Environment Canada Environnement Canada

Final Project Reports

Lake Winnipeg Basin Initiative

2008/09 – 2011/12

Canada

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Introduction

Lake Winnipeg is the 10th largest freshwater lake in the world and the 6th largest in Canada. The Lake Winnipeg watershed spans almost 1 million km^2, extending over four provinces and into four U.S. states. Water quality has deteriorated in Lake Winnipeg due to excessive amounts of nutrients, primarily phosphorus and nitrogen, from many point and non-point sources such as surface runoff and municipal wastewater effluent. Approximately half of this nutrient load originates from outside Manitoba's borders. The excessive nutrients contribute to the growth of huge tracts of blue-green algae, which rob the lake of oxygen, clog fishing nets, foul beaches and, under certain conditions, produce harmful toxins.

In 2007, as part of Canada's Action Plan for Clean Water, the Government of Canada announced an investment of $17.7 million over four years, from 2008/09 to 2011/12, to help clean up Lake Winnipeg. The Lake Winnipeg Basin Initiative (LWBI) was developed in response to the Manitoba government's request for federal support in addressing priority scientific needs within Lake Winnipeg and the broader basin, and to facilitate the coordination of government and stakeholder efforts in this transboundary watershed.

In order to improve the health of Lake Winnipeg, a sound scientific base of knowledge was first required, to determine what, and how much, action is needed. As a result, the major focus of the LWBI was to bring the Government of Canada's freshwater science and monitoring expertise to bear on the nutrient issues facing the lake and the watershed. This work was necessary in order to determine the appropriate measures needed to reduce nutrient loading into the lake, and to identify priority performance indicators to determine if such measures will be effective in improving the health of Lake Winnipeg.

The LWBI's $17.7 million resources were allocated as follows:

- scientific research, monitoring and information/data support ($12.1 million)
- community stewardship programs ($3.7 million)
- facilitating watershed governance ($1.9 million)

Activities in support of the LWBI were launched in 2008/09 on Lake Winnipeg and its major sub-basins, including the Red–Assiniboine and Winnipeg rivers, and Lake of the Woods.

Executive Summary

Activities throughout the four-year, $17.7 million Lake Winnipeg Basin Initiative (LWBI) focused on supporting stewardship activities amongst external and community groups; facilitation and coordination amongst federal and provincial agencies; and filling priority research, monitoring and information needs in Lake Winnipeg and its watershed.

Near-term results of the LWBI were generally achieved, including development of an improved science-based understanding of the dynamics of Lake Winnipeg and its Basin to support and inform policy and decision making, support for community stewardship activities, and development and implementation of a Canada–Manitoba agreement on Lake Winnipeg.

Facilitating Governance

In scope, the Lake Winnipeg Basin is both inter-provincial and international, and involves a myriad of stakeholders, jurisdictions and activities. Long-term collaboration and coordination between relevant stakeholders is fundamental to the health of the Basin. Through the LWBI, Environment Canada established a Lake Winnipeg Basin office in Winnipeg in 2009/10 to coordinate the three focus areas of the LWBI and enhance communications and coordination with existing water management bodies and other agencies.

Canada–Manitoba coordination on Lake Winnipeg water quality issues has greatly enhanced information sharing and cooperation amongst federal and provincial agencies and partners. A Canada–Manitoba Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin (MOU) was signed in September of 2010, to provide for a long-term collaborative approach to addressing the sustainability and health of the Lake Winnipeg Basin. An MOU Implementation Steering Committee comprised of federal and provincial agencies, and co-chaired by Environment Canada and Manitoba, was established to oversee the implementation of the MOU and development of subsidiary arrangements.

In addition to the MOU steering committee, Environment Canada continued to lead or participate on a number of domestic and transboundary boards, commissions, agencies and stakeholder groups within Manitoba and other provinces, as well as with U.S. agencies. Given the transboundary nature of nutrient sources into Lake Winnipeg, inclusion of the nutrient issue in such collaborations helped to support the development of nutrient management strategies and solutions throughout the vast Lake Winnipeg watershed.

Moving forward, Environment Canada will continue to deliver on its transboundary water mandate in the Lake Winnipeg Basin and will continue its role of ensuring effective communication and complementary approaches within branches of Environment Canada and among federal departments by increasing horizontal coordination of activities.

Stewardship

The Lake Winnipeg Basin Stewardship Fund was launched in 2008/09 to support high-impact, solution-oriented projects aimed at reducing nutrient loads in Lake Winnipeg and its Basin. The Fund supported a variety of "tried and proven" activities to reduce nutrients, studies and projects to aid decision making, as well as practical applications of innovative technologies within the Basin.

Fund priorities included: reducing nutrient inputs from rural and urban sources, controlling point and non-point sources of nutrients, rehabilitating priority aquatic ecosystems that support nutrient reduction and sequestration, and enhancing research and monitoring capacity to assist in decision making.

Over the course of five funding rounds, the Fund received 123 applications for funding. From among those, a total of $2.4 million was committed towards 41 community stewardship projects. The Fund leveraged $5.4 million in monetary and in-kind contributions from more than 250 project partners, multiplying the beneficial impact of the Fund. Project recipients included regional conservation authorities (20), non-profit organizations (9), post-secondary institutions (9), First Nations organizations (2) and municipal governments (1).

Projects were diverse in regards to location, design and approach, reflecting the myriad of contributing sources of nutrient loading into Lake Winnipeg. Thirty-three of the funded projects were in Manitoba, followed by five in Saskatchewan and three in Ontario. This diversity enabled broad-based stakeholder involvement across the watershed, but presented a challenge in focusing Fund resources in strategic areas and activities to maximize the positive benefits to Lake Winnipeg.

Projects addressing non-point sources of nutrients were the predominant activity funded. For example, 31 km of livestock exclusion fencing and 34 alternative watering systems were installed to restrict approximately 7000 livestock from accessing waterways draining into Lake Winnipeg. Riparian restoration efforts included protection or stabilization of 38 km of stream/lake bank. Approximately 17 000 native plants, trees and shrubs were also planted over 74 hectares. Wetland restoration and protection initiatives reclaimed 549 hectares of land, of which 126 are permanently protected by conservation agreements. Research studies of historical water quality changes in Lake Winnipeg were conducted, complementing work being done in the lake by Environment Canada and provincial scientists. The effective use of riparian zones to filter nutrients was studied. Innovative wastewater treatment systems and processes were supported to expand real-life application of available technologies and techniques. Wetland and sensitive habitat mapping was undertaken to advance current and future decision-making regarding Lake Winnipeg.

Research and stewardship efforts were complemented with capacity-building projects such as the Lake Friendly Campaign, designed to raise public awareness of the issues affecting Lake Winnipeg and actions individuals can take to reduce and mitigate nutrient loading across the Basin.

While it is too early to assess the impact of individual projects on nutrient loading to the lake, the Fund served to establish vital new partnerships and provided a foundation for organizations to move forward to deliver long-term benefits for Lake Winnipeg.

