Summary:
Ammonia Reduction in City of Winnipeg Wastewater Effluents

Report to:

Winnipeg
Embrace the Spirit

Water and Waste Department

December 2002

Acknowledgements

This report, "Summary: Ammonia Reduction In City of Winnipeg Wastewater Effluents" summarizes the findings of two reports:

"Red and Assiniboine Ammonia Criteria Study: Final Technical Report" by TetrES Consultants Inc. in association with North South Consultants, November, 2002.

"Nitrification Study: Conceptual Design Report" by Earth Tech Canada Inc., November, 2002.

Both Studies were prepared for the City of Winnipeg, Water and Waste Department

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Introduction

Scientific studies examining criteria for ammonia to protect aquatic life in the Red and Assiniboine Rivers were conducted by the City of Winnipeg. Engineering studies were simultaneously completed to investigate the means and the costs for reducing ammonia in the effluents from the three Water Pollution Control Centres (WPCCs) in the City of Winnipeg.

These studies respond to recommendations made by the Clean Environment Commission (CEC) to the Minister of Environment in 1992 regarding Water Quality Objectives for the Red and Assiniboine Rivers. The CEC recommended that site-specific studies should be undertaken to determine both acute and chronic effects of ammonia from wastewater effluent on aquatic life in the Rivers. The CEC also expected that these studies should identify the program required to deal with ammonia in wastewater from the WPCCs.

The studies were intended to develop information to allow the establishment of locally appropriate ammonia control objectives. The City intends to propose to Manitoba Conservation that site-specific ammonia criteria for the Red and Assiniboine Rivers be utilized for regulation. This report will summarize the results of these studies.

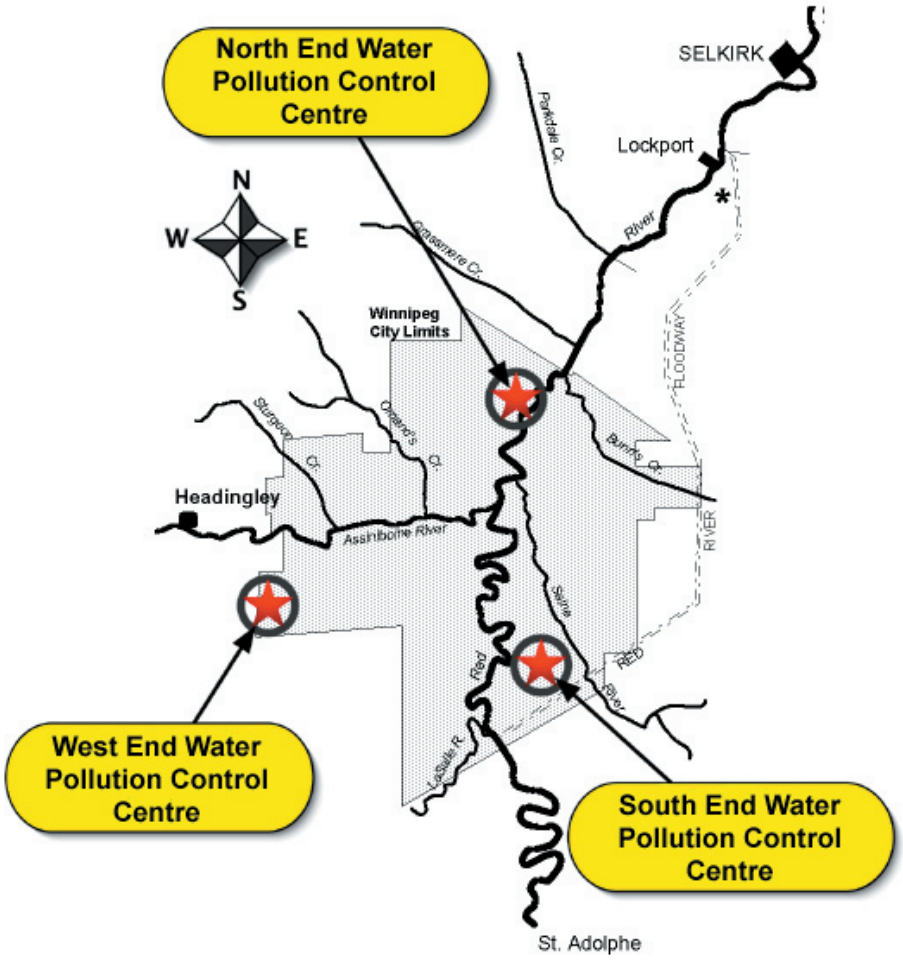

Figure 1: Locations of Winnipeg Pollution Control Centres (WPCCs)

The Ammonia Issue

Human and animal waste contain organic nitrogen and urea which breaks down through natural processes. Ammonia is a component of this ecological cycle. When present in high concentrations in effluent discharges, ammonia can stress aquatic life in the Rivers. If ammonia is present in very high concentrations, acute effects, such as fish kills, can result. For the Red and Assiniboine Rivers, the concern with respect to ammonia relates mainly to potential chronic effects, which mainly consist of reduction in growth rate of fish, tissue damage, not fish kills. Ammonia does not accumulate in the food chain and has no effect on the safety of eating fish.

