammonia. This modification was not as dramatic as it first appears when applied to the Red and Assiniboine rivers. For the pH range common in the Red and Assiniboine rivers (7.75 to 8.75), the increase in the lower limit was only from 0.0109 to 0.0184 mg/L and 0.0126 to 0.184 mg/L un-ionized ammonia. Table 3-3 illustrates the current Manitoba chronic ammonia objective (1988). Figure 3-1 illustrates the differences between the U.S. EPA and Manitoba objectives for two sets of pH 8.0 and 8.5. As can be seen from this figure, the modifications only apply to colder water conditions under 5ºC.

### 3.2.2 Frequency of Exceedence, Duration, and Application

The Manitoba objectives simplified the EPA guidance on frequency and duration of exposure by linking the criteria to a steady-state application. Manitoba recommended the use of the $7Q_{10}$ (recommended only for stressed systems by the EPA) for all waterbodies in Manitoba. No comment was given to the use of dynamic model (which was preferred by the EPA). This may have been for practical reasons in that there was limited experience in dynamic modelling within Manitoba at that time.

No direct guidance on extent (length) of a mixing zone was given; however, the generalized width of a mixing zone was given as 25% of the stream width, i.e., exceedences of the chronic criteria were allowed within the first 25% of the river width as long as the acute criteria was not exceeded within the mixing zone.

## 3.3 U.S. EPA 1998 UPDATE

### 3.3.1 Criteria Concentrations

In 1998, the U.S. EPA published an update of Ambient Water Quality Criteria for Ammonia (U.S. EPA 1998). The EPA decided to conduct this update in response to considerable criticism on the criteria and since there was significant new information available to assess the acute and chronic criteria. The document did the following:

- presented an overview of ammonia toxicology in order to provide the background needed to explain the revisions to freshwater ammonia criteria;

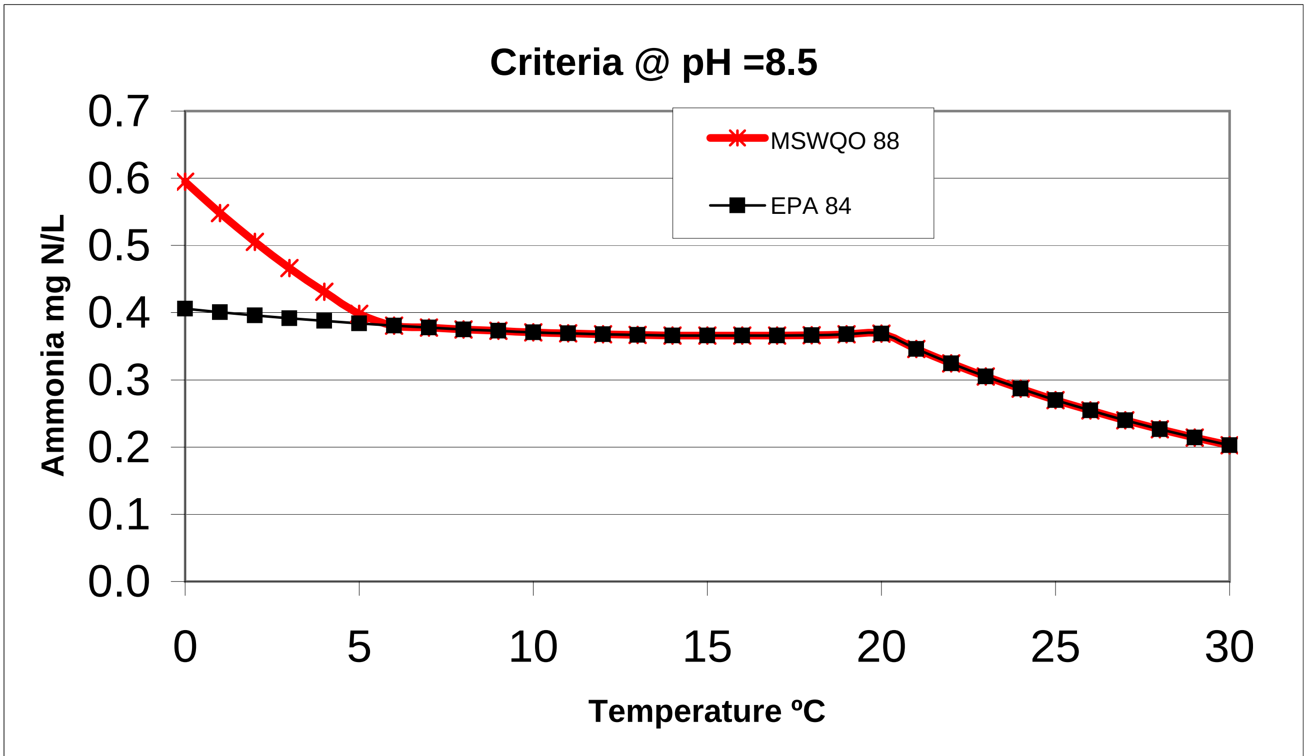
**TABLE 3-3**

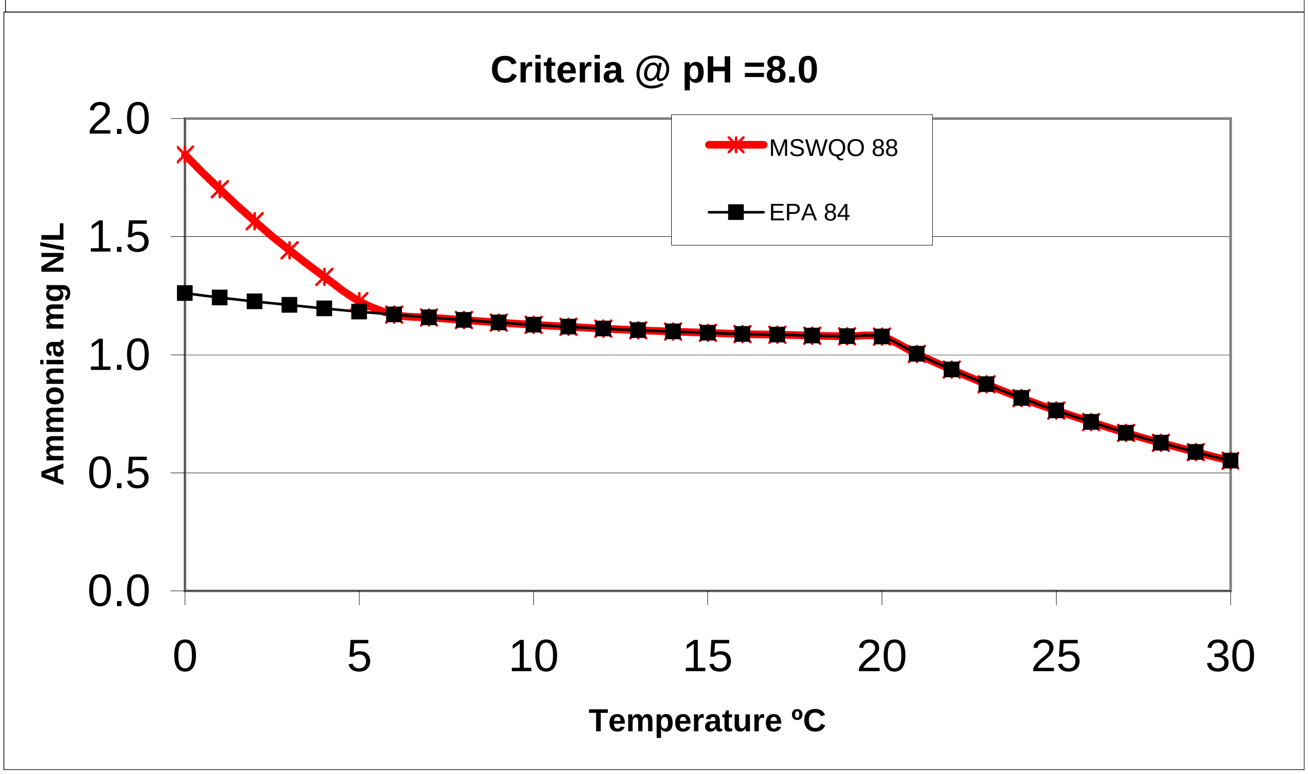
## MANITOBA SURFACE WATER QUALITY OBJECTIVES FOR AMMONIA -1985

### Chronic Un-ionized Ammonia Criteria Concentrations in mg-NH3 /L

| | | Temperature in ºC | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 5 | 10 | 15 | 20 | 25 | 30 |
| pH | 6.5 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 |
| | 6.75 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 |
| | 7 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 |
| | 7.25 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 | 0.0184 |
| | 7.5 | 0.0184 | 0.0184 | 0.0184 | 0.0186 | 0.026 | 0.026 | 0.026 |
| | 7.75 | 0.0184 | 0.0184 | 0.022 | 0.031 | 0.043 | 0.043 | 0.043 |
| | 8 | 0.0184 | 0.0184 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 8.25 | 0.0184 | 0.0184 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 8.5 | 0.0184 | 0.0184 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 8.75 | 0.0184 | 0.0184 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 9 | 0.0184 | 0.0184 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |
| | 9.25 | 0.0184 | 0.0184 | 0.025 | 0.035 | 0.050 | 0.050 | 0.050 |

Source: Williamson 1988




**Comparison of EPA 1984 and Manitoba 1988 Chronic Ammonia Criteria**

Figure 3-1

- revised the equations used in the 1984/85 ammonia criteria document to address the temperature- and pH-dependence of ammonia toxicity in freshwater to take into account newer data, better models, and improved statistical methods;
- derived new acute criteria using these revised equations and the acute toxicity data in the 1984/85 criteria document;
- evaluated new and old chronic toxicity data to derive a new chronic criteria concentration; and
- discussed cold water conditions, the chronic continuous criteria concentration (CCC), the averaging period, water effects ratios.

Concentrations of un-ionized ammonia and total ammonia were given in terms of nitrogen (mg-N/L) since most permit limits for ammonia are expressed in terms of nitrogen.

This document initially developed a model to explain the joint toxicity effect of un-ionized ammonia and the ammonium ion. The model assumed:

- ammonium ion and un-ionized ammonia jointly determine toxicity; and
- un-ionized ammonia is roughly 100 times more toxic than the ammonia ion.

The EPA developed models to describe the joint toxicity variation with variation of pH as presented below.

$$AV = (AV\ pH = 8.0)\left(\frac{0.0489}{1+10^{7.204-pH}} + \frac{6.95}{1+10^{pH-7.204}}\right) \quad \text{(Eq 1)}$$

$$CV = (CV\ pH = 8.0)\left(\frac{0.0676}{1+10^{7.688-pH}} + \frac{2.91}{1+10^{pH-7.688}}\right) \quad \text{(Eq 2)}$$

Where:

AV = acute values

CV = chronic values

The EPA also discussed temperature variations and toxicity. Generally they concluded that the toxicity effect of **total ammonia** was unchanged on average by varying temperature. With this discussion, they decided to formulate and present the ammonia toxicity as total ammonia rather than un-ionized ammonia as done in 1985.

### 3.3.1.1 Acute Criterion Concentrations

In developing an **acute toxicity** criterion or criterion maximum concentration (CMC), the same dataset that was used in 1984 was used again. This dataset includes sensitive species, such as salmonids and mountain white fish, which would not normally be found in the Red River. Although initially analyzing $LC_{50}$s and $EC_{50}$s from 34 sets of genera (48 species) to provide protection for 95% of the genera, EPA lowered this to below the derived value (14.32 mg-N/L) in order to account for the sensitivity of adult rainbow trout. The value selected was 11.23 mg-N/L (at pH = 8.0) which could then be adjusted according to the pH variance model for actual values (equation (1) above). The actual criterion selected was the species mean acute value (SMAV) for rainbow trout arbitrarily divided by two to give 5.6 mg-N/L at a pH = 8.0 (The “safety factor” of 2 was selected by judgement.) This criterion could be pH adjusted in order to protect regions with salmonids. If the four genera in the family salmonida are excluded, the fifth percentile genus mean acute value (GMAC) with salmonids absent is 16.8 mg-N/L and the CMC was selected by dividing by 2. The CMC equals 8.4 mg-N/L at pH 8. Using the joint toxicity model (Equation 1) **with salmonids** the following equation was used:

$$CMC = \left( \frac{0.275}{1+10^{7.204-pH}} + \frac{39.0}{1+10^{pH-7.204}} \right) \quad \text{(Eq 3)}$$

The criteria **without salmonids** is as follows:

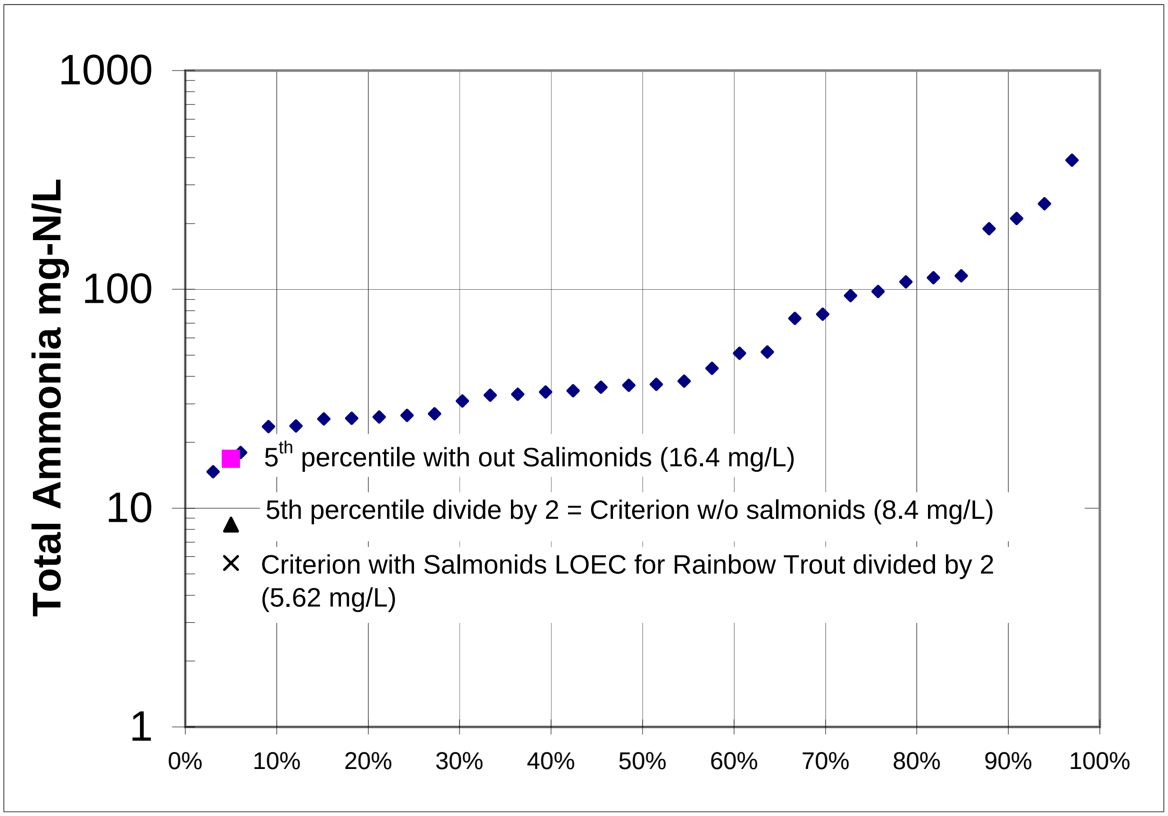
$$CMC = \left( \frac{0.411}{1+10^{7.204-pH}} + \frac{58.4}{1+10^{pH-7.204}} \right) \quad \text{(Eq 4)}$$

A table of the species used to develop the CMC is shown in Table 3-4 and an illustration of the ranked mean genus acute values (GMAVs) on an associated cumulative probability graph with an acute criteria (5%) is shown in Figure 3-2. The tests used are essentially the same as in 1985 expressed in terms of total ammonia. Some species have been reclassified as different genera.

## Table 3-4
# US EPA 1998 Ranked Genus Mean Acute Values in Total Ammonia at pH=8

| Rank | Genus Mean Acute Value (mg N/L) | Common Name | Species Name | Species Mean Acute Value (mg N/L in Total Ammonia) |
|---|---|---|---|---|
| 34 | 388.80 | Caddisfly | *Philarctus quaeris* | 388.80 |
| 33 | 246.00 | Crayfish | *Orconectes immunis* | 1466.00 |
| | | Crayfish | *Orconectes nais* | 41.27 |
| 32 | 210.60 | Isopod | *Asellus racovitzai* | 210.60 |
| 31 | 189.20 | Mayfly | *Ephemerella grandis* | 189.20 |
| 30 | 115.50 | Mayfly | *Callibaetis skokianus* | 175.60 |
| | | Mayfly | *Callibaetis sp.* | 75.93 |
| 29 | 113.20 | Beetle | *stenelmis sexlineata* | 113.20 |
| 28 | 108.30 | Amphipod | *Crangonyx pseudogracilis* | 108.30 |
| 27 | 97.82 | Tubificid worm | *Tubifex tubifex* | 97.82 |
| 26 | 93.52 | Snail | *Helisoma trivolvis* | 93.52 |
| 25 | 77.10 | Stonefly | *Arcynopteryx parallela* | 77.10 |
| 24 | 73.69 | Snail | *Physa gyrina* | 73.69 |
| 23 | 51.73 | Mottled sculpin | *Cottus bairdi* | 51.73 |
| 22 | 51.06 | Mosquitofish | *Gambusia affinis* | 51.06 |
| 21 | 43.55 | Fathead minnow | *Pimephales promelas* | 43.55 |
| 20 | 38.11 | White sucker, | *Catostomus commersoni* | 45.82 |
| | | Mountain sucker | *Catostomus platyrhynchus* | 31.70 |
| 19 | 36.82 | Cladoceran | *Daphnia magna* | 35.76 |
| | | Cladoceran | *Daphnia pulicaria* | 37.91 |
| 18 | 36.39 | Brook trout | *Salvelinus fontinalis* | 36.39 |
| 17 | 35.65 | Clam | *Musculium transversum* | 35.65 |
| 16 | 34.44 | Channel catfish | *Ictalurus punctatus* | 34.44 |
| 15 | 33.99 | Cladoceran | *Simocephalus vetulus* | 33.99 |
| 14 | 33.14 | Guppy | *Poecilia reticulata* | 33.14 |
| 13 | 32.82 | Flatworm | *Dendrocoelum lacteum* | 32.82 |
| 12 | 30.89 | White perch | *Morone americana* | 30.89 |
| 11 | 26.97 | Stoneroller | *Campostoma anomalum* | 26.97 |
| 10 | 26.50 | Smallmouth bass | *Micropterus dolomieu* | 35.07 |
| | | Largemouth bass | *Micropterus salmoides* | 20.03 |
| 9 | 26.11 | Walleye | *Stizostedion vitreum* | 26.11 |
| 8 | 25.78 | Cladoceran | *Ceriodaphnia acanthina* | 25.78 |
| 7 | 25.60 | Red shiner | *Notropis lutrensis* | 45.65 |
| | | Spotfin shiner | *Notropis spilopterus* | 19.51 |
| | | Steelcolor shiner | *Notropis whipplei* | 18.83 |
| 6 | 23.74 | Brown trout | *Salmo trutta* | 23.74 |
| 5 | 23.61 | Green sunfish | *Lepomis cyanellus* | 30.27 |
| | | Pumpkinseed | *Lepomis gibbosus* | 18.05 |
| | | Bluegill | *Lepomis macrochirus* | 24.09 |
| 4 | 21.95 | Golden trout | *Oncorhynchus aquabonit** | 26.10 |
| | | Cutthroat trout | *Oncorhynchus clarki** | 25.80 |
| | | Pink salmon | *Oncorhynchus gorbuscha* | 42.07 |
| | | Coho salmon | *Oncorhynchus kisutch* | 20.26 |
| | | Rainbow trout | *Oncorhynchus mykis** | 11.23 |
| | | Chinook salmon | *Oncorhynchus tshawytscha* | 17.34 |
| 3 | 17.96 | Orangethroat darter | *Etheostoma spectabile* | 17.96 |
| 2 | 14.67 | Golden shiner | *Notemigonus crysoleucas* | 14.67 |
| 1 | 12.11 | Mountain whitefish | *Prosopium williamsoni* | 12.11 |

**Source: USEPA 1998**
* Species Re-classified in 1998 document




**Source : EPA 1998**

**Ranked Genus Mean Acute Values (GMAVs) with Acute Ammonia Criterion**

Figure 3-2

#### 3.3.1.2 Chronic Criterion Concentrations

In developing the **chronic criterion** or the "criterion continuous concentration" (CCC), the EPA reviewed both new and old chronic toxicity tests. (There were concerns about the veracity of the old dataset.) The tests were screened in order to meet their protocols and then an $EC_{20}$ or $LC_{20}$ was selected for each test where:

- $EC_{20}$ - Effective Concentration. The concentration of a stressor that is estimated to be effective in producing a biological response, other than mortality, in 20% of organisms over a specific time interval; and

- $LC_{20}$ - Lethal Concentration. The concentration of a stressor that is estimated to be lethal to 20% of the test organisms over a specific time interval.

Species mean chronic values (SMCV) were derived, when justified, by the data. Genus mean chronic values (GMCV) were derived, when justified, by the SMCVs. The tests used to derive the genus mean chronic values are shown in Table 3-5. The EPA adjusted each of these tests to a standard pH of 8, using their pH variance model (see Equation 2).

**Nine genus mean chronic values (GMCV) were used to develop the criterion**. In order to calculate the fifth percentile EPA used the lowest four genera of the nine selected. They assumed a total *n = 10* because a GMC for insects was assumed to be greater than 4.7 mg-N/L (total ammonia was used in all cases). The calculations for doing this were checked for this report and are shown in Appendix B. Figure 3-3 shows the cumulative probability plot with the genus mean chronic values (GMCVs) and the chronic criteria. The value selected for the CCC was 1.27 mg-N/L at pH = 8.0. A criteria was then presented in the following equation as a function of pH:

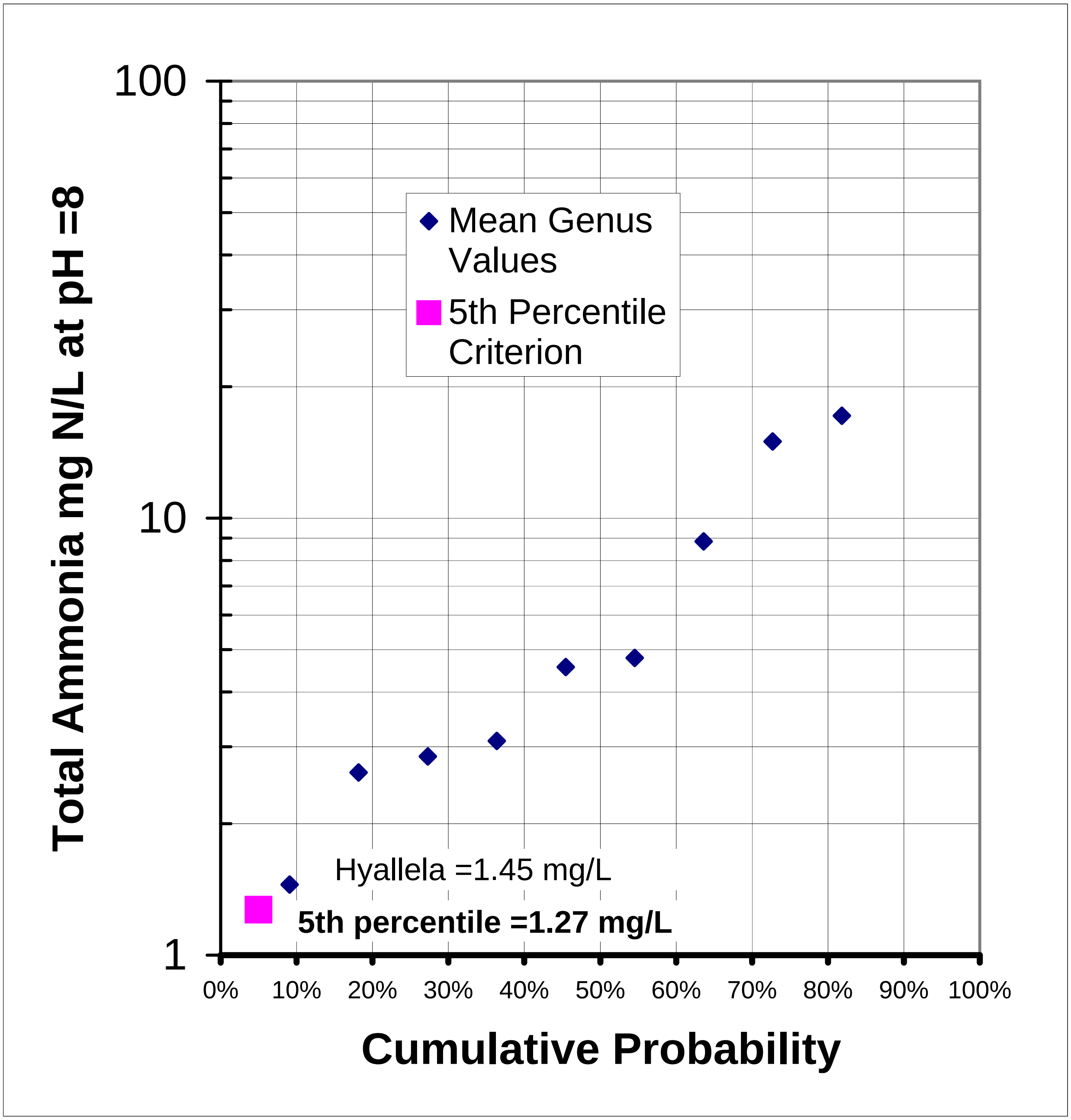
$$CCC = \left( \frac{0.0858}{1+10^{7.688-pH}} + \frac{3.70}{1+10^{pH\ 7.688}} \right) \quad \text{(Eq 5)}$$

This new equation is shown on Figure 3-4 and compared to the plots for the previous criteria at pH = 8.0 and pH = 8.5. The criterion is developed assuming no temperature variation in the

**TABLE 3-5**

## Summary of Tests used by US EPA in 1998 Ammonia for Development of GMCV

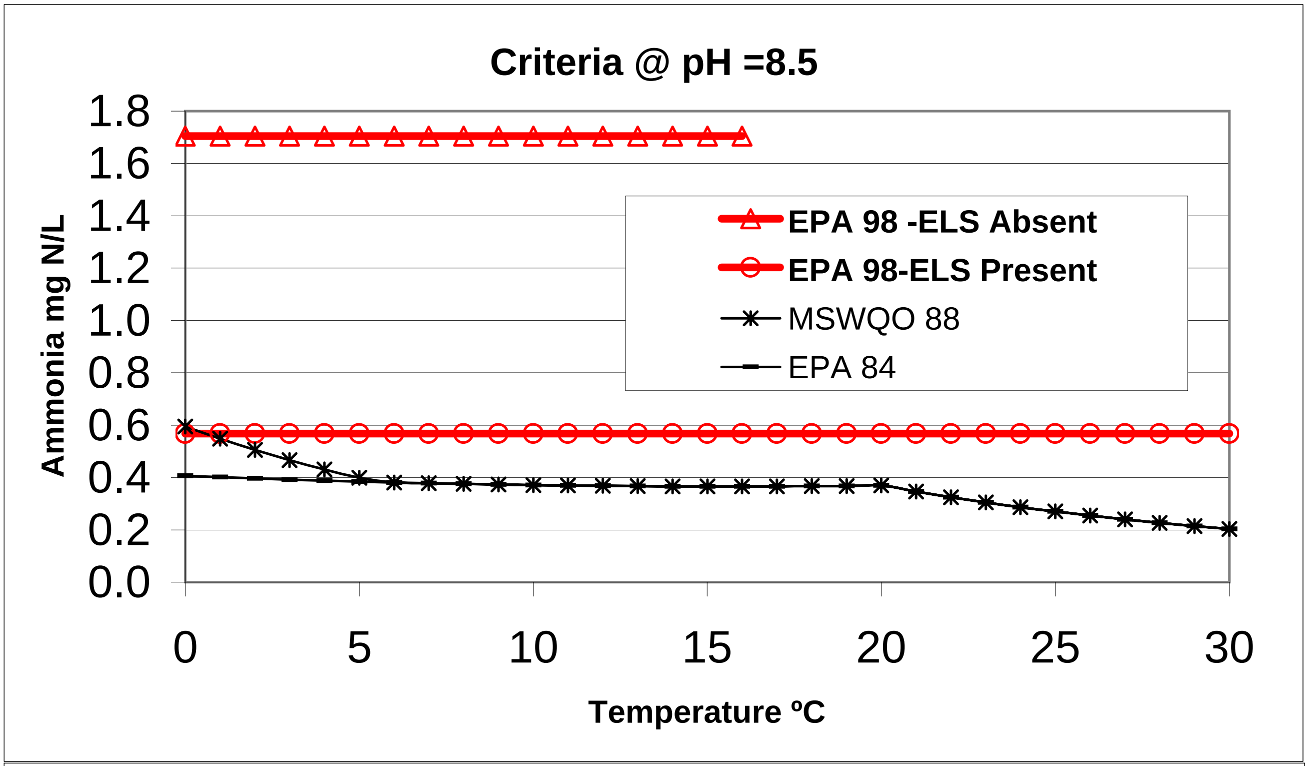
| | | | Actual | | | With EPA 1998 pH Adjustment Model | | |
|---|---|---|---|---|---|---|---|---|
| ***Common Name*** | ***Species Name*** | ***Reference*** | ***Actual Temperature*** | ***Actual pH*** | **Total Ammonia N-mg/L @ pH& T of Test** | **Total Ammonia N-mg/L @ pH=8 & T= 25 ºC** | ***Species Mean Chronic Value (Geometric Mean mg N/L)*** | ***Genus Mean Chronic Value (Geometric Mean mg N/L)*** |
| WhiteSucker | *Catostomus commersoni* | Reinbold and Pescitelli 1982a | 18.6 | 8.32 | 2.9 | 4.79 | 4.79 | 4.79 |
| Ceriodapnia acanthina | *Ceriodapnia acanthina* | Mount 1982 | 24.5 | 7.15 | 44.9 | 19.77 | 19.77 | 14.97 |
| Ceriodapnia dubia | *Ceriodapnia dubia* | Willingham 1987 | 26 | 8.57 | 5.8 | 14.60 | 13.03 | |
| | | Mimmo et al. 1989 | 25 | 7.8 | 15.2 | 11.63 | | |
| Daphnia | *Daphnia magna* | Gesich et al. 1985 | 19.8 | 8.45 | 7.37 | 15.14 | 17.14 | 17.14 |
| | | Reinbold and Pescitelli 1982a | 20.1 | 7.92 | 21.7 | 19.41 | | |
| Scud | *Hyalella Azteca* | Borgmann 1994 | 25 | 7.94 | 1.580 | 1.45 | 1.45 | 1.45 |
| Catfish | *Icatalus punctatus* | Swigert and Spacie 1983 | 26.9 | 7.76 | 11.5 | 8.39 | 8.85 | 8.85 |
| | | Reinbold and Pescitelli 1982a | 25.8 | 7.8 | 12.2 | 9.34 | | |
| Green Sunfish | *Lepomis cyanellus* | Reinbold and Pescitelli 1982a | 25.4 | 8.16 | 5.84 | 7.44 | 6.03 | 2.85 |
| | | McCormick et al. 1984 | 22 | 7.9 | 5.61 | 4.88 | | |
| Bluegill Sunfish | *Lepomis macrochirus* | Smith et al. 1984 | 22.5 | 7.76 | 1.85 | 1.35 | 1.35 | |
| Smallmouth Bass | *Micropterus dolomieu* | Broderius et al. 1985 | 22.3 | 6.6 | 9.61 | 3.57 | 4.56 | 4.56 |
| | | Broderius et al. 1985 | 22.3 | 7.25 | 8.62 | 4.01 | | |
| | | Broderius et al. 1985 | 22.3 | 7.83 | 8.18 | 6.50 | | |
| | | Broderius et al. 1985 | 22.3 | 8.68 | 1.54 | 4.66 | | |
| Fingernail Clams | *Musculium transverum* | Anderson et al. 1978 | 23.5 | 8.15 | 5.82 | 7.30 | 2.62 | 2.62 |
| | | Sparks and Sandusky 1981 | 21.8 | 7.8 | 1.23 | 0.94 | | |
| Fathead Minnow | *Pimephales promelas* | Thurston et al. 1986 | 24.2 | 8 | 1.97 | 1.97 | 3.09 | 3.09 |
| | | Swigert and Spacie 1983 | 25.1 | 7.82 | 3.73 | 2.93 | | |
| | | Mayes et al. 1986 | 24.8 | 8 | 5.12 | 5.12 | | |

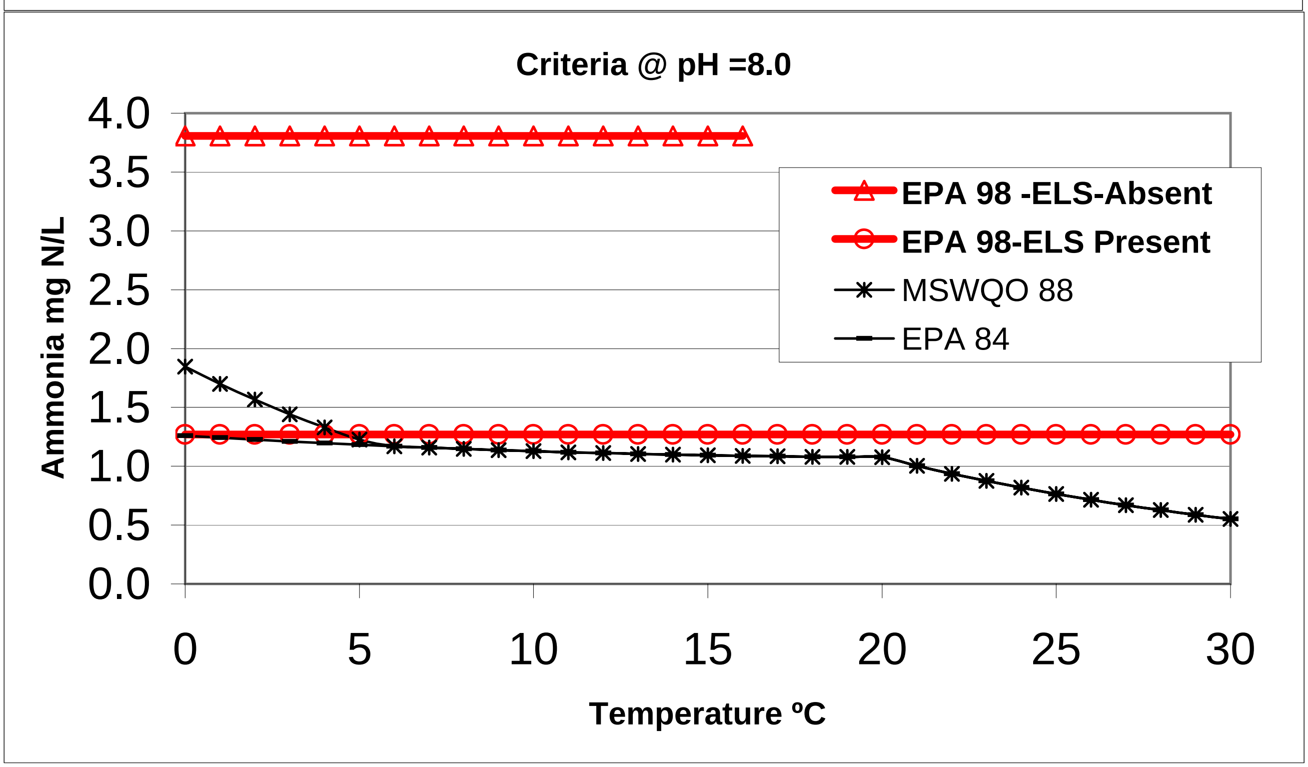



Source: EPA 1998

**Ranked Genus Mean Chronic Values (GMCVs) with1998 Chronic Ammonia Criterion**

Figure 3-3




**Note: ELS = Early Life Stages**

**Comparison of EPA 1998, EPA 1984 and Manitoba 1988 Chronic Ammonia Criteria**

Figure 3-4

criterion for total ammonia. (Note: This assumes that un-ionized ammonia criteria decrease with temperature).

### 3.3.2 Duration

The averaging period for the criterion was given as 30 days. This is a change from the EPA 1985 positions, where 4-day averages were recommended. In addition, there is a stipulation that the 4-day average not exceed the CCC by more than 2.5 times.

### 3.3.3 Allowable Frequency of Exceedence

No additional guidance was given on allowable frequency of exceedence which still remains at once in three years on average. The document referred to EPA 1991 (technical support document for water-quality based control; EPA 1991) for more discussion on frequency of exceedence and waste load allocation (WLA; i.e., model application). Section 6.6 also discusses the development of an allowable frequency by the EPA.

### 3.3.4 Cold Weather Conditions

The EPA recognized that meeting criteria under cold water conditions is difficult due to the inherent inefficiencies of biological treatment during cold weather. They also recognized that most tests were done on early life stages of fish which may not be present during the cold weather periods of the year. Therefore, they suggested that cold weather CCCs may be justified. However, highly site-specific information should be provided. In the transmittal letter, the EPA stated that if the state can make findings that identify the time of year when no sensitive life stages of any fish species are ordinarily present in numbers affecting sustainability of populations, the criteria applicable to that time of year may be set as much as **three-fold higher** than the criteria applicable to the remainder of the year. Baseline and subsequent biological modelling in accordance with currently available EPA guidance should be conducted to ensure that the integrity of the aquatic community being protected is maintained when these higher cold-season concentrations are allowed.

### 3.3.5 Water Effects Ratios

The EPA reviewed various studies on water effects ratios (WER) (see Section 4) and found a large range of potential water effects ratios for ammonia. The range of water effects ratios varied from 0.5 to about 3. Many of the studies they reviewed do not seem to be relevant as they compared water effects ratios between laboratory water and well water. It is unlikely that well water is representative of river water. The study which appears to be most relevant to the local situation was done at Moorhead, Minnesota by Camp Dresser McKee (1997) which reported a WER of 2.5 in fathead minnows, for the Red River at Moorhead. More discussion on the Moorhead study is given later in this document (Section 5.3).

## 3.4 EPA 1999 UPDATE

Following the 1998 EPA update, there was considerable comment provided to the EPA from scientific and industry perspectives. For response to these comments, the reader is referred to EPA 1999b. ("Response to comments on 1998 update of ambient water-quality criteria for ammonia"). The 1999 update (EPA 1999a) differs from the 1998 update primarily in the handling of temperature-dependency for the chronic criteria (or CCC) and therefore the formulation of the CCC and the expression of the national criteria.

### 3.4.1 Changes to Chronic Criteria Concentrations

The 1999 CCC was very dependent on toxicity tests done on the invertebrate *Hyalella*, which was tested at 25°C . The responses to the 1998 criteria indicated the need for some kind of temperature adjustment to account for apparent sensitivity of toxicity effects of total ammonia on invertebrates when temperature varied. The EPA determined that there may be reason to allow for temperature adjustment of the criteria for invertebrates of the chronic values (CVs) for invertebrates only. With the temperature dependence added, the expression for the chronic criterion is as follows for **early life stages present**:

$$CCC = \left(\frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}}\right) MIN(2.85, 1.45 \cdot 10^{0.028(25-T)}) \quad \text{(Eq 6)}$$

When fish early life stages are absent:

$$CCC = \left(\frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}}\right) 1.45 \cdot 10^{0.028(25-MAX(t,7)} \quad \text{(Eq 7)}$$

The base CCC was selected as 1.24 mg-N to 25°C and pH 8 (or 0.854 x 1.45). For deriving this, the same dataset as in 1998 was used with the exception that the SMCV invertebrates *Hyalella* and *Musculium* as well as *Cyriodaphnia* were adjusted to account for a new temperature model (see Table 3-6 for a summary of data used). The cumulative probability graph which is very similar to 1998 is shown in Figure 3-5. A comparison of the 1999 criterion to the previous 1985 EPA criterion and the MSWQO – 1988 criterion is presented in Figure 3-6. The current criterion is 2 to 3 times higher than the 1985 criteria depending upon the temperature.

### 3.4.2 Guidelines for Derivation of Site-Specific Criteria

In the summary of the 1999 criterion, the EPA again stated what methods may be used to derive site-specific criteria for ammonia:

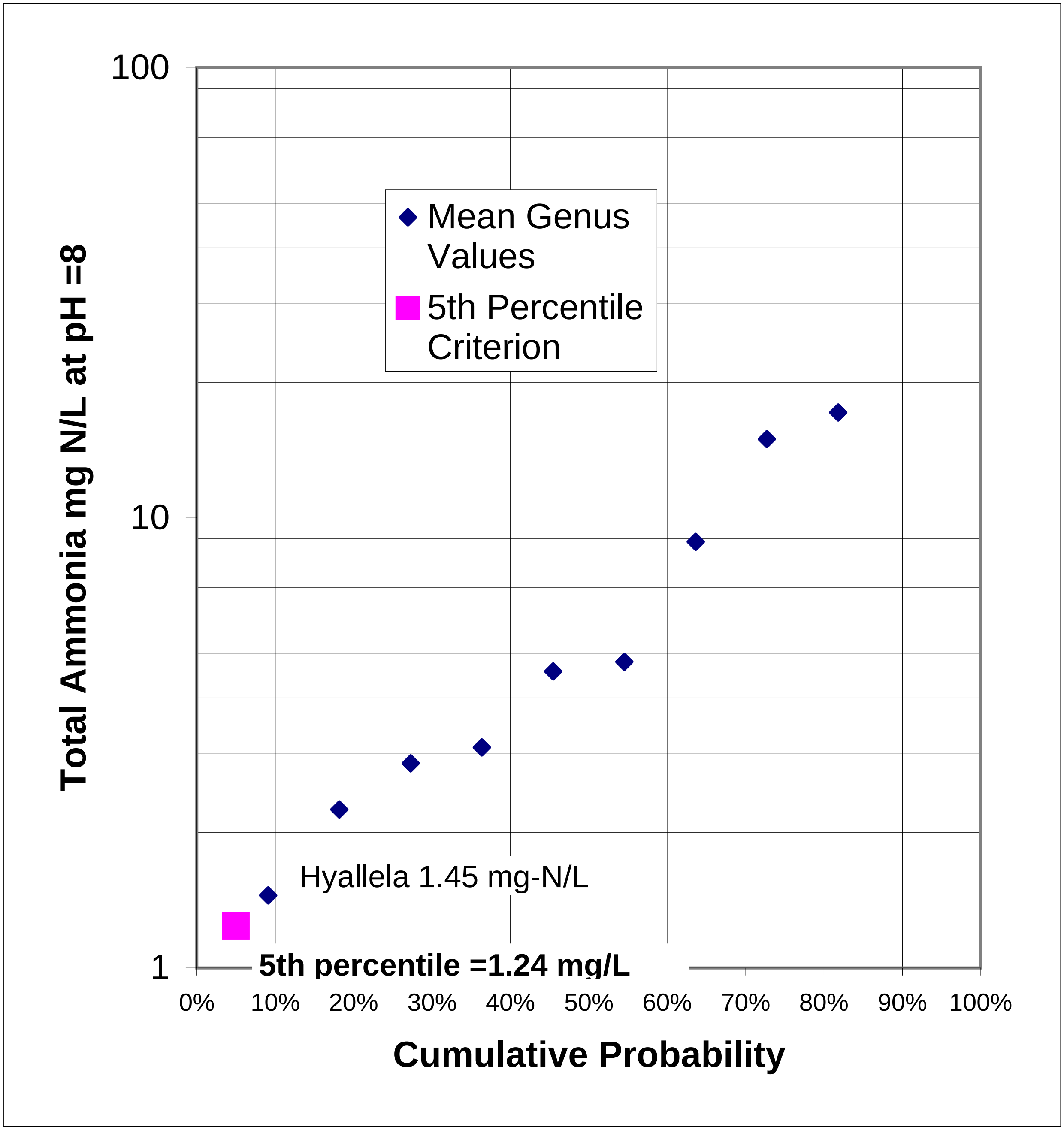
- the recalculation procedure;
- the water-effects ratio procedure; and
- the resident species procedure.

These methods are discussed later in Section 5.0 of this document.

TABLE 3-6

## Summary of Tests used by US EPA in 1999 Ammonia for Development of GMCV

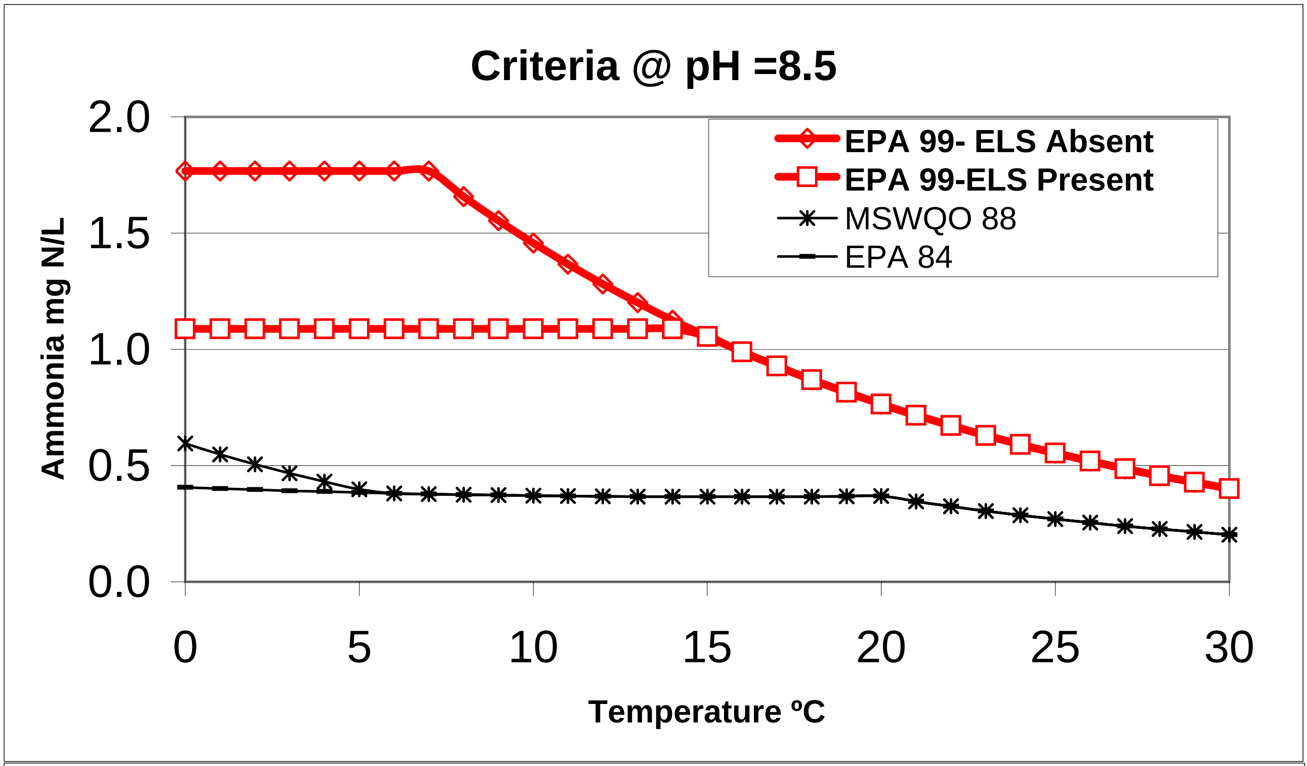
| Common Name | Species Name | Reference | Actual Temperature | Actual pH | Total Ammonia N-mg/L @ pH& T of Test | Total Ammonia N-mg/L @ pH=8 & T= 25 ºC | Species Mean Chronic Value (Geometric Mean mg N/L) | Genus Mean Chronic Value (Geometric Mean mg N/L) |
|---|---|---|---|---|---|---|---|---|
| | | | Actual | | | With EPA 1999 pH and Temperature Adjustment Models | | |
| WhiteSucker | *Catostomus commersoni* | Reinbold and Pescitelli 1982a | 18.6 | 8.32 | 2.9 | 4.79 | 4.79 | **4.79** |
| Ceriodapnia acanthina | *Ceriodapnia acanthina* | Mount 1982 | 24.5 | 7.15 | 44.9 | 19.14 | 19.14 | **15.14** |
| Ceriodapnia dubia | *Ceriodapnia dubia* | Willingham 1987 | 26 | 8.57 | 5.8 | 15.57 | 13.46 | |
| | | Mimmo et al. 1989 | 25 | 7.8 | 15.2 | 11.63 | | |
| Daphnia | *Daphnia magna* | Gesich et al. 1985 | 19.8 | 8.45 | 7.37 | 10.83 | 12.38 | **12.38** |
| | | Reinbold and Pescitelli 1982a | 20.1 | 7.92 | 21.7 | 14.15 | | |
| Scud | *Hyalella Azteca* | Borgmann 1994 | 25 | 7.94 | 1.580 | 1.45 | 1.45 | **1.45** |
| Catfish | *Icatalus punctatus* | Swigert and Spacie 1983 | 26.9 | 7.76 | 11.5 | 8.39 | 8.85 | **8.85** |
| | | Reinbold and Pescitelli 1982a | 25.8 | 7.8 | 12.2 | 9.34 | | |
| Green Sunfish | *Lepomis cyanellus* | Reinbold and Pescitelli 1982a | 25.4 | 8.16 | 5.84 | 7.44 | 6.03 | **2.85** |
| | | McCormick et al. 1984 | 22 | 7.9 | 5.61 | 4.88 | | |
| Bluegill Sunfish | *Lepomis macrochirus* | Smith et al. 1984 | 22.5 | 7.76 | 1.85 | 1.35 | 1.35 | |
| Smallmouth Bass | *Micropterus dolomieu* | Broderius et al. 1985 | 22.3 | 6.6 | 9.61 | 3.57 | 4.56 | **4.56** |
| | | Broderius et al. 1985 | 22.3 | 7.25 | 8.62 | 4.01 | | |
| | | Broderius et al. 1985 | 22.3 | 7.83 | 8.18 | 6.50 | | |
| | | Broderius et al. 1985 | 22.3 | 8.68 | 1.54 | 4.66 | | |
| Fingernail Clams | *Musculium transverum* | Anderson et al. 1978 | 23.5 | 8.15 | 5.82 | 6.63 | 2.25 | **2.25** |
| | | Sparks and Sandusky 1981 | 21.8 | 7.8 | 1.23 | 0.77 | | |
| Fathead Minnow | *Pimephales promelas* | Thurston et al. 1986 | 24.2 | 8 | 1.97 | 1.97 | 3.09 | **3.09** |
| | | Swigert and Spacie 1983 | 25.1 | 7.82 | 3.73 | 2.93 | | |
| | | Mayes et al. 1986 | 24.8 | 8 | 5.12 | 5.12 | | |

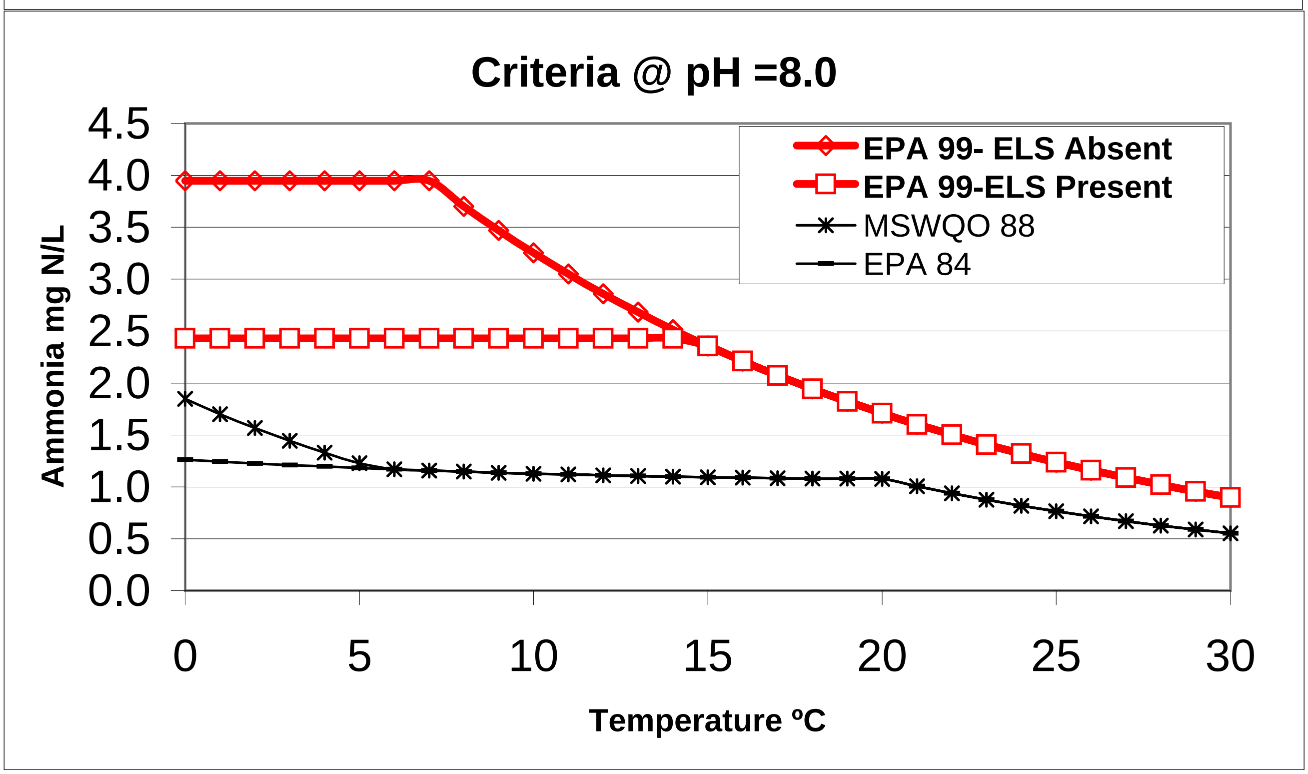



Source: EPA 1999

**Ranked Genus Mean Chronic Values (GMCVs) with 1999 Chronic Ammonia Criterion**

Figure 3-5




**Note: ELS = Early Life Stages**

**Comparison of EPA 1999 ,EPA 1984 and Manitoba 1988**
**Chronic Ammonia Criteria**
Figure 3-6

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## 3.5 MANITOBA WATER QUALITY STANDARDS OBJECTIVES AND GUIDELINES (MWQSOG) – DRAFT 2001

Manitoba has recently proposed revised Manitoba Water Quality Standards Objectives and Guidelines (MWQSOGs; Manitoba Conservation 2001) which are currently under public review in the second stage of the review process. With respect to ammonia, Manitoba has adopted the 1999 EPA Guidelines without modification and has provided tables to assist in their application. A copy of the tables for ammonia are shown in Appendix C, and summarized in Table 3-7. The objectives can be summarized as follows for Cool Water Aquatic Life and Wildlife:

- for water temperature of greater than 5°C (or early life stages present), the objectives use the EPA equation for early life stage present (see Eq 7);
    - the averaging duration of 30 days is given;
    - the allowable exceedence frequency is not more than once each 3 years on average;
    - the average flow over a 30 day period with a return period of 3 years or $30Q_3$; or
    - a 30-day, 3-year or $30Q_{10}$ design flow is recommended.
- for a 4-day averaging period, the criterion value which must be met is 2.5 x Eq 7, again consistent with EPA average. The recommended design flow for steady-state modelling assessment is a 4-day, 3-year flow or $7Q_{10}$[2].
- for acute toxicity, the EPA criterion without salmonids (Equation 4) is recommended using a 1-hour averaging duration for not more than once in 3 years on average. The design flow recommended would be a biological 1-day, 3-year flow or a $1Q_{10}$.
- for new life stages absent or less than 5°C, the EPA early life stage absent equation (Equation 7) is recommended.
- 30-day averaging periods with allowable frequency of not more than once every three years on average is recommended and for steady-state modelling waste load allocations, a 30-day, 3-year biological flow or $30Q_{10}$ is recommended.
- 2.5 times the chronic criterion should not be exceeded, using a 4-day averaging period, more than once every 3 years on average, or for steady-state modeling waste load

[2] Minimum flows are of interest in examining water quality issues. Minimum flow and the frequency of its occurrence is designated as “aQb” where “a” is the number of days used in the average and “b” is the interval in years over which the average occurs. $7Q_{10}$ is the minimum average 7-day flow that occurs once every 10 years.

**TABLE 3-7**

**SUMMARY OF MANITOBA OBJECTIVES FOR AMMONIA**

| CRITERIA CONCENTRATION | DESIGN FLOW | AVERAGING PERIOD |
|---|---|---|
| Acute – use Equation 4 | 1Q10 | 1 day |
| Chronic (x 2.5)<br>- for T > 5?C use Equation 6<br>- for T < 5?C use Equation 7 | 7Q10 | 4 days |
| Chronic<br>- for T > 5?C use Equation 6<br>- for T < 5?C use Equation 7 | 30Q10 | 30 days |

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$$CMC = \left( \frac{0.411}{1+10^{7.204-pH}} + \frac{58.4}{1+10^{pH-7.204}} \right) \qquad \text{(Eq 4)}$$

$$CCC = \left( \frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}} \right) MIN\left(2.85,\ 1.45 \cdot 10^{0.028(25-T)}\right) \qquad \text{(Eq 6)}$$

$$CCC = \left( \frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}} \right) 1.45 \cdot 10^{0.028(25-MAX(t,7))} \qquad \text{(Eq 7)}$$

allocation, a 4-day, 3-year biological flow or $7Q_{10}$ is recommended. The acute toxicity is the same for early life stages absent or present.

