Lake Winnipeg Stewardship Board December 2006

Workshop 1 Report:

Setting Long-Term Ecologically-Relevant Nutrient Objectives for Lake Winnipeg (May 31, 2006)

Lake Winnipeg Nutrient Management Workshop
May 31, 2006

Working toward Long-Term, Ecologically-Relevant Nutrient Objectives for Lake Winnipeg

Printed December, 2006

Executive Summary

The development and implementation of long-term, ecologically-relevant water quality objectives for nutrients in Lake Winnipeg and its watershed is critical to the health of the lake. Once complete, these objectives will replace the interim objectives outlined in the Lake Winnipeg Action Plan. On May 31 2006, the Lake Winnipeg Stewardship Board hosted a workshop of approximately 50 scientists from across Canada and the northern United States to examine this issue, taking an important step toward the development of these objectives.

One of the goals of the workshop was to solicit input from participants on a set of nine draft principles prepared by the Science Committee of the Lake Winnipeg Stewardship Board to be considered by Manitoba Water Stewardship in establishing these nutrient objectives. Overall, the draft principles were viewed as a very good beginning for establishing the objectives. The valuable feedback received will be applied in refining these principles further.

Secondly, participants were asked to provide comment on a literature review prepared by North/South Consultants for Manitoba Water Stewardship. The review contains 1000 references of relevant literature that would be of assistance to the Department in setting long-term, ecologically-relevant nutrient objectives for Lake Winnipeg. It also presents an annotated bibliography of approximately 100 reports, and an overview of the collective research synthesizing relevant information in approximately 300 references. Overall, participants saw the literature review as a good compilation of current, available literature.

Workshop attendees were encouraged to provide additional references and cite other information sources that would enhance the body of information described in the literature review. Many new sources were provided.

In conclusion, those attending the workshop were asked to identify what they would view as the next critical steps toward setting long-term, ecologically-relevant nutrient objectives for Lake Winnipeg and its watershed. Three steps were identified. It was generally felt that the analysis and compilation of the vast amount of existing, relevant unpublished data was a key step in setting nutrient objectives. Secondly, many expressed the need to begin preparing hydrologic and nutrient models for Lake Winnipeg, using existing data now. And finally, most agreed that critical knowledge gaps will need to be filled. Many of these gaps will be revealed as the models are being developed and tested, helping to prioritize further information gathering and research.

Contents

Acknowledgements and Photo Credits

The Lake Winnipeg Stewardship Board would like to acknowledge those who have helped organizing the workshop: Sharon Gurney (Technical Secretariat to the Lake Winnipeg Stewardship Board), Alexandra Bourne (Manitoba Water Stewardship), and Bonnie Sutton (Manitoba Water Stewardship). The facilitation of the workshop provided by Don Flaten (Lake Winnipeg Stewardship Board, Science Committee) is greatly appreciated. The efforts of Buzz Crooks (Beaverbrook Communications) as workshop recorder and in the preparation of this report are also acknowledged.

Photographs for the report have been supplied by Greg McCulllough, Sharon Gurney, Sam Murdock, Alex Salki, staff of Manitoba Water Stewardship and others. These contributions are much appreciated.

Introduction

The issues relating to water quality in Lake Winnipeg in recent years are well documented. The increasing frequency and intensity of algal blooms on the lake have been noted by scientists and broadcast by the media. Evidence points to excessive nutrient enrichment from watershed sources as the leading cause of this problem.

Action is being taken by the Province of Manitoba to address this critical environmental challenge. In April 2000, the Province released a Draft Nutrient Management Strategy to address nutrient issues in Lake Winnipeg and its watershed. Work is progressing on the complex task of finalizing that strategy.

In February 2003, the Minister of Manitoba Conservation unveiled an action plan designed to implement measures to protect Lake Winnipeg. The Lake Winnipeg Action Plan identified a commitment to reduce nitrogen loading to the lake by 13 per cent and to reduce phosphorus loading by 10 per cent - the increases in nutrient loading estimated to have occurred since the early 1970s. The Plan also called for the establishment of the Lake Winnipeg Stewardship Board to assist the Province in implementing the Lake Winnipeg Action Plan, and to identify actions necessary to reduce nitrogen and phosphorous loading to Lake Winnipeg to pre-1970 levels. The Board was established in July 2003.

In its February 2005 Interim Report, the Lake Winnipeg Stewardship Board presented a series of recommendations for action directed at protecting Lake Winnipeg and improving its state of health. One of the 32 recommendations in the report emphasized the need for Manitoba Water Stewardship to continue its work towards completing the Nutrient Management Strategy and in particular, to formulate long-term, ecologically-relevant water quality objectives for nutrients in Lake Winnipeg. This was reinforced in the Lake Winnipeg Stewardship Board's November, 2006 Report to the Minister of Water Stewardship "Reducing Nutrient Loading to Lake Winnipeg and its Watershed - Our Collective Responsibility and Commitment to Action." Once completed, these objectives would replace the interim targets identified in the Lake Winnipeg Action Plan.

In the winter of 2005, Manitoba Water Stewardship contracted North/South Consultants of Winnipeg to identify and compile a listing of relevant literature to provide the necessary scientific information to assist the Department in setting long-term, ecologically-relevant nutrient objectives for Lake Winnipeg. As part of the contract, North/South also prepared an annotated bibliography of selected relevant nutrient-related research conducted on Lake Winnipeg, prairie ecosystems, marine waters, and other systems, as well as an overview of their research findings.

Concurrently, the Lake Winnipeg Stewardship Board's Science Committee developed a set of draft principles for Manitoba Water Stewardship to consider in the development of long-term, ecologically-relevant water quality objectives for nutrients in Lake Winnipeg.

Satellite image of Lake Winnipeg

On May 31 2006, the Science Committee of the Lake Winnipeg Stewardship Board hosted a workshop of approximately 50 scientists from across Canada and the northern United States to participate in a three-fold exercise. First, discussion was invited on the draft principles prepared by the Committee for setting long-term, ecologically-relevant nutrient objectives. Secondly, participants were asked to comment on the completeness and accuracy of the literature review prepared by North/South Consultants and to offer suggestions for additional material. And finally, those attending the workshop were asked to help in identifying key themes and approaches necessary to formulate long-term, ecologically-relevant nutrient objectives for Lake Winnipeg, as well as for the environments downstream of the lake and for upstream contributing watersheds.

The Nutrient Management Workshop was a critical step in the process of establishing long-term, ecologically-relevant nutrient objectives for the lake and its watershed. But, it is only a beginning. The next steps in the process will address filling the gaps in scientific information and working toward developing a nutrient water quality model for Lake Winnipeg. In the meantime, efforts will continue in developing, reviewing, and refining long-term, ecologically-relevant nutrient objectives for Lake Winnipeg and its watershed components.

Draft Principles for Setting Objectives

To assist Manitoba Water Stewardship in setting long-term, ecologically-relevant water quality objectives for nutrients within the Lake Winnipeg watershed, the Lake Winnipeg Stewardship Board's Science Committee developed a series of draft principles for consideration. These principles emphasize that to improve Lake Winnipeg ecosystem health it will be important to:

(1) preserve or restore the important ratio between nitrogen and phosphorus, and be reflective of both in-lake concentrations and watershed loadings;
(2) reflect but not necessarily restore the historical regime of nitrogen and phosphorus concentrations in Lake Winnipeg;
(3) ensure the healthy functioning of the Lake Winnipeg ecosystem;
(4) minimize the duration, frequency, and intensity of blue-green algal blooms including the need to minimize the production of algal toxins harmful to aquatic life, recreation and drinking water;
(5) minimize the duration, frequency, and intensity of blooms of other forms of algae including those leading to fouling of commercial and subsistence fishing nets or that otherwise interfere with the successful harvest of fish;
(6) ensure that an optimum balance is achieved between nutrient enrichment, productivity of the commercial and subsistence fishery and subsequent economic return to communities, while protecting the lake's ecosystem health and recreational uses;
(7) be protective of the downstream environment in the Nelson River and Hudson Bay;
(8) recognize water quality objectives established for the contributing watersheds, and that water quality objectives for nutrients established in the contributing watersheds need to recognize Lake Winnipeg; and
(9) consider the social and economic implications of implementation and compliance.

Overall, the draft principles were viewed as a very good beginning for establishing objectives.

One of the goals of the May 31, 2006 workshop was to solicit input from participants on whether the draft principles are complete, or if there are other items that should receive consideration in their further refinement and development. Overall, the draft principles were viewed as a very good beginning for establishing objectives and the effort put forth in preparing them was commended.

To enhance public understanding of the principles, and how they relate to the development of objectives, it was suggested that the principles should be translated into lay language. An introductory paragraph could be included to help the public make better sense of the principles. Related to that suggestion was a comment that perhaps the list is too long and since many of the principles are closely related, some may be combined and the list shortened.

It was emphasized that the objectives arising from these principles must be attainable, practical, well defined and based on the best available science. They will need to be prioritized and time lines for achievement determined. A monitoring program should be put in place to chart progress and ensure the objectives are met.

Lake Winnipeg research.

Many of the draft principles drew specific comment from the participants. Concerning Principle #1 - *preserve or restore the important ratio between nitrogen and phosphorus, and reflect both in-lake concentrations and watershed loadings* - one person observed that while the principle broadly describes the "important ratio between nitrogen and phosphorus", it does not relate the statement to the science associated with N:P ratios in aquatic systems. Another point of view suggested the wording "preserve or restore" suggests a static goal that may not be possible to achieve given on-going change.