Research, Monitoring and Information Management

In response to requests from Manitoba and other stakeholders for federal freshwater expertise and support in fulfilling priority science needs within Lake Winnipeg and the broader watershed, a comprehensive science plan was developed to address research, information and monitoring gaps related to lake ecology, nutrient cycling, and the sources and transport mechanisms for nutrients. The science undertaken by Environment Canada through the LWBI was done in partnership with other agencies, including Fisheries and Oceans Canada, Agriculture and Agri-Food Canada, Manitoba Water Stewardship, the University of Manitoba, and other supporting agencies.

Research

The goal of the research undertaken through the LWBI was to characterize the physical, chemical and biological nature of Lake Winnipeg to better understand the balance of nutrient enrichment and productivity of fisheries in relation to algal blooms, assess non-point contributions of nutrients in the watershed and the lake and the effectiveness of agricultural beneficial management practices (BMPs), and investigate the economic value of clean water and the effectiveness of regulations and social policy on nutrient management in the watershed.

Research included characterizing the status and long-term trends in the biological community in Lake Winnipeg, Lake of the Woods and tributaries, the ecological impacts of blooms,[1] and the potential impacts of nutrient enrichment and invasive species on the food web. In-lake processes that promote algal and cyanobacteria blooms and their potential toxicity were explored. Results indicated that the cyanobacteria species dominating the summer blooms in Lake Winnipeg are not highly toxic, but the risk of toxins can increase dramatically in dense surface or shoreline scums, which commonly occur as a result of wind and currents. Invasive species such as dreissenid mussels could significantly impact light and nutrient regimes in the lake, potentially contributing towards more frequent blooms in the turbid south basin and a shift to more toxic cyanobacteria species in the future.

LWBI scientists used stable isotope “fingerprinting” of nutrients to obtain new information regarding nutrient sources in the Red River basin, analyze the cycling of organic matter and impacts on the food web, the processes that lead to algal bloom development and the factors that affect dissolved oxygen levels in Lake Winnipeg. Dissolved oxygen is crucial to the survival of aquatic ecosystems. Excessive algal growth and associated demands in oxygen consumption can depress oxygen levels in the water column. Despite high nutrient loadings and ongoing algal blooms in Lake Winnipeg, bottom-water oxygen depletion occurred only at a transient level in deeper parts of the north basin. The remainder of the lake is shallow and well-mixed.

[1] Broadly termed “algal” blooms, these occur throughout the year; those of most concern occur in the summer–fall period and are mainly dominated by cyanobacteria (also called “blue-green algae”).

Stable isotope analyses indicated that the Red, Winnipeg and Saskatchewan rivers have distinctive nitrate sources, providing an isotopic signature that enabled tracking of nitrates into Lake Winnipeg. Differences in nitrate sources in the north basin (decay of nitrogen-fixing cyanobacterial blooms) and south basin (primarily animal waste) were pronounced and indicate that each basin requires separate nutrient process models. Stable isotope measurements were also able to trace fish movements. This work provided a multi-year snapshot of the dissolved oxygen and metabolic status of Lake Winnipeg, and a productivity benchmark by which to compare outcomes of future nutrient management development in the lake and its watershed.

Environmental conditions in the Lake Winnipeg Basin are extremely variable, and nutrient loading is influenced by both natural conditions and human activities. As a result, field work was undertaken to examine the transport of nutrients in agricultural watersheds, the impact of snowmelt on nutrient transfer, and the impact of hydrology, climate change and variability on nutrient transfer.

Agricultural activities, particularly synthetic fertilizer application, were found to be the largest potential source of nutrients from human activities into aquatic ecosystems in most areas of the Lake Winnipeg Basin. Agriculture in areas within approximately 100 m of stream channels appeared to be the most critical driver of in-stream nutrient conditions during most seasons and under most flow conditions.

Nutrient loading is also strongly influenced by seasonal hydrology, with snowmelt being a critical period. Concentrations of nutrients varied seasonally, but showed more variability and larger values during winter and snowmelt. Vegetation (particularly winter cereals, riparian vegetation and forage crops) was found to be a significant source of nutrients in snowmelt runoff. Most BMPs have been designed to remove sediments from runoff and often use vegetation to prevent soil erosion and trap dislodged particles. However, the soil may actually buffer dissolved nutrients that are released from residues. This has implications for the development of BMPs, and for land-use management practices, which need to consider the snowmelt period in order to control nutrient loads to Lake Winnipeg and to other water bodies in the watershed.

Climate models and projections show future increases in annual precipitation and temperature, and changes to the hydrologic and nutrient transport regimes, resulting in higher total runoff and earlier snowmelt and discharge peaks. Overall, the effects of climatic changes on the nutrient transport regime need to be considered along with possible future changes in land use, crop type, fertilizer application and transformation processes in the receiving water bodies. Such changes would have significant implications for water availability and nutrient transport regimes, and for the design and implementation of practices to control nutrient loads to Lake Winnipeg and in the watershed.

Hydrologic models for Lake Winnipeg and Lake of the Woods were developed, which succeeded in reproducing thermal structure and circulation, and examining relationships between a variety of physical, chemical and biological processes. A predictive ecosystem model was developed to simulate the major nutrient and algal dynamics in Lake Winnipeg. Wind-driven circulation plays a crucial role in how materials are mixed, retained and/or flushed from each basin in Lake Winnipeg.

Similarly, watershed models were applied to aid in the understanding and management of surface runoff, nutrients and sediment transport processes, and evaluate the impact of land-use changes and practices. Stakeholder and landowner engagement played an important role in developing the watershed modelling scenarios and decision-support tools. The models indicated that conversion of cropland to hayland had a significant impact on reducing nutrient and sediment loading, followed by wetland restoration. Results of the modelling will be useful for planners and decision makers in identifying changes that may occur based on nutrient management policies.

A framework for using ecological goods and services (EG&S) was also developed and applied to two case studies in the Lake Winnipeg Basin. Several agricultural BMPs and wastewater treatment strategies were examined to estimate their costs, benefits in terms of phosphorus reduction, and EG&S co-benefits, such as greenhouse gas emission reduction, erosion control and pollination services. Results indicated that wastewater treatment strategies were generally less cost-effective than agricultural BMP strategies when the annualized net cost per tonne of phosphorus removed was considered. Some options for nutrient reduction, such as crop selection and vegetative filter strips, were associated with substantial EG&S co-benefits, although both had limited overall potential to reduce phosphorus loading, compared to other scenarios that were examined.

The value of improvements in EG&S provided by nutrient reduction strategies points to an increased need for including them in policy analysis, and for municipal, provincial, and conservation and watershed authorities to identify, measure and monitor EG&S.

Monitoring

An enhanced water-quality and biological monitoring program was implemented on Lake Winnipeg, Lake of the Woods and within the Lake Winnipeg watershed, to expand existing databases and to support modelling and research projects. Activities included deep-water bottom trawling, monitoring at east-side Lake Winnipeg river outflows, nearshore and marsh locations in the south basin and Red River delta areas, and at the outlet of Lake Winnipeg. Enhanced tributary monitoring was conducted in cooperation with the Manitoba government, to improve estimates of nutrient flux into the Red River between Emerson and Lake Winnipeg. Monitoring data was uploaded to the Lake Winnipeg Web portal.