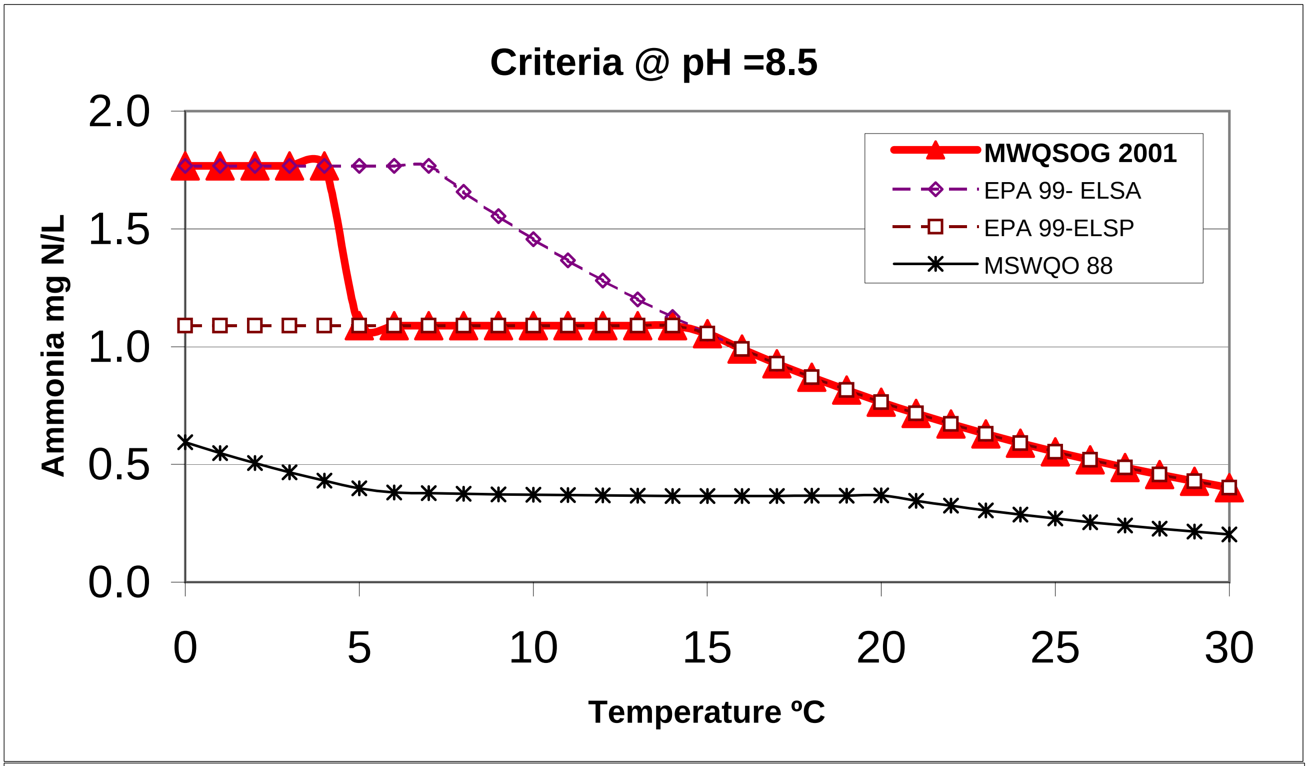
- for cold water aquatic life the same criterion is used, with the exception that the acute toxicity is determined by the EPA criterion without salmonids.

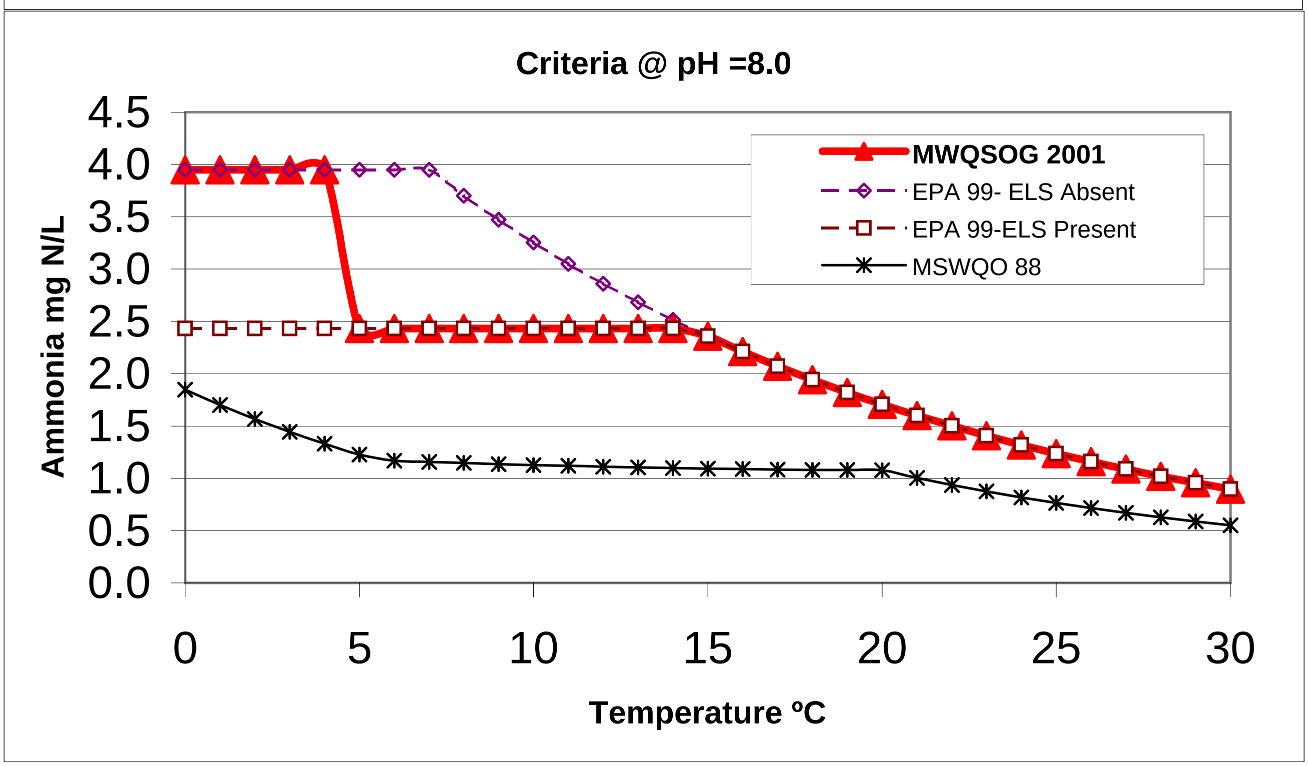
A comparison of Manitoba Ammonia Objectives in 1988 and 2001, as well as U.S. EPA 99 Objectives are shown at two pH values and varying temperature (Figure 3-7). In the proposed Manitoba Objectives, the cool water objectives are most appropriate for the Red and Assiniboine rivers location. However, the Manitoba Objectives allow that "at some sites, further modification of Tier 2 – Water Quality Objectives may be required to better account for site-specific or regional-specific factors such as the greater or lesser sensitivity of resident species, unique influence of the receiving water on toxicity, or other factors".

Manitoba's draft objective states that scientific protocols have been developed by a number of agencies (e.g., U.S. EPA 1994; McDonald 1997; CCME 1999) to guide the modification of water quality objectives at specific sites. These or other scientifically rigorous methods should be followed when site-specific or regional-specific modifications are made.

## 3.6 ENVIRONMENT CANADA PRIORITY SUBSTANCE LIST (PSL) 2000

Environment Canada has released a draft report for public comment on ammonia in surface waters titled "Priority Substance List Assessment Report - Ammonia in the Aquatic Environment" (Environment Canada-Health Canada May 2000). Pursuant to the *Canadian Environmental Protection Act* (CEPA), the Environment Canada study focussed on determining a criterion based on the toxicity of un-ionized ammonia (as opposed to the EPA methodology of the joint toxicity between total and un-ionized ammonia). Both acute and chronic criteria were developed based on the principle that 95% of the species should be protected at a criterion concentration (this is congruent with the EPA philosophy).




**Comparison of Manitoba 2001, EPA 1999 and Manitoba 1988 Chronic Ammonia Criteria**

Figure 3-7

### 3.6.1 Acute Toxicity Criteria

To determine the acute toxicity criteria, Environment Canada reviewed Table 1 of the U.S. EPA (1985) Water Quality Criteria document to select fish found in Canada and calculate the species mean $LC_{50}$ in terms of un-ionized ammonia. The species-acute mean un-ionized ammonia concentrations are the geometric means of the $LC_{50}$s reported for the respective species in the U.S. EPA (1985) document. Similarly the invertebrate-acute lethality studies also referenced in U.S. EPA 1985 were screened. Both fish and invertebrate tests are presented in Table 3-8. In order to calculate a criterion which will be protective of 95% of the species in Canada, an analysis was done by plotting the cumulative species response as a proportion of the entire aquatic community (fish and invertebrates) against concentrations of un-ionized ammonia (see Figure 3-8). Methodology developed by the Water Environment Research Foundation (WERF 1996) was used to compute this community-risk at the 5% level (i.e., 95% of the species protected). (**This methodology differs from the EPA methodology in that the entire dataset influences the criteria while in the EPA methodology only the lowest four genera are used to compute the 5% community risk value**). For an acute toxicity criterion for Canada-wide assessment, a value of 0.29 mg-$NH_3$/L as un-ionized ammonia was selected.

### 3.6.2 Chronic Criteria

The chronic toxicity for species which could be found in Canada was developed by reviewing the literature and calculating the lethal concentration at which a 20% effect was exhibited ($LC_{20}$ or $EC_{20}$). The concentrations at which this lethal or sub-lethal effect occurs are summarized for each species in Table 3-9. Using the aquatic community risk model (WERF 1996), the logistic regression of the community response analysis indicated that at un-ionized concentrations above 41 $\mu$g-$NH_3$/L, the most sensitive 5% of the species in the exposed community would be expected to exhibit 20% reduction in growth or reproduction. The range of prediction limits on this chronic criteria are fairly large (19 to 63 $\mu$g-$NH_3$/L; see Figure 3-9).

Environment Canada recognized that the ecological risk criterion developed is not specific to any waterbody in Canada. They stated that "*to conduct a site-specific assessment, a presence-absence review of each species would be required for each waterbody under study. This approach was beyond the scope of this assessment*." **The criterion selected included**

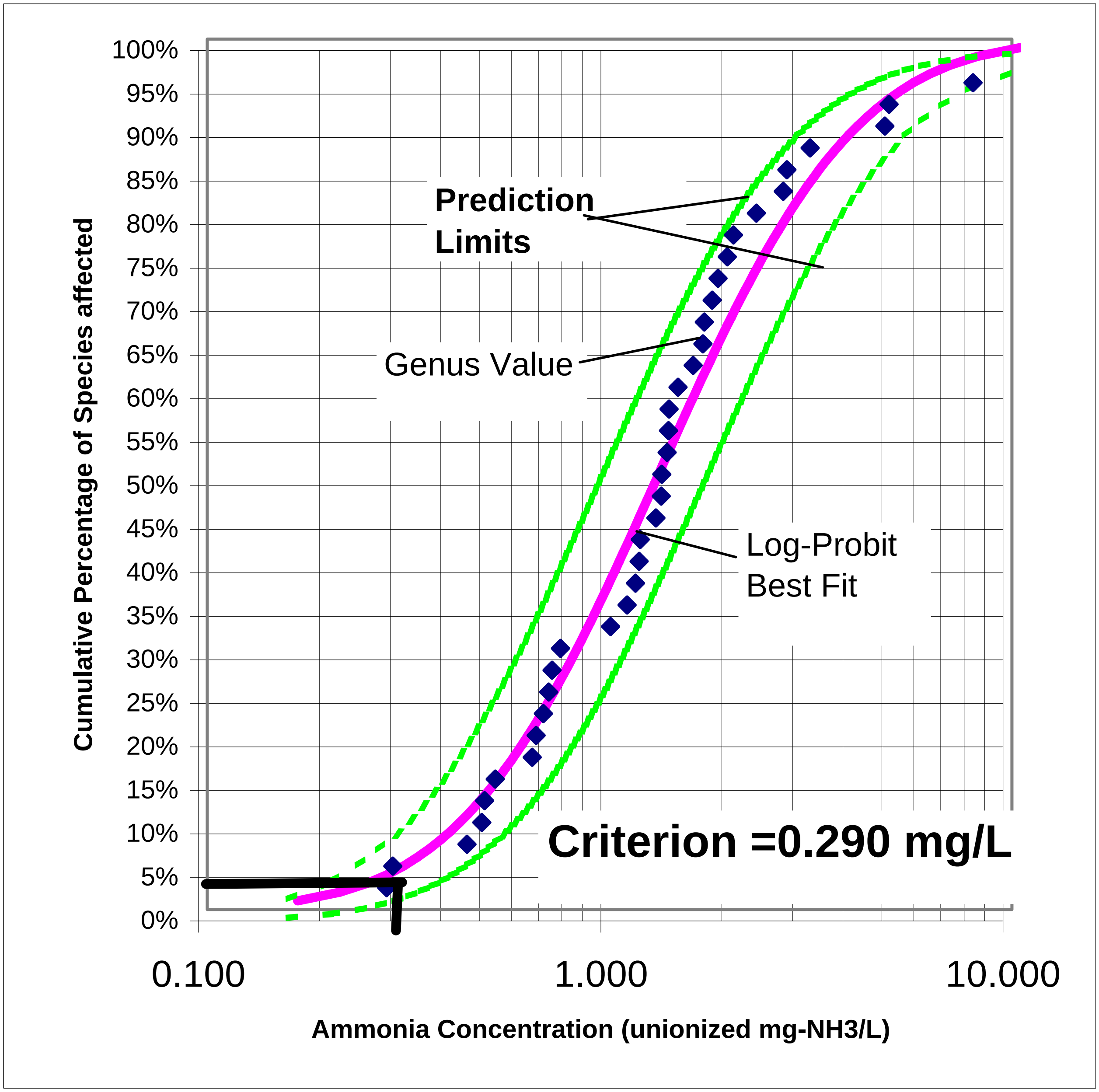
Table 3-8

## Fish and Invertebrate Tests used by Environment Canada in Acute PL-2 Criteria Development

| Species name | Common name | LC50 (mg NH3/L) | No. of studies |
|---|---|---|---|
| *Arcynopteryx parallela* | Stonefly | 2.030 | 2 |
| *Asellus racovitzai* | Isopod | 4.950 | 1 |
| *Callibaetis skokianus* | Mayfly | 4.829 | 3 |
| *Callibaetis sp.* | Mayfly | 1.800 | 1 |
| *Catostomus commersoni* | White sucker | 1.349 | 7 |
| *Catostomus platyrhynchus* | Mountain sucker | 0.685 | 3 |
| *Comostoma anonalum* | Stoneroller | 1.720 | 1 |
| *Cottus bairdi* | Mottled sculpin | 1.390 | 1 |
| *Crangonyx pseudogracilis* | Amphipod | 2.316 | 5 |
| *Cyprinella spiloptera* | Spotfin shiner | 1.479 | 3 |
| *Daphnia magna* | Daphnid | 1.613 | 12 |
| *Daphnia pulicaria* | Cladoceran | 1.160 | 1 |
| *Dendrocoelum lacteum* | Flatworm | 1.400 | 1 |
| *Helisoma trivolvis* | Snail | 2.760 | 1 |
| *Ictalurus punctatus* | Channel catfish | 1.707 | 14 |
| *Lepomis cyanellus* | Green sunfish | 1.860 | 6 |
| *Lepomis gibbosus* | Pumpkinseed | 0.489 | 4 |
| *Lepomis macrochirus* | Bluegill | 1.406 | 15 |
| *Micropterus dolomieu* | Smallmouth bass | 1.105 | 4 |
| *Micropterus salmoides* | Largemouth bass | 1.304 | 2 |
| *Morone americana* | White perch | 0.279 | 2 |
| *Musculium transversum* | Fingernail clam | 1.191 | 3 |
| *Notemigonus crysoleucas* | Golden shiner | 0.720 | 1 |
| *Oncorhynchus aguabonita* | Golden trout | 0.755 | 1 |
| *Oncorhynchus clarki* | Cutthroat trout | 0.642 | 4 |
| *Oncorhynchus kisutch* | Coho salmon | 0.520 | 8 |
| *Oncorhynchus mykiss* | Rainbow trout | 0.481 | 112 |
| *Oncorhynchus tshawytscha* | Chinook salmon | 0.442 | 3 |
| *Orconectes nais* | Crayfish | 3.150 | 1 |
| *Philarctus quaeris* | Caddisfly | 10.200 | 1 |
| *Physa gyrina* | Snail | 1.961 | 5 |
| *Pimephales promelas* | Fathead minnow | 1.344 | 45 |
| *Prosopium williamsoni* | Mountain whitefish | 0.289 | 3 |
| *Salmo trutta* | Brown trout | 0.657 | 3 |
| *Salvelinus fontinalis* | Brook trout | 1.005 | 2 |
| *Simocephalus vetulus* | Cladoceran | 1.185 | 2 |
| *Stenelmis sexilneata* | Beetle | 8.000 | 1 |
| *Stizostedion vitreum* | Walleye | 0.706 | 4 |
| *Tubifex tubifex* | Tubificid | 2.700 | 1 |

Source: Envinronment Canada 2000

Note :LC50 is the geometric mean when more than one study result is reported.




Source: Environment Canada 2000

**Aquatic Community Risk Model (Canada Wide) for Acute Criterion Development**

Figure 3-8

## TABLE 3-9

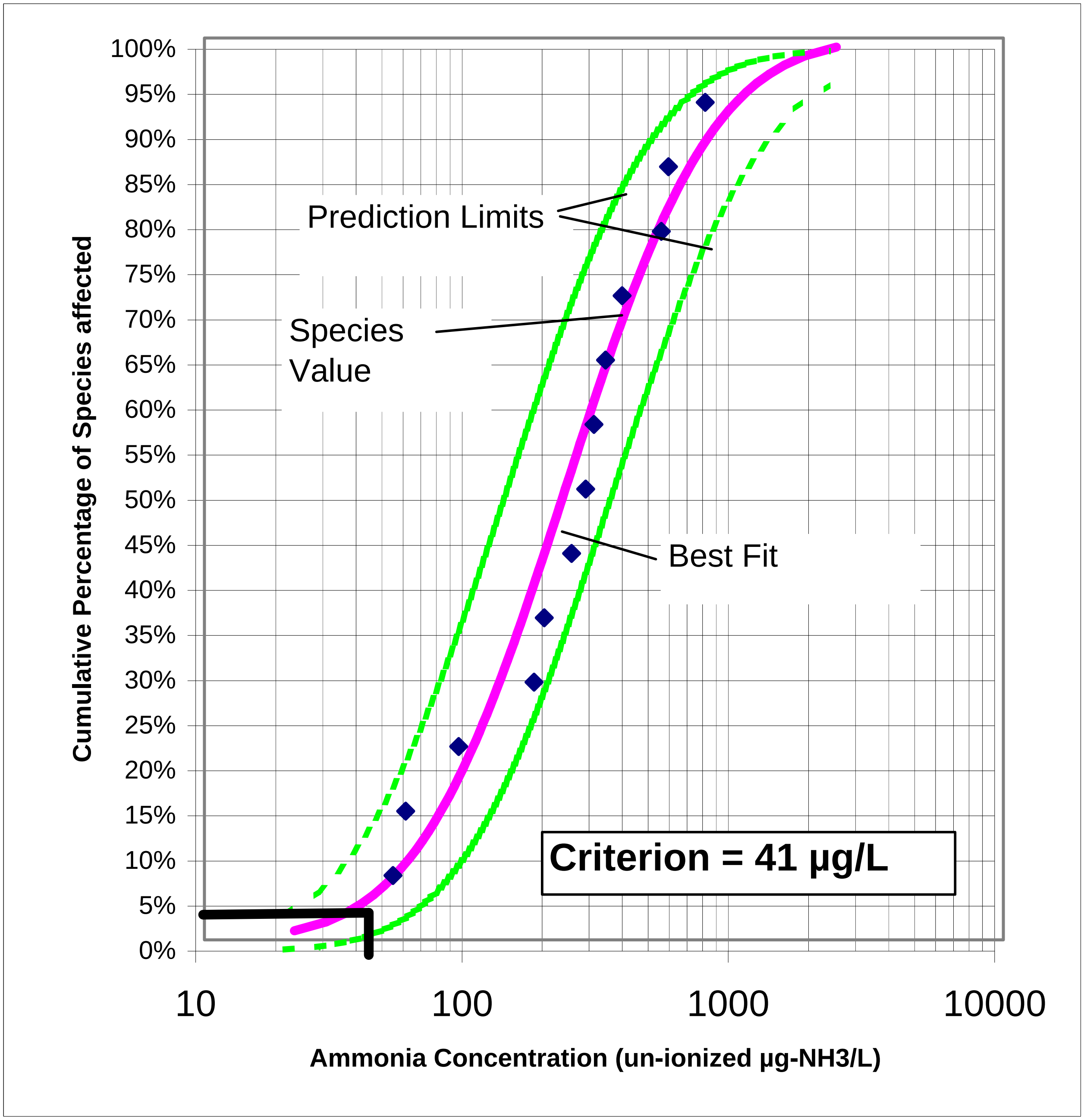
## SUMMARY OF MEAN SUBLETHAL ENDPOINTS IN FRESHWATER SPECIES

| COMMON NAME | SPECIES NAME | $EC_{20}$[1] (mg $NH_3$/L) | NO. OF STUDIES | MIN. $EC_{20}$ (?g $NH_3$/L) | MAX. $EC_{20}$ (?g $NH_3$/L) | REFERENCE |
|---|---|---|---|---|---|---|
| Scud | *Hyallela azteca* | 0.051 | 1 | | | Borgmann 1994 |
| Sockeye salmon | *Oncorhynchus nerka* | 0.057 | 1 | | | Rankin 1979 |
| Rainbow trout | *Oncorhynchus mykiss* | 0.090 | 4 | 18 | 181 | Burkhalter and Kaya 1977; Broderius and Smith 1979; Calamari *et al*. 1981; Solbé *et al*. 1986 |
| Fathead minnow | *Pimephales promelas* | 0.173 | 3 | 105 | 247 | Swigert and Spacie 1983; Mayes *et al*. 1986; Thurston *et al*. 1986 |
| Walleye | *Stizostedion vitreum* | 0.189 | 2 | 179 | 199 | Hermanutz *et al* 1987 |
| Bluegill and pumpkinseed | *Lepomismachrochirus* and *L. gibbosus* | 0.239 | 3 | 60 | 553 | Reinbold and Pescitelli 1982; McCornick *et al.* 1984; Smith *et al.* 1984 |
| Leopard frog | *Rana pipiens* | 0.270 | 1 | 162 | | Diamond *et al.* 1993 |
| Catfish | *Ictalurus punctatus* | 0.290 | 6 | 301 | 487 | Colt and Tchobanoglous 1978; Reinbold and Pescitelli 1982; Swigert and Spacie 1983; Hermanutz *et al*. 1987; Bader and Grizzle 1992 |
| Smallmouth bass | *Micropterus dolomieu* | 0.321 | 2 | | 343 | Broderius *et al.* 1985 |
| Green sunfish | *Lepomis cyanellus* | 0.553 | 1 | | | Reinbold and Pescitelli 1982 |
| Amphipod | *Crangonyx* | 0.370 | 1 | | | Diamond *et al.* 1993 |
| | *Ceriodaphnia dubia* | 0.520 | 1 | | | Nimmo *et al.* 1989 |
| | *Daphnia magna* | 0.759 | 2 | 607 | 950 | Reinbold and Pescitelli 1982; Gersich *et al.* 1985 |



[1] $EC_{20}$ is the geometric mean when more than one study result is reported.

Source: Environment Canada 2000




Source: Environment Canada 2000

**Aquatic Community Risk Model (Canada Wide) for Chronic Criterion Development**

Figure 3-9

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**species which are not found in the Red and Assiniboine rivers (Salmonids) and is therefore not directly applicable to regulation in Manitoba**.

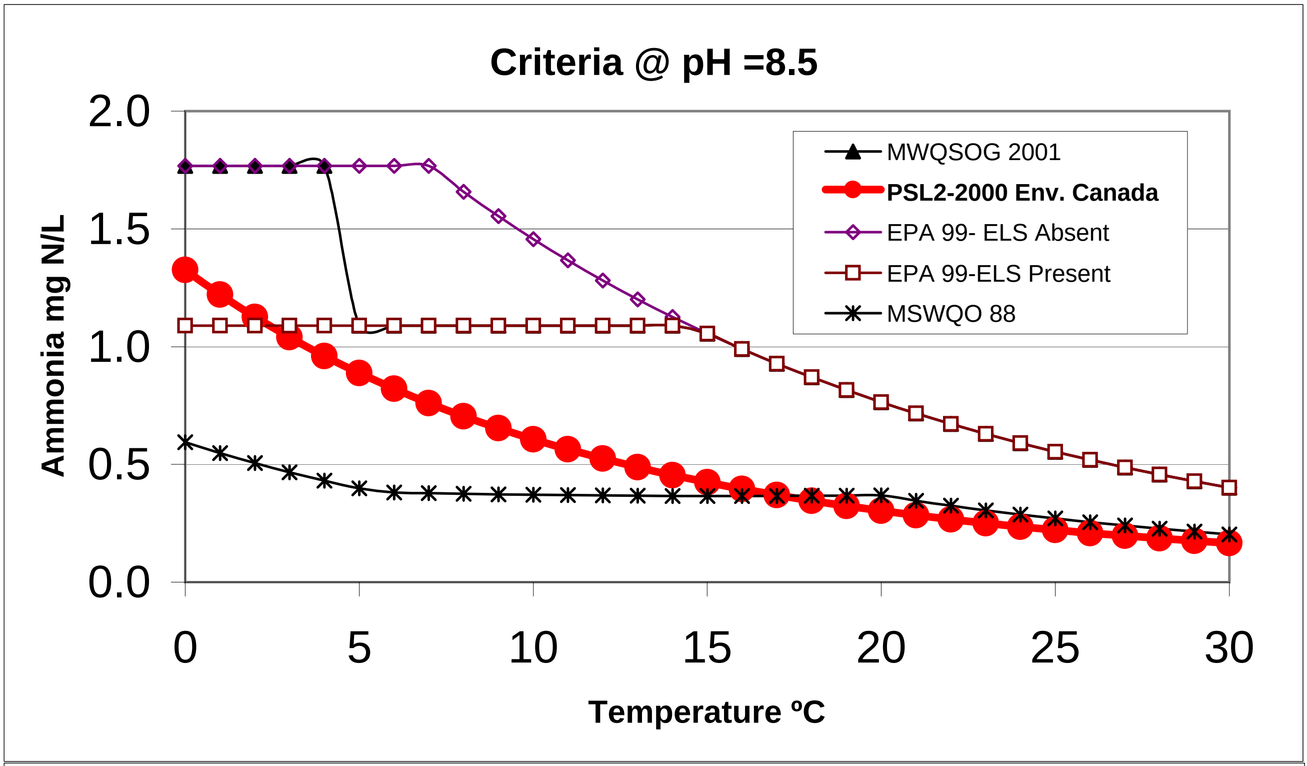
A comparison of Draft (2000) Environment Canada PSL-2 Ammonia Criteria, the Draft Manitoba (2001) Criteria and U.S. EPA (1999) criteria is shown on Figure 3-10. The criterion concentrations appear to be more stringent than EPA 99 (Manitoba 2001) criterion however the derivation includes salmonids and are not therefore directly applicable to this location.

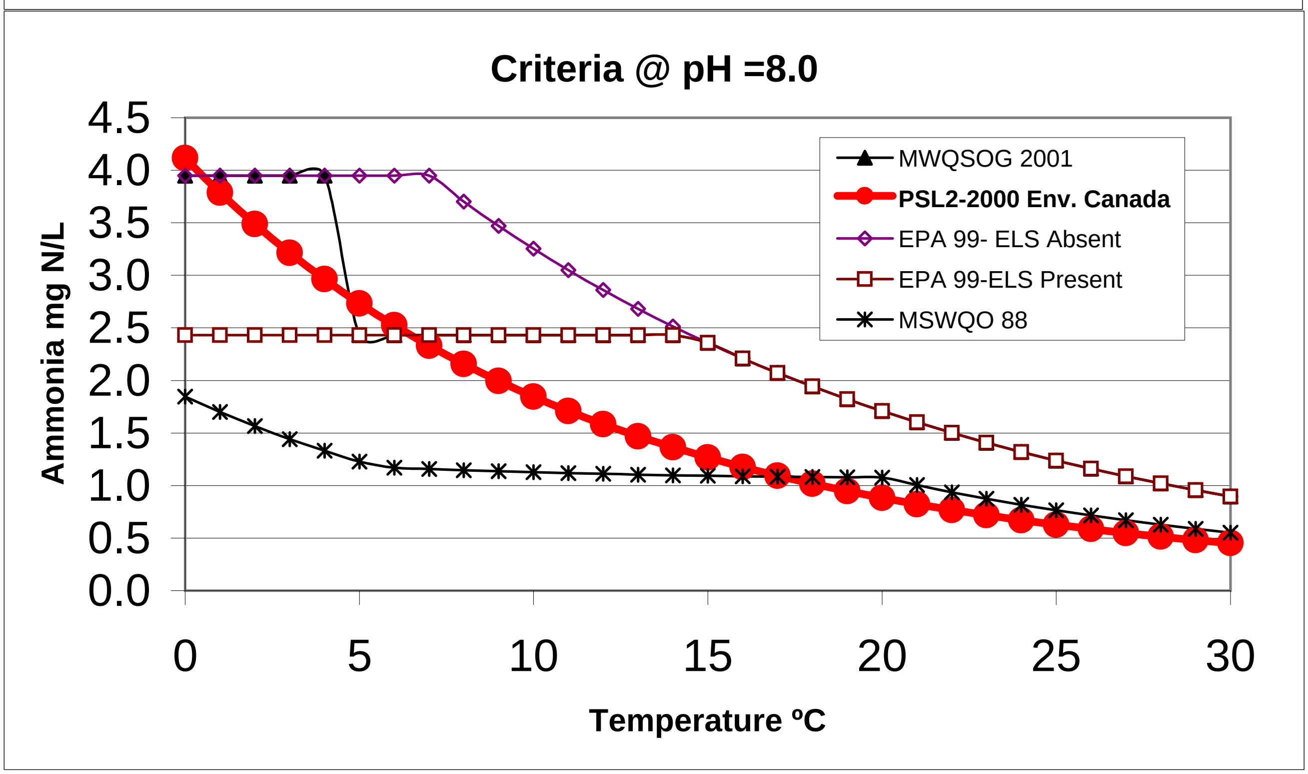
The PSL-2 document gave no direction in terms of exposure (averaging duration and frequency); however some case studies of preliminary risk assessments were conducted. The risk assessments were done to determine whether the ammonia should be declared a toxic substance under CEPA. However, these should not be considered site-specific. Criteria developed for an assemblage of species including salmonids were used in conjunction with water quality data from prairie streams (in Winnipeg and Edmonton) to determine a frequency of exceedence. No guideline (such as once in three years on average) was given as to what an allowable exceedence frequency should be.

Environment Canada has indicated that a subsequent stage will involve more comprehensive risk assessment at sites throughout Canada.

## 3.7 OVERVIEW

Development of ammonia criteria in surface waters is very complex, involving scientific uncertainties, and evolving datasets. The application of criteria is important in that it will influence waste load allocations and related wastewater treatment requirements. Relatively small differences in criteria can make significant differences in required wastewater treatment expenditures. While differences exist in U.S., Canadian and Manitoba-based ammonia criteria, both National jurisdictions, as well as mc recommend developing site-specific criteria. The investigations and analyses conducted under this study will allow the development of site-specific criteria supporting the most appropriate, local regulatory approach. The potential application of these different approaches to the Winnipeg situation will be discussed in Section 7.




**Comparison of PSL2, Manitoba 2001, EPA 1999 and Manitoba 1988 Chronic Ammonia Criteria**

Figure 3-10

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# 4. REVIEW OF TECHNICAL WORKSTREAMS

The complexity of the study dictated that it be carried out in a series of interrelated workstreams which were organized to assure flow of information between the workstreams. The conceptual interrelationships of these technical workstreams are shown in Figure 4-1.

The study team identified a number of key questions that were used as a test for the various activities in the individual workstreams to confirm their relevance to the main objective and their relative value in contributing to these objectives. These questions are shown in Table 4-1. This section will give a summary of each of the individual workstream activities, how they respond to the key questions, and the key observations or conclusions arising from these workstreams.

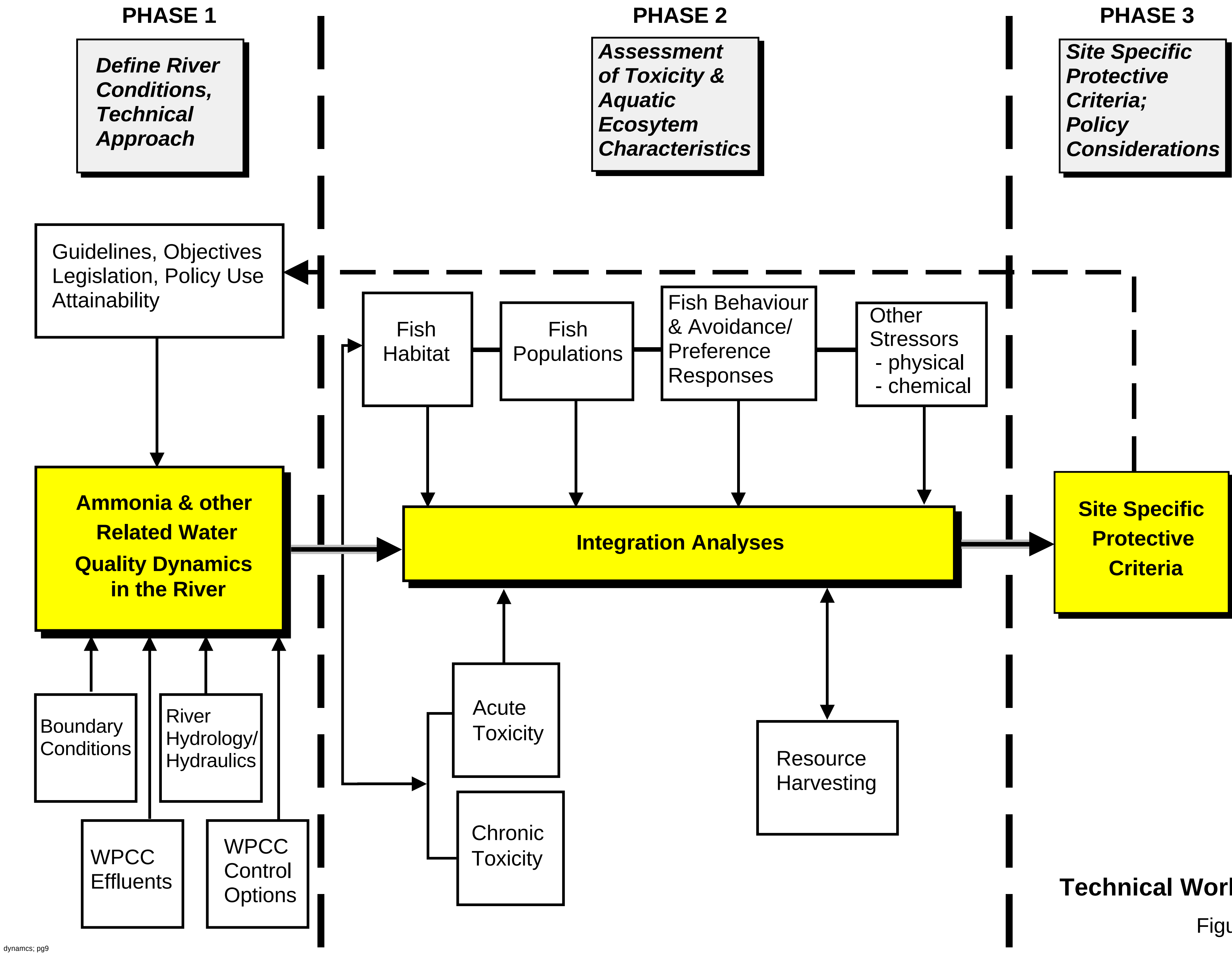
Although each of these studies produced independent technical memoranda, linkages between the studies assisted in integration of the workstreams. A summary of some of the key linkages between workstreams is shown in Table 4-2.

## 4.1 RIVER CONDITIONS

### 4.1.1 Objective

To determine the river conditions, both hydrologic and water-quality, in the study area under existing discharges to the rivers, specifically:

- to project river conditions for critical periods for which protective criteria for ammonia may apply;
- to depict existing bathymetry and flow velocity of the rivers conditions relating to various river flows (thus allowing interpretation of aquatic habitat conditions);
- to describe dynamic water-quality conditions over a continuous period of record; and
- to determine potential changes in river conditions resulting from a range of ammonia control options.




**Technical Workplan**

Figure 4-1

## TABLE 4-1

## ADDRESSING KEY QUESTIONS

| ***Problem Definition*** | | **This TM** | **Other TM** |
|---|---|---|---|
| 1 | What is the concern with ammonia concentrations?<br>- chronic<br>- regulatory view<br>- rationale<br>- scientific evidence | 3.0 | |
| 2 | What are other jurisdictions doing with respect to regulating ammonia?<br>- guidelines<br>- scientific support<br>- rationale/applicability to our situation<br>- status | 3.0 | |
| 3 | What are the ammonia dynamics in our rivers?<br>- concentrations<br>- how often (frequency)?<br>- how long (duration)?<br>- Where (extent)? | 4.1<br>7.0<br>8.0 | River Conditions |
| ***Existing Conditions*** | | | |
| 4 | What do we know about the local aquatic life and aquatic habitat and potential ammonia impairment?<br>- what's there (database)?<br>- what are we trying to protect?<br>- what condition are they in?<br>- what habitats do the fish use?<br>- do they use them?<br>- how do the fish behave?<br>- how are they exposed (frequency/duration/health)? | <br>4.2, 4.3, 4.4<br><br><br><br><br><br>8.0 | Fish Habitat<br>Fish Population<br>Fish Behaviour |
| 5 | What is the scientific basis of the toxicity data base with respect to local aquatic life?<br>- toxicity database<br>- applicability/data gaps<br>- scientific standards of practice<br>- uncertainty<br>- do we need to expand knowledge of resident species? | 3.0<br>4.7<br>6.0 | Toxicity Testing |
| ***Potential Effects of Ammonia control*** | | | |
| 6 | How would potential ammonia control affect concentrations in the rivers?<br>- frequency/duration/exposure | 4.1, 7.0, 8.0 | River Conditions |
| 7 | What would the effects of control be on river conditions and aquatic life?<br>- related impacts, e.g., algal community<br>- benefits/disbenefits | 4.0, 7.0, 8.0 | All TMs |
| 8 | What are other parameters potentially affecting aquatic life in the local rivers?<br>- biophysical<br>- resource harvesting<br>- chemical exposure | 4.5, 4.6, 4.7 | Physical Constraints<br>Resource Harvesting<br>Toxicity |
| ***Site-Specific Ammonia Criteria*** | | | |
| 9 | What are potential alternative criteria?<br>- seasonality, frequency, duration, averaging period | 7.0 | |
| 10 | What information do we need to define and evaluate alternative ammonia protective criteria?<br>- alternative criteria (seasonality/frequency/duration/exposure, impairment, etc.)<br>- costs<br>- benefits/disbenefits<br>- uncertainty<br>- policy evaluation | 6.0, 7.0, 8.0, 9.0, 10.0 | |

## TABLE 4-2
# Linkages between Workstreams

| | River Conditions | Fish Habitat | Fish Populations | Fish Behaviour | Other Stressors: Physical Constraints | Other Streesors: Resource Harvesting | Toxicity Testing |
|---|---|---|---|---|---|---|---|
| **River Conditions** | | | | | | | |
| **Fish Habitat** | Perspective on 1999 conditions vs. Historic flow, velocity and ammonia concentrations. | | | | | | |
| **Fish Populations** | Perspective on 1999 conditions vs. Historic flow, velocity and ammonia concentrations. | Fish habitat characterization assisted in the interpretation of observed differences in fish and benthic populations. | | | | | |
| **Fish Behaviour** | 3-d plume mixing modelling was used to determine likely ammonia concentraions during near-field behaviour studies. | Certain species of fish are attracted to the habitat conditions created by effluent plumes during the winter; and<br>Fish habitat utilization is influenced by fish behaviour in response to effluent plume exposure. | Information collected on species composition, abundance, and distribution of fish during winter, and during July and September under the Fish Populations workstream supported conclusions regarding movement.<br>Plumes do not appear to strongly effect fish distributions or migrations in the open water season for most species, but appear to act as an attractant to some species in the winter. | | | | |
| **Other Stressors: Physical Constraints** | River flows determine operation of potential barriers such as St. Andrews Lock and Dam. | Identification of physical constraints contributes to the characterization of fish habitat. | Information regarding other physical constraints to fish populations in the Study Area (e.g., St. Andrews Lock and Dam) that was collected in studies conducted under the Other Stressors workstream helped to explain fish species composition, abundance, and distribution among and within zones in the Study Area. | Other stressors to fish populations in the study area can effect the distribution and abundance of fish populations, which can effect behaviour. | | | |
| **Other Stressors: Resource Harvesting** | | Resource harvesting may affect the utilization of suitable habitat by fish. | Resource harvesting may affect the species composition and abundance of fish populations, particularly those species which are favoured by anglers. | Fish behaviour will determine fish distribution and consequently fish harvest locations and opportunities. | Physical Barriers May influence Resource Harvesting Locations (I.e. Lockport). | | |
| **Ammoniia Toxicity Testing** | Historic River conditions assisted in determination of range of ammonia treamtents in laboratory.<br>3- Plume modelling assisted in estimated ammonia exposure of in situ bivalve tests. | Identified benthic invertebrate taxa present locally. | Identified fish species present locally. | Northern pike have been shown to be exposed to the NEWPCC plume over long periods of time. Northern pike were also the most sensitive species tested for ammonia toxicity. | | | |

The key questions for this workstream were as follows (see Table 4-1).

- **Question 3** - What are the ammonia dynamics in our rivers?
- **Question 6** - How would potential ammonia control affect concentrations in the rivers?
- **Question 7** - What would the effects of control be on river conditions and aquatic life?

#### 4.1.2 Hydrology

- The flows in the modelled area are highly variable from year to year and can vary for a given location by an order of magnitude for the same time of year. This has a major impact in the dilution capacity available for WPCC discharges (Question 3).

- During the period of field studies in 1999, the flow in the Red and Assiniboine rivers was either in the highest 10% of historic flows for that time of year or at record high levels for that time of year. Using the MIKE11 hydraulic model (DHI 1997), and the frequency analysis of flows on the Red and Assiniboine rivers, a relationship between flow and velocity and flow and depth was developed for each reach of the rivers. A probability distribution of range of velocities and depth of each reach for each of the rivers, at any time of year, was developed for the study area (Question 3).

- Flow velocities are higher in the Assiniboine River than the Red River. Large variance in velocity can occur, as was the case in 1999, when flow velocities were 2 to 4 times the mean velocity value for both rivers.

- Red River width was not found to be variable, however depths were twice normal depths under higher flows in upstream reaches of the Red River, and depths were shallower near Lockport during high flows due to regulation effects associated with the Lockport Control Structure.

- In the lower reaches of the Assiniboine River, a backwater effect created by the Red/Assiniboine confluence occurs, raising the Assiniboine River depth up to approximately seven kilometres upstream of the Red River.

### 4.1.3 Water Quality

- The City of Winnipeg has collected over 20 years of bi-weekly water quality data at 11 stations throughout the study area (800-1,000 data per station). This was used to calibrate water-quality models and assess seasonal changes in pH (Question 3).

### 4.1.4 pH and Temperature Dynamics

- Key parameters which could be used in the development of ammonia criteria such as pH and temperature vary significantly from month to month (see Figures 4-2 and 4-3). This indicates the need for a monthly or seasonal assessment of total ammonia. The pH also varies spatially across the region with pHs being higher upstream in the City of Winnipeg, decreasing as the rivers flow through the heart of the City (i.e., at the Redwood Bridge and North Perimeter Bridge), then rising slightly again towards Lockport. This indicates that there will be a variation of un-ionized ammonia due to changes in pH throughout the study area (Question 3).

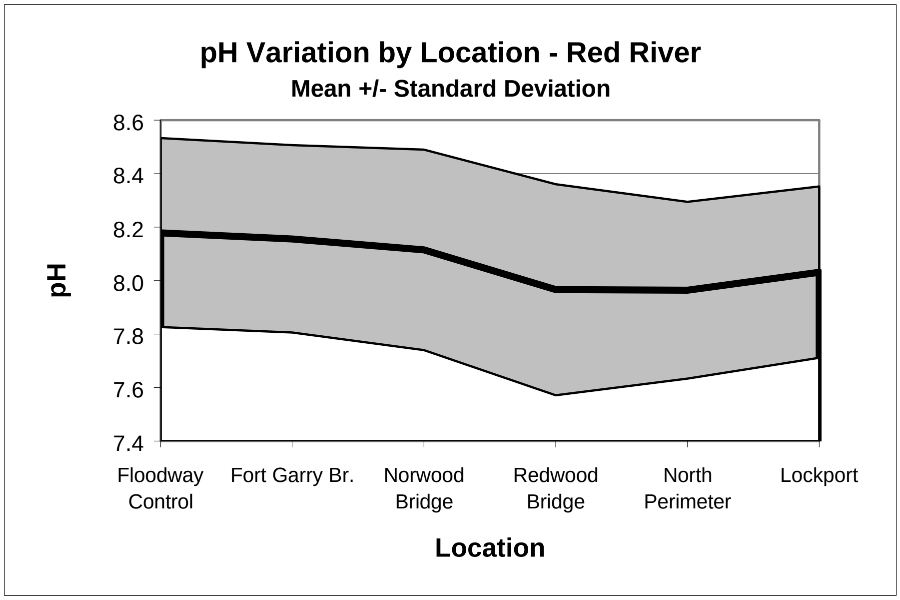
- Field pH and Chlorophyll-'a' measurement showed a strong correlation between the two parameters (see Question 3), suggesting that algae activity influenced pH (Question 3).

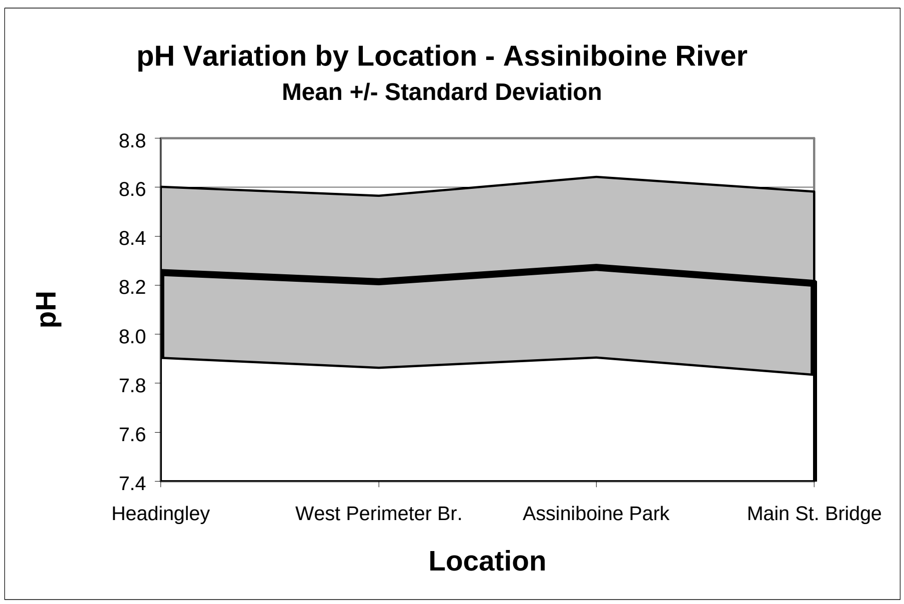
- A review of the 1988 data and studies (Ross and Hemphill 1991) indicated potential for stratification of pH with depth. The 1999 studies (during higher flow in the river) did not indicate any evidence of stratification of pH and indicated full mixing within the river (Question 3).

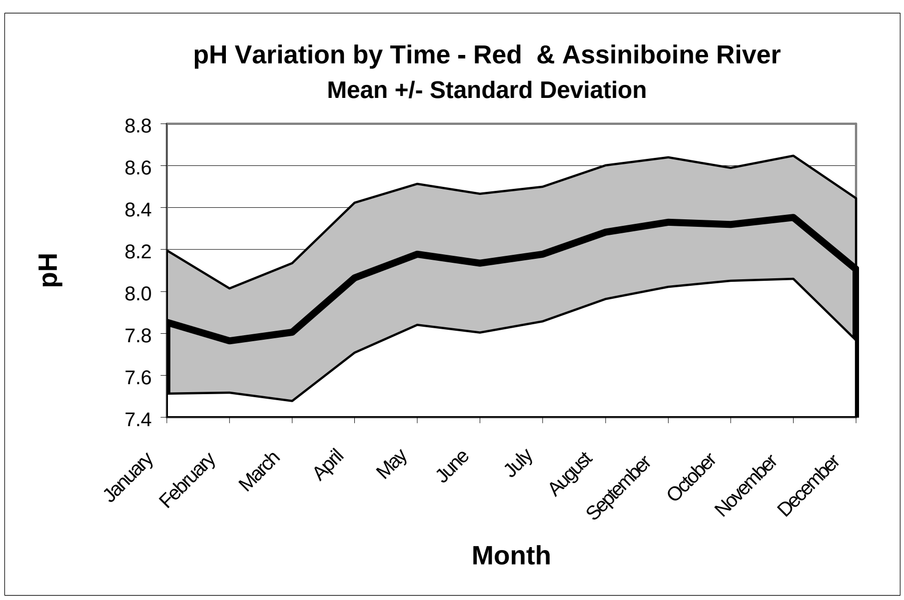
### 4.1.5 Algal Dynamics

- The 1999 monitoring program and analysis indicated that light was a limiting factor in the growth of algae (Question 3).

- Analysis of data collected in 1999 indicated a strong correlation between suspended solids and an estimated light extinction coefficient (Question 3).




**Seasonal and Spatial pH Variance**
Figure 4-2

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phvar
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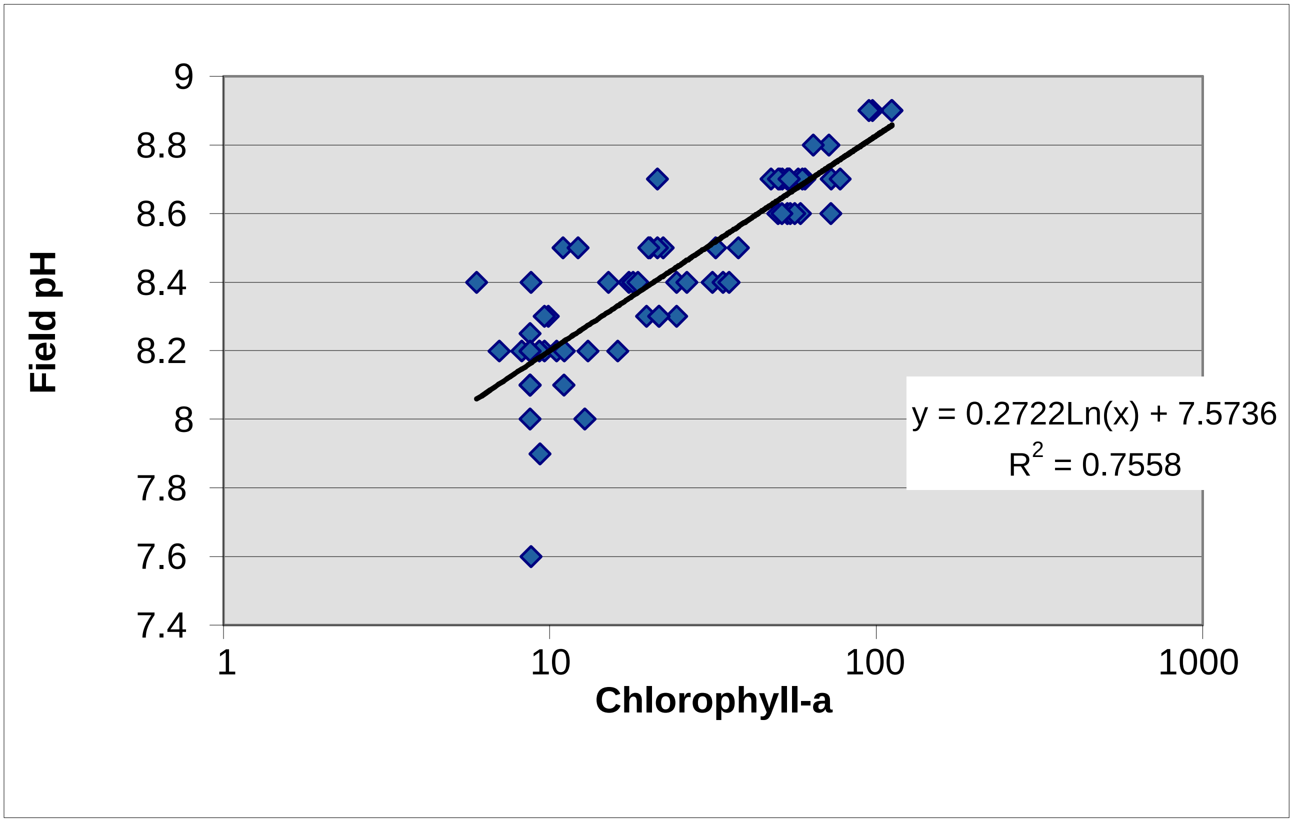


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**1999 Monitoring**
**Chlorophyll-a vs. pH**
Figure 4-3

clavsph2
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- A review of historic river conditions indicated that the change in average light within the water column could increase greatly during average and low flows in the river at certain locations. The increase in average light in water column in the lower Red is estimated to be only about 10% for low flow conditions when compared to the high flow conditions monitored in 1999 (Question 3).

- On the upper Red, the light conditions may increase by 2.5 times during low-flow conditions when compared to the conditions monitored in 1999 (Question 3).

- On the Assiniboine River, the average light exposure in the water column may increase by over 4 times during low-flow conditions when compared to the conditions monitored in 1999. This analysis indicated that during low-flow conditions, the average light in the water column may increase enough that light ceases to become the limiting factor and one of the nutrients, either nitrogen or phosphorus becomes limiting (Question 3).

#### 4.1.6 Water Pollution Control Centres Influence on Ammonia and Nutrients

- The City has monitoring data from 1984 to 1997, which can be used to develop a monthly mean and variation of the ammonia effluent quality from each of the three WPCCs (Question 3).

- The flow from the NEWPCC and WEWPCC is projected to remain roughly equivalent to today's conditions through to the year 2041. The SEWPCC will increase significantly by over 30% between 1997 and 2041 (Question 6).

- Although the treatment plant is not specifically designed for nutrient removal it should be noted that the NEWPCC removes greater than 50% of the phosphorus during treatment and the SEWPCC and WEWPCC show similar phosphorus treatment performance, although not as large a reduction in phosphorus (30% reduction). The WPCCs also reduced nitrogen load, although not as significantly as for phosphorus (Question 3).

- A parallel study on the treatment plant systems (Earth Tech 2001) is able to develop future conditions for various nitrogen-removing processes. A range of nine scenarios, including the historic conditions and the current conditions, as well as six future conditions in 2041 have been developed. These scenarios give estimations of the mean and monthly variation of ammonia discharges at each of the three WPCCs (Question 6).

#### 4.1.7 Nutrient Loadings

- Mass nutrient loadings coming from upstream of the City of Winnipeg are largely dependent upon the flow in the river. Most of the load comes during the spring freshet in March, April and May. Since 1993, the average annual load of nutrients has increased dramatically due to the high flow conditions in the river (Question 3).

- The nutrient loads from Winnipeg's WPCCs have remained relatively stable over the past 15 years (Question 3).

- On an average basis, the annual load from the WPCCs is about 20% of the total load to the river. However, in a low-flow year, the nutrient load could increase to as much as 30% or 40% of the load in the river, and in a high-flow year the load would only amount to 10% or less of the total load in the river (Question 3).

#### 4.1.8 Ammonia Impacts on the Algae and Potential for Change

- For increases in ammonia concentrations there is an increase in photosynthetic activity. However, when ammonia is increased beyond 2 or 3 mg/L productivity decreases. A regression analysis indicated that the trend is statistically significant and consistent, although not strong. Similarly, when algae are spiked with nitrate there is a statistically-significant decrease in productivity beyond 1 mg/L. The trend appears to be both strong and consistent. There is no statistically significant difference between ammonia and nitrate impact on algae. From this analysis, we would not expect nitrification to significantly impact productivity of algae in the river (Question 7).

### 4.1.9 Near-Field Water Quality Modelling (Mixing of Plume)

- In the low-flow conditions it is expected that the NEWPCC will mix thoroughly immediately downstream of the outfall. The SEWPCC discharge occurs in the middle of the river and mixing will occur relatively quickly under low-flow conditions (Question 3).

- On the Assiniboine River the mixing is much less pronounced, with the WEWPCC plume hugging the south bank for a considerable distance downstream to Assiniboine Park and beyond. However, it is expected that full mixing will occur by the time the plume reaches the Main Street Bridge near The Forks (Question 3).

### 4.1.10 Long-Term Dynamic Modelling

- Dynamic modelling is preferred by the EPA when using the water quality criteria to develop a waste-load allocation for discharges on a river (Question 6).

- The considerable amount of water-quality and river-flow data along with advances in computational hardware and software have allowed a long-term continuous simulation model to be developed (Question 6).

- The model was calibrated deterministically to verify that the dilution transport and transformation of ammonia to nitrate could be predicted (Question 6).

- The model was also calibrated stochastically to verify that future water quality and effluent predictions could be generated stochastically, which would represent the expected statistical distribution of ammonia at all stations in the study area for the future (Question 6).

- A range of potential future scenarios were generated, which can be used in conjunction with a selected criteria to assess compliance or with specific toxicity effects data to develop a probabilistic risk assessment (Question 6 – see Section 7.0).

#### 4.1.11 Steady-State Water-Quality Assessments

- The historic record was analyzed to develop steady-state design flows (i.e., 30B3, 7Q10 etc.) which can be used in developing waste-load allocations for comparison to those developed by the dynamic model and risk assessment (Question 9).

#### 4.1.12 Critical Period Algae Modelling (Impact of Nitrification on Nutrient Control)

- If nitrification leads to an increase in phosphorus, it would likely have no impact on algal concentrations, pH or un-ionized ammonia concentrations. Our assessment indicated that phosphorus is currently not the limiting nutrient on algal growth. However there may be an increased risk of nitrogen fixing by cyano-bacteria which may then dominate the algal population. This risk is difficult to quantify (Question 6).

- Phosphorus control, in general, has the potential to limit algae concentrations in the Red and Assiniboine rivers which can, in turn can reduce pHs. A reduced pH would mean a decrease in the concentration of un-ionized ammonia for a fixed concentration of total ammonia, thus reducing aquatic toxicity (Question 6).

- Phosphorus controls at the City of Winnipeg WPCCs would have no impact on pHs and un-ionized ammonia concentrations in the Assiniboine River. On the Red River, upstream of the NEWPCC, the reduction in un-ionized ammonia would be limited to less than 4%. Downstream of the NEWPCC, the impacts on un-ionized ammonia concentrations from phosphorus control in the City of Winnipeg would be more significant, ranging from 6 to 14% reduction, depending on the month and location (Question 6).

- If in addition to City of Winnipeg phosphorus controls, upstream phosphorus was maintained at 0.1 mg/L, the impact on chlorophyll ‘a’ concentrations, pH and un-ionized ammonia concentrations would be significant. On the Assiniboine River, for the month of August, the reduction in un-ionized ammonia at the Main Street Bridge could be as high as 20%. For most of the summer on the Red River within the City of Winnipeg, the un-ionized ammonia could be reduced by between 10 and 17%. The most significant change in un-ionized ammonia could occur at Lockport, where un-ionized ammonia could be reduced by 15 to 23% during the summer months (Question 6).

## 4.2 FISH HABITAT WORKSTREAM

### 4.2.1 The Objectives

The primary objective of the fish habitat workstream was to classify, quantify, and map fish habitat types in the Red and Assiniboine rivers in terms of physical, chemical, and biological characteristics in order to:

- identify and quantify fish habitat potentially affected by elevated ammonia concentrations; and,
- assist in the interpretation of observed differences, if any, in fish and benthic populations affected by different levels of exposure to ammonia.

The above information was required to determine, in conjunction with other workstreams, the amount and relative importance of fish habitat that could be affected by elevated ammonia concentrations. This workstream was linked to several other workstreams and was intended to provide information required to determine what habitats could be potentially affected seasonally, as river conditions, ammonia concentrations, and fish distribution patterns change.