Historical trends, as well as historical concentrations needed to be considered.

In relation to Principle #2 - *consider historical concentrations of nitrogen and phosphorus in Lake Winnipeg* – it was suggested that historical trends, as well as historical concentrations needed to be considered. Some also felt there is a need to go beyond strictly nutrients and consider the history of other elements such as sediment, climate, and flow rates, as these change over time.

Principle #3 - *ensure the healthy functioning of the Lake Winnipeg ecosystem* – also drew comment. A number of participants felt the issue of a healthy functioning ecosystem needed to be addressed with a more explicit definition. It was suggested a broader principle should make reference to issues such as oxygen depletion, and the entire spectrum of biological, chemical, and physical health of the lake.

Zebra mussels.

In terms of biodiversity of the ecosystem, some felt that going back in time was not likely an option since some species have already been lost and new species have been introduced. The principles should suggest a baseline – and perhaps aim at preventing any further degradation of the aquatic ecosystem.

Principle #9 – *consider the social and economic implications of implementation and compliance* – also generated a great deal of discussion centered primarily on whether these issues needed to be described in a principle. Some participants felt socio-economic issues would better be addressed in a preamble to the principles, rather than in a principle of their own. Another suggestion was that these issues be set aside for now, and left for the next phase which is presumably implementation of an action plan to achieve the objectives. One participant commented that economic, social, and cultural considerations should not be addressed at this point because these require a framework to determine "optimum balance", and defining those criteria requires explicit, quantitative treatments. This view was supported by another participant who pointed out that those involved at this point are (physical) scientists and since these factors may affect the implementation of the objectives, scientists should not attempt to define those interests.

The principles should consider the variations in characteristics between the north and south basins of Lake Winnipeg.

Other participants expressed the view that economic aspects are very important and Principle #9 should remain. It was suggested that at the very least, some re-wording of the principle could recognize there will be some costs to cleaning up the lake. During this discussion, Principle #6 - *ensure that an optimum balance is achieved between nutrient enrichment, productivity of the commercial and subsistence fishery, and subsequent economic return to communities, while protecting the lake's ecosystem health and recreational uses* - also received consideration.

As a general comment, it was suggested that the principles should consider the variations in characteristics between the north and south basins of Lake Winnipeg and the need to develop a range of nutrient objectives accordingly. The fact that Lake Winnipeg is a managed and regulated reservoir should be taken into consideration to deal with change in use, condition, and management approaches. The objectives and management approaches should be adapted to deal with further changes in the lake, such as the presence and possible further introduction of invasive species, and climate change.

The Literature Review

In late 2005, North/South Consultants of Winnipeg were contracted by Manitoba Water Stewardship to compile a review of relevant literature that would be of assistance to the Department in setting long-term, ecologically-relevant nutrient objectives for Lake Winnipeg. The resulting 450-page report, *"Literature Review Related to Setting Nutrient Objectives for Lake Winnipeg, May 2006"*, contains a listing of 1000 key references, an annotated bibliography of approximately 100 reports, and an overview of the collective research synthesizing relevant information in approximately 300 references. The report may be viewed on the "publications" page of the Lake Winnipeg Stewardship Board's website www.lakewinnipeg.org.

Workshop attendees were provided a copy of the literature review prior to the workshop and asked to be prepared to comment on the completeness and relevance of the review and to offer suggestions of other studies and sources of information that might be helpful in setting long-term, ecologically-relevant nutrient objectives for Lake Winnipeg. The intent was not to revise or re-write the literature review, but to use it as a base upon which to build.

The workshop was divided into discussion groups for three separate breakout sessions. Each session had a different focus – Lake Winnipeg, the lake's upstream and downstream waters, and finally an examination of the best strategy and probable next steps toward setting objectives for the lake. For each session, a set of questions was presented for group discussion and comment.

1. Lake Winnipeg

1a. Does the review contain the key papers and reports from research conducted on Lake Winnipeg that are directly relevant to setting long-term, ecologically-relevant nutrient objectives for Lake Winnipeg?

In general, the literature review for Lake Winnipeg itself was considered to be well done.

In general, the literature review for Lake Winnipeg itself was considered to be well done, and a good review of peer-review literature. At the same time, however, it was generally acknowledged that not a lot of Lake Winnipeg historical data exists in published form, and that reports specifically on Lake Winnipeg are relatively sparse.

The consensus was that there is a large amount of "grey" literature that may be available but not published. "Grey" literature refers to reports, study results, papers, and data that exist within various branches of government and other agencies that have not been made public nor widely circulated internally. One example cited was data and information on commercial fishing collected by the Manitoba Fisheries Branch. In addition, a number of relevant undergraduate and graduate thesis' are available from libraries at the universities of Manitoba and Winnipeg.

Commercial fishing on Lake Winnipeg.

Attention was drawn to a number of bodies of information and specific reports which are not referenced in the literature review. These include topics such as water movement and mixing in the lake (Kenney, 1979), studies related to groundwater contributions to the lake conducted by Natural Resources Canada/Geological Survey of Canada, and work conducted by Environment Canada on nutrient loading. Noting a lack of reports concerning water balance, water budget, and in-lake dynamics, several participants suggested that the Churchill and Nelson Rivers Study Board reports on studies conducted prior to the regulation of Lake Winnipeg could also be included as a potential source of valuable information on the lake.

Others expressed a need for more information regarding water uses of the lake including human consumption, hydroelectric generation, fisheries, recreation, and agricultural uses. Information about the role the lake plays in providing natural habitats would be a useful addition. It was suggested that other data, such as demographics and economic importance of the lake and surrounding area, should be included.

It was recognized that most Traditional Knowledge does not exist in printed form.

Traditional Knowledge – historical and first-hand knowledge held by First Nations people and commercial fishers in particular – has not been referenced. However, it was also recognized by participants that most of this information does not exist in printed form.

Other information gaps identified related to the hydrology of the system prior to lake regulation and the impacts of regulation on nutrients. It was suggested that data related to atmospheric deposition of nitrogen and phosphorus may be limited.

Following the workshop, participants provided citations for additional literature that may be helpful during the process of setting nutrient objectives for Lake Winnipeg. See Appendix B for a listing of these references.

1b. Does the review address the key principles developed from research conducted elsewhere that are likely to apply to Lake Winnipeg's nutrient situation?

Nutrient management strategies unique to the Lake Winnipeg situation will need to be developed.

Many participants felt that current, recent literature was well summarized in the review, and it adequately examined all peer-reviewed principles of lake nutrient management on lakes in other parts of the world. However, since these are based mostly on European lakes, caution was offered in attempting to transfer this data directly to Lake Winnipeg due to its unique morphology and geology. While studies conducted on other lakes can provide important information for comparison, nutrient management strategies unique to the Lake Winnipeg situation will need to be developed.

Some felt a more focused section on eutrophication and limnology studies of large, shallow lakes would have been helpful. It was suggested that data from throughout the world such as Lake Okechobee (Florida), Lake Balaton (Hungary), and Lake Champlain (New York/Vermont) may be useful for future reference. Also, data gathered and lessons learned on Lake Erie should prove valuable. These include Lake Erie studies relating the improvement in the walleye fishery and on changes in total phosphorus in the water column over time conducted by Murray Charlton of Environment Canada's National Water Research Institute.

Lake Winnipeg wetland.

Information relating to dynamic mass balance models is required. These models are key in enabling translation of target nutrient concentrations into desirable nutrient loads. The models should take into consideration re-suspension, internal loading, and retention.

Many felt that discussion related to studies on bio-availability of phosphorus and nitrogen could have been expanded in the review. It was noted that several studies are listed in the references, but not dealt with in the text. It was also suggested that more information on the roles and relationships of alga-toxins and nutrients would have been a valuable addition to the review. Some suggested the review was short on reports and information about the land/water interface and the roles of deltas, shallow bays, and wetlands in nutrient filtering and cycling. Background literature on urban, rural residential, recreational, and agricultural loading of nutrients was also limited.

Some participants felt that discussion of ultraviolet light and light limitation within the water column should have been included. Other information that could have been added to the review include the importance of iron to cyanobacteria, lake recovery responses in the European experience, and papers related to circulation and fluid dynamic studies that will assist in understanding nutrient cycling and transport in Lake Winnipeg.

1c) Is there critical information about Lake Winnipeg's status that is being collected or processed but is not published, yet?

Most workshop participants agreed that there is a great deal of information that has been gathered but not yet published. The same applies for data that has been collected but not yet analyzed, citing lack of resources, including qualified staff. It was recognized that much of this data needs to be compiled and analyzed. Some expressed concern that the science is not yet in place to allow for the development of long-term, ecologically-relevant objectives. Analysis of existing data would be an important step forward.

Most agreed that there is a great deal of information that has been gathered but not yet published.

Updated loading calculations for the Winnipeg River, the Saskatchewan River, and the Red River would be helpful. Additional information being assembled by the International Water Institute located at the North Dakota State University in Fargo may be available to update loadings from the United States portion of the basin.

Water balance data are needed. Some felt that enough pertinent data exists at sources such as Manitoba Hydro and the Water Survey of Canada to allow modeling of the water budget.

Other examples of information and data that exist but are not yet fully published were put forward. These include:

- Algal community – seasonal and spatial distribution, historical changes in species composition;
- Algal toxins;
- *Escherichia coli* and other pathogens;
- Sediment cores of the Lake Winnipeg lake bottom / lake history reconstruction, including work on linking algal/benthic remains to historic lake chemistry;
- Sediment phosphorus data;
- Lake Winnipeg Research Consortium abstracts and summary reports;
- Zoobenthos data collected by researchers at the University of Manitoba; and
- Under-ice studies.

