Manitoba Clean Environment Commission

An investigation into nutrient reduction and ammonia treatment at the City of Winnipeg's wastewater treatment facilities

March 2009

Manitoba CLEAN·ENVIRONMENT™ COMMISSION

Manitoba

Manitoba Clean Environment Commission

305-155 Carlton Street

Winnipeg, Manitoba

R3C 3H8

Fax: 204-945-0090

Telephone: 204-945-0594

www.cecmanitoba.ca

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305 – 155 Carlton Street
Winnipeg, MB R3C 3H8

Ph: 204-945-7091
Toll Free: 1-800-597-3556
Fax: 204-945-0090
www.cecmanitoba.ca

March 23 , 2009

Honourable Stan Struthers
Minister of Conservation
Room 330 Legislative Building
450 Broadway
Winnipeg, Manitoba R3C 0V8

Dear Minister Struthers:

Re: Nutrient reduction and ammonia treatment at the City of Winnipeg's wastewater treatment facilities

The Panel is pleased to submit the Clean Environment Commission's report on its investigation into nutrient reduction and ammonia treatment at the City of Winnipeg's wastewater treatment facilities.

Sincerely,

Terry Sargeant, Chair

Ian Halket

Edwin Yee

Manitoba

Contents

Foreword

Last fall, the Minister of Conservation asked the CEC to conduct an investigation into nutrient reduction and ammonia treatment at the City of Winnipeg's wastewater treatment facilities. More specifically, we were asked to provide advice and recommendations on the appropriate and sustainable level of nitrogen reduction.

The issue came fraught with baggage. Scientific opinion covered a very wide spectrum. Debate on the issue had become passionate, polarized, and public. The issue risked becoming overly simplified and too narrowly focused.

The question as to whether the City should remove nitrogen from its wastewater has impacts upstream and down. It goes far beyond blue-green algae in Lake Winnipeg.

We do not minimize the state of affairs in this lake. We continue to share the widespread view that Lake Winnipeg is in trouble and needs significant help, quickly. But, in our review of nutrients and, in particular, nitrogen we look beyond the lake to the larger environment of the province, as well as to the global situation.

We also look into the future to find solutions that are environmentally sustainable. To that end, at times, we rely on the "precautionary principle".

We have concluded that nitrogen, while critical to all life on the planet, in excess amounts is not an environmentally benign product. This leads us to recommend to the Minister that nitrogen must be removed as part of the wastewater treatment conducted by the City. In our view, not to do so would be irresponsible, leaving an unhealthy environmental legacy to our children and grandchildren.

We do not disagree with the scientific view, widely quoted in the Winnipeg media last summer and fall, that—to control the algal pollution of Lake Winnipeg—it is most important to reduce the amount of phosphorus entering the lake. This view further holds that removal of too much nitrogen may stimulate algal growth.

While we do not recommend changing the phosphorus requirement in the current City licences, we do urge the City to make best efforts to reduce the amount released to an even lower level. We found much evidence that this is not too difficult to achieve. (This includes the City's newly redeveloped West End facility, which regularly achieves levels lower than the 1.0 milligram per litre it is allowed by its licence.) At the same time, we recommend that the amount of nitrogen removed be kept carefully in balance with phosphorus so as not to favour algal growth.

Our conclusions should come as no surprise to anyone familiar with the history of CEC reviews. As is described in this report, the Commission's thinking and recommendations on wastewater treatment and nutrient reduction have been evolving over a number of years; since, at least 1992, when the CEC conducted a review and made recommendations in respect of water quality objectives for the rivers and streams within the City of Winnipeg and downstream.

In 2002, the Commission conducted a review of a proposal by the City of Portage la Prairie to alter its Water Pollution Control Facility. Recommendations were made to limit the discharge of phosphorus and ammonia.

The following year, 2003, in its report on the Industrial Wastewater Treatment Facility in Brandon, the Commission recommended that phosphorus should be limited to 1 milligram per litre and nitrogen limited to less than 10 milligrams per litre.

From the fall of 2002 to August 2003, the Commission conducted a review of the City of Winnipeg Wastewater Collection and Treatment Systems. The Commission called for the removal of both nitrogen and phosphorus.

We have approached this review with the same commitment to the environment. In coming to the conclusions in this report, we conducted a comprehensive review. We met with many officials from a number of departments of both the provincial and federal governments. We met—in person and by videoconference—with scientists from universities in Manitoba, Saskatchewan and Alberta. We attended conferences in Winnipeg, one specifically focused on Lake Winnipeg pollution issues; another on more general concerns about the Red River. And, we conducted a review of related scientific literature from around the world.

While this may not make us experts on the matter, it does give us confidence that our conclusions can be supported by the best available environmental science.

We note that both the provincial and federal governments have stated unequivocally their support for efforts to clean up Lake Winnipeg. The City of Winnipeg has also committed to doing its part to achieve the targets set by the Province in this regard.

In recent reports by the CEC, we have made recommendations that will call upon farmers and other residents of rural Manitoba to play their part in developing a sustainable environment by addressing nutrient management concerns. These will not be without financial implications for these folks. One scientist, with whom we met, told us that the contribution required by farmers and rural Manitobans to manage nutrients will far outstrip the demand on Winnipeg residents for the proposed wastewater treatment.

The Commission has been consistent in its view that all players must play their respective parts in addressing environmental concerns. Environmental nutrient management is about addressing incremental nutrient releases. Management of all sources of nutrients is important to the future state of Manitoba's waters.

At the same time, as a province, we are calling upon jurisdictions upstream of Manitoba—in Canada and the United States—to contribute to the clean-up of our watershed, by reducing the pollutants, including nutrients, they discharge into waters that flow through our rivers to Lake Winnipeg and, ultimately, to Hudson Bay.

The Commission is of the view that all Manitobans must contribute to this effort to the best of their capabilities. And, the Commission is not confident that those upstream, in other provinces and states, will be as agreeable to our requests if we are not seen to be making equal or even greater contributions.

The opportunity exists for the City of Winnipeg to be progressive and future-oriented by developing state-of-the art wastewater treatment. Until recent months, it was pursuing this action. We believe that the City should continue on this course.

In this report, we note the strong commitment of the Government of Manitoba to water issues. In recent years, much has been done to ensure that Manitoba's waters are of the highest quality. But, there is still much to be done. Working to achieve water quality objectives will be much easier once the province concludes development of water quality standards and a nutrient management strategy. Such province-wide strategies will also guide small cities, towns, farmers and other Manitobans as they manage their own water and wastewater issues.

We urge the province to complete these processes as quickly as possible.

We also repeat the recommendation, first made in our review of the sustainability of the hog industry, that the province establish an institute to co-ordinate studies on watershed issues.

Acknowledgements

As always, in conducting an investigation such as this one, there are a great number of people, without whose contributions, we could not have done the job adequately. In Appendix 3 of this report, we list the many government officials, scientists and others with whom we consulted, or who offered us their advice on this topic. My co-panelists were Ian Halket and Edwin Yee. Staff support was provided by Commission Secretary Cathy Johnson and Administrative Secretary Joyce Mueller. Doug Smith wrote the report. I thank all of these people for their contributions to this project.

Terry Sargeant

March 2009

Executive summary

In September 2008, the Manitoba Minister of Conservation requested that the Clean Environment Commission (the Commission/CEC) conduct an investigation into nutrient reduction and ammonia treatment at the City of Winnipeg's wastewater treatment facilities. Specifically, the Commission was requested to investigate and provide advice and recommendations on:

a) The appropriate and sustainable level of nitrogen reduction, if any additional reduction is required, for the City of Winnipeg wastewater treatment facilities, in order to protect the receiving waters, including Lake Winnipeg.

b) The feasibility and sustainability of phasing in nitrogen reduction requirements later than ammonia and phosphorus reduction requirements.

In conducting this investigation, the Commission was requested to take into account its 2003 *Report of Public Hearings, City of Winnipeg Wastewater Collection and Treatment Systems,* the current phosphorus, ammonia and total nitrogen limits included in *The Environment Act* licences for the City of Winnipeg's wastewater treatment facilities, a report from Associated Engineering regarding nutrient reduction, relevant scientific literature, and relevant scientific and technical advice.

The Commission established a three-person panel that reviewed the Commission's previous report on City of Winnipeg wastewater treatment, the relevant *Environment Act* licences, the Associated Engineering report, documentation provided by provincial and municipal agencies, and the current applicable scientific literature. In addition, it met with officials from the City of Winnipeg and the Departments of Water Stewardship and Conservation, and experts in the relevant scientific and technical fields. The panel members also attended *The Red Zone: Currents, Chemicals and Change*, a special symposium dealing with issues relating to the Lake Winnipeg watershed, sponsored by the University of Winnipeg and the Lake Winnipeg Foundation. It has assessed the evidence presented to it on the basis of the provincial Principles and Guidelines of Sustainable Development.

In its 2003 report on Winnipeg wastewater treatment, the Commission stated:

> The Commission believes there is evidence to substantiate that Winnipeg's treated municipal wastewaters and untreated combined sewer overflows are adversely impacting the aquatic environments of the Red and Assiniboine rivers and Lake Winnipeg. While the Commission understands that Winnipeg is not the only contributor of pollutants to the Red and Assiniboine rivers or nutrients to Lake Winnipeg, the City's wastewater treatment plants and combined sewer outfalls are point sources that can be controlled. This provides the City of Winnipeg with an opportunity to take responsible action and demonstrate environmental stewardship for the benefit of all Manitobans (iii).

The Commission is still of the view that, at their current levels, nitrogen and phosphorus (and ammonia, which is a nitrogen compound) discharges from the City's wastewater treatment plants are not environmentally sustainable. In reference to the questions put before it in its terms of reference, the Commission has concluded that:

- Phosphorus discharges from City of Winnipeg wastewater facilities should be as low as possible and should not exceed 1.0 milligram per litre, as determined by the 30-day rolling average. A desirable operating goal would be 0.5 milligrams of phosphorus per litre.

- Nitrogen discharges from City of Winnipeg wastewater facilities should not exceed 15 milligrams per litre, as determined by the 30-day rolling average. In future, the City's nitrogen-to-phosphorus mass ratio in the City effluent must be maintained at 15:1.

- By bringing the City of Winnipeg North and South End wastewater treatment plants into compliance with the nitrogen discharge requirements in the current *Environment Act* licences, the City will eliminate the threat that ammonia currently discharged by these plants presents to aquatic life.

If the Manitoba Government acts on the recommendations contained in this report, it will be adopting regulations on phosphorus, nitrogen, and ammonia that are environmentally responsible.

To comply with these standards, the City of Winnipeg should implement the most environmentally sustainable and responsible forms of nutrient removal. In most cases this is likely to require biological nutrient removal (BNR). In cases where full BNR is not sufficient to meet regulatory requirements, chemical processes can be applied as an enhanced treatment. The addition of chemical treatment implies reduced resource recovery and an increase in solid waste that may be landfilled. Chemical processes should only be used in situations when additional treatment is required to meet regulatory requirements while maintaining maximum resource recovery and limiting the amount of solid waste that must be landfilled. Biological nutrient removal is becoming the norm in both Western Canada and Europe. The City of Winnipeg has already implemented biological removal of phosphorus and nitrogen at its West End wastewater treatment plant.

The City has requested changes to its licence in relation to the discharge of nitrogen and ammonia. To grant these changes would place continued stress on the environment through excess loading of nitrogen to the Manitoba environment and beyond. It also would deliver a message to upstream jurisdictions, whose cooperation Manitoba depends on if it is to reduce the nutrient content of Manitoba waters, that the province does not place a high priority on nutrient management.

Background

In its 2003 report on the City of Winnipeg wastewater treatment system, the Commission recommended that the City reduce both its phosphorus and nitrogen discharges to the Red and Assiniboine rivers. The *Environment Act* licences subsequently issued for the City's three wastewater treatment plants required the plants to reduce their total discharges to 15 milligrams per litre of nitrogen and 1.0 milligram of phosphorus per litre (on a 30-day rolling average) by the end of 2014. Upgrades have been made to the City's West End plant that allow it to conform to this standard. However, the South End and North End plants, which treat the major portion of the City's wastewater, have yet to undergo the upgrades that would allow them to reduce their nutrient discharges to the levels in their *Environment Act* licences. (The dates for compliance for these plants are the end of 2012 for the South End Plant and the end of 2014 for the North End Plant.)

The City is requesting that the limits on nitrogen discharges be eliminated, thus relieving it of a portion of the cost of upgrading its North End treatment plant (a lifting of the nitrogen limit would not have a similar impact at the South End plant, where the City has stated that a conversion to full biological nutrient treatment—including the removal of nitrogen—is the most cost-efficient option). The City's request is based on the argument that nitrogen reduction would not lead to any decrease in the level of eutrophication of Lake Winnipeg and could, under certain circumstances, exacerbate the eutrophication of the lake. The City has indicated that it would continue to remove nitrogen from the effluent at its West End plant and at its South End plant once it had been upgraded even if the nitrogen limit exemption were granted (although the reductions would not likely be as large as they would be if the limit were in place).

In January 2009, the City requested further adjustments in the ammonia discharge limits for the North End plant. This request was based on an argument that the City could comply with adjusted ammonia standards without posing a threat to aquatic life. The effect of these changes would relieve the City of the costs of converting ammonia in its wastewater to nitrate (another nitrogen compound).

The Commission does not support either eliminating the nitrogen limit or granting the adjustments to the ammonia limits. As the Commission stated in 2003, the introduction of full nutrient management "provides the City of Winnipeg with an opportunity to take responsible action and demonstrate environmental stewardship for the benefit of all Manitobans."

Environmental issues associated with phosphorus, nitrogen and ammonia

The Commission was mandated to review the discharge limits for phosphorus, nitrogen and ammonia. Phosphorus is regulated because excess levels of this nutrient can play a major role in the eutrophication of lakes and rivers. Given that levels of eutrophication in Lake Winnipeg and phosphorous loading in waters flowing into

Lake Winnipeg have been increasing for the past 30 years, the Commission is in full agreement with the need to reduce City of Winnipeg phosphorus discharges to as low a level as possible.

Excess reactive nitrogen in the environment contributes to eutrophication (particularly, but not only in marine environments), loss of biodiversity, global warming, pollution of drinking water, fish kills, acid rain, and ozone depletion. There exists a strong scientific case for limiting the nitrogen load in City of Winnipeg wastewater. Since it is also the case that a low nitrogen-to-phosphorus ratio in water can stimulate the growth of certain algae and bacteria associated with eutrophication, therefore, nutrient reduction must be carefully managed.

Ammonia (a nitrogen compound) in wastewater discharges can present both chronic and acute threats to the health of aquatic life in the receiving waters. This threat can be significantly reduced or eliminated by converting the ammonia into nitrate. (Since nitrate is also a nitrogen compound, this conversion, on its own, does not reduce the other negative environmental impacts identified above.)

In 2006, the effluent from all three City of Winnipeg wastewater treatment plants contained 3,230 tonnes of nitrogen and 377 tonnes of phosphorus. This is the equivalent of the load carried by 277 13-tonne dump trucks—or of the dumping of just over one truckload of nutrients every working day into the Red and Assiniboine Rivers. Full compliance with *The Environment Act* limits on nitrogen and phosphorus discharges would reduce this nutrient load to the equivalent of 126 truckloads a year. Phosphorus discharges will be reduced by 73 per cent, nitrogen discharges will be reduced by 52 per cent, and the nitrogen-to-phosphorus ratio in the City discharge will be increased: all measures intended to reduce nutrient-stimulated growth in receiving waters.

Other issues

The Commission has also reached a number of conclusions in relation to broader nutrient management and water quality issues in Manitoba. In particular, the Commission is calling on the Manitoba Government to finalize its Nutrient Management Strategy and its *Manitoba Water Quality Standards, Objectives, and Guidelines* (which currently only exist in draft form). In implementing its Nutrient Management Strategy, it should take steps to significantly reduce non-point and point nutrient loadings in Manitoba. A provincial Watershed Studies Institute could play an important role in addressing a large number of outstanding research and monitoring questions.

The Commission is making the followings recommendations.

8.1) In order to protect the environment, City of Winnipeg wastewater treatment facilities must be regulated and operated in a manner that ensures the following:

a) Phosphorus discharges should be as low as possible. The concentration of total phosphorus in the effluent on any day must not exceed 1.0 milligram per litre, as determined by the 30-day rolling average. The City of Winnipeg should set itself an operating target of 0.5 milligrams per litre.

b) Nitrogen discharges must not exceed 15 milligrams per litre, as determined by the 30-day rolling average.

c) The mass ratio between nitrogen and phosphorus discharges must be maintained at 15:1.

d) Ammonia discharge limits must be based on the longest available period of record for river flow, a portion of no more than 75 percent of the assimilative capacity of the receiving waters, and on the provisions of the draft *Manitoba Water Quality Standards, Objectives, and Guidelines*.

8.2) There are no economic or environmental benefits to be gained from phasing in nitrogen reduction requirements after meeting the ammonia and phosphorus reduction requirements. The City must continue to move towards removal of nutrients on the basis of the timetable mandated by its current *Environment Act* licences. This would mean full compliance by the end of 2012 for the South End Plant and by the end of 2014 for the North End Plant.

8.3) The City of Winnipeg should use nutrient removal processes, such as biological nutrient removal, that increase resource recovery and reduce the City's environmental footprint to the greatest extent possible.

8.4) The Manitoba Government immediately finalize and formally accept the *Manitoba Water Quality Standards, Objectives, and Guidelines*.

8.5) Within one year from the publication of this report, the Manitoba Government determine ecologically sensitive, long-term water quality guidelines, and objectives and use them to refine the *Manitoba Water Quality Standards, Objectives, and Guidelines* as required.

8.6) Within one year from the publication of this report, the Manitoba Government complete its nutrient management strategy. This strategy must incorporate, but must be broader than, the recovery of Lake Winnipeg. Elements of such a strategy should include:

- Long-term science-based goals for nutrient load and target dates for meeting those goals.
- Maximum annual nutrient load limits, as determined for the specific watershed, need to be incorporated into regulatory actions.
- Measures to reduce point source nutrient loading in Manitoba.
- Measures to reduce non-point source nutrient loadings in Manitoba.
- An ongoing research agenda and monitoring program.
- Publication of research and monitoring results.
- Support for new technologies and procedures for nutrient loading abatement and management.

8.7) A Watershed Studies Institute be established to coordinate information collection, analysis and evaluation, direct research and provide support to agencies and organizations undertaking watershed management in Manitoba. This is a reiteration of a recommendation made in the Commission's 2007 report on the sustainability of hog production in Manitoba.

Chapter One: Introduction

Mandate and terms of reference

In September 2008, in accordance with section 6(5)(a), and (c) of *The Environment Act*, the Manitoba Minister of Conservation made a request to the Clean Environment Commission (the Commission/CEC) that it conduct an investigation into nutrient reduction and ammonia treatment at the City of Winnipeg's wastewater treatment facilities. The request included the following terms of reference:

1. The CEC will conduct an investigation and provide advice and recommendations regarding the following matters:

   a) The appropriate and sustainable level of nitrogen reduction, if any additional reduction is required, for the City of Winnipeg wastewater treatment facilities, in order to protect the receiving waters, including Lake Winnipeg.

   b) The feasibility and sustainability of phasing in nitrogen reduction requirements later than ammonia and phosphorus reduction requirements.

2. In conducting this investigation and in providing advice and recommendations, the CEC will:

a) Take into account the CEC's *Report of Public Hearings, City of Winnipeg Wastewater Collection and Treatment Systems* of 2003.

b) Take into account the current phosphorus, ammonia and total nitrogen limits included in the *Environment Act* Licences for the City of Winnipeg's wastewater treatment facilities.

c) Review a report from Associated Engineering, which will be provided to the CEC, regarding nutrient reduction including practices in other jurisdictions as described in the report.

d) Meet with officials from the City of Winnipeg and from the Departments of Water Stewardship and Conservation and review any relevant documentation from those entities.

e) Take into account current scientific literature related to nutrient reduction.

f) Seek relevant scientific and technical advice.

