Lake Manitoba and its Watershed: Knowledge Gaps & Next Steps

Sunrise over Lake Manitoba at Delta Marsh (© Marliese Peterson)

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1. Executive Summary

Lake Manitoba is a large, shallow prairie lake located in central Manitoba. The lake and watershed are subject to numerous environmental pressures including climate change, land use change, and regulation of water levels, particularly during the operation of the Portage Diversion which diverts water from the Assiniboine River into Lake Manitoba. There are substantial gaps in our scientific knowledge about the ecology, limnology, and hydrology of Lake Manitoba, which limit our ability to make informed management decisions. A science workshop was convened at the University of Winnipeg in December 2015 to summarize the state of knowledge around water quality and ecosystem functioning in Lake Manitoba and its watershed, identify key knowledge gaps, and develop ways to address these gaps. The workshop was attended by 34 participants from universities, government agencies, and non-governmental organizations, all of whom had particular expertise in one of four theme areas: Water Levels & Regulation; Watershed Management & Landscape Processes; Water Quality; and Ecology & Wetlands. This report summarizes the findings and recommendations of the workshop, and can be used to help guide research priorities into the future.

While specific, detailed recommendations were made in each theme area, two major recommendations emerged across all themes. The first recommendation is the existence of critical data gaps which must be filled before progress can be made on understanding ecosystem functioning. These gaps include physical data (e.g. bathymetric, meteorological and LiDAR data), water quality data (e.g. off-shore water chemistry, tributary nutrient loading), and ecological data (e.g. algal community composition, zooplankton characterization, macroinvertebrates population estimates). Furthermore, we do not understand the extent of spatial and temporal heterogeneity in the Lake Manitoba system. Much of the monitoring that does take place occurs along the edges of the lake during the open water season, resulting in large gaps in our understanding of processes occurring in the middle of the lake or during the winter. Without filling these critical data gaps, our scientific understanding of the system is incomplete and we are limited in our ability to make recommendations to resource managers and stakeholders.

The second general recommendation that emerged is the need to coordinate research activities across disciplines and agencies. Lake Manitoba and its watershed are complex ecosystems which are connected to the landscape and other waterbodies, including Lakes Winnipeg and Winnipegosis. To this end, we propose establishing a Manitoba Great Lakes Research Consortium to coordinate and disseminate research across Manitoba’s Great Lakes. Such an organization could also facilitate a repository to make data collected from Lake Manitoba and connected ecosystems accessible to researchers and stakeholders.

While there are major gaps in our understanding of ecosystem functions in Lake Manitoba and its watershed, this report provides a way forward. For the gaps that were identified as the most pressing, workshop participants outlined plans of action to address these gaps, including identifying collaborators, potential sources of funding, and timelines to achieve these goals. These next steps will be useful to researchers, government agencies, and non-governmental organizations as they move forward to address the issues facing Lake Manitoba.

2. INTRODUCTION

2.1. BACKGROUND TO LAKE MANITOBA

Lake Manitoba is a large (13th largest lake in North America), shallow (maximum depth = 7 metres) lake located in central Manitoba, Canada (Figure 1). Lake Manitoba is subject to many of the same environmental pressures as other prairie lakes, such as Lake Winnipeg, including land use changes in the watershed, hydrological changes due to water level regulation, and climate change. There are unique pressures on Lake Manitoba as well, including the operation of the Portage Diversion during high-flow events, which introduces water, sediment, and nutrients from outside the natural watershed into the lake. The Lake Manitoba basin contributes to nutrient loading in Lake Winnipeg, and alterations to the nutrient status of Lake Manitoba have the potential to impact the water quality and ecosystem health of Lake Winnipeg. While there is some monitoring of water quality and other ecosystem parameters in Lake Manitoba and its watershed, there are substantial gaps in our understanding of how this ecological system functions, which limits our ability to make informed management decisions moving into the future. For more information on Lake Manitoba, see Gord Goldsborough – *A review of the limnology of Lake Manitoba: A large, shallow lake in south-central Canada* (p. 35).

2.2. RATIONALE FOR WORKSHOP

The goal of this workshop was to assess the current state of knowledge of water quality and ecosystem health issues in Lake Manitoba and its watershed, identify critical knowledge gaps, and brainstorm ways to address these gaps. The workshop was held from December 9-11th 2015 at the University of Winnipeg. It was attended by 34 participants from universities, provincial and federal government agencies, and non-governmental organizations (Appendix A, p. 34). Presentations and discussions at the workshop were divided into 4 major themes:

1) Water Levels and Regulation (p. 4)
2) Watershed Management and Landscape Processes (p. 12)
3) Water Quality (p. 19)
4) Ecology and Wetlands (p. 26)

Each session of the workshop began with presentations from researchers who had worked in Lake Manitoba or similar systems. Abstracts for each of the presentations are found in Appendix B of this report (p. 35). Following each round of presentations, small group discussions were focused around identifying knowledge gaps related to the theme. These knowledge gaps were ultimately combined into one list per theme, and the whole group voted on which knowledge gaps were most important. Ranking of knowledge gaps was done based on personal criteria, including considerations such as priority relative to other gaps, feasibility of addressing the gap and size of the knowledge gap. Once the knowledge gaps were prioritized, small groups were tasked with developing the next steps to address the top knowledge gaps in each theme area. This report follows the same format, summarizing the discussions in each of these topic areas, the identified knowledge gaps and the proposed next steps.

Figure 1. Lake Manitoba and Assiniboine River watersheds, Manitoba Great Lakes (Lake Manitoba, Lake Winnipegosis, and Lake Winnipeg), and major rivers and tributaries.

3. WATER LEVELS & REGULATION

3.1. PRESENTATIONS

The following presentations were given to introduce the Water Levels & Regulation theme and used as the basis for discussing its knowledge gaps:

Rick Bowering – *The Hydrology and Regulation of Lake Manitoba*, p. 35

Steve Topping – *Lake Manitoba Hydrology: past, present and future*, p. 35

Byron Williams – *Making Space: Water Governance, Science and Legitimacy*

Parsa Aminian – *The Hydrodynamics of Delta Marsh: Using engineering tools to interpret the physical behaviour of an historic coastal wetland*, p. 36

3.2. KNOWLEDGE GAPS

Following the Water Level & Regulation presentations, workshop attendees broke into small groups to identify and discuss gaps in relevant research and data. Identified gaps were compiled into a list and attendees voted on which gaps they considered to be of highest priority. Ranking of knowledge gaps was based on personal criteria, including considerations such as priority relative to other gaps, feasibility of addressing the gap, and size of the knowledge gap. The table below is a summary of the Water Levels & Regulation knowledge gaps identified during small group discussions, and their rank based on number of votes. Following the table are synopses of knowledge gap discussion points compiled from all small groups.

Knowledge Gap	Votes
Gap 1: Improve lake bathymetry	15
Gap 2: Increase meteorological coverage of Lake Manitoba and its watershed	14
Gap 3: Create a system-wide hydrodynamic model integrating economic and environmental costs of water regulation decisions	12
Gap 4: Create downscaled regional climate models to assess impacts of climate change on Lake Manitoba	11
Gap 5: Improve interprovincial coordination of water management	6
Gap 6: Assess the historic lake level baseline to develop appropriate targets	5
Gap 7: Assess the role of groundwater in Lake Manitoba	4
Gap 8: Improve knowledge transfer and transparency at the government level	3
Gap 9: Improve sharing and integration of prairie hydrodynamics data	2

Gap 1: Improve lake bathymetry – Some bathymetric data for Lake Manitoba exist, but coverage is spotty and quality and accuracy unknown. Bathymetric data are needed to understand hydrologic systems as the data are used to calculate volume, create circulation models, determine flow paths, and estimate residence times. These in turn contribute to modelling input / output of water, sediments, and nutrients. Comprehensive, high quality, and reliable data are required for confidence in any modelling, thus there is a need for improved bathymetry of Lake Manitoba and associated waterbodies. Some of current data are dated (30+ years) and may not be of sufficient resolution for use in modelling. Bathymetric measurements should be collected at standard high resolution intervals to ensure thorough and accurate coverage of basins. Bathymetric data for Delta Marsh and other coastal marshes are also needed. These data would help determine residence times in marshes and if they are sources or sinks for nutrients. (Next Steps, p. 8)

Gap 2: Increase meteorological coverage of Lake Manitoba and its watershed – Currently there are too few meteorological stations collecting data in the Lake Manitoba watershed, given its size. Meteorological data includes temperature, wind speed and direction, humidity, atmospheric pressure, and precipitation, and are necessary to calculate evaporative water loss, determine circulation patterns within a lake, and predict the temporary but potentially drastic effects of storm events on water levels. They are also an essential component of flood forecasting, making this gap a high priority in Manitoba. Coverage of the north and south basins of Lake Manitoba is also poor. Using data collected from land-based stations is not an appropriate method for determining meteorological conditions of the lake itself, as offshore weather conditions often differ from what is experienced on land. Thus, meteorological stations are needed in Lake Manitoba itself, preferably in both basins and The Narrows to account for any geographical differences. In conjunction with addressing this gap, data could be collected to quantify atmospheric deposition of nutrients into Lake Manitoba, which is important for determining nutrient budgets for the lake and was identified as the twelfth most important Water Quality gap. (Next Steps, p. 9)

Gap 3: Create a system-wide hydrodynamic model integrating economic and environmental costs of water regulation decisions – Impacts of regulation of Lake Manitoba water levels on socio-economic and ecological / environmental parameters are rarely considered and poorly understood. This knowledge gap could be addressed by creating a Lake Manitoba system-wide hydrodynamic model that assesses the monetary and environmental consequences of water regulation decisions. Such a model would function as a big picture cost-benefit analysis and could be used as a decision-making tool.