Blue-green algal bloom at Grand Beach, Lake Winnipeg (August 2006).

2. Upstream and Downstream Waters

2a. Does the review contain the key papers, reports and principles that are directly relevant to setting long-term, ecologically-relevant nutrient objectives for the watershed upstream from Lake Winnipeg?

North Dakota, Minnesota, and Manitoba have been conducting a bio-monitoring project on the main stem of the Red River.

Given there are a limited number of published studies in existence, participants generally felt the review did a good job of including relevant papers, reports and principles. A number of other literature sources were suggested. It was mentioned that Alberta Environment has several reports on the North and South Saskatchewan rivers. The City of Saskatoon and Saskatchewan Environment have completed reports on the South Saskatchewan River near Saskatoon. Canada/ Saskatchewan study reports on the Qu'Appelle River system are also available.

One participant noted that the review does not contain recent information on sediment dynamics in the Red River. Relevant publications such as those by the Geological Survey of Canada on sediment budgets may be useful. Some felt the water quality data for the Red River on the U. S. side of the border had not been covered in depth in the literature review and suggested data collected in Minnesota on the bio-availability of phosphorus and nitrogen in the upper Red River are accessible. Others pointed out that North Dakota, Minnesota, and Manitoba have been conducting a bio-monitoring project on the main stem of the Red River through the International Joint Commission's Red River Board which may provide valuable data.

More references to in-stream processes should be added to the list of relevant studies.

It was suggested that more information on macro-invertebrates and their role in processing nitrogen and phosphorus in rivers and streams should be considered. Examples provided of studies include mollusc studies done at Lakehead University, other mollusc studies conducted in Manitoba and Saskatchewan, and similar U.S. Environmental Protection Agency-funded projects completed in North Dakota and Montana.

It was suggested that work done by Andrew Sharpley (United States Department of Agriculture, Agriculture Research Service) on phosphorus sorption/desorption capacity of stream sediment could also be added to the relevant literature base.

Some felt more references to in-stream processes, nutrient sources and sinks, macrophytes, periphyton, and the effects of light limitations in turbid rivers and streams should be added to the list of relevant studies. The *River Continuum Concept*, published in 1980 by R. L. Vannote et. al. provides an excellent resource on in-stream processes.

Other suggestions included reports discussing increasing nutrients to the Winnipeg River, information on rivers and streams on the east side of Lake Winnipeg, and publications on upstream lakes such as Lake Winnipegosis and Lake Manitoba.

2b. Does the review contain the key papers, reports and principles that are directly relevant to setting long-term, ecologically-relevant nutrient objectives for the watershed downstream from Lake Winnipeg?

It was acknowledged that while published information is scarce and data are limited, most of the available information appears to be listed in the review.

However, a number of those at the workshop felt a significant omission from the review was the Churchill and Nelson Rivers Study Board reports, circa 1975. This series of reports was prepared as a prelude to regulating Lake Winnipeg and contains some nutrient and water quality information relevant to the task in hand. In addition, a Federal-Provincial Ecological Monitoring project 1986-89 report on water quality of Churchill and Nelson rivers may also provide useful additional information. It was mentioned that the publication *Rivers of North America* by Arthur Benke and Colbert Cushing, editors (2005) contains a chapter by Dave Rosenberg et al on the Churchill/Nelson. The publication also references the Saskatchewan, Red, and Winnipeg rivers.

Some felt that the main focus should be on improving the water quality in Lake Winnipeg, believing this should translate into improvements to the system downstream of the lake by default. However, there was an expressed concern over the lack of data and research activities downstream of the lake. Some felt that outflow from the lake is not well sampled and that data such as the amount of nitrogen and phosphorus leaving Lake Winnipeg and residence times in the Nelson River are unavailable or sparse. The impact of nutrient loading on Hudson Bay is largely unknown. References to ArcticNet studies (conducted at York University) should be included.

There was an expressed concern over the lack of data and research activities downstream of the lake.

One participant said there is also a knowledge gap related to the impact of climate change on nitrogen transfer through the Nelson River to Hudson Bay, and expressed concern that wet and dry cycles in the boreal region may lead to an increase in the release of nitrous oxide.

2c. Is there critical information about Lake Winnipeg's upstream and downstream waterways that is being collected or processed but is not published, yet?

As was the case with Lake Winnipeg itself, participants cited many sources of unpublished data available for areas both upstream and downstream of the lake.

Stream water quality data for agricultural streams in southwestern Manitoba is available from the National Agri-Environmental Standards Initiative. The South Tobacco Creek study near Miami Manitoba is also a source of water quality data as it relates to small, agricultural watersheds. There exists a set of unpublished data from the University of Brandon on the Assiniboine River.

Water quality sampling station on the Red River at Lockport.

Algal studies on the periphyton communities in the Assiniboine River and the Souris River have been conducted by the University of Manitoba, Manitoba Water Stewardship, and others.

Water quality data collected in North Dakota and Minnesota on tributaries to the Red River are available. A study of the effect of dams on the Winnipeg River is being conducted by researchers at the University of Winnipeg. Other nutrient data from Manitoba streams and rivers has been collected by the Department of Fisheries and Oceans in Winnipeg, and Environment Canada.

Other potential sources of upstream data include data collected from the Ontario Ministry of the Environment in the Lake of the Woods watershed, fisheries data upstream and downstream of Grand Rapids dam just prior to Lake Winnipeg regulation, and data from Cedar Lake. Downstream, water quality data on Nelson River is being collected by Manitoba Hydro and analyzed by North/South Consultants. Water quality monitoring on the Nelson River is also being conducted by the Norway House community. The Department of Fisheries and Oceans has also been monitoring contaminants at the mouth of the Nelson River. Manitoba Water Stewardship has data related to phytoplankton in Cross Lake for the 1980s.

In general, wastewater treatment and discharge data for Manitoba communities, including Winnipeg, are available by municipality. Point source locations can be determined from Environment Act licenses issued by Manitoba Water Stewardship. A large amount of historic water quality monitoring data from Manitoba lakes and streams are available from Manitoba Water Stewardship.

Other sources of information suggested include study reports prepared by the International Joint Commission, the Prairie Provinces Water Board, and Manitoba Clean Environment Commission public hearing reports available in public registries. It was also noted that Manitoba's conservation districts have a large amount of unpublished data.

The value of Traditional Knowledge was once again emphasized.

Cottage country, Northwestern Ontario.

Nelson River at Norway House.

3. What should we do next?

3a. Given the information that we have, what is the best overall strategy for setting long-term, ecologically-relevant nutrient objectives for Lake Winnipeg and its upstream and downstream waters?

Many felt that the development of a strategy must begin with defining acceptable biological change and ecological condition. This will form the basis by which objectives may be set.

Setting long-term ecologically-relevant nutrient objectives may be best accomplished through the use of a variety of approaches including using models, paleolimnological data, or the use of reference lakes and streams. Setting nutrient objectives will need to be considerate of the biological response. Dynamic mass balance models could be used to evaluate anticipated changes in ecosystem food web structure. It will be important to understand algal-nutrient relationships in Lake Winnipeg. Nutrient objectives for Lake Winnipeg will need to consider not only ecological responses in the lake, but also the socio-economic impacts of achieving those objectives.

Setting objectives may be best accomplished through the use of a variety of approaches including using models, paleolimnological data, or the use of reference lakes and streams.

While knowledge of the condition of the lake in times past is useful, historic records should not be used as the only tool to set the objectives. It was recognized by the participants that the lake is dynamic and not in a state of equilibrium. Lake Winnipeg is different today than it was in the past, and it will never be exactly the same again. This is in part due to the arrival of new invasive species such as the rainbow smelt, and in part because the lake is now regulated. Also, natural occurrences such as wet and dry cycles are difficult to predict and these cycles will influence water quality in the lake.

The lake is dynamic and not in a state of equilibrium.

Several participants agreed it is important that the message to the public in developing a strategy should clearly state that the goal is not to return the ecosystem to its historic condition, because that cannot be achieved. Instead, the expressed objective should be to move towards a healthier functioning ecosystem in Lake Winnipeg, in consideration of the important economic and social interests of the residents in its watershed.

It was recommended that separate objectives should be set for the south basin and north basin of Lake Winnipeg, given their significant differences. The use of data and information from similar large, shallow lakes may provide a useful guide.

It was acknowledged that the current nutrient objectives for Lake Winnipeg as outlined in the Lake Winnipeg Action Plan are only interim targets, and that these will be replaced with long-term, ecologically-relevant objectives. The need to begin reducing nutrient loads to Lake Winnipeg even in the absence of these long-term, ecologically-relevant objectives was generally recognized.

Many participants suggested that for the long term, the best strategy would be to manage nutrients in the entire ecosystem – both aquatic and terrestrial – through an integrated watershed management approach.

Lake Winnipeg algal bloom.

3b. What are the critical next steps for developing those objectives?

Three steps for setting long-term, ecologically-relevant nutrient objectives for Lake Winnipeg and its associated rivers were identified during the workshop.

It will be important to analyze and compile the existing unpublished data and make this data available in an accessible database.

i) Collect, evaluate, and analyze existing data

Participants recognized that it will be important to analyze and compile the vast amount of existing unpublished data and make this data available in an accessible database. This data and information will be critical to the development of models for the lake. A framework for data coordination and integration will be required. It may be necessary to prioritize which data should be analyzed and interpreted first.