The Commission

The Clean Environment Commission is an arm's-length provincial agency established under *The Environment Act* of Manitoba. The Commission encourages and facilitates public involvement in environmental matters and offers advice and recommendations to the Minister of Conservation with respect to environmental issues, project approvals, and environmental licenses.

Its mandate is exercised through public hearings, investigations, and mediation. The Commission consists of a full-time Chairperson and part-time Commissioners appointed by Order-in-Council. A three-person panel was formed to carry out the investigation that is the subject of this report. The Panel members were the Commission Chair, Terry Sargeant (who also served as chair of the panel), Ian Halket, and Edwin Yee.

The process

As mandated, the Commission panel reviewed the Commission's previous report on City of Winnipeg wastewater treatment, the relevant *Environment Act* licences, and the Associated Engineering report, documentation provided by provincial and municipal agencies, and the current applicable scientific literature. In addition, it met with City of Winnipeg and the Departments of Water Stewardship and Conservation officials, and experts in the relevant scientific and technical fields. The Commission panel members also attended *The Red Zone: Currents, Chemicals and Change*, a special symposium dealing with issues relating to the Lake Winnipeg watershed, sponsored by the University of Winnipeg and the Lake Winnipeg Foundation.

In its deliberations, the Commission draws on the Manitoba *Sustainable Development Act*'s Principles and Guidelines for Sustainable Development. Three of the principles appear to be particularly applicable to the issues at hand. These were principles 4, 6 and 7, which read as follows.

4 Prevention

Manitobans should anticipate, and prevent or mitigate, significant adverse economic, environmental, human health and social effects of decisions and actions, having particular careful regard to decisions whose impacts are not entirely certain but which, on reasonable and well-informed grounds, appear to pose serious threats to the economy, the environment, human health and social well-being.

6 Rehabilitation and Reclamation

Manitobans should

(a) endeavour to repair damage to or degradation of the environment; and

(b) consider the need for rehabilitation and reclamation in future decisions and actions.

7 Global Responsibility

Manitobans should think globally when acting locally, recognizing that there is economic, ecological and social interdependence among provinces and nations, and working cooperatively, within Canada and internationally, to integrate economic, environmental, human health and social factors in decision-making while developing comprehensive and equitable solutions to problems.

Principle 4 is similar to the Precautionary Principle adopted at the United Nations Earth Summit in 1992. That principle holds that "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (United Nations Environment Program 1992). This principle is of significance in this case due to the ongoing debate within the scientific community over the role that nitrogen and phosphorus have on the environment. Principle 6's focus on rehabilitation and reclamation is appropriate in terms of the ongoing concern of the impact of nutrients on Manitoba waters and the need to ensure that nutrient loading does not have further deleterious impacts on Manitoba waters. The issue of global responsibility identified in Principle 7 is relevant to both of the nutrients under consideration, particularly nitrogen. The details of these implications are discussed in the body of this report.

Guideline 5 of the Principles and Guidelines is also applicable. It states:

5 Waste Minimization and Substitution - which means

(a) encouraging and promoting the development and use of substitutes for scarce resources where such substitutes are both environmentally sound and economically viable; and

(b) reducing, reusing, recycling and recovering the products of society.

This guideline's focus on the use of scarce resources is relevant given the fact that phosphorus is a non-renewable resource while the synthesis of nitrogen is largely dependent on the use of natural gas, a non-renewable resource. Where possible, measures undertaken to reduce the discharge of nitrogen and phosphorus to Manitoba waters should also ensure that these nutrients can be re-used.

The report

Based on the above, the Commission has reached the conclusions and recommendations presented in Chapter 8 of this Report.

The appendices of the report include the terms of reference, the principles and guidelines of sustainable development found in *The Sustainable Development Act,* a listing of people with whom the Commission consulted, and a glossary of scientific terms used in this report.

Chapter 2: Background

This chapter provides background on a number of the key issues in this investigation. These issues and topics include:

- Nitrogen, phosphorus and ammonia.
- Nutrients and the environment.
- Lake Winnipeg, the Nelson River, and Hudson Bay.
- Nutrients and eutrophication in Lake Winnipeg and Hudson Bay.
- The City of Winnipeg wastewater treatment system.

Nitrogen, phosphorus and ammonia

Nitrogen and phosphorus are two of the six elements crucial to sustaining life on earth, the other four being oxygen, hydrogen, carbon, and sulfur. Ammonia, a compound of nitrogen and hydrogen, can serve as an important fertilizer, but is also poisonous at certain concentrations. Because organisms take up nitrogen and phosphorus and use them to support their growth, they are considered nutrients. They are also the two most common nutrients in wastewater (and ammonia is one of the most common forms of nitrogen in wastewater).

Nitrogen

Nitrogen is a non-metallic element that serves as an essential nutrient for all life. While nitrogen accounts for 78 per cent of the Earth's atmosphere, most plants and higher animals cannot directly access most atmospheric nitrogen (which is referred to as non-reactive nitrogen and exists as N_2 or dinitrogen).

Plants are able to draw nitrogen from reactive nitrogen compounds in the soil or water. These compounds are nitrate-nitrogen (NO_3), nitrite-nitrogen (NO_2) [usually measured as nitrate-nitrite-nitrogen (NO_3 –NO_2)], or ammonia-nitrogen (NH_4).

Nitrogen is also often classified as to its organic or inorganic nature: the term organic nitrogen describes nitrogen associated with organic material such as plant or animal tissue. Its forms include organic compounds such urea, amines, proteins, and nucleic acids. Inorganic nitrogen (nitrogen not associated with organic material such as plant or animal tissue) includes ammonium (NH_{4+}), ammonia gas (NH_3), nitrite (NO_2), and nitrate (NO_3). Inorganic nitrogen is immediately available to plants, while organic nitrogen is not available for plant uptake.

Nitrogen is measured as total nitrogen (TN), which represents the total amount of nitrogen in a sample, or as total Kjeldahl nitrogen (TKN), which is the sum of organic nitrogen, ammonia (NH_3) and ammonium (NH_{4+}) in a sample. TKN represents the fraction of total nitrogen that is unavailable for growth or bound up in organic form.

While nitrogen constitutes a large portion of the atmosphere, in its non-reactive state, it is largely unavailable to plant life. There are, however, exceptions to this case. Legumes, unlike other plants, can utilize atmospheric nitrogen because bacteria that live in their roots assimilate or fix nitrogen from the atmosphere. Certain cyanobacteria (often referred to as blue-green algae) are also capable of fixing nitrogen from the atmosphere (while cyanobacteria are not technically algae, they will be discussed under that heading in this report).

Lightning strikes can create the high temperatures required to transform non-reactive nitrogen (N_2) into reactive nitrogen, creating nitrogen oxides. Dissolved in the atmosphere, the nitrogen oxides are either washed out of the atmosphere by rain or fall to the ground as dust, forming nitrates and nitrites in the soil.

Farmers also apply synthetic nitrogen and manure to fields as fertilizer. Decaying plant matter also returns nitrogen to the soil or sediments. Animals, in turn, gain access to nitrogen by eating either plants or animals that have eaten plants that contain nitrogen. When animals consume more of a nutrient than their bodies' require, the excess is excreted; in the case of nitrogen as urea in the urine, providing yet another nitrogen source. When animals die, the decomposition process releases organic nitrogen to the soil and sediments. The nitrogen can be stored in the soil or converted to inorganic nitrogen by bacteria, eventually being taken up by plants, released to the water or the atmosphere.

Even before the significance of nitrogen to agriculture was identified in the nineteenth century, farmers engaged in a number of practices that served to increase the amount of nitrogen available to their crops. These included planting nitrogen-fixing legumes and spreading plant residue, animal waste (available through mixed farming), and human waste on their fields. It was not until the twentieth century that a commercially viable industrial technique was developed to synthesize nitrogen, by mixing nitrogen and hydrogen (usually from natural gas) to create the compound ammonia. This process became the basis for the modern synthetic fertilizer industry (Smil 1997).

Phosphorus

Phosphorus is a non-metallic chemical element that is essential to such processes as heredity, muscle contraction, and photosynthesis. It usually exists as part of a phosphate molecule (PO_4). Far scarcer than nitrogen, most phosphorus on earth is present in rock deposits or in oceanic sediment deposits. The most significant deposits of phosphorus exist as sediments on the floors of the ocean. This phosphorus cycles through the oceanic food web, only leaving the ocean when seabirds consume fish and deposit their excrement on shore or when humans harvest fish. The most significant terrestrial sources of phosphorus are minerals such as apatite. It becomes available to plants through a process of leaching and weathering and, in the last 200 years, as the result of mining. Plants take up the phosphorus, while animals gain access to phosphorus by either eating plants or eating animals that have eaten plants containing phosphorus. Excess phosphorus is excreted in both urine and feces. It is also released through the decay of dead plant and animal material.

Phosphorus can exist in both organic (associated with organic material such as in plant or animal tissue) and inorganic forms (not associated with organic material). Only inorganic phosphorus is available for plant uptake.

In aquatic environments, plants and algae consume inorganic phosphorus, transforming it into organic phosphorus. These plants and algae either die or are consumed by animals (which are either eaten by other animals or die). When the plants (or the animals that have eaten them) die and decay, the organic phosphorus is released into the water. A portion of this organic phosphorus sinks to the bottom of the water where it becomes part of the lake sediments. There, bacteria transform it into inorganic phosphorus. It may remain in the sediments for a lengthy period of time, or it may be returned to the phosphorus cycle if the sediments are stirred (for example, by storms or tidal action).

The total amount of phosphorus in a water sample is designated as total phosphorus (TP). It can be subcategorized as either soluble phosphorus (SP) or particulate phosphorus (PP) (soluble phosphorus can pass through a 0.45 micron membrane filter). The term soluble reactive phosphorus (SRP) is used to describe the portion of the soluble phosphorus (usually inorganic orthophosphate) that can be directly taken up by algae and plants in water.

While phosphorus is not as mobile as nitrogen, a certain percentage of the phosphorus in the soil is lost each year through a variety of processes including erosion, leaching, and human wastewater systems. Most of this phosphorus is eventually drained into the sea, from which it is usually not recovered. Aside from its use as a nutrient in fertilizers, phosphorus is also used in detergents and animal feeds (Schindler and Vallentyne 2008).

In the past, farmers responded to the loss of phosphorus by adding phosphorus-rich manure and plant residues to the soil, essentially recycling phosphorus on the farm, along with phosphorus rock. Since the Second World War, phosphorus has been mined, treated with acids, and applied to soil as commercial fertilizer. Large phosphorus mineral deposits are located in northern Africa, Russia, and the United States.

Phosphorus should be considered a non-renewable resource. While there is considerable debate over the amount of phosphorus that remains available for terrestrial use, in recent years, some scientists have begun to describe a coming point at which world production of phosphorus fertilizers would peak and an agricultural crisis would loom (Abelson 1999).

Because the food that human beings consume contains both nitrogen and phosphorus, these nutrients are found in municipal wastewaters.

As can be seen from the above, total nitrogen or total phosphorus is not necessarily the most significant measurement of a nutrient since they do not indicate the nutrient fraction that is actually available to stimulate growth.

Urban wastewater contains forms of nitrogen and phosphorus that are highly available for plant uptake and therefore plays a potentially more significant role (when compared to some other nutrient sources) in stimulating plant growth in aquatic conditions.

Increase in the application of nitrogen and phosphorus

The development of the technologies that synthesize nitrogen fertilizer has led to a dramatic increase in the application use of such fertilizer. According to Galloway et al. (2008), reactive nitrogen creation has increased by 120 per cent since 1970, with agriculture being the main driver behind the growth. The use of phosphorus has also undergone a significant increase. Globally, its use increased 4- to 5-fold between 1960 and 2000; in Manitoba 20-million tonnes were applied as fertilizer in 1965, by 1995, the figure was over 100-million tonnes (Johnston and Roberts 2001; Vance 2001). One study reports a 4.5 fold increase in fertilizer use in Manitoba, with a near tripling of phosphorus fertilizer input between 1967 and 1993 (Mayer et al. 2006).

Nutrients and the Law of the Minimum

When nineteenth-century agricultural scientists discovered the crucial role that nutrients such as phosphorus and nitrogen played in plant growth, they also developed what has come to be known as the law of the minimum. This law holds that plant growth is limited by the nutrient in shortest supply relative to the plant's need for that nutrient. The law was conceptualized in terms of a barrel made of staves of unequal length, with each stave representing a different nutrient and with the length of the stave representing the available nutrient supply. Crop production was represented by the level of water in the barrel, which would be limited by the length of the shortest stave. Phosphorus is often the limiting element in agriculture. However, if an excess of phosphorus is applied to the soil (thus lengthening the phosphorus stave), the next scarcest element, usually nitrogen, becomes the limiting element (the shortest stave). Similarly, reducing the supply of the limiting element can reduce productivity. The law of the minimum suggests that, once a nutrient application meets the crop requirement, there is no further response to the addition of a nutrient.

Ammonia

As noted above, ammonia is a compound of nitrogen and hydrogen that forms the basis for a number of commercial fertilizers. It can enter waterways as agricultural run-off or as the result of the decomposition of biological waste. Ammonia is a component of wastewater effluent and, unless treated, is released to the aquatic environment.

Because fish lack the mechanisms that most mammals have to prevent ammonia from building up in the bloodstream, ammonia can be toxic for aquatic species. At acute levels this can lead to death, while at lower, chronic levels, it is associated with organ damage, and reductions in growth and reproduction rates. The toxicity of ammonia is related to such factors as water temperature, flow rate, acidity and alkalinity levels, and stage of development (with younger fish seen as being at greater risk). The greatest risk usually occurs in the summer and early fall. For this reason, it is common for regulators to set different discharge limits for different periods of the year. Manitoba sets different rates for each month.

When it is discharged into waters, ammonia tends to oxidize into nitrate-nitrogen (NO_3), and nitrite-nitrogen (NO_2). This oxidization process places additional pressures on the availability of dissolved oxygen in the water and, as a result, on fish and other aquatic life. These forms of nitrogen are also highly available for plant uptake.

Nutrients and the environment

Eutrophication

In the early twentieth century, scientists devised four categories to describe the level of plant and animal productivity in a water body. Unproductive water bodies with low nutrient levels were termed oligotrophic, water bodies with higher levels of productivity were mesotrophic, while those with high levels of productivity—and high nutrient levels—were eutrophic. Those with very high levels of productivity and nutrients were deemed to be hypereutrophic. While it is common now to associate eutrophic lakes with human processes, many lakes in the world are naturally eutrophic, the result of a range of factors including depth, light, temperature, the clarity of the water, the flow regime, the types of aquatic life, and the nutrient load.

Over the past two centuries, it has become apparent that human activities have caused the productivity levels of numerous water bodies, particularly lakes, estuaries, and slow-moving streams, to increase beyond natural levels. This process is referred to as cultural eutrophication. Nutrients leak off farms, golf courses, and lawns and are dumped into rivers by urban wastewater plants. In those waters, they lead to an increase in the growth of plants and algae. These algae can create blooms that cover large portions of the water, decreasing light penetration to the lower levels of the water body. When the algae die, they further affect the water quality since the decomposition process reduces the level of dissolved oxygen in the water. This can lead to fish kills as well as the demise of other aquatic organisms. When the blooms appear close to shore or are washed ashore, they render beaches unusable. The water from eutrophic lakes requires additional treatment to address the odour, taste and possible toxicity associated with some algal blooms (in addition, water intakes tend to become covered and blocked by algae). Nutrient increases can lead to higher fish production, however, the composition of the fish population may change, resulting in increases in less economically viable "rough" fish. Algae can also coat the fishing nets, drastically reducing their effectiveness.

Studies carried out from the 1930s to the 1950s led to a conclusion that good growing conditions for phytoplankton (aquatic plant and animal organisms including algae) involve a nitrogen-to-phosphorus ratio of approximately 16:1 (that is for every phosphorus atom in a phytoplankton sample or cell there would be 16 nitrogen atoms). Termed the Redfield ratio (after the researcher who identified it), this ratio provides a guide as to when nitrogen or phosphorus will be limiting to productivity (Correll 1998). In general, when the ratio is higher than 16:1, phosphorus will be limiting, while as the ratio becomes lower, nitrogen will play a limiting role. The Redfield ratio of 16:1 is an atomic ratio (comparing the number of atoms of one element with the number of atoms of another element present in a sample) not a mass ratio (comparing the mass of each element present in a sample). Expressed as a mass ratio, the Redfield ratio is approximately 7:1.

Sources for nitrogen in water include precipitation, nitrogen fixation in water and sediments, surface water and groundwater runoff and drainage, decomposition of plant and animal remains, and release from sediments. Sources for phosphorus in water include precipitation and dry disposition, leaching from agricultural land, groundwater and surface runoff, industrial and domestic sewage, decomposition of organic matter, and release from sediments.

As noted above, the presence, or absence, of nutrients is not the sole limitation on algal productivity in a lake; other limiting factors include depth, light, temperature, the clarity of the water, the flow regime, and the types of aquatic life.

A 2001 federal government report (Chambers et al. 2001) surveyed the impact of nutrients on the Canadian environment and concluded that among other deleterious impacts, nitrogen and phosphorus loading to the environment "accelerated eutrophication of certain rivers, lakes and wetlands in Canada, resulting in loss of habitat, changes in biodiversity and loss of recreational potential" (Chambers et al. 2001; v). The impacts are associated with certain nutrient forms and "most inland waters in Canada are intrinsically P limited and thus addition of P has accelerated eutrophication (Chambers et al. 2001; vi). Dodds et al. (2008) put the annual cost of freshwater eutrophication in the United States at $2.2-billion. The costs included value losses in recreational water usage, waterfront real estate, spending on recovery of threatened and endangered species, and drinking water.

Nutrients and the environment: beyond eutrophication

Eutrophication is not the only negative impact to be associated with humanity's disruption of the nitrogen and phosphorus cycles. The 2001 federal government study (Chambers et al. 2001; v) surveyed the impact of nutrients on the Canadian environment and concluded that nitrogen and phosphorus loading from human activity had:

- Increased the frequency and spatial extent to which the drinking-water guideline for nitrate has been exceeded in ground waters across Canada and caused economic burden for those Canadians who must transport household water from off-site sources.
- Caused and continues to cause fish kills due to ammonia toxicity.
- Contributed to a decline in amphibians in southern Ontario due to long-term exposure to elevated nitrate concentrations.
- Led to elevated risks to human and livestock health through increased frequency and spatial extent of toxic algal blooms in Canadian lakes and coastal waters.
- Contributed to acidification of soils and lakes in southern Ontario and Québec and resulted in incipient nitrogen saturation in some forested watersheds.
- Increased carbon production in Canada's forests due to nitrogen deposition.
- Increased concentrations of the potent greenhouse gas N_2O and increased concentrations of nitrogen oxides contributing to formation of photochemical smog in certain Canadian cities.
- Increased the economic burden to Canadians as a result of the need for treatment, monitoring and remediation of contaminated water.

Release of reactive nitrogen into the atmosphere contributes to smog, global warming and ozone depletion. When these nitrogens return to the earth's surface, they can contribute to acid rain (Erisman 2004). At the global level, the 2004 Nanjing Declaration, adopted by the participants at the Third International Nitrogen Conference in October 2004, noted that "in many parts of the world, significant amounts of reactive nitrogen are lost to the environment in agricultural and industrial production and fossil fuel combustion. This has led to disturbances in the nitrogen cycle, and has increased the probability of nitrogen induced problems such as pollution of freshwaters, terrestrial and coastal ecosystems, decreasing biodiversity and changing climate and pose a threat to human health." With further growth in the global population, they state this "disturbance of the nitrogen cycle will become worse unless adequate measures are taken" (Nanjing Declaration 2004).