The model would be run by changing input parameters, such as water inflows or outflows according to a suggested water regulation decision, and the output would provide insight into the immediate, short-term, and long-term consequences of executing that decision. For example, output from the model when set with parameters associated with activation of the Portage Diversion would summarize the monetary, ecological, and environmental costs of using the Portage Diversion as opposed to keeping water on the landscape upstream of Lake Manitoba. Model outputs would provide insight into consequences of regulatory decisions and could include:

- Changes to recreational use of the lake due to algal blooms and poor water quality
- Changes to fisheries affected by changes in fish access to spawning and feeding areas
- Consequences to lakeside infrastructure affected by shoreline erosion
- Consequences for agriculture as affected by flooding / drought

There are many challenges to creating this model, the largest being a lack of necessary data, particularly from remote regions of the watershed. Insufficient or low quality data would prevent developing a model with reliable outputs, though reasonable coverage could still lead to a model that identifies patterns useful to decision makers. Data gaps include:

- Hydrometric data for Lake Manitoba and other waterbodies in the watershed
- Bathymetric data (Water Levels & Regulation Gap 1, p. 5)
- Meteorological data (Water Levels & Regulation Gap 2, p. 5)
- Detailed land use and management data, particularly relating to drainage patterns across the landscape (Watershed Management & Landscape Processes Gap 3, p. 14)

Socio-economic components of the model should include all stakeholders within the Lake Manitoba watershed. These include private individuals (cottage owners, hunting lodges, etc.), Indigenous populations (e.g. Pinaymootang First Nation and Lake St. Martin First Nation), and commercial industries (e.g. fisheries).

There are significant computational challenges associated with running a model of this size and complexity. Furthermore, the Lake Manitoba watershed is very dynamic and a model run at a monthly or annual time interval will not be sufficient to capture the daily scale perturbations to the system. The model must also be tested to see how well forecasting works in light of climate change. (Next Steps, p. 10)

Gap 4: Create downscaled regional climate models to assess impacts of climate change on Lake Manitoba – There is considerable uncertainty around the impacts of climate change on water budgets in Lake Manitoba. The current approach to water regulation appears to be driven by our present situation; focus is on challenges associated with flooding, while drought and its potential impacts are largely ignored. But what do the next 50 to 100 years look like for Lake Manitoba and its watershed, especially in the light of climate change? How will climate change affect the frequency and intensity of floods and droughts, severity and frequency of extreme weather events, groundwater levels, and use of the Portage Diversion? Answers to these questions are important for water regulation, infrastructure and engineering decisions, and understanding how climate change will affect the ecology and economy of Lake Manitoba. To better answer these questions, small-scale detailed regional climate models with a fine focus and high resolution are needed. Such models are currently being developed by the Prairie Climate Centre[1] (PCC), a joint endeavor between the International Institute for Sustainable Development and University of Winnipeg. Collaboration with the PCC will allow regional climate change models to be incorporated into regulation decisions. (Next Steps, p. 11)

Gap 5: Improve interprovincial coordination of water management – Lake Manitoba exists in a heterogeneous watershed with many hydrological pressures originating out of province. Land use practices and water regulation in these areas directly affect Lake Manitoba creating a need for better interprovincial communication regarding management of water, land, and wetlands. Any hydrological models concerning Lake Manitoba must include, to some extent, data derived from out-of-province water regulations and land use practices, which requires coordination and collaboration with managers of those areas. For example, the natural Lake Manitoba watershed extends partially into Saskatchewan, but with construction of the Portage Diversion, floodwater from the much larger Assiniboine River watershed in Saskatchewan that used to bypass Lake Manitoba on its natural path to Lake Winnipeg via

[1] http://prairieclimatecentre.ca/

the Red River, is now diverted directly into Lake Manitoba (Figure 1). Thus coordination with Saskatchewan has become even more important, especially during high water years, as its management of runoff and flood water now directly impact Lake Manitoba hydrology and water quality.

Gap 6: Assess the historic lake level baseline to develop appropriate targets – Lake Manitoba water levels are currently managed using the Fairford River Water Control Structure to maintain a long-term average of 247.5 m above sea level by allowing minimal fluctuation between 247.0 to 247.7 m above sea level. However, Lake Manitoba experienced much larger fluctuations in water level prior to its regulation. These fluctuations are important for maintaining ecological diversity in coastal marshes. It has been suggested that regulation of the lake should focus on variability, as that is the historical norm, instead of attempting to maintain an average water level. Regulation should also include fluctuation between high and low water levels, with special consideration of periodic lows to facilitate revegetation of coastal marshes. An assessment of the historic water level baseline is needed to determine the optimal water regime and establish appropriate targets for such regulation.

In addition to altering the regulation regime from maintaining average water levels to allowing fluctuation, management should consider future hydrologic events and their impacts. The focus of current Lake Manitoba regulation is on the present-day high water level situation, with little consideration of past or future low water levels and drought, which are inevitable and should not be ignored. More data are needed on the potential impacts of drought on lake levels under the current and proposed regulation. Models may be needed because the current persistent high water situation does not provide opportunity for determining the outcomes of drought. Flood and drought conditions should be considered when changing management of existing and/or constructing new water control structures as the impacts will likely differ under different water levels.

Gap 7: Assess the role of groundwater in Lake Manitoba – Groundwater inflow to Lake Manitoba is less than that of surface water, but likely greater than that of smaller tributaries or local runoff, and therefore must be included in Lake Manitoba water and nutrient budgets. While the extent of aquifers in the Lake Manitoba watershed have been relatively well mapped, there are gaps in current groundwater chemistry, quantity, and flow data, as well as information about how these factors may be impacted by climate change.

Gap 8: Improve knowledge transfer and transparency at the government level – The current provincial system for management of Lake Manitoba water levels is not transparent. This creates a barrier to filling knowledge gaps identified in this report that can only be overcome through public transparency on the part of the provincial government and reciprocal communication between government officials, scientists / researchers, and the general public. The process of knowledge transfer is a challenge as scientists are in a constant state of research, but policy should evolve in response to emerging scientific knowledge and understanding.

Gap 9: Improve sharing / integration of prairie hydrodynamics data – As is the case for many types of data identified in this report, hydrodynamic data are not transparently available across the research community. The need for a science repository to consolidate knowledge of prairie lakes was identified as the second most important knowledge gap under Watershed Management and Landscape Processes (p. 13). Such a repository would facilitate improved sharing and integration of prairie hydrodynamic data.

3.1. Next Steps For Top-Ranked Knowledge Gaps

The next steps to address top-ranked Water Levels & Regulation knowledge gaps were developed by workshop attendees who self-identified as experts in the theme. Discussion focused on barriers to filling the knowledge gap, potential project collaborators and funding sources, and a timeline to complete the project. This section summarizes those next steps.

Gap 1: Improve lake bathymetry, p. 5

1. Precursor conditions necessary to address the knowledge gap:
    - A vehicle for equipment deployment is needed and must remain available to be used when conditions change (e.g. after use of the Portage Diversion)
2. Barriers to success:
    - No readily available watercraft capable of working in shallow water (Note: it may be possible to use the Lake Winnipeg Research Consortium's smaller boat, the *Fylgja*, or obtain a similar vessel)
3. Essential collaborators:
    - Federal government conducting a hydrometric survey
    - Provincial government
    - Researchers, specifically thesis students conducting research on bathymetric modelling
4. Other interested parties that should be included:
    - Academic and public community, including Manitoba Hydro, Ducks Unlimited Canada, Sensitive Habitat Inventory and Mapping, and First Nations
    - Lake Manitoba Research Consortium
    - Landscape modelers
    - Recreational boaters
5. Leadership for the process:
    - Lake Manitoba Research Consortium
6. Potential funding sources:
    - Federal and provincial government
    - Funding agencies for supplies / equipment (e.g. NSERC)
7. Metrics to determine if the objective has been achieved:
    - Completion of an accurate and high-resolution bathymetric map of Lake Manitoba and its wetlands
8. Timeline outlining short-term, mid-term and long-term goals:
    - Should be completed in the short-term but is highly dependent on resource availability

Gap 2: Increase meteorological coverage of Lake Manitoba and its watershed, p. 5

1. Precursor conditions necessary to address the knowledge gap:
    - Data at a finer scale than presently available
2. Barriers to success:
    - Calibration of existing data, which in turn requires active interest on part of those capable of completing calibration (e.g. Environment Canada)
3. Essential collaborators:
    - Environment Canada
    - International Institute for Sustainable Development
    - Ducks Unlimited Canada
    - Manitoba Hydro
    - Manitoba Infrastructure and Transportation for flood forecasting
    - Academic community
    - Community-based monitors (e.g. on-farm equipment)
    - First Nations
4. Other interested parties that should be included:
    - Agricultural community may be interested in rainfall maps for irrigation
5. Leadership for the process:
    - Environment Canada
6. Potential funding sources:
    - Environment Canada
7. Metrics to determine if the objective has been achieved:
    - Acquisition of high resolution data
8. Timeline outlining short-term, mid-term and long-term goals:
    - Mid-term (3-5 years) to engage bureaucracy, integrate various participants, and secure resources

Gap 3: Create a system-wide hydrodynamic model integrating economic and environmental costs of water regulation decisions, p. 5

1. Precursor conditions necessary to address the knowledge gap:
    - Create ethos of landscape management in the provincial government in all relevant departments, including Conservation and Water Stewardship, Manitoba Infrastructure and Transportation, and Manitoba Agriculture, Food and Rural Development
    - Raised awareness of the ecological implications of changing hydrodynamic conditions
2. Barriers to success:
    - Interprovincial jurisdictional challenges (Water Levels & Regulation Gap 5, p. 6)
    - Departmental intransigence
    - Interdepartmental mixed messages (e.g. “keeping water on the landscape” vs tiled drainage)
3. Essential collaborators:
    - Conservation and Water Stewardship
    - Manitoba Infrastructure and Transportation
    - Manitoba Agriculture, Food and Rural Development
    - Municipal government, planning districts and conservation districts
    - International Institute for Sustainable Development
    - Ducks Unlimited Canada
    - Manitoba Hydro
    - Academic community, including the Lake Manitoba Research Consortium
    - First Nations
4. Other interested parties that should be included:
    - Lake Winnipeg Foundation
5. Leadership for the process:
    - Manitoba provincial government
6. Potential funding sources:
    - Manitoba provincial government
7. Metrics to determine if the objective has been achieved:
    - Visible mechanism for water management decision
8. Timeline outlining short-term, mid-term and long-term goals:
    - Should be completed in the mid-term (3-5 years)