Resources (staff and money) will be required to take data that has already been gathered and move it to publication. Taxonomic experts need assistance in analyzing samples and interpreting existing data. At the moment, there is a shortage of properly trained personnel to carry out these tasks.

In the meantime, a focused data collection and monitoring effort should continue to ensure the most critical information gaps are filled first.

Existing information and data gaps can be filled over time as required.

ii) Modelling using existing data.

In spite of the acknowledged gaps, there still is a vast amount of information and data available for Lake Winnipeg and its watershed. Most of those attending the workshop expressed a need to begin modeling work now, using the existing data. Building and testing the models in the field may help identify key information gaps which will determine priorities in data gathering.

Models will need to include the complex hydrological and mixing regimes in Lake Winnipeg's basins, and be considerate of spatial and temporal variation. It will be important to understand how and when nutrients, energy, and biota/materials are transported through the system. An understanding of sedimentation within the lake will also be required.

iii) Fill knowledge gaps

The use of various models may help reveal critical knowledge gaps. Currently, there is a limited understanding of current trophic structure, oxygen regimes, in-lake hydrological conditions, and nitrogen and carbon cycles in Lake Winnipeg.

Over time, the gaps can be filled by analyzing existing information and with the collection of additional data as required.

Lake Winnipeg research vessel Namao.

Moving Forward – Next Steps

The May 31 2006 Nutrient Management Workshop summarized in this report was a critical step in the process of developing long-term, ecologically-relevant water quality objectives for nutrients in Lake Winnipeg, and its downstream environment and upstream watersheds. Once completed, these objectives will replace the interim targets identified in the Lake Winnipeg Action Plan announced on February 18, 2003.

Next steps in the process of developing long-term, ecologically-relevant water quality objectives for nutrients in Lake Winnipeg will need to include the following:

- Fill critical science gaps such as estimating the pre-historical nutrient regime of Lake Winnipeg through assessment of the paleolimnological algal record in lake bottom sediments;
- Undertake further work to develop a water quality nutrient model for Lake Winnipeg;
- Propose draft long-term, ecologically-relevant water quality objectives for Lake Winnipeg;
- Convene a second workshop to critically review the proposed draft, long-term, ecologically-relevant water quality objectives;
- Propose water quality objectives for the Lake Winnipeg downstream environment and for its upstream contributing watersheds; and
- Undertake a focused public and scientific review of the proposed objectives for Lake Winnipeg, the downstream environment, and its upstream contributing watersheds.

Appendix A: Workshop Agenda

Setting of Long-Term Ecologically-Relevant Nutrient Objectives for Lake Winnipeg

Lake Winnipeg Stewardship Board's Science Committee
Wednesday, May 31, 2006.
Freshwater Institute, University of Manitoba Campus, 501 University Crescent

Workshop Objectives

(1) To gather feedback on the "draft principles needed to establish long-term, ecologically-relevant water quality objectives for nutrients for Lake Winnipeg, its contributing basin, and its downstream environment." (Note: a copy of these draft principles is attached to the end of this agenda).

(2) To discuss the literature review prepared by North South Consultants for its completeness and accuracy.

(3) To identify key themes and approaches that should be used to develop long-term, ecologically-relevant water quality objectives for nutrients and development of subsequent nutrient management reduction strategies for Lake Winnipeg.

Agenda and Schedule

8:00 - 8:30	*Registration*, Coffee, Networking.
8:30 - 8:40	*Welcome.* Bill Barlow, Chair, Lake Winnipeg Stewardship Board.
8:40 - 9:00	*Background*; purpose of workshop; introduction of facilitator and recorder; major water quality issues facing Lake Winnipeg, next steps subsequent to workshop. Expected outcomes from the workshop. Dwight Williamson, Manitoba Water Stewardship.
9:00 - 9:30	*Overview Presentation: "Description of the Lake"* (Section 3 of the North/South Consultants Report), and overview of problems facing Lake Winnipeg. Friederike Schneider-Vieira, North/South Consultants.
9:30 - 10:00	*Group Session (1)*: Review of "Principles for Setting Ecologically-Relevant Water Quality Objectives for Nutrients for Lake Winnipeg". Overview Presentation – Dwight Williamson Discussion and Feedback Session.
10:00 - 10:30	Health Break
10:30 - 11:00	*Overview Presentation: "Nutrient Enrichment: Lakes"* (Section 4 of the North/South Consultants Report) Friederike Schneider-Vieira, North/South Consultants.
11:00 - 12:15	*Breakout Session (1)*: "Lake Winnipeg Issues (Section 3) and Nutrient Enrichment: Lakes" (Section 4).
12:15 – 1:00	Lunch Break
1:00 - 1:20	*Overview Presentation: "Rivers and Streams"* (Section 5), *and "Marine/Estuaries"* (Section 6 of the North/South Consultants Report). Friederike Schneider-Vieira, North/South Consultants)
1:20 - 2:00	*Breakout Session (2)*: "Rivers and Streams" (Section 5.0), "Marine/Estuaries" (Section 6.0)Breakout groups
2:00– 3:00	Reporting back from breakout groups on Sections 4, 5 and 6 of the North South Consultants Report.
3:00 – 3:15	Health Break
3:15 - 4:25	*Overview Presentation: "Towards Development of Nutrient Criteria"* (Section 7 of the North South Consultants Report). Friederike Schneider-Vieira, North South Consultants. *Breakout Session (3)*; Reporting back from breakout groups on Section 7.
4:25 - 4:30	*Wrap-up and next steps*; Key themes arising from the workshop. Dwight Williamson, Manitoba Water Stewardship.

Appendix B – Workshop Participants

Facilitator: Don Flaten
Lake Winnipeg Stewardship Board, Winnipeg, Manitoba
don_flaten@umanitoba.ca

Ackerman, Joe
University of Manitoba, Winnipeg, Manitoba
joe.ackerman@gmail.com

Barlow, Bill
Lake Winnipeg Stewardship Board, Gimli, Manitoba
wilbar@mts.net

Bourne, Alexandra
Manitoba Water Stewardship, Winnipeg, Manitoba
abourne@gov.mb.ca

Carey, John
National Water Research Institute, Burlington, Ontario
john.carey@ec.gc.ca

Chambers, Patricia
National Water Research Institute, Burlington, Ontario
patricia.chambers@ec.gc.ca

Charlton, Murray
Environment Canada, Burlington, Ontario
murray.charlton@ec.gc.ca

Conly, Malcolm
Environment Canada, Saskatoon, Saskatchewan
malcolm.conly@ec.gc.ca

Coughlin, Sarah
Eastern Interlake Conservation District, Arborg, Manitoba
eicd@mts.net

Coughlin, Warren
Manitoba Water Stewardship, Gimli, Manitoba
wcoughlin@gov.mb.ca

Donald, David
Environment Canada, Regina, Saskatchewan
david.donald@ec.gc.ca

Ell, Mike
North Dakota Department of Health, Bismarck, North Dakota
mell@state.nd.us

Findlay, David
Department of Fisheries and Oceans, Winnipeg, Manitoba
findlayd@dfo-mpo.gc.ca

Franzin, Bill
Department of Fisheries and Oceans, Winnipeg, Manitoba
franzinw@dfo-mpo.gc.ca

Fudge, Bob
Department of Fisheries and Oceans, Winnipeg, Manitoba
fudger@dfo-mpo.gc.ca

Gillis, Darren
University of Manitoba, Winnipeg, Manitoba
dgillis@umanitoba.ca

Glozier, Nancy
Environment Canada, Saskatoon, Saskatchewan
nancy.glozier@ec.gc.ca

Gurney, Sharon
Lake Winnipeg Stewardship Board, Winnipeg, Manitoba
sgurney@gov.mb.ca

Hann, Brenda
University of Manitoba, Winnipeg, Manitoba
hann@ms.umanitoba.ca

Hendzel, Len
Department of Fisheries and Oceans, Winnipeg, Manitoba
hendzell@dfo-mpo.gc.ca

Hobson, Keith
Environment Canada, Saskatoon, Saskatchewan
keith.hobson@ec.gc.ca

Kling, Hedy
Algal Taxonomy and Ecology, Inc., Winnipeg, Manitoba
hkling@mts.net

Koroluk, Glen
Manitoba Eco-Network, Winnipeg, Manitoba
mpo.gc.cawater@mbeconetwork.org

Kotak, Brian
Miette Consultants, Pine Falls, Manitoba
miette@granite.mb.ca

Kristofferson, Al
Lake Winnipeg Research Consortium, Winnipeg, Manitoba
krsitofa@dfo-mpo.gc.ca

Lawrence, John
Environment Canada (NHRI), Burlington, Ontario
j.lawrence@ec.gc.ca

Loadman, Nancy
University of Winnipeg, Winnipeg, Manitoba
n.loadman@uwinnipeg.ca

Lukovich, Jennifer
University of Manitoba, Winnipeg, Manitoba
jvlu@mts.net

Matkowski, Shelley
Manitoba Hydro, Winnipeg, Manitoba
smatkowski@hydro.mb.ca

McCullough, Greg
University of Manitoba, Winnipeg, Manitoba
gregmccullough@shaw.ca

McDougal, Rhonda
Manitoba Water Stewardship, Winnipeg, Manitoba
rmcdougal@gov.mb.ca