A Millennium Ecosystem Assessment (2005) on wetlands and human health concluded that, on a global scale, the excessive nutrient loading associated with the use of nitrogen and phosphorus in fertilizers had resulted in a decline in the delivery of services such as fresh water and some fish species. It also identified nitrogen loading as a direct driver in the degradation and loss of coastal wetlands and suggested that increased loading of nitrogen, phosphorus and sulfur were growing threats to rivers, lakes, marshes, coastal zones, and coral reefs.

Since 1991, the European Union has had a Nitrate Directive in place to reduce the nitrogen loading from agricultural sources. The EU's Wastewater Directive of 1998 sets discharge limits for nutrients. Table 2.1 sets out those limits for areas that have been defined as subject to eutrophication. The limits vary on the basis of the population served by the treatment system, with stricter limits imposed on communities of over 100,000.

Lake Winnipeg, the Nelson River, and Hudson Bay

Lake Winnipeg

Lake Winnipeg, covering 24,500 square kilometers, is the tenth largest body of freshwater in the world. It is also the most eutrophic of those ten lakes. It is shallow, with an average depth of 12 metres and is divided into two basins (the larger North and the South) by the Narrows, a 2.5 kilometre-wide channel. It extends through several climatic zones and experiences a significant variation in temperature and precipitation during the course of the year. Water that enters the lake has a residence period of three to five years before leaving the lake. Nutrients that are brought to the lake by these waters can have a far longer residence period.

Lake Winnipeg's 953,000 square-kilometre watershed is the second largest in Canada, feeding the lake through three major river systems, the Winnipeg, the Saskatchewan and the Red. The watershed includes parts of four provinces and four U.S. states.

There are 30 communities on the lakeshore with 23,000 permanent residents. In addition, there are over 10,000 cottages along the lake's South Basin and an increasing number of people are retiring to the area.

Lake Winnipeg is also home to both the largest commercial fishery in western Canada and important recreational and subsistence fisheries. Since 1976, Manitoba Hydro's use of the lake as a reservoir has changed its seasonal flows, increasing outflow in the winter and reducing outflow in the summer.

Approximately 5.5-million people live in the Canadian portion of the watershed, while 1.1-million people live in the U.S. portion. In Manitoba, there are 200 small

Table 2.1 Examples of European allowed effluent discharge concentrations in municipal wastewater in sensitive areas subject to eutrophication

Parameters	Concentration in milligrams per litre	or	Minimum removal
Total phosphorus	2 mg/L (10,100–100,000 Population equivalent) 1 mg/L (>100,000 Population equivalent)	or	80%
Total nitrogen	15 mg/L (10,000–100,000 Population equivalent) 10 mg/L (>100,000 Population equivalent)	or	70–80%

Source: Oleszkiewicz and Barnard 2006.

wastewater treatment facilities and 10 large municipal and industrial wastewater treatment facilities that empty into the lake (Lake Winnipeg Stewardship Board 2006).

The Nelson River and Hudson Bay

The Nelson River, the only river that drains Lake Winnipeg, flows out of Playgreen Lake at the northern tip of Lake Winnipeg through Cross Lake, Sipiwesk Lake, Split Lake and Stephens Lake. Tributaries to the Nelson include the Grass River and the Burntwood River, which passes through Thompson. Communities on the Nelson include Norway House, Cross Lake, York Landing, Split Lake, Gillam, and Bird. It enters Hudson Bay at Port Nelson. As the only river that drains Lake Winnipeg, it should be remembered that the Nelson brings the waters from the Lake Winnipeg watershed to Hudson Bay. Of the 42 rivers that drain into the Hudson, James, and Ungava Bays, the Nelson has historically had the largest discharge (although, due to river diversion in Quebec, the Le Grande River now has the largest discharge (Déry et al. 2005). An inland sea connected to both the Arctic and Atlantic oceans, Hudson Bay is a marine as opposed to freshwater environment.

Nutrients and eutrophication in Lake Winnipeg and Hudson Bay

Lake Winnipeg

Over the past ten years, there has been an increase in concern over the growing eutrophication of Lake Winnipeg. This became a matter of growing public concern following the publication of satellite photographs of algal blooms in the North Basin of the lake. Since the mid-1990s, there has been:

- A shift in the algal community towards blue-green algae (cyanobacteria), some of which are toxin producing.
- Frequent occurrence of large blue-green blooms in the North Basin.
- Large algal blooms in the South Basin during calm, warm sunny periods, particularly following flow increases associated with heavy rains.
- Declines in lake water clarity.

Nutrient loading to Lake Winnipeg

Analyses by the Manitoba Government indicate that over the past three decades phosphorus loading to Lake Winnipeg increased by 10 per cent and nitrogen loading increased by 13 per cent. Other information presented to the Commission during its investigation suggested that the phosphorus and nitrogen increases have been even higher. The government analyses, which are summarized in the Lake Winnipeg Stewardship Board report (2006), suggest:

- Higher than normal annual flows in the Red River for the past decade have contributed to the increased nutrient concentration in Lake Winnipeg.
- The dominant form and process of phosphorus loading from the watershed appears to be as dissolved phosphorus during the spring runoff.
- From 1994-2001, the Red River supplied 54 per cent of the phosphorus and 30 per cent of nitrogen to the lake, even though it supplied only 11 per cent of the flow.
- Studies done in the 1970s, prior to Lake Winnipeg regulation, suggested that 56 per cent of the nitrogen that entered the lake was being retained and 25 per cent of the phosphorus entering the lake was being retained.
- Analysis of data from 1994 to 2001 suggested that 58 per cent of the nitrogen and 74 per cent of the phosphorus entering the lake was retained in the lake.

From the above it should be noted that during a thirty-year period, nitrogen loading increased at a faster rate than phosphorus loading. At the same time, it would appear that the lake was retaining more phosphorus than nitrogen. While the increase in nitrogen retention (from 56 to 58 per cent) may not appear significant, it is important to bear in mind that the nitrogen load increased during this period by at least 13 per cent, meaning that 58 per cent of a much larger load is being retained.

Table 2.2, which is based on information in the 2006 report of the Lake Winnipeg Stewardship Board report, provides more information on nutrient loading to Lake Winnipeg.

Tables 2.3 and 2.4, which are taken from the Lake Winnipeg Stewardship Board's 2006 report, provide overviews of the sources of phosphorus and nitrogen loads to Lake Winnipeg. Point sources are sewage and industrial effluents outlets. They can be contrasted with diffuse (non-point) sources such as agricultural runoff. It should be noted that the figures relating to the loads in rivers and from point sources are based on actual measurements, while the measures of the load from natural background and undefined sources, present day agriculture, atmospheric depositions, and internal lake processes are estimates and have yet to be verified.

Key points to note are:

- Jurisdictions upstream of Manitoba contribute more than fifty per cent of the nitrogen and the phosphorus load.
- Point sources in Manitoba account for 9 per cent of the phosphorus load and 5 per cent of the nitrogen load.
- Of the point sources, Winnipeg accounts for 5 per cent of the phosphorus load and 4 per cent of the nitrogen load.

Schindler and Vallentyne (2008) identify increased use of fertilizers, increases in the number of intensive livestock operations, nutrient-rich effluent from urban wastewater treatment plants, decreased flow from the nutrient-poor Saskatchewan River (due to regulation of that river), regulation of the outflow of Lake Winnipeg by Manitoba Hydro, and the flood of 1997 (which moved significant amounts of nutrients off the land and into the lake) as contributing factors to the increase in algal growth in Lake Winnipeg.

Table 2.2: Estimate of the amount of nutrients (tonnes per year) retained in Lake Winnipeg, 1973 and period 1994-2001.

	Total Nitrogen (tonnes/year)		Total Phosphorus (tonnes/year)	
	1973*	**1994-2001****	**1973***	**1994-2001****
Nutrient Load to Lake Winnipeg (all sources)	61,920	96,000	5,215	7,900
Nutrient load leaving Lake Winnipeg via the Nelson River (East and West Channels)	27,410	39,700	3,900	2,000
Nutrient Load Retained in Lake Winnipeg	34,510 (56%)	56,300 (58%)	1,315 (25%)	5,900 (74%)

** Estimate of the amount of nutrients (tonnes per year) retained in Lake Winnipeg based on data collected from Brunskill (1973) (cited in Lake Winnipeg Stewardship Board 2006).*

*** Based on the amount of nutrients entering Lake Winnipeg via all sources, and the amount of nutrients leaving the lake via the Nelson River, 1994-2001 (cited in Lake Winnipeg Stewardship Board 2006).*

Table 2.3: Summary of estimated annual phosphorus loading to Lake Winnipeg 1994-2001 (tonnes per year, rounded to the nearest 100 tonnes).

Category	Average Total Phosphorus (tonnes/yr)	% of Total Phosphorus to Lake Winnipeg (% of Manitoba sources)
Upstream jurisdictions	4,200	53%
United States (Red River)	2,500	32
United States (Souris River)	200	3
Saskatchewan and Alberta (Assiniboine and Saskatchewan)	400	5
Ontario (Winnipeg River)	800	10
Ontario (Other rivers)	300	3
Manitoba Sources	3,700	47%
Manitoba Point Sources	700	9 (19)
City of Winnipeg	400	5 (11)
All others	300	4 (8)
Manitoba Watershed Processes	2,500	32 (67)
Natural background & undefined sources**	1,300	17 (35)
Present day agriculture	1,200	15 (32)
Atmospheric Deposition	500	6 (14)
Internal Lake Processes	Currently there are no estimates available for internal phosphorus cycling that may occur in the lake.	
Overall annual total phosphorus load to Lake Winnipeg	7,900	100%

***Estimated natural background and undefined sources would also include contributions from sources such as forests, wildlife and septic fields.*

Source: Lake Winnipeg Stewardship Board 2006.

Table 2.4 Summary of estimated annual nitrogen loading to Lake Winnipeg 1994-2001 (tonnes per year, rounded to the nearest 100 tonnes).

Category	Average Total Nitrogen (tonnes/yr)	% of Total Nitrogen to Lake Winnipeg (% of Manitoba sources)
Upstream jurisdictions	48,900	51%
United States (Red River)	19,000	20
United States (Souris River)	1,100	1
Saskatchewan and Alberta (Assiniboine and Saskatchewan)	8,300	9
Ontario (Winnipeg River)	16,800	17
Ontario (Other rivers)	3,700	4
Manitoba Sources	47,100	49%
Manitoba Point Sources	5,100	5 (11)
City of Winnipeg	3,700	4 (8)
All others	1,400	1 (3)
Manitoba Watershed Processes	23,200	24 (49)
Natural background & undefined sources**	18,100	19 (38)
Present day agriculture	5,100	5 (11)
Atmospheric Deposition	9,500	10 (20)
Internal Lake Processes - Nitrogen Fixation***	9,300	10 (20)
Overall annual nitrogen load to Lake Winnipeg	96,000	100%

***Estimated natural background and undefined sources would also include contributions from sources such as forests, wildlife and septic fields.*

**** Nitrogen fixation: it has been estimated that species of blue-green algae are adding about 9300 tonnes of total nitrogen per year to Lake Winnipeg, by fixing the nitrogen gas found in the atmosphere. (Source: Len Hendzel, Department of Fisheries and Oceans, Winnipeg, 2006 (cited in Lake Winnipeg Stewardship Board 2006).*

Source: Lake Winnipeg Stewardship Board 2006

Hudson Bay

Changes in the marine ecology of Hudson and James Bay are largely unstudied (Ingram 2006). While the movement of reactive nitrogen to oceans increased by 80 per cent from 1860 to 1990, there is little reported change in nitrogen levels in Hudson Bay (Millennium Ecosystem Assessment 2005). The estimated annual nutrient load leaving Lake Winnipeg via the Nelson River for 1994-2001 was 39,700 tonnes of nitrogen and 2,000 tonnes of phosphorus (Lake Winnipeg Stewardship Board 2006).

The City of Winnipeg wastewater treatment system

Winnipeg has three wastewater treatment plants: the North End Water Pollution Control Centre, the South End Water Pollution Control Centre, the West End Water Pollution Control Centre. Five interceptor sewer systems collect and deliver sewage to Winnipeg's three wastewater treatment plants. Once treated, wastewater is discharged into the Red and Assiniboine Rivers. The plants provide conventional secondary treatment that degrades the biological content of the sewage. The treatment of wastewater also creates a solid waste residue known as sludge.

Aside from the water delivered by the sewage system, the Winnipeg system treats centrate and leachate.

Centrate

Centrate is a liquid produced from the dewatering of digested sludge. The City ships the sludge from the West End and South End plants to the North End plant where it is dewatered. A portion of the dewatered sludge (biosolids) is land applied and a portion is landfilled. The centrate, which has a very high nutrient content, is discharged into the North End treatment system and, after treatment, is discharged to the river with the other liquid effluent. In 2006, the City land applied 86 per cent of its biosolids and landfilled the remaining 14 per cent. In 2007, it land applied 73 per cent of its biosolids and landfilled 27 per cent (City of Winnipeg 2007; City of Winnipeg 2008a). The variation in land application is dependent on weather conditions.

Leachate

Leachate is the liquid that drains from a landfill. The content of leachate is dependent on the types of wastes disposed in the landfill, landfill conditions (such acidity and alkalinity, temperature, moisture, age, and climate) and precipitation. It can contain a number of different types of potential contaminants including heavy metals, pesticides, solvents, and pharmaceuticals (Lake Winnipeg Stewardship Board 2006).

Combined sewer overflows

In addition to these sources of influent to the treatment plants, there are 79 combined sewer overflow outlets. During periods of overflow (usually heavy rainfall), some of these outlets may discharge untreated sewage overflows into the Red and Assiniboine Rivers. There are also 231 land drainage outlets, 101 of which discharge directly into either the Red or Assiniboine Rivers.

Plant size

Of the three plants, the North End plant is the largest, serving 374,000 people and much of Winnipeg's industrial capacity. The South End plant services 160,000 people and the West End plant services 86,000. The system was first put into service in 1937 and has undergone numerous upgrades since then. Prior to 2004, the City of Winnipeg was under no regulatory requirement to remove nitrogen or phosphorus from its waste effluent.

Leachate treatment

Leachate is the liquid formed when water percolates through waste in a landfill and carries with it contaminants leached from that waste. It continues to be formed even after a landfill is closed down. Leachate contains a wide range of products, including heavy metals, pesticides, solvents, and pharmaceuticals.

The current practice for Manitoba landfill sites that collect leachate (some still simply let it leach into the ground) is to ship it to wastewater treatment plants. In many cases, these plants are not able to provide the appropriate level of treatment of leachate. Treating leachate in wastewater treatment centres can lead to situations in which materials that are toxic, bioaccumulative, and persistent are present in either the wastewater effluent or in the biosolids. In the former case, this can lead to water pollution; while in the latter, it can render the biosolids unusable for land application as a crop nutrient.

Leachate from City of Winnipeg landfills is treated by the North End wastewater treatment plant (and, on occasion, the South End wastewater treatment plant). *The Environment Act* licences for these plants require the City to develop alternative leachate treatment and management plans. To date, the City has not developed plans that are acceptable to Manitoba Conservation.

In its 2006 report, the Lake Winnipeg Stewardship Board called on the provincial government to evaluate options to remove leachate from domestic wastewater treatment systems. One option would be to establish a dedicated leachate treatment facility within the province. Manitoba Conservation informed the Commission that the Manitoba Government has discussed the need for a provincial treatment facility to treat leachate collected from Manitoba landfills.

In its 2003 report on the City of Winnipeg wastewater treatment, the Commission recommended that the City be directed to stop disposing of landfill leachate at its wastewater treatment centres within 18 months. The Commission is of the opinion that this is an ongoing environmental concern that requires provincial leadership.

Chapter 3: Nutrient management: the regulatory and policy context

The questions put to the Commission to review arise from two closely related sets of issues that have come before it in recent years: 1) the regulation of nutrients and 2) the regulation and licensing of municipal wastewater treatment plants. This chapter summarizes the policy framework and decisions relevant to nutrient management, while the following chapter deals with the regulation and licensing of municipal wastewater treatment plants.

Manure management

Nutrient management in Manitoba agriculture began in 1994 with the adoption of the Livestock Waste Regulation. That regulation required:

- That animal manure be applied to fields on the basis of crop nitrogen requirements.
- Permits for manure storage tanks.
- Manure management plans.
- Setbacks from watercourses for the application of manure.

- That manure not be stored within 100 metres of watercourses.
- That large operations not apply manure to fields in winter.

The regulation was amended in 1998 and superseded in 2004 by the Livestock Manure and Mortalities Management Regulation (LMMMR). The changes in both 1998 and 2004 placed additional restrictions on the application and storage of manure in relation to its nitrogen content. In 2006, following the report of the Manitoba Phosphorus Experts Committee, the Manitoba Government amended the LMMMR to put in place manure phosphorus thresholds, further restrictions on winter application of manure, and setbacks for manure application in relation to surface water features. In its 2007 report on the environmental sustainability of the hog industry in Manitoba, the Commission recommended that the phase-in periods for the latest changes in the LMMMR be reduced, expressed concern that a stricter phosphorus threshold may be required, called for a complete ban on winter application of manure (regardless of location or size of operation), and recommended that the Province undertake research into the development of a science-based phosphorus threshold (Manitoba Clean Environment Commission 2007).

Other nutrient policy development

Development of a Nutrient Management Strategy for Surface Waters in Southern Manitoba, 2000

In April 2000, the Manitoba Government published *Development of a Nutrient Management Strategy for Surface Waters in Southern Manitoba* (Manitoba Conservation 2000). The document identified eutrophication as one of the most important water quality issues in the prairie and boreal plain eco-zones, noting that phosphorus and nitrogen were the two nutrients most commonly associated with eutrophication. It also indicated that agricultural practices and storm sewer and urban sewage effluent discharges were among the main contributors to high nutrient levels in rivers and lakes.

To develop a nutrient management strategy, the document called for a further gathering of background information on the current nutrient status of waterways in the region. The second stage in the development of the strategy was to derive numeric nutrient objectives for nutrient-related variables. These objectives would allow for informed, scientifically defensible decisions with regard to regulating nutrient inputs to surface waters. The intent was to develop regional objectives and objectives that were based on impacts on receiving waters. The receiving water focus was on Lake Winnipeg. It was noted that the development of such objectives would require extensive study and data collection and detailed statistical analysis and modelling.

In terms of implementation of a nutrient management strategy, the plan was to finalize the strategy by July 2000, decide on appropriate nutrient objective derivation methods by December 2000, and have nutrient objectives established by 2002-2003. However, no final strategy has ever been published.

Manitoba Water Quality Standards, Objectives and Guidelines, 2002

In November 2002, the Manitoba Government published what was titled the final draft of the *Manitoba Water Quality Standards, Objectives and Guidelines* (Manitoba Conservation 2002). The standards were to provide guidance on minimum levels of treatment that must be achieved by all dischargers in Manitoba, regardless of location. The objectives were meant to provide a reasonable, cost-effective level of protection in dealing with a short list of common pollutants in Manitoba. The objectives could be modified to account for unique, site-specific or regional-specific considerations. The guidelines were intended to protect the most sensitive species and were to be used primarily to identify emerging or potential water quality problems. Nutrients were addressed in the guideline section, which recommended that:

> Nitrogen, phosphorus, carbon, and contributing trace elements should be limited to the extent necessary to prevent the nuisance growth and reproduction of aquatic rooted, attached and floating plants, fungi, or bacteria, or to otherwise render the water unsuitable for other beneficial uses. For general guidance, unless it can be demonstrated that total phosphorus is not a limiting factor, considering the morphological, physical, chemical, or other characteristics of the water body, total phosphorus should not exceed 0.025 mg/L in any reservoir, lake, or pond, or in a tributary at the point where it enters such bodies of water. In other streams, total phosphorus should not exceed 0.05 mg/L. It should be noted that maintenance of such concentrations may not guarantee that eutrophication problems will not develop (Manitoba 2002; 39)

As can be seen, of these nutrients (nitrogen, phosphorus, carbon, and contributing trace elements) specific limits were set only for phosphorus. According to Manitoba Water Stewardship, phosphorus concentrations in Lake Winnipeg, when expressed as a mean for each year, exceeded the 0.025 milligrams per litre guideline for lakes in all years from 1969 to the present. In the Red River at Selkirk, 100 per cent of samples exceeded 0.05 milligrams per litre phosphorus concentration guideline. The long-term mean phosphorus concentration in the Red River is 0.329 milligrams per litre. Natural background concentrations of phosphorus in the absence of human presence would likely exceed the narrative guidelines for much of the time. This is one of the reasons why there was a commitment to develop more appropriate site and/or regional specific water quality objectives for nutrients.