Gap 4: Create downscaled regional climate models to assess impacts of climate change on Lake Manitoba, p. 6

1. Precursor conditions necessary to address the knowledge gap:
    - Data to build better climate models
2. Barriers to success:
    - Too few climatologists
    - Inadequate meteorological data (Water Levels & Regulation Gap 2, p. 5)
    - Inadequate climate change models
3. Essential collaborators:
    - Manitoba provincial government
    - Environment Canada
    - International Institute for Sustainable Development
    - Ducks Unlimited Canada
    - Manitoba Hydro
    - Prairie Climate Centre (Dr. Danny Blair, Department of Geography, University of Winnipeg)
    - Lake Manitoba Research Consortium
    - First Nations
4. Other interested parties that should be included:
    - Agricultural community
    - Manitoba Conservation Forestry Branch
5. Leadership for the process:
    - Prairie Climate Centre
    - Manitoba Infrastructure and Transportation
6. Potential funding sources:
    - Federal and provincial government
    - Manitoba Hydro
7. Metrics to determine if the objective has been achieved:
    - Ability to conduct forecasts at a high resolution scale
8. Timeline outlining short-term, mid-term and long-term goals:
    - Progress is ongoing because the related science is constantly improving

4. Watershed Management & Landscape Processes

4.1. Presentations

The following presentations were given to introduce the Watershed Management & Landscape Processes theme and used as the basis for discussing its knowledge gaps:

P.R. Leavitt, L. Bunting, Bjoern Wissel, A. St. Amand, & D.R. Engstrom – *Eutrophication of the South Basin of Lake Manitoba, Canada*, p. 36

David Lobb – *Managing the Surface Waters within Our Watersheds*, p. 37

Henry Wilson – *Recent patterns of runoff water quality for agricultural watersheds in the Manitoba's Aspen Parkland*, p. 37

Helen Baulch – *Eutrophication in the prairies – nutrient sources, and work towards solutions*, p. 37

Patrick Watson and Bobby Bennett – *Manitoba's Conservation Districts*, p. 37

4.2. Knowledge Gaps

Following the Watershed Management & Landscape Processes presentations, workshop attendees broke into small groups to identify and discuss gaps in relevant research and data. Identified gaps were compiled into a list and attendees voted on which gaps they considered to be of highest priority. Ranking of knowledge gaps was based on personal criteria, including considerations such as priority relative to other gaps, feasibility of addressing the gap, and size of the knowledge gap. The table below is a summary of the Watershed Management & Landscape Processes knowledge gaps identified during small group discussions, and their rank based on number of votes. Following the table are synopses of knowledge gap discussion points compiled from all small groups.

Knowledge Gap	Votes
Gap 1: Establish baseline conditions and nutrient loading targets for Lake Manitoba	16
Gap 2: Establish a science repository to share knowledge of prairie lakes and research activity	15
Gap 3: Improve data coverage of land use and landscape change	12
Gap 4: Improve LiDAR coverage and upstream water storage capacity	8
Gap 5: Conduct applied research on the potential for holding water on the landscape at the plant scale	8
Gap 6: Create an integrated watershed model specific to prairie landscape processes	7
Gap 7: Improve sharing and integration of prairie hydrodynamic, municipal, and land use data	6
Gap 8: Develop a Cumulative Effects Assessment processes involving the Clean Environment Commission	1
Gap 9: Consistently define the Lake Manitoba watershed to include the Assiniboine River watershed	0

Gap 1: Establish baseline conditions and nutrient loading targets for Lake Manitoba – Setting nutrient loading objectives and water quality targets that aim to restore historic conditions of Lake Manitoba require detailed understanding of baseline conditions. Without these data, it is difficult to determine how and why the conditions of Lake Manitoba have changed or are changing under current watershed management practices. Furthermore, baseline data are needed to set appropriate water quality targets for tributaries. Baseline data are also critical for modelling the impact on water quality of proposed changes in watershed management or landscape processes.

Water quality and hydrometric baseline data are lacking for Lake Manitoba and many of the smaller waterbodies in its watershed. Sampling such a large watershed is a major challenge which could be overcome by heavily sampling smaller watersheds and using those data to strategically determine which measurements are required across the entire Lake Manitoba watershed. Sampling tributaries across a spatial gradient, capturing high flow and low flow conditions, and quantifying legacy nutrient content are all important steps towards establishing nutrient loading targets for Lake Manitoba. Addressing this gap would help to determine baseline nutrient conditions and establish nutrient objectives, which were identified as the fourth most important Water Quality gap (p. 22), and also help reallocate resources for tributary monitoring, which was identified as the seventh most important Water Quality gap (p. 22). (Next Steps, p. 16)

Gap 2: Establish a science repository to share knowledge of prairie lakes and research activity – A major challenge to conducting research in a watershed as large and complex as the Lake Manitoba watershed is integration and sharing of knowledge, knowing what data already exist, are currently being collected, or missing and need attention. This challenge can be overcome by creating a centralized database to archive and make accessible all historical and current data. Such a database would connect scientists, consolidate knowledge and individual projects, and provide region-wide data to inform management decisions. It would also increase the efficiency and effectiveness of research efforts and application of emerging knowledge. The database could also be used to improve sharing and integration of prairie hydrodynamic data, which was identified as the ninth most important gap in Water Levels & Regulations (p. 7).

An example of a centralized database is the Global Lake Ecological Observatory Network[2] (GLEON). GLEON could be used as a model for integrating data not just from Lake Manitoba, but prairie lakes in general, including the Manitoba Great Lakes (i.e. Lake Winnipeg, Lake Manitoba, and Lake Winnipegosis) and their watersheds. This repository, the proposed Prairie Aquatic Ecological Observatory Network (PAEON), should be designed to easily integrate with the existing Lake Winnipeg Basin Information Network[3]. PAEON should include data from independent researchers, government research projects, other organizations, such as Conservation Districts Integrated Watershed Management Planning (IWMP), and First Nations. The PAEON database could include hydrodynamic, meteorological, municipal, land use, agricultural databases, as well as Traditional Ecological Knowledge. Data in these repositories must be entered in a standardized form and supplemented with detailed metadata, so that they are accessible to scientists and remain relevant. Roadblocks to establishing PAEON include finances needed to create and upkeep the database, and time needed to standardize and digitize all data and metadata. (Next Steps, p. 17)

[2] http://gleon.org/
[3] http://lwbi.cc.umanitoba.ca/

Gap 3: Improve data coverage of land use and landscape changes – Understanding the impacts of land use and landscape changes on hydrodynamics and water quality requires detailed land use and landscape data. Unfortunately, there is little detailed data for the Lake Manitoba watershed beyond agricultural land use, which is documented by Manitoba Agriculture, Food and Rural Development (MAFRD) and Agriculture and Agri-Food Canada (AAFC). This is particularly true for areas around the north basin of Lake Manitoba. Gaps in land use data include drainage network details, the extent of erosion, changes in cottage developments, specifics of agricultural land use (e.g. crop rotation), and changes in water storage on the landscape (e.g. wetland drainage, reservoir construction, and agricultural runoff drainage networks).

Processes such as nutrient fluxes and cycling between the land and waterbodies differ across ecozones; consequently, data coverage specific to the Lake Manitoba watershed is essential. Land use and landscape changes and their impact on water quality should be monitored in order to forecast impacts of proposed changes and develop best land use management practices. An example of this type of monitoring is the Tobacco Creek Model Watershed[4]. Historical land use and landscape data, such as where wetlands have been lost, are also needed to help determine what changes will have the largest impact on hydrodynamics and water quality.

Gap 4: Improve LiDAR coverage and upstream water storage capacity – One approach to managing flood waters in an area that has been subject to intense drainage is improving water storage capacity on the landscape. Knowing where restoration of natural or construction of artificial water storage will be most effective requires detailed drainage network data and a better understanding of where natural water storage has been lost. Some landscape topography data exist for the Lake Manitoba watershed, but may not be in usable or accessible forms, and is largely limited to agricultural areas where drainage is of high priority. Updated LiDAR data of the watershed are needed, especially of drainage networks and in non-agriculture areas. However, LiDAR is costly as it requires specialized equipment and people to collect and analyze the data.

Gap 5: Conduct applied research on the potential for holding water on the landscape at the plant scale – A gap in developing methods to increase water storage on the landscape is the capacity to hold water at the plant-based root zone level. Slowing runoff and keeping water on the landscape reduces the impact of flooding on Lake Manitoba but can be contradictory to the needs of the agriculture industry. Applied research in soil management practices on retaining water and nutrients at the plant-based level is needed. Such an approach may be the most effective way to manage water on-site. It may also generate a return for farmers, which is especially beneficial in an increasingly corporate industry where decisions area finance-driven and do not necessarily consider environmental consequences. Results of the research must also be disseminated to land users, particularly the agricultural industry.

Gap 6: Create an integrated watershed model specific to prairie landscape processes – One way to model a watershed as large and complex as that of Lake Manitoba is to use a nested hierarchical model that integrates data collected at different scales. Such a model would help researchers narrow their focus and guide research.

Data and long-term studies that focus on landscape processes specific to Lake Manitoba watershed ecosystems are needed to fully understand the watershed and create this model. A better understanding

[4] http://www.cwn-rce.ca/focus-areas/canadian-watershed-research-consortium/tobacco-creek-model-watershed/

of processes in the watershed would help with forecasting the impacts of future environmental change. Information such as data and management practices must be specific to ecosystems in the Lake Manitoba watershed as data collected elsewhere may not apply. In particular, prairie-specific data are lacking. Research must also take into account spatial and temporal differences in landscape processes. There are currently insufficient data collected during winter, and processes occurring during this time are largely ignored (Water Quality Gap 9, p. 22, and Ecology & Wetlands Gap 10, p. 29).