The fish habitat workstream responded to Question #4 and Question #7:

Q4. What do we know about aquatic life, aquatic habitat, and potential ammonia impairment?
Q7. What would the effects of ammonia control be on river conditions and aquatic life?

Habitat types which were classified on the basis of substrate type and level of compaction revealed little difference in depth and velocity. No relationship between substrate and fish catch was apparent and, consequently, the relationship between habitat types and species composition, distribution, and abundance of the fish community was not examined further.

### 4.2.2 The Studies

Fish Habitat Technical Memorandum # FH 01 - Physical Data to Characterize Fish Habitat in the Red and Assiniboine Rivers

The focus of the study was to provide information to describe regional (reach) differences in habitats (i.e., macrohabitats) to contribute to explaining regional differences in fish distributions.

To facilitate development of a sampling regime the Red and Assiniboine rivers were divided into 86 and 30 segments, respectively. To characterize each segment, water depth was measured and substrate composition and compaction were qualitatively determined at quarter points on four equally spaced transects within each segment. Shoreline and riparian features were qualitatively described. Water velocity profiles were measured across two typical Red River segments. Data to describe habitat types (see FP 02 in Section 3.3). were presented by river segment.

Fish Habitat Technical Memorandum # FH 02 - Benthic Invertebrate and Sediment Data to Characterize Fish Habitat in the Red and Assiniboine Rivers

The objective of the benthic program was to describe the benthic invertebrate community and characterize the bottom sediments of fish habitat within those portions of the Red and Assiniboine rivers within the Study Area.

A benthic sampling program was developed using the segments previously designated by the physical habitat surveys, with the Red and Assiniboine rivers divided into 86 and 30 segments, respectively. The benthic invertebrate community and bottom substrate composition were quantitatively sampled using a ”petit” Ponar dredge. Benthic invertebrate community composition was also qualitatively sampled using Artificial Substrate Samplers. All sampling locations were geo-referenced with UTM coordinates and benthic data were presented by river segment.

Data were used to compare the benthic invertebrate community observed among zones in the Study Area, among different bottom substrate types, between sampling periods (seasons), and to historical data available for the Red and Assiniboine rivers (Fish Population Technical Memorandum # FP 03).

Fish Habitat Technical Memorandum # FH 03 - Water Chemistry Data to Characterize Fish Habitat in the Red and Assiniboine Rivers

The focus of the study was to provide basic water chemistry information to describe regional (zone) differences in habitats (macrohabitats), which would assist in explaining potential regional differences in fish distributions.

Three surveys were conducted at each of the fish sampling sites during February - March, 1999, July, 1999, and September, 1999. All tributaries to the Red and Assiniboine rivers in the Study Area, and the mixing zones downstream of the Water Pollution Control Centre (WPCC) effluent outfalls, were also sampled during the second and third periods. Water chemistry data are presented by river segment within each of the major zones.

Water chemistry data collected in the Red and Assiniboine rivers during the open water period of 1999 were gathered under conditions of high river discharge. During the autumn sampling period, discharges of both rivers were the highest on record.

#### 4.2.3 Observations

- Data were used to map physical attributes and describe biological and chemical features of fish habitat in the Red and Assiniboine rivers.

- A higher than expected degree of variability in the benthic community existed within the delineated fish habitat polygons. Invertebrate taxa identified in Ponar Dredge and Artificial Substrate samples collected from the Red and Assiniboine rivers within the Study Area are listed in Table 4-3.

- Water chemistry data for the Red and Assiniboine rivers during the open water period of 1999 were collected under conditions of very high river discharge. During July, discharge in the Red and Assiniboine rivers was approximately 2.5 and 3 times, respectively, the

**Table 4-3**

## List of invertebrate taxa identified in Ponar Dredge and Artificial Substrate samples from the Red and Assiniboine rivers, 1999.

**Ph. Annelida**
- Cl. Oligochaeta
  - F. Lumbriculidae
  - F. Naididae
  - F. Tubificidae

**Ph. Arthropoda**
- Cl. Arachnida
  - O. Hydracarina
- Cl. Crustacea
  - SCl. Branchiopoda
    - O. Cladocera
  - SCl. Copepoda
  - SCl. Malacostraca
    - O. Amphipoda
      - *Hyalella* sp.[1]
- Cl. Insecta
  - O. Coleoptera
    - F. Dytiscidae
    - F. Elmidae
  - O. Diptera
    - F. Athericidae
    - F. Chironomidae
      - SF. Chironominae
      - SF. Orthocladiinae
      - SF. Tanypodinae
    - F. Ceratopogoniidae
    - F. Chaoboridae
    - F. Dolichopodidae
    - F. Empididae
    - F. Simuliidae
    - F. Tipulidae
  - O. Ephemeroptera
    - F. Ametropodidae
    - F. Baetidae
    - F. Caenidae
    - F. Ephemeridae
    - F. Heptageniidae
    - F. Leptophlebiidae
    - F. Polymitarcyidae
    - F. Siphlonuridae
    - F. Tricorythidae
  - O. Hemiptera
    - F. Corixidae
  - O. Megaloptera
    - F. Corydalidae
    - F. Sialidae
      - *Sialis* sp.
  - O. Odonata
    - F. Gomphidae
  - O. Plecoptera
    - F. Perlidae
      - *Acroneuria* sp.
    - F. Perlodidae
    - F. Pteronarcyidae
  - O. Trichoptera
    - F. Brachycentridae
    - F. Hydropsychidae
    - F. Leptoceridae
    - F. Limnephilidae
    - F. Polycentropodidae

**Ph. Cnidaria**
- Cl. Hydrozoa
  - *Hydra* sp.

**Ph. Mollusca**
- Cl. Bivalvia
  - O. Eulamellibranchia
    - F. Unionidae
  - O. Heterodonta
    - F. Sphaeriidae
- Cl. Gastropoda
  - SCl. Prosobranchia
    - F. Hydrobiidae
      - *Amnicola* sp.
    - F. Valvatidae
      - *Valvatta* sp.
  - SCl. Pulmonata
    - F. Ancylidae

**Ph. Nematoda**

**Ph. Platyhelminthes**
- Cl. Turbellaria
  - *Planaria* sp.

1. Hyallela found only on the Assiniboine River

historical mean monthly mean discharges and during autumn were the highest on record for that period.

## 4.3 FISH POPULATIONS WORKSTREAM

A total of 5,445 fish were captured in this study. Of these, 2,215 fish (31 species) were captured in the Red River (see Table 4-3); 737 fish (26 species) were captured in the Assiniboine River; and 2,493 fish (26 species) were captured from Bunns Creek, Sturgeon Creek, La Salle River, and the Seine River.

Comparison of catch data for the Red River to that of 1974 (Clarke et al. 1980) suggests that the relative abundance of four of the five most commonly captured species in 1974 (sauger, freshwater drum, white sucker, and channel catfish) have remained approximately the same. Differences in Catch Per Unit Effort (CPUE) for hoop nets set in the Red River during July, August, and September in 1974 and 1999 suggest that most species were less abundant in 1999 than they were in 1974. However, differences in sampling site selection, hoop net mesh sizes, and streamflow likely contributed to the lower CPUE observed in 1999. While comparison between 1974 and 1999 data showed differences in growth rates and weight-length relationships among species, no consistent pattern was observed.

Benthic fish species generally exhibited more DELTs than pelagic species, possibly due to their high degree of contact with sediments which typically contain the highest concentrations of contaminants in the aquatic environment. Overall, the frequencies of DELTs observed on fish captured may indicate some degree of impairment of the aquatic environment.

Indices of Biotic Integrity

The Indices of Biotic Integrity (IBI) score for the Red River in this study (40) is comparable to those of Red River mainstem sites in the United States (mean score of 39.5; Niemela et al. 1999). Using the IBI ranking system proposed by Niemela et al. (1999) for the upper Red River watershed, the fish communities of the Red (40) and Assiniboine (34) rivers within the City of Winnipeg are both classified as fair.

### 4.3.1 The Objectives

The initial intent of this workstream was to examine the fish community within specific zones of the Study Area and relate differences in health, species composition, and abundance to differences in ammonia concentrations. This was not possible due to high flows in the Red and Assiniboine rivers in 1999, as in much of the 1990's, which resulted in overall low in-stream ammonia concentrations and concentration gradients. The fish populations workstream responded to Question #4 and Question #7:

Q4. What do we know about aquatic life, aquatic habitat, and potential ammonia impairment?

Q7. What would the effects of ammonia control be on river conditions and aquatic life?

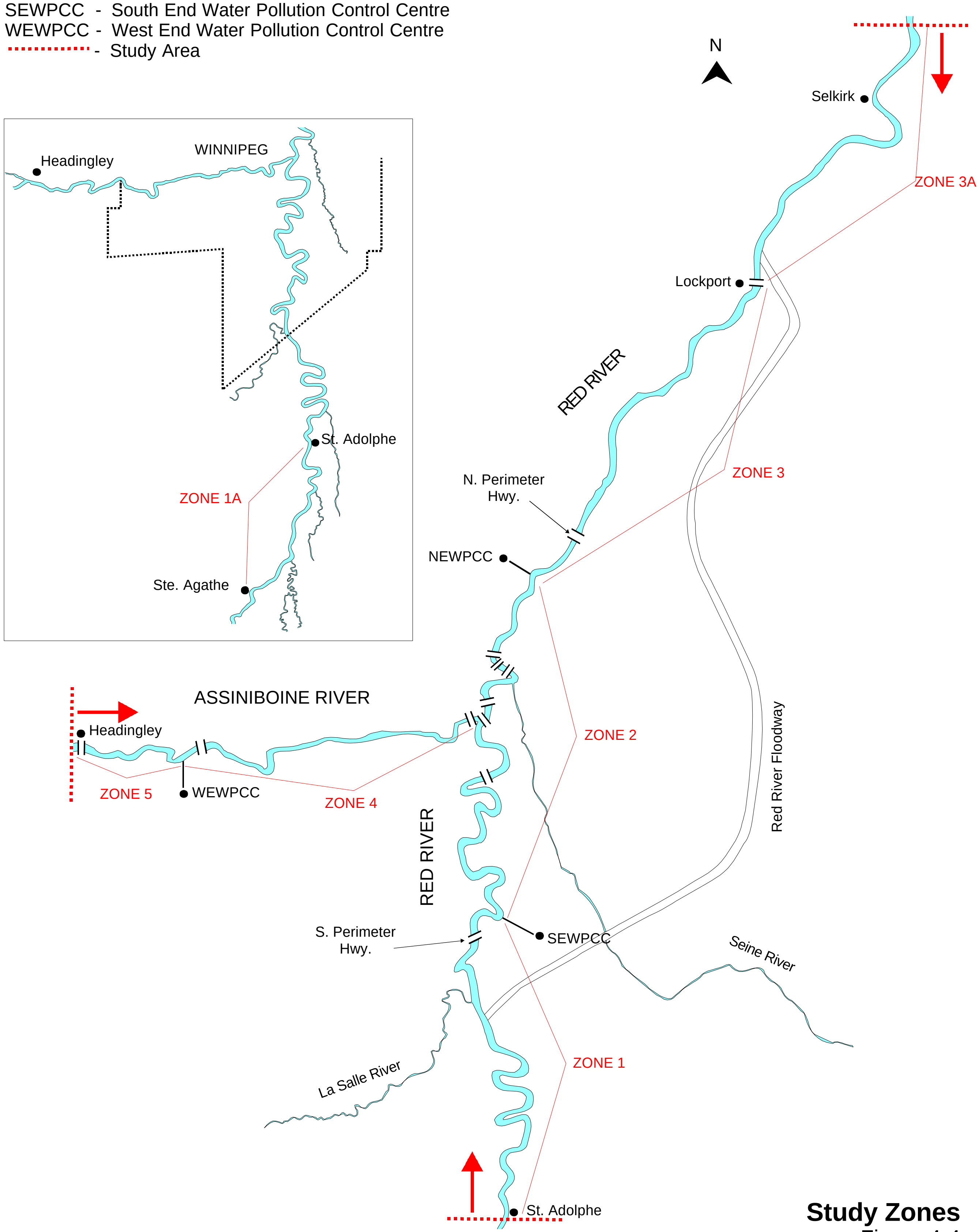
More specifically, the fish habitat workstream produced a database of existing physical, chemical, and biological conditions. No comprehensive studies describing aquatic life in the Red and Assiniboine rivers had been conducted for over 25 years.

To address this question, a number of activities were undertaken within the fish populations workstream, including:

- a review and analysis of historic information, with emphasis on the extensive work conducted by Dr. R. McV. Clarke (Department of Fisheries and Oceans) in the early 1970s;
- a description of fish species composition, abundance, and distribution (temporally and spatially);
- an evaluation of the relative condition of the aquatic ecosystem by developing Indices of Biotic Integrity (IBIs) to compare different reaches within and upstream of the Study Area;
- a description of fish health (i.e., deformities, erosions, lesions, and tumours);
- a characterization of benthic invertebrate populations and biomass; and
- a description of 1999 water chemistry conducted in association with the fish and benthic invertebrate sampling programs.

The Study Area was divided into zones based on the locations of City of Winnipeg Water Pollution Control Centre (WPCC) outfalls (Figure 4-4).

NEWPCC - North End Water Pollution Control Centre
SEWPCC - South End Water Pollution Control Centre
WEWPCC - West End Water Pollution Control Centre
- Study Area

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**Study Zones**
Figure 4-4

### 4.3.2 The Studies

Fish Population TM # FP 01 - The Occurrence of External Deformities, Erosion, Lesions, and Tumours (DELTs) on Fish from the Red and Assiniboine Rivers, 1999

Fish health was examined by recording the occurrence of deformities, erosion, lesions, or tumours (DELTs) on large fish. External parasites, haemorrhaging, and scale disorientation were also recorded. This information addressed fish condition and provided information required for the derivation of values for the Index of Biotic Integrity (IBI).

Due to low catches of fish in zones 1A and 3A, and differences in the relative abundance of fish species captured in each zone, comparisons of DELT frequencies between zones was difficult. Because fish are mobile within the study area (#FB 03), it was difficult to ascertain exposure of individual fish to municipal wastewater discharges or other stressors. Thus, fish captured in zones upstream of WPCCs or far downstream of WPCCs may in fact be exposed at other times to effluents.

The overall frequency of DELTs was twice as high in the Assiniboine River (approximately 16%) than the Red River (approximately 8% of fish). Direct comparison of DELT frequencies between the Red and Assiniboine rivers is problematic, however, due to fish mobility and differences in relative species abundance.

Tumours were observed on fish captured in Zones 2, 3 and 4, exclusively, at a frequency of approximately 1% of fish (all species pooled). Tumours may not have been detected on fish in Zones 1A and 5 due to small catches and may not have been detected in Zone 3A due to the dominance of sauger which exhibited a low rate of tumour incidence. Overall, seven of the 20 fish species captured had external tumours.

Although direct comparison of DELT frequencies from this study to those reported for other systems was not possible (due to various methodologies being used between studies) these data may be of value for future studies. Specifically, these data can serve as a tool for evaluating effects of changing effluent quality, or other activities, on fish populations.

Fish Population TM # FP 02 - Species Composition, Abundance, and Distribution of Fish in the Red and Assiniboine Rivers Within the City of Winnipeg Ammonia Criteria Study Area, 1999

Specific objectives of the study were:

- to describe the seasonal species composition, distribution, and abundance of the fish community within and between specific zones of the Red and Assiniboine rivers;
- to compare, where possible, species composition, distribution, and abundance of the fish community in 1999 to results of similar studies conducted in 1972-1974; and,
- to compare, using the IBIs, the relative health of the fish community to that of other rivers.

Three surveys were conducted to characterize the fish community of the Red and Assiniboine rivers: winter (February/March) 1999; summer (July) 1999; and fall (September) 1999. Additional data from hoop nets set in the Red and Assiniboine rivers in August 1999 to obtain fish for acoustic tagging (FB #02, Section 4.4) were also used.

During winter, fish sampling was conducted using gill nets, while during summer and fall boat electrofishing, hoop nets, gill nets, backpack electrofishing, and beach seines were used. Summer and fall sampling also were conducted in the lower reaches of Bunns Creek, Seine River, La Salle River, and Sturgeon Creek using backpack electrofishing and beach seines. All fish captured were enumerated by location, gear type, and species. Virtually all larger fish (>100 mm) captured during the open water periods were live and were released following field sampling. During winter, live fish were released and all others were sampled in the laboratory.

A total of 5,445 fish were captured (Table 4-4). Of these, 2,215 fish (31 species) were captured in the Red River; 737 fish (26 species) in the Assiniboine River; and 2,493 fish (26 species), in Bunns Creek, Sturgeon Creek, La Salle River, and the Seine River.

Although catches varied considerably between and among gear types, the five most abundant species in the Red River were channel catfish (*Ictalurus punctatus*), sauger (*Stizostedion canadense*), goldeye (*Hiodon alosoides*), white sucker (*Catostomus commersoni*), and quillback (*Carpiodes cyprinus*). In the Assiniboine River, shorthead redhorse (*Moxostoma*

**Table 4-4**

**Common and scientific names of fish species captured in the Red and Assiniboine rivers, and selected tributaries, within the City of Winnipeg Ammonia Criteria Study Area, 1999.**

| | Common Name | Scientific Name |
|---|---|---|
| 1 | Bigmouth buffalo | *Ictiobus cyprinellus* |
| 2 | Black bullhead | *Ameiurus melas* |
| 3 | Black crappie | *Pomoxis nigromaculatus* |
| 4 | Brook stickleback | *Culaea inconstans* |
| 5 | Brown bullhead | *Ameiurus nebulosus* |
| 6 | Burbot | *Lota lota* |
| 7 | Carp | *Cyprinus carpio* |
| 8 | Channel catfish | *Ictalurus punctatus* |
| 9 | Emerald shiner | *Notropis atherinoides* |
| 10 | Fathead minnow | *Pimephales promelas* |
| 11 | Flathead chub | *Platygobio gracilus* |
| 12 | Freshwater drum | *Aplodinotus grunniens* |
| 13 | Golden redhorse | *Moxostoma erythrurum* |
| 14 | Goldeye | *Hiodon alosoides* |
| 15 | Johnny darter | *Etheostoma nigrum* |
| 16 | Lake cisco | *Coregonus artedi* |
| 17 | Mooneye | *Hiodon tergisus* |
| 18 | Northern pike | *Esox lucius* |
| 19 | Quillback | *Carpiodes cyprinus* |
| 20 | Rock bass | *Ambloplites rupestris* |
| 21 | River darter | *Percina shumardi* |
| 22 | River shiner | *Notropis blennius* |
| 23 | Sauger | *Stizostedion canadense* |
| 24 | Shorthead redhorse | *Moxostoma macrolepidotum* |
| 25 | Silver chub | *Macrhybopsis storeriana* |
| 26 | Silver redhorse | *Moxostoma anisurum* |
| 27 | Spotfin shiner | *Cyprinella spiloptera* |
| 28 | Spottail shiner | *Notropis hudsonius* |
| 29 | Stonecat | *Noturus flavus* |
| 30 | Tadpole madtom | *Noturus gyrinus* |
| 31 | Trout perch | *Percopsis omiscomaycus* |
| 32 | Walleye | *Stizostedion vitreum* |
| 33 | White bass | *Morone chrysops* |
| 34 | White sucker | *Catostomus commersoni* |
| 35 | Yellow perch | *Perca flavescens* |

*macrolepidotum*), channel catfish, sauger, carp (*Cyprinus carpio*), and freshwater drum (*Aplodinotus grunniens*) were the most abundant. Fathead minnow (*Pimephales promelas*), black bullhead (*Ameiurus melas*), black crappie (*Pomoxis nigromaculatus*), white bass (*Morone chrysops*), and river shiner (*Notropis blennius*) were the most abundant species captured in the four tributaries.

Gillnet catches were low in winter, with no fish captured in zones 3 and 4. Although gillnet sets in July and September were affected by high water velocities and debris, catches in zones 1 to 3 of the Red River were still approximately five times higher than in winter. Catches in the Assiniboine River in July and September were also several times higher than in winter.

Comparison of hoopnet data for the Red River to 1974 data (Clarke et al. 1980) suggests that almost every species was less abundant in 1999 than it was in 1974. However, differences in the way sampling locations were selected, higher flows and high levels of debris in 1999 contributed to the reduced Catch Per Unit Effort (CPUE). While growth rates and weight-length relationships differed between 1974 and 1999, no consistent pattern was observed for all species.

The Index of Biotic Integrity is widely used to assess the integrity of rivers and streams. The IBI is a composite index, based on an array of the following ecological attributes of fish communities: species richness and composition; trophic status; and fish abundance and condition. IBIs were calculated to allow comparison of the relative condition of the Red and Assiniboine rivers with waters of the upper Red River basin and other systems.

The IBI scores for the Red and Assiniboine rivers within the Study Area were 40 and 34, respectively, out of a possible 60. Red River mainstem sites in the United States ranged from 32 to 48 with a mean score of 39.5 (Niemela *et al*. 1999). This suggests that the health and condition of the fish community between Canadian and American portions of the Red River are similar. Comparison of the IBI scores for the Red and Assiniboine rivers with those from Ohio (where the IBI is used extensively), indicated the Red and Assiniboine rivers appear to meet the minimum recommended IBI score for warm-water habitat use. However, examination of the IBI data suggested potential signs of stress in the fish communities of both rivers: a low proportion of large river individuals in the Assiniboine River; low evenness values in the Assiniboine River and, to a lesser extent, the Red River; a high proportion of tolerant individuals in the Red and

Assiniboine rivers; skewed trophic structure in the Red River; and, a high proportion of DELTs in the Assiniboine River and, to a lesser extent, in the Red River.

Fish Population TM 03 - Abundance, Composition, and Distribution of Benthic Invertebrates in the Red and Assiniboine Rivers Within the City of Winnipeg, 1999

The objective of this study was the characterization of benthic populations and benthic biomass in the reaches of the Red and Assiniboine within the Study Area. This study compared the benthic invertebrate communities among different zones, among different bottom substrate types, between seasons, and to historical data available for the Red and Assiniboine rivers.

Two surveys were conducted to describe the benthic invertebrate community and bottom substrate in the Red and Assiniboine rivers. The first survey was conducted in February - March, 1999 and the second in August - October, 1999

During the first survey, the benthos and bottom substrate composition were sampled using a “petit” Ponar Dredge; 26 segments were sampled on the Red River and six segments on the Assiniboine River. Generally, three dredge samples (replicates) were taken at each site to assess within-site variability. During the second survey, sampling was conducted using a “petit” Ponar Dredge; 28 segments were sampled on the Red River and nine on the Assiniboine River. Generally, three replicates were taken at each site. Benthos was also qualitatively sampled in 16 segments using Artificial Substrate Samplers (samplers) during the second survey; 10 segments were sampled on the Red River and six on the Assiniboine River. Three samplers were installed at each site.

Invertebrate taxa collected from the Red and Assiniboine rivers within the Study Area are listed in Table 4-3. In winter, 24 taxa were identified from soft-medium bottom substrates in the Red River and 10 taxa were identified in the Assiniboine River. The greatest number of taxa were observed in Zone 2 and the fewest in Zone 4. Total invertebrate abundance was greatest immediately downstream of the NEWPCC outfall. In fall, 25 taxa were identified from soft-medium bottom substrates in the Red River and 15 taxa were identified in the Assiniboine River. The greatest number of taxa were again observed in Zone 2, however, the fewest were observed immediately downstream of the SEWPCC outfall. Total invertebrate abundance was again greatest immediately downstream of the NEWPCC outfall.

From hard bottom substrates, 26 taxa were identified in the Red River and 29 taxa in the Assiniboine River. The greatest number of taxa were reported from Zone 4 and the fewest from Zone 1. Total invertebrate abundance was greatest in Zone 5. Insecta (primarily Trichoptera) was the most important group in both rivers.

Organic content in sediments was highest in the Red River while the Assiniboine River was characterized as having a greater fraction of sand than the Red River. The lower number of taxa in soft-medium bottom substrate in the Assiniboine River may be due to the lower organic content, sandy bottom substrate providing less adequate habitat for benthic invertebrates.

Prior to the present surveys, benthic invertebrates in the Red River were sampled by R. McV. Clarke (DFO) in 1973 and 1974 and by the City of Winnipeg (Laboratory Services Division of the Water and Waste Department) from 1971 to 1980 and in 1992, 1994, 1996. Surveys conducted by the City of Winnipeg from 1971 to 1980 documented temporal and spatial variation in the predominance of types of organisms; a trend toward greater or fewer numbers of taxa at any particular site was not evident over the 10 year period. In 1996, the City of Winnipeg reported that there were pollution-intolerant taxa observed throughout the Red River, including downstream of the SEWPCC and NEWPCC outfalls.

### 4.3.3 Observations and Conclusions

Fish Community

A total of 5,445 fish were captured in this study. Of these, 2,215 fish (31 species) were captured in the Red River (see Table 4-3); 737 fish (26 species) were captured in the Assiniboine River; and 2,493 fish (26 species) were captured from Bunns Creek, Sturgeon Creek, La Salle River, and the Seine River.

Comparison of catch data for the Red River to that of 1974 (Clarke et al. 1980) suggests that the relative abundance of four of the five most commonly captured species in 1974 (sauger, freshwater drum, white sucker, and channel catfish) have remained approximately the same. Differences in Catch Per Unit Effort (CPUE) for hoop nets set in the Red River during July, August, and September in 1974 and 1999 suggest that most species were less abundant in

1999 than they were in 1974. However, differences in sampling site selection, hoop net mesh sizes, and streamflow likely contributed to the lower CPUE observed in 1999. While comparison between 1974 and 1999 data showed differences in growth rates and weight-length relationships among species, no consistent pattern was observed.

During winter, gillnet catches were low in most zones. CPUE in Zone 3A (Lockport to Selkirk) was approximately six times higher than that of any other zone. Although gillnet catches in July and September, were affected by high water velocities and debris, open-water were much higher than those in winter.

While one or more weak or absent year-classes were apparent for some species, there did not appear to be a specific year (or years) in which a number of species displayed weak or absent year-classes. This suggests that the absence of specific cohorts was probably due to a variety of factors, and represented natural variation in the year-class strength of individual species.

Fish Health

Due to low catches of fish in zones 1A and 3A, and differences in the relative abundance of fish species captured in each zone, comparisons of DELT frequencies between zones was difficult. Furthermore, as fish are mobile within the Study Area (FB #03, Section 3.4), it was difficult to determine exposure of individual fish to municipal wastewater discharges.

Benthic fish species generally exhibited more DELTs than pelagic species, possibly due to their high degree of contact with sediments which typically contain the highest concentrations of contaminants in the aquatic environment. Overall, the frequencies of DELTs observed on fish captured may indicate some degree of impairment of the aquatic environment. However, in the absence of well defined ”background” levels of DELTs in the watershed or ecoregion, a more precise interpretation of this level of impairment is not possible. Direct comparisons to frequencies of DELTs reported in the literature are difficult due to the lack of a consistent methodology among researchers.

### 4.3.4 Addressing Key Questions

Each of the three studies contributed to improving the understanding of aquatic life and aquatic habitat in the Study Area. The contribution of each study can be illustrated more clearly by examining the specific components of Question #4:

- What is there?
- What are we trying to protect?
- What condition are fish in?
- What habitats do fish use?
- How do fish behave?
- How are fish exposed (frequency/duration/health)?

Fish Populations TM FP #01 provided a description of the condition and health of fish within the City of Winnipeg Ammonia Criteria Study Area.

Within this assessment of health of fish populations in the Red and Assiniboine rivers, a variety of health anomalies were observed on fish captured in these rivers. Observed deformities included: wavy fin rays; shortened fins; curved fins; curvature of the spine (tordosis, kyphosis, and scoliosis); and mouth deformities. The most frequently observed external deformities affected the fins. Observed erosion included fin erosion and rot and missing barbells, with the former occurring much more frequently than the latter. Lesions observed in this study included: cysts; cataracts and haemorrhaging eyes; missing scales associated with inflammation; raised scales; exposed tissue; raised open sores; and ulcers. Tumours were most commonly observed on or at the base of the pectoral fins, the operculum, and under the mouths of fish.

Fish Populations TM FP #02 addressed species composition, abundance, and distribution of fish, their relative condition, and what habitat types they use. Therefore, the component questions “What is there?”, “What are we trying to protect?”, “What condition are fish in?”, and “What habitats do fish use?” were all addressed in this TM.

While one of the tasks of this workstream was to relate biological parameters of the fish community to levels of aqueous ammonia in the study area, higher than usual flows in the Red and Assiniboine rivers during much of the mid to late 1990s, in particular 1999, resulted in lower in-stream concentrations of ammonia. The flow-induced lower ammonia concentrations prevented assessment of the of the relationship between biological parameters and ammonia concentrations. As a consequence of the low ammonia levels, the overall objective of this workstream (TM FP #02) shifted to providing a biological description of the fish community in the study area in order to identify which aquatic species require protection in the rivers.

The studies indicated no consistent trends between catch-per-unit effort (CPUE) and habitat type within the study area. Fish likely move freely over a variety of habitat types. The abovementioned high river flows also resulted in high debris levels, resulting in reduced effectiveness of sampling gear. Fish catches varied considerably between and among gear types.

The five most abundance species in the Red River were channel catfish, sauger, goldeye, white sucker and quillback. The five most abundant species in the Assiniboine River were shorthead redhorse, channel catfish, sauger, carp and freshwater drum. Carp, channel catfish, freshwater drum, silver redhorse and walleye captured in the Assiniboine River were larger on average than those captured in the Red River. It is suspected that higher water velocities in the Assiniboine River and/or more suitable habitat for juvenile fish in the Red River may explain this size difference.

Comparison of catch data in the Red River from the present study with that of previous studies (Clarke *et al*. 1974) suggests that the relative abundance of four of the five most commonly captured species in 1974 have remained approximately the same. Black bullhead and emerald shiner were captured more frequently. Differences in CPUE data for hoop nets between the 1974 and 1999 studies suggest that almost every species was less abundant in 1999 than it was in 1974. While comparison between 1974 and 1999 data showed differences in growth-rates and weight-length relationships among species, no consistent pattern was observed for all species. Comparison of Index of Biotic Integrity (IBI) values between Canadian and American portions of the Red River suggests that the health and condition of the fish communities are similar. However, examination of the IBI data suggested potential signs of stress in the fish communities of both rivers, including:

- a low proportion of large river fish in the Assiniboine River;
- low evenness values in the Assiniboine River;

- a high proportion of tolerant fish individuals in both the Red and Assiniboine rivers;
- skewed trophic structure in the Red River; and
- a high proportion of DELTs in the Assiniboine River and, to a lesser extent, the Red River.

Fish behaviour patterns and potential exposure to ammonia were addressed by this TM to a lesser extent. Information on species composition, abundance, and distribution of fish during winter, July, and September suggested that while some fish overwinter within the study area, a large number appear to move out prior to winter.

Fish Populations TM # FP 03 characterized the benthic invertebrate community providing information on ”What is there?” and “What are we trying to protect?” and, to a lesser extent, further describing the habitats that fish use.

Field surveys for benthic invertebrates were conducted in both the winter and fall seasons of 1999. During the winter survey, benthic vertebrates were found to be spatially heterogeneous, with the greatest number of taxa reported in a zone extending downstream of the SEWPCC outfall to upstream of the NEWPCC outfall on the Red River (Zone 2). The fewest taxa were reported in a zone extending from downstream of the WEWPCC outfall on the Assiniboine River downstream to the confluence of the Red and Assiniboine rivers (Zone 4). Total invertebrate abundance in winter was found to be greatest immediately downstream of the NEWPCC outfall. A zone (Zone 5) extending from Headingley downstream to the WEWPCC on the Assiniboine River had the lowest total invertebrate abundance.

During the fall survey, benthic invertebrates were spatially heterogeneous, as was the case in the winter survey. Total invertebrate abundance in fall was greatest immediately downstream of the NEWPCC outfall. In contrast to the winter survey, Zone 5 had one of the higher total invertebrate abundances in the fall survey.

Each of the three studies provided information to characterize the species composition, abundance, distribution, or condition of aquatic life within the Study Area and, therefore, helped to address Question #7.

## 4.4 FISH BEHAVIOUR WORKSTREAM

Studies of fish behaviour revealed that fish travelled significant distances throughout the study area. It was observed that plumes from pollution control centres do affect fish distributions. In fact, some fish displayed an attraction to areas under influence of discharge plumes. At the NEWPCC plume, pike were observed to be attracted during winter months, and at the WEWPCC plume, carp were observed to be attracted in the fall season. While evidence of fish attraction to certain plumes was observed, the ability of tagged pike to leave the NEWPCC are suggests that the presence of the plumes do not present barriers to fish in the winter. Tagged fish in general were found to be highly mobile and tracking data suggested that fish may migrate into and out of the study area on a seasonal basis. This suggests that exposure of fish to municipal sewage effluents is generally intermittent, and may vary with season.

### 4.4.1 <u>The Objectives</u>

The primary objective of the fish behaviour workstream was to determine the extent to which fish behaviour causes or minimizes fish exposure to un-ionized ammonia in effluent plumes during different seasons of the year. Several sub-objectives of the fish behaviour workstream included:

- determining if fish move among areas of varying ammonia, or are attracted to, or resident in areas of higher exposure;

- determining if effluent plumes act as chemical barriers to seasonal fish movements; and,

- determining if there are significant small-scale differences in fish distribution in relation to ammonia gradients in effluent mixing zones, to assess:

    a) the potential for exposure to ammonia concentrations associated with severe chronic affects;
    b) the potential for loss of fish habitat due to avoidance of areas with high ammonia concentrations; and,

c) using optional controlled-condition experiments, whether ammonia is the constituent in the sewage that elicits a behavioural response from fish (either avoidance or attraction).

The key question that the fish behaviour workstream responded to was Question #4:

Q4. What do we know about aquatic life, aquatic habitat, and potential ammonia impairment?

### 4.4.2 The Studies

Fish Behaviour Technical Memorandum # FB 01 - Biological and Environmental Data from Experimental Gillnetting in the Vicinity of the NEWPCC Outfall, March, 1999

This study objective was to determine the distribution of fish in relation to the ammonia gradient in the vicinity of the NEWPCC outfall. Gillnetting and water sampling for depth, pH, water temperature, dissolved oxygen, total ammonia (from which the level of un-ionized ammonia was calculated), and water velocity, were conducted in the vicinity of the NEWPCC outfall between March 16 and 23, 1999.

Total ammonia concentrations during the sampling period were highest in the surface waters immediately adjacent to the NEWPCC outfall (5.70 mg/L to 0.20 mg/L). Total ammonia was generally higher at nearshore sampling locations along the right bank (facing upstream) and declined with increasing distance downstream of the outfall.

A total of 16 fish, from four species, were captured in gill nets set immediately downstream of the NEWPCC outfall. All fish were captured in nets set near the bottom. The most abundant species was northern pike (n=11), followed by white sucker, goldeye, and mooneye. No fish were captured at the reference site upstream of the outfall (~150 m upstream of an abandoned railway bridge) and more fish were caught closer to the outfall than further downstream – an apparent trend that could not be confirmed statistically owing to the small number of samples at each location.

Fish Behaviour Technical Memorandum # FB 02 - Biological and Environmental Data from Experimental Netting in the Vicinity of the NEWPCC Outfall, October, 1999

Hoopnetting was conducted from October 4 to October 8, 1999, at four sites in the vicinity of the NEWPCC outfall to determine abundance and diversity of fish species utilizing the outfall area. Sites #1, #2, and #3 were located approximately 85m, 150m, and 350m downstream of the NEWPCC outfall, respectively. Site #4, a reference site, was located approximately 400m upstream of the NEWPCC outfall. Water samples were also collected at netting sites prior to net sets, to measure total. Water temperature, pH, and dissolved oxygen were also measured at 0.5 m depth intervals.

Total ammonia concentrations were highest at sites immediately downstream of the NEWPCC outfall (0.68 mg/L to 9.6 mg/L) and lowest at the reference site (0.01 mg/L to 0.11 mg/L). Total ammonia concentrations generally declined with increasing distance downstream of the NEWPCC outfall. Water temperature was higher (9.8$^{o}$C to 11$^{o}$C) immediately downstream of the NEWPCC outfall, while at site #3 it was similar to the control site (8.4$^{o}$C to 9.0$^{o}$C).

A total of 458 fish, comprising 15 species, were captured. The most abundant species captured were channel catfish (n=253), sauger (n=93), quillback (n=52), and white sucker (n=28). The largest single catch occurred on October 5 at the reference site (213 channel catfish, 7 sauger, and 3 white sucker). CPUE (# of fish/hoopnet/hour) was highest at the reference site (3.46), and decreased with increasing distance downstream from the NEWPCC outfall (site #1 = 1.06, site #2 = 0.42, and site #3 = 0.26).

Fish Behaviour Technical Memorandum # FB 03 - Movements of Fish Tagged with Acoustic Transmitters in the Vicinity of the City of Winnipeg's Water Pollution Control Centres, 1999-2000

The movements of 49 fish (5 species) that were captured downstream of the City of Winnipeg's Water Pollution Control Centres and tagged with acoustic transmitters were followed between August 1999 and February 2000. Three stationary receivers placed at the three boundaries of the study area (the Red River between the South Perimeter Bridge and Sugar Island north of Selkirk, and the Assiniboine River from just west of the WEWPCC and its confluence with the Red River) were used to determine the date and time that fish left or re-entered the area. A portable receiver was also used to track fish movements within the study area.

During late summer, carp and freshwater drum were located in the vicinity of the WEWPCC and NEWPCC outfalls respectively and may have been attracted to the outfalls. No tagged channel catfish or walleye were located within 2 km of any of the City of Winnipeg Water Pollution Control Centres outfalls, which suggests that these two species may not be attracted to the outfalls.

Prior to the onset of winter 57% of fish tagged within the City of Winnipeg moved out of the study area (39% north and 14% south in the Red River, and 4% west in the Assiniboine River). Fish moved past each of the City of Winnipeg Water Pollution Control Centres effluent plumes, which suggests that during the open water period plumes where not acting as barriers to fish movements. At least 18% of the fish tagged are known to have remained in the study area during the winter.

Tagged fish were highly mobile and tracking data suggest that fish may migrate into and out of the study area on a seasonal basis. As a result of these characteristics it seems likely that exposure of fish to municipal sewage effluents is generally intermittent, and may vary with season.

<u>Fish Behaviour Technical Memorandum # FB 04 - Movements of 10 Northern Pike Tagged with Acoustic Transmitters in the Red River in the Vicinity of the NEWPCC Effluent Plume, February-March, 2000</u>

The two objectives of the study were to: 1) determine the distribution of northern pike in relation to ammonia gradients in the vicinity of the NEWPCC effluent plume; and, 2) determine the duration of time that fish remain within the direct influence of the NEWPCC effluent plume. The movements of ten northern pike fitted with surgically implanted internal acoustic transmitters (with temperature sensors) were monitored with a radio-linked acoustic positioning system that recorded the position of each fish every five minutes between February 14 and March 9, 2000. To relate the movements and positions of tagged fish to ammonia concentrations a map of modeled, ”average” ammonia concentrations during the study period was created.

Results of the tracking indicated that northern pike were attracted to the vicinity of the NEWPCC effluent plume during the study period. During this time individual fish remained in the vicinity of NEWPCC plume for extended periods of time, at least 21 days. This indicates that fish were, therefore, exposed to elevated levels of ammonia for longer periods of time than if they had just been passing through the area. However, tagged fish did display definite preferences for certain areas in the vicinity of the NEWPCC plume. The area where fish were most frequently located was a short distance upstream of the NEWPCC outfall. This area was outside of the direct influence of the plume and would not have had significantly elevated ammonia levels or warmer water temperatures. Tagged fish were next most frequently located in an area immediately downstream of the NEWPCC outfall, which was in the direct influence of the plume and would have had elevated ammonia levels and warmer temperatures. Movements into the plume may have been related to feeding or other activities, and were often of short duration, followed by a return to waters upstream of the outfall.

The amount of time that individual northern pike were located within the direct influence of the NEWPCC plume varied between single detections (less than ten minutes) to periods of up to ten hours. However, certain aspects of fish behaviour that appeared to reduce potential exposure levels included:

- fish tended to be located within the plume for shorter periods of time during periods of peak effluent discharges;
- fish were located within the plume less frequently during periods of higher effluent discharge; and,
- most fish movements into the plume were short in duration, followed by a longer period of time outside the direct influence of the plume.

### 4.4.3 Conclusions

Some species of fish displayed an attraction to the NEWPCC plume during the winter months. This is evident from the general tendency for CPUE to decrease with increasing distance downstream of the outfall, and in the tendency for tagged northern pike to remain in the vicinity of the NEWPCC outfall for long periods of time. In the summer and fall, fish did not appear to exhibit as great an attraction to the City of Winnipeg’s Water Pollution Control Centres effluent plumes. Although there was a general tendency for some species to be located in the vicinity of the City of Winnipeg’s Water Pollution Control Centres effluent outfalls during the summer (carp and freshwater drum), or fall (quillback), other species (channel catfish and walleye) did not appear to have a strong attraction to the outfalls.

During the open water period the City of Winnipeg's Water Pollution Control Centres effluent plumes did not appear to be a barrier to fish movement. However, it is not known if higher ammonia concentrations in years with lower river discharge would affect fish movements. Extensive fish movements that were observed during the open water period, indicate that most exposures to high concentrations of ammonia are intermittent. During the winter some species of fish, such as northern pike, show a definite attraction to the outfall areas. **The ability of tagged northern pike to leave the vicinity of the NEWPCC outfall in both upstream and downstream directions suggests that the plumes do not act as a barrier to fish movements in the winter**. However, these areas do attract a disproportionately high number of fish, and therefore do influence fish distributions. These areas contain both higher ammonia concentrations and higher temperatures at this time of year than other areas of the rivers and therefore result in increased exposure to elevated levels of ammonia.

#### 4.4.4 Addressing the Relevant Key Question

The studies conducted in the fish behaviour workstream addressed Key Question #4. Additional questions related to Key Question #4 included:

- What is there?
- What are we trying to protect?
- What condition are they (fish in this workstream) in?
- What habitats do fish use?
- How do fish behave?
- How are they exposed (frequency/duration/health)?

Fish Behaviour Technical Memorandum # FB 01 addressed the questions of what species and abundances of fish where located within the vicinity of the NEWPCC effluent plume in the winter (March), while Fish Behaviour Technical Memorandum # FB 02 addressed the same questions for the fall (October). High catches of fish in the areas immediately downstream of the

NEWPCC plume also confirmed that fish are exposed elevated ammonia levels, but did not indicate the duration of exposure.

Fish Behaviour Technical Memorandum # FB 03 addressed the question of whether the effluent plumes act as a barrier to fish movements. Field studies involving tracking the movements of 49 fish representing five species were conducted using tagging with acoustic transmitters in locations downstream of the City of Winnipeg's Water Pollution Control Centres from August 1999 to February 2000. A large percentage (57%) of fish tagged within the City of Winnipeg moved out of the study area prior to the onset of winter; 39% and 14% moved north and south of the Red River, respectively, and 4% moved west on the Assiniboine River. In these movements, fish moved through or around each of the City's effluent plumes, suggesting that the plumes were not acting as barriers to fish during the open water period. This study also examined the timing and patterns of fish movement in the study area and the possible influence of effluent plumes on these patterns. The study also revealed overwintering habitats of some species and provided a general concept of the potential for fish exposure to elevated ammonia levels in the City of Winnipeg's Water Pollution Control Centres effluent plumes.

Fish Behaviour Technical Memorandum # FB 04 examined the frequency and duration of winter-time exposure of fish to elevated ammonia levels that are associated with the NEWPCC effluent plume. The fact that northern pike remained in the vicinity of the NEWPCC plume for long periods of time, and the observed small-scale habitat preferences, suggested that the plume was having a definite effect on patterns of fish movement.

## 4.5 OTHER STRESSORS: PHYSICAL CONSTRAINTS WORKSTREAM

### 4.5.1 Objectives of Workstream

The primary objective of the Other Stressors; Physical Constraints Workstream was to describe biophysical stressors within the study area, to provide a context for the consideration of ammonia as a stressor on aquatic life in the Red and Assiniboine Rivers.

A number of key questions were identified by the study team for the Red and Assiniboine Ammonia Criteria Study to confirm the relevance of the individual workstreams. The Other Stressors; Physical Constraints Workstream directly responded to Question #8:

Q8. What are other parameters potentially affecting aquatic life in local rivers?

### 4.5.2 Studies Conducted

Other Stressors; Physical Constraints Technical Memorandum #OSPC01

The Other Stressors; Physical Constraints Technical Memorandum represented a synthesis of information obtained from literature searches, original research conducted as part of other workstreams of the Ammonia Criteria Study, and key person interviews.

A list of potential physical constraints to fish populations in the Red and Assiniboine rivers was presented, with discussion regarding the nature and relative severity of individual stressors to fish populations. Types of physical constraints included habitat loss and alteration, obstruction to fish passage, and fish injury and mortality. The discussion of specific potential biophysical stressors included:

- St. Andrews Lock and Dam;
- Historical loss of tributary and headwater habitat;
- Rip-rap and bank stabilization;
- Bridges, docks, and boat launches;
- Floodway control structure;
- Entrainment and impingement of fish in water intakes;
- Thermal effluents; and,
- Physical damage to fish caused by boat traffic.

### 4.5.3 Observations/Conclusions

Biophysical constraints that have the potential to significantly affect either the short-term or long-term productive capacity of the study area may include the historical loss of habitat caused by the channelization and drainage of tributary and headwater areas, the habitat alteration and possible obstruction to fish passage caused by operation of the St. Andrews control structure, and the temporary blockage to fish passage which occurs during operation of the Floodway gates. Other potential constraints are not, individually, expected to significantly affect the capacity of the study area to support fish populations. The potential cumulative effect of these stressors on reproductive capacity was beyond the scope of this study.

### 4.5.4 Addressing the Relevant Key Question

The Other Stressors Workstream directly responded to Question #8:

Q8. What are other parameters potentially affecting aquatic life in local rivers?

Parameters to be addressed in Question #8 included biophysical constraints, resource harvesting, and chemical exposure. Other Stressors; Physical Constraints Technical Memorandum # OSPC 01 addressed biophysical constraints within the study area. Resource harvesting and chemical exposure were addressed in their respective workstreams.

## 4.6 OTHER STRESSORS: RESOURCE HARVESTING

The key question relating to this workstream was:

- **Question 8** – What are other parameters potentially affecting aquatic life in the local rivers?

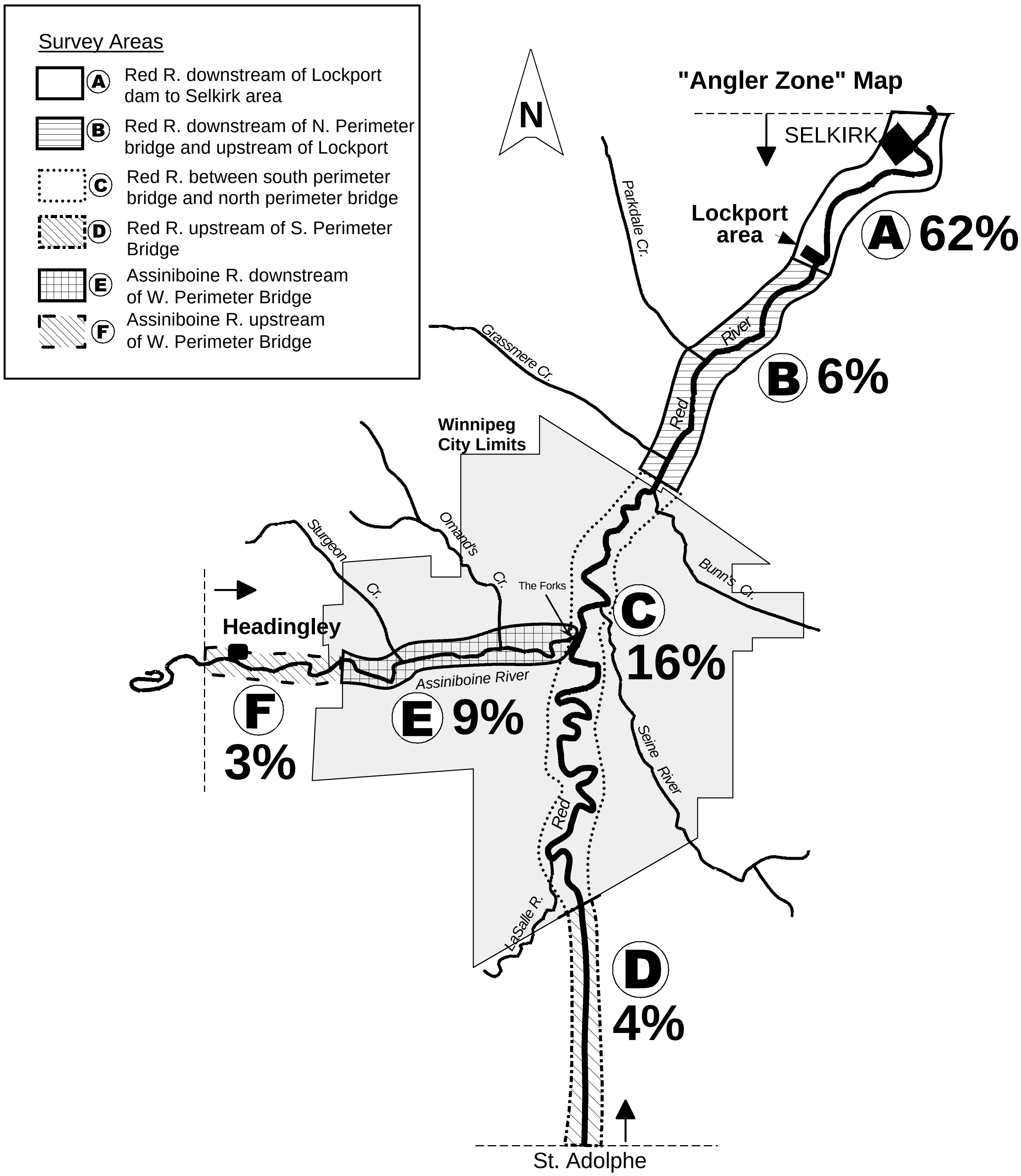
The following presents the key observations of this Resource Harvesting Workstream. The resource harvesting information is based on a questionnaire of anglers and cannot be considered a rigorous scientific assessment of the fisheries.

### 4.6.1 Relative Impact to Fish Populations

Angler questionnaire results show that the reach of the Red River within the study area (ref. Figure 1-2) receives approximately 6 to 7 times more harvesting pressure in terms of angler-days than the Assiniboine River with the majority of angler-days (approximately 62%) spent in the Lockport area 20 km downstream of the City of Winnipeg (data from this study and DNR 1995; ref. Figure 4-5). This disproportionate number of angler-days spent on the Red River correlates with a significantly larger proportion of fish angled from the Red River compared to the Assiniboine River. Manitoba Conservation data from a questionnaire survey of anglers conducted in 1995 estimate that approximately seven times more fish are caught in the Red River than the Assiniboine River (Wall *pers. comm.* 1999). Regarding forage fish species, licenced bait fishing only occurs upstream of Lockport within the study area.

Although proportionally more fish are caught in the Red River compared to the Assiniboine River each year, the Red River also provides significantly more fish habitat area within the study area and therefore likely supports much larger fish populations, although estimate ranges of total fish populations in the two rivers within the study area cannot be accurately determined with existing data (Remnant *pers. comm.* 2000).

A certain proportion of the fish populations in both rivers are caught each year by anglers, however, it is unlikely that all fish caught are removed from the populations since certain proportions of fish caught are subsequently released. Results of this and other studies indicate that, overall, the majority of fish caught by anglers on the Red and Assiniboine rivers are released (approximate range 81% to 86%; refer to this study's angler questionnaire results and DNR/DFO 1995 questionnaire data [Wall *pers. comm.* 1999 in Section 4.1.1.3 of Resource Harvesting TM]). Observations of anglers during on-site angler surveys along these rivers suggest that most fish are immediately released rather than held in live wells since approximately 81% to 94% of anglers along these rivers fish from shore, docks or other structures rather than boats (ref. Appendices D to F of Resource Harvesting TM and Kitch 1994) and do not have live well storage with them as opposed to some fishing boats. Immediate release of angled fish may increase probability of released fish survival. A certain proportion of fish that are caught then released by angling likely die as a result of injury and stress.




n = 218 respondents

**Average Percent Fishing Time in Each Angler Zone in 1998**

Figure 4-5

TetrES
CONSULTANTS INC.

Q2 s\01\0110\22\reshvst

The few studies that have investigated mortality rates resulting from catch and release angling suggest that mortality rates vary considerably and are influenced by factors such as fish species, size of fish, type of bait (especially size and type of hook), angling time, season and air temperature (e.g., Carbines 1999; Thompson *et al*. 1999; Bettoli and Osborne 1998; Lukacovic and Uphoff 1998; Nelson 1998). Therefore, the mortality rates for fish caught and released in the Red and Assiniboine rivers cannot be accurately estimated. Although all forage fish species caught by bait fishers are removed from the population, no population studies of forage fish in the Red River are available. Therefore the proportion of forage fish removed annually from the Red River cannot be estimated.

There is also a species bias regarding fish that are removed from the Red and Assiniboine rivers by angling and bait fishing practices. Anglers catch proportionately more catfish species, walleye and freshwater drum than any other fish species. Walleye are more commonly kept than the other most commonly caught species (ref. Section 4.1.1.3 and Tables 4-4 and 4-7 of Resource Harvesting TM). Bait fishers primarily remove two species of forage fish (emerald shiners and spottail shiners; ref. Section 4.2.1 of Resource Harvesting TM). Since the various fish species that occur in the Red and Assiniboine river systems occupy different “niches” in these two riparian ecosystems it is likely that any “significant” disruption or shift in any one species population will likely affect other species populations to varying degrees. Results of the various Red and Assiniboine river angler surveys that have been done to date provide no evidence to suggest any significant impact has occurred to fish populations as a result of sport or bait fishing.

### 4.6.2 <u>Relative Health of the Fishing Industry</u>

It is assumed that any significant decrease in key fish species populations would affect the numbers of anglers and bait fishers willing to spend time and other resources fishing on these rivers and would thus negatively affect the overall perceived “health” of the fishing industry. The relative “health” of the fishing industry on the Red and Assiniboine rivers is closely related to the overall “health” of fish populations and is gauged primarily by changes in overall fishing effort each year and sport and bait fishers’ perceptions of their fishing success over time.

Regarding the sport fishing industry on the Red and Assiniboine rivers, results of Manitoba Conservation angler surveys conducted every five years since 1985 have indicated increased angler effort (in terms of angler-days) during the 1990s in the southern designated sport fishing area of Manitoba which includes the Red and Assiniboine rivers (ref. Figure 4-1 of Resource Harvesting TM). Bait fishing efforts by licenced bait fishers on the Red River have remained relatively stable over the past 10 years (Scaife *pers. comm*. 1999).

In general, angler perceptions of their fishing success and the quality of fishing along the Red and Assiniboine rivers since 1994 have been primarily described as "increasing or staying about the same" for fishing success and "good" to "excellent" for quality of fishing (ref. Section 4.1.4.1 of Resource Harvesting TM). Only one bait fisher indicated an overall decrease in bait fishing success with four bait fishers indicating an overall increase or no change in success (ref. Table 4-17 of Resource Harvesting TM).

This study's assessment of angler and bait fishers' perception of their fishing success over time suggests that there is no overall negative trend in fishing success even though many anglers remain concerned about river water quality (ref. Section 4.1.4.2 of Resource Harvesting TM). In general, the "health" of the fishing industry appears to be stable, suggesting that fish populations are also generally stable. Resource Harvesting does not appear to be impacting fish populations in the Red and Assiniboine rivers to any detectable level.

### 4.6.3 Implications Regarding Ammonia Control

Although no conclusions can be made regarding possible effects of ammonia discharges from City WPCCs on fish populations or angler and bait fishing success, results of this study and previous angler surveys indicate that key sport and bait fish populations have remained relatively stable for at least the past six years.

Overall, the results of this resource harvesting study of the Red and Assiniboine rivers indicate that the sport and bait fisheries of the study area appear healthy and display no patterns which could be attributed to potential stresses such as ammonia discharges from the City's WPCCs.

## 4.7 TOXICITY TESTING PROGRAM

Following the workshop held in February 1999, several key questions (Questions 5, 7 and 8, Table 4-1) were considered to "drive" the design of the testing program. The most important question is:

- **Question 5** – what is the scientific basis of the toxicity database with respect to local aquatic life?

These questions relate to:

- data gaps in existing toxicity literature which would otherwise aid in derivation of locally-appropriate site-specific criteria for the Red and Assiniboine Rivers; and
- the general test design needed to be adopted to fill these data gaps.

With the completion of the toxicity-testing program, answers to the suite of questions driving the development of the program have emerged. The key points which "drove" the design of the test program in order to provide a solid scientific basis for development of a criteria are discussed below.

### 4.7.1 <u>Data Gaps</u>

There was inadequate data available in the public domain to describe the sensitivities of local Red and Assiniboine River biota to both acute- and chronic-ammonia exposures.

Chronic exposure data are lacking, particularly at low temperatures, and for juvenile fish. Some of the public-domain data are inapplicable and/or methodologically questionable.

The key local Red and Assiniboine River species for which there are inadequate toxicity data on ammonia sensitivity are northern pike, walleye, sauger, white sucker, mooneye, goldeye, mussels and clams. There is a moderate amount of information of ammonia sensitivities of bullhead, channel catfish and carp.

Those which have sufficient ecological, economic or social significance as to require testing to determine their sensitivity to un-ionized ammonia are pike, walleye, white sucker, catfish, mussels and clams.

Good data exist for standard test matrices that are known or suspected to be present in the Red and Assiniboine Rivers (e.g., fathead minnow, channel catfish, Ceriodaphnia, Hyalella) but the test conditions for these species are not representative of local conditions. Because the data reported for these species were created under conditions unreflective of local limnological conditions, the case exists for these species to be re-tested under local conditions such that the confounding effect of "standard laboratory conditions" on toxicity results can be identified.

All these species will be exposed to effluent plumes with elevated un-ionized ammonia, especially in late summer and fall under low-flow conditions. Northern pike and white sucker have been shown (see Fish Behaviour TM #03) to be exposed to plumes in winter, as have mooneye (Tetr*ES* Consultants 1993), and carp have been shown to be exposed to plumes in summer and fall (see fish Population and Behaviour TM).

The life-cycle stages typically used in testing are appropriate for developing locally-appropriate protective criteria for these species. However, many data in the public-domain dataset are for adults. In fall and winter, sub-adults of many local species would be exposed when un-ionized ammonia concentrations are most problematic, suggesting the need to create data for more sensitive sub-adult (juvenile, larval) life-cycle stages. Young fish are more practical to work with than older, larger fish, but more importantly, the early life stage of fish is a highly sensitive period and criteria derivation with young fish will more closely reflect threshold limits for the toxicant. This is a conservative assumption which provides confidence in the protective value of a criteria.

The test-exposure conditions most appropriate for determining locally-appropriate protective criteria are; low-flow conditions, high pH (>8.0), and high- and low-temperature conditions, using river water (including its microscopic life) as the aqueous medium instead of dechlorinated and/or filtered laboratory tap water.