The document also contained ammonia objectives that were expected to protect up to 95 per cent of all genera from unacceptable impacts, provided they are not exceeded more than once every three years. (Genera are a classification of organism above species, but below family.) Exceeding the limits more than once every three years would mean that the aquatic environment would be in a state of constant recovery (Manitoba Conservation 2002; ii, 8-9). Because ammonia impacts vary depending on a range of factors (including the time of year, flow level, temperature, and the presence or absence of early life stages), the ammonia objectives are not expressed as a single limit but as a formula.

As noted above, this document was published as a draft. As such, there was an invitation for public comment on the document with a deadline of March 31, 2003. However, no final version of the document was ever published. Instead, the Manitoba Government has been using the final draft as its *Manitoba Water Quality Standards, Objectives and Guidelines* document.

Lake Winnipeg Action Plan

In February 2003, the Manitoba Government announced a six-point Lake Winnipeg Action Plan (Manitoba Government news release 2003). Central to the plan was a commitment to reduce nitrogen and phosphorus loads to Lake Winnipeg to pre-1970s levels (this would involve a reduction of the nitrogen load by 13 per cent and a reduction of the phosphorus load by 10 per cent). At the time, the government stated that the plan "was developed in part from scientific research conducted through the Nutrient Management Strategy and will be updated as studies continue." The six points included the creation of a Lake Winnipeg Stewardship Board, measures intended to protect natural growth along the Red and Assiniboine Rivers, an expansion of soil testing to ensure appropriate fertilizer application, a new sewage and septic field regulation, a shoreline protection project for Lake Winnipeg, and the commencement of cross-border nutrient management discussions. At the same time, the Province announced that it intended to include nutrient management requirements in the City of Winnipeg wastewater treatment licence. Action has been taken on a number of these proposed initiatives.

The Manitoba Water Strategy—2003

In 2003, the Manitoba Government published *The Manitoba Water Strategy*. Key to the Province's overall water strategy was comprehensive watershed planning, which would develop benchmarks for sustainable water withdrawals, water retention, and treated effluent discharges. Conservation Districts were envisioned as the bodies best placed to co-ordinate this planning process.

The strategy referenced the intent to reduce nutrients in Lake Winnipeg to pre-1970 levels through such measures as tightened regulations for sewage and septic systems and additional requirements for larger treatment systems.

Six policy areas were identified, including water quality. Under that heading, the strategy identified a number of what were termed "Actions today." These included the preparation of the final draft of *Manitoba Water Quality Standards, Objectives and Guidelines*; the completion of the nutrient management strategy and scientific assessments of nutrient loads in surface waters; and the CEC hearing into the City of Winnipeg's wastewater treatment systems, out of which it was expected, would come "recommendations to ensure protection of the Red River, Lake Winnipeg, downstream communities and ecosystems" (Manitoba Government 2003; 10). Future actions would include the development of scientifically based nutrient management zones, watershed planning, policies to protect against invasive species, the implementation of the nutrient management strategy, and the adoption of tightened private sewage disposal standards and regulations.

Nutrient Management Regulation, 2006

In 2006, the Manitoba Government announced that it would be adopting a nutrient management regulation (NMR). The regulation, which came into force in 2008 (and is expected to be fully implemented by 2011), would regulate the application of synthetic fertilizers. In general, the provisions of the NMR followed those in the LMMMR (which regulates the application of manure). The NMR also established water quality zones. It applies not only to agriculture, but other large-scale users of fertilizer, such as golf courses. The regulation will also limit the application of phosphorus in lawn fertilizers, while flowerbeds, gardens, trees and shrubs are excluded from regulation. Beginning in 2011, municipalities will no longer be allowed to apply wastewater sludge and biosolids (sludge that has undergone a treatment process) during the winter period.

While the Nutrient Management Regulation is an important first step, it should be noted that the limitations that it places on agriculture in large measure reflect current practices and therefore are not likely to lead to a significant reduction in nutrient loadings from the agricultural sector.

Lake Winnipeg Stewardship Board

In July 2003, the Lake Winnipeg Stewardship Board was established to assist in identifying actions needed to reduce nitrogen and phosphorus loads to Lake Winnipeg. In December 2006, the Board released its plan for nutrient reduction: *Reducing Nutrient Loading to Lake Winnipeg and Its Watershed*. The report concluded "Gaps in scientific knowledge need to be filled, but this must not delay the implementation of the plan, since there is enough information and experience at hand to begin the talks. Upstream jurisdictions in the watershed must be brought into the effort, and Manitoba must lead by example" (Lake Winnipeg Stewardship Board 2006; iv).

The Lake Winnipeg Stewardship Board reported that provincial policy in the future was to have all new and expanding plants that are discharging waste into surface waters not to exceed a concentration of 1.0 milligram of phosphorus per litre and 15 milligrams of nitrogen per litre. (While the 15:1 relationship between the nitrogen and phosphorus limits appears similar to the 16:1 Redfield ratio, the two should not be confused. The 15:1 ratio in wastewater discharge limits is a mass ratio. If the 15:1 ratio were expressed as an atomic ratio, it would be 33:1 or slightly more than double the Redfield ratio of 16:1).

Since its release, the Manitoba Government has used the Lake Winnipeg Stewardship Board report in lieu of its promised nutrient management strategy.

The Board acknowledged the existence of a debate over the roles that nitrogen and phosphorus play in stimulating algal productivity and influencing algal community structure. Until the issue was resolved, through the development of ecologically sensitive, long-term water quality objectives for Lake Winnipeg, the Board felt priority should be placed on phosphorus reduction.

Literature review: 2006

Manitoba Water Stewardship commissioned North/South Consultants to undertake a literature review that would provide the necessary background information to assist in setting long-term ecologically sensitive nutrient objectives for Lake Winnipeg. *Literature Review Related to Setting Nutrient Objectives for Lake Winnipeg*, published in the spring of 2006, described the current understanding of nutrient enrichment in Lake Winnipeg as being at an early stage. In some cases, information that had been gathered had yet to be analyzed, while in other cases, additional data collection was required. Areas where further information was required included the water balance, the nutrient balance, factors limiting phytoplankton growth, shoreline processes and the littoral zone (the area of the lake near the shore), and trophic cascades (the types of changes that come about when increases in certain predators in a food web lead to decreases in their prey, reducing the pressure on species further down in the food web). The report also noted that nutrient targets have to be set in the context of goals, which themselves must take into consideration a range of site-specific factors of considerable complexity given the size and configuration of Lake Winnipeg.

On the question of nutrient regulation as part of a response to eutrophication, the report summarized the complex debate and noted, "the literature indicates that the question of whether to remove nitrogen, phosphorus, or both, needs to be considered on a case-by-case basis. There is some indication that high or moderate levels of nitrogen may exert adverse effects in aquatic ecosystems (e.g., effects to macrophytes, effects of nitrate on P mobilization in sediments), that some cyanobacteria may flourish in environments low in P and high in N:P ratios, and that downstream environments may require nitrogen reductions from upstream systems" (North/South 2006; 104).

The Water Protection Act *amendments, 2008*

Amendments to *The Water Protection Act* that restrict the phosphorus content in dishwashing detergents and allow for the regulation of the phosphorus content in other cleaning products and chemical water conditioners were given royal assent in 2008.

The Canadian Council of Ministers of the Environment

In 2009, the Canadian Council of Ministers of the Environment (CCME) endorsed a Canada-wide strategy for the sustainable management of municipal wastewater effluent (Canadian Council of Ministers of the Environment 2009). The strategy addresses issues related to governance, wastewater facility performance, effluent quality and quantity, and infrastructure needs. It is intended to provide consistency and clarity to the wastewater sector across Canada while ensuring funding for improved treatment is managed in an equitable and sustainable way. While the strategy has been endorsed by the CCME, it remains the responsibility of the appropriate federal, provincial and territorial jurisdictions to implement its recommendations through legislation, regulation or guidelines.

The strategy addresses municipal wastewater effluent from wastewater facilities, including combined sewer overflows. Environmental risk assessments of the receiving environment are intended to guide the development of site-specific effluent discharge objectives (EDO) for substances in wastewater effluent, including those not covered by National Performance Standards.

In a 2006 publication, the CCME noted that numerous emerging contaminants, previously not thought to be widely distributed within the environment "have been found to be persistent, bioaccumulative, and toxic". These include "natural and synthetic estrogens, pharmaceuticals, personal care products, surfactants, and flame retardants. These substances have the potential to cause subtle ecological and human health responses at low environmental concentrations". The CCME called for additional study of the long-term environmental and human health effects of these contaminants and the optimum point of treatment (Canadian Council of Minister of the Environment 2006; 2).

Federal legislation

There are two pieces of federal legislation that pertain to the presence of ammonia in Manitoba waters: the *Fisheries Act* and the *Canadian Environmental Protection Act* (CEPA). The *Fisheries Act* regulates the introduction of substances to waterways that could be deleterious to fish or fish habitat or to the use by humans of fish. Under the CEPA, the federal government has developed a Guideline for the Release of Ammonia Dissolved in Water Found in Wastewater Effluents. Under this guideline, wastewater treatment plants are expected to protect against acute ammonia impacts by maintaining a concentration of ammonia in the effluent that will ensure the protection of freshwater life. To protect against chronic impacts, wastewater treatment plants should not release ammonia in volumes or concentrations that result in a concentration of un-ionized ammonia greater than 0.019 milligrams per litre in the aquatic environment. An acutely lethal concentration of ammonia is defined as "a level of ammonia in an effluent at 100% concentration that kills more than 50% of the rainbow trout subjected to it over a 96-hour period when tested in accordance with the acute lethality test" (Environment Canada).

Federal Wastewater Effluent Guidelines limit total phosphorus discharges to 1.0 milligram per litre (Federal Activities Environmental Branch 1976). These limits were first established in 1976.

Chapter 4: Municipal wastewater licences

Wastewater nutrient removal systems

Municipal wastewater effluent typically contains human and other organic waste, nutrients, pathogens, microorganisms, suspended solids, and household and industrial chemicals not removed by the treatment process. In some cases, urban runoff or storm water is collected with sanitary waste in combined sewers, adding additional substances to municipal wastewater (Canadian Council of Ministers of the Environment 2009).

There are two major processes that can be used to remove nutrients from wastewaters: physical/chemical removal and biological removal (usually referred to as biological nutrient removal or BNR).

Physical/chemical nutrient removal

Physical/chemical nitrogen removal

According to Sedlak "Although under most circumstances biological treatment is the most attractive nitrogen control technology, physical and chemical processes may be technically and economically feasible in certain situations" (1991; 34). The major processes are breakpoint chlorination, air stripping, and ion exchange.

Breakpoint chlorination involves adding a sufficient amount of chlorine to the waste stream to oxidize ammonia nitrogen to nitrogen gas. It requires high volumes of chlorine and is impractical for large-scale treatment, although it is used for follow-up treatment (polishing) following biological treatment. Air stripping (sometimes referred to as ammonia stripping) involves transforming the dissolved solid ammonium to ammonia gas by raising the alkalinity level in the wastewater. While high levels of nitrogen removal can be achieved, the cost is generally prohibitive for large-scale processes. In ion exchange, wastewater is passed through a column packed with mesh particles containing natural or synthetic resins. In this process, ammonium ions in the wastewater are exchanged for ions in the resins. The absorbed ammonia is then released through a process of air stripping. As is the case with ion exchange, this is an effective but expensive method of nitrogen removal (New Mexico Environment Department 2007).

Physical/chemical phosphorus removal

The physical chemical method of phosphorus removal is to use salts of iron, aluminum, or lime to precipitate the phosphorus out of the solution. The cost of disposing of the chemical sludge this process produces can be significant (USEPA 2004). In a presentation to the Commission, the City stated that sludge production could be increased by up to 40 per cent through this method. Chemical removal renders the phosphorus in the resulting biosolids less available for use as a fertilizer.

When there is a very high concentration of nitrogen and phosphorus in wastewater, magnesium can be added to the wastewater stream to remove both nutrients, creating a product called struvite. However, this form of chemical removal is usually coupled with an initial biological treatment to create a waste stream with an elevated nutrient level. For this reason, it is discussed in greater detail below.

Biological nutrient removal

In biological nutrient removal, the waste passes through various zones containing different types of bacteria. The zones are usually described as anoxic, aerobic, or anaerobic, depending on their oxygen levels. Different oxygen levels stimulate bacteria to process nutrients in different fashions.

Biological nitrogen removal

Nitrogen is removed in a two-step process: 1) nitrification and 2) denitrification. In nitrification, certain bacteria, under aerobic conditions (in the presence of oxygen), oxidize the nitrogen (which exists largely in ammonia form) in the wastewater, transforming it into nitrate-nitrogen (NO_3), and nitrite-nitrogen (NO_2). In denitrification, different bacteria, in an anoxic zone (one with no dissolved oxygen), convert the nitrogen to non-reactive nitrogen gas (N_2), which can be safely released into the atmosphere. Non-reactive nitrogen should not be confused with those nitrous oxide emissions that are linked to ozone depletion and acid rain.

If the goal of the treatment is simple ammonia removal, the denitrification process can be eliminated and the nitrates and nitrites are released into the effluent. This, however, means that the nitrogen is released in the wastewater effluent in forms that are readily available for plant uptake.

Biological phosphorus removal

In biological phosphorus removal, bacteria are first placed in anaerobic zones (zones which do not have either dissolved oxygen or nitrates). The lack of oxygen stresses the bacteria, causing them to release phosphorus. The stressed bacteria are moved to an aerobic zone, in which the previously stressed bacteria absorb large amounts of phosphorus. These bacteria are then separated from the wastewater, forming part of the sludge produced by wastewater treatment. While this creates a high-quality fertilizer, concerns have been raised about the environmental consequences of other constituents of the solid waste, including heavy metals.

In their article on biological nutrient removal in western Canada, Oldham and Rabinowitz write "Biological means of nutrient removal are generally preferred, as they result in lower waste sludge production, produce a sludge that is more amenable to land application, and have the public perception that biological processes are more 'environmentally friendly' than chemical processes" (2002; 33).

According to the Canadian Council of Ministers of the Environment, typical systems with nutrient removal can achieve concentration levels of total phosphorous as low as 0.1 milligrams per litre and total ammonia-nitrogen levels of 5.0 milligrams per litre in winter and less than 1.0 milligrams per litre in summer (Canadian Council of Ministers of the Environment 2009). Jeyanayagam (2005) puts the limit of technology for biological nutrient removal in larger treatment plants at 3.0 milligrams of nitrogen per litre and 0.1 milligrams of phosphorus per litre.

The United States Environmental Protection Agency concluded that when compared to biological removal, chemical phosphorus processes have higher operating costs. When phosphorus levels of 0.1 milligrams per litre are mandated, the EPA stated that "a combination of biological and chemical processes may be less costly than either process by itself" (USEPA 2007; 3). A study carried out for the Minnesota Environmental Science and Economic Review Board concluded that when enhanced biological phosphorus removal was compared to chemical phosphorus removal, the biological process was more cost effective (HydroQual 2005; 7-1).

The City of Winnipeg has indicated that, according to its estimates, biological phosphorus removal would have higher operating costs than chemical removal at its North End wastewater treatment plant. It also indicated that full BNR was the most cost-effective option for its South and West End plants.

Additional benefits of biological nutrient removal

Biological nutrient removal offers enhanced opportunities for the treatment of centrate, struvite removal, the removal of emerging contaminants of concern, and the adoption of enhanced nutrient removal systems.

Centrate treatment and struvite removal

As noted above, centrate, the product of the dewatering of sludge, has a very high nutrient content. While it can be treated by both chemical and biological means, chemical phosphorus removal increases sludge production and results in a product that is a less attractive fertilizer. Another method of removing phosphorus and nitrogen (when the nutrient concentrations are very high) is to add magnesium to the centrate. The phosphorus, ammonia (which contains nitrogen) and magnesium then crystallize to form struvite, which can be land applied as a fertilizer. This process also reduces the build-up of struvite in the plant, which can form naturally as a scale that can clog pipes.

Struvite recovery is complementary to biological nutrient removal since it requires a centrate stream that has the high nutrient concentrations that result from BNR processes. Furthermore, struvite recovery is rendered difficult to impossible at plants that use chemicals to remove nutrients from their wastewater since the chemical removal renders the phosphorus largely unavailable for crystallization.

In Oregon, the Clean Water Service, a public utility serving the Tualatin River Watershed, incorporated struvite recovery into one of its wastewater treatment plants. According to the utility's annual report, "This innovation is expected to pay for itself in several years through sales and by saving costly wear and tear on the treatment facility. Another sustainable aspect of this project is the offset of environmental impacts of conventional fertilizer mining and transportation" (Clean Water Service 2008; 16). A pilot project at the Oregon plant was able to recover 95 per cent of phosphate and 19 per cent of ammonia from the centrate. This was used to develop "a high grade fertilizer product with remarkably low levels of heavy metals, and pathogen levels below detection limits" (Bauer et al. 2008).

Removing emerging contaminants of concern

The presence of natural and synthetic reproductive hormones, such as estrogen, in municipal wastewater is an emerging issue of concern. These hormones, which enter the wastewater system as waste from pharmaceuticals such as contraceptive drugs, can, in aquatic environments, act as endocrine disruptors, causing fish to develop sexual abnormalities. Traditional sewage treatment does not remove these hormones. However, full biological nutrient removal treatment has been found to effectively remove most hormones from municipal wastewater (Andersen et al. 2003). A recent study of the Brandon wastewater treatment plant, which employs a BNR system, found that between 75 and 90 per cent of various endocrine-disrupting compounds were removed (Cicek et al. 2007). This result may not arise from the bacterial activity, but from the process, which has a longer treatment period than more traditional processes and from the presence of both aerobic and anaerobic zones in the treatment process.

Enhanced nutrient removal

A number of jurisdictions in the United States have found that the nutrient discharge reductions achieved through biological nutrient removal have not been sufficient to protect receiving waters. This has led to the adoption of what are known as enhanced nutrient removal techniques. These are capable of bringing total nitrogen to levels as low as 3 milligrams per litre and total phosphorus to 0.3 milligrams or less. It is reported that systems that have converted to BNR are able to employ ENR techniques with minimal alterations (Freed 2007; Maryland Department of the Environment 2009).

Canadian experience with BNR

Kelowna, British Columbia became the first Canadian city to use BNR in 1982. By 2004, there were more than 10 such facilities operating in western Canadian jurisdictions. This is in keeping with general European and North American trends, which are in turn driven by tighter emission standards (Oleszkiewicz and Barnard 2006).

Calgary's Bonnybrook plant and Edmonton's Gold Bar plant are two of the largest BNR plants in the world. The Calgary plant, which treats the waste of a population of 750,000, first installed BNR technology in 1989. It became a 100 per cent BNR plant in 1999. Its effluent discharge has consistently met provincial effluent limits.