Aquatic colour methods were developed for use with satellite observations, to support remote sensing imagery for Lake of the Woods and Lake Winnipeg. Remote sensing is a useful tool for tracking of surface algal blooms, and offers a cost-effective approach for monitoring, particularly when ground-based monitoring may not be logistically obtainable on a frequent basis and over large areas. There is evidence of intense bloom activity during dry, warm years, with a suggestion of blooms occurring later each year. Near-real-time images for Lake Winnipeg and Lake of the Woods are being posted to the Lake Winnipeg Web portal.

Using national Canadian Aquatic Biomonitoring Network (CABIN) protocols, a boreal reference condition model and a Prairie wetland biomonitoring protocol were developed. Collaboration was undertaken with other agencies to establish a Prairie biomonitoring network, which would greatly enhance the availability of biomonitoring data in the future. Work was also undertaken to develop a prototype indicator of local nutrient enrichment, based on biomonitoring data.

Monitoring was undertaken at 30 larger lakes and reservoirs in the Lake Winnipeg Basin, to evaluate the role of natural lakes and human-made reservoirs in reducing nutrient transfer from the watershed to Lake Winnipeg. Preliminary results indicate that large lakes and reservoirs in the Basin, particularly those with long water-retention times, sequester a variable but often high proportion of inflowing nutrients—up to 80% in some cases—playing an important role in reducing nutrient loading to Lake Winnipeg.

Funding support was provided to the Lake Winnipeg Research Consortium on an annual basis through the LWBI, to support the Consortium's activities. The Consortium includes a large group of government and non-government agencies dedicated to coordination of research and monitoring, as well as public education and outreach about the state of Lake Winnipeg. The Consortium also operates the MV *Namao* vessel, the only research and monitoring platform operating on Lake Winnipeg. Environment Canada also designed and supplied a new combined control room and lab addition to the *Namao*'s upper deck, to enhance research capabilities.

Information

LWBI information management activities included creating a single-window, online information portal for sharing data amongst key scientific partners and networks, and providing a basis, based on the results of research and monitoring activities, to inform the development of nutrient objectives and performance indicators for Lake Winnipeg.

The Lake Winnipeg Web information portal was developed, in conjunction with stakeholders, to gather, store and share data concerning the watershed, and to provide users with the tools and information they need to make effective water management decisions. The portal enables users to freely upload their data and information and model results for sharing with others. The portal currently contains about 137 datasets, and was transferred to the University of Manitoba in March 2012, where it will continue to grow and evolve as a comprehensive source of information and a resource for students, scientists and the public.

Environment Canada also partnered with Manitoba and other agencies to produce the *CA/MB State of Lake Winnipeg 1999–2007* report. This comprehensive report compiled historic data, highlighted recent research, and explored current and emerging issues of concern to the health and integrity of Lake Winnipeg—providing a baseline against which the results of current research and monitoring activities can be compared. Environment Canada also provided support to the Partners for the Saskatchewan River Basin for production of the 2009 *State of the Saskatchewan River Basin* report.

The Lake Winnipeg special edition of the *Journal of Great Lakes Research* was coordinated by Environment Canada, for publication in 2012. Eighteen papers from various government and non-government authors were submitted to the special edition, including many reports stemming from the research undertaken through the LWBI.

Finally, work was undertaken through the LWBI to support Manitoba in developing a science framework for establishing and evaluating nutrient objectives for Lake Winnipeg and tributaries. Environment Canada also worked with Manitoba to identify, finalize and evaluate 18 priority performance indicators to assess the health and detect changes in the lake and watershed. A report was drafted and is pending peer review, prior to being finalized. The indicators are anticipated to be used to direct future monitoring and research activities, and complement the development of ecologically relevant nutrient objectives.

Further details about the progress and achievements of the LWBI are available on Environment Canada's website at www.ec.gc.ca. More detailed LWBI project reports and technical information about the LWBI science activities, methodologies and research results can be obtained on the Lake Winnipeg Web information portal at http://lwbi.cc.umanitoba.ca.

Facilitating Governance

In scope, the Lake Winnipeg Basin is both inter-provincial and international, and involves a myriad of stakeholders, jurisdictions, and activities. Long-term collaboration and coordination between relevant stakeholders is fundamental to the health of the basin.

There are long standing and successful transboundary water management bodies in place in the Lake Winnipeg Basin (e.g. Prairie Provinces Water Board, International Joint Commission Boards, Lake of the Woods Control Board). However, without an over-arching mechanism to engage multiple stakeholders in such a large geographic area, efforts to integrate and coordinate activities in a cohesive and efficient manner for the entire Lake Winnipeg Basin can be fragmented and challenging.

The LWBI was developed to help facilitate government and stakeholder efforts across this transboundary watershed, as well as to address science needs.

Progress and Achievements

- Environment Canada established a Lake Winnipeg Basin office in Winnipeg in 2009/10 to coordinate the three focus areas of the LWBI and enhance communications and coordination with other agencies.
- Environment Canada participated as an ex-officio member of Manitoba's Lake Winnipeg Stewardship Board. The Board was established by Manitoba to make recommendations on how to reduce nutrient loading to Lake Winnipeg. The Board's term ended in January 2010.
- A five year Canada-Manitoba Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin (MOU) was developed under Section 4 of the *Canada Water Act* and signed on September 13, 2010. The MOU is intended to ensure the sustainability and health of the Lake Winnipeg Basin through long-term collaboration and coordination between the two governments.
- An MOU Implementation Steering Committee was established in 2010 to oversee the implementation of the MOU and development of subsidiary arrangements. The Committee is co-chaired by Environment Canada and Manitoba Water Stewardship and comprised of federal and provincial agencies.
- Environment Canada continues to participate or lead a number of transboundary water boards with Manitoba and other provinces, as well as with U.S. agencies, in order to facilitate the development of nutrient management strategies across Lake Winnipeg's transboundary watershed.

Conclusions

Canada/Manitoba coordination on water quality issues in Lake Winnipeg has enhanced information sharing among federal and provincial partners. Environment Canada has a continued role to ensure effective communication and complementary approaches within branches of Environment Canada and among federal departments by increasing horizontal coordination of activities.

Due to the transboundary sources of nutrients, there is an ongoing federal role in contributing to solutions for water quality issues in the Lake Winnipeg Basin. Federal efforts in transboundary watersheds complement Manitoba's efforts within the Province. Future focus should be on the inclusion of the nutrient issue in collaborations with domestic and international transboundary mechanisms and partners in a manner that supports the implementation of a broad bi-national nutrient management strategy across the Red River Basin. Opportunities also exist to increase engagement of other governments to address nutrient issues in the U.S. portion of Lake of the Woods, and the Winnipeg River system.

Moving forward, Environment Canada will continue to deliver on its transboundary water mandate in the Lake Winnipeg Basin and will continue its role of ensuring effective communication and complementary approaches within and among federal, provincial, and state governments by increasing horizontal coordination of activities.