The dynamics of "exposure" in available data adequately represent site-specific exposures. Public-domain data are based on testing under "standard laboratory conditions"; e.g., "tap" water at “room temperature” (usually 20°C) with relatively unvarying concentrations of the test chemical. The exposure conditions inherent in “standard laboratory conditions” are, themselves, a stress which confounds the testing for effects of a test chemical. The extent of this stress, and the confounding of the data in the public-domain dataset, is an emerging area of careful scientific inquiry (e.g., Salazar and Salazar 1999, 2000) causing, in some case, reconsideration of regulatory criteria derived from this dataset (e.g., Kemper *et al.* 1997).

### 4.7.2 Test Design and Method

The methods most appropriate for determining thresholds for responses of the selected test species to acute- and chronic-exposures of $NH_3$ include combinations of toxicant-spiked river water and toxicant-spiked effluent under actual river-temperature conditions, supplemented with data from variable *in situ* exposures of selected test matrices (e.g., mussels).

No single test system can fill the data gaps. Both laboratory and *in situ* tests are needed. The “real world” non-representativeness of the obligate exposures in lab testing requires complementary data from the non-obligate exposures from *in situ* tests.

To establish the linkage between “exposure” and “effects” in *in situ* testing, biomarkers in the flesh of test matrices and relating any pattern observed against trends in water chemistry, survival and/or growth were used.

The effects (“endpoints”) in selected test biota appropriate for testing ammonia sensitivity under controlled “laboratory” conditions are; a combination of growth (i.e., morphometrics), and survivorship. *An “*$EC_{20}$ *or* $LC_{20}$*”* (as noted by the U.S. EPA [1999]) were used as locally appropriate indicators of “significant” response.

### 4.7.3 Discussion of Difference in Public Domain and Local Tests

In 1999, the U.S. EPA published its *Update of Ambient Water-quality Criteria for Ammonia* for the protection of freshwater aquatic life. Both acute and chronic-exposure data are documented. Chronic-exposure data generated in studies reported by the U.S. EPA (1999a) can be compared with data derived by Tetr*ES* Consultants in the toxicity-testing program for the City of Winnipeg.

Table 4-5 tabulates LC/$EC_{20}$s for chronic-exposure studies with three species of fish (i.e., fathead minnows, white sucker and channel catfish) and two species of invertebrates (i.e., *Ceriodaphnia dubia* and *Hyalella azteca*) that are common to both the EPA dataset and to Tetr*ES*' dataset. All public domain results have been converted from total ammonia to $NH_3$ by reversing the calculations described by U.S. EPA (1999, p. 107). Datasets were considered comparable if test-duration, life-stage of test-organisms, and endpoint-of-interest were the same or similar for a particular species.

Fathead minnow survival data showed a high degree of variance between $LC_{20}$'s calculated using data generated by Mayes *et al.* (1986) versus Tetr*ES* Consultants. The lethal un-ionized ammonia concentration affecting 20% of the test-population studied by Mayes *et al.* (1986) was 0.33 mg/L. Alternately, neither of the two tests conducted by Tetr*ES* on fathead minnows produced a lethality response in more than 20% of the population. Therefore, the concentration required to achieve this result is greater than the highest exposure concentration used during the two tests (i.e., >0.58 mg $NH_3$/L and >0.30 mg $NH_3$/L) (c.f., Table 4-5). These variances may reflect differences between test-conditions used by the two research groups, varying sensitivities between the test-populations or age differences between test-populations. The third suggestion is probable because Tetr*ES* conducted tests on juvenile fish whereas fathead minnow fry were tested by Mayes *et al.* (1986 as cited by EPA 1999a). Generally, fish fry exhibit a higher degree of sensitivity to environmental stressors than older, juvenile fish (U.S. EPA, 1999a). Test-conditions established by each of the two research groups were similar; both exposed fathead minnows to various concentrations of dissolved ammonium chloride diluted with river water for 28 to 30 days. However, differences in test-temperatures, test-pHs, exposure-technique, and source of river water may have also influenced the relative sensitivities of the two test-populations.

A 20% reduction in growth of juvenile fathead minnows studied by Tetr*ES* was observed at 0.52 mg $NH_3$/L, a concentration more than 1.5X greater than the lethal concentration produced from data generated by Mayes *et al.* (1986). Also, a 30-day early life-stage test conducted by Swigert and Spacie (1983) reported sublethal responses at concentrations much lower than that

**Table 4-5**
**COMPARISON BETWEEN TETR*ES*' RESULTS AND RELEVANT PUBLIC-DOMAIN RESULTS FOR SELECTED CHRONIC-EXPOSURE TESTS**

| | Species | *Reference (from USEPA 1999) /Test No. (TetrES) | Test Description | Endpoint[a] | $LC/EC_{20}$[b] (mg $NH^3$/L)[c] | Comparable Datasets? | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Public-Domain results | Fathead minnow | Swigert and Spacie (1983) | 30-day ELS[d] test with fry[e] | biomass[f] | 0.165 | N | | | | |
| | Fathead minnow | Mayes et al. (1986) | 28-day ELS[d] test with fry[e] | survival | 0.330 | Y | | | | |
| TetrES' results | Fathead minnow | T9 | 30-day ELS[d] test with juveniles[g] | growth | 0.520 | N | | | | |
| | Fathead minnow | T9 | 30-day ELS[d] test with juveniles[g] | survival | >0.58 | Y | | | | |
| | Fathead minnow | T9 | 29-day ELS[d] test with juveniles[g] | survival | >0.30 | Y | | | | |
| Public-Domain results | White sucker | Reinbolt and Pescitelli (1982[a]) | 31-day ELS[d] test with fry[e] | survival | >0.245 | | Y | | | |
| Tetr*ES*' results | White sucker | T3A | 10-day ELS[d] test with fry[e] | survival | 0.360 | | Y | | | |
| Public-Domain results | Channel Catfish | Swigert and Spacie (1983) | 30-day ELS[d] test with fry[e] | biomass[f] | 0.504 | | | N | | |
| | Channel Catfish | Reinbolt and Pescitelli (1982[b]) | 30-day ELS[d] test with fry[e] | growth | 0.542 | | | N | | |
| | Channel Catfish | Colt and Tchobanoglous (1978) | 31-day ELS[d] test with juveniles[g] | survival | $\geq$0.823 - $\leq$0.936 | | | Y | | |
| Tetr*ES*' results | Channel Catfish | T8 | 30-day ELS[d] test with juveniles[g] | survival | 0.170 | | | Y | | |
| Public-Domain results | Ceriodaphnia dubia | Willingham (1987) | 7-day LC[h] test with neonates[i] | reproduction | 1.300 | | | | Y | |
| | Ceriodaphnia dubia | Nimmo et al. (1989) | 7-day LC[h] test | reproduction | 0.640 | | | | Y | |
| Tetr*ES*' results | Ceriodaphnia dubia | T12A | 7-day LC[h] test with neonates[i] | reproduction | 0.500 | | | | Y | |
| Public-Domain results | Hyalella azteca | Borgmann (1994) | 10-wk LC[h] test with neonates[i] | reproduction | <0.091 | | | | | Y |
| Tetr*ES*' results | Hyalella azteca | T22 | 28-day LC[h] test adults | reproduction | >0.783 | | | | | Y |

a - *Endpoint* refers to a biological response that can be measured and expressed quantitatively

b - $LC_{20}$ = the concentration of a stressor that produces a mortality-response in 20% of test-organisms

FINAL TECH RPT TABLE 4-5.xls

$EC_{20}$ = the concentration of a stressor that produces an inhibitory, sublethal-response in 20% of test-organisms

c- $NH_3$ = unionized ammonia

d - ELS = early life-stage (i.e., from shortly after fertilization through embryonic, larval, or early juvenile development)

e - fry = newly hatched or young fish

f - biomass = the product of a survival and a growth response

g - juvenile = young fish that have not reached sexual maturity

h - LC = life cycle (i.e., all life stages including the reproductive cycle)

i - neonates = newly hatched (<24hrs) invertebrates required by Tetr*ES*' test-population (c.f. Table 4-5). The endpoint used by Swigert and Spacie (1983) was biomass, the product of survival and weight data, and generated an $EC_{20}$ value of 0.17 mg $NH_3$/L. This value is more than 3X lower than the one generated by Tetr*ES* (i.e., 0.52 mg $NH_3$/L). The greater degree of tolerance to sublethal toxicity-effects exhibited in Tetr*ES*' test-organisms is consistent with observations noted above and may also reflect differences in life stages of the fish, test-conditions used or relative sensitivities of the test-organisms themselves.

Results generated by Tetr*ES* regarding $NH_3$ toxicity to white sucker are comparable with those reported by Reinbolt and Pescitelli (1982a) because both research groups conducted chronic-exposure tests with fry using survival as an endpoint. However, the exposure-concentrations used by Reinbolt and Pescitelli (1982a) were not high enough to bracket a 20% reduction in survival and therefore, an undefined concentration greater than 0.25 mg/L, (i.e., the highest exposure-concentration tested) is required to produce this result. This conclusion supports Tetr*ES'* results of an $LC_{20}$ of 0.36 mg/L (c.f., Table 4-5).

Tetr*ES*' test-results with channel catfish are most readily comparable with results generated by Colt and Tchobanoglous (1978). Both research groups conducted ammonia toxicity tests on juvenile channel catfish for one-month using survival as an endpoint. However, $LC_{50}$ values generated by these tests vary considerably (c.f. Table 4-5) and results generated by Tetr*ES* suggest that channel catfish are approximately 5X more sensitive to un-ionized ammonia exposure than data reported by Colt and Tchobanoglous (1978) would otherwise suggest. Furthermore, tests conducted by Swigert and Spacie (1983) and Reinbolt and Pescitelli (1982b) using channel catfish fry (i.e., a more sensitive life-stage than juveniles) monitored growth to yield $EC_{20}$'s of 0.50 mg $NH_3$/L and 0.54 mg $NH_3$/L, respectively that are 3X greater than the $LC_{20}$ value of 0.17 mg $NH_3$/L (c.f. Table 4-5) reported by Tetr*ES*.

An $EC_{20}$ for *Ceriodaphnia dubia* calculated by Tetr*ES* was similar to, but slightly more conservative than, the $EC_{20}$ reported by Nimmo *et al.* (1989) (i.e., 0.50 mg $NH_3$/L versus 0.64 mg $NH_3$/L). However, both of these studies suggest that the sensitivity of *C. dubia* to $NH_3$ is more than two times greater than results produced during a similar test by Willingham (1987) would otherwise indicate. Willingham (1987) reported an $EC_{20}$ of 1.30 mg $NH_3$/L (c.f. Table 4-5).

Finally, tests conducted on *Hyalella azteca* yield vastly different results as illustrated in Table 4-5. Borgmann (1994) conducted two 10-week life-cycle tests with less than one week old *H. azteca* and found that reproduction (measured as the number of neonates produced per replicate) in the lowest exposure-concentration tested was compromised by 25% compared to the control group. From these results U.S. EPA (1999) report an $EC_{20}$ value of <1.58 mg N/L at pH=7.94 and 25°C which is equivalent with an $EC_{20}$ of <0.09 mg $NH_3$/L. Alternately, reproduction was not affected by 20% at un-ionized ammonia concentrations up to 0.78 mg/L in *H. azteca* tested by Pollutech and reported by Tetr*ES*. This test was conducted for 28 days using adult amphipods, but these variations in test-protocols cannot fully explain the 9-fold increase in tolerance levels of *H. azteca* to un-ionized ammonia. The more probable explanation is that a constituent of Red River water reduces the toxicity effects of un-ionized ammonia to *Hyalella* observed by Borgmann.

In general, the local tests indicated both more and less sensitivity than the public domain dataset for the same species. No simple trend was observed indicating the importance of comprehensive testing of local species using local river water to develop criteria.

### 4.7.4 <u>Summary and Conclusions</u>

Throughout the Toxicity Workstream, 26 ammonia toxicity tests were completed on 11 different species of aquatic life including 7 fish species and 4 invertebrate species. This is a considerable technical accomplishment when compared with:

- 27 tests completed on 13 species which were found to be technically acceptable in an Environment Canada literature review of world-wide ammonia toxicity tests used to evaluate the toxicity of ammonia and in deriving a national protective criteria for Canada; and
- 28 tests completed on 12 species accepted by the U.S. EPA in its world-wide literature review of the tests applicable for deriving a protective ammonia criteria for the USA.

Of the tests completed, in the present study, seven can be used directly in the derivation of a chronic-criteria for ammonia. These tests were conducted on five fish species and two invertebrate species. Each test meets the objective of being an in-laboratory chronic-exposure test, using ammonia spiked river water (as opposed to effluent spiked river water), on local species found in the Red and Assiniboine rivers. A summary of these tests and the $LC_{20}$ or $EC_{20}$ values for each species is given in Table 4-6. Three of the tests were completed using the most sensitive key sport species, northern pike, channel catfish and walleye, and have very good time-exposure-mortality datasets which can be used in the development of species-specific risk assessments.

Ten acute-toxicity tests were done on three fish species using both NEWPCC effluent and ammonia treatments. Resulting $LC_{20}$ values are very similar despite the treatment and consequently, these tests confirm that ammonia is likely the main toxicant in NEWPCC effluent.

Four tests on two species of bivalves were done both in the laboratory and *in situ* downstream of the NEWPCC discharge-plume. The exposure to effluent of the *in situ* test was confirmed using coprostanol/cholesterol ratio. This ratio is considered a biomarker for human fecal exposures. The in-laboratory testing of bivalves showed signs of high mortalities in the controls indicating that laboratory testing of bivalves is difficult due to problems with feeding. The *in situ* bivalve tests assessed the impact of NEWPCC effluent (rather than ammonia only) and therefore are useful as “other lines-of-evidence” to corroborate that the site-specific criteria selection is appropriate.

## TABLE 4-6

# Summary of Tests to be Used Directly in Criteria Development

| | Common Name | Species Name | Number of tests | Un-ionized Ammonia-NH3 µg/L[1] | Test Type | EndPoint[2] | Duration Days | Mean pH[3] | Mean Temperature[3] ºC |
|---|---|---|---|---|---|---|---|---|---|
| Fish | Catfish | *Ictalurus punctatus* | 1 | 163 | Flow Through | LC20 | 30 | 8.4 | 8.5 |
| | Fathead Minnow | *Pimephales promelas* | 1 | 518 | Flow Through | EC20-Growth | 30 | 8.4 | 8.5 |
| | Northern Pike | *Esox lucius* | 1 | 130 | Flow Through | LC20 | 13 | 8.5 | 17 |
| | Walleye | *Stizostedion vitreum* | 1 | 204 | Flow Through | LC20 | 30 | 8.1 | 18 |
| | White Sucker | *Catostomus commersoni* | 1 | 359 | Semi Static | LC20 | 10 | 8.2 | 17.5 |
| Invertabrates | | *Ceriodaphnia dubia* | 1 | 490 | Semi Static | EC20-Reproduction | 7 | 8.2 | 24 |
| | | *Hyalella azteca* | 1 | >780 | Semi Static | LC20 EC-20 Reproduction | 28 | 8.2 | 24 |

**Notes:**

1. All Tests used Ammonium Chloride as ammonia source (rather than effluent) and Red River
2. The lowest of either the LC20 (lethal concentrations at with 20% mortality) or EC20 (effective
3. Temperature and pH varied throughout the test (details given in Appendix A).

# 5. SITE-SPECIFIC CRITERIA DEVELOPMENT PROCEDURES

In 1992, after the Clean Environment Commission hearings on objectives for the Red and Assiniboine rivers, the Clean Environment Commission recommended to the Minister of Environment that a site-specific criterion for ammonia be developed for the Winnipeg reaches of the Red and Assiniboine rivers.

This section will review some of the approaches to developing site-specific criteria as outlined by various agencies such as the U.S. EPA and British Columbia Environment. In addition, the section will review relevant experience on developing site-specific criteria for an upstream site on the Red River at Moorhead, Minnesota.

## 5.1 U.S. EPA GUIDANCE

The U.S. EPA, in advancing its national guidelines, has always provided for site-specific adaptation of the guidelines. The following discusses the guidance provided by EPA for such adaptation.

### 5.1.1 Recalculation Procedure

In it's publication "Water Quality Standards Handbook"; Second Edition (U.S. EPA 1994), the U.S. EPA outlines three procedures for developing site-specific criteria. General guidance includes that site-specific criteria, as with all water-quality criteria, must be based on sound, scientific rationale in order to protect the designated use. In addition, they state the derivation of the site-specific criteria should not change the intended level of protection of the aquatic life at the site. Site-specific criteria are intended to provide the same level of protection (i.e., 95% of the species protected at the criterion concentration value). However, they recognized that the allowable criterion concentration could change because of a difference in the assemblage of species at the site or a difference in how the toxicity of the parameter of question is influenced by the local water quality.

The EPA discussion on recalculation contains many administrative procedures. However, the basic scientific premise is the national dataset of toxicity effects either may be corrected, deleted or added to. There should be sound rationale for each of the corrections, additions or deletions. Once a new site-specific dataset is developed, then recalculation of the criterion using the same methods used to develop a national criterion should be used in order to develop a site-specific criterion. Some limitations have been stated; if deletions occur in which fewer than 8 genera are available for the dataset then either additional data must be provided or it must be shown that there are fewer than 8 genera occurring at the site.

### 5.1.2 Water Effects Ratios Procedure

Water effects ratio accounts for the variance in toxicity due to changes in the ambient water quality. The procedure is based on the fact that the physical and/or chemical characteristics of water at various in-stream locations may influence the bio-availability and hence the toxicity of environmental contaminants. To use the water effects ratio, both or either acute and short-term chronic toxicity tests are conducted on an indicator species using both laboratory and site water. A ratio is developed to determine the difference in toxicity from each of the waters (e.g., ratio equals the $LC_{50}$ using the site water divided by the $LC_{50}$ using the laboratory water). Tests should be done on one fish species and one invertebrate species and the geometric mean of the water effects ratio should be calculated with results from both species. The water effects ratio can then be used to develop a site-specific water-quality criterion. The national criterion is multiplied by the water effects ratio to determine the new site-specific criterion.

This procedure has some advantages in that, although test procedures must follow tight protocols, the number of new tests required is limited.

### 5.1.3 Resident Species Procedure

The resident species procedure for the derivation of site-specific criteria accounts for the differences in resident species sensitivity and the differences in biological availability and/or toxicity of the substance due to the variability and physical and chemical characteristics of the site water. The derivation of a site-specific acute criterion and chronic criterion are performed after completing acute toxicity tests and chronic toxicity tests with resident species in site water.

Although this procedure has the greatest scientific validity, it is often not performed due to its higher costs relative to the other methodologies. However, when compared to the capital and operating costs of waste treatment facilities for most urban municipalities, all of the above procedures are a very cost effective way to determine the most appropriate level of control required. In the case of Winnipeg, these studies were planned and carried out (Section 4.7). These studies then are assessed (Section 6) and become the basis for this report.

## 5.2 BRITISH COLUMBIA GUIDANCE

In the document "Water Quality Assessment and Objectives: Methods for Deriving Site-Specific Water Quality Objectives in British Columbia and the Yukon" (MacDonald 1997b), the recalculation procedure, the water effects ratio procedure, and resident species procedures were described and assessed for their applicability to British Columbia and Yukon waters. In addition, this document added a fourth procedure, the background concentration procedure. The background concentration procedure is applicable to pristine waters in which the objective is to have no impact on the environment. This procedure is not appropriate for the Red and Assiniboine rivers site-specific study.

The British Columbia document provided a summary of the various procedures and their strength and weaknesses, which is presented here in Table 5-1. Although the resident species procedure has the highest scientific rigor, it was not recommended by British Columbia due to its expected high cost relative to the other procedures (although the cost of associated ammonia control was not provided). It should be noted that the City of Winnipeg was prepared to incur the costs of such testing. Three other procedures plus an analytical limit of quantification procedure were recommended as potential methods of devising site-specific criteria. Most of the ensuing discussion in their document related to the water effects ratio and its application to development of criteria for B.C. and the Yukon.

As will be shown later (Section 6), the method used in this study corresponds to a combination of Resident Species Procedures and the Recalculation Procedure.

**TABLE 5-1**

## EVALUATION OF THE VARIOUS APPROACHES FOR DERIVING WATER QUALITY OBJECTIVES

| EVALUATION CRITERIA | BACKGROUND CONCENTRATION PROCEDURE | RECALCULATION PROCEDURE | WATER EFFECT RATIO PROCEDURE | RESIDENT SPECIES PROCEDURE |
|---|---|---|---|---|
| ***Scientific Defensibility*** | | | | |
| Based on biological effects data? | No | Yes | Yes | Yes |
| Considers potential for bioaccumulation? | No | No | No | No |
| Considers site-specific conditions? | Yes | Yes | Yes | Yes |
| Applicable to all classes of chemicals? | Yes | Yes | Yes | Yes |
| ***Applicability*** | | | | |
| Degree of site-specificity | High | Moderate | High | Very High |
| Uncertainty in the applicability of the WQOs | Low | Moderate | Low | Very Low |
| Acceptability to stakeholders | Unknown | Moderate | Unknown | Unknown |
| ***Practicality*** | | | | |
| Supports the development of numerical WQOs? | Yes | Yes | Yes | Yes |
| Level of Complexity | Moderate | Low | High | High |
| Timeliness | Moderate | High | Moderate | Low-Moderate |
| ***Cost Effectiveness*** | | | | |
| Expensive to implement? | Moderate | Low | High | Very High |
| Requires generation of new data? | Often | No | Yes | Yes |
| ***Most Appropriate Applications*** | Pristine waters; High value waters; Waters with threatened or endangered species. | Sensitivity range of resident species differs from that of complete toxicological dataset. | Factors present which could influence the bio-availability of contaminants. | Unique sensitivity range of resident species and presence of factors influencing bio-availability; Parameters with insufficient data. |



Source: MacDonald 1997

Note: Winnipeg tests corresponded most closely to the “Resident Species Procedure”

## 5.3 MOORHEAD, MINNESOTA EXPERIENCE

In 1997, the City of Moorhead commissioned a study on “Site-Specific Limits for Un-ionized Ammonia Red River of the North” (Camp Dresser McKee 1997). The Moorhead study was initiated to develop a site-specific criterion for the Red River to assist in the design of tertiary treatment for their wastewater treatment plant. The report examined two parts of the criterion; first the low flow criterion, and second, the site-specific acute and chronic un-ionized ammonia criterion.

The study used the EPA model D-FLOW to develop low flow criteria. Because of the inability of this model to develop seasonal flows, some adjustments were made to develop seasonal flows for winter, spring, summer and fall. A seasonal analysis was performed by providing the program with data from the months of interest. Because the biologically-based method uses the **forward harmonic mean** (see EPA 1988), flow data were also provided for the month following each season when calculating the 30-B-3. For the months outside the period of interest, a large uniform flow was substituted forcing D-FLOW to identify low flows only in the months of interest. The months that were used to determine the seasons were:

- winter – December 1 through March 31;
- spring – April 1 to May 31;
- summer – June 1 to September 30; and
- fall – October 1 to November 30.

A 50-year period of record was used for this analysis (1954 through 1994).

In order to develop a site-specific criterion concentration, the approaches recommended by the U.S. EPA were combined. These were:

- the derivation of site-specific criteria by modifying the national species database to consider only site species; and
- the derivation of site-specific criteria by adjusting for the effects of site water compared to laboratory water (water effects ratio).

The Moorhead study used the national acute databases provided by the EPA in 1985 (EPA 1985 and Table 3-1).

The fish species that were eliminated from the national database are shown on Table 5-2. The authors felt this was a conservative approach since it retained all invertebrates in the national database and all fish species that are:

- known to exist on site (e.g., green sun fish [*Lepomis cyanellus*]);
- within a genus include other on-site species (e.g., other *Lepomis, Catostomus, Micropterus, Murene, Etheostoma*, etc.).
- known to occur elsewhere in the region or nearby drainages, e.g., largemouth bass (*Micropterus Salmoides*).

Upon completing the revised species database, the site-specific final acute value (FAV) was calculated to equal 0.8164 mg-$NH_3$/L, while the site-specific acute to chronic ratio (ACR) was calculated to equal 7.9. To determine the chronic site-specific criteria, the acute criteria is divided by the ACR, thus providing a criteria of 0.103 mg-$NH_3$/L, which was based on a pH range of 8 to 8.9 and temperatures of 20 to 30°C. This was a preliminary objective proposed by Moorhead which was then further revised using a water effects ratio procedure.

To determine the water effects ratio, fathead minnows (*Pimephales promelas*) were exposed for 7 days to ammonia spiked dilution water collected in February from the Red River, upstream of the City's discharge point. The chronic value (CV) at pH 8.5 and temperature of 25°C was determined to be 0.59 mg-$NH_3$/L for early life stage survival. In order to determine the water effects ratio, previous public domain tests reported in EPA 1985 were used. The chronic value from the laboratory water tests used to provide the EPA national database averaged 0.24 mg-$NH_3$/L. The ratio of site-water CV to laboratory water CV is therefore 0.59/0.24 or approximately 2.5.

This calculated water effects ratio (2.5) was then used with the initial site-specific recalculated chronic un-ionized ammonia standard (0.103 mg-$NH_3$/L) to obtain a new criteria of 0.27 mg-$NH_3$/L. Moorhead then reported the 95$^{th}$ percentile of ranked estimated CVs for the site to be approximately 0.27 mg-$NH_3$/L (Note: our estimate using these numbers would be closer to 0.25). To remain on the conservative side, Moorhead proposed rounding this number down to

## TABLE 5-2

## FISH SPECIES ELIMINATED FROM THE EPA NATIONAL DATABASE FOR THE DERIVATION OF SITE-SPECIFIC UN-IONIZED AMMONIA CRITERIA AT MOORHEAD, MN

| FISH SPECIES | SCIENTIFIC NAME | SMAV (mg/L) |
|---|---|---|
| Mountain Whitefish | *Prosopium williamsoni* | 0.56 |
| Chinook Salmon | *Oncorhynchus tshawytscha* | 0.80 |
| Rainbow Trout | *Oncorhynchus mykiss* | 0.93 |
| Coho Salmon | *Oncorhynchus kisutch* | 1.02 |
| Brown Trout | *Salmo trutta* | 1.10 |
| Cutthroat Trout | *Oncorhynchus clarki* | 1.20 |
| Golden Trout | *Oncorhynchus aquabonita* | 1.21 |
| Stoneroller | *Campostoma anomalum* | 1.30 |
| Guppy | *Poecilla reticulata* | 1.48 |
| Brook Trout | *Salelinus fontinalis* | 1.69 |
| Pink Salmon | *Oncorhynchus gorbuscha* | 2.37 |
| Mosquitofish | *Gambusia affinis* | 2.48 |

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Source:  CDM 1997

0.2 mg-$NH_3$/L in order to develop a maximum chronic un-ionized ammonia standard. Such arbitrarily rounding-down of the lowest CV to derive a final standard with a margin of safety beyond the 95$^{th}$ percentile level of protection is not generally followed by the EPA. However, Moorhead felt it was a prudent application of a safety factor.

Moorhead used this study to enter negotiation with the State of Minnesota to develop a site-specific criterion. During that time, the EPA 98, and EPA 99 update was released. The recent EPA criterion was used in combination with a seasonal design flow to develop a licence.

## 5.4 SUMMARY

This section reviewed general procedures recommended by regulatory agencies to develop site-specific criteria. A case study upstream of Winnipeg on the Red River was also reviewed. The next section will apply this scientifically-defensible procedure to develop site-specific criteria for the Winnipeg Region of the Red and Assiniboine rivers.

# 6. DEVELOPING A SITE-SPECIFIC CRITERIA FOR THE RED AND ASSINIBOINE RIVERS

## 6.1 OVERVIEW

The previous section reviewed general procedures used to develop criteria concentrations. In this section, the procedures are used to develop site-specific criteria for the Red and Assiniboine Rivers. This section will look at two parts: effects and exposure.

To determine the effects portion of a criterion, both acute and chronic criteria concentrations were developed, based on the statistical models used by the EPA and Environment Canada in the development of their respective national criteria, and the use of data on species found locally in the Red and Assiniboine Rivers. Therefore, two candidate site-specific criterion concentrations will be developed.

The exposure portion of the criteria development will discuss:

- an allowable duration in which these criteria concentrations should be assessed (i.e., the averaging period);
- the allowable frequency in which these criteria could be exceeded without adversely impacting the aquatic ecosystem in the Red and Assiniboine Rivers; and
- the extent or mixing-zone dimensions in which within the chronic criteria may be exceeded, prior to complete mixing.

## 6.2 EFFECTS

The previous section (Section 5) described the guidance from various regulatory agencies for developing site-specific criteria concentrations. Those methods included the **resident species** procedure, the **water effects ratio** procedure, and the **recalculation** procedure.

The **resident species procedure** involves developing a completely new dataset for which to apply the statistical models to protect 95% of the genera at that concentration. In this study, 7 site-specific tests are applicable to develop chronic values for 7 species and 7 genera (see Toxicity TM and Section 4.7). The EPA resident species method requires 8 genera in order to meet the guidelines. This falls short of the 8 needed for a chronic criterion. A weakness of this procedure is that it completely omits the public domain dataset, some of which could be of particular use to development of the criterion at a specific site.

In order to have the highest degree of confidence in a local criterion and use both the public domain and local datasets, a modified **recalculation procedure** method, which included the strength of both the recalculation and resident species methods, was used. The method used was to substitute the genus mean acute and chronic values from the public domain dataset with the data from tests of the local species when the same species or genus was used. Species which do not occur in local rivers were eliminated from the local dataset. However, the remaining public domain dataset was used in conjunction with the toxicity test local data to create a new site-specific dataset.

The development of the **water effects ratio** (WER) involves testing indicator species with both laboratory water and local river water. Chemicals whose activity or solubility are well understood to be affected by dilution water hardness, alkalinity or dissolved solids are often further assessed with benchmark species and tests to determine the water effects ratio that might be applied to a wider range of public domain data. It was noted that many species showed a range of sensitivities when tested among different laboratories. Where multiple measurements were made on the same species, the geometric mean of all results was used for the community evaluation. In some cases, there were considerable disparities among tests within a species and these were rationalized based on control performance within the tests or unique requirements of the organism that affected sensitivity. Our comparison of local and public domain dataset (see Toxicity TM and Section 4.7) showed no consistent trend in relative sensitivity. Therefore the water effects ratio procedure was not applied.

Since there are differences between the U.S. EPA (1999) procedures (used by Manitoba Conservation) and the Environment Canada (2000) procedures (used in the Priority Substance List declaration), both methods were employed and the results compared in the Winnipeg study. Both methods have the same general objectives for protection, which is that 95% of the species within the area should be protected at the criterion concentration. However, different methods for calculating this 95% protection value are employed. The EPA uses a log-linear interpolation or extrapolation, based on the lowest 4 genus mean values. The Environment Canada method uses the complete dataset and a log-probit analysis program developed for the Water Environment Research Foundation (WERF 1996). This method is similar to procedures used by hydrologists in developing flood frequency curves.

The major difference between the two methods is that Environment Canada assumes un-ionized ammonia is the key constituent in toxicity, while the EPA (1999) uses a joint un-ionized ammonia and ammonium model. (In the EPA model, un-ionized ammonia is considered to be approximately 100 times more toxic than ammonium). These two studies also used different species, which reflect both the difference in species found within each country, as well as slightly different procedures in screening the studies, and the acceptance of test data for the national dataset.

The un-ionized ammonia and total ammonia species mean or genus mean values (i.e., concentrations) are different within the U.S. EPA (1999) and Environment Canada (2000) studies since different methods are employed to adjust the values to reference pH and temperatures. Environment Canada used the actual un-ionized ammonia calculated for each of the studies, while the U.S. EPA adjusted the values to determine a total ammonia (normalized to pH using the actual pH and temperature and their joint toxicity models.)

## 6.3 ACUTE CRITERION CONCENTRATIONS

Alternative **acute** criteria concentrations will be developed in this sub-section using local and public domain dataset, the combined resident species/recalculation procedure and both EPA/Manitoba and Environment Canada statistical methods.

### 6.3.1 Selection of Dataset

For **acute toxicity**, the species used for the U.S. EPA 1999 criteria updates and the Environment Canada PSL-II assessment (the public domain set) are shown in conjunction with the locally-developed species list of relevant ammonia tests. Organisms whose home range did not include the Red or Assiniboine rivers or those that were not reported in a number of river surveys were excluded from all data evaluations. Table 6-1 identifies all species referenced in both the U.S. EPA and Environment Canada evaluations and provides the rationale for excluding specific species from consideration as local species.

### 6.3.2 Based on Environment Canada Methods

Using the dataset developed and shown in Table 6-1 the procedure used by Environment Canada was used to select the **acute criterion**. As described earlier, the Environment Canada method uses the WERF log-probit analysis (WERF 1996) on a complete dataset. Figure 6-1 illustrates this analysis, along with prediction limits, which would predict that 95% of the genus are protected within an in-stream criterion concentration of 0.352 mg-$NH_3$/L.

### 6.3.3 Based on U.S. EPA/Manitoba Methods

To develop a site-specific **acute** criterion using EPA methods, the genus mean acute values need to be calculated. To do this, pH adjustments must be done for each datum in the applicable dataset, using the following equation based on the joint toxicity model (EPA 1998):

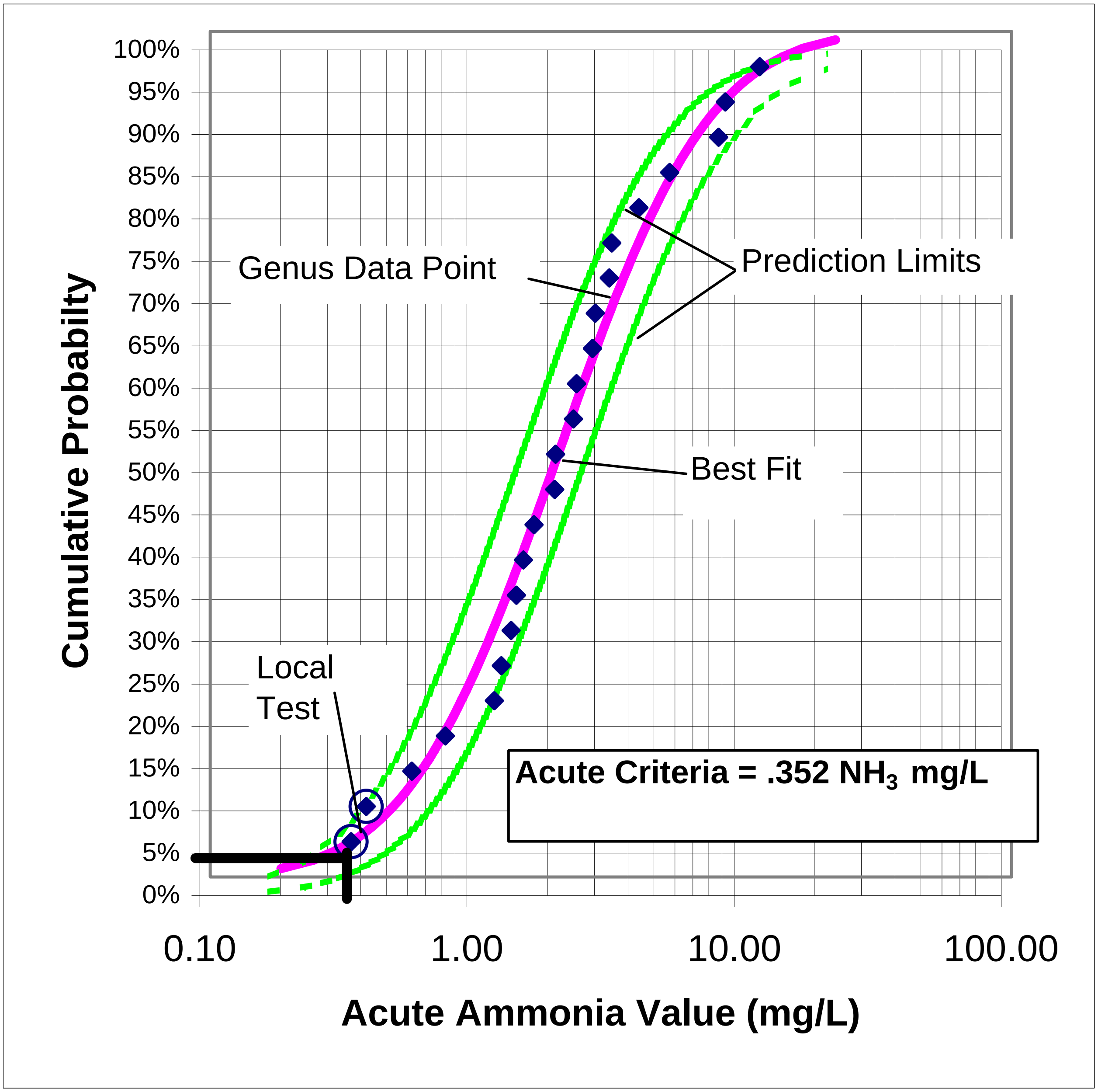
$$AV = (AV \text{ at } (pH = 8) \quad + \quad \left( \frac{0.0489}{1+10^{7.204-pH}} \quad + \frac{6.95}{1+10^{pH-7.204}} \right) \qquad \text{Eq 8}$$

Table 6-1 shows the species list developed for locally applicable genera, as well as the mean acute value (total ammonia) for each genus. The genus mean values were calculated by using a geometric mean of each of the studies or species values. To calculate the 95% (or the $5^{th}$ percentile) cumulative value, the EPA methodology of using the lowest 4 data points was employed. Appendix B shows the calculations used to determine the acute criterion (5%) value of 9.34 mg-N/L (see Figure 6-2). Arbitrarily applying a safety factor of two as above would arrive at an acute criterion of 4.67 mg-$NH_3$/L. Since the tests used 96-hour exposure periods and the intent of the criteria is to be for a 1-hour or 1-day exposure period, we believe this additional arbitrary safety factor is unnecessary. Therefore, 9.34 mg-N/L was used in the site-specific acute criterion. Since the EPA uses the joint toxicity model, based on variations in pH for developing acute criteria, the criterion is expressed in terms of pH as:

**TABLE 6-1**

## Comparison of ***Acute Value Tests*** used in EPA,Environment Canada (PSL2) and Site Specific Criteria Development

| | Public Domain Data Set Used | | | Ammonia | | |
|---|---|---|---|---|---|---|
| ***Genus name*** | **Used In EPA 85 & 99** | **Used In PSL2** | **Used in Winnipeg Site Specific Criteria** | **LC50 (mg NH3/L un-ionized )** | **LC50 (mg - N/L total )** | **Rational** |
| *Arcynopteryx* | Y | Y | Y | 2.29 | 77.1 | |
| *Asellus* | Y | Y | Y | 4.02 | 210.6 | |
| *Callibaetis* | Y | Y | Y | 3.18 | 115.5 | |
| *Campostoma* | Y | N | N | - | - | Not Found in Canada |
| *Catastomas* | Y | Y | Used Local Test | 0.38 | 10.1 | |
| *Catostomas* | Y | Y | N | - | - | Not Found Locally |
| *Ceriodaphnia* | Y | Y | Y | 1.96 | 25.8 | |
| *Cottus* | Y | Y | Y | 2.35 | 51.7 | |
| *Crangonyx* | Y | Y | Y | 3.12 | 108.3 | |
| *Daphnia* | Y | Y | Y | 1.49 | 36.8 | |
| *Dendrocoelum* | Y | Y | Y | 1.40 | 32.8 | |
| *Ephemerella* | Y | Y | Y | 5.25 | 18.9 | |
| *Etheostoma* | Y | N | N | - | - | Not Found in Canada |
| *Gambusia* | Y | N | N | - | - | Not Found in Canada |
| *Helisoma* | Y | Y | Y | 2.76 | 93.5 | |
| *Ictaluras* | Y | Y | Y | 1.63 | 34.4 | |
| *Lepomis* | Y | Y | Y | 1.16 | 23.6 | |
| *Micropterus* | Y | Y | Y | 1.34 | 26.5 | |
| *Morone* | Y | Y | N | - | - | Not Found Locally |
| *Musculium* | Y | Y | N | - | - | Tests indicate Starvation |
| *Notemigonus* | Y | Y | Y | 0.76 | 14.7 | |
| *Notropis* | Y | Y | Y | 1.23 | 25.6 | |
| *Oncorhynchus* | Y | Y | N | - | - | Not Found Locally |
| *Orconectus* | Y | Y | Y | 8.47 | 246.0 | |
| *Philarctus* | Y | Y | Y | 11.40 | 388.8 | |
| *Physa* | Y | Y | Y | 1.95 | 73.7 | |
| *Pimephales* | Y | Y | Used Local Test | 0.57 | 13.2 | |
| *Poecilia* | Y | N | N | - | - | Not Found in Canada |
| *Prosopium* | Y | Y | N | - | - | Not Found Locally |
| *Salmo* | Y | Y | N | - | - | Not Found Locally |
| *Salvelinus* | Y | Y | N | - | - | Not Found Locally |
| *Simocephalus* | Y | Y | N | - | - | Not Found Locally |
| *Stenelmis* | Y | Y | Y | 8.00 | 113.2 | |
| *Stizostedion* | Y | Y | Used Local Test | 0.34 | 9.3 | |
| *Tubifex* | Y | Y | Y | 2.70 | 97.8 | |




**Aquatic Community Risk Model (Local Data) for Acute Criteria Development**

Figure 6-1

**Tetr*ES***

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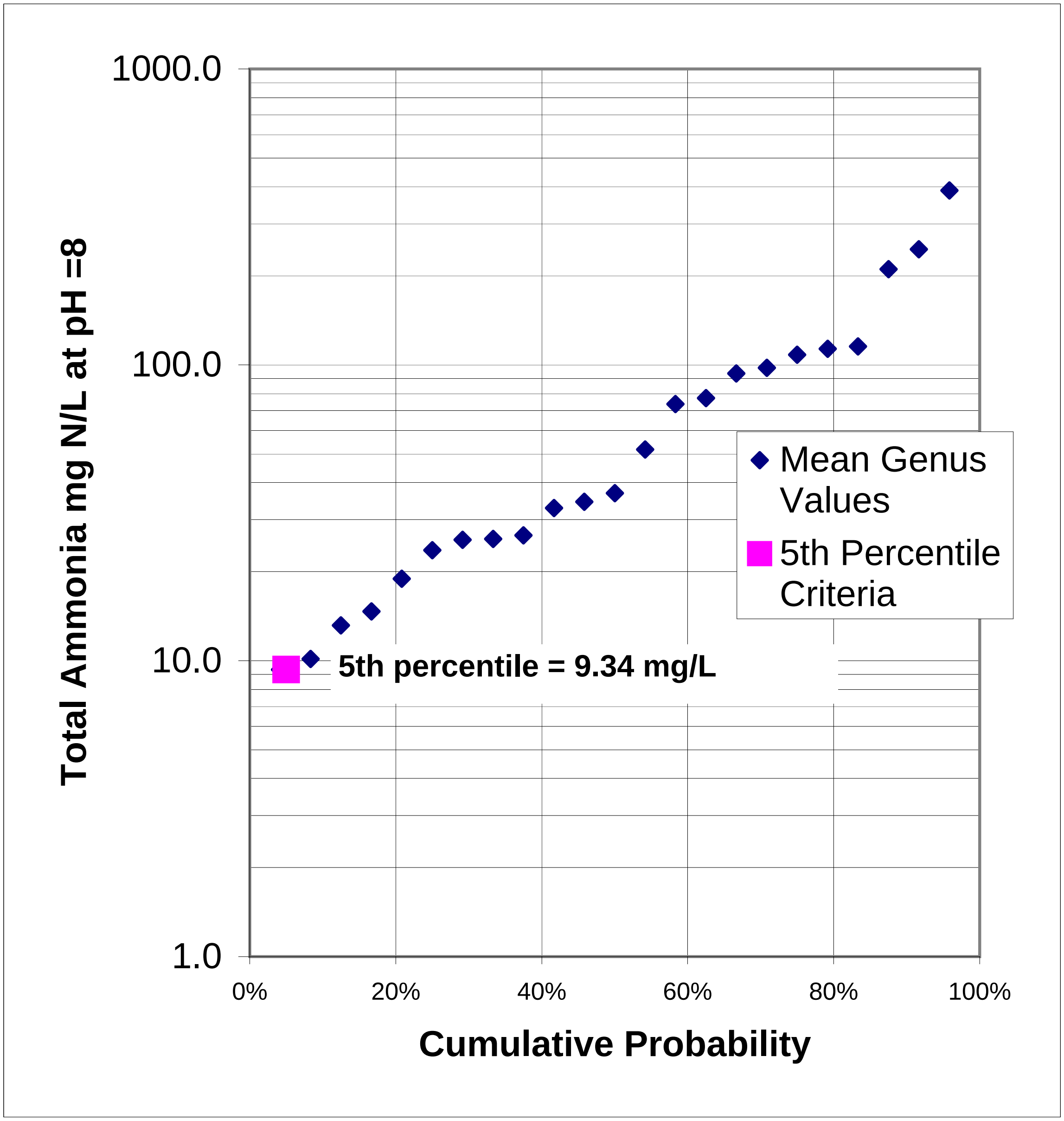



**Ranked Genus Mean Chronic Values (GMCVs)**

Figure 6-2

$$\text{Acute Criterion Concentration} = 9.34\left(\frac{0.489}{1+10^{7.204-pH}} + \frac{6.95}{1+10^{pH-7.204}}\right) \quad \text{Eq 9}$$

Figures 6-3 and 6-4 compare the criteria developed using both Environment Canada methods and recent EPA methods, along with the current generalized Manitoba objective (based on EPA 1998 and 1999 and PLS-2 criteria). In Figure 6-3, pH values of 7.0 and 7.5 are compared while in Figure 6-4, the comparison is done on pH values of 8.0 and 8.5.

## 6.4 CHRONIC CRITERIA CONCENTRATIONS

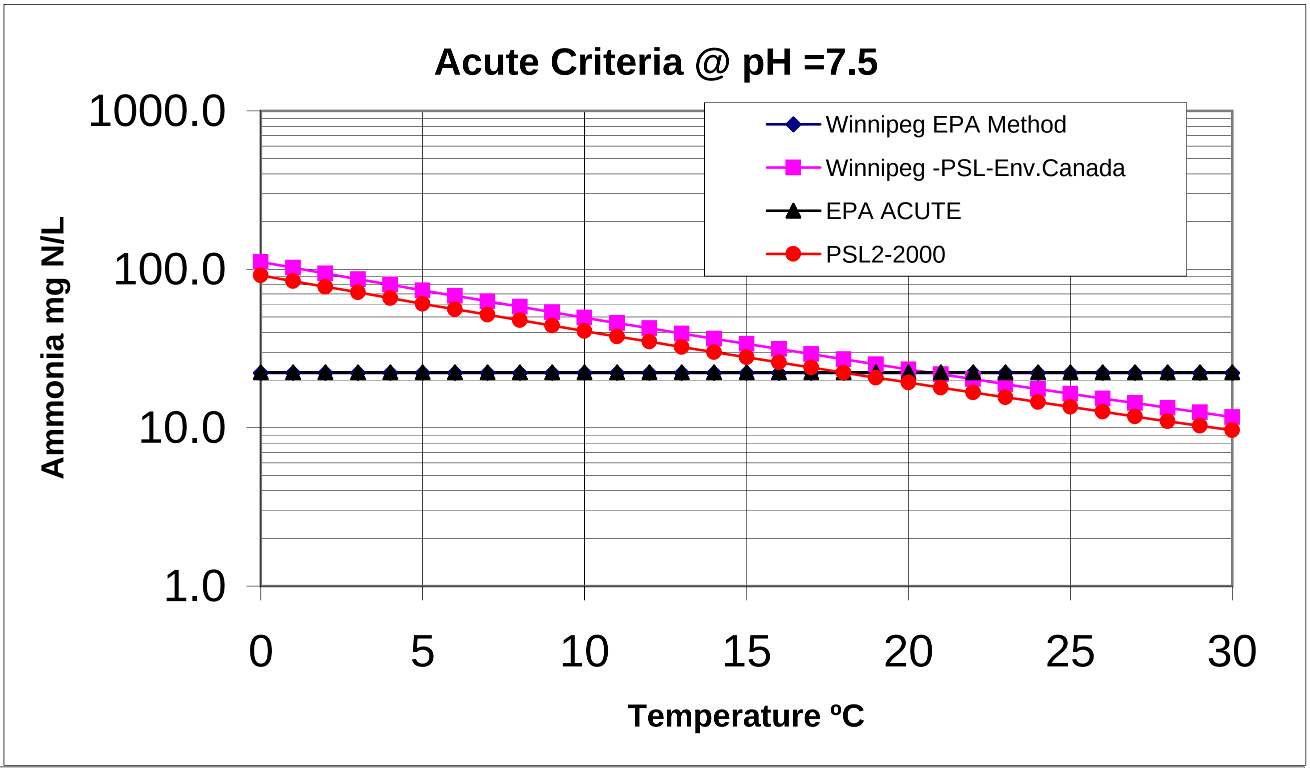
The alternative **chronic criteria** concentrations will be developed in this sub-section using local and public domain datasets, the combined resident species/recalculation procedure and both EPA/Manitoba and Environment Canada statistical methods.

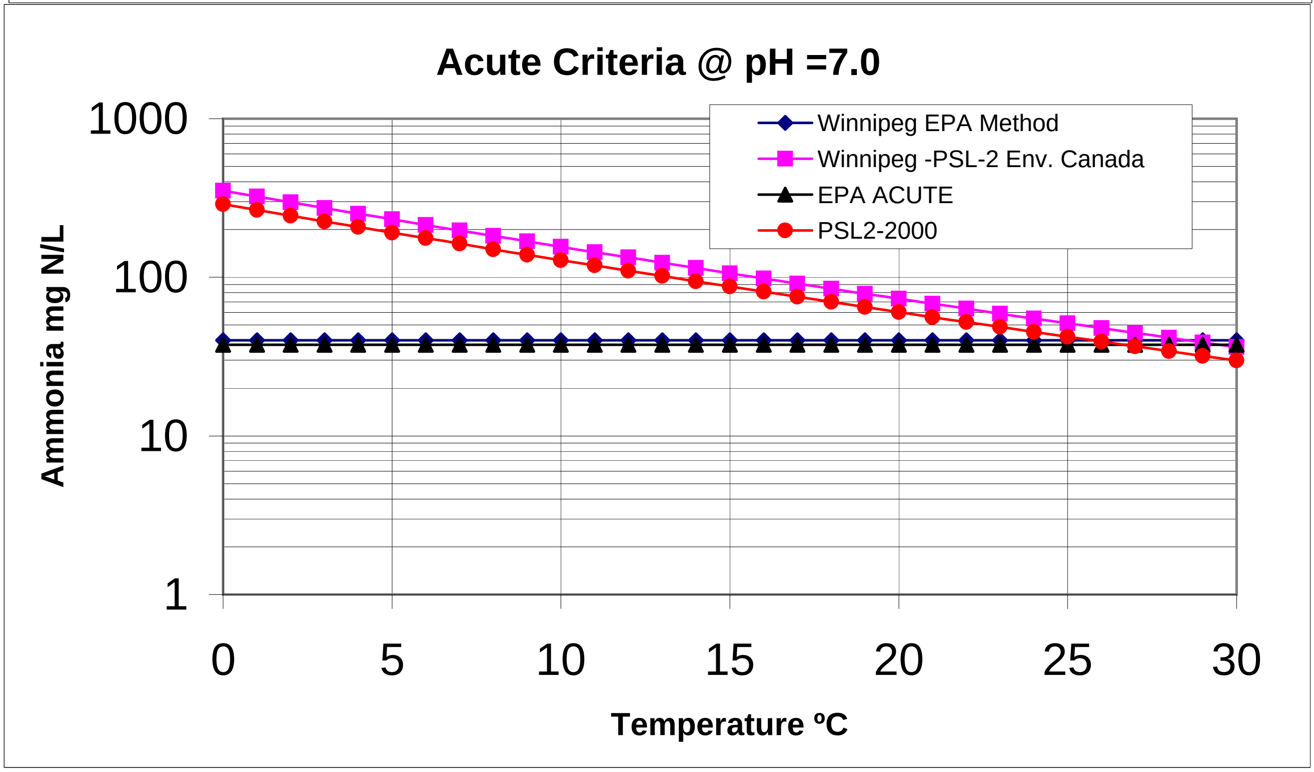
### 6.4.1 Selection of Dataset

Table 6-2 shows the dataset of tests used in the development of the criteria for the Winnipeg study, Environment Canada PSL-II study and the U.S. EPA 1999 criterion development, and shows a rationale for excluding specific national species from consideration as local species. These local data show that fish (i.e., northern pike, walleye, catfish) are consistently more sensitive to ammonia than invertebrates.