Bonnybrook has achieved considerable costs savings for the City of Calgary through reduced expenditures on the chemicals that would have been required for chemical removal of nutrients. One paper on the plant states that its "capital cost is small and insignificant when compared to the large and continual savings in annual chemical costs" and estimates the 2002 saving on chemicals at $2.8-million (Do et al. 2005; 12). Compared to plants using chemical nutrient removal, the Bonnybrook plant not only produces less sludge, the sludge it does produce has a lower metal content and is more available for crop uptake (Do et al. 2005).

Starting in 2006, the City of Edmonton piloted a struvite process at its Gold Bar wastewater treatment plant. The test demonstrated that the process was capable of recovering 75 per cent of phosphate and 20 per cent of ammonia from the centrate. This would result in a 20 per cent reduction in the plant's phosphorus load and a five per cent reduction in its ammonia load. It would also result in the offset of 12,000 tonnes of carbon dioxide equivalent emissions per year relative to conventional fertilizer manufacturing (Britton et al. 2007). It has been claimed by the developers of this technology that the Edmonton plant is the world's first industrial-size nutrient treatment facility to remove phosphorus and other nutrients from municipal biosolids and recycle them into environmentally-safe commercial fertilizer (Ostara news release 2007).

Licensing of municipal wastewater treatment plants in Manitoba

Over a 12-year period starting in the early 1990s, the Commission held hearings into the licensing of wastewater treatment operations in three Manitoba cities. While the process commenced with a hearing in the City of Winnipeg, there was a considerable delay between the initial hearing and the eventual licensing of the City operations. In the intervening years, the Commission held a hearing relating to the Portage la Prairie wastewater treatment plant. Following the second Winnipeg hearing, the Commission held a hearing relating to the Brandon wastewater plant. The following sections provide a chronological summary of the process.

The City of Winnipeg wastewater system: the 1991-92 hearing

In 1991, the Manitoba Government instructed the Commission to conduct a public hearing on the uses and water quality of the Red and Assiniboine Rivers in the Winnipeg area. This hearing was intended as a prelude to the licensing of the Winnipeg wastewater treatment plants under the provisions of *The Environment Act*. It was held throughout 1991 and 1992 and led to a report in which the Commission called for the disinfection of effluents and multi-year studies into issues related to the release of ammonia (NH_3) into the rivers and the impacts of overflows from the City's combined sewer system (Manitoba Clean Environment Commission 1992). The Commission expected that those studies would be completed within a few years and would lead to a further hearing and the eventual licensing of the Winnipeg water pollution control centres. However, the studies were not completed until well into the twenty-first century. The ammonia study commissioned by the City was not completed until 2008, for example.

Portage la Prairie: the 2001-2002 hearing

The hearing into the conditions surrounding an *Environment Act* licence for the Portage la Prairie wastewater treatment plant arose out of the development of a potato-processing plant. At the Portage la Prairie hearing, held in late 2001 and early 2002, Manitoba Conservation officials took the position that there was not sufficient evidence to require reductions in either phosphorous or nitrogen (or to determine which of the two elements should be given priority in any reduction process). The provincial position was that ongoing water-quality studies would help determine which nutrients should be targeted for removal. Environment Canada officials, however, took the position that phosphorus in Manitoba waters was already a serious problem that needed to be addressed.

The Commission recommended that Portage la Prairie be required to remove phosphorus from its effluent at a level consistent with Regina, Moose Jaw, Saskatoon and Calgary (Manitoba Clean Environment Commission 2002). It did not make any recommendation with regard to nitrogen. It also rejected a request from the City of Portage la Prairie for an increase to its allowable ammonia discharges.

The Portage la Prairie licence was issued in 2002. It contained no limitations on either phosphorus or nitrogen in effluent. Manitoba Conservation stated that, because nutrients are not directly toxic and nutrient enrichment is reversible, it was not imposing a phosphorus discharge limit.

The expanded Portage la Prairie water pollution control facility was commissioned in 2003. Cooley et al. (2005) concluded that, in 2004, monthly loads of total nitrogen and total phosphorus discharged from the Portage facility had increased by approximately 1.6 and 1.4 times from 2002 and that effluents increased the concentrations of nitrogen and phosphorus in the Assiniboine River downstream of the City of Portage la Prairie during all monitoring events in 2002 and 2004, with greater effects being recorded in 2004.

The 2003 licence required a review of the licence for variation and consideration of the inclusion of nutrient removal requirements after three years. The Commission understands that this review is currently underway.

City of Winnipeg: the 2002-2003 hearing

The City of Winnipeg anticipated that there would be a new CEC hearing on its application for an *Environment Act* licence in the fall of 2003. However, in September 2002, a malfunction at the City's North End wastewater treatment plant resulted in 427-million litres of untreated sewage being discharged into the Red River. This prompted the Manitoba Government to request the Commission to advance the date of the hearing into the Winnipeg wastewater treatment plants. The hearing (which was held in January and April of 2003) focused on:

- Effluent ammonia reduction.
- Combined Sewer Overflow (CSO) control.
- Effluent limits.
- Reduction of nutrients in effluent discharges.
- Wastewater system reliability issues.

The Commission was initially under the impression that the 2003 hearing was a review of the system and not a licensing hearing. However, during the course of the hearing, one of the interveners informed the Commission of receipt of a letter from the Minister of Conservation stating that a licence would be issued following the conclusion of the hearing. The Province took the position that the documentation provided in 1990 could form the basis of the licence.

The Commission eventually agreed to allow the hearing process to serve as a licensing hearing, but it expressed its reservations with this development, noting that:

1) At the time of the commencement of the hearing, the Commission was under impression that a specific hearing would be called in the future to address the licensing of the Winnipeg system.

2) The 1990 documents were not adequate in 2003.

3) A full and complete Environmental Impact Statement (EIS) would have served to better focus the hearing.

While the Commission did require the City of Winnipeg to prepare a new EIS, it was prepared on short notice (30 days) and subsequently deemed inadequate by the Commission.

In its 2003 EIS, the City stated that the water pollution control centres contribute 6.3 per cent of the phosphorus and 5.2 per cent of the nitrogen entering Lake Winnipeg. At that time, there were no effluent limits for the City on its discharges of either phosphorus or nitrogen. During the hearing, the City took the position that it was premature for the Province to establish limits on its nitrogen and phosphorus discharges.

There was also considerable debate over the issue of ammonia regulation. The debate focused around which criteria were to be used to set the limits, the percentage of the assimilative capacity of the Red and Assiniboine Rivers that was to be apportioned to each wastewater treatment plant, and the period of record that was to be used in determining the potential low-flow rate of the river when apportioning assimilative capacity.

During the hearing, the City stated that the ammonia limits should be based on site-specific impact statements rather than the *Manitoba Water Quality Standards, Objectives and Guidelines*. However, the City's site-specific study, which the CEC had first recommended in 1992, had not been completed by 2002 (as noted above, this study was not completed until 2008). As a result, Manitoba Conservation developed ammonia limits using existing water-quality criteria.

One of the factors taken into consideration in setting limits for ammonia discharges is the assimilative capacity of the receiving waters at the end of what is termed the mixing zone. This is the zone of water extending from the end of the City's discharge point (usually referred to as the end of pipe) within which the City is permitted to exceed the water quality objectives. Water beyond the end of the mixing zone should not exceed those objectives. A river's assimilative capacity is its ability to absorb materials, particularly wastes and pollutants, without exceeding water quality objectives. The assimilative capacity is determined by calculations involving the existing ammonia load in the river and the discharge to be regulated. A discharge level is determined that would, when added to the existing load, reach the limit set by the provincial water quality objectives at the edge of the mixing zone. That discharge level represents the river's assimilative capacity for the City's ammonia discharge.

It is customary to limit wastewater treatment facilities to a portion of the river's available assimilative capacity of its discharge: for example, Brandon and Portage la Prairie are limited to 25 per cent of the Assiniboine's assimilative capacity at the edge of their respective mixing zones. This reflects a precautionary approach that anticipates that, in future years, additional operations may be established that may require a portion of the available assimilative capacity.

During the Winnipeg hearing, the City argued that its West End plant should be assigned 75 per cent of the Assiniboine River's assimilative capacity, while its South and North End should be assigned 90 per cent of the Red River's assimilative capacity. Manitoba Conservation took the position that all three plants should be assigned 75 per cent of the available assimilative capacity.

While the City's ammonia discharge is relatively constant, the assimilative capacity varies with the river's flow rate. For this reason, the calculation of the ammonia limit involves the use of long-term river flow records. During the hearing, the City argued for the use of the post-1962 flow record, taking the position that the high flows for the post-1962 period indicate that there have been significant changes in river flow over the past century. Using only the post-1962 numbers would have resulted in a higher discharge limit. Manitoba Conservation argued that it was more prudent to use the longest available period of record, which dates from 1913 (Manitoba Clean Environment Commission 2003a). If the longest period were not used, the Province argued, there was a greater possibility that the plant would be underbuilt and that during a future dry period, the City's ammonia discharge would exceed the water quality guideline limits.

The overall position that the City took on ammonia regulation at the hearing was that, with the exception of the North End plant during low-flow periods, its ammonia discharges did not present a toxicity concern. It proposed to address the issues at the North End plant by removing nutrients from the centrate stream, which accounted for 25 per cent of the nutrient discharge from the North End plant (Earth Tech 2002). The City's position was that, once centrate treatment was implemented, the ammonia discharges from all three plants would not have a significant impact on aquatic life (Manitoba Clean Environment Commission 2003a).

This approach was disputed during the 2003 hearing by Environment Canada, which made presentations to the effect that treatment of the centrate stream alone was inadequate to bring the City into compliance with federal *Fisheries Act* ammonia requirements. Compliance, it indicated, would require nitrification at all three plants (Manitoba Clean Environment Commission 2003a).

In its 2003 report (Manitoba Clean Environment Commission 2003a), the Commission observed that:

- The City should begin removing nutrients in the near future, placing a priority on phosphorus removal. Nutrient control should involve both water treatment and measures to limit nutrient input to the wastewater system.
- While the City had made only limited progress toward nutrient reduction, Manitoba Conservation had not provided adequate direction.
- Manitoba should complete its Nutrient Management Strategy for Southern Manitoba as soon as possible. Such a strategy should include water quality objectives for nitrogen and phosphorus in Manitoba's rivers and receiving lakes.
- The *Manitoba Water Quality Standards, Objectives and Guidelines* did not provide sufficient guidance for nitrogen and phosphorus levels in wastewaters and receiving environments.

Other issues associated with the City licence

Other issues that were addressed in the hearing were the City's plan to reduce combined sewer overflows, reduce ammonia discharges from the wastewater treatment plants, and the treatment of leachate from city landfills.

The Commission concluded that the City's 50-year plan to address the issues created by overflows from its combined sewer system should be accomplished in 20 to 25 years. It also noted that the combined sewage outflows should be managed to control nutrient loadings as well as public-health issues. Finally, the Commission questioned whether the four-overflows-a-year goal was adequate given the size of the overflows involved. In the case of ammonia, the Commission recommended that the City comply with the *Canadian Environmental Protection Act* and the *Fisheries Act,* making use of the longer 1913-onward period of record and assigning the City plants 75 per cent of the assimilative capacity of the receiving waters. The Commission opposed the disposal of landfill leachate at the wastewater treatment plants since they are not capable of properly treating the leachate and its constituent toxins.

The Commission recommendations

The Commission recommended that if an *Environment Act* licence were to be granted to the City of Winnipeg, it should be an interim licence, valid for only two years. At the end of that period, the City should re-apply, having prepared an environmental impact statement that would be acceptable to the Commission.

The Commission also recommended that "The City of Winnipeg should be directed to plan for the removal of nitrogen and phosphorus from its municipal wastewaters, and to take immediate steps in support of the nutrient reduction targets established for Lake Winnipeg. The city's nutrient removal plan should be a key element of a licence review hearing to be scheduled within two years" (Manitoba Clean Environment Commission 2003a; iv). The Commission stated that the City should not delay action on nutrient removal until the completion of the provincial nutrient management strategy. The Commission stated that while “Winnipeg is not the only contributor of pollutants to the Red and Assiniboine rivers or nutrients to Lake Winnipeg, the City’s wastewater treatment plants and combined sewer outfalls are point sources that can be controlled” (Manitoba Clean Environment Commission 2003a; iv).

The Commission made a number of recommendations to the provincial government. In particular, it recommended that:

- Manitoba Conservation establish ‘interim’ effluent limits for Winnipeg’s three water pollution control centres in accordance with the *Manitoba Water Quality Standards, Objectives and Guidelines*.

- Manitoba should accelerate the schedule to complete the Nutrient Management Strategy for Southern Manitoba by December 2004.

The Winnipeg licences

Manitoba Conservation chose to grant licences to the three Winnipeg wastewater treatment plants (since there is no category as an interim licence, the City was granted full *Environment Act* licences).

Separate licences were granted for each of the City wastewater treatment plants, with differing dates by which the City was required to reach compliance for each facility. The initial dates for compliance were the end of 2006 for the West End plant, the end of 2012 for the South End plant and the end of 2014 for the North End plant. All three licences state that by the effective date, the City shall not release effluent where:

- The concentration of total nitrogen in the effluent on any day is in excess of 15.0 milligrams per litre, as determined by the 30-day rolling average.

- The concentration of total phosphorus in the effluent on any day is in excess of 1.0 milligram per litre, as determined by the 30-day rolling average.

In addition, beginning in 2007, the City was prohibited from discharging centrate from the North End plant where:

- The total phosphorus load exceeds 119 kilograms per day as determined by the 30-day rolling average.

- The total nitrogen load removed is less than 838 kilograms per day as determined by the 30-day rolling average.

The level of ammonia nitrogen content was also to be limited, with different daily maximums of ammonia nitrogen for each month of the year. The licences also prohibited the City from releasing a quality of effluent that causes the mixing zone to be acutely lethal to aquatic life passing through the zone.

Since the licence was originally issued, it has been discovered that the ammonia regulation was miscalculated. The ammonia restrictions are discussed in Chapter 7 of this report.

Winnipeg was also required to develop alternative leachate treatment plans.

In 2006, prior to the implementation of its nutrient removal processes, the City’s wastewater treatment plants were discharging 3,230 tonnes of nitrogen and 377 tonnes of phosphorus into the Red and Assiniboine Rivers. This is the equivalent of the load carried by 277 13-tonne dump trucks—or of the dumping of just over one truckload of nutrients a working day into the Red and Assiniboine Rivers. Full compliance with *The Environment Act* limits on nitrogen and phosphorus discharges would reduce this nutrient load to the equivalent of 126 truckloads a year. Phosphorus discharges will be reduced by 73 per cent and nitrogen discharges will be reduced by 55 per cent. With full compliance, the City will still be discharging 1,540 tonnes of nitrogen and 102 tonnes of phosphorus a year into the Red and Assiniboine Rivers.

In 2006, the nitrogen-to-phosphorus ratio in the City of Winnipeg effluent discharge was 8.6:1 (as a mass ratio) or only slightly above the Redfield mass ratio of 7:1 that is associated with high levels of phytoplankton productivity and eutrophication). After the City comes into full compliance with its licence, the nitrogen-to-phosphorus ratio will be 15:1 (as a mass ratio), a ratio associated with lower levels of productivity.

Brandon: the 2003 hearing

The Brandon hearing of June and July 2003 were sparked by the expansion of the Maple Leaf meat-processing plant. In its report (Manitoba Clean Environment Commission 2003b), the Commission recommended that the licence limits for nutrients in the effluent from the City of Brandon Industrial Wastewater Treatment Facility be set at 1.0 milligram per litre for total phosphorus and less than 10 milligrams per litre for total nitrogen. It also recommended that Brandon prepare annual sludge management plans for biosolids that demonstrated sustainability and addressed nutrient loading. The Brandon licence, issued by Manitoba Conservation, states that the licencee shall not release effluent where:

- The concentration of total nitrogen in the effluent on any day is in excess of 15.0 milligrams per litre, as determined by the 30-day rolling average.
- The concentration of total phosphorus in the effluent on any day is in excess of 1.0 milligram per litre, as determined by the 30-day rolling average.

Manitoba Conservation has informed the Commission that the plant regularly discharges at rates well below the licensed concentrations.

Smaller treatment systems

Few of the small lagoons that provide secondary sewage treatment in Manitoba have any nutrient limits. These lagoons usually discharge at a rate of 5 milligrams of phosphorus per litre. Some of the exceptions are Falcon Lake, which has a 1.0-milligram-per-litre phosphorus limit but no nitrogen limit. The Gimli and Hecla plants were expected to meet a 1.0-milligram-per-litre phosphorus limit.

Many septic fields, holding tanks and treatment lagoons in Manitoba do not provide adequate environmental protection. Some lagoons are undersized and, as a result, need to seek permission from Manitoba Conservation to make emergency discharges. Many licences issued by Manitoba Conservation since 2005 do not include nutrient provisions, while others require only nutrient monitoring.

Nutrient management in Lake Winnipeg watershed territory beyond Manitoba's boundaries

In 2006, Fargo and Grand Forks, while they did not have limits for phosphorus discharges, did have ammonia controls on their wastewater discharges. In 2006, Minnesota was going to require that phosphorus discharges be reduced to 1.0 milligram per litre in the Lake Superior basin and the interstate waters of Lake St. Croix. New and expanding wastewater plants of a certain size were also expected to meet this standard.

Nutrient regulation in wastewater in western Canada is discussed in Chapter 5 in the context of the Associated Engineering report. To summarize that discussion, in all the facilities in western Canada surveyed by Associated Engineering (not including Winnipeg) phosphorus discharge limits were either in place or are pending. In no case is the allowable phosphorus discharge greater than 1.0 milligram per litre. There are pending nitrogen discharge rates of 15 or less milligrams per litre in Calgary, 14 milligrams per litre in Saskatoon, and between 10 and 12 milligrams per litre (depending on the season) in Regina (Associated Engineering 2008).

Aside from these point sources, agriculture is also a significant source of nutrients. There are 55-millon hectares of farmland in the Canadian portion of the Lake Winnipeg drainage basin and 10-million hectares of farmland in the U.S. portion of the watershed.

Commission observations on the above issues

The Commission believes that the Manitoba Government has over the past decade taken a number of important and positive steps in nutrient management. However, it also expresses concern over:

- The fact that the Nutrient Management Strategy for Southern Manitoba has never been completed or published. Instead, the Province has relied on the 2006 Lake Winnipeg Stewardship Board report in lieu of a formal strategy. It should be noted that, while the Manitoba Government has considerable involvement in the Board, it is not a provincial government agency. Furthermore, while Lake Winnipeg represents a significant issue, there are risks that arise if one allows it to become the sole focus of all nutrient regulation.

- The fact that the *Manitoba Water Quality Standards, Objectives, and Guidelines* never went beyond the final draft stage. As noted above, the Commission does not believe that the *Manitoba Water Quality Standards, Objectives and Guidelines* in its draft form provides sufficient guidance for nitrogen and phosphorus levels in wastewaters and receiving environments. Completion of both the Nutrient Management Strategy for Southern Manitoba and the *Manitoba Water Quality Standards, Objectives and Guidelines* are necessary to provide appropriate guidance to all parties to the regulatory process.

- The decision not to regulate phosphorus discharges at the Portage la Prairie wastewater treatment plant. This decision was made at a time when the link between phosphorus and eutrophication was well established.

- The quality of the City of Winnipeg environmental impact statement in both the 1991 and 2003 process. During both hearings, the Commission raised concerns about the quality of the environmental impact statement, and indicated that it expected that future reviews would be conducted in the light of a fuller review of environmental impacts. The City has not been required to provide an EIS for the current review of its nitrogen regulation.

- The fact that the Manitoba Government does not include total nutrient loading in its nutrient discharge limits. The decision to regulate solely on the basis of concentration (1.0 milligram per litre phosphorus and 15 milligrams per litre nitrogen) ignores the fact that the real issue is the total nutrient load to the receiving water. Increases in population or development in the City will lead to increases in the flow of water through the City's wastewater treatment system (unless the growth is coupled with increased water conservation measures). As a result, the loads could increase. Concentration limits, while appropriate for pollutants whose impact is dissipated by dilution, should not be the sole limit on nutrients, which accumulate in the environment. The Commission believes that the Manitoba Government should incorporate total load in the limits that it develops under its nutrient management strategy.