Molot, Lewis
York University, Toronto, Ontario
lmolot@yorku.ca

Morgan, Dave
TetrES Consulting, Winnipeg, Manitoba
dmorgan@tetres.ca

Nelson, Richard
U.S. Bureau of Reclamation, Bismarck, North Dakota
rnelson@gp.usbr.gov

Paton, Bill
University of Brandon, Brandon, Manitoba
patonw@brandonu.ca

Pip, Eva
University of Winnipeg, Winnipeg, Manitoba
eva.pip@uwinnipeg.ca

Salki, Alex
Lake Winnipeg Stewardship Board, Winnipeg, Manitoba
salkia@dfo-mpo.gc.ca

Salvano, Esther
Manitoba Agriculture, Food and Rural Initiatives,
Winnipeg, Manitoba
esalvano@gov.mb.ca

Schneider-Vieira, Friederike
North/South Consultants,Winnipeg, Manitoba
fschneider@nscons.ca

Schreyer, Ed
Lake Winnipeg Stewardship Board, Winnipeg, Manitoba
erschreyer@shaw.ca

Scott, Karen
Lake Winnipeg Research Consortium, Winnipeg, Manitoba
outreach@lakewinnipegresearch.org

Stainton, Mike
Department of Fisheries and Oceans, Winnipeg, Manitoba
staintonm@dfo-mpo.gc.ca

Szoke, Nick
Lake Winnipeg Stewardship Board, Winnipeg, Manitoba
nzsoke@winnipeg.ca

Wakelin, Sarah
Manitoba Hydro, Winnipeg, Manitoba
swakelin@hydro.mb.ca

Wassenaar, Len
Environment Canada, Saskatoon, Saskatchewan
len.wassenaar@ec.gc.ca

Watson, Sue
National Water Research Institute, Burlington, Ontario
sue.watson@ec.gc.ca

Williamson, Dwight
Lake Winnipeg Stewardship Board, Winnipeg, Manitoba
dwilliamso@gov.mb.ca

Zbigniewicz, Halina
Lake Winnipeg Stewardship Board, Winnipeg, Manitoba
hszbigniewicz@hydro.mb.ca

Workshop participants.

Appendix C - Additional Papers, Reports, Other Sources

Following is a list of papers and reports, in addition to those listed in the Literature Review, submitted by participants of the workshop that may prove useful in the development of objectives for Lake Winnipeg.

Carlson, R.E. 1977. A trophic status index for lakes. Limnology and Oceanography. 22(2): 361-369.

Childers, Daniel L. Boyer, Joseph N. Davis, Stephen E. Madden, Christopher J. Rudnick, David T. Sklar, Fred H. 2006. Relating precipitation and water management to nutrient concentrations in the oligotrophic “upside-down” estuaries of the Florida Everglades. Limnology and Oceanography. Volume 51. Issue 1. Pages 602-616.

Chróst, Ryszard J. Siuda, Waldemar. 2006. Microbial production, utilization, and enzymatic degradation of organic matter in the upper trophogenic layer in the pelagial zone of lakes along a eutrophication gradient. Limnology and Oceanography. Volume 51. Issue 1. Pages 749-762.

Dillon, P.J., Rigler, F.H.1974. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. Journal of the Fishers Research Board of Canada. Vol. 31 pg 1771-1778.

Dillon, P.J. Rigler, F.H. 1975. A simple method for predicting the capacity of a lake based on a lake trophic status. J. Fish. Res. Board Can.; 32: 1519-1531.

Erlandsson, Carina P. Stigebrandt, Anders. Arneborg, Lars. 2006. The sensitivity of minimum oxygen concentrations in a fjord to changes in biotic and abiotic external forcing. Limnology and Oceanography. Volume 51. Issue 1. Pages 631-638.

Fisher, T. R., Hagy, J. D. III, Boynton, W. R. Williams, M. R. 2006. Cultural eutrophication in the Choptank and Patuxent estuaries of Chesapeake Bay. Limnology and Oceanography. Volume 51. Issue 1. Pages 435-447.

Gaiser, Evelyn E. Childers, Daniel L. Jones, Ronald D. Richards, Jennifer H. Scinto, Leonard J. Trexler, Joel C. 2006. Periphyton responses to eutrophication in the Florida Everglades: Cross-system patterns of structural and compositional change. Limnology and Oceanography. Pages 617-630.

Gardner, Wayne S. McCarthy, Mark J. An, Soonmo, Sobolev, Dmitri, Sell, Karen S. Brock, David. 2006. Nitrogen fixation and dissimilatory nitrate reduction to ammonium (DNRA) support nitrogen dynamics in Texas estuaries. Limnology and Oceanography. Volume 51 Issue 1. Pages 558-568.

Gerdeaux, Daniel. Perga, Marie-Elodie. 2006. Changes in whitefish scales delta- ä^{13}C during eutrophication and reoligotrophication of subalpine lakes. Limnology and Oceanography. Volume 51. Issue 1. Pages 772-780.

Kotak, B.G. Kenefick, S.L. Fritz, D.L, Rousseaux, C.G., Prepas, E.E. Hrudey, S.E. 1993. Occurrence and toxicological evaluation of cyanobacterial toxins in Alberta lakes and farm dugouts. Wat. Res. Vol. 27 No. 3 pp 495-506.

Kotak, B.G. Lam, K-Y, Prepas, E. and Hrudey, S. 2000. Role of chemical and physical variables in regulating microcystin-LR concentration in phytoplankton of eutrophic lakes. Can. J. Aquat. Sci 57: 1584-1593.

Kotak, B.G. Lam, A. K-Y, Prepas, E. 1995. Variability of the hepatotoxin microcystin-LR in hypereutrophic drinking water lakes. J. Phycol. 31, 248-263.

Kotak, B.G. Zurawell, R.W. Prepas, E. E. Holmes, C.F.B. 1996. Microcystin-LR concentration in aquatic food web compartments from lakes of varying trophic status. Can. J. Aquat. Sci. 53: 1974-1985.

Matthews, David A. Effler, Steven W. 2006. Long-term changes in the areal hypolimnetic oxygen deficit (AHOD) of Onondaga Lake: Evidence of sediment feedback. Limnology and Oceanography. Volume 51. Issue 1. Pages 702-714.

Ménesguen, Alain, Cugier, Philippe, Leblond, Isabelle, 2006. A new numerical technique for tracking chemical species in a multi-source, coastal ecosystem, applied to nitrogen causing *Ulva* blooms in the Bay of Brest (France). Limnology and Oceanography. Volume 51 Issue 1. Pages 591-601.

Parsons, Michael L. Dortch, Quay, Turner, R. Eugene, Rabalais, Nancy R. 2006. Reconstructing the development of eutrophication in Louisiana salt marshes. Limnology and Oceanography. Volume 51. Issue 1. Pages 534-544.

Reckhow et. al. 2005. A predictive approach to nutrient criteria. Env. Sci. Technol 39 (9): 2913-29189.

Rosenberg, D.M. Chambers, P.A. Culp, J. M. Franzin, W. G, Nelson, P. A. Salki, A. G., Stainton, M. P., Bodaly, R. A., Newbury, R.W. Chapter 19: Nelson and Churchill River Basins. In: Benke, A. C., and C. E. Cushing (editors). 2005. Rivers of North America. Academic Press/Elsevier, Boston/Amsterdam, 1168 pages.

Smith, Stephen V. Hollibaugh, James T. 2006. Water, salt, and nutrient exchanges in San Francisco Bay. Limnology and Oceanography. Volume 51. Issue 1. Pages 504-517

Vannote, R,L. Minshall, G.W. Cummins, K. W. Sedell, J.R. and Cushing, C.E. (1980) The river continuum concept. Can, J. Fish. Aquat. Sci. 37, 130-137.

Vreca, Polona, Muri, Gregor. 2006. Changes in accumulation of organic matter and stable carbon and nitrogen isotopes in sediments of two Slovenian mountain lakes (Lake Ledvica and Lake Planina), induced by eutrophication changes. Limnology and Oceanography. Volume 51. Issue 1. Pages 781-790.

Wolowicz, Maciej, Sokolowski, Adam, Bawazir, Abdullah Salem, Lasota, Rafal, 2006. Effect of eutrophication on the distribution and ecophysiology of the mussel *Mytilus trossulus* (Bivalvia) in southern Baltic Sea (the Gulf of Gdañsk), Limnology and Oceanography. Volume 51. Issue 1. Pages 580-590.

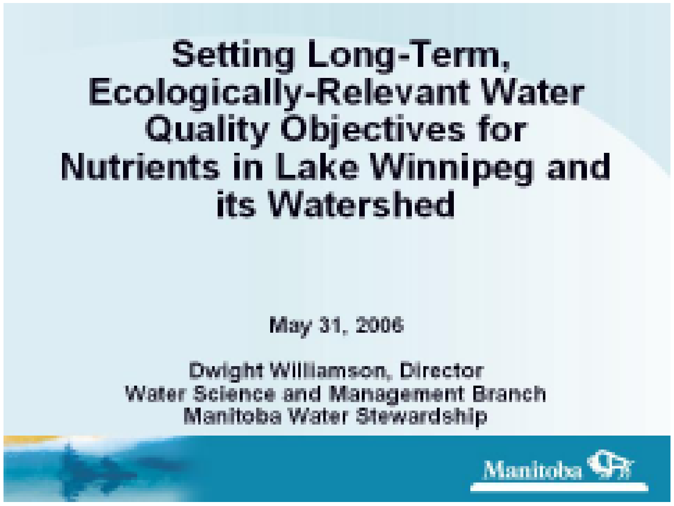
Worm, Boris, Lotze, Heike K. 2006. Effects of eutrophication, grazing, and algal blooms on rocky shores. Limnology and Oceanography. Volume 51. Issue 1. Pages 569-579.