An integrated watershed model would include detailed topography, hydrodynamics, prairie-specific nutrient processes, surficial soil information, understanding the effect of distance to Lake Manitoba, land use, non-agriculture contributions in rural watersheds, cottage districts, water resources, and public opinion. Conservation Districts (CD) and their Integrated Watershed Management Plans (IWMP) could be major data contributors to this model. However, CDs are currently based on rural municipalities and not watersheds, leaving some areas unmanaged by CDs. One challenge with including CDs is that participation is entirely voluntary for the municipalities; implementing incentives for participating in CDs could help improve involvement.

A large centralized monitoring program, such as the suggested Lake Manitoba Research Consortium (LMRC) is needed to standardize and integrate data, coordinate research, and communicate with the involved parties (Ecology & Wetlands Gap 1, p. 27). The LMRC would ensure CDs work cooperatively and IWMPs are cohesive.

Gap 7: Improve sharing and integration of prairie hydrodynamic, municipal, and land use data – Much of the hydrodynamic, municipal, and land use data that exist for the Lake Manitoba watershed are not transparently available to researchers. The need for a science repository linking knowledge of prairie lakes was identified as the second most important knowledge gap in Watershed Management and Landscape Processes (p. 13), and these data could form a part of this proposed repository (the Prairie Aquatic Ecological Observatory Network [PAEON]).

Gap 9: Consistently define the Lake Manitoba watershed to include the Assiniboine River watershed – A consistent and standard definition of the Lake Manitoba watershed is necessary for comparing, sharing, and integrating data. Unfortunately, there is disagreement over what is currently included in the watershed. With construction of the Portage Diversion, which diverts Assiniboine River flood water directly into Lake Manitoba from its natural path to the Red River and Lake Winnipeg, it can be argued that the Lake Manitoba watershed should now include the Assiniboine River watershed (Figure 1). The definition of "contributing" areas should also be updated to include a larger portion of the drainage network in the Lake Manitoba watershed.

4.3. Next Steps for Top Ranked Knowledge Gaps

The next steps to address top-ranked Watershed Management & Landscape Processes knowledge gaps were developed by workshop attendees who self-identified as experts in the theme. Discussion focused on barriers to filling the knowledge gap, potential project collaborators and funding sources, and a timeline to complete the project. This section summarizes those next steps.

Gap 1: Establish baseline conditions and water quality targets for Lake Manitoba, p. 13

1. Precursor conditions necessary to address the knowledge gap:
    - Inventory of available monitoring data
    - Strategic hydrological and water quality monitoring to accurately calculate loads
    - Assessing water quality in the north basin, which can be used as a reference condition
2. Barriers to success:
    - Insufficient data to establish the current water quality state
    - Collecting enough information (including landscape, hydrological, water quality, and biological parameters) to establish baseline conditions
    - Tradeoffs between flooding and phosphorus loading
    - Poor understanding of the Lake Manitoba system ecology; water quality and ecological targets must be specific to the system
3. Essential collaborators:
    - Conservation and Water Stewardship
    - Environment Canada
    - Department of Fisheries and Oceans
    - Manitoba Agriculture, Food and Rural Development
    - Agriculture and Agri-Food Canada
    - Manitoba Infrastructure and Transportation
    - Manitoba Conservation Districts
    - Rural municipalities
    - Scientific community including researchers, specifically thesis students conducting research on bathymetric modelling
    - Ducks Unlimited Canada
    - Saskatchewan and North Dakota
4. Other interested parties that should be included:
    - Cottage owners
    - Fisheries
    - First Nations
5. Leadership for the process:
    - Scientific community
    - Federal agencies
    - Universities

6. Potential funding sources:
   - Provincial and federal agencies to address management
   - Note: additional funding if new channels are subject to Environmental Impact Assessments or and Cumulative Environmental Management Association regulation
7. Metrics to determine if the objective has been achieved:
   - Establishment of baseline conditions
   - Establishment of water quality targets with consensus
8. Timeline outlining short-term, mid-term and long-term goals:
   - Short-term: use existing data to identify gaps, come up with a good number for the baseline conditions for each tributary, and a reasonable water quality target for the Assiniboine River and Lake Manitoba
   - Mid-term (5-10 years): collect additional monitoring data to refine calculation of nutrient loads and water quality targets
   - Long-term (20-30 years): reassess targets in light of changes in climate change, land use, and infrastructure; review baseline

Gap 2: Establish a science repository to share knowledge of prairie lakes and research activity, p. 13

1. Precursor conditions necessary to address the knowledge gap:
   - An all-scientists meeting to define standardize methods
2. Barriers to success:
   - Lack of funding for federal and provincial staff
   - Lack of funding for monitoring Lake Manitoba watershed
   - Need a catalyst to increase cooperation and integration across the prairies
3. Essential collaborators:
   - Canadian and American scientists
   - Government and non-government organizations
4. Other interested parties that should be included:
   - Stakeholders, determined as the repository is developed
   - Scientists from other regions
5. Leadership for the process:
   - Lake Manitoba Research Consortium
   - Representatives across the concerned provinces and states
   - Representatives from involved lakes and watersheds
6. Potential funding sources:
   - Multinational funding
   - NSERC
   - National Science Foundation (e.g. the Research Coordination Network program)
   - International Joint Commission
7. Metrics to determine if the objective has been achieved:
   - Gaining knowledge from the different projects, districts, collaborations, and outputs

8. Timeline outlining short-term, mid-term and long-term goals:
    - Short-term: existence/website/membership, identify sentinel sites
    - Mid-term: joint projects with partners across the network, all jurisdictions with outputs and collaborations
    - Long-term: long-term datasets, collaborations, and outputs gaining insights into aquatic processes that cross jurisdictions

5. WATER QUALITY

5.1. PRESENTATIONS

The following presentations were given to introduce the Water Quality theme and used as the basis for discussing its knowledge gaps:

Elaine Page – *A water quality assessment of Lake Manitoba*, p. 38

Joe Ackerman – *Lake Remediation studies in Killarney Lake: phosphorus budget and sediment capping*, p. 38

Greg McCullough & Claire Herbert – *The Manitoba Great Lakes Project*, p. 38

Eva Pip – *Nutrients, algal blooms and microcystin: a lesson in how our big lakes go wrong*, p. 38

Hedy Kling – *Phytoplankton in Lake Manitoba and surrounding lakes*, p. 39

5.2. KNOWLEDGE GAPS

Following the Water Quality presentations, workshop attendees broke into small groups to identify and discuss gaps in relevant research and data. Identified gaps were compiled into a list and attendees voted on which gaps they considered to be of highest priority. Ranking of knowledge gaps was based on personal criteria, including considerations such as priority relative to other gaps, feasibility of addressing the gap, and size of the knowledge gap. The table below is a summary of the Water Quality knowledge gaps identified during small group discussions, and their rank based on number of votes. Following the table are synopses of knowledge gap discussion points compiled from all small groups.

Knowledge Gap	Votes
Gap 1: Collect offshore water quality data	19
Gap 2: Determine long-term effects of the Portage Diversion on Delta Marsh and Lake Manitoba water quality	19
Gap 3: Quantify internal nutrient loading in Lake Manitoba	10
Gap 4: Determine baseline nutrient conditions and establish nutrient objectives for Lake Manitoba	9
Gap 5: Determine the nutrient-limitation vs. light-limitation status of phytoplankton	4
Gap 6: Develop remote sensing tools to detect algal blooms	4
Gap 7: Strategically reallocate tributary monitoring resources to consistently calculate tributary nutrient loads	4
Gap 8: Resolve the Lake Manitoba nitrogen and phosphorus budgets	2
Gap 9: Describe under-ice processes and establish their importance	1
Gap 10: Determine environmental factors that affect phytoplankton communities under changing anthropogenic pressures	1
Gap 11: Investigate efficacy of phosphorus removal tools	1
Gap 12: Quantify atmospheric nutrient deposition	1
Gap 13: Determine potential impacts of zebra mussels on phosphorus and sediment removal	0

Gap 1: Collect offshore water quality data – Littoral (near shore) data alone are not sufficient to determine the overall water quality status of a lake; limnetic (offshore) and profundal (deep water) data also contribute to assessment of lake water quality and are necessary to characterize any spatial heterogeneity of lake characteristics. Currently most Lake Manitoba data are from the littoral zone and there is a lack of limnetic sampling, especially for nutrient content, water quality, and plankton community data.

Sampling should include littoral and limnetic zones in order to determine horizontal heterogeneity in Lake Manitoba. One approach would be to sample at regular intervals along transects that run from shoreline to open water. In offshore areas, data should be collected over vertical profiles, including samples from the limnetic, profundal, and benthic zones, to determine vertical heterogeneity. Offshore mooring stations could be used to maintain consistent vertical profile sampling sites. Access to offshore areas of Lake Manitoba is made difficult by its shallow waters (average and maximum depths of only five and seven meters, respectively), large fetch, and rapid generation of large waves or storm conditions. However, it is possible to gain access by engaging the cooperation of fisheries or using the Lake Winnipeg Research Consortium's smaller sampling boat, the *Fylgja*, or a similar vessel. It should be noted that Lake Manitoba does not stratify except for the occasional pseudo-cline which is quickly eliminated by wind and wave action.

There are known differences, such as sediment type and source water, that may result in different water quality in the south and north basins of Lake Manitoba. Characterization of these differences and littoral and limnetic sampling must therefore be conducted in both basins, as data from one cannot be applied to the other. There is bidirectional interchange of water between the basins through The Narrows (Figure 1), which should also be included. More data are needed to know how many transects and mooring stations are needed in each basin to accurately determine water quality in Lake Manitoba and whether there is spatial heterogeneity or homogeneity in lake characteristics. (Next Steps, p. 24)

Gap 2: Determine long-term effects of the Portage Diversion on Delta Marsh and Lake Manitoba water quality – While the natural dominant flow of water in Lake Manitoba is from the north basin to the south basin, the constructed Portage Diversion has become a major input of Assiniboine River floodwater directly into the south basin (Figure 1). Recent data suggest the Portage Diversion is also a major source of nutrients, especially phosphorus. Elevated phosphorus levels are well understood to be the main driver of algal blooms in lakes, and phosphorus added through the Portage Diversion could play an important role in increasing algal blooms in the south basin of Lake Manitoba. However, we do not currently have enough data to understand the impacts of using the Portage Diversion either on Lake Manitoba water quality or on water quality in Delta Marsh or other nearshore habitats. We are therefore unable to forecast changes in water quality under different management scenarios, leading to uncertainty of the impacts of the Portage Diversion. The data gaps include such information as nutrient-loading rates, sedimentation rates following an episode of inflow, whether resuspension of nutrients occurs, and effects on water levels in Lake Manitoba and its coastal marshes.