In conventional secondary treatment, such as is used in the three Winnipeg WPCCs, limited removal of ammonia takes place. Accordingly, the effluents discharged to the Rivers contain ammonia. The toxicity of aqueous ammonia solutions to aquatic life, such as fish, is mainly attributed to the un-ionized form of ammonia. The concentration of un-ionized ammonia varies with river temperature and pH. Historical data indicates that concentrations in the urban reaches of the Rivers occasionally exceed the Manitoba Conservation objectives, due to WPCC effluent discharges. As the river flows downstream, the ammonia concentrations reduce due to natural

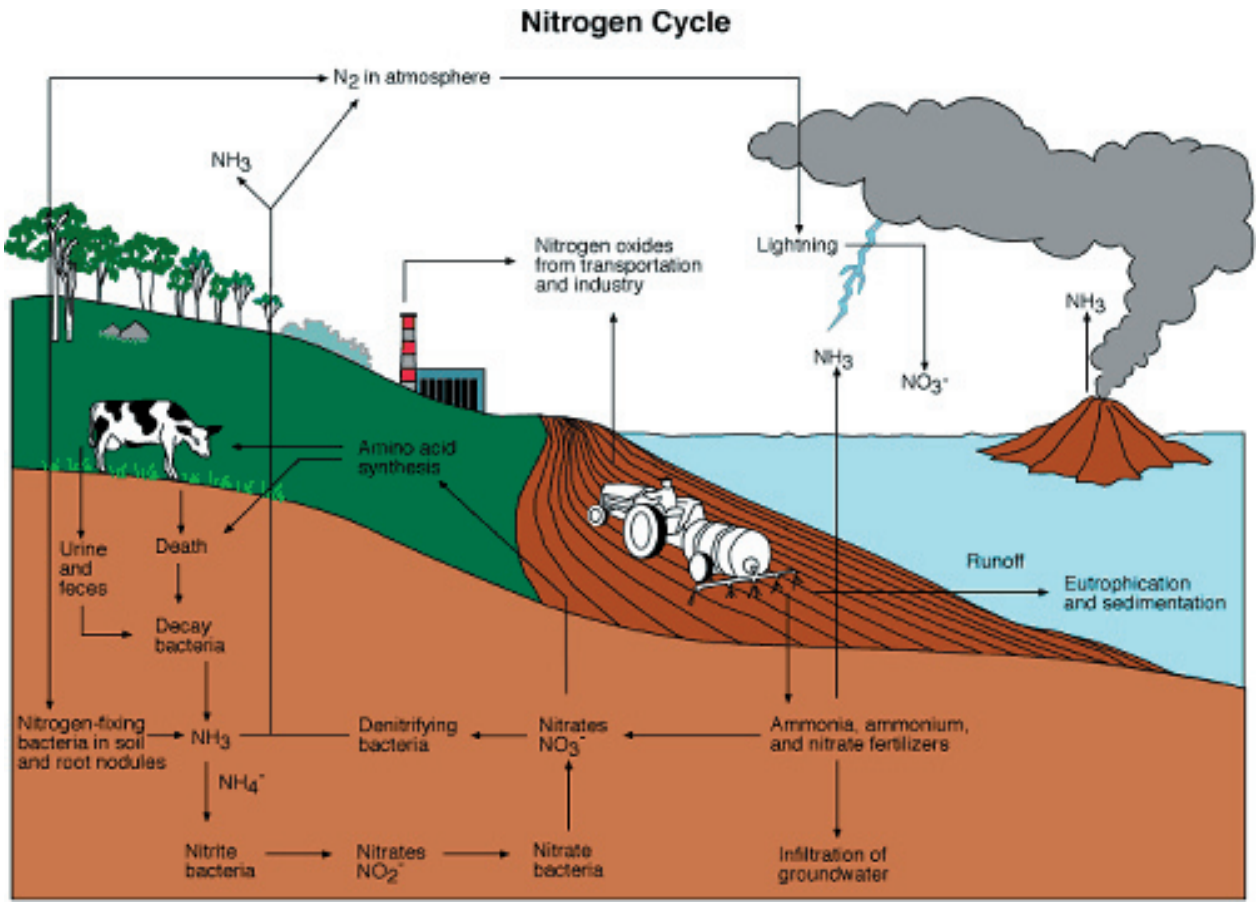

Figure 2: The Nitrogen Cycle.
Source: US Office of the Chief of Naval Operations Risk Assessment

conversion of ammonia to nitrates and the uptake of ammonia and nitrates by algae.

The scientific rationale for the allowable concentration of ammonia in the river, which will provide appropriate protection for aquatic life, has been evolving across North America. Additional toxicity testing data has been reviewed by various regulatory agencies, including Manitoba Conservation, which has resulted in modification of protective criteria. These national criteria were developed using methods which included results from tests

The Ammonia Issue..

on fish that are not indigenous to our local Rivers. For Winnipeg, the issue is to define the appropriate protective criteria for the local fish and other organisms in the Red and Assiniboine Rivers.

Ammonia levels in the Rivers and their potential effects on aquatic life are a complex water quality issue. The relationships require site-specific studies to estimate the effects of present levels and the benefits for the local aquatic community from improved control.

Ammonia in wastewater can be converted at the WPCCs to a stable form known as nitrate-nitrogen in a biological process called nitrification. Such advanced treatment is costly. The studies that have just been completed will provide sufficient information for the City to propose appropriate criteria for the local Rivers to Manitoba Conservation. This will allow consideration of potential programs for reduction of ammonia in the wastewater effluents to meet these criteria.

Objectives of Studies

The objectives of these studies were to :

•study the potential effects of ammonia in the Red and Assiniboine Rivers under variable river conditions;

•test toxicity of ammonia on selected indigenous aquatic species;

•assess the characteristics of the local aquatic ecosystem;

•develop alternative 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 the WPCCs to meet the protective criteria.

The first phase of the ammonia study involved discussion of the issues and identification of the scope of work required. This resulted in the development of a workplan, which integrated the various scientific and technical activities.

These activities were carried out in the second phase. The third phase involved the identification of alternative protective criteria for review with Manitoba Conservation.

This phased approach involved holding three workshops, with each workshop summarized by the production of technical memoranda.