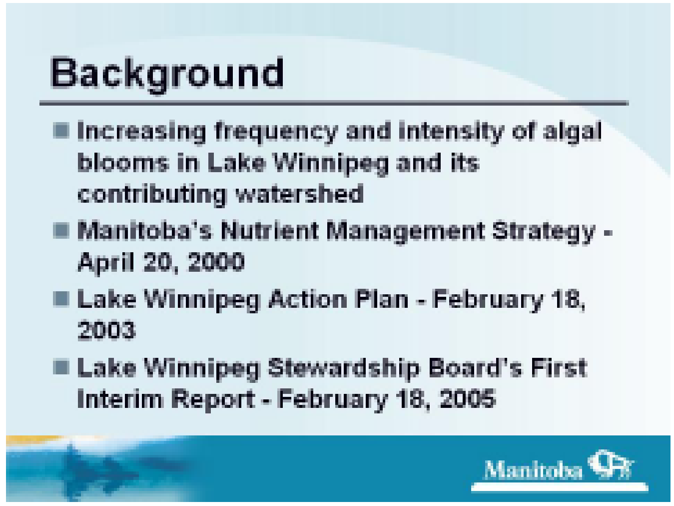
Appendix D: Other Points Raised During the Workshop

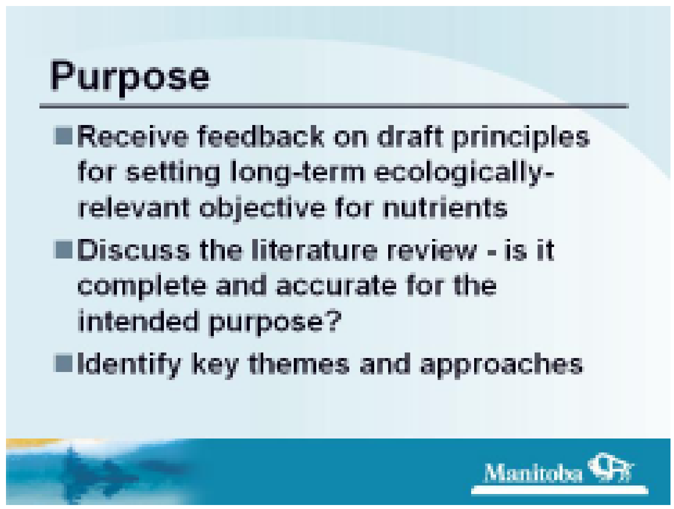
During the workshop, several other points and issues were raised that had peripheral reference to the discussion of the principles or the literature review. These are listed below. These points will receive consideration as the process to develop nutrient objectives for Lake Winnipeg moves forward.

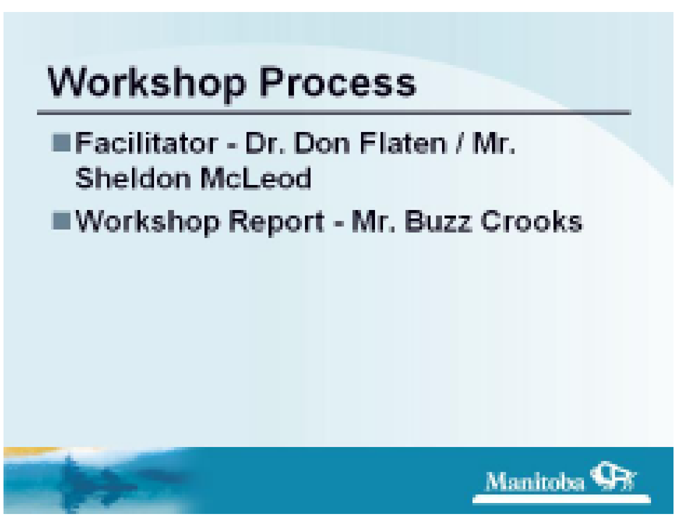
- Identify point and non-point sources of nutrient loading.
- Develop a basin-wide monitoring program to gather additional data to be used to adjust objectives as needed to account for reductions (or increases) in nutrient loads.
- Begin a proactive public education on both sides of the border to develop support for basin-wide changes that can positively impact the Red River watershed and ultimately Lake Winnipeg.
- More information is required on nitrogen cycling in the Lake Winnipeg watershed.
- Better definition of soil classification is required.
- Information is required on Trifluralin, a herbicide that stimulates blue-green algal growth.
- Information is required on the use of copper sulfate.
- Data related to the response of lakes to global issues – changes in solar influences (e.g. ultra-violet light) atmospheric deposition, and water cycle is required.
- Land use maps of the early 1990s should be obtained.
- Churchill River Estuary – Beluga whale data.
- A number of potential sources of information were noted without reference to specific reports/data:
  - Canadian Museum of Nature
  - U.S. bodies of literature
  - Australian publications
  - Ministries of agriculture and soils – land use and livestock numbers.
  - Geological mapping – Energy, Mines and Resources
  - Information related to dynamic food web interactions, fish-eating birds, species at risk, and macrophyte communities should be considered in the future steps.

Appendix E: Workshop Presentation - Dwight Williamson









Draft Principles

Long-term, Ecologically-Relevant Water Quality Objectives for Nutrients for Lake Winnipeg, its Contributing Basin, and its Downstream Environment should:

(1) preserve or restore the important ratio between nitrogen and phosphorus, and reflect both in-lake concentrations and watershed loadings

(2) consider historical concentrations of nitrogen and phosphorus in Lake Winnipeg

(3) ensure the healthy functioning of the Lake Winnipeg ecosystem

Manitoba

Draft Principles (continued)

(4) minimize the duration, frequency, and intensity of blue-green cyanobacteria blooms including the need to minimize the production of cyanobacterial toxins harmful to aquatic life, recreation, and drinking water

(5) minimize the duration, frequency, and intensity of blooms of other forms of algae including those leading to fouling of commercial and subsistence fishing nets or that otherwise interfere with the successful harvest of fish

Manitoba

Draft Principles (continued)

(6) ensure that an optimum balance is achieved between nutrient enrichment, productivity of the commercial and subsistence fishery, and subsequent economic return to communities, while protecting the lake's ecosystem health and recreational uses

(7) protect of the downstream environment in the Nelson River and Hudson Bay

(8) recognize water quality objectives established for the contributing watersheds, and that water quality objectives for nutrients established in the contributing watersheds need to recognize Lake Winnipeg

Manitoba

Draft Principles (continued)

(9) consider the social and economic implications of implementation and compliance

Manitoba

Thank You

Manitoba

Appendix F: Workshop Presentation - North/South

Literature review related to setting nutrient objectives for Lake Winnipeg

Friederike Schneider-Vieira, PhD
Megan Cooley, MSc
North/South Consultants Inc.

Scope of report

- RFP required:
  - Identify and compile necessary background information to assist MWS in setting long-term nutrient objectives for Lake Winnipeg (also the upstream and downstream watershed in Manitoba).
  - Prepare an annotated bibliography.
  - Prepare an overview of the literature.

Scoping of review

- Lake Winnipeg
  - Goal was to review all published relevant research.
  - Much of recent work not published – review included limited raw data.
  - Information not available to allow identification of key issues (e.g., nutrient concentrations, role of internal P cycling).

Scoping of review

- Global literature review:
  - Cross section of issues to be considered, in particular topics in most recent research.
  - Practically not feasible to be comprehensive.
- Information sources
  - Electronic databases
  - In-house sources
  - Internet sites
  - Key person contacts (Technical Secretariat)

Synopsis of studies

- 1920s – first biological surveys
- Fisheries research
- Pollution research – 1960s
- Brunskill – 1969
- Lake Winnipeg Project – 1994+ (GSC)
- Red River Flood
- LWRC 1999+

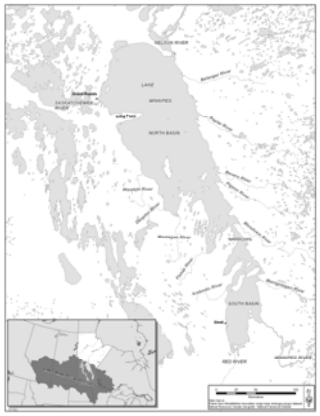
Recent research

- Targeted a variety of questions:
  - Effect of climate change on fisheries.
  - Nitrogen fixation and algal physiology.
  - Satellite imagery to measure turbidity and chlorophyll *a*.
- No integrated program in support of development of nutrient objectives:
  - Much of information has bearing on this question but analysis required to develop objectives is lacking.