### 6.4.2 Based on Environment Canada Protocols

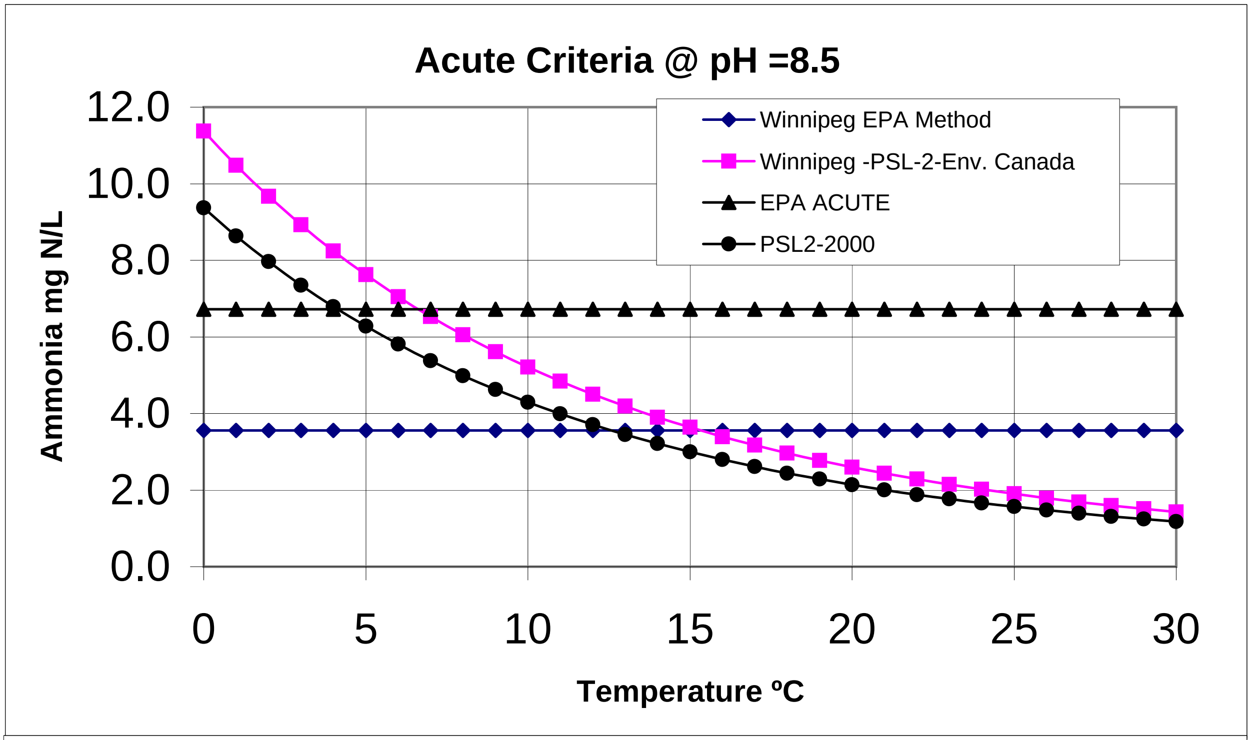
The dataset was developed by using the un-ionized ammonia causing an $EC_{20}/LC_{20}$ for each study as the species mean average value. If more than one test per species was available, then the geometric mean was used to calculate the species mean average value for un-ionized ammonia. The genus mean value was calculated by taking the geometric mean of each species' value. These sets of genus mean chronic values were then ranked and analyzed, using the WERF probit analysis (WERF 1996) as shown in Figure 6-5. The $5^{th}$ percentile

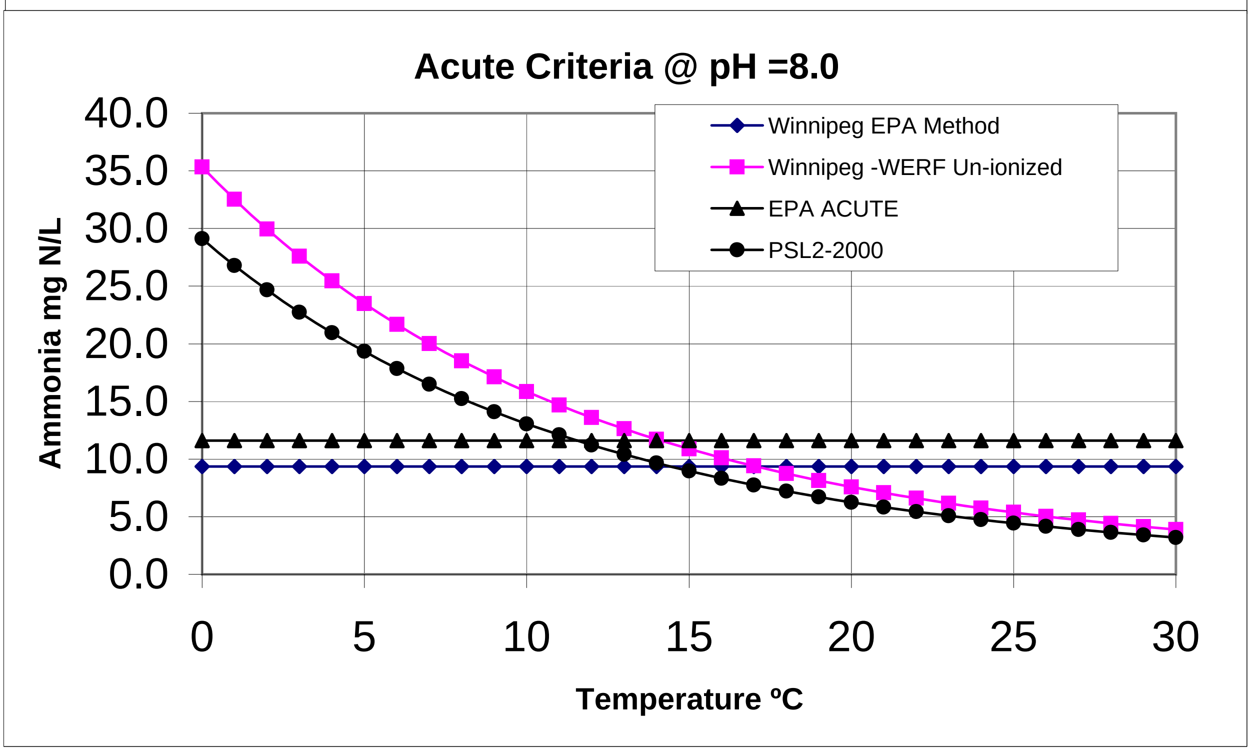



**Comparison of EPA 1998,PSL-2 and Winnipeg Acute Ammonia Criteria For ph 7.0 and 7.5**

Figure 6-3




**Comparison of EPA 1998,PSL-2 and Winnipeg Acute Ammonia Criteria For ph 8.0 and 8.5**

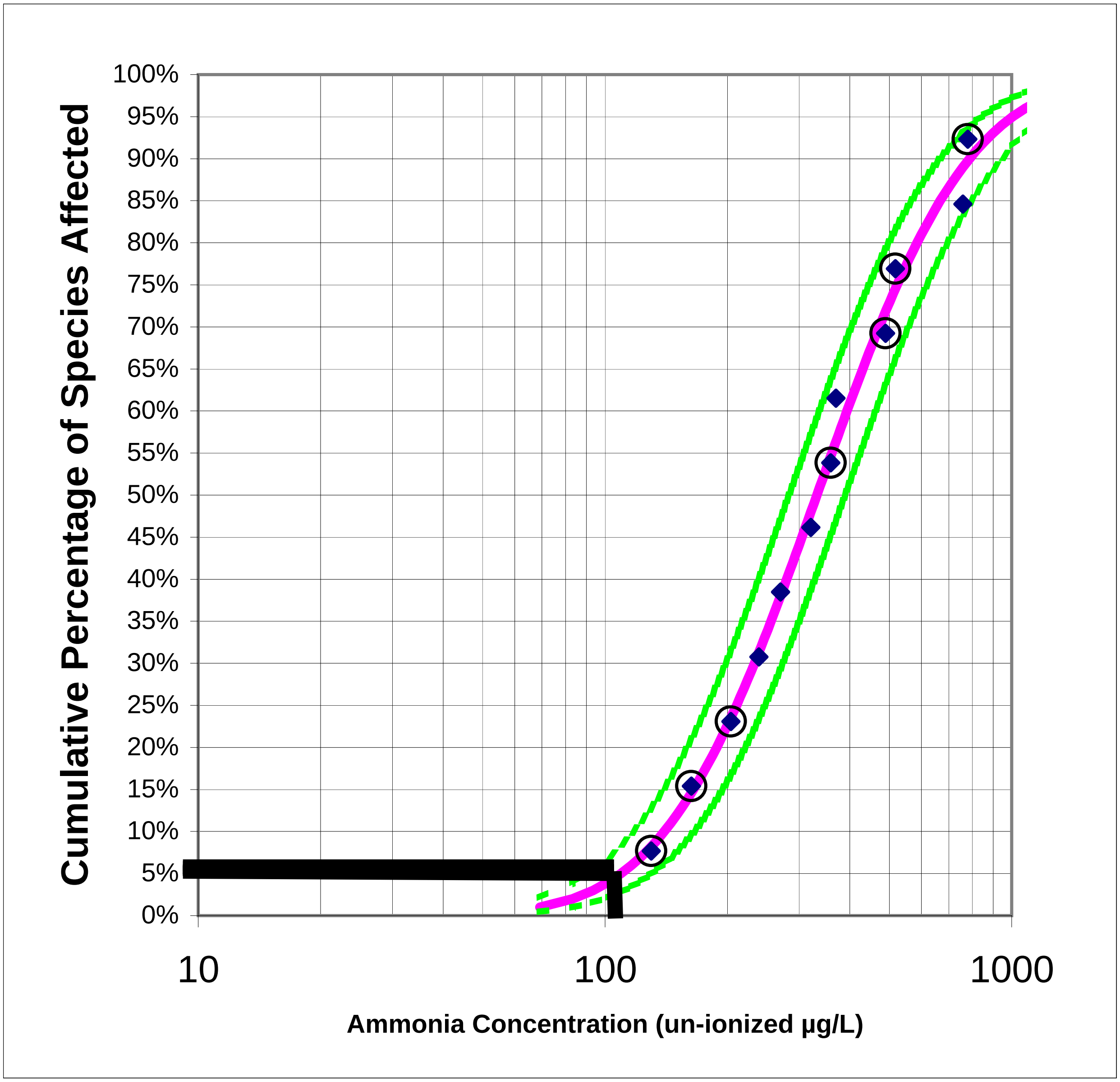
Figure 6-4

## TABLE 6-2

# Comparison of Tests used in Various Chronic Criteria Development Studies

| | | Red and Assiniboine Site Specific | | US EPA 99 | | Environment Canada PSL-2 2000 | | |
|---|---|---|---|---|---|---|---|---|
| **Common Name** | **Genus -Species Name** | *Number of Studies* | Un-ionized Ammonia µg/L | *Number of Studies* | Un-ionized Ammonia µg/L | *Number of Studies* | Un-ionized Ammonia µg/L | ***Comment*** |
| **Northern Pike[1]** | ***Esox lucius[1]*** | ***1*** | ***130*** | - | - | - | - | Unique and most Sensitive Species & Key Sport Fish |
| **Catfish[1]** | ***Ictalurus punctatus[1]*** | ***1*** | ***163*** | 3 | 475 | 6 | 290 | Local Test More Sensitive than National & Key Sport Fish |
| **Walleye[1]** | ***Stizostedion vitreum[1]*** | ***1*** | ***204*** | | | 2 | 189 | Local Test Slightly Less Sensitive than National & Key Sport Fish |
| Sunfish | *Lepomis* | ***3*** | ***239*** | 1 | 72 | 3 | 239 | Same as Environment Canada Is Punkinseed in this |
| Leopard Frog | *Rana pipiens* | ***1*** | ***270*** | | | 1 | 270 | Same as Environment Canada |
| **WhiteSucker[1]** | ***Catostomus commersoni[1]*** | ***2*** | ***280*** | 1 | 257 | | | Local Test Slightly Less Sensitive than National Literature Review |
| Smallmouth Bass | *Micropterus dolomieu* | ***2*** | ***321*** | 4 | 245 | 2 | 321 | Same as Environment Canada |
| Amphipod | *Crangonyx* | ***1*** | ***370*** | | | 1 | 370 | Same as Environment Canada |
| | ***Ceriodaphnia dubia[1]*** | ***1*** | ***490*** | 2 | 725 | 1 | 520 | Local Test More Sensitive than National Literature Review |
| **Fathead Minnow[1]** | ***Pimephales promelas[1]*** | ***1*** | ***518*** | 3 | 166 | 3 | 173 | Local Test much Less Sensitive than National Literature Review |
| | *Daphni Magna* | ***2*** | ***759*** | 2 | 660 | 2 | 759 | Same as Environment Canada |
| | ***Hyalella Azteca[1]*** | ***1*** | ***780*** | 1 | 78 | 1 | 51 | Local Test used same protocols but Red River Water used instead of Tap water |
| Sockeye Salmon | *Oncorhyhynchus nerka* | | | 1 | 223 | 1 | 57 | Not Local Speicies |
| Fingernail Clams | *Musculium transverum* | | | 2 | 121 | | | Muscilium dropped by Environment Canada since showed Evidence of Starvation |
| | *Ceriodapnia acanthina* | | | 1 | 1026 | | | Not Local Speicies |
| Rainbow Trout | *Oncorhyhynchus mykiss* | | | | | 4 | 90 | Not Local Speicies |

1. Used Local Site-species Results Only For Site Specific Study




**Aquatic Community Risk Model (Local Data) for Chronic Criteria Development**

Figure 6-5

cumulative probit value was determined to be 0.101 mg-$NH_3$/L (**un-ionized ammonia**) for this local assemblage of genera.

### 6.4.3 Based on U.S. EPA/Manitoba Objectives Protocols

The same species tests used to develop the Environment Canada type protocol were used in this approach. All test values were converted to total ammonia, using the pH and temperature adjustment model, as developed by the EPA (U.S. EPA 1999; see Equation 2 and Table 6-3). To determine the 5$^{th}$ percentile, the EPA protocol of using the lowest 4 data points and extrapolating down to the 5$^{th}$ percentile was used (see Appendix B and Figure 6-6). The value in terms of **total ammonia** was calculated to be **2.02 mg-N/L**. Since none of the four sensitive species used to develop the criterion were invertebrates, it is unnecessary to use the temperature adjustment model in the criterion equation. The pH adjustment model can be used to develop an expression for the criterion, based on variations in pH. The following equation can be used to express a site-specific criterion, based on EPA methods:

$$\text{Chronic Criteria Concentration} = 2.02\left(\frac{0.0676}{1+10^{7.688-pH}} + \frac{2.91}{1+10^{pH-7.688}}\right) \quad \text{Eq 10}$$

Although no temperature adjustment is used in this equation, the guidance of the EPA in developing a criterion indicates that an early life stage "presence" or "absence" should be used to determine whether there should be an adjustment to the criterion. Since the most sensitive species (northern pike) was tested at a very early life stage (fish fry at 17°C), this adjustment would apply in the Winnipeg situation. The EPA in 1998 recommended an adjustment of 3 times, when early life stages weren't present, based on testing of blue gill at early life stages and juvenile life stages. Below 5°C the criterion concentration should be three times the base value (Equation 10).

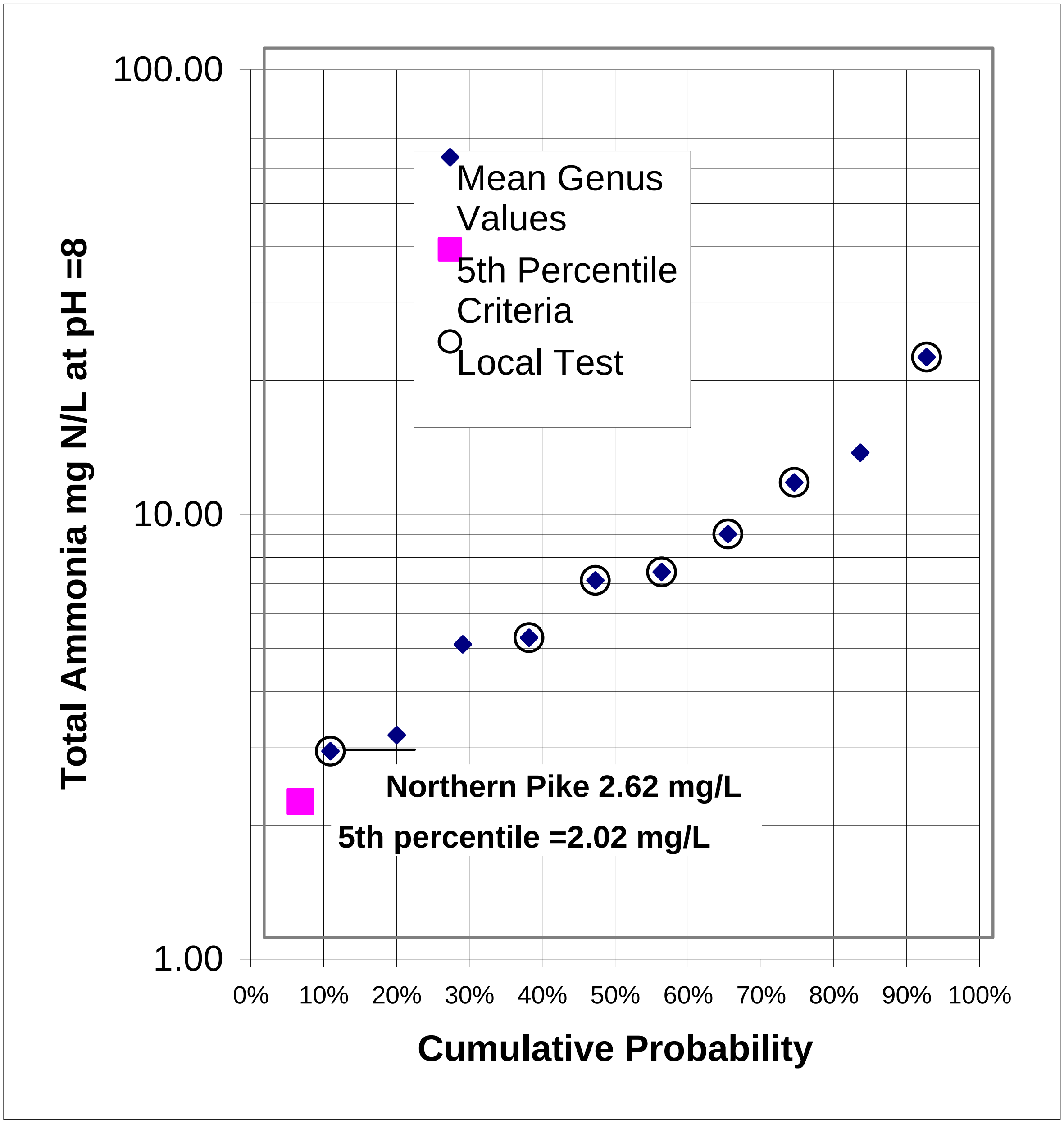
## 6.5 DISCUSSION OF VARIOUS CRITERIA

It should be noted that the site-specific criteria development indicated that fish species were more sensitive than invertebrates. This differs from both the EPA and PSL-2 criteria

**Table 6-3**

## Summary of Tests used in Site-Specific (US EPA Methods) Chronic Ammonia Criterion Concentration Development

| | | | Actual | | | With EPA 1999 pH and Temperature Adjustment Models | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Common Name*** | ***Species Name*** | ***Reference*** | ***Actual Temperature*** | ***Actual pH*** | **Total Ammonia N-mg/L @ pH& T of Test** | ***pH Adjust*** | ***Temperature Adjust*** | **Total Ammonia N-mg/L @ pH=8 & T= 25 ºC** | ***Species Mean Chronic Value (Geometric Mean mg N/L)*** | ***Genus Mean Chronic Value (Geometric Mean mg N/L)*** |
| Daphnia | *Daphnia magna* | Gesich et al. 1985 | 19.8 | 8.45 | 7.37 | 0.49 | 1.40 | 10.83 | 12.38 | 12.38 |
| | | Reinbold and Pescitelli 1982a | 20.1 | 7.92 | 21.7 | 1.12 | 1.37 | 14.15 | | |
| Green Sunfish | *Lepomis cyanellus* | Reinbold and Pescitelli 1982a | 25.4 | 8.16 | 5.84 | 0.78 | 1.00 | 7.44 | 6.03 | 2.85 |
| | | McCormick et al. 1984 | 22 | 7.9 | 5.61 | 1.15 | 1.00 | 4.88 | | |
| Bluegill Sunfish | *Lepomis macrochirus* | Smith et al. 1984 | 22.5 | 7.76 | 1.85 | 1.37 | 1.00 | 1.35 | 1.35 | |
| Smallmouth Bass | *Micropterus dolomieu* | Broderius et al. 1985 | 22.3 | 6.6 | 9.61 | 2.70 | 1.00 | 3.57 | 4.56 | 4.56 |
| | | Broderius et al. 1985 | 22.3 | 7.25 | 8.62 | 2.15 | 1.00 | 4.01 | | |
| | | Broderius et al. 1985 | 22.3 | 7.83 | 8.18 | 1.26 | 1.00 | 6.50 | | |
| | | Broderius et al. 1985 | 22.3 | 8.68 | 1.54 | 0.33 | 1.00 | 4.66 | | |
| Catfish | *Ictalurus punctatus* | TetrES 2001 | 8.5 | 0.00 | 8.4 | 0.53 | 1.00 | 6.35 | 6.35 | 6.35 |
| Fathead Minnow | *Pimephales promelas* | TetrES 2001 | 8.5 | 0.01 | 8.4 | 0.53 | 1.00 | 20.17 | 20.17 | 20.17 |
| Northern Pike | *Esox lucius* | TetrES 2001 | 17 | 0.00 | 8.5 | 0.45 | 1.00 | 2.62 | 2.62 | 2.62 |
| Walleye | *Stizostedion vitreum* | TetrES 2001 | 18 | 0.00 | 8.1 | 0.86 | 1.00 | 4.72 | 4.72 | 4.72 |
| White Sucker | *Catostomus commersoni* | TetrES 2001 | 17.5 | 0.01 | 8.2 | 0.74 | 1.00 | 8.07 | 8.07 | 8.07 |
| Ceriodapnia dubia | *Ceriodaphnia dubia* | TetrES 2001 | 24 | 0.01 | 8.2 | 0.74 | 1.07 | 6.63 | 6.63 | 6.63 |
| Scud | *Hyalella azteca* | TetrES 2001 | 24 | 8.29 | 8.2 | 0.74 | 1.07 | 10.55 | 10.55 | 10.55 |




Source TetrES 2001

**Ranked Genus Mean Chronic Values (GMCVs) with Site-Specific Chronic Ammonia Criteria**

Figure 6-6

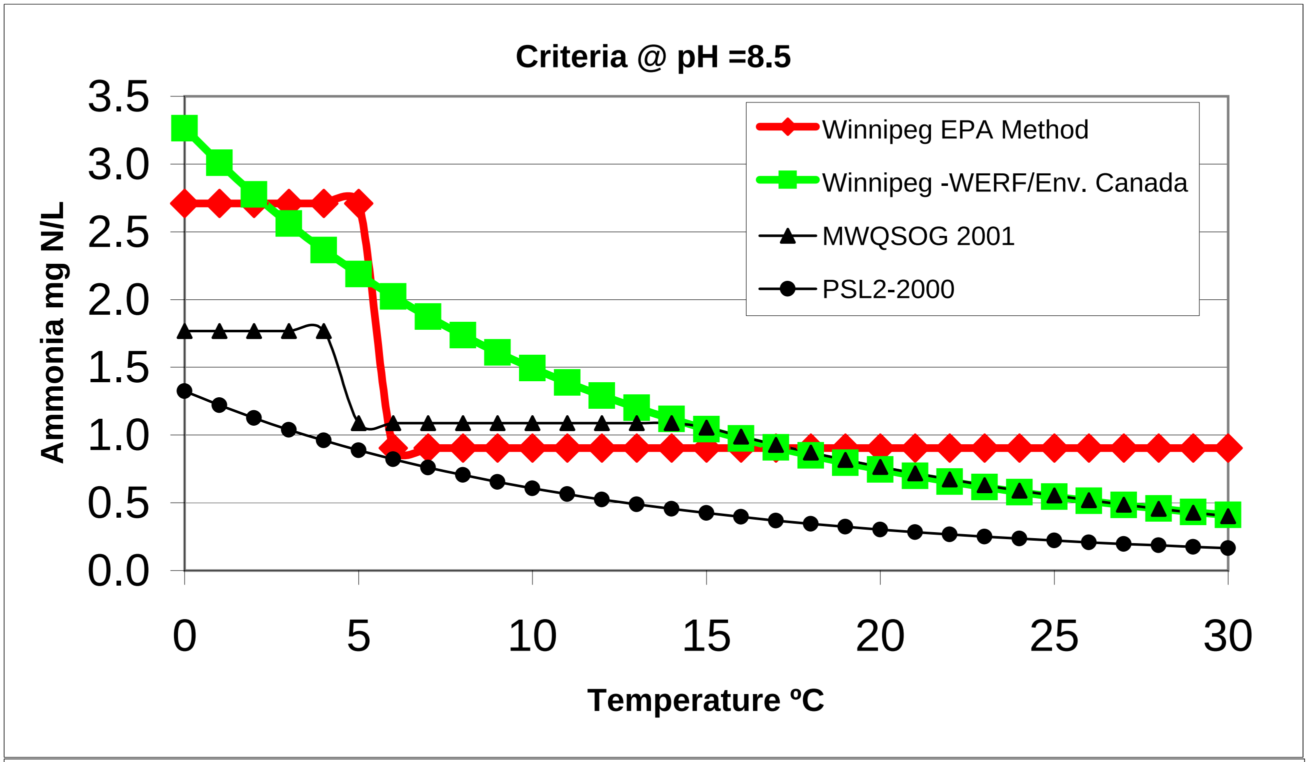
developments, which indicated *Hyalella* an invertebrate was the most sensitive species. The toxicity test done in the Winnipeg study indicated that *Hyalella* was no more sensitive than other invertebrates, such as *Ceriodaphnia* and *Daphnia magna*.

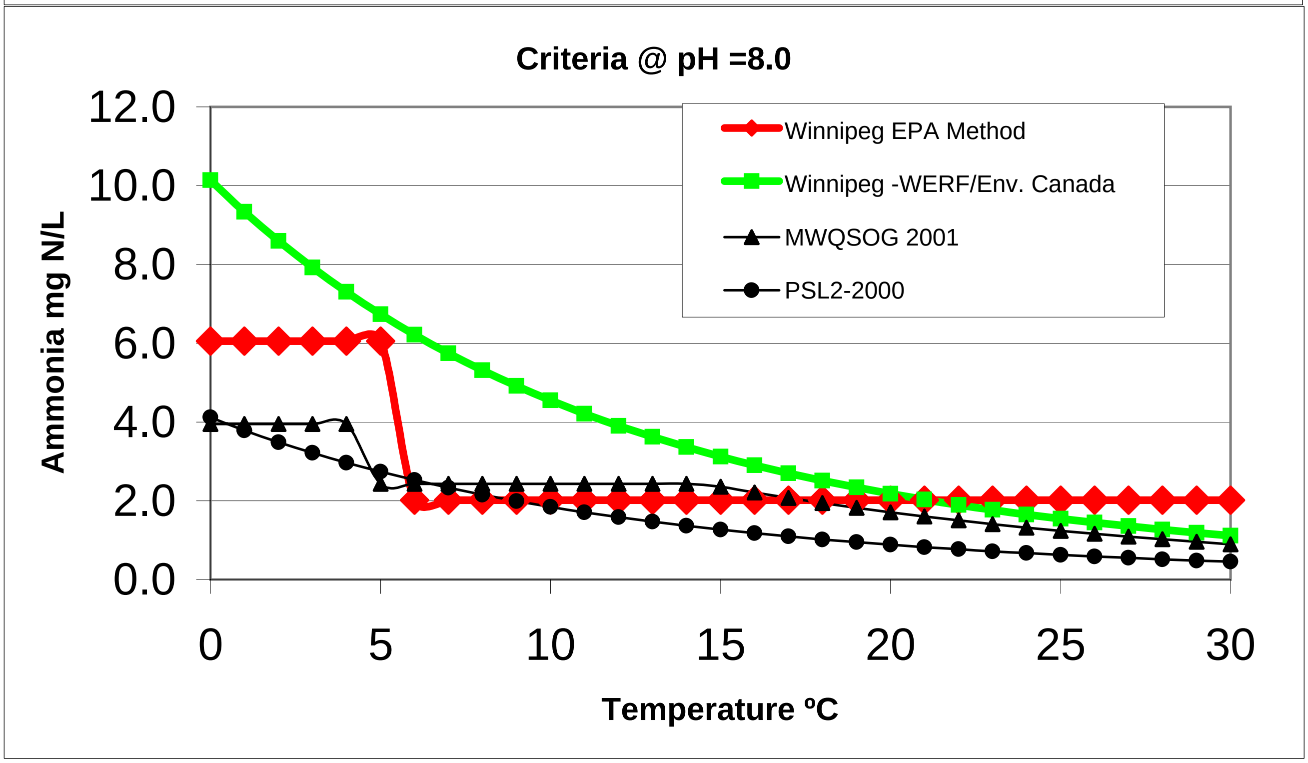
The local dataset, when analyzed using the WERF model ($r^2$ = .99), indicated much tighter prediction limits for the local dataset, when compared to the PSL-2 national dataset ($r^2$ = 0.95). The PSL-2 national dataset indicated that the *Hyalella* tests were not reflective of sensitivity within natural waters and this was further confirmed by the testing done using Red River water for dilution. It is suspected that the river water was rich in potassium or sodium which is essential to *Hyalella* and may have afforded them greater tolerance (Borgmann *pers comm*. 2001). This high degree of confidence in the dataset, when analyzed statistically, gives us confidence that the criterion selected for site-specific conditions is very appropriate. A comparison of the different approaches to site-specific criteria when expressed as total ammonia at pH = 8 and 8.5 for a range of temperatures is shown in Figure 6-7.

The Winnipeg site-specific criterion concentration developed using EPA protocol criteria is both more and less stringent than the EPA 99 (draft Manitoba criterion) at pH = 8.5 and T >17°C or T >5°C it is less stringent, however, between 5°C and 17°C it is more stringent.

Although we have removed the most sensitive species, i.e., *Hyallela*, this is an invertebrate which was tested at 25°C. Therefore, the data shown in Figure 3-5 and Figure 6-6 are standardized for pH 8 and temperature 25°C. The EPA method allows a temperature adjustment when the most sensitive species is an invertebrate. Therefore, the *Hyallela* value is actually adjusted to higher numbers for the lower temperatures (i.e., between 7 and 17 degrees). The species which was found to be the most sensitive using the Winnipeg site-specific testing procedure was northern pike, a fish. When a fish is the most sensitive species, no temperature adjustments to the criterion value are allowed. However, criterion value adjustments (i.e., 3 x) are allowed for fish when no early life stages are noted. Manitoba Conservation has suggested 5 degrees as a limit for early life stages and our biologists generally concurred, although we have no strong site-specific data for this assumption.

The site-specific criterion developed using PSL-2 protocols is similar to EPA 99 (Manitoba 2001) at T >17°C (pH = 8.5) but is less stringent below 17°C.




**Comparison of Winnipeg Site-Specific Criteria (for both Environment Canada and EPA Protocol) and Manitoba 2001 (EPA 1999) Chronic Ammonia Criteria**

Figure 6-7

All criteria shown on Figure 6-7 are considerably higher than the current (Manitoba 1988) objective which was used for licence development in the region as late as 1999. The variation in criteria developed using different (very defensible) protocols, as well as the significant change in criteria from 1988 to 2000 should illustrate why these criteria should be considered an objective or guideline and cannot be applied rigorously without consideration of the uncertainty inherent in their development.

## 6.6 ALLOWABLE FREQUENCY

Aside from defining a protective criterion concentration, it is also very necessary to consider the allowable frequency, duration of, and extent of expanse of aquatic life to the “target” criterion concentration. The purpose of selecting an average frequency of allowable excursions of the criterion concentration is to provide an appropriate average period of time during which the aquatic community can recover from the effect of an excursion, and then function normally for a period of time before the next excursion (U.S. EPA 1991). The EPA states that the average frequency is intended to ensure that the aquatic community is not constantly recovering from the effects caused by excursions of aquatic life criterion. In developing a frequency of exceedence guideline, the EPA determined that the community as a whole should be assessed. Natural disturbances, such as floods and droughts are common in lotic (river) systems, and may vary in intensity between headwaters in streams and large rivers, and also between different climatic regions. Communities which are predisposed to disturbances may recover from them relatively quickly by being able to recolonize and reproduce quickly.

In a review of the literature, the EPA (1991) determined that for a short term (non-persistent) disturbance, approximately 80% of all macro invertebrate end-points indicated a recovery in less than 2 years. Macro invertebrate biomass, density, and taxonomic richness recovered in less than 1 year for approximately 95% of the reported end-points. Fishes recovered in 2 years or less over 80% of reported end-points. EPA stated that the case studies reviewed caused more severe impacts than most criteria excursions are expected to cause. The data indicated that, as a general rule, the objective of the recovery period will be achieved if an allowable frequency is set once every three years on average, based on **acute criteria** excursions. Excursions of the **chronic criteria** were more difficult to evaluate, and could not be evaluated from the data assessed. The EPA indicated, however, that it would be reasonable to expect that too frequent excursions of the chronic criteria also would result in unacceptable degradation of aquatic communities.

The above discussion indicates that the selection of frequencies of excursions is highly uncertain and judgemental. However, three years may be considered reasonable for acute toxicity effects. Using the three year allowable excursion for chronic or non-lethal effects **is likely conservative**. However, at this time, there is no other basis for selecting a different allowable excursion frequency.

## 6.7 ALLOWABLE DURATION

Early guidance from the U.S. EPA indicated that a 4-day or 96-hour averaging period was recommended for the application of **chronic** criteria concentrations. This was due, most likely, to a limited number of longer term tests done. In the most recent ammonia criteria update (EPA 1999), the EPA stated that **30 day averaging periods** could be used, as long as the 4 day average was not more than 2.5 times the chronic criteria. The testing done to develop local site-specific criteria was done for 30 days on many of the critical species (13 days for northern pike, 30 days for walleye and 30 days for catfish). It would therefore seem reasonable to use the 30 day averaging period for a local site-specific criterion. Our analysis of the 30-day exposure studies done on walleye and catfish indicate that the 4 day acute value ($LC_{20}$) for these species is 3.2 times higher than 30 day chronic value ($LC_{20}$). For northern pike, the 4-day acute value ($LC_{20}$) average is 2.8 times higher than the 13 day average chronic value used for acute value.

## 6.8 MIXING ZONE

The draft Manitoba Water Quality Standards, Objectives and Guidelines state; "*the mixing zone should be as small as practicable and should not be of such size or shape as to cause or contribute to the impairment of water uses outside the zone*;".

In addition "*the mixing zone should be designed to allow an adequate zone of passage for the movement or drift of all stages of aquatic life*".

For those materials that elicit an avoidance response, the mixing zone should contain not more than 25% of the cross-sectional area or volume of flow. However, fish behaviour studies can provide us additional guidance. During the winter some species of fish, such as northern pike (the most commonly sensitive species tested), show a definite attraction to the outfall areas. The ability of tagged northern pike to leave the vicinity of the NEWPCC outfall in both upstream and downstream directions suggests that the plumes do not act as a barrier to fish movements in the winter.

The Manitoba objectives also state; "*The mixing zone should not be acutely lethal to aquatic life passing through the mixing zone. Thus, for toxic materials, acute lethality within the mixing zone is a function of concentration and the duration of exposure. Whole effluents should not be acutely lethal to aquatic life, as demonstrated by 96 hour* $LC_{50}$ *tests done on appropriate species, unless it can be shown either through mixing zone modelling that mixing of the effluent with the receiving water will be achieved in a relatively rapid and complete manner (e.g., no more than a 10% difference in bank-to-bank concentrations within a longitudinal distance of not more than two streams or river widths) or through other scientifically rigorous methods that acute lethality will not occur within the mixing zones;*".

Three dimensional CORMIX modelling indicated that complete mixing will occur at the SEWPCC and WEWPCC during critical low flow condition. During high flow conditions mixing will not occur rapidly. However, the dilution occurring within the first several metres of the outfall is significant. Three to five times dilution will occur within 5 to 10 metres of the outfall. Northern pike tagged passed through the plume without apparent acute toxicity effects. In addition, *in situ* toxicity testing of mussels indicated no statistically-significant difference in growth for samples within the plume (at varying concentrations of ammonia 5 to 150 m downstream) or at the upstream control site. These mussels were exposed for 65 days during varying river and effluent flows.

The multiple mixing zone assessments (behaviour, toxicity, mixing models) indicate that a modification of the mixing zone (by use of a diffuser) is not necessary. At the WEWPCC, the plume remains attached to the south bank and does not surpass a 25% cross-sectional area of the Assiniboine River.

## 6.9 SITE-SPECIFIC CRITERIA

Section 6 develops surface water criteria to provide an appropriate level of protection to aquatic life from impacts of ammonia. Guidance has been developed for an appropriate acute and chronic criterion concentration, and appropriate averaging period, allowable excursion frequency and the requirements of a mixing zone. Since this is a site-specific criterion, which will be applied to specific discharges for the City of Winnipeg, it is appropriate that guidelines be developed to ensure that potential licences provide appropriate direction in the design and operation of future Water Pollution Control Centres. Therefore, this direction should ensure that the intended level of protection of the surface water be satisfied when the license is satisfied. The following Section (7.0) discusses how an effluent licence can be developed in order to provide the level of protection required to meet a site-specific surface water objective for ammonia in the Red and Assiniboine Rivers.

# 7. SITE-SPECIFIC CRITERIA APPLICATION TO PERMITTING

The site-specific surface water criteria which will eventually be adapted for the Red and Assiniboine Rivers will be applied to develop licences for the three City of Winnipeg Water Pollution Control Centres (WPCCs). The locations of these WPCCs on the two rivers is shown on Figure 7-1.

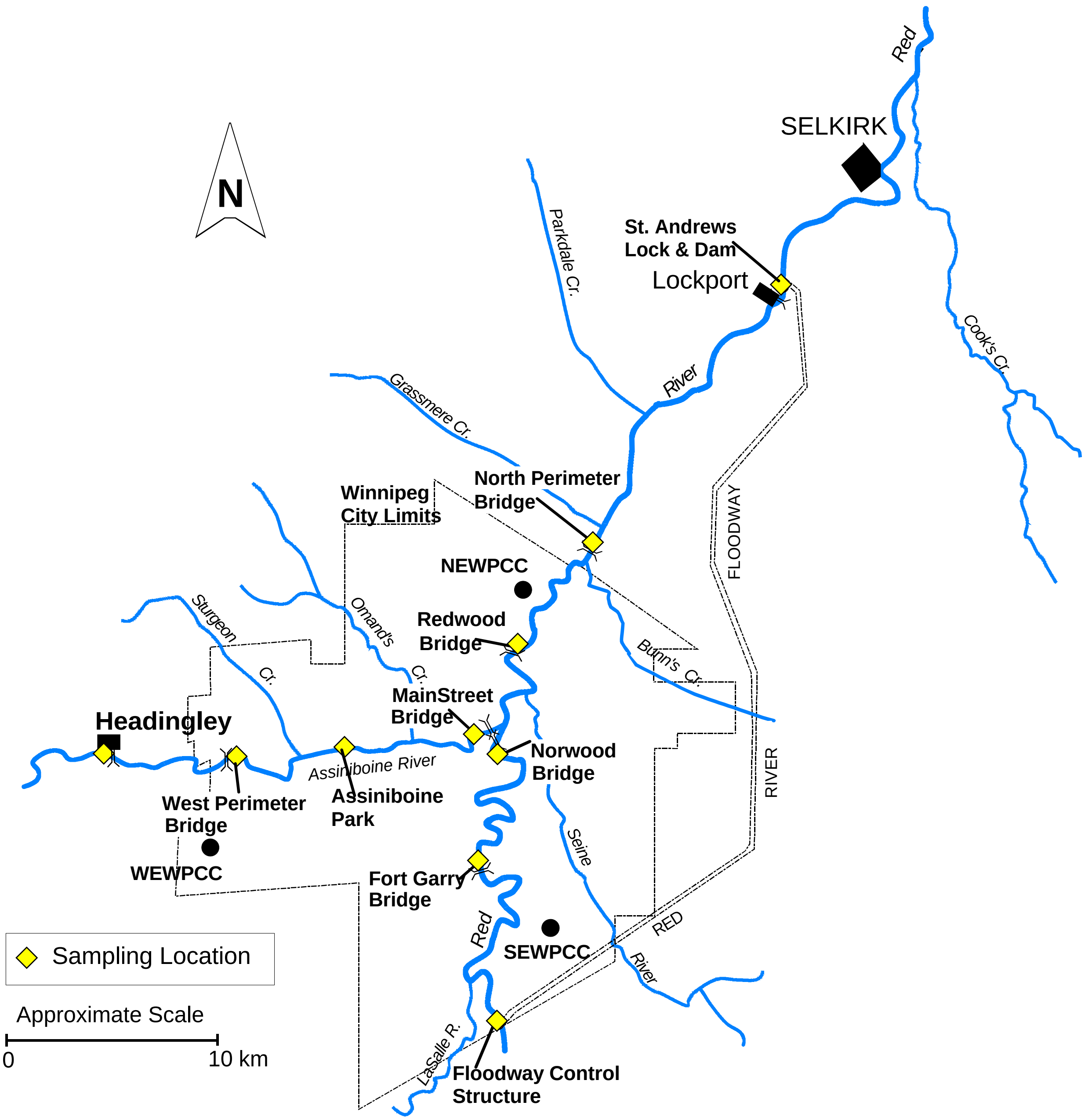
In order to develop acceptable annual or monthly discharge concentration targets for the WPCCs, methods have to be employed which would correlate these targets to surface water criteria concentrations. Criteria concentrations are allowed excursions once in three years on average when the water quality samples averaged over 30 days are considered. For ammonia, the ambient water temperature and pH needs to be considered in order to either convert un-ionized ammonia criteria to total ammonia or, conversely, to adjust the total ammonia criterion concentration. In order to determine the allowable discharge or waste load allocation (WLA) for the WPCC, a water quality model needs to be employed. The methods described by the EPA in their Technical Support Document for Water Quality Based Toxics Control (EPA 1991) are to use either a steady-state model or a dynamic model. Applications using both these methodologies for alternative surface water criteria are discussed below and compared.

The various potential criteria which will be applied were discussed in Sections 3 and 6. The alternative criteria are:

- EPA 1999 (or Manitoba 2001 draft);
- Winnipeg Site-Specific Criteria Developed using EPA protocols;
- Winnipeg Site-Specific Criteria – Developed, using Environment Canada PSL-2 national criteria; and
- Manitoba Surface Water Quality Objective Criteria developed in 1988.

Both steady-state and dynamic modelling techniques will be employed to derive allowable waste allocations for each WPCC. These results will be compared to potential discharges for the year 2041 to determine if Licences for each of the plants could result in:

- the plant design and operation could be accepted as is;

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**Locations of WPPCs and City of Winnipeg Bi-Weekly Routine Sampling Locations**

Figure 7-1

- minor alterations could be required in order to meet licence discharge limits; or
- major upgrades could be required in order to meet licence discharge limits.

Potential upgrades from a conceptual design developed in a parallel study (Earth Tech 2001) will be assessed to determine the level of upgrade which may be required.

## 7.1 STEADY-STATE APPLICATION

The EPA (1991) considers a surface water criterion to be met if the criterion concentration is exceeded less frequently than once in three years on average when a 30-day average of surface water quality samples is considered.

### 7.1.1 Design Flows

To develop a waste load application using a steady-state water quality model which will provide the appropriate level of protection, a single river flow (design flow) must be selected. This design flow is to provide the desired probability or return period. Two methods are generally employed in order to calculate the design flow:

- *Hydrologically-based method*. This method has been used historically in many parts of the U.S. and the Province of Manitoba. It is used to identify extreme values such as the 7Q10 flow (7 day average flow with 10 year return period). This method can define monthly low flow values (i.e., monthly 7Q10s).

- *Biologically-based design flow method* (also developed by the U.S. EPA) directly uses the averaging periods and the frequency specified in the aquatic life water-quality criteria for each parameter (i.e., ammonia). This method allows the use of exact duration of frequency as specified in the criteria. The method that is often used to develop criteria is the 30-B3 (30 day duration biologically-based design flow with once in three years excursions on average). This methodology cannot be used to develop monthly flows.

For more discussion on this steady-state design flows development see the River Conditions TM or the Technical Support Document for Water Quality Based Toxicity Control (U.S. EPA 1991).

The two procedures for calculating design flows are significantly different. The method we used was embedded in an EPA program called "DFLOW". We will describe the differences in the programs which may lead to these different calculations.

The biologically-based method allows the counting of multiple excursions within one year, which is different from the calculation of a hydraulically-based "$1Q_{10}$". On the Red River, there is a history of low flows occurring for long durations during a single year (i.e., for 90 days or more). Therefore the biologically-based method will count multiple excursions in that year, and a hydraulically-based method will only have one excursion in that year. Accordingly, over the same period of record, a lower design flow will occur using the biologically-based method.

A summary of these design flows based on the period of record from 1962 to 1997 for 1Q10, 7Q10, 7Q30 and 1B3, 4B3 and 30B3, is shown on Table 7-1. Also calculated were the monthly 1Q10, 7Q10 and 7Q30 for each of the three rivers (see Table 7-2). In order to apply an ammonia criterion, pH and temperature values are required for the receiving stream design conditions. For the annual design flow conditions, the average annual pH and temperature are used for each stream. For the monthly design flows, the monthly average for pH (for each station) and the temperature was used and is tabulated in Table 7-3. Background ammonia concentrations are shown in Table 7-4.

### 7.1.2 Potential Discharge Limits

A representation of a typical output from a steady-state model is shown on Figure 7-2. For each of the three local treatment plants, discharge limits were calculated using the following methods:

- The discharge rate (ML/D) (for the year 2041) was estimated for each plant (see River Conditions TM and Table 7-4). For the WEWPCC and NEWPCC, the projected discharge rates are very close to current conditions. Most of the growth in the City of Winnipeg will take place in the south end of the City and the SEWPCC is expected to grow by about 50%.

# TABLE 7-1
# ANNUAL DESIGN FLOWS (1962-1997)

| | Extreme Value[1] m³/s) | | | Biologically-Based[2](m³/s) | | |
|---|---|---|---|---|---|---|
| | 1Q10 | 7Q10 | 30Q10 | 1B3 | 4B3 | 30B3 |
| **St. Agathe** | 6.37 | 6.88 | 7.85 | 3.55 | 3.75 | 6.52 |
| **Lockport** | 17.01 | 18.67 | 20.45 | 14.99 | 15.87 | 18.75 |
| **Headingley (adj)** | 4.65 | 4.98 | 6.20 | 5.60 | 5.63 | 6.38 |
| **Headingley** | 3.39 | 3.82 | 4.69 | 3.76 | 4.01 | 4.65 |

*[1] Based on Log Pearson Type III Distribution*
*[2] Length of clustering period = 120 days; Maximum number of excursions counted per cluster = 5 (as recommended by the US EPA)*

# TABLE 7-2
# MONTHLY DESIGN FLOWS ($m^3/s$)

| | 1Q10 | | | 7Q10 | | | 30Q10[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| | St. Agathe | Lockport | Headingley (adjusted) | St. Agathe | Lockport | Headingley (adjusted) | St. Agathe | Lockport | Headingley (adjusted) |
| **Jan** | 4.4 | 16.3 | 6.5 | 4.5 | 16.8 | 6.7 | 5.1 | 18.2 | 8.0 |
| **Feb** | 4.8 | 16.8 | 7.4 | 5.0 | 17.2 | 7.9 | 6.3 | 19.0 | 8.4 |
| **Mar** | 8.1 | 20.7 | 7.6 | 8.3 | 21.5 | 8.0 | 13.6 | 32.4 | 11.0 |
| **Apr** | 24.0 | 34.0 | 6.3 | 26.2 | 41.0 | 9.4 | 78.4 | 135.8 | 26.2 |
| **May** | 39.8 | 64.4 | 6.7 | 43.8 | 67.8 | 11.3 | 48.6 | 86.8 | 17.5 |
| **Jun** | 31.5 | 55.5 | 8.8 | 34.7 | 58.0 | 9.6 | 47.3 | 76.8 | 12.9 |
| **Jul** | 13.3 | 31.8 | 5.7 | 15.9 | 33.8 | 5.9 | 22.3 | 46.9 | 9.9 |
| **Aug** | 9.6 | 22.2 | 5.7 | 11.9 | 27.6 | 5.8 | 13.7 | 35.4 | 7.9 |
| **Sep** | 10.9 | 21.8 | 5.7 | 13.2 | 23.5 | 5.9 | 17.9 | 41.5 | 8.5 |
| **Oct** | 8.6 | 23.1 | 5.7 | 10.0 | 24.6 | 7.1 | 12.3 | 34.2 | 9.7 |
| **Nov** | 6.2 | 17.5 | 5.7 | 7.3 | 22.1 | 6.5 | 8.4 | 27.4 | 10.4 |
| **Dec** | 5.1 | 18.9 | 7.0 | 5.5 | 21.5 | 9.0 | 7.3 | 22.7 | 10.6 |

*1 February values based on 28-day a*
Based on Water Survey of Canada 1962-1997

**TABLE 7-3**
**MEAN MONTHLY pH and TEMPERATURE at VARIOUS STATIONS**

| | Mean pH | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December | Average |
| Floodway Control | 7.94 | 7.84 | 7.87 | 8.10 | 8.22 | 8.10 | 8.16 | 8.32 | 8.38 | 8.39 | 8.47 | 8.27 | ***8.18*** |
| Fort Garry Br. | 7.88 | 7.78 | 7.82 | 8.07 | 8.23 | 8.13 | 8.18 | 8.30 | 8.37 | 8.33 | 8.42 | 8.26 | ***8.16*** |
| Norwood Bridge | 7.85 | 7.78 | 7.81 | 8.04 | 8.16 | 8.04 | 8.11 | 8.27 | 8.33 | 8.36 | 8.37 | 8.17 | ***8.11*** |
| Redwood Bridge | 7.69 | 7.63 | 7.62 | 7.96 | 8.00 | 7.98 | 8.00 | 8.15 | 8.17 | 8.14 | 8.26 | 7.94 | ***7.97*** |
| North Perimeter | 7.75 | 7.64 | 7.70 | 7.97 | 8.03 | 8.00 | 8.02 | 8.03 | 8.10 | 8.09 | 8.17 | 7.92 | ***7.96*** |
| Lockport | 7.84 | 7.72 | 7.77 | 7.98 | 8.08 | 8.10 | 8.10 | 8.14 | 8.17 | 8.18 | 8.20 | 8.05 | ***8.03*** |
| Headingley | 7.93 | 7.84 | 7.90 | 8.19 | 8.30 | 8.30 | 8.37 | 8.45 | 8.50 | 8.45 | 8.47 | 8.15 | ***8.25*** |
| West Perimeter Br. | 7.90 | 7.82 | 7.89 | 8.16 | 8.27 | 8.28 | 8.33 | 8.40 | 8.45 | 8.42 | 8.40 | 8.13 | ***8.21*** |
| Assiniboine Park | 7.94 | 7.80 | 7.77 | 8.16 | 8.36 | 8.40 | 8.38 | 8.54 | 8.60 | 8.43 | 8.36 | 8.05 | ***8.27*** |
| Main St. Bridge | 7.89 | 7.83 | 7.90 | 8.12 | 8.27 | 8.22 | 8.28 | 8.39 | 8.43 | 8.45 | 8.45 | 8.05 | ***8.21*** |
| Average | ***7.85*** | ***7.77*** | ***7.81*** | ***8.07*** | ***8.18*** | ***8.13*** | ***8.18*** | ***8.28*** | ***8.33*** | ***8.32*** | ***8.35*** | ***8.11*** | ***8.13*** |

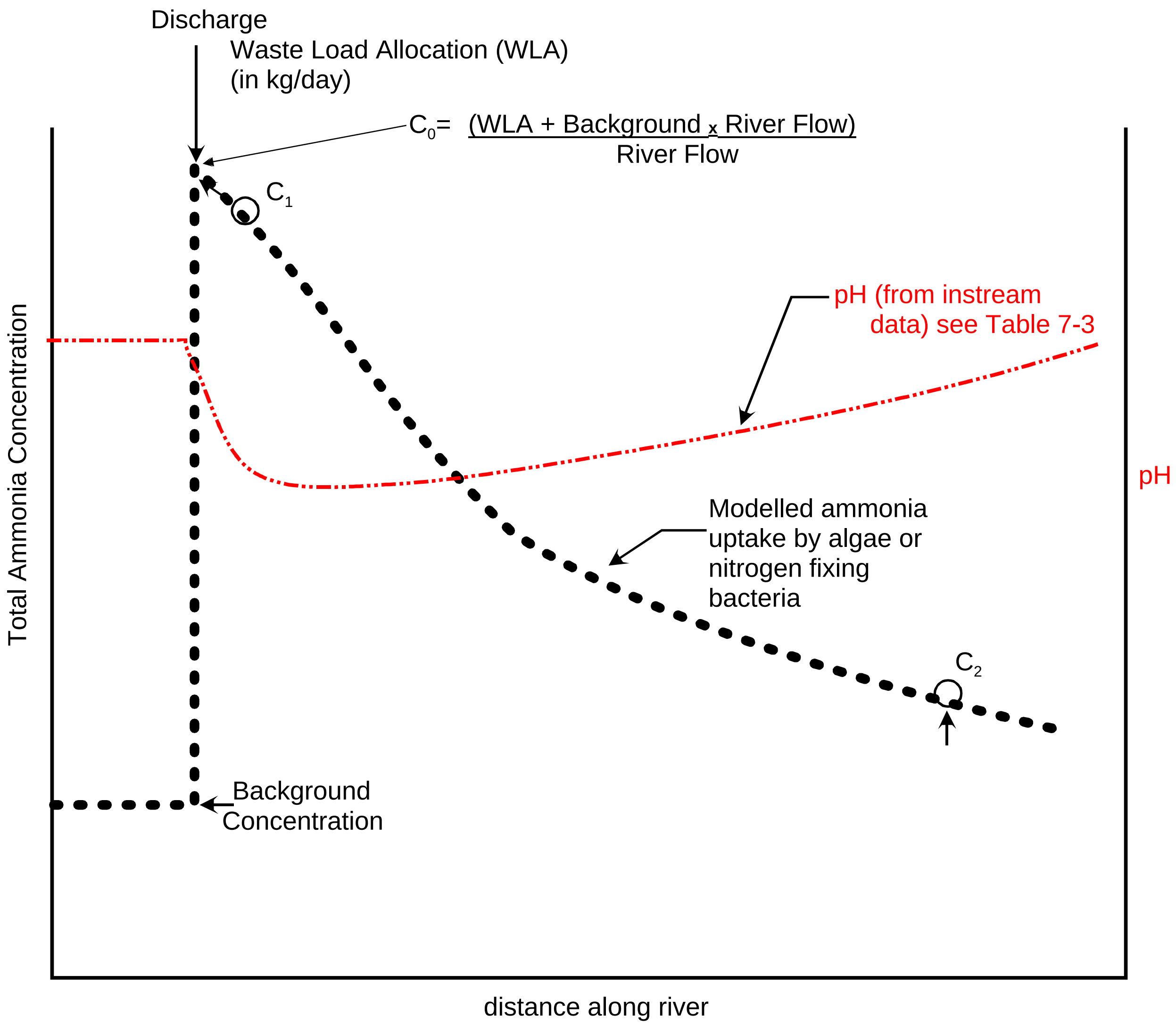
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature °C | 1.7 | 1.8 | 2.0 | 7.2 | 15.3 | 20.1 | 22.8 | 21.3 | 15.6 | 8.4 | 3.4 | 1.3 | 10.1 |

Based on City of Winnipeg Data (1977 to 1997)

**Table 7-4**

## Background Ammonia Concentrations and Assumed WPCC Discharge

| | | Treatment Plant | | |
|---|---|---|---|---|
| | | SEWPCC | NEWPCC | WEWPCC |
| | Discharge Rate (MLD) in 2041 | 87.0 | 267.1 | 34.7 |
| | | Upstream Location | | |
| | Month | Floodway Control | Redwood Bridge | Headingley |
| 1 | January | 0.34 | 0.51 | 0.32 |
| 2 | February | 0.36 | 0.50 | 0.32 |
| 3 | March | 0.27 | 0.36 | 0.25 |
| 4 | April | 0.38 | 0.22 | 0.34 |
| 5 | May | 0.15 | 0.08 | 0.14 |
| 6 | June | 0.22 | 0.18 | 0.16 |
| 7 | July | 0.15 | 0.12 | 0.12 |
| 8 | August | 0.14 | 0.08 | 0.14 |
| 9 | September | 0.13 | 0.10 | 0.12 |
| 10 | October | 0.13 | 0.12 | 0.11 |
| 11 | November | 0.13 | 0.22 | 0.11 |
| 12 | December | 0.17 | 0.25 | 0.23 |




Notes: Determine 2 potential WLAs

1) $C_1$ = Criteria at first station downstream of WPCC
2) $C_2$ = Criteria at downstream location (higher pH)
3) ph is lowered by discharge or treated wastewater

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**Using Steady-State Model and Design Flows to Determine Waste Load Allocation**

Figure 7-2

- The potential surface water criterion was converted to the appropriate total ammonia equivalent for the given ambient pH and temperature.
- The same "uptake" model was used to calculate uptake for both steady-state and dynamic analysis from 1962 to 1997. The uptake was calculated using a first order decay model which was temperature-dependent. This model was calibrated for data from the plant and the upstream and downstream locations, i.e., for NEWPCC, the North Perimeter bridge, and Lockport. Actual plant flows and effluent data were used to calibrate the model along with river flows, calculated travel times, and water temperature (see River Conditions TM for details).
- The discharge concentration, given the future discharge rate, was calculated such that the surface water criterion would just be met at each of the two downstream sample stations. For the NEWPCC, those sample stations were at Lockport and the North Perimeter Bridge. The SEWPCC sample stations were at the Fort Garry Bridge and the Norwood Bridge, and for the WEWPCC the sample stations were at the West Perimeter and Main Street Bridges.
- Each downstream sample station could have a different surface water criterion in terms of total ammonia due to varying pH within the river. Water temperature remains fairly consistent throughout the study area on a given day.
- If different discharge limits were calculated in each of the two sample stations, the lower of the two discharge limits was selected.

The monthly mean concentration of total ammonia allowable from each of the three WPCCs is summarized in Table 7-4 for a range of potential surface water criteria. The criteria which were assessed include:

- *The Manitoba Water Quality Standards, Objectives and Guidelines ammonia criteria* (MWQSOG; Manitoba Conservation 2001). This is essentially the 1999 EPA criteria (EPA 1999). This criterion is based on total ammonia which varies with both pH and temperature.
- *The Winnipeg site-specific criterion based on EPA Methods* (see Section 5). This criteria is based on total ammonia however varies only with pH, not temperature. There is an allowance for increasing the criteria concentration by three-fold during periods where surface water temperature is less than 5°C and therefore early life stages are not considered to be present.

- *The Winnipeg site-specific criterion based on the PSL-2 Environment Canada methods*. This criterion is based on un-ionized ammonia. The concentration criteria when converted to total ammonia will vary with pH and temperature.
- *The PSL-2 National criterion (41 $\mu$g-$NH_3$/l) (Environment Canada 2000)*. This criterion is also based on un-ionized ammonia, however, it included salmonid species not present in Winnipeg streams and therefore is not considered appropriate for this location.
- *The Manitoba Surface Water Quality Objective for ammonia developed in 1988* is also shown since it remains the formal guideline and it was the criterion which would have been applied had discharge permits been developed prior to the initiation of this study.

An estimate of the allowable discharge concentration using the EPA 1999 criterion and an **annual** 30-B3 design flow was also made for each of the plants. This methodology provides only a single discharge limit for all months. This is not considered appropriate for a constituent such as ammonia since the toxicity of ammonia is shown to vary considerably depending on pH and temperature. For the Red and Assiniboine rivers the variation of pH and temperature from month to month is significant.

For each of the treatment plants, these tables illustrate the range in effluent discharge limits which could be developed based on various criteria. To illustrate, the allowable concentration for the month of October could range from 4.5 to 40.9 mg/L for the NEWPCC (Table 7-5) and 5.9 to 35.5 mg/L for the SEWPCC (Table 7-5a). Even criteria which use the same dataset in the development (i.e., the two Winnipeg site-specific criteria) will arrive at different discharge limits at the licencing stage. This illustrates the lack of precision possible in criteria and licence development.