Scientific Consultation

Scientific consultation was an integral part of this study. Representatives of regulatory agencies in Manitoba and Canada participated in the consultation process, along with local and international scientists experienced in ammonia toxicity and ammonia regulation issues. Scientists with local knowledge of aquatic life in the Rivers and riverwater quality characteristics were involved.

Input and guidance from this group of biologists and scientists was encouraged at multiple steps in the study workplan process. Comments and recommendations obtained from the scientific panel were included in subsequent study workshops.

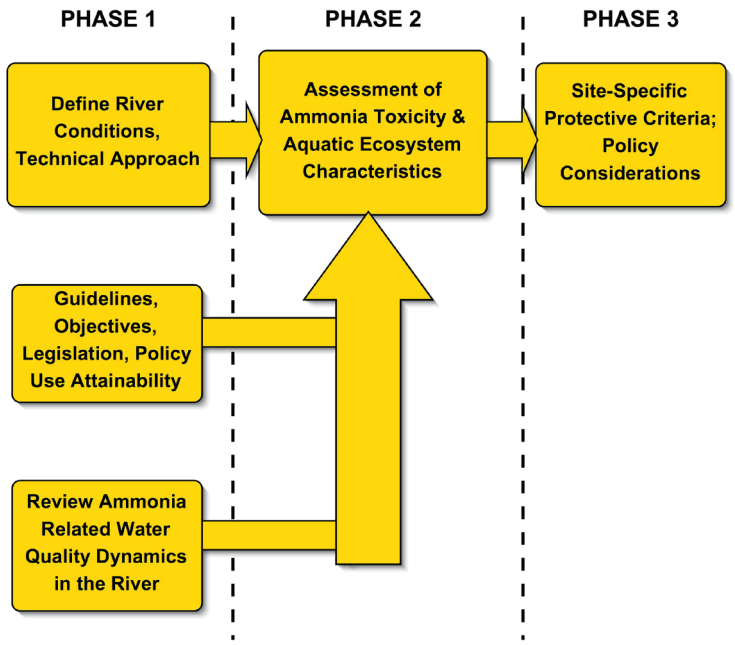

Figure 3: The Ammonia Study was consisted of three distinct phases, leading to a proposed site-specific criteria.

History of Ammonia Regulation

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. One of the earliest documents to address ammonia criteria was issued by the United States Environmental Protection Agency (EPA) in 1985. The study proposed national criteria for both acute (short-term, high concentration exposure) and chronic toxicity (long-term, low concentration exposure) to ammonia. In the development of criteria, the EPA found that there were limited studies on chronic ammonia toxicity. The EPA also gave guidance that the national criteria were subject to modification, if appropriate, to reflect local conditions.

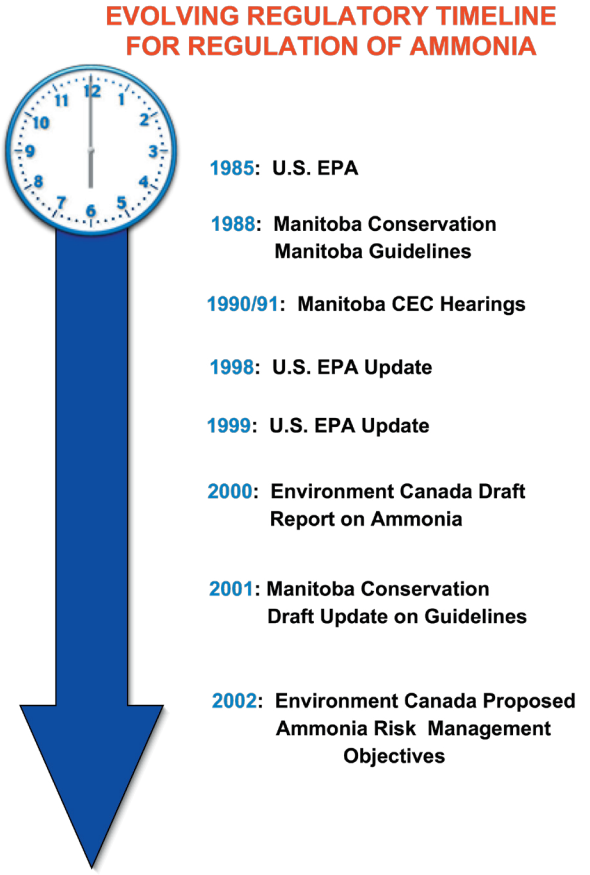

Figure 4: Evolution of ammonia regulations

In 1988, Manitoba developed water quality objectives for surface water which included new criteria for ammonia. These criteria were adapted from the EPA 1985 criteria and were developed for chronic exposures only. These were the subject of the CEC hearings in 1990 and 1991, where the CEC recommended additional study on the criteria.

In 1998, the EPA published an update of its criteria document. This was prepared in response to considerable criticism on the past criteria, and to consider substantial new information on ammonia toxicity. Following the 1998 EPA Update, there were again significant comments from scientific, municipal, and industry perspectives. Accordingly, the EPA issued a 1999 Update to the National Guidelines Criteria document. In 2001, Manitoba proposed revised Manitoba Water Quality Standards, Objectives and Guidelines, which are currently under public review. Manitoba proposed the adoption of the 1999 EPA Guidelines with minor modifications.

In May 2000, Environment Canada released a draft report for public comment on ammonia in surface waters pursuant to the Canadian Environmental Protection Act. Environment Canada has deemed ammonia to be a toxic substance in the context of the Canadian Environmental Protection Act.

Since the CEC report of 1992, there is a much improved understanding of ammonia toxicity, especially chronic toxicity. Much new data have been developed and improved statistical methods are now available for analysis. Significant uncertainty still exists in the development of national criteria; for example, Canadian criteria are more stringent than similar U.S. criteria using the same database.