- The needs for standardization in licensing. The Manitoba Government should standardize its licensing procedures, providing clarity, for example, on when an environmental impact statement is required and its expectations of such a statement.

The City of Winnipeg licences and nutrient reduction

The City has developed a near- and long-term implementation plan to meet the requirements of *The Environment Act* licences that have been granted to its wastewater treatment plants. In following this plan, it has:

- Implemented a disinfection system at the North End plant.
- Implemented a biological nutrient removal process at the West End. According to the City, the West End treatment plant has been, on a 30-day rolling average during its first months of operation, discharging total nitrogen at a rate of 7 milligrams per litre or less and total phosphorus at 0.8 milligrams per litre.
- Put in place a system to remove nitrogen and phosphorus from its centrate and sludge at the North End plant. (Biological treatment is used to nitrify and denitrify the nitrogen, while chemical processes are used to remove the phosphorus.) (City of Winnipeg 2008b).

It is also in the planning stage for major upgrades to the South End Plant and the North End plant. These upgrades would implement full biological treatment of nutrients in the City of Winnipeg wastewater stream. It would not however provide the full benefits of biological nutrient removal. The phosphorus that is removed from the wastewater is incorporated in the City's sludge. As noted above, all of the City's sludge is treated at the North End plant. There, chemicals are used to remove the phosphorus as a part of the dewatering process. The use of chemicals significantly inhibits the reuse of the phosphorus removed from wastewater as a fertilizer.

The licences issued to the City set both a long-term and an interim target. The interim target was for the City to reduce its phosphorus discharge by 10 per cent and its nitrogen discharge by 13 per cent on a citywide basis. The goals were in keeping with the provincial strategy to reduce loadings to pre-1970 levels. The City reached the interim goal by December 31, 2006. By the time all three licences come into effect at the end of 2014, the City is expected to have reduced its phosphorus discharge to 1.0 milligram per litre and its nitrogen discharge to 15 milligrams per litre.

Table 4.1 shows the average discharge rate from Winnipeg's three wastewater treatment plants for the period from 2001 to 2006, inclusive, based on daily composite sampling.

Table 4.1: Nitrogen, phosphorus and ammonia discharge in milligrams per litre

Parameter	NEWPCC		SEWPCC		WEWPCC	
	Raw	Final	Raw	Final	Raw	Final
Total Kjeldahl Nitrogen	39.8	27.8	40.0	25.6	33.5	22.0
Total Phosphorus	5.8	3.5	6.7	3.7	5.6	3.7
Ammonia	26.3	23.5	26.3	22.0	24.2	17.8
Nitrite Nitrate		3.9		1.7		1.0
Flow	211 Mega Litres per Day		61.4 Mega Litres per Day		32 Mega Litres per Day	

Data are averages for the period from 2001 to 2006, inclusive, based on daily composite sampling.

Source: City of Winnipeg.

Table 4.2: City of Winnipeg phosphorus and nitrogen load in 2006 and once full licensing compliance has been achieved.

	Nitrogen				Phosphorus			
	2006 contribution		Contribution at 15 milligrams per litre		2006 contribution		Contribution at 1 milligram per litre	
	Tonnes	Percent of total load[1]	Tonnes	Percent of total load[2]	Tonnes	Percent of total load[3]	Tonnes	Percent of total load[4]
Wastewater treatment plants	3230	3.36	1540	1.63	377	4.77	102	1.34
Combined Sewer Overflows	150	0.16	150	0.16	18	0.23	18	0.24
Land Drainage System	150	0.16	150	0.16	15	0.19	15	0.20
Total	3530	3.68	1840	1.95	410	5.19	135	1.78
Total Reduction			1690	1.76			275	3.48
Per cent reduction of total Winnipeg contribution			47.5				67.1	
Per cent reduction of Wastewater treatment discharge			52.3				72.9	
Pre-regulation wastewater treatment N P ratio	8.6 to 1							
Post-regulation wastewater treatment N to P ratio	15 to 1							

1. Estimated annual nitrogen load to Lake Winnipeg = 96,000 tonnes (Source: Lake Winnipeg Stewardship Board Report to Minister of Water Stewardship, December 2006)

2. Revised estimate of annual nitrogen load to Lake Winnipeg= 94,310 tonnes

3. Estimated Annual Phosphorus load to Lake Winnipeg = 7900 tonnes (Source: Lake Winnipeg Stewardship Board Report to Minister of Water Stewardship, December 2006)

4. Revised estimate of annual phosphorus load to Lake Winnipeg= 7625 tonnes

Source: City of Winnipeg.

Table 4.2 provides a breakdown of the nitrogen and phosphorus loads from the City of Winnipeg. It differs from the information provided in Tables 2.2 and 2.3 in that those tables present averages over a seven-year period. Furthermore, Table 4.2 provides a breakdown of the Winnipeg contribution, showing the contribution of the wastewater treatment plants, the combined sewer overflows and the land drainage system.

In information presented to the Commission, the City stated that when it reaches full compliance with the licence it would have reduced nitrogen loading by 47.5 per cent and phosphorus loading by 67.1 per cent. As noted above, the impact of these measures would be to increase the nitrogen-to-phosphorus mass ratio in the effluent from the City of Winnipeg wastewater treatment plants from 8.6:1 to 15:1.

To summarize from information provided by the City, compliance with the current licence will result in:

- A 47.5 per cent reduction in Winnipeg's nitrogen load (and a 52.3 per cent reduction in the portion of the load coming from the wastewater treatment plants).
- A 67.1 per cent reduction in Winnipeg's phosphorus load (and a 72.9 per cent reduction in the portion of the load coming from the wastewater treatment plants).
- A near doubling of the N:P ratio of the City Winnipeg's nutrient load. The significance of this increase is discussed below.

The City is seeking exemptions from the current license requirements for nitrogen and ammonia discharge, particularly for its North End plant. If such exemptions were granted, the City would not proceed with a number of initiatives described above. The rationale for the City requests are discussed in Chapters 6 and 7.

Chapter 5: Associated Engineering Report

In 2008, Associated Engineering was commissioned to prepare a report on 1) the regulation of nitrogen in wastewater in other jurisdictions, 2) the costs associated with nitrogen reduction, and 3) the impact of staging or phasing in nitrogen reduction. Its report, *An Assessment of Cost of Nitrogen Removal of City of Winnipeg Wastewater* (2008), was based on this underlying assumption: that to meet the phosphorus and ammonia limits in its licence, the City would have to install biological treatment processes that would remove phosphorus and nitrify ammonia into nitrate-nitrogen.

The report estimated that denitrification would increase the cost of the projects by between 6 to 7 per cent. The report estimated the cost of nutrient removal at the South End plant to be $202.7-million, with $14-million (7 per cent) attributable to denitrification. The total cost of the North End nutrient treatment was estimated to be $531-million, with $32.7-million (6.2 per cent) of that being attributable to denitrification.

While the report focused on capital costs, it noted that denitrification would reduce both the sludge production rate and the oxygen requirement at the treatment plants. In the case of the South End plant, this would result in a $62,000 annual reduction in operating costs. The report did not provide a similar estimate for the larger North End plant, where denitrification is not in as advanced a state of design.

The report concluded that there would be little benefit in phasing in denitrifcation within the timeframe of the current licence, particularly since it would increase costs and create additional engineering challenges.

Given issues that have arisen during the course of this review, it is worth noting that the Associated Engineering report did not examine any issues related to phosphorus removal (particularly in terms of the comparative advantages of chemical and biological nutrient removal), nor did it examine the necessity of nitrification to meet ammonia discharge limits.

The report's survey of other jurisdictions looked at the regulation of phosphorus, orthophosphate, ammonia and nitrogen. The federal government requires site-specific values based on environmental risk assessment for total phosphorus and total nitrogen and site-specific values based on acute toxicity test results and the receiving environment for ammonia. Manitoba regulates nitrogen and phosphorus on a site-specific basis and ammonia on the basis of a calculation based on water quality objectives for the receiving waters. Saskatchewan regulates all four parameters on a site-specific and technology-based basis. Alberta, for operations serving over 20,000 people, sets a 1-milligram-per-litre phosphorus limit and regulates ammonia and nitrogen on a site-specific basis. British Columbia regulates phosphorus and orthophosphate on a 1-milligram and 0.5-milligrams-per-litre basis, respectively, based on site-specific requirements of the receiving environment. It regulates ammonia on the basis of an initial dilution zone based series of factors and limits nitrogen discharges in the Okanagan Basin to 6 or less milligrams per litre.

In all the facilities in western Canada that were surveyed (not including Winnipeg), phosphorus discharge limits are either in place or are pending. In no case is the allowable phosphorus discharge greater than 1.0 milligram per litre. The limits are: Penticton, 0.25 milligrams per litre; Banff, 1.0 milligram or less per litre; Edmonton, less than 1.0 milligram per litre, Alberta Capital Region, 1.0 milligram per litre. Calgary's Bonnybrook facility has a limit of 1.0 milligram per litre, while the proposed regulation for Calgary's Pine Creek facility is 0.5 milligrams per litre or less. Saskatoon has nutrient goals: a yearly average of 1.0 milligram per litre and a monthly average of 0.5 milligrams per litre. The existing and proposed phosphorus limits for the Regina facility are 1.0 milligram per litre.

The Alberta facilities that were surveyed all regulate ammonia discharges (the rates vary between 5 and 10 milligrams per litre depending on the season). The British Columbia jurisdiction surveyed does not have a specific ammonia regulation: however, its nitrogen regulation of 6 milligrams per litre would serve to restrict ammonia discharges. Ammonia discharges from the Regina and Saskatchewan facilities are not currently regulated provincially, however summer and winter discharge rates of 4 and 10 milligrams per litre are proposed for Regina.

Of the facilities surveyed, only the Penticton facility is currently regulated on the basis of nitrogen discharges. However there are pending nitrogen discharge concentrations of 15 or less milligrams per litre in Calgary, 14 milligrams per litre in Saskatoon, and between 10 and 12 milligrams per litre (depending on the season) in Regina.

Chapter 6: Issues surrounding nitrogen removal from urban wastewater

While nutrient management is a complex and evolving field, the Commission has been asked to examine a relatively focused question: what the appropriate level of nitrogen reduction should be, if any, for City of Winnipeg wastewater facilities.

The Commission has been asked to review the current regulation (15 milligrams per litre) because of concerns over the impact that this level of nitrogen limitation could have on efforts to reverse the eutrophication in Lake Winnipeg. Simply put, an argument, based on scientific evidence, is being made that reducing nitrogen in City of Winnipeg effluent is unlikely to have any positive impact on lake recovery and may well have a negative impact. This chapter reviews key research in this area, dividing the discussion into a review of research that tends to support policies that would see the City restrict its phosphorus discharge while maintaining its current nitrogen dishcharge and research that tends to support the placing of controls on both nitrogen and phosphorus discharges.

It should be noted that there is unanimity on the position that phosphorus must be controlled. The importance of controlling urban wastewater point sources is underscored by British research that point sources of phosphorus, as opposed to diffuse sources, provide the most significant risk for river eutrophication. This is the case, even in rural areas with high agricultural phosphorus losses. This is due to the fact that point source total phosphorus loads contain a high concentration of soluble reactive phosphorus (Jarvie et al. 2006).

Evidence favouring phosphorus regulation alone

The nitrogen-to-phosphorus ratio

At the risk of simplifying very complex arguments, there is considerable research that links low nitrogen-to-phosphorus ratios with eutrophication in general (Downing and McCauley 1992) and, in particular, with the development of nitrogen-fixing cyanobacteria blooms. In lakes with high nutrient content and a low nitrogen-to-phosphorus ratio, it is argued that algae and bacteria with the ability to fix nitrogen exploit this advantage and outproduce other algae (Barica 1990; Burgi and Stadelmann 2002; Havens et al. 2003; Levine and Schindler 1999; Smith 1982; Smith 1983; Smith 1986; Smith and Bennett 1999; Stockner and Shortreed 1988). Because of the nitrogen-fixing capabilities of some cyanobacteria, some researchers warn against policies focused solely on nitrogen reduction (Vrede et al. 2008).

The centrality of phosphorus reduction in controlling eutrophication

There is also a considerable degree of evidence that demonstrates that in many eutrophic lakes phosphorus is the underlying nutrient to be controlled. Nitrogen limitation of productivity is, according to this argument, a symptom of a surplus of phosphorus and can be addressed through phosphorus reduction. For example, a 2005 meta-analysis of 35 studies of the impact of nutrient loading on lakes found that reductions in phosphorus loading led to lower phosphorus levels and reductions in eutrophication. Recovery times were influenced by the amount of phosphorus available for internal loading from sources such as the lake sediments. Nitrogen loadings were not reduced in all cases, and when they were, the decreases (in nitrogen levels) were not as high as for phosphorus in most cases. As a result, the nitrogen-to-phosphorus ratio was increased in 80 per cent of the cases reviewed (Jeppesen et al. 2005). Reducing phosphorus, then, becomes the most effective form of nutrient management to assist in lake recovery (Bergman 1999; Coveney et al. 2005; Hecky and Kilham 1988; Jeppesen et al. 2002; Marsden 1989; Phillips et al. 2005; Schindler 1975; Schindler 2006; Schindler and Vallentyne 2008; Sondergaard et al. 2001).

The position is summarized by Smith and Schindler's (in press) survey, which argues that the control of eutrophication in freshwaters has relied largely on controlling phosphorus. While nitrogen limitation may be identified in eutrophic lakes, they conclude that this is a short-term response to excess phosphorus and should not be taken as an indication that the solution lies in exclusive nitrogen reduction. "Decades of evidence indicate that the successful control of eutrophication in lakes involves reducing inputs of phosphorus to lake waters, whether the sources are external, such as sewage or land-use changes, or internal, by the recycling of phosphorus from sediments" (Smith and Schindler in press).

In short, it is being argued that the City can make a significant contribution to Lake Winnipeg recovery by reducing phosphorus (as it is being required to) but that nitrogen reduction will make no additional contribution (Schindler et al. 2008).

The risk that nitrogen control will lead to an expansion of nitrogen-fixing cyanobacteria

Furthermore, to the degree that nitrogen reduction encourages nitrogen fixation by certain types of cyanobacteria, it could increase the prevalence of blue-green algal blooms on the lake. When authors who are skeptical of the benefits of nitrogen reduction contemplate nitrogen reduction they stress that it must done in such a manner that changes in the nitrogen-to-phosphorus ratio do not encourage the growth of nitrogen-fixing cyanobactera (Noges et al. 2008; Smith and Schindler in press).

Evidence favouring controls on both nitrogen and phosphorus

Conditions where phosphorus control may be difficult to achieve

There is another body of work that holds that in certain conditions phosphorus reduction should be matched with nitrogen reduction (Jeppesen et al. 2007; Leavitt et al. 2006; Lewis and Wurstbaugh 2008). These conditions include:

- Lakes with naturally high phosphorus supplies.
- Lakes with strong internal loading of phosphorus.
- Lakes in agriculturally impacted landscapes where it may be difficult to reach phosphorus concentrations sufficiently low to eliminate the impact of nitrogen.

The synergistic impacts of phosphorus and nitrogen

Others (Elser et al. 2007; Elser et al. 1990) conclude that when phosphorus and nitrogen are added simultaneously, they produce synergistic responses in freshwater, and marine ecosystems (although lake benthic autotrophs [primarily attached algae] appeared to be more strongly limited by phosphorus than nitrogen and synergistic responses were weak). Some authors call for regulation of both nitrogen and phosphorus in lake restoration efforts (González Sagrario et al. 2005; Jeppesen et al. 2007; Leavitt et al. 2006; Moss et al. 2005).

The degree of reliance on cyanobacteria

There is also debate over the impact that nitrogen reduction would have on the development of cyanobacteria capable of fixing nitrogen from the air. It is argued that, in the case of nitrogen limitation, the amount of fixation that takes place is minimal and the predominance of the cyanobacteria is linked to factors other than their ability to fix nitrogen. These factors include their protection from herbivores, tolerance for higher temperatures, monopolization of ammonia sources, and the fact their blooms shade other competitors, reducing their access to light (Downing et al. 2001; Ferber et al. 2004; Lewis and Wurstbaugh 2008). These views are countered by Vrede et al. (2008), who maintain that fixation is a significant source of nitrogen in cases where other nitrogen sources were limited.

The impact of nitrogen on biodiversity

Elevated nitrogen levels have been associated with reduction in both the richness and extent of macrophyte communities in lakes (González Sagrario et al. 2005; James et al. 2005; Jeppesen et al. 2007). Macrophytes, aquatic plants large enough to be seen with the naked eye, play an important role in the structure and function of aquatic systems. Macrophyte communities, for example, serve as refuges for small fish and zooplankton. “Furthermore they support epiphytic [plants that grow on top of or are supported by other plants] and macroinvertebrate [animals that lack a backbone and are visible to the naked eye such as water mites and caddis flies] communities that serve as food sources for higher trophic levels [a food web has several trophic levels, with green plants forming the first level, herbivores the second, and carnivores a third]. They also help control erosion and minimize turbidity and play a role in increasing the diversity of food sources for higher tropic levels” (James et al. 2004 and references therein; 538). The reduction of these communities due to high nitrogen levels could have wide-ranging impacts for lake biodiversity. James et al. (2005) state the removal of ammonia in sewage by conversion to nitrites and nitrates creates conditions that need to be managed to ensure there are no impacts to macrophyte communities. Li et al. (2008) have, however, concluded that the macrophyte loss observed in other studies was probably related to shading by periphyton and/or phytoplankton rather than to any toxic effects of nitrogen.

Nitrate-nitrogen is highly toxic to amphibians and has been detected in surface waters at levels that have both acute and chronic toxic effects on several amphibian species. As such, it has been described as one of the most pervasive contaminant threats to amphibian survival in North America (Camarago and Alsonso 2006; Rouse et al. 1999).

Nitrogen limitation in riverine environments

Riverine situations may be different from lakes. Dodds et al., in their study of the relationship between nitrogen and phosphorus to algal biomass at the bottom of temperate streams, identified the occurrence of nitrogen limitation in streams. Noting that this was inconsistent with the view that phosphorus is the primary limiting factor in inland freshwaters, they state "data reveal a significant N–P interaction in streams and suggest that it is necessary to consider both N and P as potentially limiting nutrients for periphyton [aquatic plant and animal organisms that attach to objects in the bed of a body of water] biomass accrual in lotic [swiftly moving water bodies] ecosystems" (2002, 869). They suggest that a pattern of co-limitation will become evident as more flowing waters are studied.

Nitrogen limitation in rivers and streams has been identified in a number of studies, including two in Manitoba (Armstrong 2005; Cooley et al. 2003; Lin et al. 2008; Scrimgeour and Chambers 2000). Lin et al. (2008) recommended that management practices include the reduction of both nitrogen and phosphorus.

Nitrogen limitation in marine waters and estuaries

While the initial view was that phosphorus was the dominant element to be controlled in order to address eutrophication in both fresh and marine waters, this view has come under reconsideration. A review by Correll (1998) concluded that phosphorus was the most common cause of eutrophication in freshwater lakes, reservoirs, streams, and headwaters. Nitrogen was identified as the limiting nutrient in the ocean, while in estuaries and continental shelves both nitrogen and phosphorus might serve as limiting nutrients. Howarth and Marino (2006) argue that a new consensus has developed, which holds that nitrogen is probably the major cause of eutrophication in most coastal systems in the temperate zone. This consensus has also maintained that it is preferable to control both nitrogen and phosphorus to effectively control eutrophication. In contrast, Smith and Schindler (in press) hold that phosphorus reduction alone may be effective in estuaries as well, citing work in Sweden, Australia, and Russia.