### 7.1.3 Potential WPCC Treatment

We have estimated the potential outcome in terms of the requirements of WPCC upgrades for the application of the different potential criteria. For this purpose, the results of a parallel study conducted by the City to develop conceptual treatment plant designs (nitrification) for a range of levels of control (LOC) for each of the three WPCCs were used (Earth Tech 2001). The total mean ammonia concentration of the effluent for various levels of control for each of the three WPCCs is given in Table 7-6. The mean discharge concentration can then be compared to the

**TABLE 7-5**

# Potential WPCC Ammonia Targets Based on Various Criteria

**TABLE 7-5a**

**SEWPCC Mean Ammonia Concentration (mg N/L) Objective for Effluent Based on Various Criteria**

( Using 30Q10 Design Flow and 2041 Discharge)

| Number | Month | MWQ SOG 2001/EPA 99 | Winnipeg Site Specific EPA Method | Winnipeg Site Specific PSL2 Method | PSL2 National | MSWQO 1988[1] | EPA 99 30B3 (Annual) |
|---|---|---|---|---|---|---|---|
| 1 | January | 31.2 | 41.3 | 75.8 | 29.8 | 11.5 | 12.7 |
| 2 | February | 41.2 | 54.6 | 109.6 | 43.2 | 15.6 | 12.7 |
| 3 | March | 73.0 | 96.7 | 184.3 | 72.6 | 20.7 | 12.7 |
| 4 | April | 141.7 | 91.7 | 339.0 | 119.8 | 18.1 | 12.7 |
| 5 | May | 81.4 | 58.9 | 93.5 | 33.6 | 26.3 | 12.7 |
| 6 | June | 68.4 | 69.8 | 83.1 | 27.7 | 28.1 | 12.7 |
| 7 | July | 31.4 | 38.5 | 36.1 | 12.7 | 13.5 | 12.7 |
| 8 | August | 19.4 | 21.4 | 20.4 | 7.2 | 8.7 | 12.7 |
| 9 | September | 28.0 | 20.7 | 29.5 | 10.6 | 7.8 | 12.7 |
| 10 | October | 21.0 | 14.4 | 35.5 | 13.4 | 5.9 | 12.7 |
| 11 | November | 19.4 | 25.8 | 28.4 | 10.9 | 3.9 | 12.7 |
| 12 | December | 24.0 | 31.8 | 46.9 | 18.3 | 6.2 | 12.7 |

1) Based on 7Q10 As was recommended in 1988 all others on 30Q10

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**TABLE 7-5b**

**NEWPCC Mean Ammonia Concentration (mg N/L) Objective for Effluent Based on Various Criteria**

( Using 30Q10 Design Flow and 2041 Discharge)

| Number | Month | MWQ SOG 2001/EPA 99 | Winnipeg Site Specific EPA Method | Winnipeg Site Specific PSL2 Method | PSL2 National | MSWQO 1988[1] | EPA 99 30B3 (Annual) |
|---|---|---|---|---|---|---|---|
| 1 | January | 27.7 | 28.9 | 99.2 | 34.8 | 9.9 | 14.1 |
| 2 | February | 31.6 | 35.1 | 124.2 | 44.7 | 13.5 | 14.1 |
| 3 | March | 56.4 | 56.4 | 189.4 | 69.9 | 17.4 | 14.1 |
| 4 | April | 85.7 | 51.9 | 250.1 | 83.5 | 8.7 | 14.1 |
| 5 | May | 61.0 | 43.7 | 83.3 | 29.6 | 20.0 | 14.1 |
| 6 | June | 32.1 | 32.9 | 45.8 | 10.2 | 12.0 | 14.1 |
| 7 | July | 18.9 | 24.0 | 25.5 | 6.9 | 7.5 | 14.1 |
| 8 | August | 14.0 | 15.6 | 16.5 | 5.1 | 5.6 | 14.1 |
| 9 | September | 22.0 | 15.7 | 26.6 | 8.4 | 4.5 | 14.1 |
| 10 | October | 19.6 | 12.7 | 40.9 | 14.2 | 4.5 | 14.1 |
| 11 | November | 18.4 | 24.8 | 33.6 | 10.0 | 1.0 | 14.1 |
| 12 | December | 27.7 | 31.7 | 75.5 | 27.3 | 8.7 | 14.1 |

1) Based on 7Q10 as was recommended in 1988, all others based on 30Q10

**TABLE 7-5c**

**WEWPCC Mean Ammonia Concentration (mg N/L) Objective for Effluent Based on Various Criteria**

( Using 30Q10 Design Flow and 2041 Discharge)

| Number | Month | MWQ SOG 2001/EPA 99 | Winnipeg Site Specific EPA Method | Winnipeg Site Specific PSL2 Method | PSL2 National | MSWQO 1988[1] | EPA 99 30B3 (Annual) |
|---|---|---|---|---|---|---|---|
| 1 | January | 89.1 | 117.5 | 214.9 | 85.7 | 31.2 | 26.0 |
| 2 | February | 104.5 | 137.7 | 270.8 | 108.3 | 44.4 | 26.0 |
| 3 | March | 126.3 | 166.2 | 304.6 | 122.0 | 39.2 | 26.0 |
| 4 | April | 111.6 | 76.5 | 235.3 | 90.3 | 15.3 | 26.0 |
| 5 | May | 60.0 | 44.2 | 63.7 | 24.4 | 14.5 | 26.0 |
| 6 | June | 31.1 | 31.7 | 31.7 | 11.6 | 11.6 | 26.0 |
| 7 | July | 19.5 | 23.7 | 20.0 | 7.4 | 5.8 | 26.0 |
| 8 | August | 15.0 | 16.6 | 15.0 | 5.5 | 5.2 | 26.0 |
| 9 | September | 21.0 | 15.7 | 20.0 | 7.5 | 5.1 | 26.0 |
| 10 | October | 29.0 | 20.3 | 47.0 | 18.4 | 7.1 | 26.0 |
| 11 | November | 49.2 | 64.8 | 71.6 | 28.4 | 7.8 | 26.0 |
| 12 | December | 84.5 | 111.4 | 177.7 | 70.7 | 25.8 | 26.0 |

1) Based on 7Q10 As was recommended in 1988 all others on 30Q10

TABLE 7-6

# Mean Ammonia Concentration at WPCCs for Various Levels of Control

TABLE 7-6a

SEWPCC Mean Ammonia Concentration (mg/L) for Various Levels of Control

| Number | Month | No Nitrification | Moderate Level of Control | High Level of Control | Best Practicable Treatment |
|---|---|---|---|---|---|
| 1 | January | 22.8 | 8.3 | 5.1 | 0.8 |
| 2 | February | 23.7 | 7.6 | 4.7 | 0.9 |
| 3 | March | 15.3 | 5.3 | 3.5 | 0.7 |
| 4 | April | 11.6 | 5.6 | 4.2 | 2.6 |
| 5 | May | 15.1 | 6.5 | 4.5 | 5.4 |
| 6 | June | 18.6 | 7.4 | 5.1 | 3.9 |
| 7 | July | 8.5 | 4.6 | 3.2 | 0.9 |
| 8 | August | 18.9 | 9.5 | 6.9 | 1.2 |
| 9 | September | 19.6 | 7.6 | 4.9 | 0.6 |
| 10 | October | 16.1 | 7.2 | 5.0 | 0.5 |
| 11 | November | 19.6 | 7.0 | 4.4 | 0.7 |
| 12 | December | 23.6 | 8.7 | 4.9 | 0.7 |

TABLE 7-6b

NEWPCC Mean Ammonia Concentration (mg/L) for Various Levels of Control

| Number | Month | No Centrate Removal | Centrate Removal | Moderate Level of Control | High Level of Control | Best Practicable Treatment |
|---|---|---|---|---|---|---|
| 1 | January | 29.7 | 20.6 | 14.1 | 9.9 | 0.778 |
| 2 | February | 29.3 | 18.6 | 12.4 | 8.6 | 0.888 |
| 3 | March | 22.0 | 14.8 | 10.4 | 7.5 | 0.653 |
| 4 | April | 13.7 | 9.2 | 8.8 | 8.0 | 2.601 |
| 5 | May | 21.8 | 14.7 | 10.8 | 10.3 | 5.425 |
| 6 | June | 22.7 | 14.0 | 9.2 | 6.5 | 3.911 |
| 7 | July | 17.2 | 11.4 | 8.0 | 5.9 | 0.931 |
| 8 | August | 22.7 | 14.0 | 9.1 | 6.3 | 1.224 |
| 9 | September | 25.2 | 15.4 | 10.1 | 7.0 | 0.642 |
| 10 | October | 22.7 | 15.7 | 10.4 | 7.4 | 0.474 |
| 11 | November | 25.1 | 15.4 | 10.1 | 7.0 | 0.703 |
| 12 | December | 29.3 | 18.6 | 12.3 | 8.5 | 0.738 |

TABLE 7-6c

WEWPCC Mean Ammonia Concentration (mg/L) for Various Levels of Control

| Number | Month | No Nitrification | Lagoon Polishing | Best Practicable Treatment |
|---|---|---|---|---|
| 1 | January | 22.8 | 27.4 | 0.8 |
| 2 | February | 23.7 | 28.2 | 0.9 |
| 3 | March | 15.3 | 26.8 | 0.7 |
| 4 | April | 11.6 | 9.8 | 2.6 |
| 5 | May | 15.1 | 2.2 | 5.4 |
| 6 | June | 18.6 | 3.8 | 3.9 |
| 7 | July | 8.5 | 3.7 | 0.9 |
| 8 | August | 18.9 | 2.6 | 1.2 |
| 9 | September | 19.6 | 4.3 | 0.6 |
| 10 | October | 16.1 | 7.1 | 0.5 |
| 11 | November | 19.6 | 12.9 | 0.7 |
| 12 | December | 23.6 | 21.3 | 0.7 |

mean allowable discharge concentration (Table 7-5) for each in-stream criterion to determine the required level of control in order to meet the different criteria. The limits of control which were assessed at each plant include for the SEWPCC;

- no nitrification (status quo - secondary treatment);
- a moderate level of control (5-10 mg/L);
- high level of control (3-7 mg/L);
- best practicable treatment (BPT)(1-6 mg/L);

and for the NEWPCC:

- no centrate treatment or nitrification (status quo – secondary treatment);
- centrate treatment (centrate is removed from biosolids from all three plants during the dewatering process located at the NEWPCC facility. Centrate has a very high concentration of ammonia, and is currently returned directly into the NEWPCC. Centrate treatment would treat this individual waste stream prior to returning it to the treatment plant);
- moderate level of control (6-15 mg/L ammonia in the effluent);
- high level of control (7-10 mg/L);
- best practicable treatment (BPT) (1-6 mg/L);

and for the WEWPCC:

- no nitrification (status quo – secondary treatment);
- lagoon polishing (lagoon polishing uses the existing WEWPCC lagoons to provide tertiary treatment to the effluent. The treatment is effective during summer and into the fall. However, is not effective during the winter);
- best practicable treatment (BPT) (1-6 mg/L).

In addition to estimating the mean discharge concentration for each month for each plant, process modelling and judgement was used to determine the coefficient of variation for each plant for each month and for each level of treatment (Earth Tech 2001). Each coefficient of variation is used to determine the concentration which would not be exceeded for 95% of the time for each month. This requirement is often part of a licence and requires plant design such that there is only a 5% chance that the geometric mean effluent concentrations over 30 days will exceed the licence.

This appears to be a reasonable precaution and is recommended by the EPA to ensure that there is a low probability that permits will be exceeded. However, when this probability is combined with the low probability of a design flow event, the combined probability is overprotective and costly. For example, the surface water criteria will only be exceeded if the permit is exceeded over a 30-day average during a once in 10-year event. If the effluent concentration is below the discharge criteria 95% of the time, then the surface water criteria will only be exceeded once in every 20 times for the period when the design flow occurs. This would mean that the surface water criteria would be expected to be exceeded once in 200 years rather than the once in 10 years or once in three years on average for which the criteria concentration is designed. This kind of protection could be expensive and is generally only afforded to people (rather than aquatic life) for flood protection of major cities.

The above discussion illustrates how the segregation of process criterion development and criterion application can actually lead to extremely over-protective designs for treatment plants. The coefficient of variation for each of the months for each of the scenarios of the three plants is given in Appendix I. The 30-day mean ammonia concentration which will not be exceeded 95% of the time for the various levels of controls is shown for the three plants in Table 7-7.

The control requirements at the WPCCs to meet the various criteria assessed by applying steady state models is shown in Table 7-8. This results from comparing Table 7-6 and 7-7 with Table 7-5.

For the SEWPCC:

- To meet the proposed general Manitoba SWSOG 2001 (and EPA 1999 Objectives) for the SEWPCC would require measures approaching moderate treatment. The “no nitrification” option would satisfy the criteria in all months except November. Therefore, it is possible some alterations in process or reduction in load may be able to meet this criteria. Since the assessment was done for projected flows (in the year 2041) it is likely no nitrification is currently required to meet the criteria.

**TABLE 7-7**

## 30 Day Mean Ammonia Concentration at WPCCs Not Exceeded 95 % of Time for Various Levels of Control

**TABLE 7-7a**

**SEWPCC 30 Day Mean Ammonia Concentration (mg/L) Not Exceeded 95 % of Time for Various Levels of Control**

| Number | Month | No Nitrification | Moderate Level of Control | High Level of Control | Best Practicable Treatment |
|---|---|---|---|---|---|
| 1 | January | 25.4 | 9.0 | 5.5 | 1.0 |
| 2 | February | 27.0 | 8.4 | 5.1 | 1.1 |
| 3 | March | 16.9 | 5.7 | 3.8 | 0.7 |
| 4 | April | 13.0 | 6.2 | 4.6 | 3.4 |
| 5 | May | 16.7 | 7.1 | 4.8 | 6.5 |
| 6 | June | 22.3 | 8.6 | 5.8 | 5.1 |
| 7 | July | 10.3 | 5.4 | 3.6 | 1.1 |
| 8 | August | 22.5 | 11.1 | 8.0 | 1.6 |
| 9 | September | 22.3 | 8.4 | 5.4 | 0.9 |
| 10 | October | 18.7 | 8.1 | 5.6 | 0.6 |
| 11 | November | 22.3 | 7.7 | 4.8 | 0.9 |
| 12 | December | 27.0 | 9.7 | 5.4 | 0.8 |

**TABLE 7-7b**

**NEWPCC 30 Day Mean Ammonia Concentration (mg/L) Not Exceeded 95 % of Time for Various Levels of Control**

| Number | Month | No Centrate Removal | Centrate Removal | Moderate Treatment | High Level of Treatment | Best Practicable Treatment |
|---|---|---|---|---|---|---|
| 1 | January | 33.1 | 22.9 | 15.6 | 10.9 | 1.0 |
| 2 | February | 33.6 | 21.2 | 14.0 | 9.6 | 1.1 |
| 3 | March | 24.5 | 16.4 | 11.4 | 8.2 | 0.7 |
| 4 | April | 15.4 | 10.3 | 9.8 | 8.9 | 3.4 |
| 5 | May | 24.2 | 16.2 | 11.9 | 11.2 | 6.5 |
| 6 | June | 27.3 | 16.5 | 10.8 | 7.5 | 5.1 |
| 7 | July | 21.3 | 13.9 | 9.6 | 7.0 | 1.1 |
| 8 | August | 27.2 | 16.5 | 10.6 | 7.3 | 1.6 |
| 9 | September | 28.8 | 17.4 | 11.2 | 7.7 | 0.9 |
| 10 | October | 26.7 | 18.2 | 12.0 | 8.4 | 0.6 |
| 11 | November | 28.7 | 17.4 | 11.3 | 7.8 | 0.9 |
| 12 | December | 33.6 | 21.1 | 13.8 | 9.5 | 0.8 |

**TABLE 7-7c**

**WEWPCC 30 Day Mean Ammonia Concentration (mg/L) Not Exceeded 95 % of Time for Various Levels of Control**

| Number | Month | No Nitrification | Lagoon Polishing | Best Practicable Treatment |
|---|---|---|---|---|
| 1 | January | 25.4 | 33.5 | 1.0 |
| 2 | February | 27.0 | 33.1 | 1.1 |
| 3 | March | 16.9 | 30.5 | 0.7 |
| 4 | April | 13.0 | 12.2 | 3.4 |
| 5 | May | 16.7 | 3.0 | 6.5 |
| 6 | June | 22.3 | 5.2 | 5.1 |
| 7 | July | 10.3 | 5.0 | 1.1 |
| 8 | August | 22.5 | 3.7 | 1.6 |
| 9 | September | 22.3 | 5.8 | 0.9 |
| 10 | October | 18.7 | 9.0 | 0.6 |
| 11 | November | 22.3 | 16.7 | 0.9 |
| 12 | December | 27.0 | 24.6 | 0.8 |

**TABLE 7-8**

**Levels of Control Requirements at WPCCs to Meet Various Criteria Using Steady State Modelling Approach to Assessment**

| **SEWPCC** | | |
|---|---|---|
| **Criteria** | **Steady State Approach** | |
| | **Direct WLA** | **To meet 95% Effluent Variation** |
| **MWQ SOG 2001/EPA 99** | Moderate LOC (No nitrification OK in all but November) | Moderate LOC (No nitrification OK in all but August, November & December) |
| **EPA 99 30B3 (Annual)** | Moderate LOC | Moderate LOC |
| **Winnipeg Site Specific EPA Method** | Moderate LOC (No nitrification OK in all but October) | Moderate LOC (No nitrification OK in all months except September & October) |
| **Winnipeg Site Specific PSL2 Method** | No Nitrification Required | Moderate LOC (No nitrification OK in all but August) |
| **PSL2 National** | High LOC | BPT (High LOC OK in All Months except August) |
| **MSWQO 1988** | BPT (High OK in All Months except November) | BPT (High OK in All Months except November) |
| **NEWPCC** | | |
| **Criteria** | **Steady State Approach** | |
| | **Direct WLA** | **To meet 95% Effluent Variation** |
| **MWQ SOG 2001/EPA 99** | **Centrate Treatment** | **Moderate LOC (Centrate removal OK in all but August)** |
| **EPA 99 30B3 (Annual)** | Moderate LOC | Moderate LOC |
| **Winnipeg Site Specific EPA Method** | Moderate LOC (Centrate Treatment OK in all but one October) | Moderate LOC (Centrate Treatment OK in all but September & October) |
| **Winnipeg Site Specific PSL2 Method** | Centrate Treatment | Centrate Treatment |
| **PSL2 National** | Best Practicable Treatment High LOC meets all except August | Best Practicable Treatment High LOC meets all except August |
| **MSWQO 1988** | Best Practicable Treatment | Best Practicable Treatment |
| **WEWPCC** | | |
| **Criteria** | **Steady State Approach** | |
| | **Direct WLA** | **To meet 95% Effluent Variation** |
| **MWQ SOG 2001/EPA 99** | Lagoon Polishing | Lagoon Polishing |
| **EPA 99 30B3 (Annual)** | No Nitrification Required | No Nitrification Required |
| **Winnipeg Site Specific EPA Method** | Lagoon Polishing | Lagoon Polishing |
| **Winnipeg Site Specific PSL2 Method** | Lagoon Polishing | Lagoon Polishing |
| **PSL2 National** | Lagoon Polishing | Lagoon Polishing |
| **MSWQO 1988** | Best Practicable Treatment | Best Practicable Treatment |

**Notes**
LOC = Level of Control
Design Flows based on 1962 to 1997 data
WLA are based on 2041 projected loads

- Other procedures to reduce loads or flows to the plant could be developed over time to maintain effluent quality within the allowable potential limits. Upstream nutrient reduction may reduce algal growth and related pH, thus enabling the criteria to be met (see River Conditions TM for relationship between pH and nutrients). The control of upstream nutrients is beyond the control of the City of Winnipeg and the determination of the potential for other jurisdictions to reduce nutrients is beyond the scope of this study.

- If the annual flow temperature and pH is used (i.e., the 30B3 design flow) then a moderate level of treatment would be required to meet year-round effluent discharge limits.

- The site-specific criteria developed for the Winnipeg region provide two different potential decisions for the SEWPCC. Using the criteria developed with the EPA method would indicate that no nitrification would satisfy the criterion except in October when an increased level of treatment would be required (an effort approaching a moderate level of control).

- Using the Winnipeg site-specific criterion developed with the methodology employed by Environment Canada in the PSL-2 ammonia assessment, indicates that no nitrification would be required for the SEWPCC discharges projected for the year 2041.

- Using the PSL-2 national criteria (which includes salmonids in the development) a high level of control would be required to satisfy this objective.

- Application of the criterion proposed for this region in the 1991 public hearings, i.e., the Manitoba Surface Water Quality Objectives (1988) at this time, would have indicated a best practicable treatment for the SEWPCC. The high treatment would satisfy the objectives in all months except November.

- The addition of a licence condition that the geometric mean of a 30-day sample period should be at the licence limit 95% of the time would require additional treatment. To illustrate, when the Winnipeg site-specific criterion using the PSL-2 methods was applied (with the 95% rule), this resulted in a moderate level of treatment being imposed. At the same time, an assessment of the mean effluent discharge would have required no nitrification. As discussed earlier, this additional constraint, often applied at the licencing stage, will likely decrease the probability of exceedence to a probability of 1 in 200 years.

For the NEWPCC:

- Using the draft Manitoba 2001 objectives (same as EPA 1999) would lead to a requirement for centrate treatment at the NEWPCC.

- If the objectives were applied using the 30-B-3 design flow, average annual temperature and average annual pH, then a moderate level of control would be required.

- The site-specific criteria would again provide different direction on upgrades. Winnipeg site-specific criteria using the EPA method of development shows centrate treatment satisfies the criteria in all but one month. Therefore additional upgrades (i.e., towards moderate treatment) may be required.

- The Winnipeg site-specific criterion developed using Environment Canada's PSL-2 methodology would require centrate treatment only.

- As with the SEWPCC, the PSL-2 national criterion is much more restrictive and would require best practicable treatment. The high level of control meets this criterion at all months except August.

- The Manitoba Surface Water Quality Objectives (1988) ammonia criteria would have required best practicable treatment at the NEWPCC.

- The addition of a restrictive clause in the licence requiring that the 30-day geometric mean of the effluent be met 95% of the time would require higher levels of treatment in some cases. However, the site-specific criteria using the PSL-2 method would still require centrate treatment only (see Table 7-8) for both types of assessments.

For the WEWPCC:

- A review of the application using the Manitoba 2001 draft criterion (same as EPA 1999) would indicate that the lagoon polishing tertiary treatment would be an effective method of meeting this criterion.

- Using the 30-B-3 design flow (with EPA 1999) on an annual basis along with average annual pH and average annual temperature would result in the assessment that no tertiary treatment is required at the WEWPCC. This result illustrates the inappropriateness of using an annual assessment in determining the required level of control rather than seasonal assessment. The treatment requirements at the WEWPCC are generally driven by the high pH and temperature within the river during the summer months. Using average conditions does not reflect this reality.

- Applying the site-specific criterion employing both the EPA and Environment Canada methodologies of criteria development both indicate that lagoon polishing would be an effective method of meeting these criterion.

- Even the PSL-2 national criterion, which is generally more restrictive since it includes more ammonia sensitive salmonids not found in these rivers, would be satisfied by a lagoon polishing tertiary treatment process.

- The previous Manitoba Surface Water Quality Objectives using the flows from 1962 to 1997 would have resulted in the development of a best practicable treatment option at the WEWPCC.

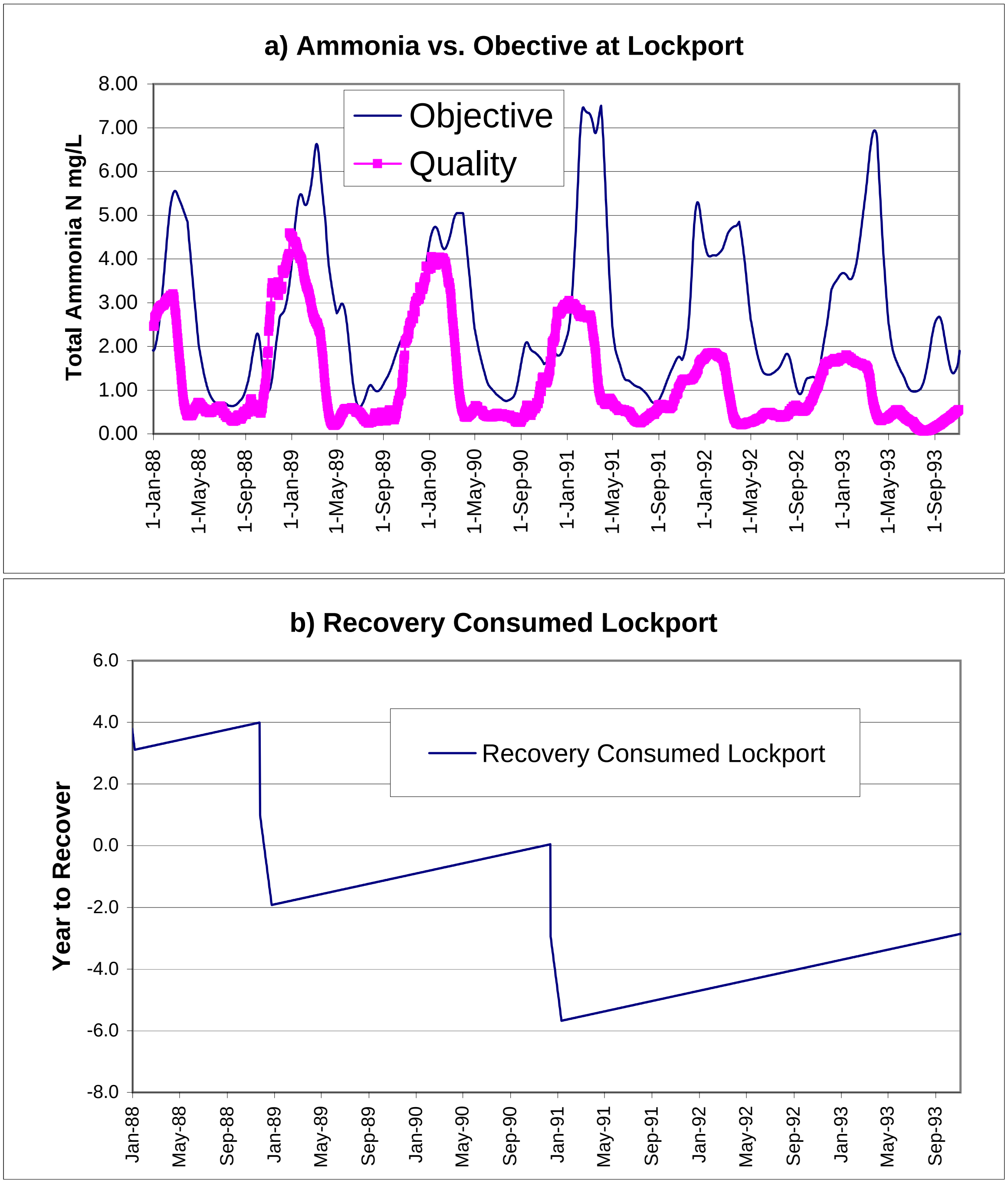
## 7.2 DYNAMIC MODEL APPLICATIONS

The EPA has recommended that dynamic model outputs are the "least ambiguous and most exact way that a WLA for specific chemicals" (EPA 1991) can be used to develop a permit. A dynamic model considers the variability of the river flow, pH, temperature and treatment plant effluent simultaneously over a long period of record to estimate exposure of aquatic life to prescribed in-stream concentrations of a chemical. The dynamic modelling was used for flows from 1962 to 1997, and is described in more detail in the River Conditions Technical Memorandum. Using the dynamic model and effluent quality for the various levels of control as developed in a parallel study (Earth Tech 2001), an assessment could be done as to how frequently each of the criterion concentrations discussed earlier would be exceeded. The EPA technical support document (EPA 1991), however, gives little guidance on how to determine whether the exceedence frequency of once in three years has been surpassed.

In order to develop a methodology which assesses whether the frequency of excursions is more than once in three years on average, a separate EPA document on the “Technical Guidance on Supplemental Stream Design Conditions for Steady State Modelling” was used (EPA 1988). In this document, a description of how the biological design flow was developed provides some guidance on how to develop a methodology to assess the frequency and duration of excursions with a dynamic model. The biologically-based method allows an average of one water-quality excursion every three years. In accordance with the guidance, in order to determine if there is an excursion, a moving geometric mean taken over 30-days was computed for the daily ammonia concentrations predicted at each of the key stations downstream of the WPCCs. The water quality criterion also varies in terms of total ammonia with varying pH and temperature. Therefore a moving geometric mean of the water quality ammonia objective was calculated for each of the potential criteria discussed in the previous section. An example of this comparison of the objectives and water quality model output is shown in Figure 7-3a.

Each time an excursion occurs, it was assumed to consume three years of recovery as per the EPA guidance. It is possible for the excursion to occur for longer than the 30-day averaging period. For example, if the average concentration remained above the objective for 45 days, it would be considered to be equivalent to 1.5 excursions (i.e., 45/30 = 1.5). Therefore the number of years of “recovery consumed” would be 4.5 (i.e., 3 x 1.5 = 4.5). An accounting procedure was developed for each station from the year 1962 through to the year 1997. Each time there was an excursion or an extended excursion, recovery was “consumed”. For each year without an excursion, one year of recovery was added to the cumulative accounting. Figure 6-3b illustrates how this accounting procedure would occur during a 5 year period of record. When there was an extended excursion occurring in the fall of 1988, the recovery accounts would drop from 4 years to minus 2 years. (This would be due to a 60 day excursion of the objective [i.e., 60/30 = 2, 2 x 3 = 6 years consumed]). In the next two years, there would be some recovery, until late fall 1990, in which another 6 years of recovery was consumed. Again, for the years following 1990, recovery would continue.

This analysis was done for each level of control and each of the possible criteria. An example of an accounting procedure over the full 36-years of record at two stations under historic ammonia concentrations is shown in Figure 7-4. In this case, at Lockport, the accounting procedure has indicated that on average the period of record would have ended with a positive recovery account. This would indicate that, on average, the criteria had been exceeded at




# Illustration of how Excursion "Consumes" Recovery

Figure 7-3

Lockport less than once in three years. This would indicate that the intent of the criteria has been met.

However, at the North Perimeter Bridge, the accounting procedures indicate that we have ended the period with 22 years of "recovery" required to balance the account. This would indicate that the intent of the criteria is not met, in that the excursions were more frequent than once in three years on average.

Table 7-9 compares WPCC control requirements for the dynamic model assessments for different in-stream objectives against those made with the steady state models. In most cases, the requirements are fairly similar.
For the SEWPCC:

- The dynamic model shows no nitrification is necessary for the current situation for the proposed general 2001 Manitoba objective (the EPA 1999 objective also) and the site-specific criteria developed by the EPA and PSL-2 methods. For the projected flows in the year 2041, there is a need for a moderate level of control when applying the objectives with the general Manitoba or site-specific Winnipeg criteria using EPA methods of development.

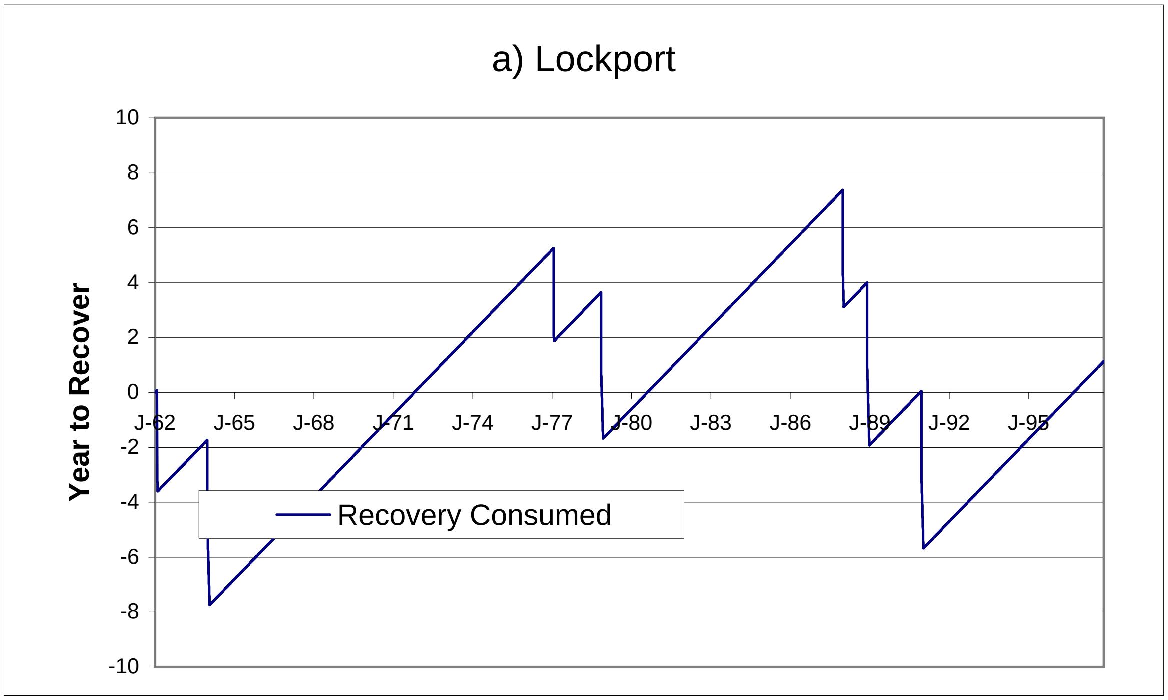
- The Winnipeg site-specific criterion using the PSL-2 method again shows no nitrification is required.

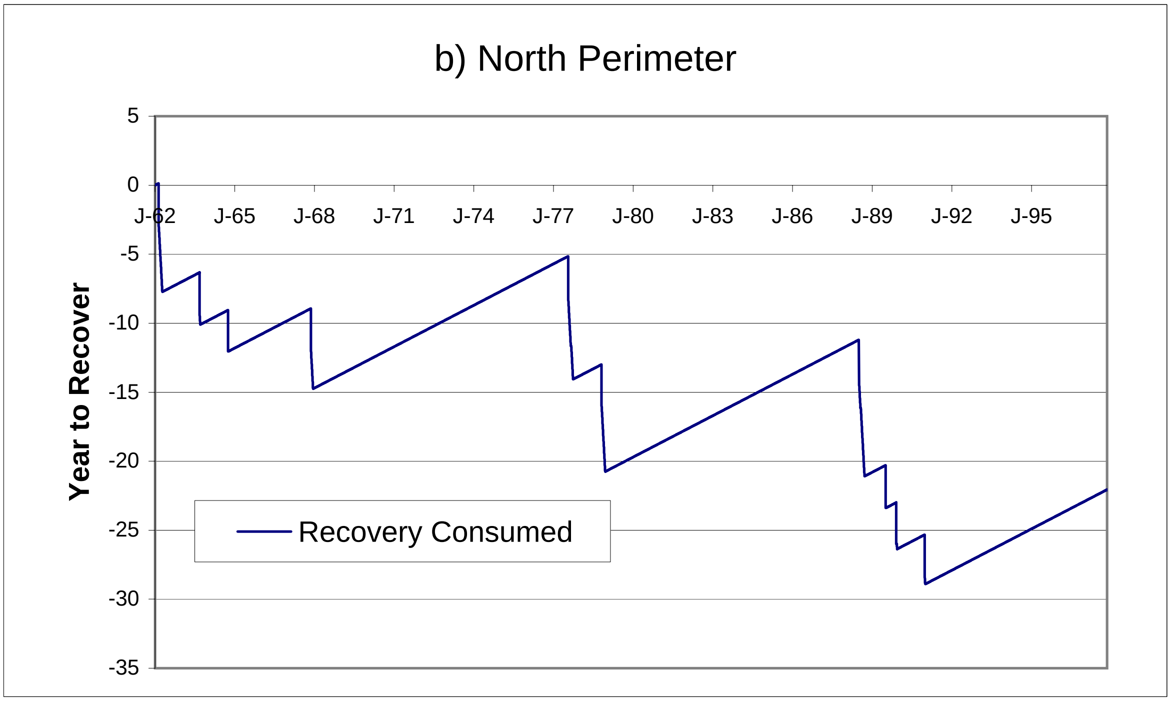
- Using the PSL-2 national criterion shows that moderate to high treatment would be required.

- **Generally the results indicate that the direct use of the long-term average effluent concentration, rather than using the more restrictive requirement that 95% of the time the criteria must be met, is a more appropriate licencing procedure.**

For the NEWPCC:

- The dynamic modelling assessment generally shows that centrate treatment is required for all the potential criteria.




**Recovery Consumed by Criteria Exceedance using Dynamic Model Assessment (Historic Ammonia Concentrations at NEWPCC US EPA 99 Criteria)**

Figure 7-4

TABLE 7-9

## Levels of Control Requirements at WPCCs to Meet Various Criteria Using Steady State and Dynamic Modelling Approaches to Assessment

| SEWPCC | | | |
|---|---|---|---|
| Criteria | Steady State Approach | | Dynamic Models |
| | Direct WLA | To meet 95% Effluent Variation | |
| **MWQ SOG 2001/EPA 99** | Moderate LOC (No nitrification OK in all but November) | Moderate LOC (No nitrification OK in all but August, November & December) | No Nitrification in 2000 Towards Moderate LOC in 2041 |
| **EPA 99 30B3 (Annual)** | Moderate LOC | Moderate LOC | |
| **Winnipeg Site Specific EPA Method** | Moderate LOC (No nitrification OK in all but October) | Moderate LOC (No nitrification OK in all months except September & October) | No Nitrification in 2000 Towards Moderate LOC in 2041 |
| **Winnipeg Site Specific PSL2 Method** | No Nitrification Required | Moderate LOC (No nitrification OK in all but August) | No Nitrification in 2041 |
| **PSL2 National** | High LOC | BPT (High LOC OK in All Months except August) | Moderate LOC in 2000 Moderate(almost) to High LOC 2041 |
| **MSWQO 1988** | BPT (High OK in All Months except November) | BPT (High OK in All Months except November) | - |
| **MSWQO 1988 (1912-1990 flows)** | Best Practicable Treatment | Best Practicable Treatment | - |
| **NEWPCC** | | | |
| Criteria | Steady State Approach | | Dynamic Models |
| | Direct WLA | To meet 95% Effluent Variation | |
| **MWQ SOG 2001/EPA 99** | Centrate Treatment | Moderate LOC (Centrate removal OK in all except August) | Between Centrate Treatment and Moderate LOC |
| **EPA 99 30B3 (Annual)** | Moderate LOC | Moderate LOC | |
| **Winnipeg Site Specific EPA Method** | Moderate LOC (Centrate Treatment OK in all except October) | Moderate LOC (Centrate Treatment OK in all but September & October) | Between Centrate Treatment and Moderate LOC |
| **Winnipeg Site Specific PSL2 Method** | Centrate Treatment | Centrate Treatment | Centrate Treatment |
| **PSL2 National** | Best Practicable Treatment High LOC meets all except August | Best Practicable Treatment High LOC meets all except August | Moderate to High LOC |
| **MSWQO 1988** | Best Practicable Treatment | Best Practicable Treatment | - |
| **MSWQO 1988 (1912-1990 flows)** | Best Practicable Treatment May not have complied at pH> 8.5 | Best Practicable Treatment May not have complied at pH> 8.5 | - |
| **WEWPCC** | | | |
| Criteria | Steady State Approach | | Dynamic Models |
| | Direct WLA | To meet 95% Effluent Variation | |
| **MWQ SOG 2001/EPA 99** | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing |
| **EPA 99 30B3 (Annual)** | No Nitrification Required | No Nitrification Required | |
| **Winnipeg Site Specific EPA Method** | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing |
| **Winnipeg Site Specific PSL2 Method** | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing |
| **PSL2 National** | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing |
| **MSWQO 1988 (1962-1997 flows)** | Best Practicable Treatment | Best Practicable Treatment | - |
| **MSWQO 1988 (1912-1990 flows)** | Best Practicable Treatment | Best Practicable Treatment | - |

**Notes**
LOC = Level of Control
Design Flows based on 1962 to 1997 data
WLA are based on 2041 projected loads

- Using the Manitoba general criterion or the Winnipeg site-specific criterion derived by EPA methods would indicate a level of treatment between centrate treatment and moderate LOC may be required.

- The Winnipeg site-specific criterion developed with PSL-2 methods indicates that centrate treatment only will be required.

- To meet the PSL-2 national criteria, moderate to high levels of control would be required.

For the WEWPCC:

- The levels of control required to meet various criteria using dynamic modelling approach indicates that for the WEWPCC lagoon polishing would be the only option which would be required to meet all criteria.

## 7.3 PERIOD OF FLOW RECORD

The period of record used to develop the steady state design flows and perform the dynamic modelling assessment was from 1962 to 1997. This 36-year record was used since it is the only period in which daily gauged water-flow records are available at all three stations; Headingley, St. Agathe and Lockport. The Headingley database includes records back to year 1912. The use of a longer period of record at Headingley would likely not change any of the conclusions, since the Assiniboine River is currently a regulated river; therefore the minimum flow is based on regulation. The firm flow is 5.6 $m^3/s$ (200 cfs) which is equivalent to the 7Q10 or 30Q10.

For the Red River, the gauging records from Emerson Gauging Station at the Canada/U.S. border have been used in the past, in conjunction with regression analysis, to produce artificial flow data for the period 1912 to 1962 at the St. Agathe station. This data was then used to calculate a potential longer-term 7Q10 for the Red River. This method of including the artificial data produced 7Q10s which were two to three times lower than those produced using the actual historic data. **This type of analysis is not used in this study.** We believe that the inclusion of this artificial data which includes the drought period of 1939 to 1941 would give an unrealistically-low design flow.

If the MSWQOs (from 1988) were applied using the Q710 design flows developed from the period of record from 1912 to 1990 (as proposed in 1991), then best practicable treatment would be the only upgrade which would have satisfied these criteria. In fact, best practicable treatment may not have complied with the criteria at the design flow if the pH was greater than 8.5 (which is likely).

In other research independent from this study, it has been shown that the inclusion of this period of drought and the use of standard hydrological assessment may produce unrepresentative low-flow frequencies.

In a paper describing the spatial characteristics of drought events using synthetic hydrology, Burn and Dewitt (1996) developed an approach to drought analysis which can be used to assist in the quantification of the return period for the drought of record (i.e., 1939 to 1941) for the Nelson-Churchill River basin in Manitoba. The Red River is part of this basin and has a drought of record which coincided with the droughts they analyzed. The analysis indicated that the drought of record could likely have a return period of 381 years. This was considerably higher than would be considered using standard statistical analysis.

Other new methods are being developed to determine the occurrence of floods in historic record by using tree-rings or lake-bottom sediments. These same methods could be used to determine periods of drought and the true frequency of the drought of 1939 to 1941. At this time we believe there is enough evidence to indicate that the creation of an artificial dataset at St. Agathe to include the drought of record from 1939 to 1941 could lead to an unrealistically-low design flow for assessing ammonia criteria. Since ammonia criteria consider a low-frequency event, such as one excursion in three years on average, the 36-year historic record would generally be considered more than adequate to develop design flows. Designing treatment plants based on very low probability events could lead to significantly increased costs with marginal environmental benefits.

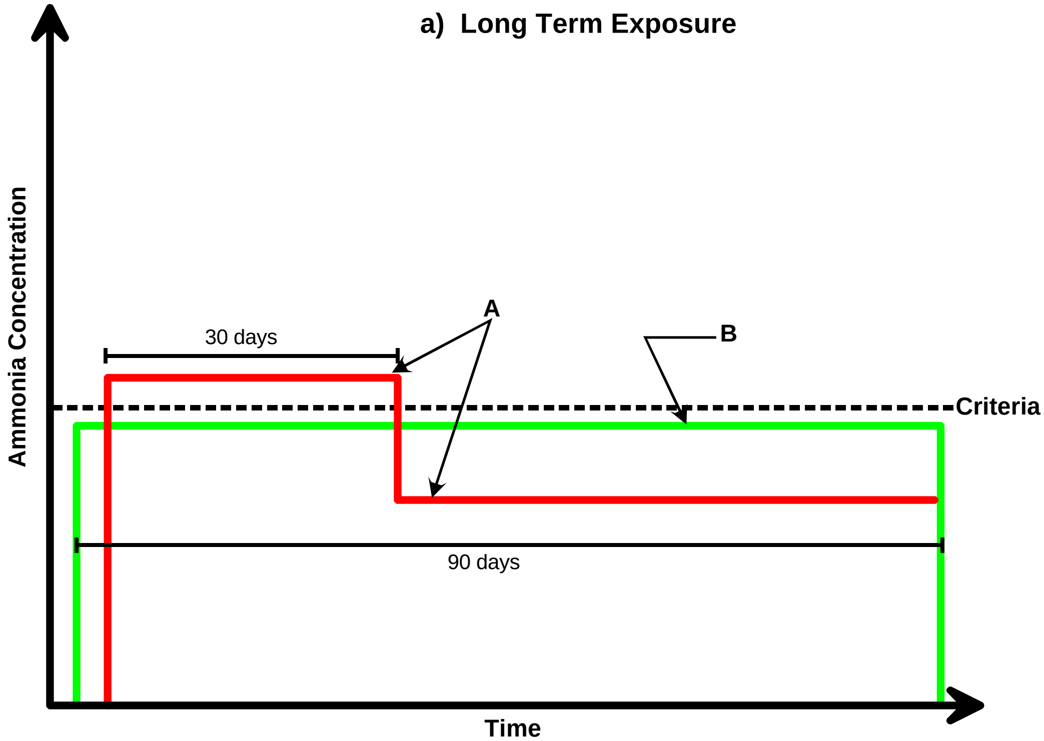
# 8. INTEGRATED RISK ASSESSMENT

## 8.1 GOALS

Criteria are developed to be relatively simple to apply for general application across a jurisdiction. For this reason, regulators generally select one criterion concentration to be applied to a single design flow. Although this relative ease of use allows for administrative simplicity, it may not reflect the real impact and cost of that criterion. In reality, there is considerable variation in toxicant concentrations within a stream, due to variability in river flows, as well as in variability in concentrations of waste and non-point discharges. In addition, many of the resident species which are relatively sensitive to a stressor such as ammonia (e.g., walleye, catfish and northern pike) are highly mobile and would not be exposed to an obligate and constant concentration.

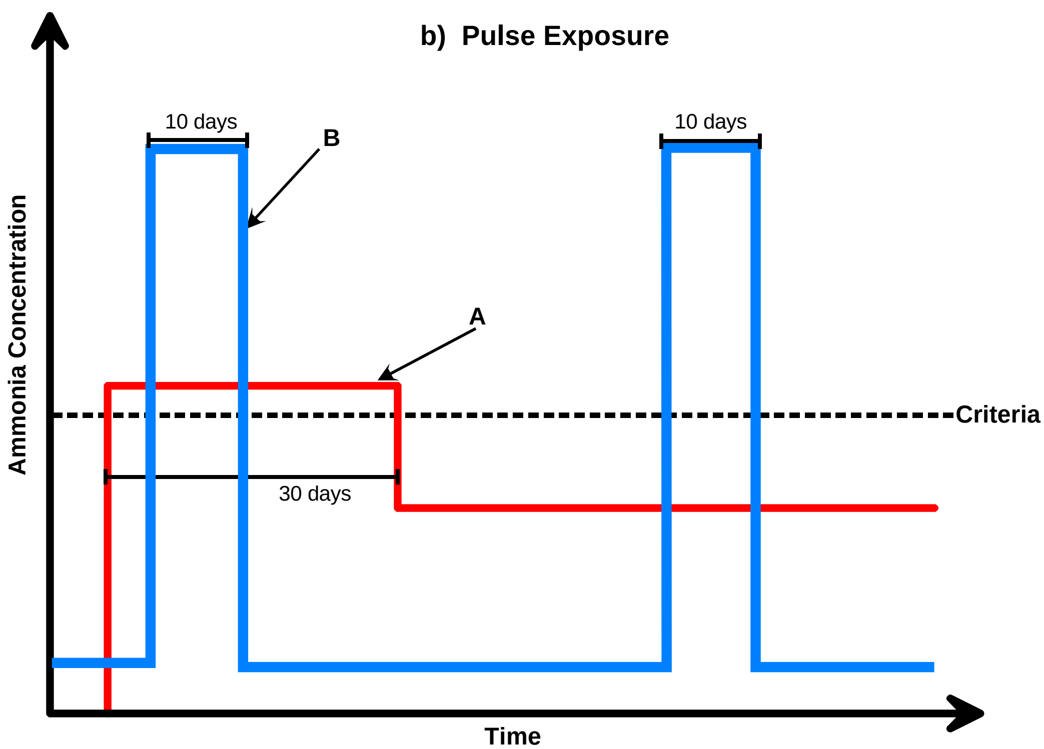
A criterion is usually satisfied (considered to be met) if the average toxicant concentration for a 30 day period is not exceeded during a design flow condition. There may be cases when the concentration remains just below a criterion for an extended period of time greater than 30 days (i.e., 90 days) but meets criteria objectives, and technically the criterion could be met (cf. Figure 8-1a). Under such conditions, there could be a greater impact on the ecosystem than cases where the criterion is not met for a short time frame. A second scenario could arise if the criterion is exceeded for a period shorter than the averaging period (e.g., 10 days, as in Figure 8-1b), but maintained an average concentration less than the maximum allowable criterion for a 30 day period. High 10 day exposures, for example, could occur several times throughout the year and not be considered significant by simple criteria assessment. Regulators have attempted to deal with these uncertainties by having multiple criteria and design flows (see EPA 99 AND Manitoba 2001 Section 3.0), which are to be met simultaneously. While this approach increases the complexity, it does not consider all possibilities.

In this section, a more direct use of toxicity data and dynamic water-quality model output will be jointly used, in order to corroborate or refute the simpler methods of criteria development and application assessed in the previous chapters. An overview of the uncertainties considered in developing this integrated and comprehensive risk assessment is shown in Figure 8-2. This




**A - D*<u>oes not</u>* meet criteria**

**B - Meets criteria but *<u>may have more impact</u>***

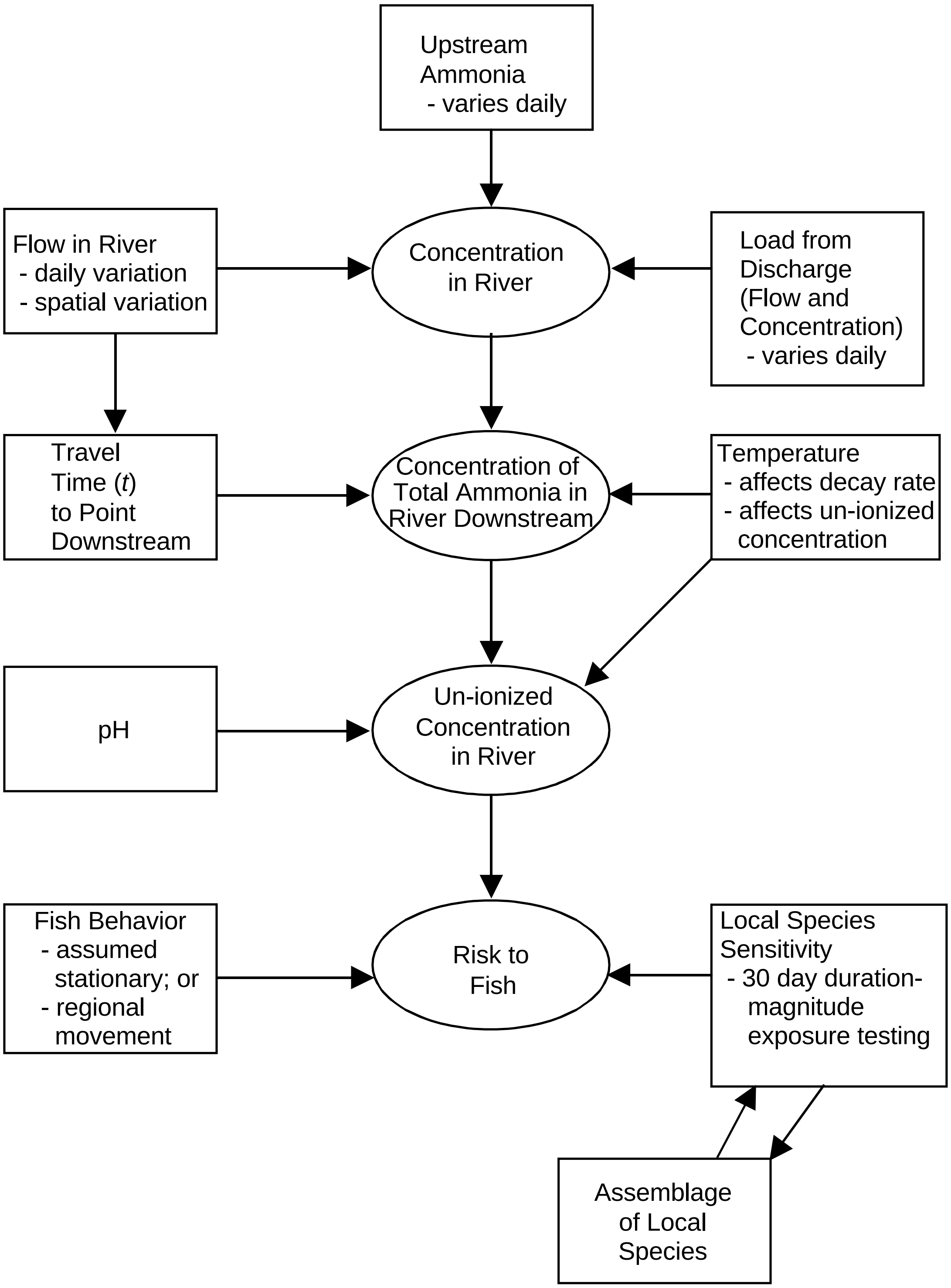



**A - D*<u>oes not</u>* meet criteria**

**B - Meets criteria but *<u>may have greater consequences</u>***

**Comparison of Scenarios which May or May Not meet Criteria**

Figure 8-1

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**Uncertainties Considered in Risk Assessment**

Figure 8-2

chapter develops methods and presents an application of a risk assessment of three key and sensitive species native to the Red and Assiniboine Rivers:

- walleye;
- channel catfish; and
- northern pike.

The effects of un-ionized ammonia on these species for various concentrations and durations of exposure can be assessed due to the data-rich toxicity testing performed on these species, using a flow-through facility which mixed Red River water with un-ionized ammonia.

We can also determine the estimated concentrations of ammonia over:

- historic conditions;
- current risk conditions (year 2000);
- a full range of future potential levels of control at the three treatment plants (NEWPCC, SEWPCC and WEWPCC).

Dynamic water-quality models that assess both the variability within the treatment system and the river can be used to provide details of these various scenarios for the future (2041). A joint application of these effects and exposure models can determine how frequently ammonia effects will have significant responses on these key species (i.e., $LC_{20}$ or $EC_{20}$) for a full range of river flow and effluent variability possible during a 35 year period.

This risk assessment will determine whether these key and sensitive species will have significant responses more frequently than once every three years on average, as the criterion is designed to provide this level of protection. By estimating the risk to these key species, either at the worst-case location downstream (i.e., point with the highest total ammonia in-stream after mixing) of each plant, or on a regional basis, a cost versus risk trade-off analysis can be done to determine the most cost effective level of risk reduction that may be provided.

This risk assessment should provide corroboration for the simpler single design flow criterion and licencing procedure (see Section 7). In addition, it could be used to meet future requirements by Environment Canada that site-specific risk assessments be performed.

## 8.2 DEVELOPMENT OF MODELS TO DETERMINE EFFECTS

The three most un-ionized ammonia-sensitive species assessed in the present study were walleye, catfish and pike. Each of these was tested using a flow-through system, with Red River water dilution. Although only the final 13-day or 30-day test results were shown in a previous section (cf. Section 6), mortality was measured daily for each test. The survival rates for each species' test-population held at various un-ionized ammonia concentrations over the duration of each test are shown in Figure 8-3. Recall these as mortality of early life stages and not adult fish. It is generally considered that growth of adult fish may be impaired if an LC20 is reached. For all three species, population decline appears to follow a first order decay model, varying with time, for each treatment. An example of such a model is:

Survival = initial population $e^{-kt}$

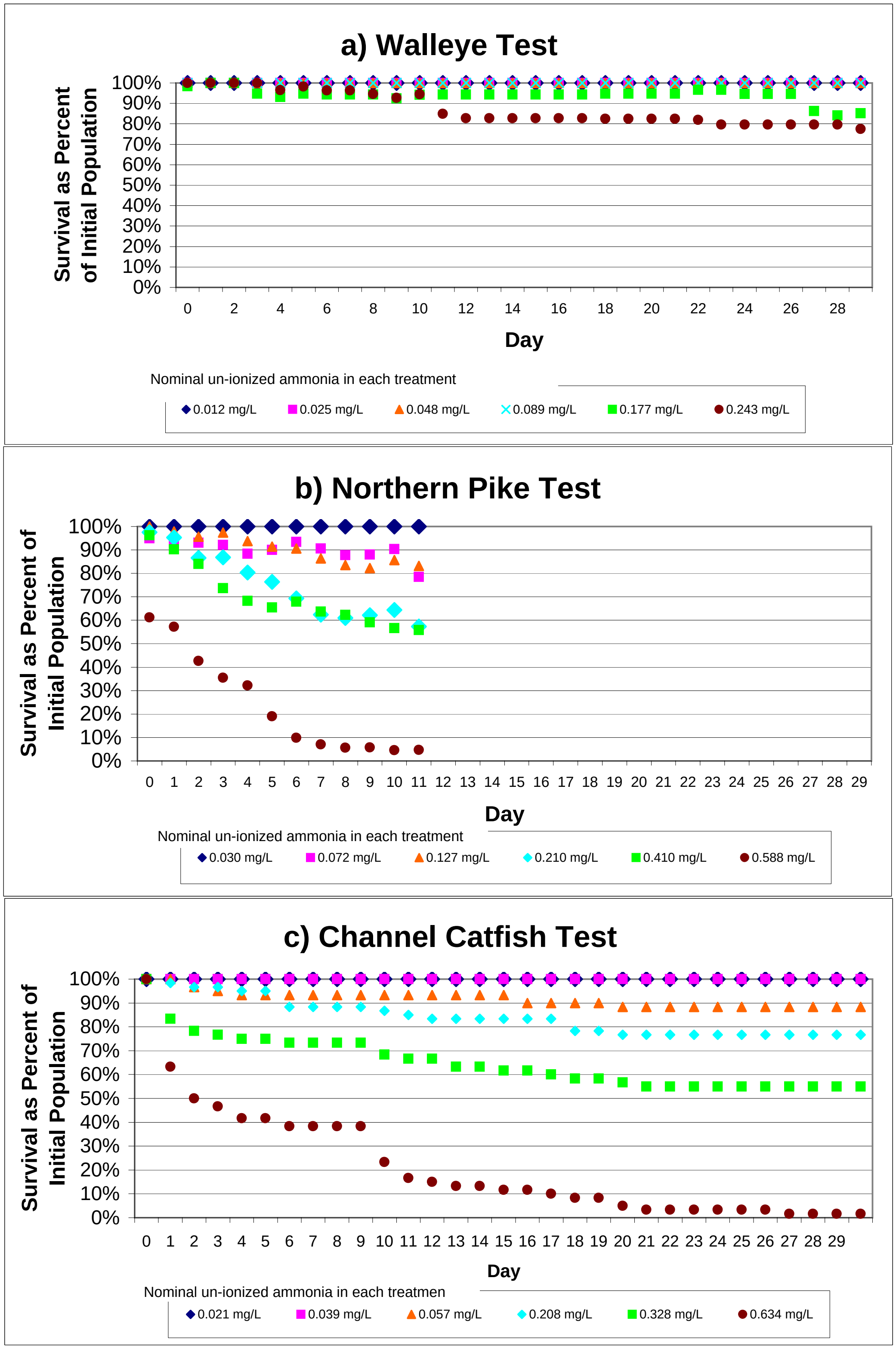
Where:

k = daily mortality

t = time in days

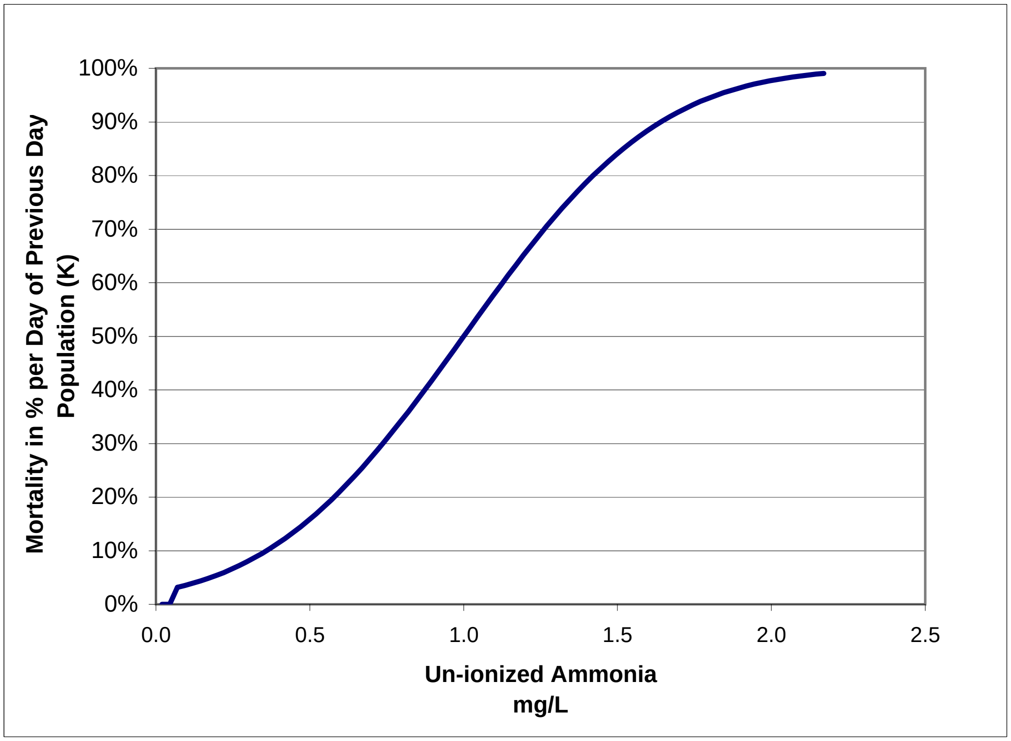
This type of model will allow for a prediction of daily survival over time. Daily mortality rate (K), however, should vary with un-ionized ammonia concentration. With increasing concentration, the daily mortality rate would be expected to increase. An example of a statistical model representing the cumulative daily mortality for various concentrations of un-ionized ammonia is shown in Figure 8-4. This example assumes a normal distribution of mortality with a 24 hour LC50 value of 1 mg-$NH_3$/L. The standard deviation is 0.5 mg-$NH_3$/L (coefficient variation of 0.5) for this example. This type of model assumes that some individuals in a species are more sensitive to un-ionized ammonia than others. The model is slightly modified in the lower end to reflect the reality that at a certain low concentration, there would likely be no mortality relative to the control (i.e., k = 0 for < no observable effect concentration). This is realistic, since ammonia is a natural substance found in the Red and Assiniboine Rivers; therefore fish must have some tolerance to minimum amounts of environmental ammonia.