A particularly difficult challenge in analyzing data is understanding what portion of changes in Delta Marsh can be attributed to the Portage Diversion, as opposed to other disturbances such as common carp (*Cyprinus carpio*) invasion. While the Portage Diversion is a point-source of nutrients into Lake Manitoba, it diverts water from the entire Assiniboine River watershed and therefore is much more complex than a typical point-source and must be treated differently.

Gap 3: Quantify internal nutrient loading in Lake Manitoba – There is no information about rates of internal nutrient loading in Lake Manitoba, a process which may contribute substantially to nutrient budgets in this system. Internal loading occurs through the processes of nutrient recycling and suspension / resuspension, and there is some research that demonstrates these processes are particularly important in shallow prairie lakes. However, there are relatively little data available on these processes for Lake Winnipeg and our understanding across the Manitoba Great Lakes is extremely limited, despite the importance of understanding internal nutrient loading to understanding nutrient dynamics. Some of the processes that contribute to internal nutrient loading might be particularly important in anaerobic under-ice conditions; however, studies on winter nutrient processes are particularly lacking, and thus more under-ice studies are needed (Water Quality Gap 9, p. 22). (Next Steps, p. 24)

Gap 4: Determine baseline nutrient conditions and establish nutrient objectives for Lake Manitoba – Baseline nutrient conditions are needed to properly forecast changes in Lake Manitoba water quality under different lake conditions and management schemes, set nutrient objectives for the lake, and determine if those objectives have been met. Establishing baseline conditions and nutrient loading targets for Lake Manitoba was identified as the number one knowledge gap in Watershed Management & Landscape Processes (p. 13). Filling that knowledge gap would directly address this gap, as it would include determining baseline nutrient conditions and defining nutrient objectives as part of establishing water quality targets.

Gap 5: Determine the nutrient-limitation vs. light-limitation status of phytoplankton – The extent to which the phytoplankton community of Lake Manitoba is limited by availability of nutrients and/or light is unknown. The link between algal productivity and availability of nutrients and light needs further study in order to forecast potential changes in Lake Manitoba productivity caused by altered nutrient levels and turbidity associated with increased use of the Portage Diversion or climate change. The impact of changing oxygen content on phytoplankton communities is a related gap that needs to be addressed.

Gap 7: Strategically reallocate tributary monitoring resources to consistently calculate tributary nutrient loads – There are currently more than sixty water quality and flow monitoring stations located in Lake Manitoba watershed tributaries. However, due to limited resources these are not sampled thoroughly and only a few times a year, meaning data collected at these sites are incomplete and do not have good temporal coverage. To fill these data gaps, a subset of stations should be monitored in order to sample more intensively and more often, especially during periods of high flow. Choosing which stations to monitor should be done strategically, though developing criteria on which to base the monitoring location is a challenge that requires more data and careful consideration. In general, larger rivers such as the Red, Assiniboine, and Whitemud have continuous flow and sufficient nutrient monitoring. Smaller tributaries are less studied, leaving a gap in local data. Areas that account for larger portions of external nutrient loading should be given priority. Conservation Districts may be able to help monitor water flow and nutrient loads, but advice and instruction would be required to guide their volunteers, make better use of their limited resources, and improve data quality. Using more efficient and cost-effective equipment may also help improve monitoring. This gap could be addressed as part of establishing baseline conditions and nutrient loading targets for Lake Manitoba, which was identified as the number one knowledge gap in Watershed Management & Landscape Practices (p. 13).

Gap 8: Resolve the Lake Manitoba nitrogen and phosphorus budgets – There are many unknown terms in the nitrogen and phosphorus budgets of Lake Manitoba, which limits our ability to forecast future water quality changes and establish water quality targets. Gaps in both budgets include incomplete quantitative data on the amount of each nutrient entering the lake through atmospheric deposition (Water Quality Gap 12) and tributary loading (Water Quality Gap 7, p. 22), especially during high flow events, rates of changes in nutrient state and speciation (e.g. nitrification / denitrification and suspension / resuspension), and what is being recycled through internal nutrient loading (Water Quality Gap 3, p. 21).

Gap 9: Describe under-ice processes and establish their importance – There is very little understanding of winter processes and their importance to Lake Manitoba water quality. Under-ice studies are required to fill this data gap. These studies include, but are not limited to, investigation of internal phosphorus loading during winter when sediments are likely anaerobic, changes in organic matter decay from summer to winter, and under-ice oxygen availability. Lack of under-ice population dynamics data was identified as the tenth gap in Ecology & Wetlands (p. 29) and could be addressed alongside this gap.

Gap 10: Determine environmental factors that affect phytoplankton communities under changing anthropogenic pressures – A model that can predict changes to phytoplankton communities and algal bloom events, particularly of species that produce toxins potentially harmful to lake users, is an important management tool. A better understanding of the relationship between phytoplankton communities and environmental and ecological factors, and what drives that relationship in Lake Manitoba is needed to produce such a model. One challenge to this model is that the effect of climate change on temperature, evaporation, and mixing on nutrient availability and phytoplankton communities in Lake Manitoba is unknown, but may be substantial. Understanding these relationships is critical for forecasting cyanobacterial blooms. Phytoplankton should not be the only focus; data on benthic algae, which can be major contributors to photosynthesis and toxin production, is also a large knowledge gap. Understanding the nutrient limitation vs. light limitation status of phytoplankton (Water Quality Gap 5, p. 22) is a precursor to filling this knowledge gap.

Gap 11: Investigate efficacy of phosphorus removal tools – Once phosphorus enters an aquatic system it is very difficult to remove, especially in a shallow waterbody such as Lake Manitoba where phosphorus can easily undergo resuspension. Viability and efficacy of phosphorus removal tools must be investigated in order to determine if any methods should be recommended for use in Lake Manitoba. Cost-effective tools could be useful for mitigating algal blooms, especially if Lake Manitoba is subject to increased eutrophication.

5.3. Next Steps for Top Ranked Knowledge Gaps

The next steps to address top-ranked Water Quality knowledge gaps were developed by workshop attendees who self-identified as experts in the theme. Discussion focused on barriers to filling the knowledge gap, potential project collaborators and funding sources, and a timeline to complete the project. This section summarizes those next steps.

Gap 1 & 3: Collect offshore water quality data (p. 20) & Quantify internal nutrient loading in Lake Manitoba (p. 21)

1. Solution:
    - Develop a mass balance model for phosphorus and nitrogen
2. Precursor conditions necessary to address the knowledge gaps:
    - Inventory of existing data and organizations
    - Estimate internal loading using sediment core incubations, *in situ* flux chambers, and satellite imagery to assess reduction in total suspended solids over time, which has been done successfully in Lake Winnipeg
    - Place permanent thermistors gauges in the limnetic zone to assess episodic stratification
3. Barriers to success:
    - Inaccessible limnetic zone
        - Winter may be the optimal time for sediment core sampling
    - Researcher to collect sediment cores
4. Essential collaborators:
    - Centre for Earth Observation Science, University of Manitoba
        - Dr. Greg McCullough will be examining satellite imagery for the potential to estimate settling velocity / resuspension rates
        - Claire Reis (MSc candidate) will be collecting much of the necessary mass balance data
    - Lake Winnipeg Research Consortium, which may provide access to their smaller boat, the *Fylgja*
    - Provincial government and its water quality program for in-lake nutrient concentrations
    - International Institute for Sustainable Development, Experimental Lakes Area Project
5. Other interested parties that should be included:
    - International Institute for Sustainable Development, Manitoba Prairie Lakes and Eutrophication Project, which is currently planning to take sediment cores from multiple prairie lakes to assess internal loading
    - Lake Winnipeg Foundation, which may wish to make this a joint project as internal nutrient loading is an issue in Lake Winnipeg
    - Department of Fisheries and Oceans, which considers internal loading a serious issue for aquaculture
6. Leadership for the process:
    - Centre for Earth Observation Science, University of Manitoba
    - Provincial government
7. Potential funding sources:
    - Loblaw Fund
    - Lake Winnipeg Basin Initiative
    - RBC Bluewater Fund

8. Metrics to determine if the objective has been achieved:
    - Completed mass balance model
9. Timeline:
    - Expected completion within two to three years

6. Ecology & Wetlands

6.1. Presentations

The following presentations were given to introduce the Ecology & Wetlands theme and used as the basis for discussing its knowledge gaps:

Brian Parker – *The Lake Manitoba Fishery*

Dale Wrubleski – *Restoring a Large Freshwater Coastal Wetland; Delta Marsh, Manitoba*, p. 39

Scott Higgins – *The ecological implications of Zebra Mussel establishment in Lake Manitoba*, p. 39

Rebecca Rooney – *Wetland Monitoring and Assessment: Tool Development and Validation*, p. 40

6.2. Knowledge Gaps

Following the Ecology & Wetlands presentations, workshop attendees broke into small groups to identify and discuss gaps in relevant research and data. Identified gaps were compiled into a list and attendees voted on which gaps they considered to be of highest priority. Ranking of knowledge gaps was based on personal criteria, including considerations such as priority relative to other gaps, feasibility of addressing the gap, and size of the knowledge gap. The table below is a summary of the Ecology & Wetlands knowledge gaps identified during small group discussions, and their rank based on number of votes. Following the table are synopses of knowledge gap discussion points compiled from all small groups.