Lake Winnipeg is not the final receiving water for the effluent from the City of Winnipeg. The lake is drained by the Nelson River, which flows into Hudson Bay. The dynamics of the Hudson Bay marine ecosystem are poorly known. The literature review prepared for Manitoba Water Stewardship on nutrient objectives noted the nutrient chemistry, biomass and productivity of Hudson Bay are not well documented and that information published to date on the Nelson River estuary is inadequate to describe the seasonal cycle of production (North/South Consultants 2006). A number of studies (Maestrini et al. 1986; Smith et al. 1997) concluded that the growth of sea ice algae is nitrogen limited. Cargill and Jefferies (1984) found nitrogen to be the limiting nutrient for sub-arctic salt marshes along the southern shores of Hudson Bay.

The global nitrogen cascade

Finally, there is the issue of the excess mobilization of nitrogen in the broader environment. As noted in Chapter 2, the application of reactive nitrogen has increased dramatically in the past century. Galloway et al. (2003) estimate that between 1860 and 2000, the anthropogenic reactive nitrogen creation rate increased from approximately 15 megatonnes per year to approximately 165 megatonnes of nitrogen per year. This reactive nitrogen is being created at a far faster rate than it is being denitrified. As a result, reactive nitrogen is accumulating in the environment, moving from one environmental system to another (from the soil, to an aquatic environment, to the atmosphere) in what has been termed a nitrogen cascade. At each step, it can have a negative as well as a positive environmental impact. In some cases, nitrogen is resident in the environmental system for a short time, while in other cases it is resident for a lengthy time. Lags in the cascade lead to accumulations of reactive nitrogen that amplify its environmental impact. These can include:

- Production of tropospheric ozone and aerosols that induce serious respiratory illness, cancer, and cardiac disease in humans.
- Decreases in biodiversity in many natural habitats.
- Acidification in lakes and streams in many regions of the world.
- Global climate change and stratospheric ozone depletion, both of which have impacts on human and ecosystem health.

Nitrogen in water has also been linked to increases in greenhouse gases. Stief et al. (2009) report that a large variety of aquatic animals emit nitrous oxide when nitrate is present in the environment. They estimate "that nitrous oxide emission by aquatic animals is quantitatively important in nitrate rich aquatic environments like freshwater, coastal marine, and deep-sea ecosystems" and that this might increase because of the dominance of filter- and deposit-feeders in eutrophic ecosystems. Filter-feeders (so named because they strain suspended matter and food particles from water) and deposit-feeders (so named because they feed on the detritus that collects at the bottom of water) show the highest rates of greenhouse-gas emission (2009; 1).

It is estimated that rivers, estuaries, and continental shelves account for approximately 30 per cent of the total global anthropogenic N_2O (a major greenhouse gas) emissions (Galloway et al. 2003).

According to Smil, "Only a complete denitrification, converting NO_3-N to N_2, has no negative environmental impacts. All the other transfer and transformations of the element have some undesirable consequences, ranging from risks to human health to possibly major alterations of affected aquatic and terrestrial ecosystems" (Smil 2001; 177).

Summary

In short, while there is general agreement on the need to reduce phosphorus loading as much as possible to allow lakes to recover from eutrophication, there is ongoing debate in the scientific community over the benefits and risks of reductions in nitrogen loading to lakes—although there is agreement that nitrogen reductions should not serve to decrease the nitrogen-to-phosphorus ratio. Furthermore, elevated nitrogen levels are associated with loss in biodiversity, eutrophication, and toxicity to amphibians.

While the Commission does not presume to be able to resolve these debates, particularly since, in some instances, the issues are site-specific and results may not be transferable, it will be taking a precautionary approach in making recommendations based on this research. Employing such an approach will require policies that reduce nitrogen loading and increase the nitrogen-to-phosphorus ratio in receiving waters.

Chapter 7: The recalculation of the City of Winnipeg ammonia limits

During the period in which the Commission was conducting this review, it was discovered that the ammonia limits in the City of Winnipeg licence for its North End wastewater treatment plant had been miscalculated. The result of this miscalculation (which was based on an inputting error in a calculation) had led to the establishment of a limit that would not have provided the intended level of protection for aquatic life.

The error had not been previously discovered because it had been assumed, prior to 2008, that the City would be required to nitrify most of its ammonia discharge as part of the process of conforming to the licence requirement to limit its nitrogen discharge to less than 15 milligrams per litre. In light of the Province's decision to refer the nitrogen limit to the Commission, the City revisited the ammonia limit and detected the error.

As a result, Manitoba Water Stewardship and Manitoba Conservation consulted with the City and developed a new ammonia limit. During this process, the City also met with the Commission and revisited a number of the issues that were addressed in the 2003 licence hearing. In essence, the City reverted to its 2003 position that, with the implementation of centrate treatment at the North End plant (which uses biological processes to remove nitrogen from the centrate), the City's ammonia discharge would not have a significant impact on aquatic life. The City took the position that, if the Province were to significantly increase or eliminate the nitrogen regulation, the City would not have to invest in any further biological nutrient removal processes at the North End plant to meet its ammonia limits.

The City's 2009 requests to the Commission

In a presentation to the Commission, the City requested that the Commission instruct the provincial government to 1) remove its requirement to reduce its nitrogen discharge limit, and 2) provide a new ammonia limit based on site-specific data and an abridged period of record (using the post-1962 period of record as opposed to the post-1913 period of record). In its discussions with Manitoba Conservation and Manitoba Water Stewardship in January 2009, the City also requested changes regarding the calculation of ammonia limits including 3) the portioning of assimilative capacity and 4) the use of the full period of record for calculating minimum river flows.

The Commission's responses to the 2009 requests

1) Recommending on the nitrogen limit prior to the Province recalculating the ammonia limit

The City asked the Commission to recommend on the nitrogen limit prior to the Province recalculating the ammonia limit. The Commission's mandate was to take into "account the current phosphorus, ammonia and total nitrogen limits included in the *Environment Act* Licences for the City of Winnipeg's wastewater treatment facilities" in reaching its recommendation on nitrogen reduction. Any recommendation on changes to the nitrogen limit would be premature without consideration of the ammonia limit. For this reason, the Commission declined to come to a conclusion about the nitrogen regulation until after the ammonia limit had been determined. The Commission's views on this issue are found in the concluding chapter of this report.

2) Site-specific ammonia limits

The City's request regarding site-specific ammonia limits arises from the fact that its report on site-specific ammonia studies was completed in 2008 and available for use in developing the new limits. This recently received report requires considerable study. It is appropriate that the current limits be based on the existing provincial guidelines.

3) Portioning the assimilative capacity of the rivers

In its 2003 report, the Commission recommended that the City be assigned 75 per cent of the assimilative capacity of the receiving waters. The 75 per cent figure is much more generous than the percentage portioned to other Manitoba cities. The Commission believes that portioning is an appropriate and precautionary approach to this issue. It does not support expanding the City's portion of the assimilative capacity of the receiving waters beyond 75 per cent.

4) The period of record

In the Commission's 2003 report, it recommended that the longest available period of record be used in determining the assimilative capacity of receiving waters. The Commission continues to hold that this is the most appropriate basis on which to determine the ammonia limit. The post-1962 years have been wetter than the previous decades, but that is certainly no guarantee that this precipitation pattern will continue into the future.

The recalculated ammonia limit

In February 2009, Manitoba Conservation recalculated the ammonia license limit for the City of Winnipeg North End wastewater treatment plant. In doing so, it incorporated updated information on ammonia concentrations, alkalinity and acidity, and water temperature in the Red

River and flow data. According to Manitoba Conservation, a comparison of historical ammonia data from July 2002 to December 2008 indicates that the City would be out of compliance with the updated ammonia license limits 31 per cent of the time. The City has taken the position that treatment of the centrate stream at the North End plant could eventually result in a 30 per cent reduction in ammonia concentrations in the plant effluent. However, according to Manitoba Conservation, even if this reduction were achieved the City would still be exceeding its licence limit 14 per cent of the time.

Compliance with the ammonia limits

The City is making an argument that it would only occasionally exceed the ammonia limit on a limited number of days a year (and that these exceedances would be eliminated if it were allowed to use a monthly average in calculating its ammonia discharges). However, it should be borne in mind that the ammonia limits already have provision for exceedances calculated into them. They are intended to protect up to 95 per cent of all genera from unacceptable impacts, provided they are not exceeded more than once every three years. Exceeding the limits more than once every three years would mean that the aquatic environment would be in a state of constant recovery (Manitoba Conservation 2002; ii, 8-9).

In addition, there are issues of acute ammonia toxicity. The City's *Environment Act* licences for its wastewater treatment plants prohibit it from releasing a quality of effluent that causes the mixing zone to be acutely lethal to aquatic life passing through the zone. The licences also require that, when the licence for each plant came into force, the plants would be prohibited from releasing effluent that can be demonstrated to be lethal to fish within the mixing zone based on tests carried out according to Environment Canada protocols. To comply with the requirements of this test, more than 50 percent of the fish exposed to 100 per cent concentration of the City effluent for 96 hours must survive.

While the City of Winnipeg has until 2014 to come into compliance with the acute fish toxicity provisions of its North End wastewater treatment plant licence, it has been conducting acute toxicity tests at the North End plant since 2005. The City has failed to meet this standard in 13 of the 15 tests conducted at the North End plant prior to 2009. This not only means that the current ammonia discharges are not compliant with the future *Environment Act* licence requirements, it is currently not complying with the federal Guideline for the Release of Ammonia Dissolved in Water Found in Wastewater Effluents.

Given the above, the Commission does not accept:

1) the City's arguments for changes to its ammonia limits.

2) the City's arguments that it can meet its ammonia limits without nitrification.

Chapter 8: Conclusions and recommendations

Nutrient removal from Winnipeg wastewater

Conclusions

The Commission has been asked to provide advice on the following two issues:

a) The appropriate and sustainable level of nitrogen reduction, if any additional reduction is required, for the City of Winnipeg wastewater treatment facilities, in order to protect the receiving waters, including Lake Winnipeg.

b) The feasibility and sustainability of phasing in nitrogen reduction requirements later than ammonia and phosphorus reduction requirements.

At the outset of this report, the Commission identified a number of sustainable development principles and guidelines applicable to the issues at hand. These were the Prevention Principle (4), the Rehabilitation and Reclamation Principle (6), the Global Responsibility Principle (7) and the Waste Minimization and Substitution Guideline (5).

Based on the application of these principles and guidelines to the information presented in the preceding chapters, the

Commission has reached the following conclusions:

1) Phosphorus control should be the leading element in the provincial nutrient management strategy. City of Winnipeg phosphorus discharges from wastewater facilities should be set as low as possible. A desirable operating goal would be 0.5 milligrams of phosphorus per litre. The concentration of total phosphorus in the effluent on any day should not be in excess of 1.0 milligram per litre, as determined by the 30-day rolling average.

2) There is a body of evidence that links high nitrogen levels with the eutrophication of lakes.

3) The issues under consideration go beyond eutrophication in lakes. There are valid and responsible environmental reasons for the Province to also engage in nitrogen control measures, including nitrogen's impacts on marine waters, riverine environments, and biodiversity. Nitrogen discharges in City of Winnipeg wastewater are part of a global nitrogen cascade (the mobilization of reactive nitrogen in the air, water and soil) with negative environmental impacts. It is in keeping with Manitobans' global responsibilities to limit those discharges and, if not prevent, limit their negative impacts. This is also in keeping with the Precautionary Principle.

4) Phosphorus and nitrogen both play a role in contributing to the eutrophication of Manitoba waters. To address the damage that these nutrients have caused, they should be regulated in a way that contributes to the rehabilitation of the landscape. Nitrogen control measures must be managed in such a manner that changes in the nitrogen-to-phosphorus ratio do not stimulate the growth of nitrogen-fixing bacteria and algae. This means reductions in nitrogen and phosphorus discharges must be accomplished by maintaining the nitrogen-to-phosphorus mass ratio at 15:1.

5) By bringing the City of Winnipeg North and South End wastewater treatment plants into compliance with the nitrogen discharge requirements in the current *Environment Act* licences, the City will eliminate the threat that ammonia currently discharged by these plants presents to aquatic life.

6) The literature points out that biological nutrient removal represents the most environmentally sustainable and responsible approach to phosphorus, nitrogen and ammonia management. Removal processes that create increased sludge and render nutrients less available for use as fertilizer do not meet the test of sustainability. Biological nutrient removal is working effectively not only in Europe and Western Canada, but in Brandon and in the City of Winnipeg's West End wastewater treatment plant. It represents a forward-thinking approach that is rapidly becoming the norm.

7) The reclamation of phosphorus through biological nutrient removal (BNR) allows for the recycling of nutrients and is in keeping with the Guideline regarding waste minimization. An additional benefit of BNR is that the biological nitrification and denitrification of ammonia and nitrogen in City wastewaters complements biological phosphorus removal. The Commission is concerned that the City has chosen to only use chemical processes to remove phosphorus from its solid waste stream, thus negating many of the advantages associated with BNR. It urges the City to incorporate technologies that increase resource recovery and reduce sludge creation throughout its treatment system to the greatest extent possible.

8) Aside from the issue of sustainability, there are a number of advantages associated with biological nutrient removal processes in other locations. They include the ability to make future upgrades to enhanced nutrient removal, compatibility with struvite recovery, reduced operating costs (particularly, if they do not require the ongoing chemical inputs associated with chemical removal), and treatment of emerging potential contaminants of concern.

9) The potential exists that, in future years, the City of Winnipeg will be expected to further reduce the nutrient content of its wastewater effluent. In designing the coming upgrades, the City should give consideration to technologies that can be adapted to reduce discharges below those set in the current licence.

10) Regulation of phosphorus and nitrogen from point sources such as urban wastewater treatment systems should be a key element of the long-awaited provincial nutrient management strategy. The sooner the City of Winnipeg develops full nutrient management capability, the more effective role it will be able to play in implementing the provincial strategy. Phasing in nitrogen control is not appropriate.

11) Nutrient reduction in Manitoba waters is in large measure dependent on actions taken by jurisdictions beyond Manitoba's boundaries. Manitoba cannot expect transboundary cooperation in the reduction of nutrient loading unless it is prepared to reduce its point and non-point nutrient loads.

Recommendations

8.1) In order to protect the environment, City of Winnipeg wastewater treatment facilities must be regulated and operated in a manner that ensures the following:

a) Phosphorus discharges should be as low as possible. The concentration of total phosphorus in the effluent on any day must not exceed 1.0 milligram per litre, as determined by the 30-day rolling average. The City of Winnipeg should set itself an operating target of 0.5 milligrams per litre.

b) Nitrogen discharges must not exceed 15 milligrams per litre, as determined by the 30-day rolling average.

c) The mass ratio between nitrogen and phosphorus discharges must be maintained at 15:1.

d) Ammonia discharge limits must be based on the longest available period of record for river flow, a portion of no more than 75 per cent of the assimilative capacity of the receiving waters, and on the provisions of the draft *Manitoba Water Quality Standards, Objectives, and Guidelines*.

8.2) There are no economic or environmental benefits to be gained from phasing in nitrogen reduction requirements after meeting the ammonia and phosphorus reduction requirements. The City must continue to move towards removal of nutrients on the basis of the timetable mandated by its current *Environment Act* licences. This would mean full compliance by the end of 2012 for the South End Plant and by the end of 2014 for the North End Plant.

8.3) The City of Winnipeg should use nutrient removal processes, such as biological nutrient removal, that increase resource recovery and reduce the City's environmental footprint to the greatest extent possible.

The incremental impact debate

Arguments have been made to the effect that the reductions required by the current regulation will have no significant impact. The nitrogen limitation is usually the target of this line of argument with critics stating that nitrogen reduction will only result in a 1.73 per cent reduction in the total nitrogen load to Lake Winnipeg (see Table 4.2). It should be borne in mind that the phosphorus reduction, which is supported by all parties in this debate, would bring about a 3.43 per cent reduction in the total phosphorus load to Lake Winnipeg (see Table 4.2). Furthermore, the phosphorus limit will result in a load reduction of 275 tonnes, while the nitrogen limit will bring about a reduction of 1690 tonnes. Should one choose to, it is possible to minimize the significance of either one or both of these reductions. This, however, would be imprudent for four reasons.

First, as noted above, the nitrogen and phosphorus discharged from wastewater treatment plants are in forms that are most available for plant uptake and therefore are most likely to contribute to eutrophication. Controlling these sources will make a disproportionately greater contribution towards improving water quality than controls placed on many other contributors to the total nutrient load.

Second, because there are so many sources of nutrients to Lake Winnipeg, the measures taken at any one source are not likely to be of more than incremental significance. However, the overall impact of numerous small reductions can be significant. The Manitoba Government estimates that point sources in Manitoba account for 9 per cent of the phosphorus load and 5 per cent of the nitrogen load to Lake. The Manitoba Government also estimates that Winnipeg accounts for approximately 5 per cent of the phosphorus load and 4 per cent of the nitrogen load (see Tables 2.3 and 2.4). The City of Winnipeg estimated that in 2006 its wastewater treatment plants contributed 4.77 per cent of the phosphorus load and 3.36 cent of the nitrogen load (see Table 4.2). When compared to any other single source, these are large sources that can be effectively controlled. The 15-milligrams-per-litre (nitrogen) and 1-milligram-per-litre (phosphorus) limits will provide a 52 per cent reduction in the nitrogen load (according to the City, reducing it from 3,230 to 1,540 tonnes) and a 73 per cent reduction in the portion of the phosphorus load (according to the City, reducing it from 377 to 102 tonnes) coming from the City's wastewater treatment plants.

Third, the size of the nitrogen reduction is limited by the need to increase the nitrogen-to-phosphorus ratio. As the City of Winnipeg reduces its phosphorus discharge to levels below 1.0 milligram per litre, the City will be able to bring about further reductions in nitrogen discharges.

Finally, Manitoba is depending on upstream jurisdictions (which contribute more than fifty per cent of the nitrogen and the phosphorus load to Lake Winnipeg) to implement their own nutrient control measures. These measures will increase costs in those jurisdictions while providing only incremental reductions: if Manitoba declines to regulate its largest point source of nitrogen, it will be sending a powerful and negative message to other jurisdictions.

The argument that the reductions of either phosphorus or nitrogen are insignificant is a red herring. By complying with the regulation, the City will be behaving in an environmentally sustainable fashion and reducing its environmental footprint in a forward-looking manner.

Nutrient management and water policy in Manitoba

Conclusions

Through its review the Commission also came to the following conclusions relating to nutrient management and water policy in Manitoba.

1) The Manitoba Government must finalize its *Manitoba Water Quality Standards, Objectives, and Guidelines*.

2 The Manitoba Government must establish ecologically sensitive, long-term water quality guidelines and objectives that can be used to refine the *Manitoba Water Quality Standards, Objectives, and Guidelines*.

3) The Manitoba Government must complete its nutrient management strategy. For a variety of reasons, it is not appropriate to have the Lake Winnipeg Stewardship Board report serve as a stand-in for such a strategy. The goals of a nutrient management strategy must, by nature, be broader than the recovery of Lake Winnipeg and include all of Manitoba's waters.

4) The Manitoba Government should include annual maximum nutrient loads in future *Environment Act* licences for wastewater treatment plants. The loads should be part of the provincial nutrient management strategy and be based on the assimilative capacity of the watershed. As noted in Chapter 4, concentration-based limits may be appropriate for pollutants whose impact is reduced with dilution, but in the cases where the significance lies in the cumulative load, annual maximum loads are appropriate.

5) Through its consultations, the Commission was advised on several occasions that it may be necessary to reduce phosphorus loading to Lake Winnipeg by upward of 25 per cent to have any impact on the level of eutrophication in the lake. Manitoba's interim nutrient reduction goals of 13 per cent nitrogen and 10 per cent phosphorus should be replaced by long-term science-based goals and target dates for meeting those goals.