In order to estimate the daily mortality within each test laboratory chamber, the daily concentrations within each treatment for each species was determined (cf. Figure 8-5a). As can be seen from this figure, the laboratory actually exposed the specimens to a "pulsed" or variable un-ionized ammonia concentration. Once the daily concentration was determined, a daily

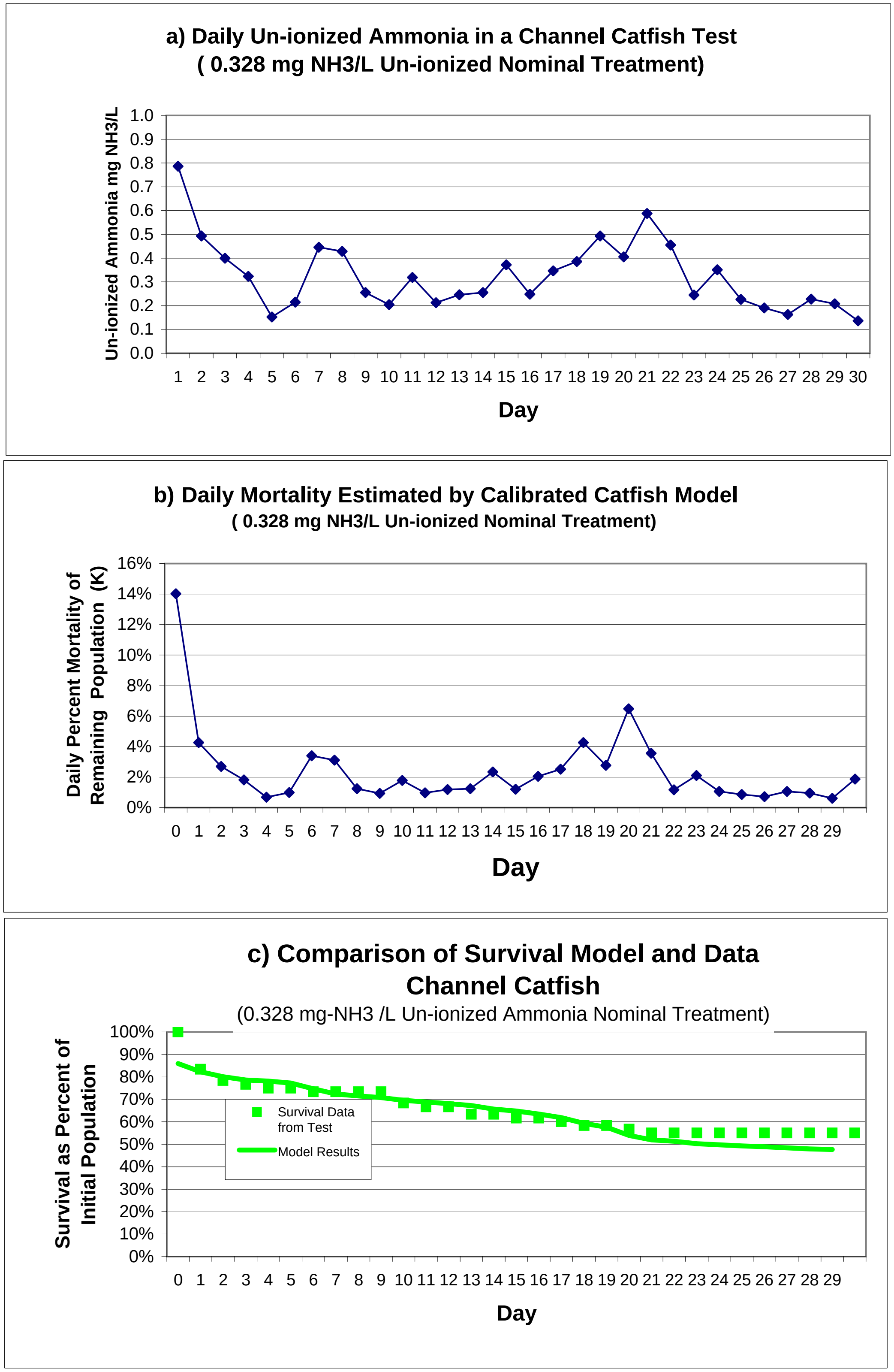



**Percent Survival for Variation of Duration and Magnitude of Un-ionized Ammonia Exposure**

Figure 8-3




**Example of a**
**Statistically Based Mortality Model**
Figure 8-4




**Stages of Modelling Survival Using Ammonia Duration-Magnitude Model and River Model Output**

Figure 8-5



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mortality rate was calculated, using a statistical mortality model as shown in Figure 8-4. Each day a mortality rate is applied to the remaining population (Figure 8-5b), the cumulative survival rate from the beginning of the test can be estimated (cf. Figure 8-5c). The concentration-duration-exposure model can be expressed as below:

$$P(t,c) = P_o e^{-kt}$$

$P_o$ = initial population (100%)

t = time in days

k = daily mortality factor

= which is a cumulative normal distribution function

$\mu$ - mean daily mortality (i.e., 24-hours $LC_{50}$)

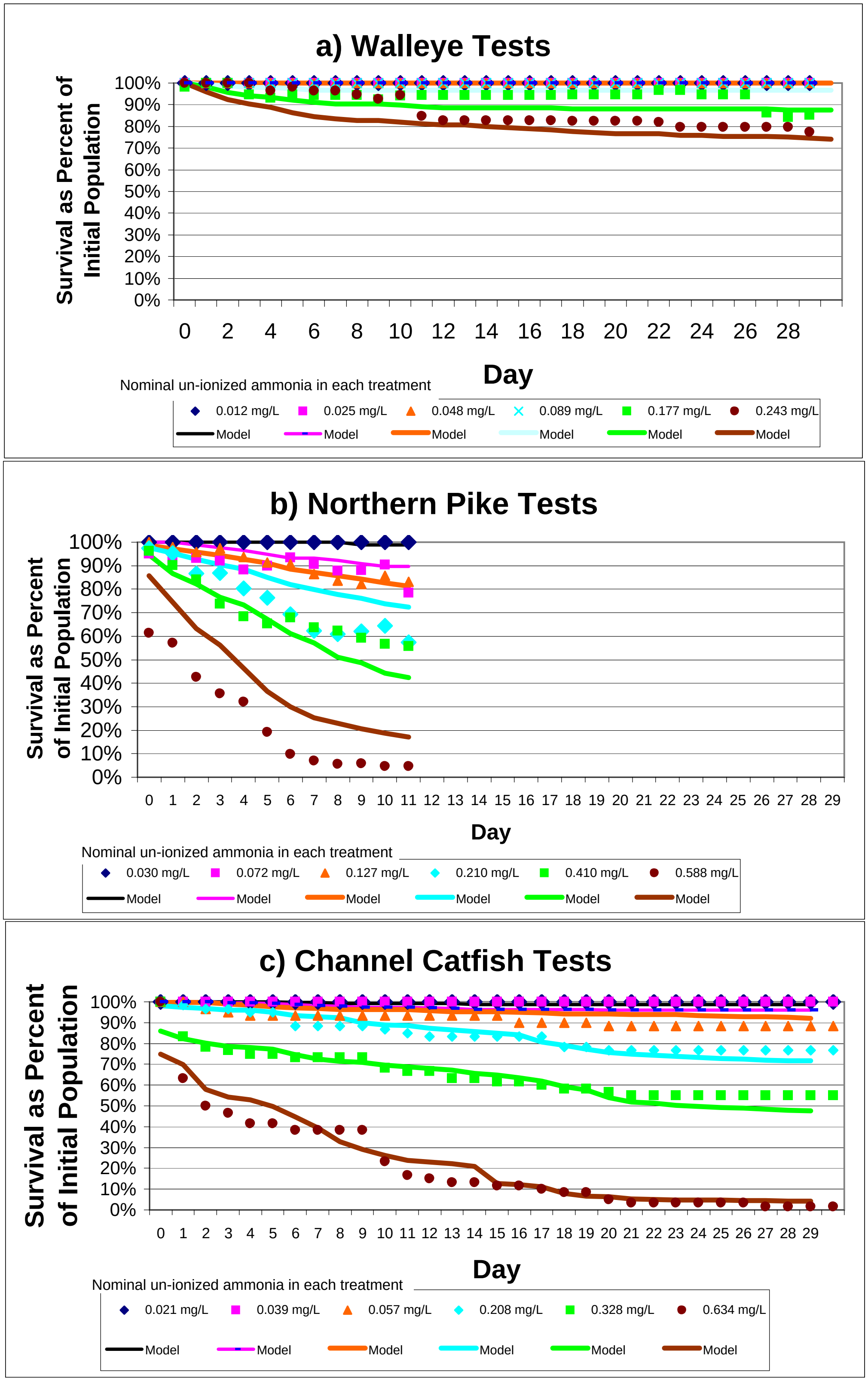
S – standard deviation

Then K = 0 if $C<C_{min}$

$C_{min}$ = no observable effects concentration

By varying three parameters, the mean 24-hr $LC_{50}$ (N), the standard deviation of the $LC_{50}$(S), and the no-effect concentration ($C_{min}$), daily estimates of population survival could be developed for each of the ammonia treatments, for each of the species. Each of the species was considered to have a different set of parameters reflecting their relative sensitivities to ammonia. Results of the calibration are shown in Figure 8-6. The model prediction for each treatment for each species is compared against the actual dataset for each treatment for each species. It should be noted that the model for each species uses only 3 parameters to develop a prediction which matches over 180 data points for walleye and catfish, and almost 80 data points for northern pike. The channel catfish calibration (Figure 8-6c) shows remarkably close results between the model and the data. For northern pike, the date is less consistent, due to the difficulty in holding this species and higher control mortality. Walleye results indicate a species less sensitive to un-ionized ammonia exposure than northern pike and channel catfish.

The calibrated model parameters used in the statistical mortality model to estimate the daily mortality are shown in Table 8-1. A graphical representation of the variation in the daily mortality is shown in Figure 8-7. This figure shows the relative sensitivity of each of the species. Northern pike is the most sensitive of the three species, showing some effects at 0.053 mg-$NH_3$/L. Daily mortalities could rise as high as 2-3% under conditions that could occur in the Red



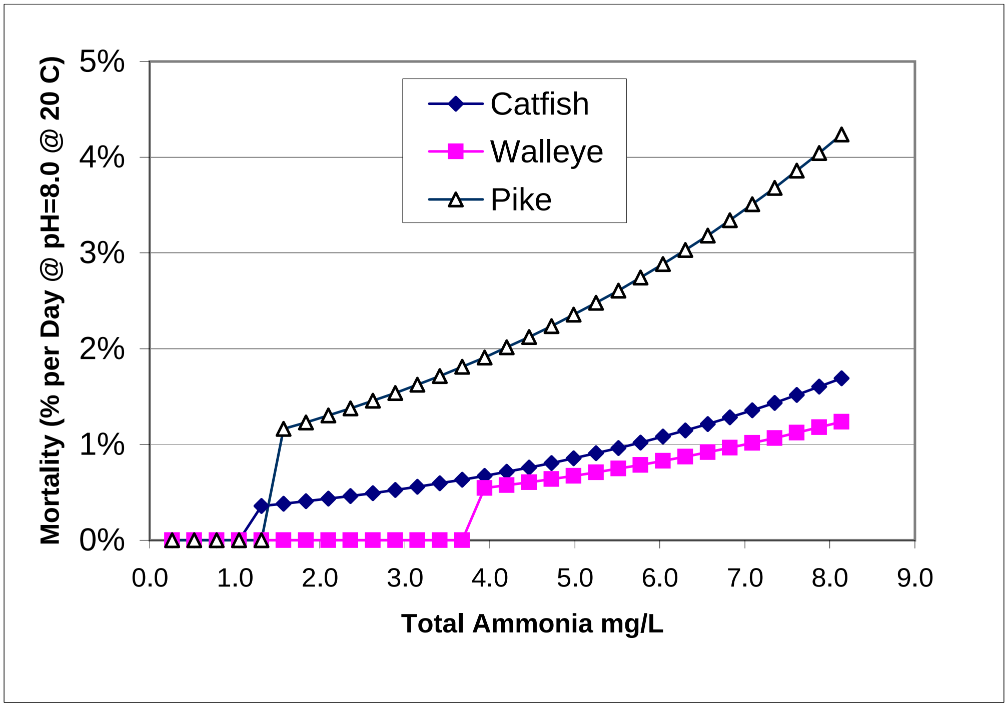

**Calibration of Un-ionized Ammonia Duration-Magnitude Survival Model**

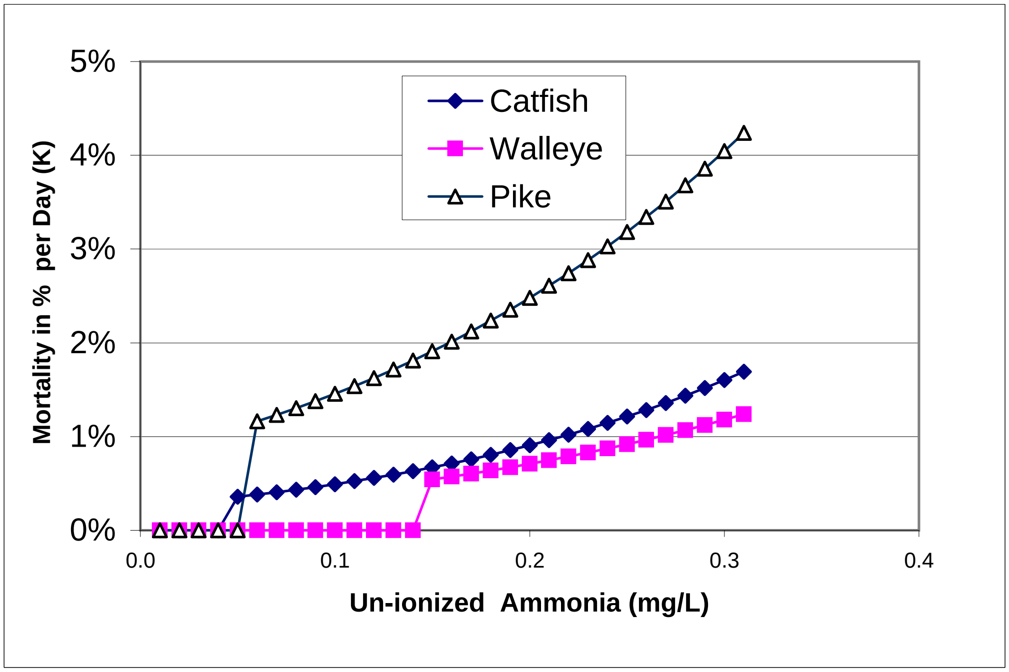
Figure 8-6

TABLE 8-1

## Parameters for Statistical Mortality Models to Estimate Daily Mortality

| Species | Mean (i.e. 24 hour LC50) (mg/L) | Standard Deviation (mg/L) | Coefficient Of Variation | No Risk Concentration (mg/L) | Test Duration (days) |
|---|---|---|---|---|---|
| Walleye | 1.50 | 0.530 | 0.35 | 0.150 | 30 |
| Northern Pike | 1.10 | 0.458 | 0.42 | 0.053 | 13 |
| Channel Catfish | 1.28 | 0.457 | 0.36 | 0.041 | 30 |




**Comparison of Daily Mortality Models for Catfish, Northern Pike and Walleye**

Figure 8-7

and Assiniboine Rivers. Catfish and walleye show more similar sensitivities, however, walleye appear to have a higher "no effects" concentration of close to 0.15 mg-$NH_3$/L. This indicates that, although walleye populations could be affected during periods of high concentration, there would likely be no effect during moderate concentrations. A summary of the daily mortality rate (k) for each of the three key species is shown in Table 8-2.

Since, in the Red and Assiniboine Rivers, each of these species have the potential to be exposed to un-ionized ammonia at higher concentrations for longer durations than those used in the laboratory, (13 days for pike, and 30 days for walleye and catfish), several methods of extrapolating the effects beyond the test durations were assessed. The various extrapolation methods are illustrated in Figure 8-8. Figure 8-8a illustrates two assumptions which could be used to extrapolate the data. If the population mortality reaches a lower limit at the end of the test, which appears to be occurring for channel catfish (see Figure 8-8c), then the extrapolation beyond 30 days should be constant and equivalent to the 30-day test result. This assumes that the weaker individuals of the population are culled and the more ammonia-resistant individuals will not be affected or have acclimated to high ammonia. The second and more conservative model assumes that the daily mortality rate within the population will continue to occur up to 90 days.

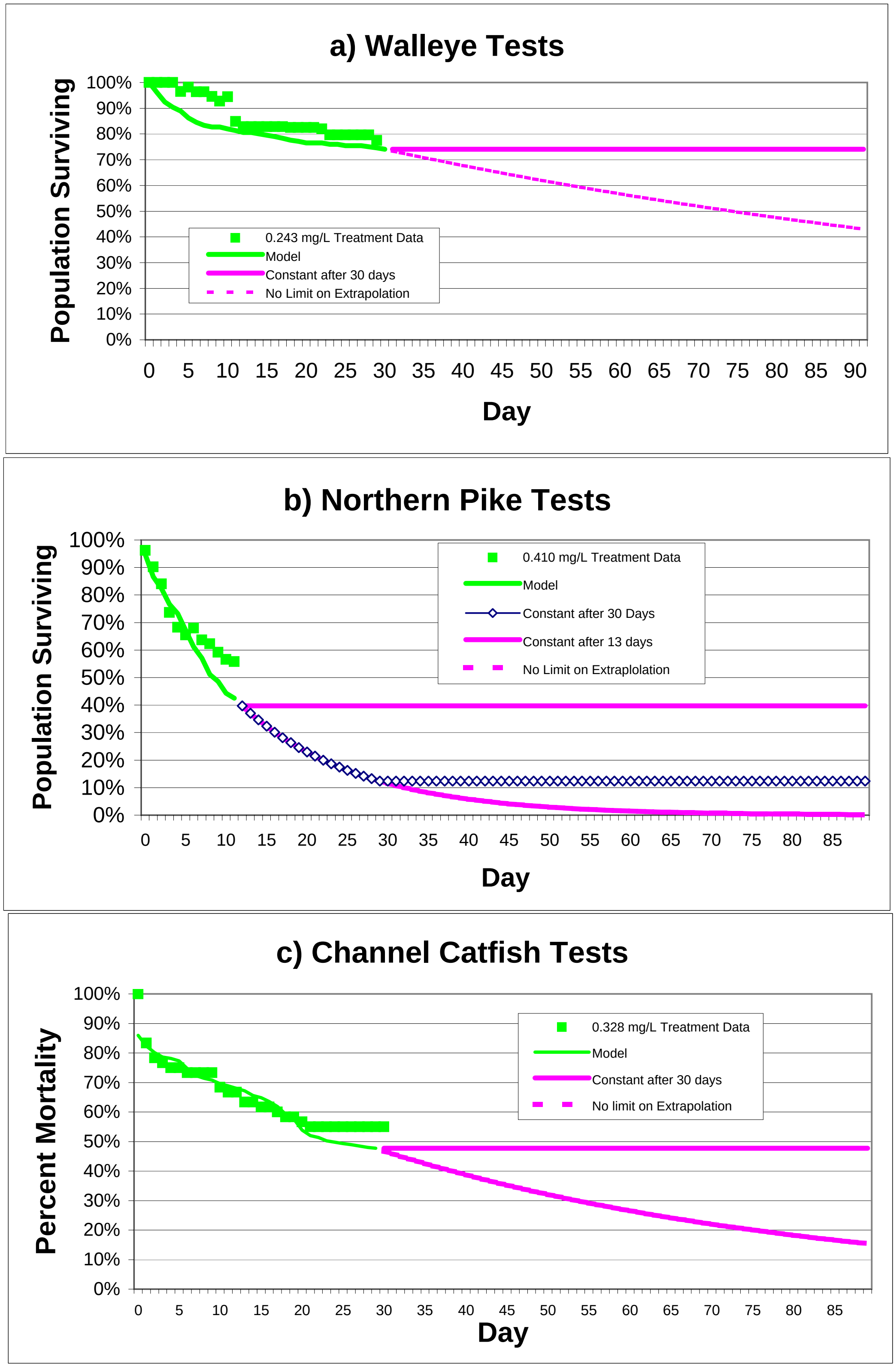
For the northern pike (Figure 8-8b), the tests only continued for 13 days due to high mortalities. (Control chambers had average mortalities over 20%). One method of extrapolation would be to continue the model using nominal ammonia concentrations and calculating the daily mortalities until the 30-day mark (the day when channel catfish showed a levelling off in mortality; see Figure 8-8c). For northern pike, using the end-of-test or 13-day limit appears to be relatively conservative when compared to the data (see Figure 8-8b). A more conservative model would extrapolate continued mortality until 90 days.

For the analysis of historic scenarios and future potential control scenarios, the mortality was considered to level off for each concentration at the end of the test period, i.e., the data was not extrapolated assuming continued mortality). However, a sensitivity analysis was done for each of the scenarios using the most conservative approach (90 day extrapolations) described to determine if there is a significant result in the final risk analysis. This will be discussed later in Section 8.5.

**TABLE 8-2**

## Percent Mortality Each Day of Fish Population

| Total Amonia @ 20 C and pH =8.0 | Unionized Ammonia | Mortality in % of Remaining Population per Day | | | Daily Mortality Factor (K) | | |
|---|---|---|---|---|---|---|---|
| | | Catfish | Walleye | Pike | Catfish | Walleye | Pike |
| 0.26 | 0.01 | 0.00% | 0.00% | 0.00% | 0.0000 | 0.0000 | 0.0000 |
| 0.52 | 0.02 | 0.00% | 0.00% | 0.00% | 0.0000 | 0.0000 | 0.0000 |
| 0.79 | 0.03 | 0.00% | 0.00% | 0.00% | 0.0000 | 0.0000 | 0.0000 |
| 1.05 | 0.04 | 0.00% | 0.00% | 0.00% | 0.0000 | 0.0000 | 0.0000 |
| 1.31 | 0.05 | 0.36% | 0.00% | 0.00% | 0.0036 | 0.0000 | 0.0000 |
| 1.57 | 0.06 | 0.38% | 0.00% | 1.16% | 0.0038 | 0.0000 | 0.0117 |
| 1.84 | 0.07 | 0.41% | 0.00% | 1.23% | 0.0041 | 0.0000 | 0.0124 |
| 2.10 | 0.08 | 0.43% | 0.00% | 1.30% | 0.0043 | 0.0000 | 0.0131 |
| 2.36 | 0.09 | 0.46% | 0.00% | 1.38% | 0.0046 | 0.0000 | 0.0139 |
| 2.62 | 0.1 | 0.49% | 0.00% | 1.46% | 0.0049 | 0.0000 | 0.0147 |
| 2.89 | 0.11 | 0.52% | 0.00% | 1.54% | 0.0053 | 0.0000 | 0.0155 |
| 3.15 | 0.12 | 0.56% | 0.00% | 1.63% | 0.0056 | 0.0000 | 0.0164 |
| 3.41 | 0.13 | 0.59% | 0.00% | 1.72% | 0.0060 | 0.0000 | 0.0173 |
| 3.67 | 0.14 | 0.63% | 0.00% | 1.81% | 0.0063 | 0.0000 | 0.0183 |
| 3.94 | 0.15 | 0.67% | 0.54% | 1.91% | 0.0067 | 0.0054 | 0.0193 |
| 4.20 | 0.16 | 0.71% | 0.57% | 2.01% | 0.0072 | 0.0058 | 0.0203 |
| 4.46 | 0.17 | 0.76% | 0.60% | 2.12% | 0.0076 | 0.0061 | 0.0215 |
| 4.72 | 0.18 | 0.81% | 0.64% | 2.24% | 0.0081 | 0.0064 | 0.0226 |
| 4.99 | 0.19 | 0.86% | 0.67% | 2.35% | 0.0086 | 0.0067 | 0.0238 |
| 5.25 | 0.2 | 0.91% | 0.71% | 2.48% | 0.0091 | 0.0071 | 0.0251 |
| 5.51 | 0.21 | 0.96% | 0.75% | 2.61% | 0.0097 | 0.0075 | 0.0264 |
| 5.77 | 0.22 | 1.02% | 0.79% | 2.74% | 0.0103 | 0.0079 | 0.0278 |
| 6.04 | 0.23 | 1.08% | 0.83% | 2.88% | 0.0109 | 0.0083 | 0.0293 |
| 6.30 | 0.24 | 1.15% | 0.87% | 3.03% | 0.0115 | 0.0088 | 0.0308 |
| 6.56 | 0.25 | 1.21% | 0.92% | 3.18% | 0.0122 | 0.0092 | 0.0323 |
| 6.82 | 0.26 | 1.28% | 0.97% | 3.34% | 0.0129 | 0.0097 | 0.0340 |
| 7.09 | 0.27 | 1.36% | 1.02% | 3.51% | 0.0137 | 0.0102 | 0.0357 |
| 7.35 | 0.28 | 1.44% | 1.07% | 3.68% | 0.0145 | 0.0107 | 0.0375 |
| 7.61 | 0.29 | 1.52% | 1.12% | 3.86% | 0.0153 | 0.0113 | 0.0394 |
| 7.87 | 0.3 | 1.60% | 1.18% | 4.05% | 0.0162 | 0.0119 | 0.0413 |
| 8.14 | 0.31 | 1.69% | 1.24% | 4.24% | 0.0171 | 0.0125 | 0.0433 |




**Examples of Extrapolating the Model Beyond Test Durations for Selected Treatments**

Figure 8-8

## 8.3 DYNAMIC MODELLING OUTPUT

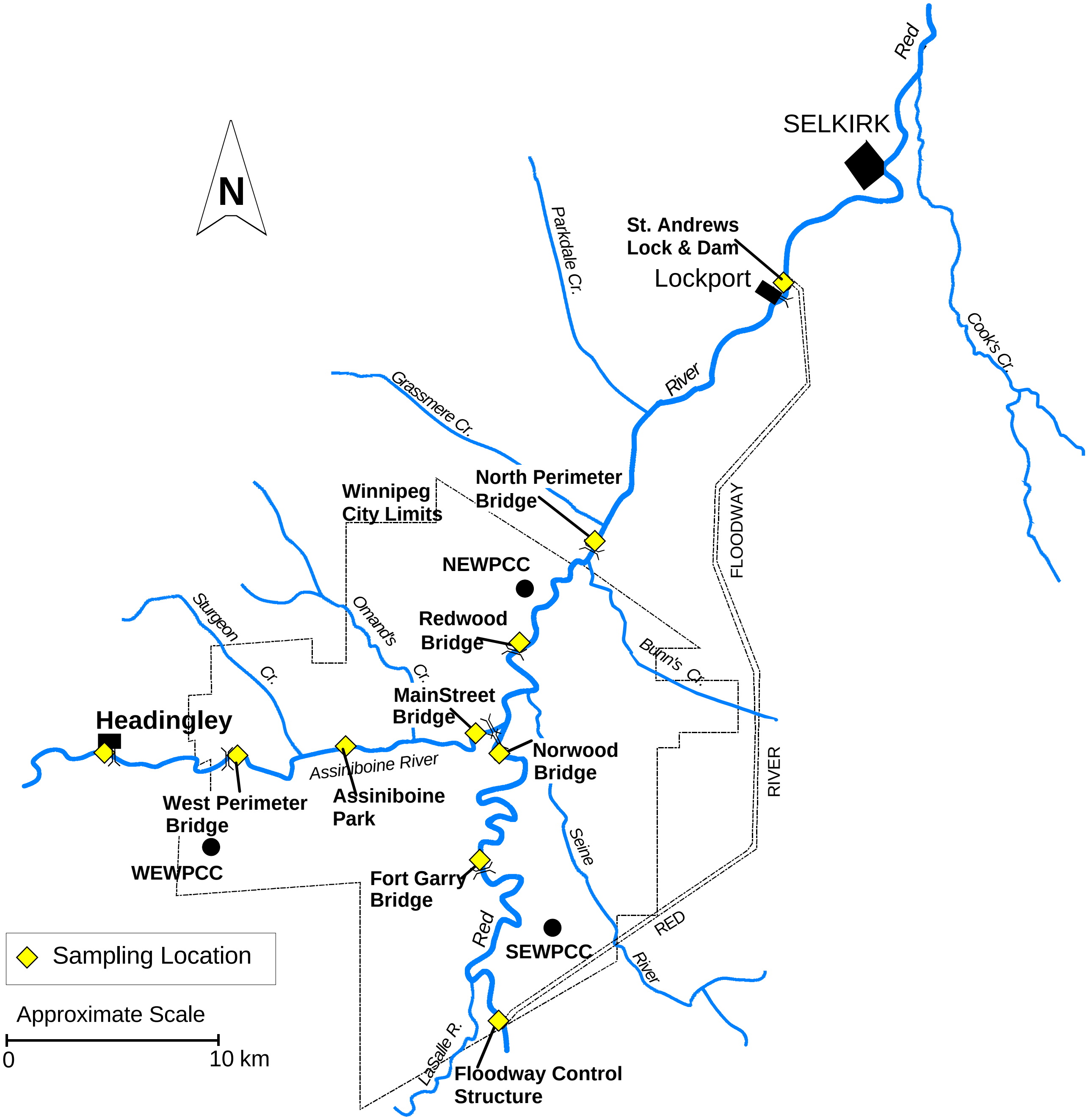
A full description of the dynamic model and its calibration is given in the River Conditions Technical Memorandum. The output of this dynamic modelling exercise provided a daily time series of total and un-ionized ammonia concentrations at key stations within the Red and Assiniboine rivers. The key locations which were assessed are shown in Figure 8-9. For each Water Pollution Control Centre (WPCC) there is one sample station located upstream and two downstream. The model is 1-dimensional and assumes full mixing relatively quickly within the river. This generally is true for the SEWPCC and NEWPCC at low flows in the Red River (refer to River Conditions TM). However, on the Assiniboine River, full mixing does not occur readily. Diffusers can be developed to create full mixing within the river at a relatively low cost (when compared to the cost of nitrification). Therefore, this assessment is still valid for the assessment of site-specific surface water criteria.

At each of these stations a 35-year daily record can be developed to estimate in-stream un-ionized ammonia concentrations (see Figure 8-10a). An example of the un-ionized ammonia concentrations predicted for a seven-year timeframe is shown on Figure 8-10a. (Only a 7-year record is shown in Figure 7-10 for illustrative purposes).

Daily mortality rates will vary with the daily un-ionized ammonia concentrations (see Section 7.3) at each sample station (see Figure 8-10b). For each year class (assumed from May through to May of the following year), the estimated impact on survival on an early life stage population was determined (see Figure 8-10c). The population is assumed to be 100% each May 1$^{st}$ and population survival is calculated from that time.

**It should be noted that these graphs do not indicate the survival of the complete adult population. Since the toxicity testing was done on early life stages it indicates survival of early life stages which may be representative of sub-lethal effects on the entire population (such as reduced growth)**.

The cumulative impact on the early life stage population is shown in Figure 8-10c. On May 1$^{st}$ of each year, the population is assumed to be 100% and then subsequently reduced by daily mortalities estimated during that year. By completing the analysis through the full 35-years of data, the population survival rate for each year can be estimated and plotted on a ranked

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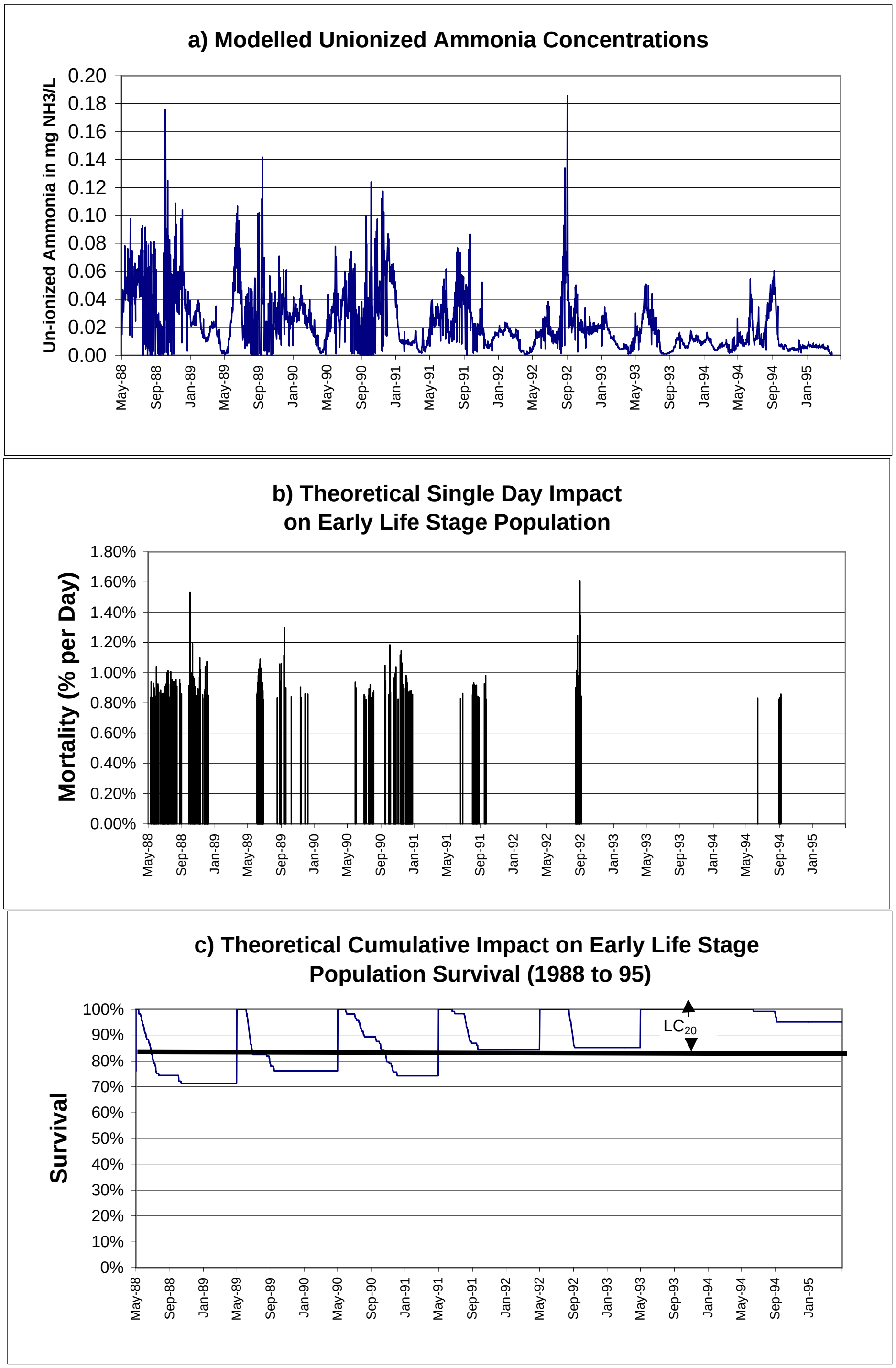
**City of Winnipeg Bi-Weekly Routine Sampling and Risk Assessment Locations**

Figure 8-9




**Notes:**

**Survival** indicates the theoretical survival of Northern Pike Fry exposed to the ammonia regime, it does **not** represent the mortality of Northern Pike in the River. **LC20** is equivalent to the theshold used in EPA and Environment Canada criteria development t

## Example of Estimating Annual Impact on Early Life Stage Fish Population

Figure 8-10

cumulative frequency curve. The frequency of years in which the significant effects concentration ($LC_{20}$) would occur can then be determined for each station. An example is shown on Figure 8-11.

The 35-year record can be used to estimate the risk in the following manner:

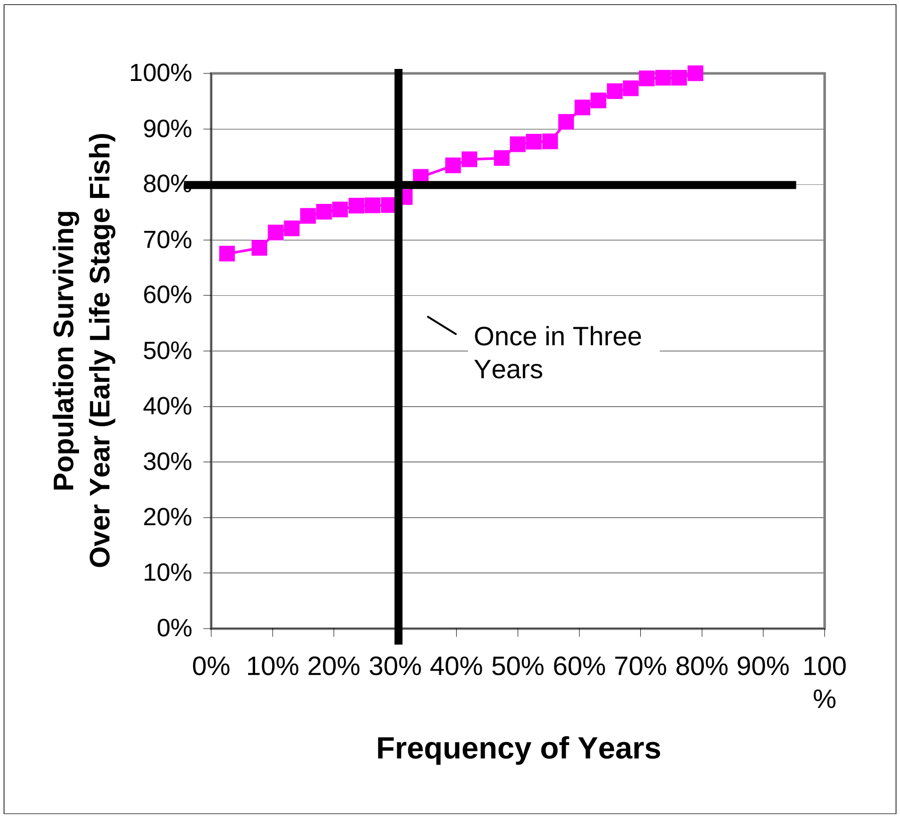
- For the historic period of record the actual risk to each species could be assessed from 1962 to 1997. During this time, the NEWPCC plant discharges remained relatively constant until the addition of centrate from the sludge dewatering process in the early 1990s, while the WEWPCC and SEWPCC grew significantly during that time.

- To estimate the current level of risk, the river flow for each of the past 35 years (modified to consider regulation of the Assiniboine River) was considered to occur with equal probability within the next year (i.e., any given year could be a drought or flood year). Current plant discharges were used.

- The loads to the treatment plants were estimated for a projected Winnipeg population in the year 2041. As in the current assessment, all 35 years of river flow data were used to assess the impacts at each station. Using these loads, various levels of control (LOC) of nitrogen were assessed and a dynamic model of ammonia loads to the river was developed. This model reflected the seasonal variation due to biological treatment plant sensitivities. (Biological treatment systems generally have more difficulty treating waste in late winter and early spring when cold water infiltrates to the treatment plants via the sewer systems).

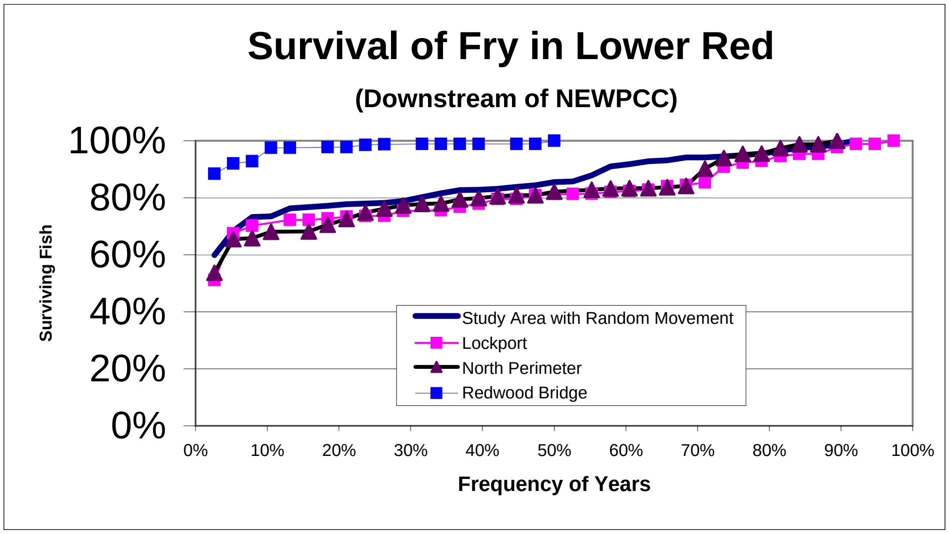
The cumulative effects for each year were calculated for each station for each of the three species. The results of the current risk to northern pike are shown in Figure 8-12. The survival of pike fry on the lower Red was assessed at the Lockport, the North Perimeter and the Redwood Bridge stations. The survival of fry in the upper Red was assessed at the Norwood Bridge, Fort Garry Bridge and Floodway Control Structure stations. The survival of fry in the Assiniboine River (Figure 8-12) was assessed at the Main Street Bridge, Assiniboine Park, and Headingley stations.

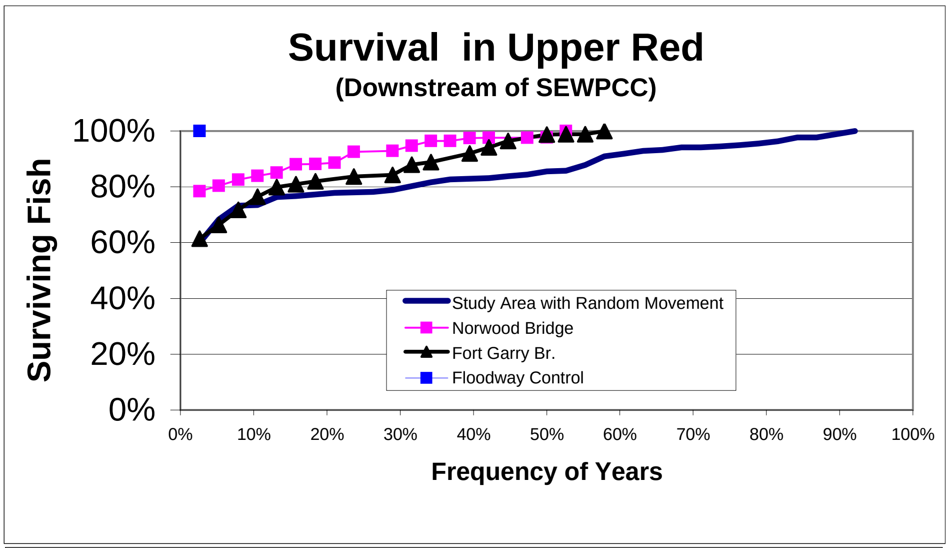
This analysis of each species population-impact assumes that the entire population remains stationary at the sample station. This is likely not realistic as behavioural studies indicate a

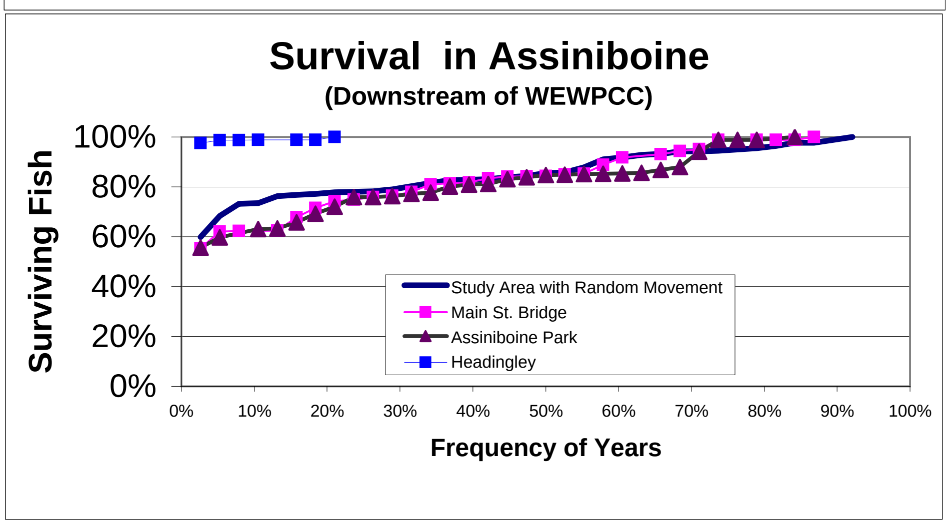



**Theoretical Survival of Early Life Stage Fish at Single Station in River (over 35 Years)**

Figure 8-11




**Current Risk For Northern Pike Based on 13 Days Test Results (no extrapolation)**

Figure 8-12

large range of movement for these species within the study area (see Fish Behaviour Technical Memoranda). Therefore, a second analysis was done assuming the random movement of the population throughout the full study area. The species population was assumed to be in any one of the 132 km of river within the study area on any given day. The ammonia concentration and the daily mortality rate were calculated using the concentration from that station on that day. The regional cumulative impact on the species population was then estimated on this randomly-moving group. For comparative purposes, this is also plotted on each of the three graphs as the study area survival assuming random movement.

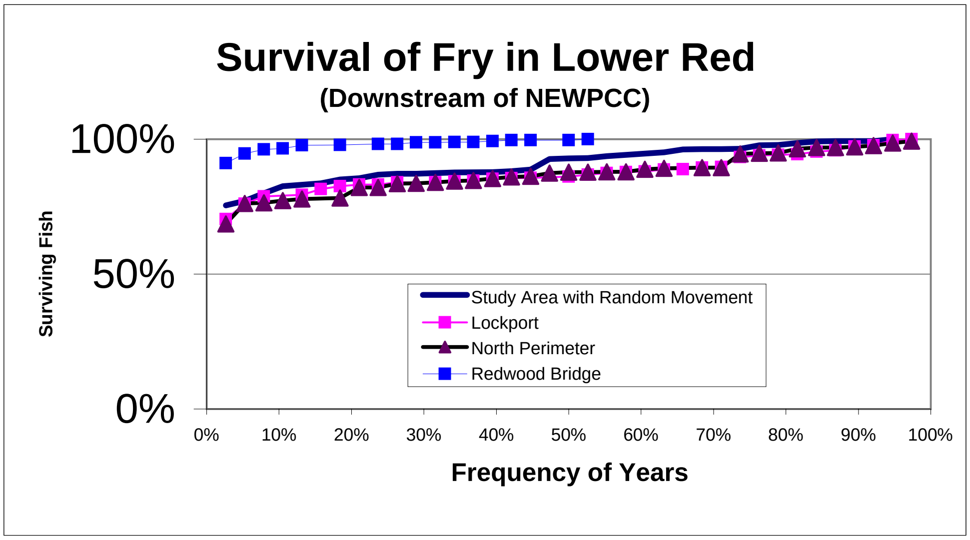
A similar analysis was done for channel catfish on the lower Red, upper Red and Assiniboine (see Figure 8-13). Channel catfish, as expected, show much less impacts than northern pike, since they are less sensitive to ammonia. The current risk to walleye at the 9 sample stations, assuming movement throughout the study area, is shown on Figure 8-14.

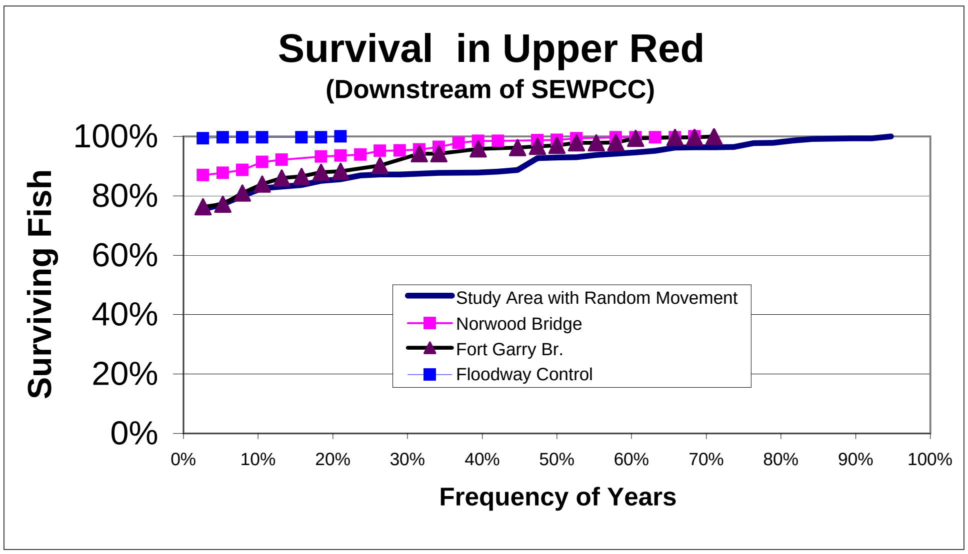
## 8.4 APPLICATION FOR DECISIONS ON THE RED AND ASSINIBOINE RIVERS AMMONIA WPCC LEVEL OF CONTROL REQUIREMENTS

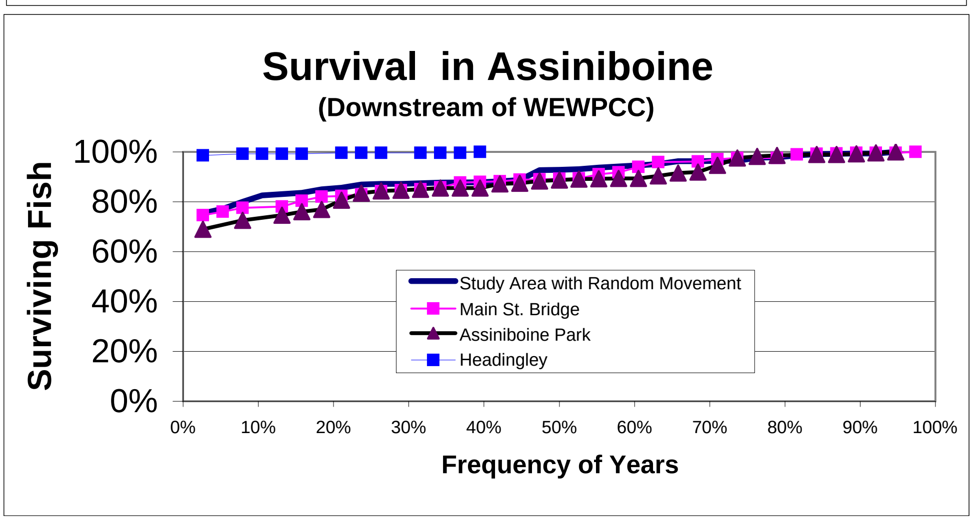
Risk analysis was performed on the historic dataset, the current dataset, and multiple levels of control for future loads to the Red and Assiniboine rivers. For each scenario, the frequency in which the significant effects occur (greater than $LC_{20}$) was determined for the most sensitive species (i.e., northern pike).

Graphs of the historic, current and future risks to northern pike are shown in Figure 8-15. The future scenarios included various combinations of different levels of control at each of the three plants:

- no nitrification at any of the plants;
- optimizing the existing systems;
  - centrate treatment at the NEWPCC
  - lagoon polishing tertiary treatment
- optimizing existing systems plus add moderate treatment at the South End plant; or

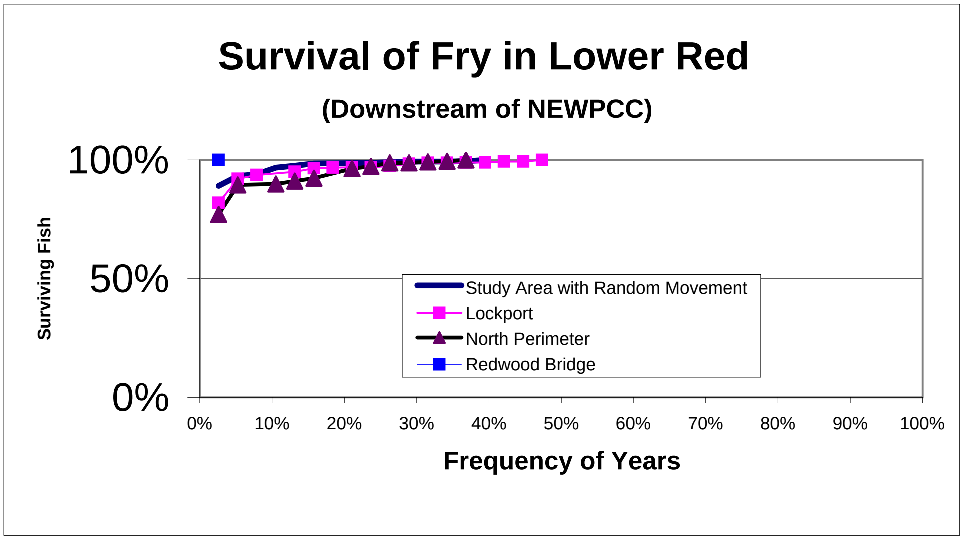


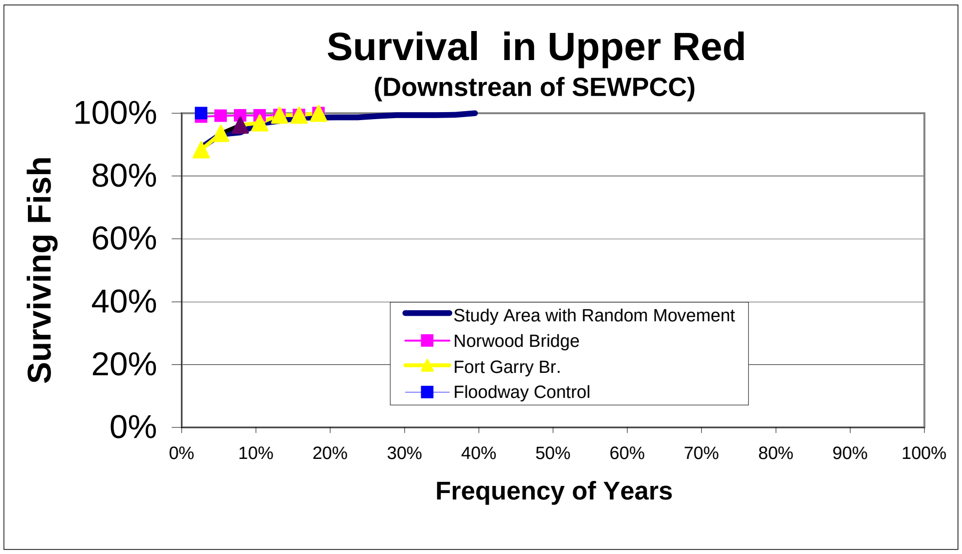



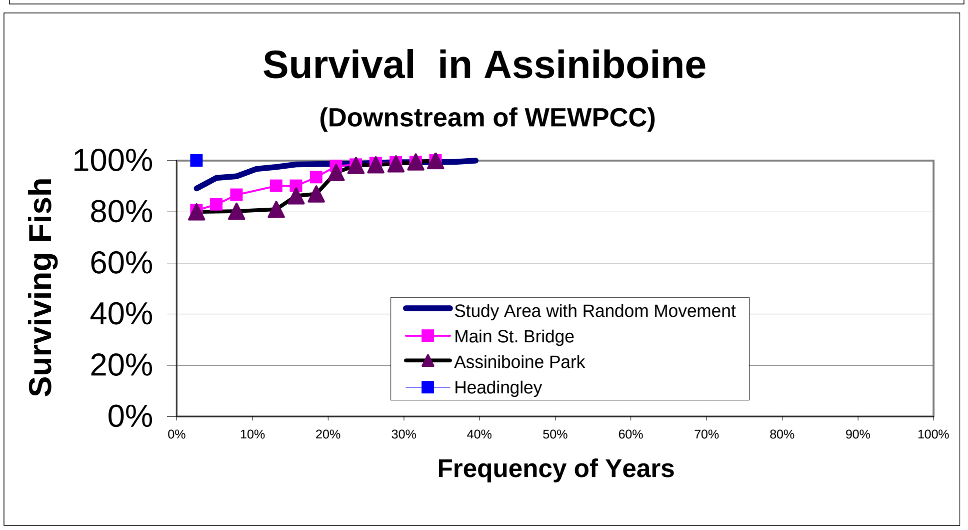




**Current Risk For Channel Catfish Based on 30 Days Test Results (no extrapolation)**

Figure 8-13

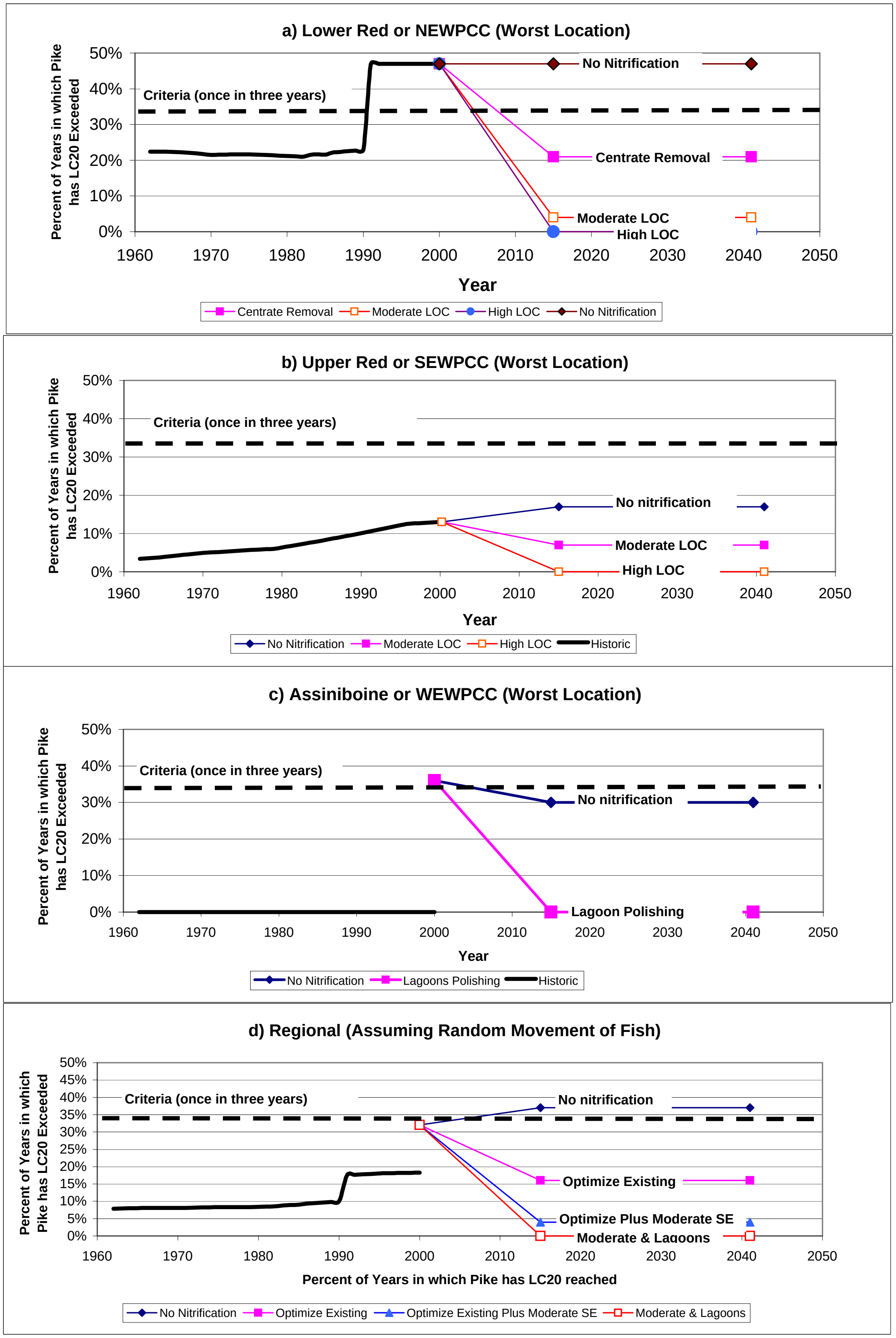



**Current Risk For Walleye Based on 30 Days Test Results (no extrapolation)**

Figure 8-14




**Change over Time in the Frequency of Years in which LC20 is Exceeded for Multiple Scenarios**

Figure 8-15

- have moderate treatment levels on the Red River plants (SEWPCC and NEWPCC), and use the lagoons at the WEWPCC.