Knowledge Gap	**Votes**
Gap 1: Create a Lake Manitoba Research Consortium and Manitoba Great Lakes Research Consortium to coordinate and disseminate research	20
Gap 2: Characterize food webs and assess the impact of hydrological changes and other environmental drivers	20
Gap 3: Conduct Sensitive Habitat Inventory Mapping (SHIM) analysis	7
Gap 4: Quantify fisher effort to adequately compute fish stocks	7
Gap 5: Create a map of lake sediments	3
Gap 6: Identify indicators of ecosystem function before and after zebra mussel invasion and conduct an economic assessment of the impact of zebra mussels	3
Gap 7: Conduct a wetland survey to identify reference sites	3
Gap 8: Develop a mechanistic understanding of recovery in waterfowl population	1
Gap 9: Determine the contribution of heterotrophy and secondary productivity	1
Gap 10: Investigate under-ice population dynamics	1

Gap 1: Create a Lake Manitoba Research Consortium and Manitoba Great Lakes Research Consortium to coordinate and disseminate research – A governing body that organizes and archives knowledge, coordinates current and future research activities, sets ecosystem and water quality targets, and advocates on behalf of Lake Manitoba and its ecosystems is needed. The Lake Manitoba Research Consortium (LMRC) could be modelled after the existing Lake Winnipeg Research Consortium[5] (LWRC). The concept of the LMRC should be taken one step further, and an overriding organization should be established to coordinate and disseminate research concerning all of the large lakes in Manitoba (i.e. Lake Winnipegosis, Lake Manitoba, and Lake Winnipeg), which are interconnected and experiencing many of the same problems. The suggested Manitoba Great Lakes Research Consortium (MGLRC) would integrate data from the smaller research consortiums but also include landscape data. The MGLRC could be involved in establishing and maintaining the Prairie Aquatic Ecological Observatory Network (PAEON) (Watershed Management & Landscape Processes Gap 2, p. 13). (Next Steps, p. 30)

Gap 2: Characterize food webs and assess the impact of hydrological changes and other environmental drivers – There are data on phytoplankton and piscivorous fish in Lake Manitoba, but much of the intermediary food web data is lacking and presents a large knowledge gap, despite the number of environmental impact assessments conducted by industries associated with the lake. To fully characterize the food web in Lake Manitoba more research on zooplankton, macroinvertebrates, planktivores, benthivores, and forage fish are needed. This should also include organisms found outside the lake, such as piscivorous birds and mammals. Benthic data are particularly lacking, and could be addressed by collecting and analyzing sediment cores. Qualitative forage fish data could be obtained by looking at the piscivorous bird population and fisheries bycatch. A more comprehensive monitoring system that collects data on basic food web parameters and includes offshore food web analyses would help fill this knowledge gap.

In addition to improving food web data, a better understanding of Lake Manitoba ecology in relation to its environmental conditions is needed. In particular, the impacts of hydrological changes, such as inter-annual water level fluctuations, are important to understand as they drive many other variables, including lake salinity and productivity in coastal habitats. Other potential environmental drivers include nutrient levels, sediment type, and intensity of wind / wave action. The assessment of environmental drivers should be lake-wide as processes associated with these drivers are likely spatially heterogeneous, and the impacts on food webs and lake ecology will be different in littoral, limnetic, profundal, and marsh areas. However, lack of offshore data was identified as the number one gap in Water Quality and therefore presents a challenge to filling this knowledge gap (p. 20). Historical food web data are needed to determine the impact of hydrological changes, and also to help set objectives for the lake. Assessing impacts of environmental drivers on food webs and lake ecology might be most effectively done within a modelling framework which would allow managers to forecast the impact of changes in environmental drivers, such as water level, on food webs and lake ecology. (Next Steps, p. 31)

Gap 3: Conduct Sensitive Habitat Inventory Mapping (SHIM) analysis – A comprehensive study of different habitats in and around Lake Manitoba is needed. One way to address this gap is to conduct Sensitive Habitat Inventory Mapping (SHIM), which documents the location, extent, and condition of different aquatic habitats, including waterbodies and wetlands. A habitats map would define sensitive

[5] http://www.lakewinnipegresearch.org/

areas, such as fish spawning and feeding habitats, the locations of which are largely unknown. This information will be useful for lake management, by identifying habitats important to fisheries. To maximize this tool, SHIM should include coastal wetlands, tributaries, and drainage ditches that feed into Lake Manitoba which are potentially used by fish for spawning. SHIM could also be used to categorize sensitivity of shorelines to disturbances, which would be useful for shoreline development planning. SHIM could be conducted in conjunction with other knowledge gaps including lake bathymetry (Water Levels & Regulation Gap 1, p. 5), water quality (Watershed Management & Landscape Processes Gap 1, p. 13), food web characterization (Ecology & Wetlands Gap 2, p. 27), and sediment mapping (Ecology & Wetlands Gap 5, p. 28).

Gap 4: Quantify fisher effort to adequately compute fish stocks – Accurate fish population estimates require reliable and comprehensive data. Currently the province conducts index netting in Lake Manitoba, to aid lake management decision-making, but without a measure of fisher effort, the fish population estimates have considerable uncertainty. Fisher effort data include net size, amount of net set, and the duration and timing of fishing. This information should be gathered from commercial, recreational, and First Nations fishers to fully capture fish harvest from Lake Manitoba.

Gap 5: Create a map of lake sediments – A comprehensive map of Lake Manitoba and marsh sediments is needed to improve understanding of sediment processes and potential spatial heterogeneity in the lake. Knowledge of sediment types would help with understanding the effects of suspension / resuspension rates and sediment-water interactions on nutrient internal loading (Water Quality Gap 3, p. 21). Mapping sediment particle size would help locate areas of rough substrate suitable for zebra mussel (*Dreissena polymorpha*) colonization and help determine where to focus monitoring efforts for initial invasion. This has been done for parts of the lake, but there is likely substantial heterogeneity, so it is needed for the whole system. Differences in Lake Manitoba and Assiniboine River sediments is largely unknown; with increased use of the Portage Diversion, it is important to understand these differences and the potential effects sediment loading from the diversion will have on the lake. Sediment sampling could be done in concert with bathymetric analysis. Cores could be analyzed for sediment composition and isotopes to compare pre- and post-diversion conditions.

Gap 6: Identify indicators of ecosystem function before and after zebra mussel invasion and conduct an economic assessment of the impact of zebra mussels – A comprehensive limnological study of Lake Manitoba is needed before zebra mussels arrive. These data would provide baseline conditions necessary to assess the impacts of zebra mussels on lake water quality and ecology. They would also help managers establish a plan for the arrival of zebra mussels, as it is unlikely that it can be prevented. Research and planning should be strategic; indicators should be used to determine what research is of highest priority, where it should be conducted, and whether data gaps can be filled in conjunction with other research. For example, sediment mapping (Ecology & Wetlands Gap 5, p. 28) would help identify areas suitable / unsuitable for zebra mussel colonization, and lower levels of the food web need to be surveyed (Ecology & Wetlands Gap 2, p. 27) as they will most likely be affected first.

An assessment of economic impacts of zebra mussels would also help develop management plans that relate to other areas of Lake Manitoba. For example, will the efficacy of the current carp exclusion gates be impacted, or do alternatives need to be investigated? Will drainage canals need to be widened if colonization impedes water flow and increases flooding? Currently individual stakeholders conduct their own assessments of economic impacts, but there is no overall provincial assessment.

Gap 7: Conduct a wetland survey to identify reference sites – A survey and assessment of wetlands associated with Lake Manitoba is needed in order to evaluate their condition and determine which should be established as reference sites and monitored long-term. A wetland inventory map is currently being created by the Manitoba Habitat Heritage Corporation in collaboration with Ducks Unlimited Canada.

Gap 8: Develop a mechanistic understanding of recovery in waterfowl population – Duck populations in Delta Marsh have been improving but mechanisms behind the change are unknown and/or not fully understood. Identifying the environmental drivers behind this improvement is necessary to developing restoration plans for other waterfowl populations. This research could be done in conjunction with conducting a lake-wide assessment of environmental drivers on lake ecology and food webs (Ecology & Wetlands Gap 2, p. 27).

Gap 9: Determine the contribution of heterotrophy and secondary productivity – While primary production receives the bulk of research attention, less is known about the contributions of heterotrophy and secondary productivity in shallow prairie lakes, and in Lake Manitoba specifically. These processes may be important components of Lake Manitoba ecology and thus deserve research attention. For example, further research into how common carp affect other fish populations, turbidity, and resuspension of phosphorus is needed.

Gap 10: Investigate under-ice population dynamics – The impact of under-ice conditions on succession and other ecological changes in Lake Manitoba is not fully understood, despite the annual occurrence and long duration of ice cover. This information is needed to fully understand the ecology of Lake Manitoba, particularly in the face of climate change which may alter the duration of ice cover. A specific gap that needs addressing is how under-ice hypoxia / anoxia affects aquatic flora and fauna. The effects of under-ice environmental processes on water quality was identified as the ninth most important gap in Water Quality (p. 22) and could be addressed in conjunction with this gap.

6.3. NEXT STEPS FOR TOP RANKED KNOWLEDGE GAPS

The next steps to address top-ranked Ecology & Wetlands knowledge gaps were developed by workshop attendees who self-identified as experts in the theme. Discussion focused on barriers to filling the knowledge gap, potential project collaborators and funding sources, and a timeline to complete the project. This section summarizes those next steps.