The Lake Winnipeg Basin Stewardship Fund

In an on-going effort to promote stewardship, protect water resources and achieve desired outcomes, Lake Winnipeg Basin Initiative was allocated $3.64 M ($2.67 M in grants and contributions) to develop and administer a Lake Winnipeg Basin Stewardship Fund. The Fund supported high-impact, solution oriented projects aimed at reducing pollutants, and in particular, nutrient loads.

The Fund supported 'tried and proven' activities, studies and projects in addition to innovative techniques, technologies and measures to:

- reduce nutrient inputs from rural and urban sources;
- control point and non-point sources of nutrients;
- rehabilitate priority aquatic ecosystems that support nutrient reduction and sequestration; and
- enhance research and monitoring capacity to assist in decision making.

Additional consideration was given to projects and activities demonstrating:

- cost effective reductions in nutrient loads to the lake;
- on-going benefits to the lake and watershed;
- a high probability of success; and,
- a high level of support for the project from credible third parties.

Installation of livestock exclusion fencing in the Little Saskatchewan River Conservation District. Photo: L. Remillard. © Environment Canada 2011.

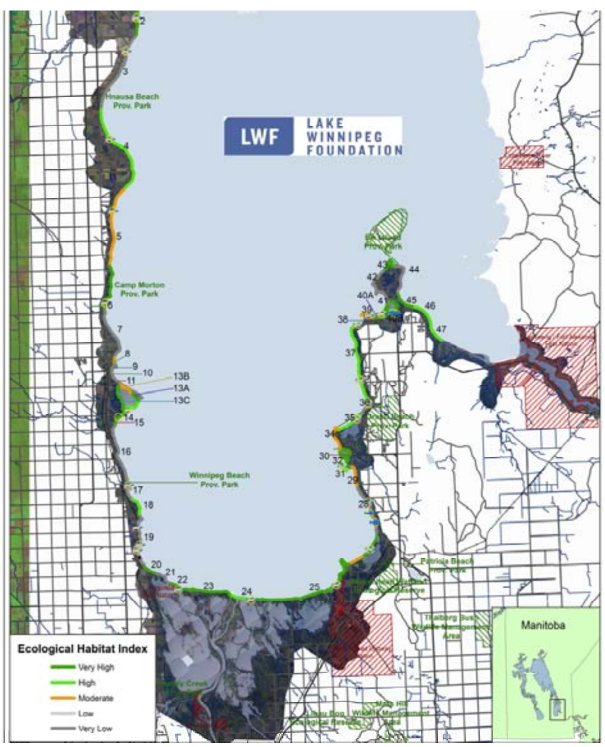
The Fund contributed to and leveraged other community resources to address challenges to Lake Winnipeg and its watershed. The Fund targeted a federal contribution of one-third, and a one-third provincial contribution, but could provide up to two-thirds of total project costs. Emphasis was placed on leveraging other funding sources and collaborative partnerships.

The Lake Winnipeg Basin Stewardship Fund was administered by Environment Canada with the assistance of multi-agency technical reviewers and a Public Advisory Committee (PAC).

Achievements

- Proposals requesting funding in excess of $9.7M, in support of projects valued at $22.7M were received.
- From 2008-2012, Environment Canada approved contribution funding of $2.4 M to 41 recipient groups to implement stewardship projects in the Lake Winnipeg Basin.
- Project recipients included: regional conservation authorities (20); non-profit organizations (9); post-secondary institutions (9); First Nations peoples, organizations and governments (2); and municipal governments (1).

- More than 250 participating projects partners provided approximately $5.8M in project funds and in-kind contributions. For every dollar provided by the Lake Winnipeg Basin Stewardship Fund, approximately $2.25 in partner funds and in-kind contributions were generated.
- Aggregate results, as reported by funding recipients, include:
  - 6,492 kg of phosphorus diverted from use or reduced per year
  - 30.8 km of livestock fencing erected to restrict 7000 livestock from accessing waterways
  - 34 alternative livestock watering systems installed
  - 548.5 hectares of wetlands/aquatic ecosystem created/restored
  - 126 hectares of habitat permanently protected
  - 37.8 km of stream/lank bank protected or stabilized
  - 75 km of riparian zones surveyed to identify pollution and rehabilitation sites
  - 1575 m of erosion control structures constructed
  - 17,169 native plants, trees and shrubs planted over 74 hectares
  - 5 Environmental Farms Plans implemented



Sensitive Habitat Inventory and Mapping in the south basin, Lake Winnipeg. Courtesy of the Lake Winnipeg Foundation.

Challenges and Lessons Learned

Over the course of five funding rounds, the Fund received 123 applications for funding. The introduction of an initial Letter of Intent (LOI) stage in round three enabled both applicants and the Fund administrator to identify deficiencies and clarify project details, resulting in strengthened project proposals.

Project funding applications were diverse in regards to location, design and approach, reflecting the myriad of contributing sources to the Lake Winnipeg nutrient loading challenge. This diversity allowed for broad-based stakeholder involvement across the watershed, yet presented a challenge in focusing Fund resources in strategic areas and activities to maximize the positive benefits to Lake Winnipeg. This was particularly evident among agricultural and livestock beneficial management practices (BMP) initiatives, which were driven more by landowner interest, existing land management practices and capacity among project partners, and less so by overall strategic importance to the larger Lake Winnipeg watershed.

Another challenge arose when attempting to quantify project nutrient loading reductions. To properly measure changes in nutrient loading in the watershed, long-term water quality monitoring is necessary. The majority of Lake Winnipeg Basin Stewardship Fund projects were initiated and completed within two years, using short term localized water quality sampling as a means to determine associated nutrient loading reductions. The long term assessment of project impact and nutrient loading outcomes therefore became challenging within the Fund's reporting timeframe.

Public awareness and knowledge of water quality issues in Lake Winnipeg, while expanding, remains an area for continued attention. Increased engagement of watershed residents to garner their support and participation in potential remedies to address the issues affecting Lake Winnipeg is paramount for community-driven stewardship to take hold and grow.

Conclusions

The Fund succeeded in leveraging significant community support and action, providing a solid foundation for organizations to move forward with continued initiatives to deliver long-term benefits. In addition to the immediate results achieved, the Fund served to connect various individuals and organizations and establish vital new partnerships.

Lake Friendly presentation to Gimli area students. Photo: L. Remillard. © Environment Canada 2011.

The Fund expended 89% of its grants and contribution allocation, in large part through active partner engagement and detailed monitoring of project progress. Site visits were conducted at more than half of the project locations, complementing frequent meetings and information exchanges, to assess activities, identify issues and adjust work plans accordingly to achieve desired objectives and financial projections.

Greater focus and targeted support to sub-watersheds shown to be the significant sources of loading, combined with a more tailored and aligned approach to supporting project initiatives, may produce more immediate and demonstrable benefits to Lake Winnipeg.

Due to the inherent challenges and limitations of short-term water quality sampling, scientifically validated modelling to assess a project's nutrient loading impacts should be explored as a means to determine overall outcomes.

Targeted initiatives to engage watershed residents in individual and collective behavioural changes would be beneficial in realizing short-term outcomes and garnering support for longer-term systemic solutions.