National jurisdictions in Canada and the U.S., as well as Manitoba Conservation support the development of site-specific criteria as being the most appropriate regulatory approach. The studies that have been completed by the City of Winnipeg will allow this to take place for the Red and Assiniboine Rivers.

Existing Conditions

The Red and Assiniboine Rivers experience wide variations in flows from year to year and seasonally within the study area. This variation in flow can have major influences on their assimilative capacity available for WPCC discharges.

The impacts of ammonia to aquatic species are dependent on the river flow, and the receiving water's pH and temperature. Ammonia is of greatest concern when river flows are low and river temperature and pH levels are high. These conditions typically occur in late summer/ early fall. This combination typically results in the highest concentration of the un-ionized form of ammonia, which is the most toxic to fish.

Ammonia exists in the Rivers prior to the waters flowing within the City of Winnipeg boundaries due to upstream ammonia sources such as agricultural runoff and other point sources.

As shown in Figure 1, wastewater effluent is discharged to the rivers from the three WPCCs in Winnipeg. These three plants conduct secondary treatment of wastewater which results in limited removal of ammonia. Within the city, NEWPCC effluent discharges are the greatest loading on the Red River. Ammonia levels in the Red River downstream of the NEWPCC can occasionally exceed Manitoba water quality guidelines during certain conditions. Regulation of allowable ammonia concentrations usually requires the concentration to be below a threshold level under a designated river flow.

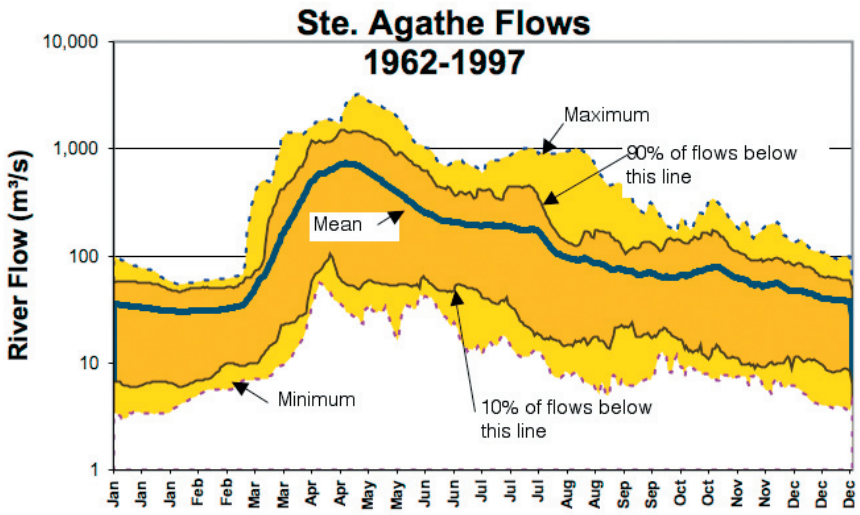

Figure 5: Measured river flows plotted for the Red River at St. Agathe from 1962 to 1999. Flows in the Rivers are extremely variable.

For this study, "river design flows" of this type were calculated and models were used to estimate ammonia concentrations in the river under such low flows and current WPCC treatment. Models were calibrated using data obtained by the City over 20 years of bi-weekly water quality data from 11 sampling stations. These results were compared to alternative ammonia criteria values.

The review of river conditions also considers the role of algae in the river. Algae are active in maintaining dissolved

Figure 6: A plume from the North End Pollution Control Centre extends into the Red River south of the Chief Peguis Bridge.

Existing Conditions..

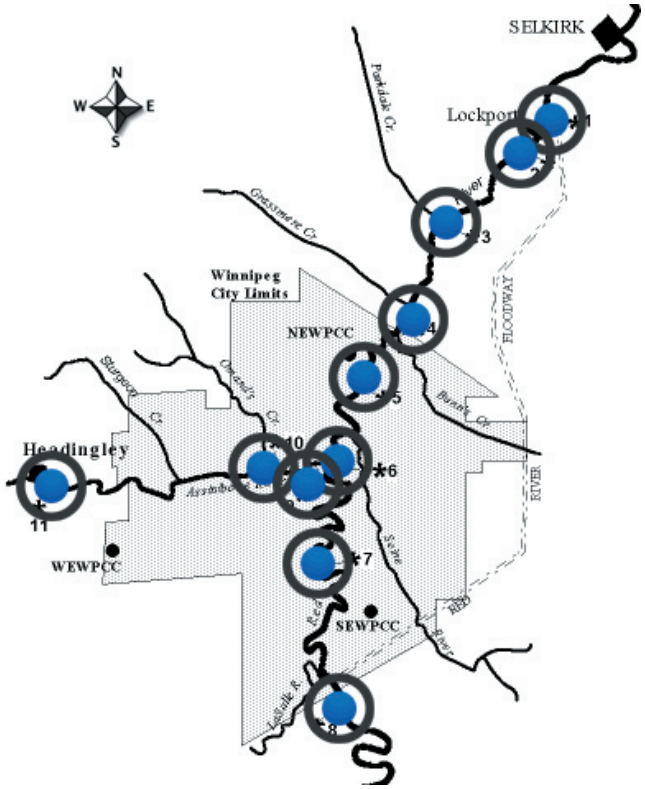

Figure 7: The City monitors water quality in the Rivers at 11 locations along the Red and Assiniboine Rivers.

oxygen levels and can cause increases in pH levels in the river. Non-point loadings to the Rivers upstream of the City stimulate algae growth which often results in high levels of pH. Higher pH in turn causes formation of more un-ionized ammonia and is a concern for fish toxicity.