North Basin
Area (km^2) 17,520
Mean depth (m) 13.3

Narrows
Area (km^2) 3,450
Mean depth (m) 7.2

South Basin
Area (km^2) 2,780
Mean depth (m) 9.7

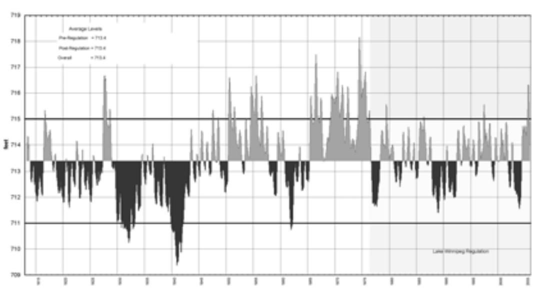


Drainage Basin

Basin	Tributary	Geology of drainage area	Drainage area (km^2)	Runoff (cm)*
South	Winnipeg River	Precambrian Shield	126,400	31
	Red River	85% Sedimentary	287,500	2.8
	Other	-	16,700	-
North / Narrows	East side rivers	Precambrian Shield	41,050	-
	Saskatchewan River	Sedimentary	340,000	6.4
	Dauphin River	Sedimentary	80,000	3.7
	Other	Sedimentary	61,200	-

* Runoff = annual river discharge (1969-1974)/drainage area

Hydrology



Temperature and stratification

- North and south basins differ:
  - North basin warms and cools more slowly.
  - 1969: mid summer 20-22 ºC in south; 18-20 in north.
  - During 1909-2000 August temperature in south basin increased 1.4 ºC.
- Thermal stratification:
  - Lake does not stratify strongly for prolonged periods.
  - Stratifies during calm periods.

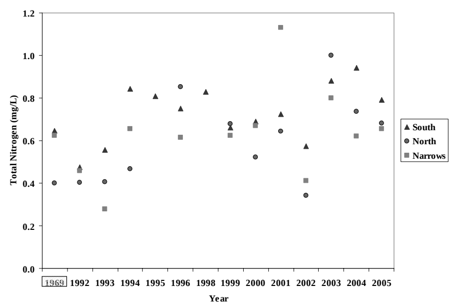
Erosion and sedimentation

- Studied during CGS surveys (1990).
- Shoreline and nearshore erosion are important sources of sediments (and likely nutrients) to the lake.

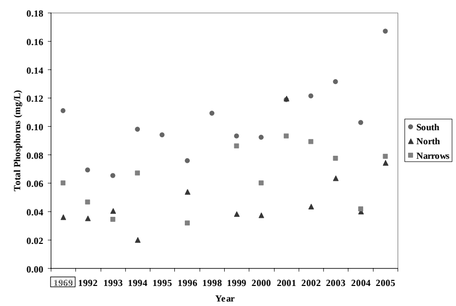
Nitrogen and Phosphorus

- No published reports with data.
- MWS provided unpublished data (averages):
  - Differences between years must be interpreted cautiously as data sets not entirely comparable.

Nitrogen



Phosphorus



Nutrient ratios

- Ratio of <10:1 (by mass) of N:P is generally considered to indicate N limitation (if other factors aren't limiting).
- Average N:P (growing season)
  - 1992-2005 - < 10 in south basin; 10-20 (3 years < 10) in north basin.
  - 1969 – 6 in south and 11 in north.
- Stainton et al. (2004) – in 2002 concentrations of N declined relative to P in both basins and by August N:P centered on 10.

Sources and sinks of N and P

- Nitrogen fixing cyanobacteria bring in N; denitrification is occurring (measure nitrous oxide) but extent not known.
- P release from sediments not measured to date – increases in P concentrations in water column in late summer/fall and phosphatase activity indicate this is occurring.

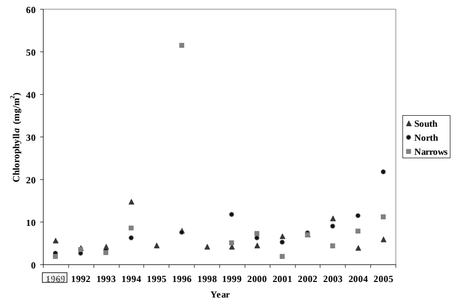
Nutrient loads in the watershed

- No nutrient budget though some analyses of incoming and outgoing loads.
- Challenge is obtaining good data – much of loading over brief periods of high flow.
- For 1994-2001, Red River supplied 46% of the TP and 73% of the TN.

Oxygen

- Generally oxygen sufficient.
- Historic studies have found periods of oxygen depletion during thermal stratification.
- 2003 found large area in north basin with low oxygen – prolonged periods of calm lead to stratification.

Chlorophyll *a*



Satellite imagery

- Snap shots of north basin show dramatic cyanobacterial blooms.
- Comparison of 1983-1994 with 1995-2003 shows a greater frequency of blooms in the latter period.

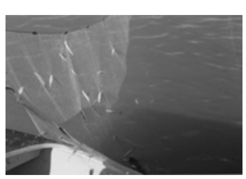
Species composition

- 1969 survey: spring and fall diatom growth with cyanobacteria dominating in late summer.
- Comparison with 1994 suggests greater abundance of eutrophic species.
- Diatom blooms under ice.
- Analysis of a long sediment core (collected 1994) showed a history of cyanobacterial blooms alternating with diatoms.

Factors affecting algal growth

- 2000/1 measurements indicated that neither N or P limiting growth for much of the open water season.
- Blooms of heterocystous cyanobacteria developed where N was limiting; ultimately became P limited.

Fish



- 52 species
- Invasive species including smelt – around 25% of biomass in trawl nets in north basin.
- Commercial fishery harvests walleye (mainly south basin and narrows) and lake whitefish (north basin).

Conclusions

- Lake Winnipeg should be considered as a 2 basin system with a transitional area between.
- Much of current information on lake is not published and needs to be synthesized for a better current snapshot.
- Recent increases in algal biomass and nutrient levels raise a concern.

Review of Eutrophication in the Global Environment: Lakes

Major Topics

- Not feasible to conduct a comprehensive review of entire literature – addressed major topics:
  - Key Factors Affecting Algal Growth
  - Internal Loading
  - Nutrient Criteria Development
  - Nutrient/Eutrophication Management
  - Oligotrophication

Key Factors Affecting Algal Growth

- Nutrients (N and P)
- Physical Factors
- Top-Down vs. Bottom-up Controls
- Alternative Stable States
- Reservoirs vs. Lakes

Nutrients

- Small lakes and ponds in the Canadian Prairies particularly prone to nutrient enrichment.
- Some prairie lakes were eutrophic prior to European settlement.
- Literature indicates that phosphorus is typically more limiting to algae than nitrogen.
- However, nitrogen has been found to be more limiting in some ecosystems, including the Canadian prairies.

Nutrients – N:P ratio

- Typically, the N:P ratio declines with increasing nutrient enrichment.
- The low N:P hypothesis states that certain algal groups, most notably cyanobacteria, are favoured at low ratios.
- This “low N:P hypothesis” has been supported by numerous studies.
- More recently, a modified hypothesis has been proposed in which it is argued that low N:P ratios favour N-fixing cyanobacteria.

Nutrients – Nitrogen

- Recent literature in Europe has indicated that high TN concentrations can adversely affect macrophytes and/or delay lake recovery after external nutrient reductions.
- Although additions of TP alone often stimulate algal growth in lakes, addition of both P and N typically causes greater algal growth.
- These observations, among others, have lead to the suggestion that both nutrients should be controlled.

Nutrients – Nitrogen or Phosphorus Reductions

- The low N:P hypothesis is also the basis for arguments of controlling external P loading.
- However, increasing N:P ratios does not necessarily prevent development of algal blooms, including potentially toxic cyanobacteria in lakes.
- Increasing lake TN:TP ratios has also lead to replacement of N-fixing to non N-fixing cyanobacteria.

Other factors

- There are numerous other factors that affect nutrients and phytoplankton in lakes, including:
  - Light/water clarity;
  - Water residence times;
  - Lake depth;
  - Water level changes;
  - Water column stability;
  - Sediment resuspension
  - Temperature;
  - Biological effects (i.e., top-down controls).

Other factors

- Shallow lakes typically respond differently to nutrient enrichment than deep lakes.
- For example, shallow lakes may have higher chlorophyll a at a given TP relative to deep lakes and typically recover more slowly than deep lakes.

Other factors

- Top-down controls highly significant in some lakes.
- Nutrient enrichment causes a trophic cascade:
  - increased phytoplankton,
  - increased planktivorous fish;
  - increased grazing of zooplankton (especially large bodied Daphnids),
  - positive reinforcement of phytoplankton.
- Biomanipulation (us. removal of planktivores) – method of improving water quality and reducing phytoplankton.

Internal Loading

- Numerous studies have shown that lake eutrophication can lead to or enhance internal loading of P.
- Many factors affect internal loading (e.g., DO, Redox conditions, iron availability).
- Internal loading can surpass external loading in some lakes and lakes may shift from a sink to a source.
- Internal loading also frequently delays lake recovery, often by decades.

Lake Nutrient Criteria Development

- Site-specific criteria address natural differences in lake condition and response.
- Approaches for developing nutrient criteria for lakes:
  - Define regional reference site conditions;
  - Use historical data for a lake;
  - Use paleolimnological techniques to reconstruct a nutrient history;
  - Develop water quality models;
  - Scientific/ecological studies to derive or refine criteria (e.g., define the relationship between nutrients and algae).

Lake Nutrient Criteria

- CCME has developed a guidance framework for TP, based on the OECD trophic categorization and departures from baseline conditions.
- USEPA has issued a guidance document for the derivation of nutrient criteria for lakes and proposed interim criteria according to ecoregions.
- USEPA criteria are developed for both causal indicators (i.e., N and P) and response indicators (i.e., Secchi depth and chlorophyll *a*).

Lake Nutrient Criteria

- Response indicators provide biological effects of nutrients, in conjunction with other factors that may limit algal growth.
- USEPA indicates criteria should consider effects in the immediate downstream environment.
- Interim criteria for the aggregate ecoregion to the south of MB (defined on the basis of "reference conditions") are characterized by the highest TP, second highest TN and chlorophyll *a*, and the third highest Secchi Depth of all of the aggregate ecoregions.