The LWBI Science Plan (Research, Monitoring and Information Management)

The Lake Winnipeg Basin Initiative (LWBI) and more specifically the LWBI science plan, was designed to address requests from the Province of Manitoba and other organizations for support in delivering on priority science needs within Lake Winnipeg, and the broader watershed area.

The Lake Winnipeg watershed is geographically daunting, encompassing almost one million km^2. The work undertaken by LWBI scientists was intended to help partners across the watershed act on the lake's condition based upon solid scientific data.

The goal of the LWBI science plan was to understand the gaps related to ecology and nutrient cycling, and the sources and transport mechanisms for nutrients, in order to provide the information needed by decision makers to develop appropriate nutrient objectives and inform nutrient management policies and decisions in support of the lake. Performance indicators were also needed to assess the health of the lake and watershed and determine how Lake Winnipeg and its watershed respond to nutrient management decisions taken within the basin.

The LWBI science plan encompassed the following six key deliverables or objectives:

- Characterize the physical, chemical and biological nature of Lake Winnipeg to better understand the balance of nutrient enrichment and productivity of fisheries in relation to algal blooms.
- Establish watershed and in-lake nutrient budgets, and undertake additional monitoring throughout the basin.
- Assess non-point contributions of nutrients in the watershed and the lake, and the effectiveness of agricultural beneficial management practices (BMPs).
- Assess the economic value of clean water and the effectiveness of regulations and social policy on nutrient management.
- Create a single window on-line information portal for sharing data amongst key scientific partners and networks.
- Provide the scientific basis, based on the results of research and monitoring activities, to develop nutrient objectives and performance indicators.

Activities in support of these deliverables were initiated in 2008/09 on Lake Winnipeg and its major sub-basins, including the Red-Assiniboine and Winnipeg rivers, and Lake of the Woods.

Deliverable 1: Nutrient bioavailability in Lake Winnipeg and major rivers: influence on water quality, food webs and harmful algal/cyanobacterial[2] blooms

Project Team: Sue Watson, Jay Guo, Ram Yerubandi, Leonard Wassenaar, Brian Parker, John Lawrence, Malcolm Conly, Veronique Hiriart-Baer, Jane Elliot, D. Lam, Bill Booty; Environment Canada

Partners: Fisheries and Oceans Canada, Algal Taxonomy and Ecology Inc. (AETI) - Hedy Kling, University of Manitoba, Lake Winnipeg Research Consortium, Miette Environmental Consulting

This project focused on basin nutrient loading and in-lake processes that promote algal and cyanobacteria blooms, and the potential toxicity of the latter. The key objectives were to characterize the status and long-term trends in the biological community in Lake Winnipeg and major tributaries, the ecological impacts of blooms, and the potential impacts of nutrient enrichment and invasive species on the food web. This included the development of hydrological models, which can be used as tools to evaluate the potential effects of different nutrient management actions and on the distribution and abundance of algal blooms in Lake Winnipeg.

Progress and Achievements

- The Red and other major rivers were sampled annually in spring melt, summer low flow, fall and winter flow conditions for water quality, nutrients, including phosphorus (P), nitrogen (N), and carbon (C), plankton, suspended (and where possible) bottom sediment. Suspended sediment was collected using an improved bulk-volume method for increased sensitivity.

- P and N are the key nutrients controlling algal[3] growth and therefore of primary management concern. Nutrients from different sources (fertilizers, wastewater etc) differ in their bioavailability and ability to stimulate different algal[2] species' growth, which can be assessed using nutrient ratios and bioassays. This was carried out with water from sites along the Red and Assiniboine River, using cyanobacteria species representative of the Lake Winnipeg blooms.

- Summer/fall algal[2] lake samples were collected and analyzed for microcystins and other toxins.

- Benthic invertebrates, zooplankton, and algal[2] lake samples were collected and analyzed for major species and taxonomic groups.

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[2] Cyanobacteria are also (incorrectly) called 'blue-green algae'. In fact they are not true algae, but specialized bacteria (which range in colour) and, like algae, can use the sun's energy and can dominate summer plankton communities in nutrient enriched waters. Some cyanobacteria produce toxins.

[3] For the sake of brevity, 'algae' will be used to refer to both algae and cyanobacteria unless specified

- The potential for internal P loading from areas prone to the development of depleted oxygen in bottom layers in the north basin (NB) was raised during this research study, and further explored with York University. Cores and overlying water were collected at five selected sites during lake surveys in 2011, analyzed for chemistry and nutrients, and incubated to evaluate the potential for anoxic P release and the role of iron. They were also analyzed for chemistry, algal[2] and zooplankton remains for comparison with other studies and to allow a robust evaluation of long-term trends in the aquatic food web.

- Analyses of suspended and bottom river sediment sample are in process, and will be integrated with other measures in a report or publication evaluating water quality trends in relation to basin characteristics and flow, with particular focus on flooding events.

Research Results

- There are marked differences in water quality and nutrients among sites along the Red and Assiniboine rivers, with a general decrease in turbidity downstream of the U.S.-Canada border towards the outflow to the lake. Estimates show the Red River as the major source (>60%) of phosphorus to Lake Winnipeg.

- Total dissolved nitrogen (TDN) showed differences in chemistry among sites. Total dissolved organic N represented a high proportion of the TDN at all sites.

- Nutrient ratios and bioassays showed no evidence of significant N or P deficiency in the Red River at any site, but point to localized differences in bioavailability in summer and fall periods.

- Initial assessment of data indicated little nutrient deficiency across Lake Winnipeg in the spring, but an increase in P, and to a lesser extent N deficiency from summer through fall in both basins.

- Cyanobacteria increased as the summer season progressed. Microcystin-producing cyanobacteria were present but not predominant in blooms. The risk of toxins increases dramatically, however, in dense surface or shoreline scums, which commonly occur as a result of wind and currents. Concentrated surface scums can show elevated toxin content and the recreational guideline is periodically exceeded at public beaches and in nearshore mats of bloom material. Other toxins were not detected.

- Final results are pending for analysis of the lower food web over space and time. Summer/fall blooms are dominated by N-fixing cyanobacteria. Over the past few years there is inter-annual variation among the dominant Lake Winnipeg cyanobacteria species, and these may also vary in toxicity.

- Hydraulic variability may strongly influence zooplankton and benthic invertebrate (zoobenthos) species structure in the south basin (SB). Comparison of Lake Winnipeg SB zooplankton communities with data and flow conditions from the Red

River indicates strong differences that may be directly related to the Netley-Marsh widening at the mouth of the Red River. This has allowed more flow through the marsh and likely also flushes littoral inhabitants, zooplankton and some bait fish into the lake. Inclusion of additional years of Red River and zooplankton data from archived samples will allow a better evaluation of this mechanism, which has significant implications both for the resilience of the marsh food web and Lake Winnipeg fisheries and algal blooms.

- Preliminary comparison of spring surveys in both basins in 2010 and 2011 showed distinct differences in abundances and species richness of four major zoobenthos families. Water levels differed in 2011 from 2010, and the 2011 samples showed more fine decomposed organic debris.

- There were significant differences in sediment nutrient and organic composition between sites and in particular, between spring and fall samples in 2008 and 2009. There was a marked increase in total P in fall surficial sediments in both basins, while N showed less distinctive patterns.