Full river mixing occurs during low flow on the Red River, and plume analysis indicated that dilution of at least 5 times occurs quickly at all flows, thus quickly reducing ammonia concentrations.

Mixing zone analysis and fish behaviour studies indicated that there is no apparent barrier effect presented by the discharge plumes from the WPCCs; fish are not impeded by the plumes.

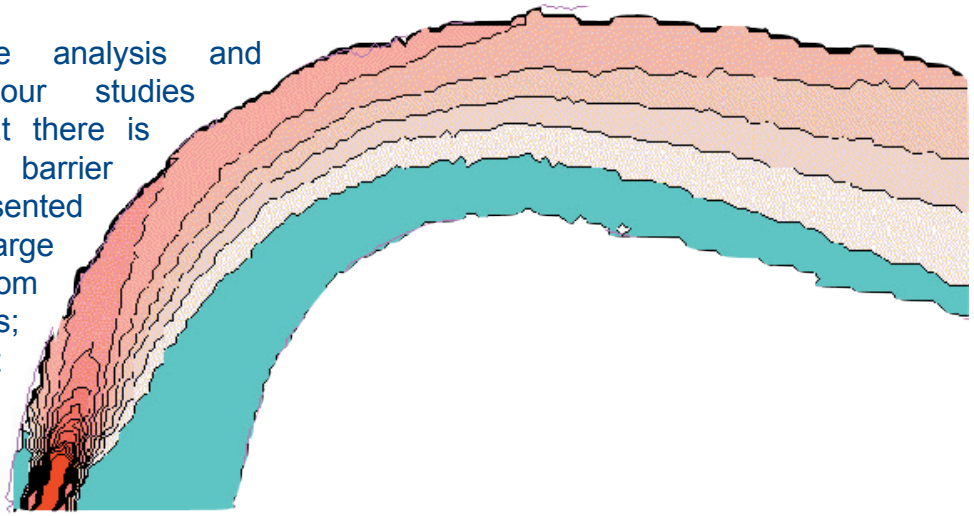

Figure 8: Models were applied to assess mixing of effluent discharges into the Rivers.

Aquatic Life

Local Fish Species:

Bigmouth buffalo
Black bullhead
Black crappie
Brook stickleback
Brown bullhead
Burbot
Carp
Channel catfish
Emerald shiner
Fathead minnow
Flathead chub
Freshwater drum
Golden redhorse
Goldeye
Johnny darter
Lake cisco
Mooneye
Northern pike
Quillback
Rock bass
River darter
River shiner
Sauger
Shorthead redhorse
Silver chub
Silver redhorse
Spotfin shiner
Spottail shiner
Stonecat
Tadpole madtom
Trout-perch
Walleye
White bass
White sucker
Yellow perch

The Red and Assiniboine Rivers support a rich and diverse assemblage of aquatic species. About 35 fish species were captured from the Rivers in the current studies. The current studies found that fish travelled significant distances throughout the study area. The plumes from the WPCCs do not appear to affect fish movements.

However, some fish displayed an attraction to the areas influenced by the plume. For example, it was observed that northern Pike were attracted to the NEWPCC plume during the winter months, and carp to the WEWPCC plume in the fall.

A number of fish were monitored using acoustic tags, and it was found that the fish were able to pass through the NEWPCC area suggesting that plumes are not barriers to their movement. Tagged fish in general were found to be highly mobile. 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 wastewater effluents is generally intermittent, and varies with the season.

Figure 9: Several species of fish were fitted with acoustic tags to track their movements.

Toxicity Testing

A key component of the studies was to carry out a test program to establish the chronic toxicity of ammonia in representative cool water species. These test results were intended to be used to expand the existing toxicity dataset on which the current regulatory guidelines are based and to assist in the definition of locally appropriate ammonia objectives. The tests used species indigenous to the local Rivers to ensure the results of the testing would be applicable locally.

Twenty-six ammonia toxicity tests were completed using 11 different indigenous species of aquatic life including 7 fish species and 4 invertebrate species. The results from seven chronic exposure tests can be used directly in the derivation of a local chronic criterion for ammonia. Ten acute toxicity tests were done on 3 fish species. Integration of the local data in the public domain database significantly improved the scientific foundation to support regulation of ammonia for local conditions. Local scientific review resulted in acceptance of the protocols and results of the toxicity studies. It is recommended that these results be used in development of site-specific criteria by the Province.

Figure 10: Fish were exposed to various levels of ammonia and observed for toxicity effects at the Toxicity Lab established at the NEWPCC.