6) There is a need for additional reductions in non-point nutrient loading in Manitoba. Current regulations will not yield significant reductions from this sector. Reduction of nutrient loading from agriculture may require treatment of animal wastes, changes in application practices, changes in application rates, and improved retention of nutrients on the field and within the drainage and water collection system. In some cases, management practices developed in other locations can be adopted. In other cases, it will be necessary to develop Manitoba-specific practices. The Commission reminds the government that it recommended that the phosphorus regulation in the Livestock Manure and Mortalities Management Regulation needed additional study.

7) While Lake Winnipeg is a very complex system, the available information paints very simple pictures of this system. For example, there is a need for a much greater understanding of such issues as:

   - The role that the sediments play in sequestering and releasing these nutrients back to the water column.
   - The biodiversity status of the lake and opportunities for improvement of biodiversity.
   - The role of light limitation and hydrodynamics on algae and cyanobacteria.
   - The mobility of cyanobacteria in relationship to the

availability of various forms of nitrogen in the lake.

- Predation and the trophic cascade (impacts arising from changes in the food web).
- Nutrient cycles in the lake and watershed. A model should be developed that can simulate nutrient cycles in Lake Winnipeg and provide mass balance information.
- The effects of reactive nitrogen on the riverine, marsh and lake environments.
- There is a need for verification of the non-point nutrient loads and load sources to Lake Winnipeg. This would include natural background and undefined sources, agriculture, atmospheric deposition, and internal lake process, and nitrogen fixation.

The need for research into these areas applies not just to Lake Winnipeg but to the Manitoba watershed in general.

8) Many licences issued by Manitoba Conservation since 2005 do not include nutrient provisions while others require only nutrient monitoring. Most treatment plants do not appropriately address phosphorus and nitrogen removal. All new and expanding sewage treatment plants should be required to meet the nutrient discharge limits that are being mandated for the City of Winnipeg. The nutrient management strategy should establish a target date by which cities with populations over 10,000 and those in ecologically sensitive areas should have adopted nutrient removal processes.

9) There is a need for regulatory initiatives that would establish reasonable criteria for better management of septic fields, holding tanks and treatment lagoons. Many of these systems are contributing nutrients and contaminants to the watershed. Evidence was presented to the Commission of poorly sited, installed, and maintained septic fields and holding tanks. Some lagoons are undersized and, as a result, require permission from Manitoba Conservation to make emergency discharges. The nutrient management strategy should promote the regionalization of wastewater treatment and the phasing out of lagoon and septic systems wherever possible. Priority should be given to those systems that discharge directly into the Red River and Lake Winnipeg.

10) There is a need for an institution to coordinate watershed research in Manitoba. In its 2007 report on the sustainability of hog production in Manitoba, the Commission recommended that the Manitoba Government conduct, facilitate, collaborate on and commission research in a number of areas. The Commission noted that, in its universities and colleges the province had a well-developed set of resources that could be brought together to establish a multidisciplinary inter-institutional Watershed Studies Institute. Aside from carrying out research into watershed issues common to all Manitobans, the Institute could serve as a resource to the provincial government, municipalities, and conservation districts as they address watershed-planning issues. Such an institute could play an important role in addressing the numerous research questions that this investigation has identified.

11) One issue of ongoing concern for the Commission is the manner in which

compliance with *Environment Act* licences is currently monitored. At present the Manitoba Government relies on the licencee to provide all required reporting information. It rarely does its own monitoring or spot checks or requires independent scrutiny of these measurements. Independent scrutiny, verification, and monitoring will only help to standardize environmental data, improve the quality of information on Manitoba's ecosystems and identify potential areas of concern so that they can be addressed proactively. While the Commission is not making a recommendation on this point in this report, it wishes to record its concerns that Manitoba's long-term environmental sustainability would benefit from improved compliance monitoring performance standards.

Recommendations

Based on the above, the Commission is making the following recommendations:

8.4) The Manitoba Government immediately finalize and formally accept the *Manitoba Water Quality Standards, Objectives, and Guidelines*.

8.5) Within one year from the publication of this report, the Manitoba Government determine ecologically sensitive, long-term water quality guidelines, and objectives and use them to refine the *Manitoba Water Quality Standards, Objectives, and Guidelines* as required.

8.6) Within one year from the publication of this report, the Manitoba Government complete its nutrient management strategy. This strategy must incorporate, but must be broader than, the recovery of Lake Winnipeg. Elements of such a strategy should include:

- Long-term science-based goals for nutrient load and target dates for meeting those goals.
- Maximum annual nutrient load limits, as determined for the specific watershed need, to be incorporated into regulatory actions.
- Measures to reduce point source nutrient loading in Manitoba.
- Measures to reduce non-point source nutrient loadings in Manitoba.
- An ongoing research agenda and monitoring program.
- Publication of research and monitoring results.
- Support for new technologies and procedures for nutrient loading abatement and management.

8.7) A Watershed Studies Institute be established to coordinate information collection, analysis and evaluation, direct research and provide support to agencies and organizations undertaking watershed management in Manitoba. This is a reiteration of a recommendation made in the Commission's 2007 report on the sustainability of hog production in Manitoba.

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Appendix 1
Terms of Reference

Minister of Conservation

Legislative Building
Winnipeg, Manitoba, CANADA
R3C 0V8

SEP 2 6 2008

Mr. Terry Sargeant.
Chair, Clean Environment Commission
305-155 Carlton Street
Winnipeg MB R3C 3H8

Dear Mr. Sargeant:

I have announced that I would be asking the Clean Environment Commission (CEC) to review nutrient reduction and ammonia treatment at the City of Winnipeg's wastewater treatment facilities.

As you are aware, the CEC, in its 2003 report on the City of Winnipeg's wastewater collection and treatment systems, recommended that there should be a further review of the City's plan and that the review should be conducted by the Commission.

Therefore, pursuant to section 6(5) (a) and (c) of *The Environment Act*, I am asking that the CEC conduct an investigation and make recommendations to me regarding nutrient reduction and ammonia treatment at the City of Winnipeg's wastewater treatment facilities.

I have provided terms of reference which will help guide your consideration of this issue.

Thank you for undertaking this important task.

Yours sincerely,

Stan Struthers

Stan Struthers
Minister

Attachment

Appendix 2: Principles and Guidelines for Sustainable Development

Principles:

1 Integration of Environmental and Economic Decisions

1(1) Economic decisions should adequately reflect environmental, human health and social effects.

1(2) Environmental and health initiatives should adequately take into account economic, human health and social consequences.

2 Stewardship

2(1) The economy, the environment, human health and social well-being should be managed for the equal benefit of present and future generations.

2(2) Manitobans are caretakers of the economy, the environment, human health and social well-being for the benefit of present and future generations.

2(3) Today's decisions are to be balanced with tomorrow's effects.

3 Shared Responsibility and Understanding

3(1) Manitobans should acknowledge responsibility for sustaining the economy, the environment, human health and social well-being, with each being accountable for decisions and actions in a spirit of partnership and open cooperation.

3(2) Manitobans share a common economic, physical and social environment.

3(3) Manitobans should understand and respect differing economic and social views, values, traditions and aspirations.

3(4) Manitobans should consider the aspirations, needs and views of the people of the various geographical regions and ethnic groups in Manitoba, including aboriginal peoples, to facilitate equitable management of Manitoba's common resources.

4 Prevention

Manitobans should anticipate, and prevent or mitigate, significant adverse economic, environmental, human health and social effects of decisions and actions, having particular careful regard to decisions whose impacts are not entirely certain but which, on reasonable and well-informed grounds, appear to pose serious threats to the economy, the environment, human health and social well-being.

5 Conservation and Enhancement

Manitobans should

(a) maintain the ecological processes, biological diversity and life-support systems of the environment;
(b) harvest renewable resources on a sustainable yield basis;
(c) make wise and efficient use of renewable and non-renewable resources; and
(d) enhance the long-term productive capability, quality and capacity of natural ecosystems.

6 Rehabilitation and Reclamation

Manitobans should

(a) endeavour to repair damage to or degradation of the environment; and
(b) consider the need for rehabilitation and reclamation in future decisions and actions.

Global Responsibility

7 Manitobans should think globally when acting locally, recognizing that there is economic, ecological and social interdependence among provinces and nations, and working cooperatively, within Canada and internationally, to integrate economic, environmental, human health and social factors in decision-making while developing comprehensive and equitable solutions to problems.

Guidelines:

1 Efficient Use of Resources - which means

(a) encouraging and facilitating development and application of systems for proper resource pricing, demand management and resource allocation together with incentives to encourage efficient use of resources; and
(b) employing full-cost accounting to provide better information for decision makers.

2 Public Participation - which means

(a) establishing forums which encourage and provide opportunity for consultation and meaningful participation in decision making processes by Manitobans;
(b) endeavouring to provide due process, prior notification and appropriate and timely redress for those adversely affected by decisions and actions; and
(c) striving to achieve consensus amongst citizens with regard to decisions affecting them.

3 Access to Information - which means

(a) encouraging and facilitating the improvement and refinement of economic, environmental, human health and social information; and
(b) promoting the opportunity for equal and timely access to information by all Manitobans.

4 Integrated Decision Making and Planning - which means

encouraging and facilitating decision making and planning processes that are efficient, timely, accountable and cross-sectoral and which incorporate an inter-generational perspective of future needs and consequences.

5 Waste Minimization and Substitution - which means

(a) encouraging and promoting the development and use of substitutes for scarce resources where such substitutes are both environmentally sound and economically viable; and
(b) reducing, reusing, recycling and recovering the products of society.

6 Research and Innovation - which means

encouraging and assisting the researching, development, application and sharing of knowledge and technologies which further our economic, environmental, human health and social well-being.

Appendix 3: Consultations and submissions

Individuals and organizations consulted

Nicole Armstrong, Manitoba Water Stewardship

Bill Borlase, City of Winnipeg

Tracey Braun, Manitoba Conservation

Lynda Bunting, University of Regina

Nazim Cicek, University of Manitoba

Don Flaten, University of Manitoba

Gordon Goldsborough, University of Manitoba

Moira Greer, City of Winnipeg

Ray Hesslein, Department of Fisheries and Oceans

Kelly Kjartanson, City of Winnipeg

Peter Leavitt, University of Regina

Barry McBride, City of Winnipeg

David Morgan, City of Winnipeg (TetrES Consulting)

Jan Oleszkiewicz, University of Manitoba

Brian Parker, Environment Canada

Mike Patterson, Department of Fisheries and Oceans

Eva Pip, University of Winnipeg

George Rempel, City of Winnipeg (TetrES Consulting)

David Schindler, University of Alberta

Serge Scrafield, Manitoba Conservation

Mike Shkolny, City of Winnipeg

Mike Stainton, Department of Fisheries and Oceans

Nick Szoke, City of Winnipeg

Mike Van Den Bosch, Manitoba Conservation

Dwight Williamson, Manitoba Water Stewardship

Written Submissions

Anne Adkins and 62 other signatories, Concerned Scientists from Canada, the United States And Israel

Paul Campbell, Private

Peter Leavitt, University of Regina

Michael Trevan, University of Manitoba

Appendix 4: Glossary

The following glossary has been created as an aid in reading this report. As such the definitions focus on issues that are related to the report and are not intended as definitive statements about the various elements, compounds, processes, and life forms described below.

acidification: the process of making soils and water bodies more acidic through the inputs of chemicals.

aerobic: having or providing oxygen. In the case of biological nutrient removal, under anaerobic conditions, certain organisms will oxidize ammonia.

algae: simple, chlorophyll-containing organisms that live in most habitats, including aquatic habitats.

algal blooms: a rapid increase in the population of algae in an aquatic system, often recognized by discoloration of the water resulting from the high density of pigmented cells.

ammonia (NH_3): a compound of nitrogen and hydrogen that is a component of wastewater effluent. Since fish lack the mechanisms that most mammals have to prevent ammonia from building up in the bloodstream, ammonia can be toxic for aquatic species.

anaerobic: having or providing no oxygen. In the case of biological nutrient removal, anaerobic treatment zones (containing no dissolved oxygen or nitrates) cause certain organisms to release phosphorus (this allows them to absorb even greater amounts of phosphorus at a subsequent treatment stage).

anoxic: an inadequate supply of oxygen. In biological nutrient removal, anoxic zones have no dissolved oxygen, requiring organisms to draw their oxygen supply from nitrates leading to a process of denitrification

anthropogenic: impacts that are the results of human activity.

atomic ratio: ratio of atoms in a sample.

autotroph: organism that uses energy from light or inorganic chemical reactions to produce organic compounds from simple inorganic molecules.

benthic: the ecological region at the lowest level of a body of water.

biodiversity: variation of life forms within a defined area.

biological nutrient removal: the use of bacteria to mimic natural processes to remove nutrients from wastewater.

biomass: the mass of all the organisms of a given type and/or in a given area.

biosolids: sludge that has undergone a treatment process.

blue-green algae: (see cyanobacteria)

centrate: a nutrient-rich liquid produced from the dewatering of digested sludge.

Combined Sewer: a sewer system that provides partially separated channels for sanitary sewage and stormwater runoff. It is vulnerable to sewer overflows during peak rainfall events.

Combined Sewer Overflow (CSO): an apparatus built into a combined sewer system to allow a certain amount of flow to discharge into a water course untreated. This is done to keep the system from overflowing in storm conditions.

cultural eutrophication: increases in productivity and nutrient levels in water bodies that have arisen as the result of human activity.

cyanobacteria (blue-green algae): a species of phytoplankton that has been described as blue-green algae (although they are technically not algae since they do not have chloroplasts). Some cyanobacteria produce toxin and some are capable of fixing nitrogen from the atmosphere. Many have sheaths that allow them to bind with other cyanobacteria into floating colonies; they are often associated with large-scale algal blooms.

denitrification: a process that removes oxygen from nitrate and nitrite molecules, thereby reducing nitrates and nitrites to nitrogen gas (N_2). It is the final step in biological nitrogen removal.

dewatering: to remove water from, particularly in the case of large-scale processing or construction.

effluent: the outflow from a sewage treatment facility or the wastewater discharge from industrial facilities.

epiphytic: plants that grow on top of or are supported by other plants.

eutrophic: the lake productivity category associated with high levels of productivity and high nutrient levels.

eutrophication: increases in productivity and nutrient levels that result in excessive growth of organisms, particularly algae.

food web: a system of linked food chains.

hypereutrophic: the lake productivity category associated with very high levels of productivity and nutrients.

inorganic nitrogen: nitrogen not associated with organic material such as in plant or animal tissue. Inorganic nitrogen is available for plant uptake.

inorganic phosphorus: phosphorus not associated with organic material. Inorganic phosphorus is available for plant uptake.

law of the minimum: plant growth is limited by the nutrient in shortest supply relative to the plant's need for that nutrient.

littoral zone: the area of the lake near the shore.

leachate: the liquid formed when water percolates through landfill waste and carries with it contaminants leached from that waste.

lotic: swiftly moving water bodies.

macroinvertebrate: animals that lack a backbone and are visible to the naked eye.

macrophytes: aquatic plants large enough to be seen with the naked eye.

mesotrophic: the lake productivity category associated with water bodies with middling levels of productivity and nutrient levels.

nitrate (or nitrate-nitrogen (NO_3): an oxide of nitrogen; specifically one atom of nitrogen in combination with three atoms of oxygen. It is created in the biological removal of nitrogen from wastewaters.

nitrification: a process in which bacteria combines oxygen with nitrogen compounds (usually ammonia) to create nitrate-nitrogen (NO_3) and nitrite-nitrogen (NO_2). It is the first step in the biological removal of nitrogen.

nitrite (or nitrite-nitrogen (NO_2): an oxide of nitrogen; specifically one atom of nitrogen in combination with two atoms of oxygen. It is created in the biological removal of nitrogen from wastewaters.

nitrogen: a non-metallic chemical element and nutrient that is essential in the formation of proteins and nucleic acids. Nitrogen is one of the two most common nutrients in municipal wastewater.

nitrogen cascade: the primarily negative environmental effects that occur when excessive amounts of reactive nitrogen move through terrestrial, marine, freshwater, and atmospheric ecosystems.

nitrogen cycle: the chemical path of molecular nitrogen as it is transformed through fixation into forms of reactive nitrogen and back to its molecular state (N_2) through denitrification.

nitrogen fixation: the process by which atmospheric nitrogen is assimilated into organic compounds either in living organisms or through an industrial process.

non-point source: pollution from diffuse sources. Non-point pollution is caused by rainfall or snowmelt moving over and through the ground.

nutrient: a substance required for the nourishment of an organism. Nitrogen and phosphorus are the two most common nutrients in wastewater.

oligotrophic: the lake productivity category associated with unproductive water bodies with low nutrient levels.

organic nitrogen: nitrogen associated with organic material such as plant or animal tissue. Organic nitrogen is not available for plant uptake.

organic phosphorus: phosphorus associated with organic material such as in plant or animal tissue. Organic phosphorus is not available for plant uptake.

orthophosphate: an inorganic, stable phosphate, sometimes referred to as reactive phosphorus; it is the form used by plants.

oxide: compounds of oxygen and another element.

particulate phosphorus (PP): phosphorus in a sample that cannot pass through a 0.45 micron membrane filter.

periphyton: aquatic plant and animal organisms that attach to objects in the bed of a body of water.

phosphorus: a non-metallic chemical element and nutrient that is essential to such processes as heredity, muscle contraction, and photosynthesis. Phosphorus is one of the two most common nutrients in municipal wastewater.

phosphorus cycle: the path through which phosphorus in various forms circulates through nature. It differs from other major matter cycles in that it does not include a gaseous phase. Through the phosphorus cycle there is a steady loss of terrestrial phosphorus to the oceans.

physical/chemical removal of nutrients: the use of salts of iron, aluminum or lime to precipitate nutrients out of the wastewater.

phytoplankton: minute free-floating plants or plant-like organisms, including species often associated with lake eutrophication.

plankton: minute organisms that drift or float passively with the current in a sea or lake. The plankton community is made up of zooplankton and phytoplankton.

point source: a single identifiable localized source of pollution. In terms of water pollution, it generally refers to wastewater treatment plants or industrial operations that discharge effluent directly into water bodies.

reactive nitrogen: all active nitrogen compounds in the atmosphere and biosphere. It includes forms of nitrogen, such as ammonia and ammonium, nitric oxide, nitrogen dioxide, nitric acid, nitrous oxide, and nitrate, and organic compounds such as urea, amines, proteins and nucleic acids.

Redfield ratio: proportions of elements equal to 106 atoms of carbon per 16 atoms of nitrogen per 1 atom of phosphorus that exist in phytoplankton when nutrients are not limiting.

sludge: the semi-solid material residue created by wastewater treatment processes.

soluble phosphorus: phosphorus in a sample that can pass through a 0.45 micron membrane filter.

soluble reactive phosphorus (SRP): The portion of the soluble phosphorus that can be directly taken up by algae in water.

stratosphere: the second major layer of the atmosphere.

synthetic nitrogen: nitrogen that has been fixed and made reactive through an industrial process.

total Kjeldahl nitrogen (TKN): the sum of organic nitrogen, ammonia (NH_3) and ammonium (NH_4+) in a sample. It represents the fraction of total nitrogen that is unavailable for growth or bound up in organic form.

total nitrogen (TN): the total amount of nitrogen in a sample.

t**otal phosphorus (TP):** the total amount of phosphorus in a sample.

trophic cascades: the types of changes that come about when increases in certain predators in a food web lead to decreases in their prey, reducing the pressure on species further down in the food web.

trophic levels (food web): the position that an organism holds within a food chain or food web, with green plants forming the first level, herbivores the second, and carnivores a third.

trophic levels (lake productivity): categories to describe the level of plant and animal productivity in a water body, ranging from oliogotrophic to hypereutrophic.

troposphere: the lowest region of the atmosphere.

zooplankton: the microscopic or minute free floating animal component of plankton.