- Iron and P release rates from incubated Lake Winnipeg sediment cores were relatively high compared to release rates measured from other lakes, and may be related to differences in sulphate concentrations, and organic carbon, P and iron content in the sediments.

Challenges and Lessons Learned

River bioassays conducted between 2007-2009 provided insight into nutrient bioavailability in the Red River between the border and outflow to Lake Winnipeg, however, due to logistical and resource constraints, other major tributaries were not characterized, and flood periods were not assessed using these assays, leaving a data gap. Completion of archived/remaining algal and zooplankton samples was also delayed.

While preliminary modelling of the lake has been conducted, there are significant data gaps and final modelling and recommendations require further work. The role of physical factors in Lake Winnipeg responses and management requires better delineation, in terms of flooding, ice/snow cover, lake and tributary water levels, lake flushing, re-suspension and hydraulic engineering in the rivers. This is particularly critical to derive valid scenario-based models in the face of climate change. Similarly, reports of invasive species in the Lake Winnipeg Basin underline the need to establish baseline data on food web and nutrient cycling to understand how invasive species will modify lake response to nutrient management actions, and how this will affect hydroelectric, fisheries, and other major Lake Winnipeg related industries.

Conclusions

Nutrient related issues in Lake Winnipeg show parallels with those currently in the Lake Erie West Basin, where high levels of P – a large fraction of which is dissolved and highly bioavailable - in the major tributaries are promoting extensive blooms.

Comparison and analyses of these two systems will allow insight into the factors modifying the lake's response to current and future Basin actions.

Assays and in-lake measures show P as the major nutrient requiring management; while short-term nitrogen limitation modifies the lake's biota responses.

The research has highlighted the major role of flooding on nutrient inputs and how it is modified by Basin development. Under some climate scenarios, these events are anticipated to increase in severity and frequency, and are an area needing further investigation.

Surface sediments in Lake Winnipeg do not represent a fixed and predictable reserve for nutrients, but are variable in composition and nutrient content. Major seasonal shifts in sediment chemistry across the two lake basins have implications for current models of sediment loading, and for the interpretation of cores in paleolimnological and other studies.

Initial evidence indicates that sediments and iron may play a role in algal blooms. Iron is required for effective N fixation, a process that facilitates the dominance of the current cyanobacterial species. This is another area for potential future exploration.

Algal blooms continue to be a major concern with potential for toxins and severe impacts on water quality, recreational and tourist industries and property value. Currently, the dominant algal species in Lake Winnipeg are not highly toxic; however, the threat of invasive species such as dreissenid mussels could significantly impact light and nutrient regimes in the lake, potentially contributing towards more frequent blooms in the turbid south basin and a shift to more toxic cyanobacteria species in the future.

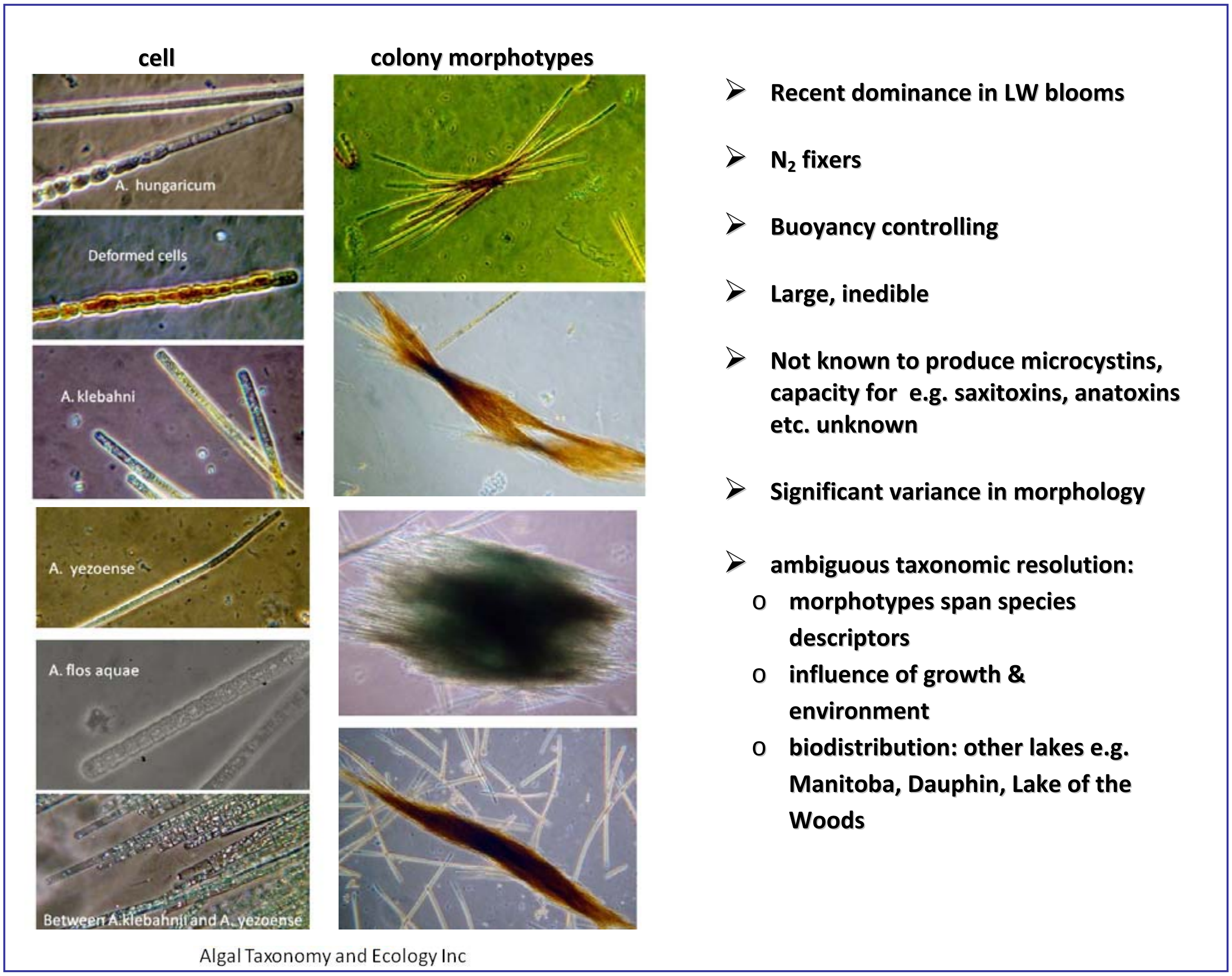


Figure 1: Lake Winnipeg *Aphanizomenon* species complex

Deliverable 1: Lake Winnipeg physical limnology and modelling

Project Team: Ram Yerubandi, Jun Zhao, Weitao Zhang, Padala Chittibabu, Leonard Wassenaar, Sue Watson; Environment Canada

Partners: Fisheries and Oceans Canada, Manitoba Water Stewardship, Lake Winnipeg Research Consortium

This project involved field studies and development of databases and models to study the impact of water movements and mixing on nutrient balance, depleted oxygen levels (hypoxia) and algal blooms in Lake Winnipeg. Activities included deployment of fixed moorings to obtain meteorology, circulation, temperature and water quality data on Lake Winnipeg, using sequential sediment traps to study sediment re-suspension processes, development of hydrodynamic models, and coupling of the models to water quality and ecosystem models to assess current and projected nutrient loads on Lake Winnipeg. Knowledge and information regarding water and nutrient movements from the watershed to the lake, and circulation patterns within the lake is important for assessing and managing nutrient loading and impacts within the Lake Winnipeg Basin.