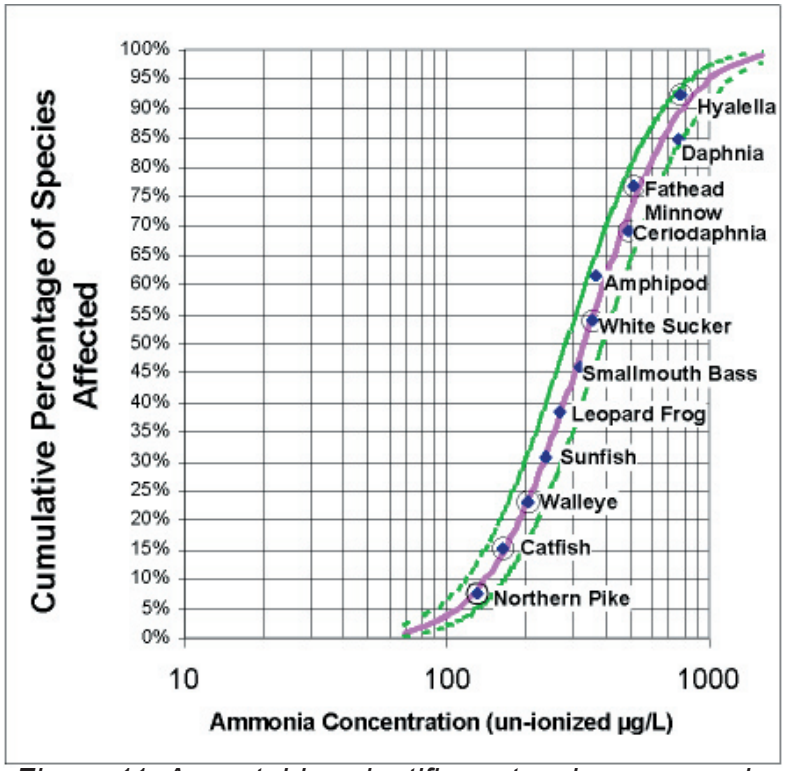

Figure 11: Acceptable scientific protocols were used to derive potential site-specific criteria from toxicity tests on local aquatic species for consideration by Manitoba Conservation.

Potential Site-Specific Criteria

Various protocols for developing site-specific ammonia criteria were reviewed and applied to identify potential criteria. The protocols involved the use of relevant public domain data on toxicity testing with the addition of local test results. Numerical values were developed using protocols advocated by the EPA in their 1998 and 1999 Updates, and also from Environment Canada's protocols developed in the year 2000. These numerical values were derived from a stronger scientific database, due to the addition of local toxicity test results, than the general criteria. These study results can thus be used to develop locally appropriate criteria.

Manitoba Conservation used the EPA protocols in the proposed Manitoba Water Quality Guidelines (currently under review), and accordingly, after consultations with Manitoba, it was agreed that the EPA protocols be used for the Winnipeg site-specific criteria.

Application of Ammonia Criteria

The site-specific ammonia criteria should protect aquatic life from unacceptable acute and chronic stresses.

It is generally accepted that WPCC discharges into the river should not be acutely toxic to fish (no fish kills). With respect to chronic toxicity, as well as the allowable numerical ammonia values, it is important to consider the duration of exposure of the aquatic life to these values and the allowable frequency of this occurrence.

The allowable in-stream chronic concentration is expressed as an average over at least 30 days. This duration is consistent with the duration of the toxicity tests used to develop the chronic criteria (i.e., 30 day exposures of fish and invertebrates were used in chronic toxicity tests).

In considering the frequency of exceedance of this 30-day concentration, the regulators typically use simplifying approaches. Typically, a "design flow" in the river is calculated from a statistical review of historical flows in the river. The "design flow" would be exceeded 90% of the years, i.e., the flow may be less only once in 10 years.

Since pH and temperature vary significantly throughout the open water season, the use of the monthly average

Potential Site-Specific Criteria..

design flows in combination with monthly pH and temperature is the most appropriate method to assess compliance with the chronic criteria.

The recommended period of record used to calculate the monthly design flows should be the period of records for which flow data are available on the Red River at St. Agathe from 1962 to present. A longer period of record can be reconstructed by use of transformation of data from Emerson, where data exists from 1912. However, there were changes in the upstream management of flows in the U.S.A. up to the mid-1950's. It is considered that the period from 1962 to present is sufficiently long for determining design flows for assessment of chronic effects to aquatic species.

A point of further discussion with Manitoba Conservation is the amount of the river's assimilative capacity that it considers appropriate to be assigned to the City of Winnipeg. Ammonia concentrations reduce naturally in the Rivers. The City believes that as long as concentrations in the river are not a concern for toxicity, even at low river flows, that it should be allowed the full assimilative capacity of the river within the urban reaches. The City believes that their information shows that this will provide ample ammonia-assimilative capacity downstream for foreseeable development.

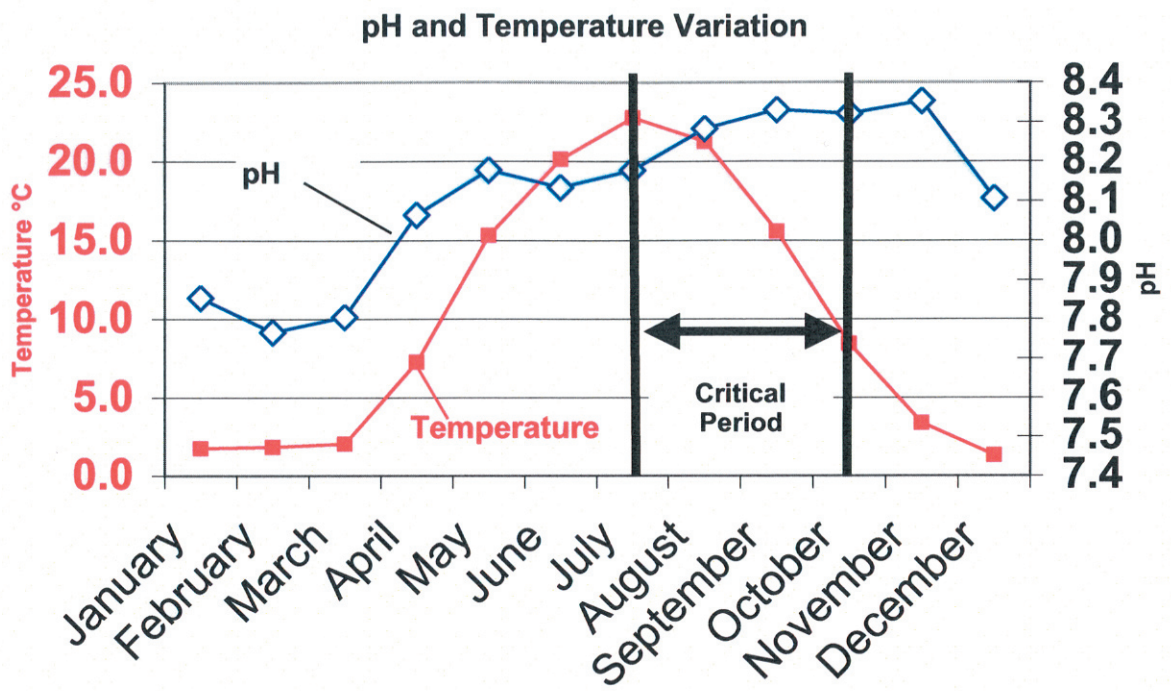

Figure 12: River water pH and temperature vary widely from month to month. The critical period for ammonia exposures is predominantly influenced by pH. Monthly values should be used to assess compliance.