Gap 1: Create a Lake Manitoba Research Consortium and Manitoba Great Lakes Research Consortium to coordinate and disseminate research, p. **27**

1. Precursor conditions necessary to address the knowledge gap:
    - Expand and improve upon the large amount of work already conducted by the Lake Winnipeg Research Consortium
2. Barriers to success:
    - Limited financial resources and available researchers
    - Identification and inclusion of currently unknown core stakeholders
3. Essential collaborators:
    - Lake Winnipeg Research Consortium
    - Federal, provincial, and municipal government
    - Academic community
    - First Nations
    - Interested NGOs
4. Other interested parties that should be included:
    - Commercial and recreational fishers
    - Cottage Owners Associations
    - Delta Agriculture Conservation Coop
    - Assiniboine River Basin Initiative
    - Interested industries
5. Leadership for the process:
    - Lake Winnipeg Research Consortium and Manitoba Great Lakes researchers in the early stages
    - Manitoba Great Lakes Research Consortium following establishment of the organization
    - Possibly a high-profile, politically connected champion to promote the program
6. Potential funding sources:
    - Industries that use or affect watersheds in Manitoba, such as Coca-Cola®, J. R. Simplot Company, and McCain Foods Ltd.
    - Federal, provincial, and municipal government
    - Environmental foundations
    - Sustainable fisheries organizations
    - Research grants
    - Private donors
7. Metrics to determine if the objective has been achieved:
    - Establishment of Lake Manitoba Research Consortium and Manitoba Great Lakes Research Consortium that receive stable funding
    - A base of operations

8. Timeline outlining short-term, mid-term and long-term goals:
    - Short-term (1 year): hold preliminary meetings with the Lake Winnipeg Research Consortium to identify a path forward and create a steering committee
    - Mid-term (1-3 years): Convene a group meeting of all relevant stakeholders to discuss the role of the Lake Manitoba Research Consortium and Manitoba Great Lakes Research Consortium and the terms and conditions under which they will operate
    - Long-term (3-5 years): Establishment of the Lake Manitoba Research Consortium and Manitoba Great Lakes Research Consortium under a sustainable funding model and with a dedicated base of operation and appropriate infrastructure and human resources to successfully carry out its mandate

Gap 2: Characterize food webs and assess the impact of hydrological changes and other environmental drivers, p. 27

1. Precursor conditions necessary to address the knowledge gap:
    - Centralized database of existing food web data, historical and current, for Lake Manitoba
2. Barriers to success:
    - Lack of background / baseline food web data
    - Accessibility of and ability to sample such a large lake
    - Lake of appropriate infrastructure from which to sample (e.g. a boat or mooring stations)
    - Need for a base of operation and human resources
3. Essential collaborators:
    - University researchers
    - Government scientists
    - Federal and provincial resources managers
4. Other interested parties that should be included:
    - Community monitors / citizen scientists
    - Commercial fishers
5. Leadership for the process:
    - Academic researchers in conjunction with government scientists
    - Possibly a high-profile, politically connected champion to promote the program
6. Potential funding sources:
    - Federal, provincial, and municipal government
    - Environmental foundations
    - Sustainable fisheries organizations
    - Research grants
    - Private donors
7. Metrics to determine if the objective has been achieved:
    - Compilation of all existing food web data
    - Adequate representation of the current trophic structure for both basins that can be used to develop long-term monitoring programs
8. Timeline outlining short-term, mid-term and long-term goals:
    - Short-term (1-2 years): source, compile, and upload all existing food web data
    - Mid-term (2-5 years): conduct initial spatially extensive and temporally intensive food web sampling across all trophic levels to fully characterize the current food web

7. CONCLUSIONS

Lake Manitoba is an important freshwater resource in the province of Manitoba. Both the lake and watershed serve many important ecological, economic and recreational functions. However, the water quality and ecosystem health of this system are threatened by environmental and anthropogenic pressures, both specific to the lake and general to the prairie region. However, our current understanding of the system is not sufficient to make informed decisions about how to manage this important resource.

The goal of this workshop was to assess the current state of knowledge around ecosystem processes in Lake Manitoba and its watershed, identify critical knowledge gaps, and develop the next steps for addressing the knowledge gaps, all with a view to making better decisions about the lake in the future. The participants at the workshop represented a wide range of disciplines, including hydrology, limnology, ecology and watershed science, all with particular experience working in Lake Manitoba or other prairie lakes and watersheds. The knowledge gaps identified here draw on this considerable expertise, and are representative of the current state of scientific understanding of the Lake Manitoba system. While this report summarizes the discussions and findings of the workshop, it is not intended as a final document, but rather as a blueprint that can be used by researchers, government officials, funding agencies to guide future research directions.

8. ACKNOWLEDGEMENTS

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APPENDIX B: ABSTRACTS

Background to Lake Manitoba

Gordon Goldsborough – A review of the limnology of Lake Manitoba: A large, shallow lake in south-central Canada
Lake Manitoba is the world's 33rd largest freshwater lake with a surface area of 4,700 km^2. The lake is remarkably shallow with a mean depth of 5 m and maximum depth of 7 m. Two rivers flow into the lake, the larger of which contributes 90% of the total surface input, equal to that of precipitation. There is one surface outlet, which accounts for half of total outputs, with evaporation making up the remainder. The lake is divided into two basins; the south basin has a longer residence time than the north basin. Annual precipitation averages 0.5 m with an annual deficit from 90 to 190 mm. The lake is ice-covered from November to May. Lake levels have been managed since 1961 with a consequent reduction in the total range, from about 1.8 meters pre-regulation, to about 0.3 m. Water quality monitoring is limited, with one sample collected monthly in the south basin, and none in the north basin. These data show that the lake is chemically brackish, and mesotrophic to eutrophic. In early 2007, a Lake Manitoba Stewardship Board was formed by the Manitoba government to examine the state of knowledge about the lake and to recommend ongoing research and management.

Water Levels & Regulation

Rick Bowering – The Hydrology and Regulation of Lake Manitoba
Since early settlement the Lake Manitoba has experienced extensive flooding as well as very low levels during periods of drought. Major flooding from 1953 to 1957 led to the construction of the Fairford River Water Control Structure at the outlet of the lake. The structure was put into operation in 1961. The structure proved to be very effective in controlling Lake Manitoba levels within a narrow range, but the frequent flow changes through the Fairford Control Structure resulted in more frequent flooding on Lake St. Martin. There was also concern that regulation was damaging shoreline marshes (including Delta Marsh) and restricting fish passage. In 1970 the Portage Diversion started operation, diverting excess flows from the lower Assiniboine River to Lake Manitoba. Operation of the diversion has largely eliminated flooding along the Assiniboine River from Portage la Prairie to Winnipeg, but in some years has aggravated flooding on Lake Manitoba. There is also concern about the water quality impacts of the diverted water. The presentation will review the hydrology of the lake's watershed, the history of operation of the Fairford River Water Control Structure and the Portage Diversion, and discuss future options.

Steve Topping – Lake Manitoba Hydrology: past, present and future
The flood of 1882 demonstrated that the Assiniboine River naturally overflowed its banks and flowed north to Lake Manitoba. Today, the Portage Diversion diverts the Assiniboine River to Lake Manitoba. The outlet to Lake Manitoba, the Fairford Diversion, mitigates the impact of the Portage Diversion flows. Lake Manitoba often exceeds its operating range (810.5 to 812.5) feet asl particularly for the 2011 and 2014 floods. The recent government announcement of constructing a 7500 cfs Lake Manitoba outlet channel will provide better Lake level regulation.

Byron Williams – Making Space: Water Governance, Science and Legitimacy
No abstract provided.

Parsa Aminian – The Hydrodynamics of Delta Marsh: Using engineering tools to interpret the physical behaviour of an historic coastal wetland
Delta Marsh is an immense and historic wetland along the southern coast of Lake Manitoba. The role of the marsh has been to store nutrients and to host a wide variety of plant and animal species – notably waterbirds. Over the past half-century, the deterioration of Delta Marsh has led to diminished water quality, decreased nutrient storage capacity, and decreases in the abundance of native species. The 'Delta Marsh: Restoring the Tradition' project was initiated in 2013, with the goal of restoring the ecological and anthropological tradition of Delta marsh. Part this project is the collection of baseline knowledge for use in future rehabilitation planning. While plenty of research exists regarding the impact of water on wetland function, there is limited understanding of the specific water movement processes that govern at Delta Marsh. A hydrodynamic model of the marsh was built in MIKE 21, and was used to simulate water movement between Delta Marsh and Lake Manitoba. Modelling provided insight into the impact of the Portage Diversion, The Fairford River Water Control Structure, wind setup, and other physical controls. Modelling can inform future wetland rehabilitation efforts, and support evidence-based decision making regarding the regulation of the Lake Manitoba hydrologic system

Watershed Management & Landscape Processes

P.R. Leavitt, L. Bunting, Bjoern Wissel, A. St. Amand, and D.R. Engstrom – Eutrophication of the South Basin of Lake Manitoba, Canada
Analysis of well-dated and highly resolved sediment cores demonstrated that the south basin of Lake Manitoba has undergone substantial eutrophication since ca. 1890. Baseline conditions in the south basin existed ca. 1800-1880 in which surface waters were moderately productive (TP_{spring} 35-55 $\mu g\ L^{-1}$, summer Chl a 6.0-8.5 $\mu g\ L^{-1}$), influxes of nitrogen (N), carbon (C), and phosphorus (P) were stable, algal abundance was constant and much lower than at present, and N2-fixing cyanobacteria were rare. Following this period, water quality in Lake Manitoba south degraded rapidly, with a two- to three-fold increase in the abundance of cyanobacteria and chlorophyte algae, taxa which bloom during the late summer and fall. In general, eutrophication was most rapid during ca. 1890-1930, although the abundance of chlorophytes, cyanobacteria and total algae continued to increase throughout the 20th century in direct proportion to the growth of the non-aboriginal human population. In contrast to the southern basin of Lake Winnipeg, analysis of morphological fossils from phytoplankton revealed little evidence of ecosystem state after 1990, although fossils from N2-fixing cyanobacteria (*Aphanizomenon*, *Anabaena* spp.) were present in lake sediments only after the Portage Diversion was established in 1970. Given the similarity in onset, trajectory and magnitude of eutrophication in the southern basins of lakes Manitoba and Winnipeg during the 20th century, we conclude that water quality degradation is likely regulated by similar processes, particularly development of agricultural nutrient sources within Manitoba, rather than by sudden climate change in the past 25 years. Although operation of the Portage Diversion appears to have had limited effects on lake production, major element biogeochemistry, or gross algal composition, the presence of low densities of fossils from N2-fixing cyanobacteria after ca. 1970 may represent an early-warning signal of impending changes in the lake's nutrient status.