The lower Red where the NEWPCC is located is shown in Figure 8-15a. For the lower Red, historic risk would have had significant effects ($LC_{20}$ exceeded) to northern pike for about 20% to 25% of the years, rising to almost 45% of the years in the 1990s. (Recall this is a theoretical risk assuming equal probability of flow in any given year from 1962 to 1997. Actual river flows were significantly higher after 1992. Therefore, this actual risk and impact on the pike did not occur.) The risk to northern pike on the lower Red River could be reduced to historic levels with centrate treatment (i.e., 20% of years). This is lower than the once in three years on average level of risk which is recommended by U.S. EPA and accepted by Manitoba Conservation in their development of design flows. For the moderate level of treatment, the risk could be reduced to 5% or once in 20 years. High level of treatment would reduce the risk to northern pike altogether. Best practicable treatment would show no additional benefit.

On the upper Red where the SEWPCC is located (see Figure 8-15b), the theoretical risk to northern pike likely grew from 1962 to the current conditions. The risk likely grew from 4% to about 12% over that 35-year stretch. In the future, if no nitrification control was developed, the risk could continue to grow to a level of 17%. This is still significantly below the once in three years on average (33%) frequency of significant impacts which has been used in the development of design flow criteria by U.S. EPA and Manitoba Conservation. A moderate level of treatment would reduce the risk back to the historic levels found in 1980 and high level treatment could reduce the risks altogether. Again, best practicable treatment has no additional benefits.

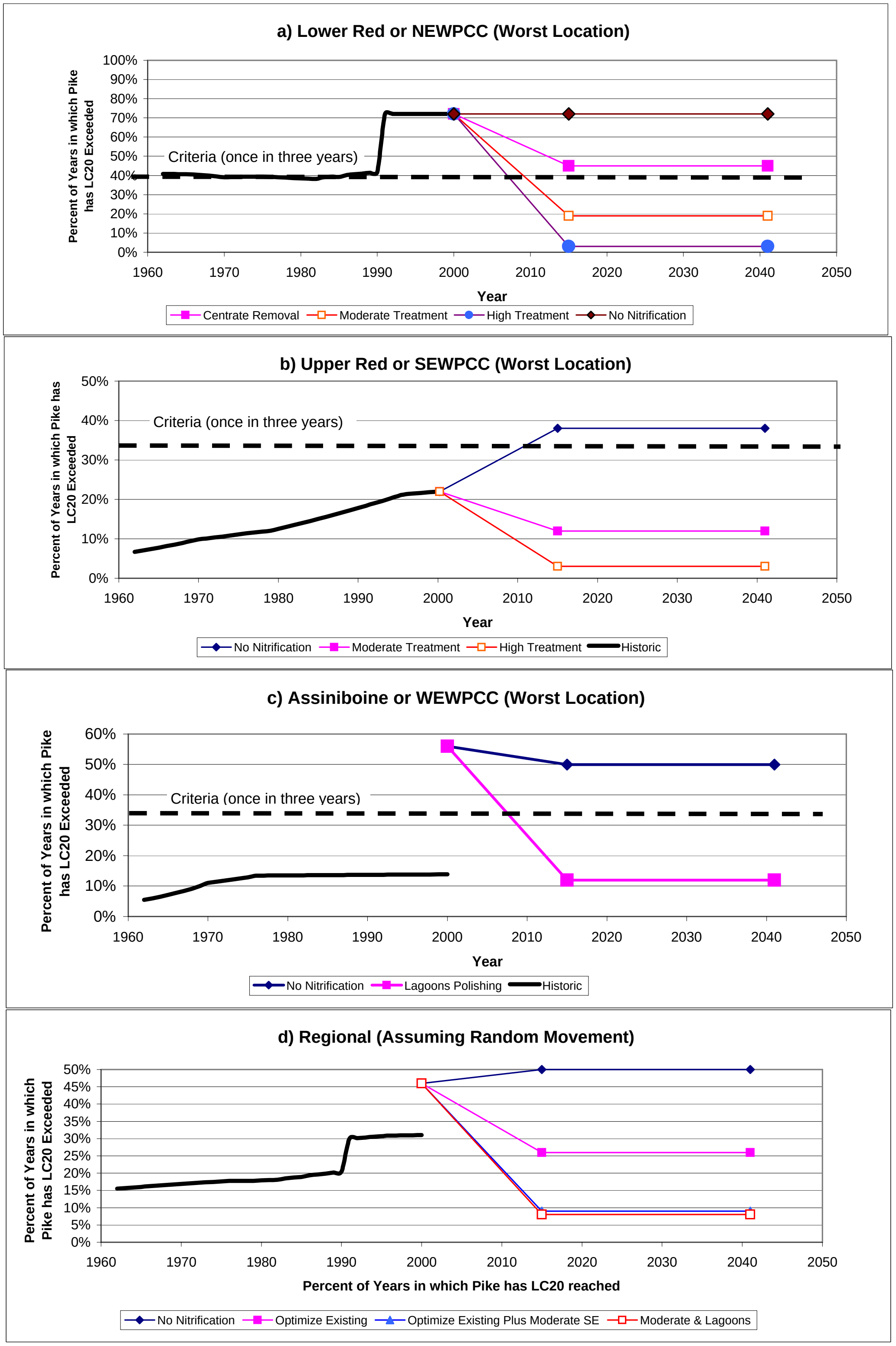
On the Assiniboine River where the WEWPCC is located (see Figure 8-15c), the historic risk has likely been negligible due to the use of lagoons in treatment. (In actual fact, with incomplete mixing there may be a level of risk within the first 10 metres of the bank. This however is less than the 25% cross-sectional area allowed for in Manitoba and U.S. EPA in application of surface water criteria.) Without the use of the lagoons, the risk (i.e., of $LC_{20}$ being exceeded) on the Assiniboine River would be greater than once on three years on average, at about 35% frequency. Since the WEWPCC plant loads are expected to decrease slightly in the future, the frequency of occurrence on a fully-mixed Assiniboine River would be once in three years on average (33%). However, the City has committed to maintaining the lagoons as a polishing pond which would eliminate the risk to a sensitive species like northern pike in the future. Best practicable treatment show no additional benefits.

The regional risk to pike is shown in Figure 8-15d. This shows a 10% historic risk in any year increasing to about 18% in the 1990s. The current risk could be as high as 30% of the years for a random moving population of northern pike if the lagoons at the WEWPCC are not used as a polishing pond. Each of these scenarios showing a range of potential risks from 30% of exceeding an $LC_{20}$ response for the years to 0% of the years could be provided for various levels of control (LOC). To reduce the regional risks (assuming that pike are not stationary at any point), optimization of the existing system (centrate treatment at the NEWPCC and lagoon polishing at the WEWPCC) would be an effective method of maintaining or slightly reducing the current risk of 20% per year. A moderate level of control at the SEWPCC would reduce the regional risk to less than 5% of the years (below historic levels). Moderate level of control at the NEWPCC would virtually eliminate regional risk. Additional levels of treatment (high of best practicable) would have no additional benefits.

## 8.5 SENSITIVITY ANALYSIS

As northern pike was the most sensitive species to ammonia, sensitivity analysis was done assuming that the effects model could be extrapolated to show continuing effects to 90 days (see Figure 8-8). Timelines of risks for the various historic, current and future scenarios are shown on Figure 8-16. An assessment of the estimated risk for the lower Red River (downstream of the NEWPCC) shows the historic risk to pike of an LC20 affect occurring in 40% of the years. The current risk could be as high as 70% of the years. The amount again shows that centrate treatment would lower the risk back to historic levels of between 40 and 50% of the years showing LC20 effects. In order to lower the risk to below the once in three years on average, a moderate level of control would be required.

For the upper Red River (see Figure 8-16b), or area affected by the SEWPCC, this very conservative analysis shows that the number of years in which an LC20 affect may be incurred is close to 40% of the years. In order to reduce the risk below one in three years on average (33%) down to close to 10%, a moderate level of control would be required at the SEWPCC.




**Change over Time in the Frequency of Years in which LC20 is Exceeded for Multiple Scenarios (With Conservative Assumptions)**

Figure 8-16

For the Assiniboine River (see Figure 8-16c), or the area downstream of the WEWPCC, the conservative analysis indicates that using lagoons would reduce the risk to well below the one in three years on average back to historic risk of 10 to 15% of the years showing $LC_{20}$ effects.

On a regional basis (see Figure 8-16d), the analysis shows the historic risks to pike (i.e., $LC_{20}$ being exceeded) being about 15% of the years rising to close to 30% of the years at current levels of treatment. Without any level of tertiary treatment (i.e., no lagoon polishing) the current risk could be as high as 45% of the years. Optimizing the existing system by using the polishing ponds and including centrate treatment at the NEWPCC would reduce the regional rates to below one in three years on average, to 25% of the years. A moderate level of control at the SEWPCC would reduce the risks on a regional basis to 10%, while a moderate level of control at the NEWPCC would have marginal incremental benefits. In order to reduce the risks to near zero, a high level of control would be required at both the NEWPCC and SEWPCC.

Overall the sensitivity analysis concludes that the best option for the WEWPCC is the lagoon polishing. At the SEWPCC and NEWPCC moderate levels of control may show additional benefits. Using a regional movement analysis, there appears to be no requirement for a moderate level of control at any of the WPCCs.

## 8.6 COMPARISON OF RISK ASSESSMENT AND THE CONVENTIONAL CRITERIA ASSESSMENT METHODS

A comparison of the level of control requirements at each of the WPCCs to meet areas' criteria using both steady state and dynamic approaches is shown on Table 8-3. This is compared to the levels of the control determined by the risk assessment method. The integrated risk assessment showed general agreement with the Manitoba general (i.e., EPA 99) and Winnipeg site-specific criteria. The analysis indicates that at this current time, no additional level of control is required at the SEWPCC. It is likely these controls will not be required in the future although efforts should be made to reduce load and flow to the plant. At the NEWPCC, centrate treatment is a common decision for all the various assessments. Some methods of assessment may indicate there should be a move towards a higher level of treatment. The City should investigate whether there is potential to increase the level of treatment in the NEWPCC using various process changes within the existing plant. All assessment techniques indicate that

**TABLE 8-3**

**Levels of Control Requirements at WPCCs to Meet Various Criteria Using Different Approaches to Assessment**

| Criteria | Steady State Approach: Direct WLA | Steady State Approach: To meet 95% Effluent Variation | Dynamic Models | Integrated Risk Assessment |
|---|---|---|---|---|
| **SEWPCC** | | | | |
| **MWQ SOG 2001/EPA 99** | Moderate LOC (No nitrification OK in all but November) | Moderate LOC (No nitrification OK in all but August, November & December) | No Nitrification in 2000 Towards Moderate LOC in 2041 | No Nitrification |
| **EPA 99 30B3 (Annual)** | Moderate LOC | Moderate LOC | | |
| **Winnipeg Site Specific EPA Method** | Moderate LOC (No nitrification OK in all but October) | Moderate LOC (No nitrification OK in all months except September & October) | No Nitrification in 2000 Towards Moderate LOC in 2041 | |
| **Winnipeg Site Specific PSL2 Method** | No Nitrification Required | Moderate LOC (No nitrification OK in all but August) | No Nitrification in 2041 | |
| **PSL2 National** | High LOC | BPT (High LOC OK in All Months except August) | Moderate LOC in 2000 Moderate(almost) to High LOC 2041 | |
| **MSWQO 1988** | BPT (High OK in All Months except November) | BPT (High OK in All Months except November) | - | |
| **MSWQO 1988 (1912-1990 flows)** | Best Practicable Treatment | Best Practicable Treatment | - | - |
| **NEWPCC** | | | | |
| **MWQ SOG 2001/EPA 99** | Centrate Treatment | Moderate LOC (Centrate removal OK in all except August) | Between Centrate Removal and Moderate LOC | Centrate Treatment |
| **EPA 99 30B3 (Annual)** | Moderate LOC | Moderate LOC | | |
| **Winnipeg Site Specific EPA Method** | Moderate LOC (Centrate Treatment OK in Except October) | Moderate LOC (Centrate Treatment OK in September & October) | Between Centrate Removal and Moderate LOC | |
| **Winnipeg Site Specific PSL2 Method** | Centrate Treatment | Centrate Treatment | Centrate Treatment | |
| **PSL2 National** | Best Practicable Treatment High LOC meets all except August | Best Practicable Treatment High LOC meets all except August | Moderate to High LOC | |
| **MSWQO 1988** | Best Practicable Treatment | Best Practicable Treatment | - | |
| **MSWQO 1988 (1912-1990 flows)** | Best Practicable Treatment May not have complied at pH> 8.5 | Best Practicable Treatment May not have complied at pH> 8.5 | - | - |
| **WEWPCC** | | | | |
| **MWQ SOG 2001/EPA 99** | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing |
| **EPA 99 30B3 (Annual)** | No Nitrification Required | No Nitrification Required | | |
| **Winnipeg Site Specific EPA Method** | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing | |
| **Winnipeg Site Specific PSL2 Method** | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing | |
| **PSL2 National** | Lagoon Polishing | Lagoon Polishing | Lagoon Polishing | |
| **MSWQO 1988 (1962-1997 flows)** | Best Practicable Treatment | Best Practicable Treatment | - | |
| **MSWQO 1988 (1912-1990 flows)** | Best Practicable Treatment | Best Practicable Treatment | - | - |

**Notes**

LOC = Level of Control

Design Flows based on 1962 to 1997 data
WLA are based on 2041 projected loads

lagoon polishing is an effective tertiary treatment to reduce risks to aquatic life from ammonia downstream of the WEWPCC.

# 9. OTHER CONSIDERATIONS

## 9.1 *IN SITU* MUSSEL TESTS

During the summer of 1999, giant floater mussels, a proven environmental indicator organism, were exposed for 65 days to varying concentrations of ammonia within the NEWPCC plume. Replicate *in situ* cages containing mussels of standardized size were placed at multiple distances between 5 and 150 metres downstream of the outfall. The cages placed near to the outfall had non-continuous or “pulsed” exposure due to changes in the centreline of the plume trajectory arising from large variations in river flow rate. Mussel exposure to effluent was corroborated by coprostanol biomarkers in the sampled mussel tissue, which indicated human fecal exposure. Additional information (i.e., monitoring done in the river and 3-dimensional CORMIX plume modelling) indicated the stations close to the outfall were exposed to ammonia concentrations between 4 and 9 mg/L total ammonia.

A large number of mussels were statistically analyzed for effects on growth rate (see Toxicity TM). There was no significant difference found between the mussel weights from any of the stations and from the control station upstream of the NEWPCC. The same growth rate analysis was done on length of mussels and there was, however, a statistical difference found between some of the stations. This testing provides a general confirmation that this species of mussel, when exposed for long periods of time (65 days), did not show statistically-significant growth effects when exposed to ammonia concentrations higher than the proposed site-specific criterion (2.0 mg-N/L total ammonia, for the EPA method).

## 9.2 EFFECTS OF UPSTREAM NUTRIENT CONTROL

River monitoring and modelling was used (see River Conditions TM) to illustrate that nutrient control could reduce algal growth in the Red and Assiniboine rivers. This may in turn reduce the peak summer pHs found in the reaches of the river for which a site-specific ammonia criteria would apply. The correlation between algal concentration and pH was shown to be strong (see Section 4.1 and River Conditions TM). Reduction of phosphorous (to 1 mg/L) at the NEWPCC may have an effect on algal concentrations, thus pH, and in turn un-ionized ammonia concentrations, at Lockport. The reduction in un-ionized ammonia (for the same concentration of total ammonia) may be as high as 14% at Lockport and between 6 and 9% at the North Perimeter Bridge (see River Conditions TM, Section 10). No benefit would be seen immediately downstream of the SEWPCC and WEWPCC. However, if in addition to the City of Winnipeg controls, a successful upstream phosphorous control program reduced maximum background concentrations of phosphorous to 0.1 mg/L, then the reduction of un-ionized ammonia within the study area during the summer may be between 14 and 23%. This benefit was not assessed in terms of meeting criteria or reducing risk to aquatic life.

This assessment indicates that there may be factors other than direct nitrification which may impact un-ionized ammonia concentrations in compliance to a criteria. Some of these factors, such as upstream nutrient control, are out of the control of the City of Winnipeg, although are being considered in an overall nutrient control strategy by the Province of Manitoba. Since much of the Red River basin lies outside of Manitoba, this may be a complex undertaking.

## 9.3 FISH BEHAVIOUR STUDIES

Fish behaviour studies done on the species most sensitive to ammonia (northern pike) indicated that although the northern pike are generally attracted to the area of the outfall, they do not reside in the outfall for long periods of time. In addition to not acting as a barrier to fish movement, as discussed in Section 6, these behaviour studies showed that the fish that were tagged did not stay within the plume area for up to 30 days. Therefore, the assumption applied in developing criteria that the sensitive species of fish would be exposed for 30 days continuously is likely conservative.

## 9.4 SUMMARY

These other corroborating studies should be taken account when deciding whether or not to apply a criterion strictly (i.e., a small level of non-compliance being used as a decision to upgrade a treatment plant). The consequence of a small exceedence of a criterion is not expected to be large and may not be measurable.

# 10. ECONOMIC CONSIDERATIONS

## 10.1 APPLICATION OF STEADY-STATE AND DYNAMIC MODELS

In Section 7, steady-state and dynamic models were applied to determine the levels of control which may be required in order to meet a potential licence for each of the WPCCs. Table 10-1 summarizes the present value cost of each Level of Control assessed at the WPCCs. Table 10-2 summarizes the costs which could be incurred for meeting these licences. A range of costs is given for some criteria alternatives which reflect uncertainty of how strictly the definition of a non-compliance is interpreted. For example, some level of controls such as centrate treatment at the NEWPCC will satisfy the objectives for all but one month during low flow conditions. Considering the uncertainty in developing effluent quality predictions from a treatment plant, consideration should be given to implementing the first stage of centrate treatment only prior to assessing the need for a higher (and very costly) level of treatment. The higher costs in the range reflect the potential treatment costs if no allowance is given for this uncertainty in licencing stage of regulation of effluent quality.

## 10.2 COST VERSUS RISK TRADE-OFF CURVES

Cost estimates for each scenario were used to develop the cost versus risk trade-off analysis for each treatment plant on a regional basis (see Figure 10-1). For the lower Red (NEWPCC) the trade-off curve shows that for a cost of $20 million the risk (i.e., of years in which $LC_{20}$ is exceeded for pike) could be reduced from around 50% to 20%, however, moving to moderate or high levels of control would increase the cost to $120 to $140 million, for only a marginally improved reduction of risk.

On the upper Red (the SEWPCC), future risks are expected to occur during 20% of the years. This is below the once in three years on average frequency (i.e., 33%) expected to maintain a healthy ecosystem. However, the City could cut the risk in half for a cost of $25 million, or reduce the risk altogether for a cost of $30 million. Since this plant effects a length of river almost equivalent to the larger North End plant, this option may be more cost effective method of risk reduction than moving to moderate treatment at the NEWPCC.

**TABLE 10-1**

## Present Value Capital and Operating Costs for WPCC Upgrades

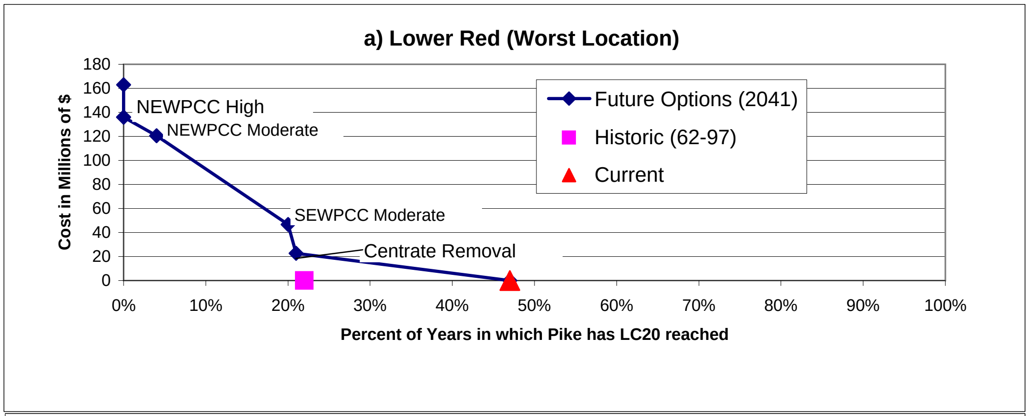
| | Cost in Millions of $ | | | |
|---|---|---|---|---|
| | ***NEWPCC*** | ***SEWPCC*** | ***WEWPCC*** | ***Total*** |
| BP | 157 | 46 | 6 | 209 |
| High | 132 | 31 | | 163 |
| Moderate | 117 | 23 | | 140 |
| Lagoons (Committedl) | - | - | 0 | |
| Centrate Treatment | 22 | - | - | |

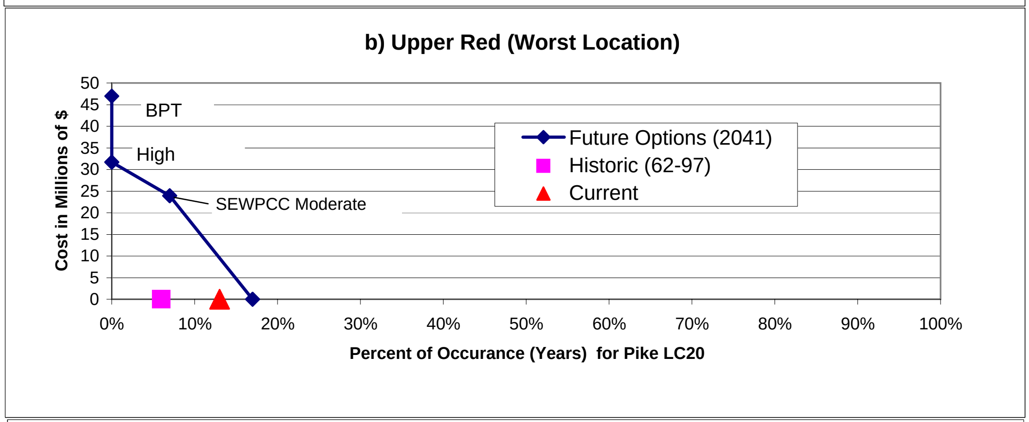
Source: EarthTech 2001
The present value of operating costs are estimated using a 40 year period and 4% discount factor (95% confidence)

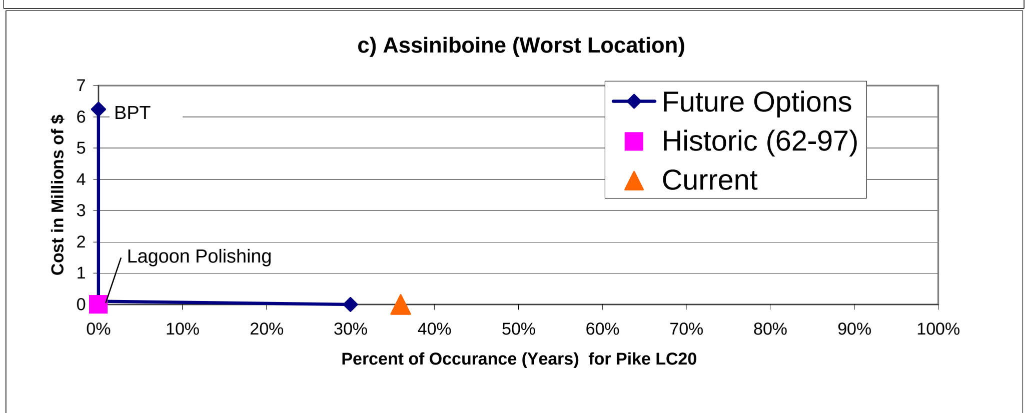
**TABLE 10-2**

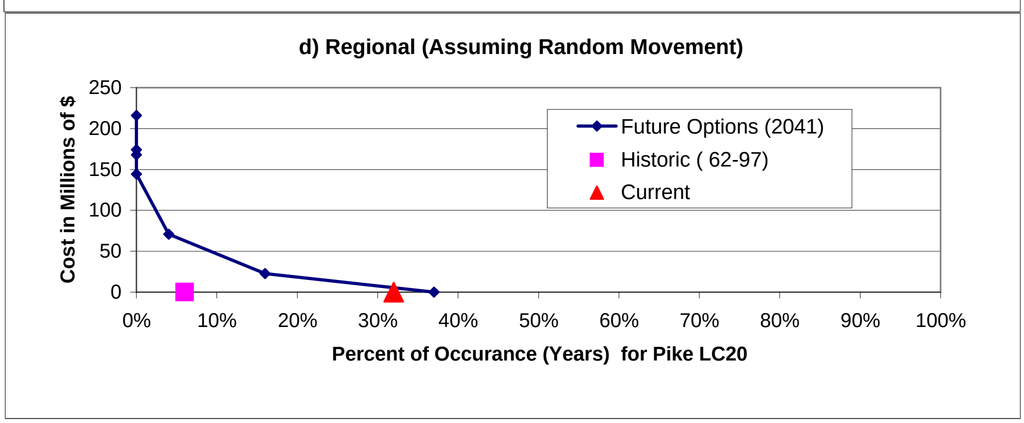
## Present Value Costs of Meeting Alternative Criteria at all WPCCs ( Millions of $)

<table>
<tr><th rowspan="2">Criteria</th><th colspan="2">Steady State Approach</th><th rowspan="2">Dynamic Models</th><th rowspan="2">Risk Assessment</th></tr>
<tr><th>Direct WLA (use Mean Effluent Concetration)</th><th>To meet 95% Effluent Variation</th></tr>
<tr><td>MWQ SOG 2001/EPA 99</td><td>22 to 45</td><td>45 to 140</td><td rowspan="2">45 to 140</td><td rowspan="6">22</td></tr>
<tr><td>EPA 99 30B3 (Annual)</td><td>140</td><td>140</td></tr>
<tr><td>Winnipeg Site Specific EPA Method</td><td>22 to 140</td><td>22 to 140</td><td>45 to 140</td></tr>
<tr><td>Winnipeg Site Specific PSL2 Method</td><td>22</td><td>22 to 45</td><td>22</td></tr>
<tr><td>PSL2 National</td><td>163 to 188</td><td>163 to 203</td><td>140 to 163</td></tr>
<tr><td>MSWQO 1988 (1962-1997 flows)</td><td>194 to 209</td><td>194 to 209</td><td>-</td></tr>
<tr><td>MSWQO 1988 (1912-1990 flows)</td><td>209+</td><td>209+</td><td>-</td><td>-</td></tr>
</table>




**Trade-off of Cost versus Aquatic Risk For Various Scenarios**

Figure 10-1

On the Assiniboine River (or at the WEWPCC), each of the lagoons provides a very cost-effective method of reducing risk to the most sensitive species of fish. Moving to a full nitrification process would add no benefit in terms of reducing risk to aquatic life.

On a regional basis, various combinations of the previously-discussed options were selected in order to produce a cost versus risk trade-off curve. As stated earlier, for $20 million, the regional risk could be reduced from roughly 40% to less than 20%, while additional treatment costs of around $30 million at the South End would reduce the regional risk (% of year in which $LC_{20}$ exceeded) to the sensitive species (pike) down to roughly 5% or equivalent to historic conditions. Moving to eliminate risk for the most sensitive species (northern pike) would cost an additional $100 million. Further treatment at $50 to $70 million additional cost would reduce ammonia concentrations in the effluent and the river, but, would not have any significant benefit in terms of reduced risk to the most sensitive species tested from the Red and Assiniboine rivers.

# 11. CONSERVATIVE ASSUMPTIONS IN THE DEVELOPMENT AND APPLICATION OF CRITERIA

Surface water criteria are a set of rules which give guidance to the regulator in the development of licences for wastewater discharges. Each licence in turn provides guidance to treatment plant designers and operators in the development and maintenance of processes to treat wastewater. One objective in the process should be the wise use of public funds to appropriately protect a valuable resource. At each step of this process, scientists and engineers make conservative assumptions given the information they have available. This section reviews the conservative assumptions in the development and application of a site-specific criteria and comments on whether these assumptions are necessary. The assumptions are summarized in Table 11-1.

At the toxicity testing stage, fish are tested at early life stages. These early life stages are more sensitive than juvenile or adult life stages, often three times more than juvenile and considerably more than adults. The mortality rates reported in this study, i.e., $LC_{20}$, $LC_{50}$, refer to the mortality of these early life stages. These responses are very unlikely to transfer to the adult life stages which will have less severe response to ammonia such as limited growth rates. These assumptions are necessary experimental procedures due to the difficulties of testing larger adult stages in a laboratory.

Fish and invertebrates are tested out of their natural environment (usually in laboratory water), which adds additional stress to them. This additional stress could end up in greater sensitivity to any toxicant introduced. In toxicity testing procedures, a great percentage of the tests started actually fail due to high mortalities in the controls. This is an indication of the stress involved in the procedure. The effect on risk calculations is that often tests are introduced in which the unrelated stress on species (often starvation) has caused a much lower acute toxicity value than was appropriate. This starvation effect has been noted on mussels and may have been a contributing factor to the low *Hyallela* acute toxicity value found for tests in laboratory water. When compiling all potentially-available tests, caution must be taken to include or exclude datasets in which other factors contributed to aquatic life mortality.

**TABLE 11-1**

**SUMMARY OF CONSERVATE ASSUMPTIONS IN CRITERIA DEVELOPMENT AND APPLICATION**

| | Conservative assumption | Effect on Risk | Comment |
|---|---|---|---|
| **Criteria Concentration Derivation** | 1.) Fish tested at early life stages | likely 3x more sensitive than juveniles, more when compare to adults | necessary experimental procedure |
| | 2) Fish and invetebrates tested out of natural environment, (usually in laboratory water) adding additional stress | unknown, very large for some species (mussels) | potential for questionable test to be included in data set, must be cautious |
| | 3) Only 20% of test organisms show effects (80% unaffected) | 1 in 5 of sensitive individuals from each genus affected | necessary experimental procedure |
| | 4) Only 5% of species assemblage affected | Only 1 in 20 genus affected | cautious statistical approach |
| **Averaging period** | 5) 30 days averaging period assumes fish stationary at position immediately downstream of outfall | fish generally not stationary only spend limited of time in once place, unknown safety factor | probably not applicable for all species |
| **Frequency of Exposure** | 6) Protect at design flow 1Q10,7Q10,30Q10 or 30B3 assumes it takes 3 years to recovery from endpoints effects. | EPA sites studies that show recovery from severe disturbances in 1 to 2 years | overprotective if River has refuge from which species can re-colonize impacted reaches |
| **Period Of Record Used** | 7) If record to 1912 used, includes events with 400 years return period (I.e. 1939 to 1941 drought) | likely provides estimate of dilution capacity which is 2 to 3x to low | unnecessary since 36 years of record generally considered more than adequate to develop design flows, **use 1962-1997 flow consistant with Minnesota approach** |
| | 8) To extend to 1912 requires transfer of data from Emerson Gauging Station to City of Winnipeg and routing Model including U.S. Reservoirs | data transformation could produce questionable results | |
| **Definition of Permit Exceedance** | 9) Consider permit violation if 95% or 99% of effluent data not below permit limit | surface water criteria only exceeded when effluent equal or greater than permit value one month in 3 to 10 years (or 0.8% to 2.8% of time) , if permit only exceeded 5% of time joint probablity is very low (0.1% or less) | unnecessary and could lead to 1 in 1000 year protection levels, **just require long term average to equal permit limit** |

It should be noted that when a species or genus is reported to be affected, only 20% of the test organisms showed effects (i.e., for LC20, 80% of the individuals were unaffected). This is important since the typical mortality of aquatic species populations within the first year is likely greater than 90% due to other factors such as predation, starvation, etc. This method of analysis is a necessary experimental procedure.

The criterion concentration is developed to protect 95% of the species from effects of that concentration. Since the number of genera used in the criterion development is generally less than 20, this value has to be extrapolated downward. It should be noted that with a natural substance such as ammonia there is likely a value at which there is no effect on any of the local assemblage. Therefore this extrapolation should be considered a cautious statistical approach.

The duration of the exposure to the toxicant in the laboratory is used to develop a portion of the criteria called the “averaging period”. The averaging period of 30 days assumes fish are stationary at the location the criterion is assessed. For a number of the sensitive species and the most sensitive species (northern pike) this has not been shown to be the case. Fish generally spend only a limited amount of time in one place unless over-wintering. This assumption is probably not applicable for all species at all times.

The development of a design flow, such as a 1Q10, 7Q10, 30Q10 or 30B3 assumes it takes three years to recover from endpoint effects. The studies used to develop this assumption showed that recovery from very severe disturbances (i.e., 100% loss) from the measured endpoints occurred within one to two years. If a significant population of the species can be shown to have refuge from the effects, then a one in three year (on average) criteria is likely over-protective. Species which are not affected move into the area and recolonize.

In the past, often an extended period of record was developed for the Red River at Winnipeg by transferring data from the Emerson Gauging Station (with regression analysis) to the City of Winnipeg. This transformation could produce questionable results. In addition, the use of this artificial dataset includes the drought of record for the region, i.e., 1939 to 1941. Other independent studies have shown that this drought of record may have close to a 400 year return period. It will therefore inappropriately influence the development of the design flow when standard hydrological statistical techniques are used. This will provide an estimate of the design flow which is 2 or 3 times too low. This additional development of an artificial dataset is unnecessary since the actual 36 years of record are generally considered more than adequate to develop design flows for a low frequency event such as once in three years on average.

Discharge permits and standard engineering design often end up in the development of a process in which the permit is considered violated if 95% to 99% of the effluent concentration data is not below the permit limit. However, when the discharge is at the permit limit, the surface water criteria will only be exceeded once in three, to once in 10 years. This is an additional safety factor which could lead to one in 60 year to one in 1,000 year protection levels. Appropriate design would require that the long-term average of effluent concentration be equal to the permit limit.

In summary, it should be recognized by those reviewing and applying this protective criteria that conservative assumptions are made at many stages within the criteria development and it is unnecessary and inappropriate to apply significant and costly additional conservative assumptions at the application stage.

# 12. CONCLUSIONS AND RECOMMENDATIONS

## 12.1 REGULATORY HISTORY

Review of the scientific basis of regulation of ammonia in North America surface waters since 1984 reveals that it is complex, uncertain, not site-specific and evolving. The regulations developed by the national agencies in Canada (Environment Canada) and the U.S. (Environmental Protection Agency) rely upon essentially the same limited toxicological and biological information although each agency assesses the information using different (although credible) scientific protocols. The result of the agencies using different protocols is significantly different national criteria. Both agencies state that these criteria should not be considered as site-specific and applicable to each river system within the specific jurisdiction, and rather that they be considered as general guidelines.

Review of the trends in regulation of ammonia from the early 1980s until the late 1990s indicated that as more credible toxicological data became available to the regulatory community, the stringency of prescribed ammonia criteria decreased. In general, the allowable in-stream criteria concentrations prescribed by both North American regulatory regimes have increased in numeric value over the past decades, indicating that rigorous application of early protective criteria resulted in over-protection (i.e., ineffective and/or unnecessary investments of public funds).

Based on the history of regulation ammonia, and mindful of its continuing evolution, it is recommended that new criteria adopted by Manitoba not be considered as definitive standards but rather as guides to assessing and reducing risk to aquatic life in the most locally appropriate and cost-effective manner.

## 12.2 TOXICITY TESTING

In order to improve the scientific basis of ammonia regulation by provision of site-specific toxicological information, 26 toxicity tests were completed on 11 different species of native (and non-native) aquatic life, including 7 fish species and 4 invertebrate species. Of the tests completed, 7 can be used directly in the derivation of a site-specific chronic criterion for ammonia.

Integration of the local data into the extensive toxicological database considered credible by the U.S. EPA and Environment Canada has significantly improved the scientific foundation to support regulation of ammonia, especially for creation of locally-appropriate regulatory regimes.

## 12.3 SITE-SPECIFIC CRITERIA DEVELOPMENT PROCEDURES

A review of U.S. EPA and British Columbia site-specific criteria-development methods determined that a combination of the "Resident Species Method" and "Recalculation Method" are the most appropriate procedures for incorporation of new toxicity test results into the current credible public domain toxicological database. A workshop with the scientific community led to a review and endorsement of this approach.

## 12.4 NUMERICAL VALUES OF SITE-SPECIFIC PROTECTIVE CRITERIA

Two approaches for site-specific derivation of the numerical values of candidate chronic-exposure protective criteria were relied upon which use both local and public domain toxicological data:

- One approach is based on U.S. EPA protocols outlined in their 1998 and 1999 updates to the 1984 document on developing ammonia criteria.

- Another approach was developed using Environment Canada PSL-2 protocols developed in their assessment of ammonia for the second Priority Substance List ("PSL-2") in 2000.

The numerical values developed from these approaches are both more and less stringent than the proposed Manitoba Conservation protective criteria, depending upon the ambient pH and temperature.

It is recommended that Manitoba Conservation consider using the site-specific numerical values developed from the City's toxicological test in finalizing the ammonia criteria for the urban reaches of the subject rivers because they have been derived from a stronger scientific database than the current provincial prescription for ammonia criteria. Discussions should take place with Manitoba Conservation as to which protocol would be most suited to the development of site-specific criteria for the urban reaches of the Red and Assiniboine rivers, mindful that these will then likely serve as a basis for prescriptions in licences for the City's WPCCs.

## 12.5 FREQUENCY AND DURATION OF CRITERIA EXCEEDANCE

The frequency of exceedance of a protective criterion as prescribed by Manitoba and the EPA criteria (i.e., once in 3 years, on average) appears to be reasonable, although no strong scientific evidence is available to support or refute this determination.

Using a 30-day duration of the averaging period for surface water data analysis is consistent with the test protocols used in the chronic ammonia testing and is therefore considered reasonable.

The multiplier used to increase the numerical values of the 30-day criteria (i.e., by 2.5) when applying a 4-day average period (as proposed by the EPA and Manitoba Conservation) is generally supported by the results of the toxicity testing done in this study.

We recommend that numerical criterion be applied in a regulatory regime that can be exceeded once-in-three-years, on average, with a 30-day period used in averaging the surface water data.

## 12.6 APPLICATION OF CRITERIA

### 12.6.1 Conservative Assumptions in the Development and Applications of Criteria

It is important that regulators reviewing toxicological and risk-assessment data and applying protective criteria understand and acknowledge that conservative assumptions have been relied upon in the many stages of development of protective criteria and that it is unnecessary and inappropriate to apply significant and costly additional conservative assumptions in the application of accepted protective criteria.

### 12.6.2 Design Flows

In applying criteria, specific low flows (i.e., design flows) are chosen below which the numerical criteria value does not apply. Based on the frequency and duration of criteria exceedance methodology have been developed to select these design flows.

The large monthly variations in pH and temperature indicate the need for monthly or seasonal design flows.

- Biologically-based design flow calculations (i.e., 30B3 or 30B10) are not suitable because they provide only annual and not monthly flows.
- Monthly 30Q10s were estimated for assessments using steady-state modelling.

The period of record used in this study to calculate the design flows was from 1962 to 1997 at St. Agathe, Headingley and Lockport. This period was selected because it is the only actual record gauged at all three stations (St. Agathe station upstream of Winnipeg on the Red River only has data from 1960 to 1997). This period of record is generally in accordance with period of record used elsewhere in licencing treatment plants on the same receiving stream within the United States (i.e., the licence for Moorhead, Minnesota used a period of record from 1954 to 1994).

A longer period of record for flows within Winnipeg could be estimated by using a gauging record from Emerson. This period of record could extend from 1912 to 1997. This record may not produce representative design flows because it includes a record drought from 1930 to 1940. Other independent studies have indicated that this drought may be considered a 1-in-300-year drought, and thus not representative of droughts occurring within a typical 100-year period.

The use of a period of record from 1962 to the present is recommended for licencing purposes, however regulators should be open to recalculating the design flow every 5 years to ensure that if river flows change, a representative design flow is used.

It is also recommended to investigate whether new information (i.e., tree-ring data), or statistical methods could be used to estimate design flows using a longer period of record.

## 12.7 WATER POLLUTION CONTROL CENTRE REQUIREMENTS

Dynamic and steady-state modelling approaches were used to assess the potential requirements for additional (i.e., tertiary) treatment at the three WPCCs for reducing discharges of ammonia in effluent under current conditions and future growth conditions. Assessments using both the candidate site-specific criteria derived from the newly-expanded ammonia-toxicity database and Manitoba's proposed general ammonia criteria, indicated that to achieve compliance with both criteria, the following is required:

- at the WEWPCC, lagoon polishing of the final effluent;
- at the SEWPCC, no additional nitrification under 2000 conditions; and
- at the NEWPCC, a process to treat the biosolids centrate side-stream.

The most stringent application of one of the criteria, which assumes 95% of the effluent data must meet an effluent target, may require:

- lagoon polishing of the final effluent at the WEWPCC;
- a moderate level of control at the SEWPCC for some months under future growth conditions (2041); and
- a moderate level of control at the NEWPCC for some months.

## 12.8 INTEGRATED AQUATIC ENVIRONMENT RISK ASSESSMENT

A risk analysis was performed focussing on the most sensitive species tested (Northern pike) to identify the extent of possible additional tertiary treatment to mitigate risk of ammonia exposures to this key sensitive species. The analysis indicated that:

- lagoon polishing would virtually eliminate risk from the WEWPCC in the Assiniboine River;
- treatment of the centrate side-stream at the NEWPCC would greatly reduce the risk of effluent exposures to pike downstream of the NEWPCC; and
- nitrification at SEWPCC is not required.

This risk assessment, which explicitly considers variability in WPCC discharge rates, river flows, temperature and pH and associated exposure of the fish to ammonia, confirmed that the more traditional application of steady-state modelling which assumes the most stringent interpretation of that assessment was not applicable.

The less stringent application of requiring the **mean** ammonia effluent quality to satisfy a licence limit (rather than requiring 95% of effluent quality data to satisfy a licence) would provide the aquatic protection intended by the ammonia criteria and is recommended as a guide to development of a potential implementation plan to reduce risk to aquatic life.

## 12.9 POTENTIAL AMMONIA-RISK MANAGEMENT IMPLEMENTATION PLAN

Based on the conclusions of this study, the following implementation is recommended for consideration in managing risks to indigenous aquatic biota from exposures to ammonia in WPCC effluents:

- continue using lagoons for polishing at the WEWPCC;
- implement treatment of the biosolids centrate side-stream at the NEWPCC;
    - monitoring of the effectiveness of this process and its impact on the main treatment processes.

- develop monitoring plans to assess aquatic impacts during critical periods of ammonia criteria exceedances, i.e., during low river flows which would cause ammonia concentrations to exceed the criteria concentration value;
- develop a focussed systematic monitoring plan in order to create a solid baseline of the fish species affected and a determination of their life-stage in the critical months;
- continue assessing river flows which could entail recalculating the design flow every 5 years to ensure that if river flows change, a representative design flow is used, and investigating whether new information or techniques could be used to estimate design flows used for a longer period of record;
- review this implementation plan with the province to obtain input and advice.

Because there is always scientific uncertainty in both the toxicity information and in the future river flows, the City and Province should develop a protocol for periodic reviews of licence conditions to assure that aquatic life is being adequately protected in the future.

The above concepts should be considered by the City as a possible basis for a proposal to Manitoba Conservation as a response to the CEC Recommendations on ammonia.

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# APPENDIX A

## EQUATIONS FOR CALCULATING ACUTE & CHRONIC AMMONIA CRITERIA CONCENTRATIONS FOR A RANGE OF pH AND TEMPERATURES

FROM: USEPA. 1985. Ambient Water Quality Criteria for Ammonia - 1984. Washington, D.C. EPA DOCUMENT NO. 440/5-85-001. NTIS ORDER NO. 85-227114.

## NATIONAL CRITERIA

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if:

(1) the one-hour* average concentration of un-ionized ammonia (in mg/liter $NH_3$) does not exceed, more often than once every three years on the average, the numerical value given by 0.52/FT/FPH/2, where:

$$FT = 10^{0.03(20-TCAP)}; \quad TCAP \leq T \leq 30$$

$$\quad\;\; 10^{0.03(20-T)}; \quad 0 \leq T \leq TCAP$$

$$FPH = 1; \quad 8 \leq pH \leq 9$$

$$\quad\;\; \frac{1 + 10^{7.4-pH}}{1.25}; \quad 6.5 \leq pH \leq 8$$

TCAP = 20 C; Salmonids or other sensitive coldwater species present

= 25 C; Salmonids and other sensitive coldwater species absent

(*An averaging period of one hour may not be appropriate if excursions of concentrations to greater than 1.5 times the average occur during the hour; in such cases, a shorter averaging period may be needed.)

(2) the 4-day average concentration of un-ionized ammonia (in mg/liter $NH_3$) does not exceed, more often than once every three years on the average, the average* numerical value given by 0.80/FT/FPH/RATIO, where FT and FPH are as above and:

RATIO = 16 ; $7.7 \le pH \le 9$

$$24 \cdot \frac{10^{7.7-pH}}{1 + 10^{7.4-pH}} \quad ; 6.5 \le pH \le 7.7$$

TCAP = 15 C; Salmonids or other sensitive coldwater species present

20 C; Salmonids and other sensitive coldwater species absent

(*Because these formulas are nonlinear in pH and temperature, the criterion should be the average of separate evaluations of the formulas reflective of the fluctuations of flow, pH, and temperature within the averaging period; it is not appropriate in general to simply apply the formula to average pH, temperature and flow.

The extremes for temperature (0, 30) and pH (6.5, 9) given in the above formulas are absolute. It is not permissible with current data to conduct any extrapolations beyond these limits. In particular, there is reason to believe that appropriate criteria at pH > 9 will be lower than the plateau given above between pH 8 and 9.

Criteria concentrations for the pH range 6.5 to 9.0 and the temperature range 0 C to 30 C are provided in the following tables. Total ammonia concentrations equivalent to each un-ionized ammonia concentration are also provided in these tables. There is limited data on the effect of temperature on chronic toxicity. EPA will be conducting additional research on the effects of temperature on ammonia toxicity in order to fill perceived data gaps. Because of this uncertainty, additional site-specific information should be developed before these criteria are used in wasteload allocation modelling. For example, the chronic criteria tabulated for sites lacking

# APPENDIX B

## CALCULATIONS USED TO DETERMINE FIFTH PERCENTILE EPA FOR GENUS MEAN CHRONIC AND ACUTE VALUES (GMCV)

**Table B-1**
**EPA METHOD OF CALCULATING FIFTH PERCENTILE ACUTE CRITERION**

| | Acute Value | ln ( Value) | ln ( Value)^2 | Probability | Probability ^.5 | |
|---|---|---|---|---|---|---|
| 4 | 14.7 | 2.685805 | 7.213546 | 0.166667 | 0.408248 | Golden Shiner |
| 3 | 13.2 | 2.576802 | 6.639908 | 0.125 | 0.353553 | Fathead Minnow |
| 2 | 10.1 | 2.315304 | 5.360632 | 0.083333 | 0.288675 | White Sucker |
| 1 | 9.3 | 2.233449 | 4.988296 | 0.041667 | 0.204124 | Walleye |
| | | 9.81136 | 24.20238 | 0.416667 | 1.254601 | |

n= 10

s^2 5.901681

s 2.429338

L 1.690878

A= 2.234094

Acute Value 9.34 mg/L

**Table B-2**
**EPA METHOD OF CALCULATING FIFTH PERCENTILE**
**CHRONIC CRITERION**

| | Chronic Value | ln (Chronic Value) | ln (Chronic Value)^2 | Probability | Probability ^.5 | |
|---|---|---|---|---|---|---|
| 4 | 4.72 | 1.551809 | 2.408111 | 0.363636 | 0.603023 | Waleye |
| 3 | 4.56 | 1.517323 | 2.302268 | 0.272727 | 0.522233 | Small Mouth Bass |
| 2 | 2.85 | 1.047319 | 1.096877 | 0.181818 | 0.426401 | Sunfish |
| 1 | 2.62 | 0.963174 | 0.927705 | 0.090909 | 0.301511 | Northern Pike |
| | | 5.079625 | 6.73496 | 0.909091 | 1.853168 | |

n= 10

s^2 5.626338

s 2.37199

L 0.170982

A= 0.701375

Chronic Value 2.02 mg/L

CHECK OF EPA CUM FREQ METHOD

# APPENDIX C

## MANITOBA CONSERVATION AMMONIA TABLES

## TIER II - WATER QUALITY OBJECTIVES

| Water Quality Variable | Units and Form | Water Use | Tier II - Water Quality Objectives[a] | Applicable Period | Averaging Duration | Allowable Exceedance Frequency | Design Flow[b] | References |
|---|---|---|---|---|---|---|---|---|
| Ammonia | mg/L Total Ammonia as N | Surface Water: Cool Water Aquatic Life and Wildlife | $= \left[\left(\left[\frac{0.0577}{1+10^{7.688-pH}}\right]+\left[\frac{2.487}{1+10^{pH-7.688}}\right]\right)\times a\right]$ (Eq. 1)<br>where $a = 2.85$ or<br>$= 1.45\times 10^{0.028\times(25-\text{Temperature})}$<br>whichever is less<br>and pH ≥6.5 and ≤ 9.0;<br>and | Water Temperature >5°C or Early Life Stages are Present | 30 Days[c] | Not More Than Once Each 3 Years, On Average | 30-Day, 3-Year or 30Q10 | US EPA (1999a) |
| | | | $= 2.5\times\left[\left(\left[\frac{0.0577}{1+10^{7.688-pH}}\right]+\left[\frac{2.487}{1+10^{pH-7.688}}\right]\right)\times a\right]$ (Eq. 2)<br>where $a = 2.85$ or<br>$= 1.45\times 10^{0.028\times(25-\text{Temperature})}$<br>whichever is less<br>and pH ≥6.5 and ≤ 9.0;<br>and | Water Temperature >5°C or Early Life Stages are Present | 4 Days[c] | Not More Than Once Each 3 Years, On Average | 4-Day, 3-Year or 7Q10 | |
| | | | $= \left[\frac{0.411}{1+10^{7.204-pH}}\right]+\left[\frac{58.4}{1+10^{pH-7.204}}\right]$ (Eq. 3)<br>**or** | All Periods | 1 Hour[d] | Not More Than Once Each 3 Years, On Average | 1-Day, 3-Year or 1Q10 | |

| Water Quality Variable | Units and Form | Water Use | Tier II - Water Quality Objectives[a] | Applicable Period | Averaging Duration | Allowable Exceedance Frequency | Design Flow[b] | References |
|---|---|---|---|---|---|---|---|---|
| Ammonia | mg/L Total Ammonia as N | Surface Water: Cool Water Aquatic Life and Wildlife (continued) | $= \left[\left(\left[\frac{0.0577}{1+10^{7.688-pH}}\right]+\left[\frac{2.487}{1+10^{pH-7.688}}\right]\right)\times b\right]$ (Eq. 4) where $b = 1.45 \times 10^{0.028\times(25-c)}$ and $c$ = Maximum Temperature or 7°C whichever is greater and pH ≥6.5 and ≤ 9.0; and | Water Temperature ≤5°C or Early Life Stages are Absent | 30 Days[c] | Not More Than Once Each 3 Years, On Average | 30-Day, 3-Year or 30Q10 | |
| | | | $= 2.5 \times \left[\left(\left[\frac{0.0577}{1+10^{7.688-pH}}\right]+\left[\frac{2.487}{1+10^{pH-7.688}}\right]\right)\times b\right]$ (Eq. 5) where $b = 1.45 \times 10^{0.028\times(25-c)}$ and $c$ = Maximum Temperature or 7°C whichever is greater and pH ≥6.5 and ≤ 9.0; and | Water Temperature ≤5°C or Early Life Stages are Absent | 4 Days[c] | Not More Than Once Each 3 Years, On Average | 4-Day, 3-Year or 7Q10 | |
| | | | $= \left[\frac{0.411}{1+10^{7.204-pH}}\right]+\left[\frac{58.4}{1+10^{pH-7.204}}\right]$ (Eq. 6) | All Periods | 1 Hour[d] | Not More Than Once Each 3 Years, On Average | 1-Day, 3-Year or 1Q10 | |

| Water Quality Variable | Units and Form | Water Use | Tier II - Water Quality Objectives[a] | Applicable Period | Averaging Duration | Allowable Exceedance Frequency | Design Flow[b] | References |
|---|---|---|---|---|---|---|---|---|
| Ammonia | mg/L Total Ammonia as N | Surface Water: Cold Water Aquatic Life and Wildlife | $= \left[\left(\left[\frac{0.0577}{1+10^{7.688-pH}}\right]+\left[\frac{2.487}{1+10^{pH-7.688}}\right]\right)\times a\right]$ (Eq. 7)<br>where $a = 2.85$ or<br>$= 1.45 \times 10^{0.028\times(25\text{-Temperature})}$<br>whichever is less<br>and pH $\geq 6.5$ and $\leq 9.0$;<br>and | Early Life Stages are Present | 30 Days[c] | Not More Than Once Each 3 Years, On Average | 30-Day, 3-Year or 30Q10 | US EPA (1999a) |
| | | | $= 2.5 \times \left[\left(\left[\frac{0.0577}{1+10^{7.688-pH}}\right]+\left[\frac{2.487}{1+10^{pH-7.688}}\right]\right)\times a\right]$ (Eq. 8)<br>where $a = 2.85$ or<br>$= 1.45 \times 10^{0.028\times(25\text{-Temperature})}$<br>whichever is less<br>and pH $\geq 6.5$ and $\leq 9.0$;<br>and | Early Life Stages are Present | 4 Days[c] | Not More Than Once Each 3 Years, On Average | 4-Day, 3-Year or 7Q10 | |
| | | | $= \left[\frac{0.275}{1+10^{7.204-pH}}\right]+\left[\frac{39.0}{1+10^{pH-7.204}}\right]$ (Eq. 9)<br><u>or</u> | All Periods | 1 Hour[d] | Not More Than Once Each 3 Years, On Average | 1-Day, 3-Year or 1Q10 | |

| Water Quality Variable | Units and Form | Water Use | Tier II - Water Quality Objectives[a] | Applicable Period | Averaging Duration | Allowable Exceedance Frequency | Design Flow[b] | References |
|---|---|---|---|---|---|---|---|---|
| Ammonia | mg/L Total Ammonia as N | Surface Water: Cold Water Aquatic Life and Wildlife (continued) | $=\left[\left(\left[\frac{0.0577}{1+10^{7.688-pH}}\right]+\left[\frac{2.487}{1+10^{pH-7.688}}\right]\right)\times b\right]$ (Eq. 10)<br>where $b=1.45\times10^{0.028\times(25-c)}$<br>and<br>$c$ = Maximum Temperature or 7°C<br>whichever is greater<br>and pH ≥6.5 and ≤ 9.0;<br>and | Early Life Stages are Absent | 30 Days[c] | Not More Than Once Each 3 Years, On Average | 30-Day, 3-Year or 30Q10 | |
| | | | $=2.5\times\left[\left(\left[\frac{0.0577}{1+10^{7.688-pH}}\right]+\left[\frac{2.487}{1+10^{pH-7.688}}\right]\right)\times b\right]$ (Eq. 11)<br>where $b=1.45\times10^{0.028\times(25-c)}$<br>and<br>$c$ = Maximum Temperature or 7°C<br>whichever is greater<br>and pH ≥6.5 and ≤ 9.0;<br>and | Early Life Stages are Absent | 4 Days[c] | Not More Than Once Each 3 Years, On Average | 4-Day, 3-Year or 7Q10 | |
| | | | $=\left[\frac{0.275}{1+10^{7.204-pH}}\right]+\left[\frac{39.0}{1+10^{pH-7.204}}\right]$ (Eq. 12) | All Periods | 1 Hour[d] | Not More Than Once Each 3 Years, On Average | 1-Day, 3-Year or 1Q10 | |

# APPENDIX D

## COEFFICIENT OF VARIATION OF MONTHLY EFFLUENT QUALITY FOR VARIOUS WPCC TREATMENT SCENARIOS

## NEWPCC CV Various Levels of Control

| Number | Month | No Centrate Removal | Centrate Removal | Moderate Treatment | High Level of Treatment | Best Practicable Treatment |
|---|---|---|---|---|---|---|
| 1 | January | 0.14 | 0.12 | 0.11 | 0.09 | 0.52 |
| 2 | February | 0.20 | 0.18 | 0.15 | 0.13 | 0.44 |
| 3 | March | 0.12 | 0.11 | 0.09 | 0.08 | 0.06 |
| 4 | April | 0.16 | 0.13 | 0.13 | 0.12 | 0.72 |
| 5 | May | 0.12 | 0.11 | 0.10 | 0.09 | 0.34 |
| 6 | June | 0.37 | 0.32 | 0.27 | 0.22 | 0.77 |
| 7 | July | 0.51 | 0.44 | 0.37 | 0.32 | 0.35 |
| 8 | August | 0.37 | 0.32 | 0.26 | 0.22 | 0.76 |
| 9 | Septembe | 0.19 | 0.16 | 0.14 | 0.12 | 1.01 |
| 10 | October | 0.28 | 0.25 | 0.21 | 0.18 | 0.46 |
| 11 | November | 0.19 | 0.16 | 0.14 | 0.12 | 0.46 |
| 12 | December | 0.20 | 0.18 | 0.15 | 0.13 | 0.22 |

## SEWPCC CV Various Levels of Control

| Number | Month | No Nitrification | Moderate Level of Control | High Level of Control | Best Practicable Treatment |
|---|---|---|---|---|---|
| 1 | January | 0.13 | 0.08 | 0.07 | 0.52 |
| 2 | February | 0.19 | 0.12 | 0.09 | 0.44 |
| 3 | March | 0.11 | 0.07 | 0.05 | 0.06 |
| 4 | April | 0.15 | 0.10 | 0.09 | 0.72 |
| 5 | May | 0.11 | 0.08 | 0.06 | 0.34 |
| 6 | June | 0.35 | 0.24 | 0.19 | 0.77 |
| 7 | July | 0.39 | 0.27 | 0.21 | 0.35 |
| 8 | August | 0.35 | 0.27 | 0.23 | 0.76 |
| 9 | Septembe | 0.18 | 0.12 | 0.10 | 1.01 |
| 10 | October | 0.25 | 0.18 | 0.14 | 0.46 |
| 11 | November | 0.18 | 0.12 | 0.09 | 0.46 |
| 12 | December | 0.19 | 0.13 | 0.10 | 0.22 |

## WEWPCC CV Various Levels of Control

| Number | Month | No Nitrification | Lagoon Polishing | Best Practicable Treatment |
|---|---|---|---|---|
| 1 | January | 0.13 | 0.45 | 0.52 |
| 2 | February | 0.19 | 0.28 | 0.44 |
| 3 | March | 0.11 | 0.18 | 0.06 |
| 4 | April | 0.15 | 0.52 | 0.72 |
| 5 | May | 0.11 | 1.02 | 0.34 |
| 6 | June | 0.35 | 0.97 | 0.77 |
| 7 | July | 0.39 | 1.08 | 0.35 |
| 8 | August | 0.35 | 1.24 | 0.76 |
| 9 | Septembe | 0.18 | 0.98 | 1.01 |
| 10 | October | 0.25 | 0.66 | 0.46 |
| 11 | November | 0.18 | 0.74 | 0.46 |
| 12 | December | 0.19 | 0.23 | 0.22 |