Progress and Achievements

- Large scale physical limnology experiments were conducted in Lake Winnipeg (Figure 2) using surface meteorology, temperature structure, currents, light transmission and bottom layer oxygen. Variations in water column temperature and lake circulation were also assessed. Mean transport was observed to be towards the north in the lake with two cyclonic gyres (swirling vortex patterns) in the north basin (NB) and one in the south basin (SB).
- Models from simple dynamics (box-type) to moderately complex 2D (CEQUAL, ADCIRC) to highly complex 3D models (ELCOM-CAEDYM) were developed for the lake. The models showed considerable success in reproducing thermal structure and circulation. Models predicted isothermal conditions in the SB and narrows for the whole modelling period, and produced weak thermal stratification during the early summer in the NB.
- The modelled currents were used to examine the transport, dispersion of passive tracers and local flushing time in the lake (Figure 3). Simulations using passive tracers generally agreed with field measurements of oxygen isotopes.
- The ELCOM model was used to provide an assessment and simulation of a Red River flood event and an October 2010 storm surge and their impacts on water quality. During the flood event, Red River plume movement was primarily controlled by the wind-driven currents. The winds from the north confined the plume to a small area

within Lake Winnipeg, near the mouth of the river, over a long time period. (Figure 4).

- For the first time, an unstructured grid model (ADCIRC) was developed to predict storm surges and other water level fluctuations in the lake (Figure 5). Water balance and residence times were assessed using both models and lake observations.
- A eutrophication model based on WASP (Water Quality Analysis Simulation Program) was developed to simulate the major nutrient and algal dynamics in Lake Winnipeg (Figure 6). The model was transferred to Manitoba for potential future use in assessing nutrient management actions and impacts on the lake.

Challenges and Lessons Learned

During the course of this project, the need to study the impact of climate variability and change scenarios on nutrient loads in the lake and water quality and hydrodynamics was identified, however this work was unable to be completed due to staffing constraints in 2011.

A number of data gaps remained at the end of this project. Lake Winnipeg is covered with significant ice-cover for a long period, which impacts lake ecology, however winter measurements were not sufficient to calibrate and validate the models. Hydrodynamic models should be further developed to include ice-cover on the lake or to couple ice models.

Internal recycling of nutrients (sedimentation, re-suspension, remobilization) remains an area requiring further assessment. The nitrogen and phosphorus interaction between lake water column and sediment is extremely complex. In shallow lakes, sediment resuspension is an important factor in increasing the water column concentrations of total nitrogen and phosphorus.

The effect of environmental factors such as low wind speeds and increased residence times of nutrients, and differences in light conditions between the north and south basins also requires further assessment, as does the effect of different climate scenarios and climate variability on factors such as lake levels, currents, nutrient delivery, algal blooms and hypoxia. The effect of near shore inputs is another area for potential evaluation, particularly in bays with high residence times.

Conclusions

Knowledge of physical and hydrodynamic conditions in Lake Winnipeg has been enhanced by this research project.

A three dimensional hydrodynamic model was developed to simulate water levels, temperature, currents, and the transport of stable isotopes in Lake Winnipeg. This study also resulted in the first attempt to use a 3D model for developing high-resolution circulation in Lake Winnipeg. Water quality components were included to study the ecosystem response under different nutrient loading conditions. A predictive ecosystem model was developed to simulate the major nutrient and algal dynamics in Lake Winnipeg.

The models showed considerable success in reproducing thermal structure and circulation in Lake Winnipeg, and in providing knowledge about nutrient dynamics and balance, trophic structure and interactions. Wind-driven circulation plays a crucial role in how the materials are mixed, retained and/or flushed from each Basin in the lake. Thermal stratification and low oxygen concentrations are limited to a short period in the north basin.

Hydrodynamic and eutrophication models require a large amount of data to provide a realistic reflection of an aquatic ecosystem. While the data sets gathered during this four year project are well-suited for reasonable calibration of Lake Winnipeg models, additional observations, including winter measurements, would provide more robust validation and development of the models. In addition, more information about the internal recycling of nutrients within Lake Winnipeg, as well as climate change and variability scenarios, impacts of environmental factors, and the effects of nearshore nutrient inputs, are potential areas of future exploration.