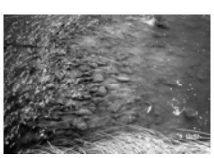
Oligotrophication

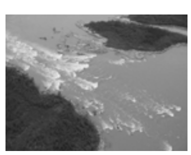
- Many studies span decades.
- Restoration generally targets external P.
- Recent European studies have found:
  - Delays in TP reductions due to internal loading.
  - Rapid decline in TN when external N loading reduced.
  - Increases in TN:TP ratio.
  - Reduced phytoplankton biomass.
  - Fish community – generally reduced biomass and increase in piscivores.
  - Often a reduction of cyanobacteria dominance.

Oligotrophication – the exceptions

- Some lakes responded differently to load reductions:
  - Phytoplankton in 2 Danish hypereutrophic lakes shifted from chlorophytes to cyanobacteria despite reduction in external loading and an increase TN:TP
  - Phytoplankton and dominance of cyanobacteria increased in a Swiss lake despite reductions in TP loading
  - Others have reported increases in heterocystous cyanobacteria following external loading reductions
- Complete recovery and reversibility of eutrophication does not always occur.

Review of Eutrophication in the Global Environment: Streams





Introduction

- Streams generally less responsive than lakes to nutrient enrichment.
- Response of streams less well known than lakes.
- Nutrients are high in many streams in Manitoba (average for long-term monitoring sites: 1.32 mg/L TN and 0.16 mg/L TP).

Response to Nutrient Enrichment

- Depends on dominant primary producers:
  - Periphyton dominates fast-flowing, gravel/cobble bed streams and phytoplankton in slow-moving, depositional rivers.
  - Periphyton saturated at much lower nutrient levels.
  - Macrophytes more linked to nutrients in sediments than water.
- Response is highly variable and depends on:
  - Hydrology (e.g., flooding events affect periphyton)
  - Grazing (e.g., zebra mussel and phytoplankton)

Response to Nutrient Enrichment

- Response varies considerably among streams:
  - Periphyton biomass usually increases.
  - Accurate measurement of periphyton biomass can be difficult (e.g., due to scouring, temporal and spatial variability).
  - Species composition may be more reliable monitoring tool (i.e., tendency to shift to green and blue-green algae).

Response to Nutrient Enrichment

- TP is most often the limiting nutrient.
- N limiting in some ecosystems (Canadian prairies).
- Restoration strategies may be different from lakes:
  - N limitation more common in streams.
  - Periphyton may be N limited even where N:P suggests P limitation (due to "luxury consumption")
  - N and P increase biomass more than P alone.
  - N reduction may be better for controlling plants.

Nutrient Criteria for Streams

- Site-specific or on an ecoregional basis.
- Consider 'key' primary producers (i.e., periphyton vs. phytoplankton).
- Consider ecoregions in the development of criteria to account for 'natural' enrichment of streams.

Nutrient Criteria

- Generally, approaches used to develop criteria for streams are similar to those applied to lakes.
- Use one or more approaches:
  - 'Reference' conditions
  - Historical data
  - Water quality models
  - Studies evaluating nutrient/algal relationships

Nutrient Criteria

- USEPA has provisional criteria for aggregate ecoregions:
  - reference condition approach.
  - similar basis used by other (e.g., Alberta rivers, Clark Fork River, Montana).
  - causal indicators (TN and TP) and response indicators (chlorophyll *a* and Turbidity).
- Of 13 aggregate ecoregions, the highest reference condition TP and TN in the ecoregion to the south of Manitoba.

Nutrient Management

- Fewer stream than lake studies.
- Nutrient loading reduction has met with variable success.
- Recovery slow and variable.
- Prairie rivers are particularly slow to respond to P reductions due to the importance of macrophytes.
- Consider point vs non-point sources.
- Consider dominance of periphyton vs. phytoplankton.

Estuaries

Estuaries

- Hudson Bay is the ultimate receiving environment for waters leaving Lake Winnipeg:
  - Report provides a brief overview of information on the Nelson River estuary and adjacent marine waters of Hudson Bay.
- Extensive global literature related to nutrient enrichment in estuarine and coastal environments:
  - Report only touched on some recent reviews that may be relevant to Hudson Bay.

Hudson Bay and the Nelson Estuary

- Based on limited data, production in Hudson Bay appears low and comparable to other arctic estuaries.
- Coastal waters appear to contain more N and P then incoming rivers (based on available data):
  - Upwelling of deep marine waters appears to be a source of N and P.

Estuaries

- Recent review concluded that in coastal waters with salinity greater than 10-12, N is generally the cause of eutrophication problems.
- Complex situation: some estuaries are N limited, some P limited and some experience a switch from N to P over the growing season.
- Notable exceptions to N limitation are in brackish waters (e.g., Baltic Sea) and shallow systems with abundant rooted vegetation.

Towards the Development of Nutrient Criteria – Next Steps

Next steps

- Intent of work conducted by NSC was to provide background information to assist MWS in the development of nutrient objectives.
- Last section of report addressed considerations in the development of objectives.

Nutrient criteria

- Identify goals:
  - ???
- Site-specific.
- Often based on past conditions.
- Consider whether protective of downstream watershed.

Nutrient criteria

- Linked to site-specific conditions:
  - Reference condition.
  - Historical nutrient data.
  - Water quality models to hindcast conditions.
  - Paleolimnological models.
  - Site-specific nutrient/algal studies to identify critical thresholds.

Options

- Paleolimnological model:
  - Some core data are available.
  - Could provide a long term record (variable conditions).
- Water quality model:
  - Simple nutrient balance model could at least indicate fate of nutrients; assess potential effects of change in land use.
- Site-specific nutrient/algal studies:
  - Current conditions different from historic conditions.

Other considerations for Lake Winnipeg and its watershed

- Develop criteria for upstream waters that protect uses in those waters:
  - Assess whether sufficient to protect Lake Winnipeg.
- Develop criteria for Lake Winnipeg:
  - Consider criteria for incoming waters.
  - Assess whether sufficient to protect downstream waters.

Upstream watershed

- Site specific:
  - Expect that major river systems will have different criteria:
    - E.g., Winnipeg River and Red River
  - Natural background conditions – prairie systems are naturally P rich.
  - Presence of periphyton an important factor.
  - Turbidity.
  - Flow (variability).

Downstream watershed

- Nelson River is a large, turbid river.
- Passes through numerous lakes and reservoirs prior to entering Hudson Bay:
  - Lakes generally shallow and turbid, short water residence time.
  - Large river (Burntwood) enters at Split Lake.
- Expect that objectives to protect Lake Winnipeg would also protect downstream environments.

Downstream watershed

- Nelson River flows into Hudson Bay.
- Cold marine environment:
  - Low productivity.
  - In early 90s N and P concentrations in river were lower than in Bay (limited data).
- Likely protected by objectives that protect upstream waters, in particular if criteria based on historic conditions.

Considerations for Lake Winnipeg

- Lake is the remnant of glacial Lake Agassiz and is still evolving:
  - Morphology changing – isostatic rebound.
  - On-going erosion of nearshore and shore.
  - New species are entering.
- Hydrology/climate:
  - Wet and cool vs dry and warm.
  - Large changes in inflow –cyclical.

Considerations for Lake Winnipeg:

- Long-term change
  - Long term warming?
  - Observed changes in discharge in major tributaries (e.g., decline in Saskatchewan R.).
  - Regulation of lake and tributaries.
  - Changes in land use (agriculture/urban).

Considerations for Lake Winnipeg

- Spatial variability:
  - Basins are essentially two different lakes.
  - Not well mixed horizontally – large influence of major tributaries.
  - Nearshore influences – eroding shorelines.

Considerations for Lake Winnipeg

- “Pristine” conditions need to be defined as a range.
- Sampling programs need to consider spatial and temporal variation.
- Comparisons to past programs must consider conditions under which sampling was conducted.

Information needs/data gaps

- Water balance:
  - Foundation of a nutrient balance.
  - Full accounting of inflows/outflows/storage (include groundwater).
  - Backbone of water quality models.
  - Assess effects of change in flow (anthropogenic and natural).
  - Critical for developing objectives.
- Much of information is available but has not been synthesized to form a water balance.

Nutrient balance

- Thorough accounting of external and internal sources:
  - Nitrogen cycle.
  - Phosphorus cycle.
- Internal loading:
  - Vertical depth profiles.
- Seasonal changes in N, P, chlorophyll/algae.
- Erosion and resuspension.
- Requires synthesis of existing data and some additional data collection.

Factors limiting phytoplankton

- Some studies have been done of nutrient limitation and light in Lake Winnipeg.
- Lake Winnipeg is complex – 2 basins, variable inputs of TSS from shore erosion and rivers.
- Need to concurrently measure nutrients, light, phytoplankton species composition and nitrogen fixation/denitrification.

Shoreline processes and the littoral

- Majority of work in offshore areas.
- As lake is relatively shallow, shore areas can have lake wide effects.
- Need to consider shore zones – sources of TSS and nutrients, rooted plants present??

Trophic cascades and food webs

- Top down effects and shifts in food webs:
  - Indicator of eutrophication.
  - Food web effects can control phytoplankton in many lakes:
    - Biomanipulation studies have shown that this can be both a major cause and control of eutrophication.
    - Rainbow smelt.

Questions?

Lake Winnipeg Stewardship Board
P.O. Box 305
Gimli, Manitoba R0C 1B0
Phone: 204-642-4899
E-mail: info@lakewinnipeg.org

www.lakewinnipeg.org