David Lobb – Managing the Surface Waters within Our Watersheds
This presentation provides an overview of the major surface water management challenges we face in the Lake Winnipeg Basin, including Lake Manitoba and its watershed – flooding and algae blooms. It also examines several management practices and their effectiveness in mitigating these problems.

Henry Wilson – Recent patterns of runoff water quality for agricultural watersheds in the Manitoba's Aspen Parkland
A large portion of the land base that may contribute water to Lake Manitoba in a given year falls within the Aspen Parkland Ecoregion, which covers most of the southwestern corner of Manitoba and significant areas of the larger Assiniboine River watershed. In this presentation patterns of water quality (as defined by C, N, and P chemistry) will be described for 20 agricultural (70-90% cropland) tributaries of the Assiniboine, Souris, and Whitemud Rivers, as measured between 2012 and 2014. Patterns as observed at the finer scale for micro-watersheds (2-6 ha.) draining fields within the region will also be described for 18 sites covering a range of soil fertility and tillage practices. Highlights from preliminary analyses of relationships between water chemistry and nutrient export, weather conditions, watershed characteristics, and agricultural management will be presented for both the regional watershed and micro-watershed scales. Particular focus will be placed on phosphorus given the likely importance of this element as a driver of eutrophication in Lake Manitoba, but potential implications of changing nitrogen and organic matter export for heterotrophic processes in the Lake and its tributaries will also be mentioned to initiate discussion.

Helen Baulch – Eutrophication in the prairies: nutrient sources, and work towards solutions
Prairie landscapes are naturally nutrient rich, and, subject to cyclical wet-dry periods. This combination of landscape character and hydrology, have created unique challenges in terms of eutrophication management. In this talk, recent research addressing a suite of topics relevant to Lake Manitoba will be discussed. These include our findings that phosphorus concentrations in potholes increase markedly through winter, and appear to be linked to the onset of anoxia, suggesting that light conditions (affecting oxygen), combined with wet-dry cycles (affecting connectivity) will dictate the importance of wetlands as phosphorus sources in the landscape. Biogeochemical models are a common tool applied to explore drivers of nutrient export, and select options to help mitigate elevated fluxes. Our hydrological modelling results indicate that simulation of fall moisture conditions, as well as the potential for ice lens development, are critical to modelling flow during snowmelt; however, more work is required to improve biogeochemical simulations of snowmelt. Finally, given the importance of snowmelt to hydrology of this region – many BMPs developed for rainfall-runoff dominated catchments are unlikely to be effective. Headwater dams have demonstrated efficacy in areas of the prairies; however design and siting attributes may lead to tradeoffs in ecosystem services associated with their implementation. Nutrient source management, and management of P fluxes from reduced tillage systems represent key areas where load reductions may be attained.

Patrick Watson and Bobby Bennett – Manitoba's Conservation Districts
The Conservation Districts Program in Manitoba provides unique opportunities for municipalities and environmental stewards to discuss issues affecting water quality and ecosystem health and develop locally-led and provincially-supported integrated watershed management plans. The presentation will introduce the Conservation Districts Program and highlight the Conservation Districts adjacent to Lake Manitoba that not only possess great background knowledge and life-long experiences with the lake, but also the ability to make significant land and water management improvements.

Water Quality

Elaine Page – A water quality assessment of Lake Manitoba
Water quality of Lake Manitoba is poorly understood in comparison to other large lakes and a study was undertaken to characterize the spatial and temporal variation in water quality. To characterize the lake wide water quality conditions, samples were collected from 15 stations over a 2 year period. Geospatial mapping and principal components analysis revealed that the south basin of the lake was more turbid, nutrient rich, and more dilute in comparison to the north basin. Water samples collected daily during the operation of the Assiniboine River Diversion over several years indicated that the Assiniboine River Diversion was the single largest source of phosphorus and sediment and was the second largest source of nitrogen to the lake. A non-parametric trend analysis of a 17 year historical water quality dataset from a station in the south basin indicated that Lake Manitoba has become more dilute and nutrient rich over time.

Joe Ackerman – Lake Remediation studies in Killarney Lake: phosphorus budget and sediment capping
Killarney Lake is a hypereutrophic shallow prairie lake in southern Manitoba that has had summer total phosphorus (P) levels of 350 µg/L and higher. Its small size (180 ha), shallow depth (~4 m) and tiny watershed makes Killarney Lake a good site to test ways of reducing P flux from sediment to the water column. An ongoing three-year study has looked at P sorption capacity of local clays in southern Manitoba and conducted both laboratory and in-lake sediment-capping trials. The effectiveness of applying a thin layer of selected commercial and Manitoba clays to immobilize sediment P release was tested with in-lake enclosures during the summer of 2015. A phosphorus mass balance within each enclosure suggested clays lost most of their P adsorbing effectiveness when used in situ, possibly due to the high organic content of the sediment. The experiment produced valuable data for the whole-lake P mass balance, and coupled with 2015 input restrictions, the water-tight enclosures revealed about two thirds of the mid-summer P spike comes from internal loading.

Greg McCullough, Claire Herbert, and David Barber – The Manitoba Great Lakes Project
The Centre for Earth Observations Science’s Manitoba Great Lakes Project is a study of climate and land use effects on Lakes Winnipegosis, Manitoba and Winnipeg. Our approach is to use remote sensing and GIS tools to better understand the impacts of flows of water and nutrients through this system of large lakes, and to relate water quality and algal biomass in these lakes with forcing mechanisms in their watersheds. To date, we have used a combination of moored instruments and in situ sampling to measure sediments, nutrients and chlorophyll in the lakes. Beginning this winter, an MSc student will use remote sensing and in situ sampling to study and compare suspended sediments, nutrients, and algal biomass and community structure among the lakes. We have begun analysis of historical discharge, lake level and nutrient fluxes through the systems with the goal of developing a mass balance model of nutrient loading to investigate nutrient flow and sequestration through the system. Our next step will be to organize and analyze land use data to support studies of relationships between land use and nutrient exports in selected MBGL watersheds.

Eva Pip – Nutrients, algal blooms and microcystin: a lesson in how our big lakes go wrong
Inorganic nitrogen (NN) and inorganic phosphorus (OP) were examined for several years in Lake Winnipeg. Chlorophyll a, a measure of algal biomass, was significantly correlated with preceding OP and NN fluctuations, suggesting that imminent blooms could be predicted from ambient nutrient concentrations. Microcystin fluctuations were correlated with chlorophyll a, as well as with OP and

NN, and inversely with the NN/OP ratio. More vigorous blooms, as reflected by the phaeophytin/chlorophyll a ratio, were more toxic. The neurotoxins anatoxin a and BMAA were also identified throughout the season, but were particularly high in bloom conditions. Variation in algal response to nutrients in different years indicated that other factors also contribute to the determination of the character and intensity of blooms in any given year. Watershed management and nutrient reduction strategies remain the primary targets for lake refurbishment. The greater total dissolved solids and nutrient concentrations of Lake Manitoba may present an even more pressing challenge for remediation.

Hedy Kling – Phytoplankton in Lake Manitoba and surrounding lakes
This presentation will briefly show some of the differences in Phytoplankton communities between these large shallow prairie lakes (Lake Winnipegosis, Waterhen and Lake Manitoba) and Lake Winnipeg with some reference to historic algal communities in Lake Manitoba and Lake Winnipeg.

Ecology & Wetlands

Brian Parker – The Lake Manitoba Fishery
No abstract provided.

Dale Wrubleski – Restoring a Large Freshwater Coastal Wetland; Delta Marsh, Manitoba
Delta Marsh is the largest coastal wetland on Lake Manitoba, and represents important fisheries and wildlife habitat. A multi-agency partnership has embarked on a ten-year restoration project to address the factors contributing to the deterioration of the marsh. Complicating restoration efforts is the fact that Delta Marsh cannot be managed in isolation. It is intimately connected to Lake Manitoba with which it exchanges water, nutrients and fish. The first phase of the restoration project consists of management efforts to reduce the impacts of an invasive fish species, Common Carp (*Cyprinus carpio*), that overwinters in the lake. Experimental field studies have already demonstrated that Carp are responsible for several changes observed in the marsh, including increased turbidity, phytoplankton blooms and loss of submersed vegetation. Carp exclusion structures have been constructed on the channels connecting the marsh to Lake Manitoba, and are designed and operated to reduce Carp access to the marsh while minimizing impacts on native fish species. A five-year monitoring program will adjust management efforts as required to favor improvements and balance needs of the native fish community. Initial monitoring results are showing improved water clarity and increased abundance of submersed vegetation. Additional scientific investigations of marsh hydrology, hydraulics, and nutrient inputs are now underway.

Scott Higgins – The ecological implications of Zebra Mussel establishment in Lake Manitoba
Zebra Mussels are a small non-native mussel with a natural range within the Ponto Caspian region of eastern Europe. Facilitated by trans-Atlantic commerce the species was first detected in Lake Erie in 1986 and then rapidly expanded through the Laurentian Great Lakes and inland lakes over the following decades, most recently in Lake Winnipeg. Given the proximity to Lake Winnipeg, Lake Manitoba and other provincial water bodies are considered at high risk for Zebra mussel invasion. A meta-analysis of Zebra mussel impacts from North American and European lakes and rivers is presented, highlighting the ecological implications to Lake Manitoba.

Rebecca Rooney – Wetland Monitoring and Assessment: Tool Development and Validation
Developing an appropriate monitoring and assessment plan requires clearly articulated objectives. This is because the umbrella term "monitoring and assessment" captures a wide range of sampling design and tool types, each suited to particular management objectives. For example, the best approach to tracking the trajectory of newly restored wetlands differs from that for monitoring wetland functions within a management area. Are we concerned with condition or function? Are we focused on detecting the local effects of a point source of disturbance or with cumulative effects across a larger management area? Do we need to be integrative or diagnostic? Regardless, monitoring and assessment tools are applicable only in the wetland type and region for which they were developed and for the type of stress or disturbance against which they were calibrated. We cannot import tools from other areas without appropriate validation.