Ammonia Reduction at WPCCs

Flows from the NEWPCC and WEWPCC are projected to show little change over the next 40 years. The SEWPCC flows are projected to increase significantly, by over 30% over this time period. Total nutrient loads from Winnipeg's WPCCs have remained stable over the past 15 years. Models were used to predict ammonia concentrations in the river for present and future conditions and for conditions with additional treatment applied at the treatment plants.

Both dynamic and steady-state modelling of water quality in the Red and Assiniboine Rivers were used to assess additional treatment requirements at the three WPCCs to achieve specific ammonia targets under current and future growth conditions. A separate engineering study considered a variety of nitrification processes at each of the WPCCs. The study assessed different levels of ammonia control and their costs that might be required as indicated from the river modelling.

Process options were reviewed for various levels of ammonia reduction ranging from: operational improvements at the existing plants; added treatment for moderate ammonia reduction; to best practicable level of ammonia reduction. Adding a nitrification process to the WPCCs involves the addition of substantial treatment works to convert ammonia to nitrates. Estimated capital and maintenance costs were based on conceptual designs. The estimated capital cost for achieving site-specific nitrification at the three plants is shown in the Table 1 below.

TABLE 1: CAPITAL COST ESTIMATES FOR AMMONIA REDUCTION

Treatment:	Target Ammonia Concentration in Effluent mg/L	NEWPCC	SEWPCC	WEWPCC	TOTAL
Best Practicable Level of Control	2	$112	$33	$4	$149
High Level of Control	8	$93	$21	--	$114
Moderate Level of Control	14	$84	$14	--	$98
Centrate Treatment	18	$10	--	--	$10

All costs in millions (year 2000)

Ammonia Reduction at WPCC's..

Centrate Treatment at NEWPCC

In the case of the NEWPCC, there is a process improvement that can have significant reductions on the ammonia concentration in the effluent. The solids residuals from treatment at the SEWPCC and WEWPCC are transported to the NEWPCC, where together with the NEWPCC residuals, they are given further treatment. In this treatment process, the residuals are passed through centrifuges for the purpose of dewatering the material and producing a treated product, called biosolids. The dewatering process produces a liquid sidestream, called centrate, which is added to the raw wastewater at the NEWPCC for treatment. While this sidestream is only 1% of the NEWPCC flow, it adds approximately 30% to the raw wastewater ammonia concentration at the NEWPCC.

One potential for ammonia reduction at the NEWPCC is to provide nitrification treatment for the centrate sidestream. This treatment option would significantly reduce ammonia concentrations in the NEWPCC effluent. Centrate treatment is estimated to cost about $10 million. This treatment is expected to result in compliance with proposed site-specific criteria. The provision for centrate treatment has been included in the City's capital budget for implementation by 2005. Should additional nitrification or nutrient control be required in the future, centrate treatment would still be operated and is not considered a "throw-away" cost.

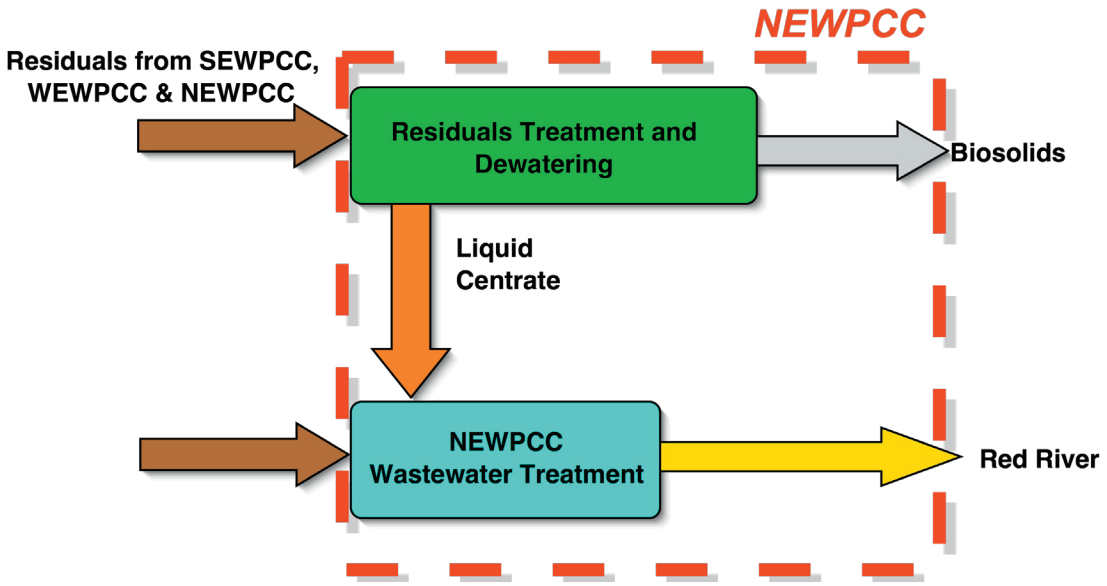

Figure 13: The NEWPCC provides treatment for residuals from all 3 WPCC's and the associated by-product (centrate). This centrate is high in ammonia.

Potential Ammonia Reduction Strategy

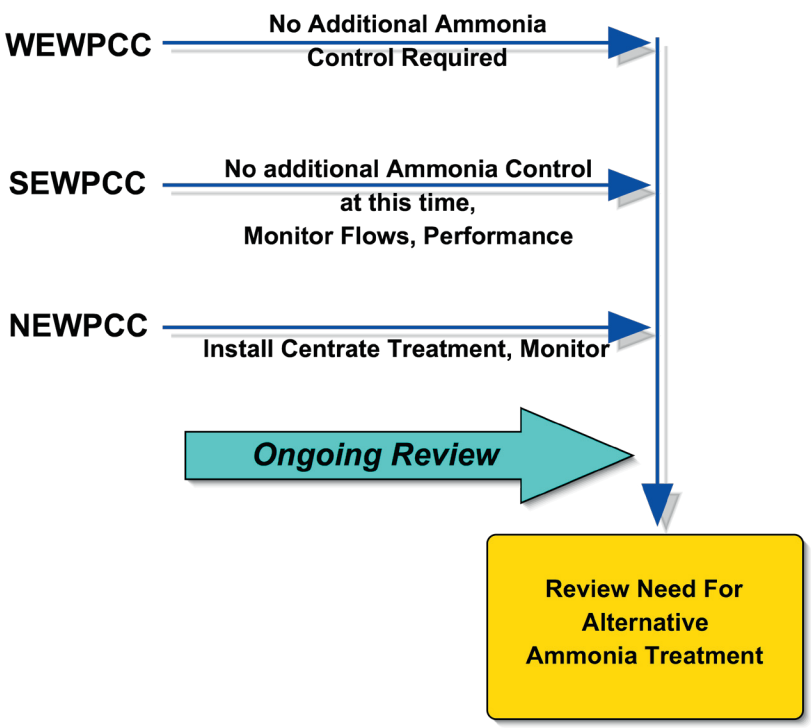

Figure 14: The City is proposing a potential Ammonia Reduction Strategy that will comply with site-specific criteria, to be reviewed after about 10 years.

A potential overall ammonia reduction strategy has been developed based on the assumption that Manitoba Conservation and the City will agree to use site-specific criteria based on U.S. EPA protocols. This would include the use of local and public domain data on toxicity of ammonia to local aquatic species. The potential program would allow for compliance with the proposed site-specific criteria and comprises the following:

•**At the WEWPCC:** -existing treatment, including the use of lagoons for polishing the treated effluent, provides sufficient ammonia reduction to meet the proposed criteria. No additional ammonia control is required at this WPCC.

•**At the SEWPCC:** -additional ammonia control (nitrification) is not required to meet the proposed criteria at this time. As flows to the plant increase, however, the need for additional control should be reviewed. It is estimated that additional controls to maintain compliance may be required in about 20 years at a potential capital cost of about $14 million in year 2000 dollars.

•**At the NEWPCC:** -additional ammonia reduction is required to meet the proposed criteria. Treatment of the centrate sidestream should be implemented. This represents a capital cost of about $10 million and could be completed in 3 years. The effectiveness of the centrate treatment, in terms of ammonia reduction, and its associated improvements on the NEWPCC treatment performance, should be evaluated after commissioning. Monitoring of the river quality should be done to confirm that compliance with the criteria is being achieved. This should take place over approximately 5 years.

Manitoba Conservation and the City should evaluate the strategy within 10 years to determine if additional nitrification is required at the WPCCs. The potential capital cost of these additional controls could range up to about $150 million, depending on the degree of control that would be deemed necessary.

Potential Ammonia Reduction Strategy..

Linkage to Nutrients

The Province has served notice that it will be developing a nutrient management strategy. It believes it has evidence of a trend for increasing concentrations of nitrogen and phosphorous in the surface waters. It is concerned about the effects of these nutrients on water quality in the Rivers and Lake Winnipeg. Such effects could include excessive algae and aquatic weed growth. Much work is still to be done before the Province will have a strategy and significant public consultation is expected in defining the strategy. As a result, an implementation strategy is at least several years away.

Nutrient control at the three WPCCs in Winnipeg could cost about $180 million, considerably more than the nitrification treatment process. If full nutrient control was implemented, ammonia reduction would be achieved at the same time.

The proposed potential ammonia risk reduction strategy would allow time for the provincial nutrient management strategy to be defined and would not preclude any potential nutrient control measures at any of the WPCCs.

Additional Considerations

Personnel sampling water quality on the Red River.

Acquisition of additional information through monitoring programs and additional toxicity testing is recommended. These actions are required to confirm the ammonia control strategy and compliance with the criteria. These include the following:

•Conduct additional toxicity testing to improve the confidence in the local test data, it is recognized that a number of very important tests were single replicate tests, and these proved to be important data points.

•Develop and conduct a focused monitoring program to create a baseline of fish species potentially affected and determine the presence of the early life stages (a period of highest sensitivity to ammonia) of key fish species in the critical fall months. There is a potential that this monitoring will show that the early life stages of fish are not present during the fall period when compliance with the criteria is difficult.

•Develop and conduct a water quality monitoring program during times of summer/fall low flows. This will assist in understanding the distribution of ammonia concentrations during such critical conditions, the natural decay of ammonia in the river, and assist in assessing the influence of upstream conditions with respect to the ability to achieve compliance.

•Continue to assess design river flows and allocation of the river's assimilative capacity.

Going Forward

The potential ammonia criteria and the proposed ammonia reduction program will be reviewed by the City of Winnipeg and then taken through the provincial regulatory process. The public will be provided opportunity to participate during their review process and also through the Clean Environment Commission public hearings.