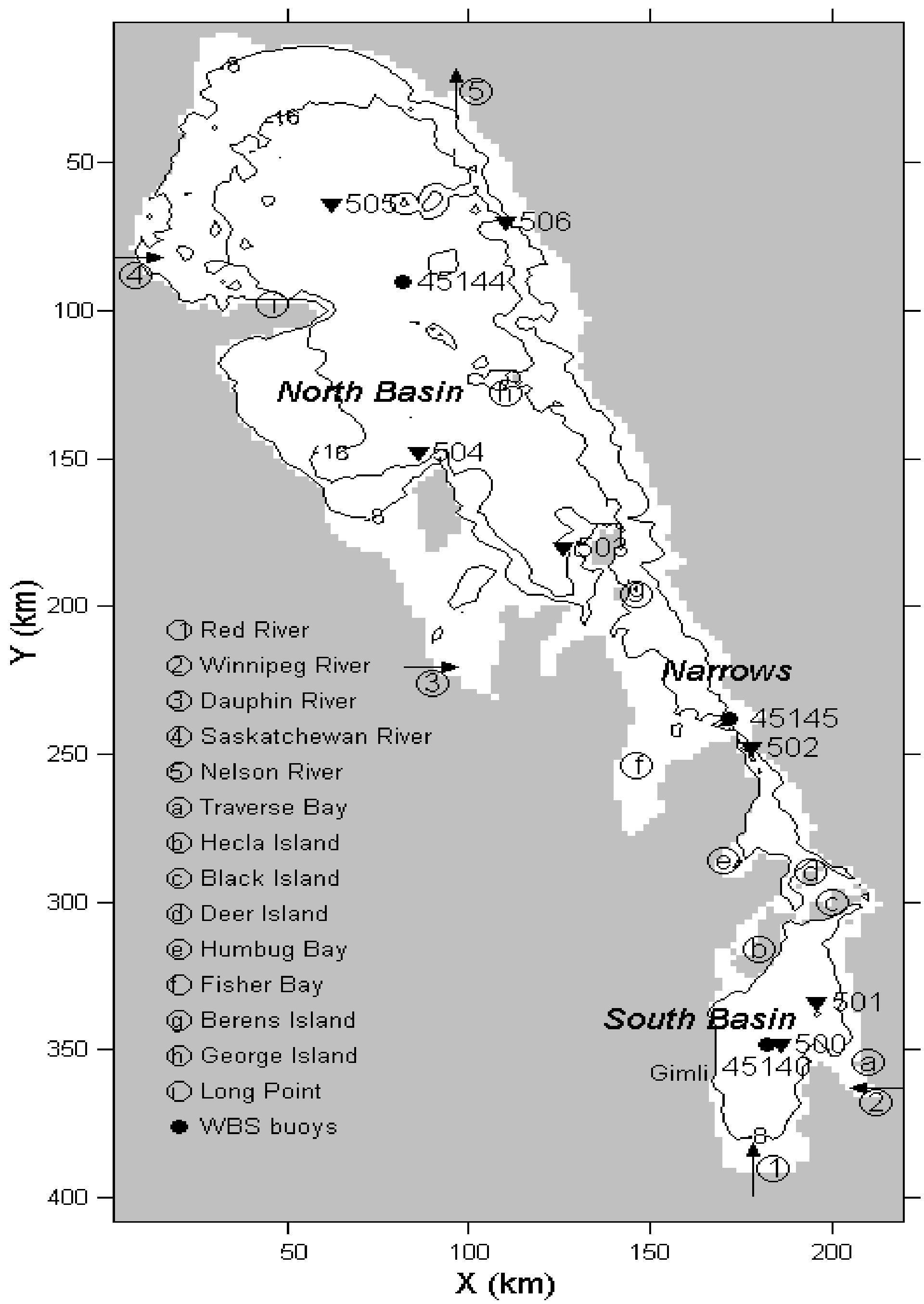


Figure 2: Map of instrument locations and selected bathymetric features within the numerical model domain of Lake Winnipeg. River inflows and outflow are identified with arrows.

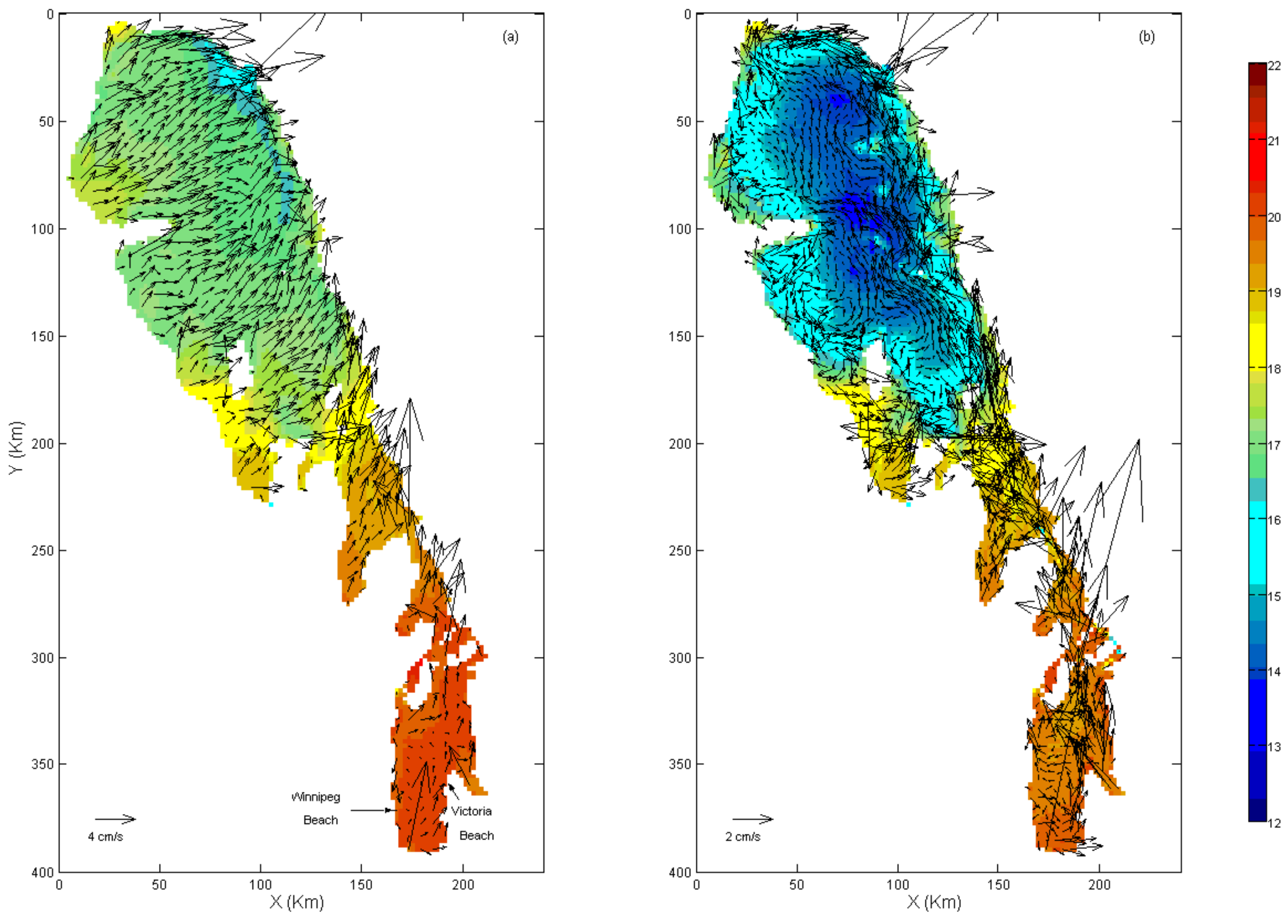


Figure 3: Time mean circulation and temperature at (a) surface and (b) depth-averaged values.

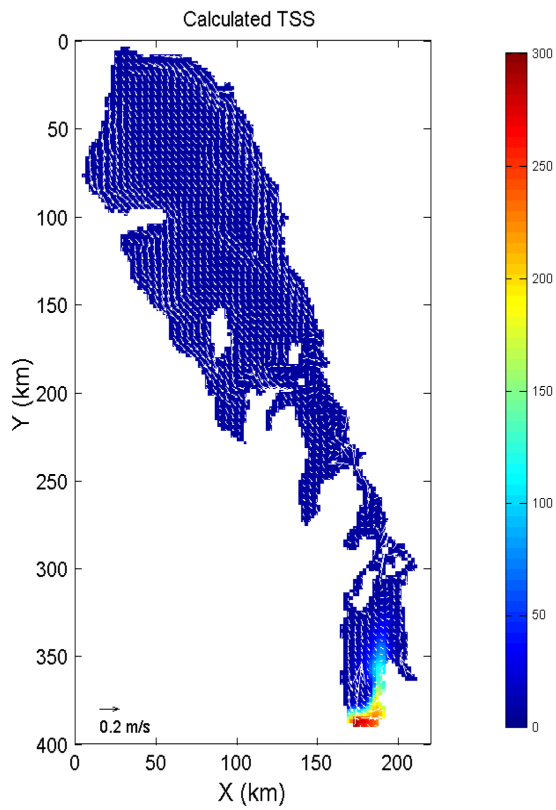


Figure 4: Mean surface circulation (m/s) and TSS concentration (mg/L) distribution during the flood event in Lake Winnipeg.

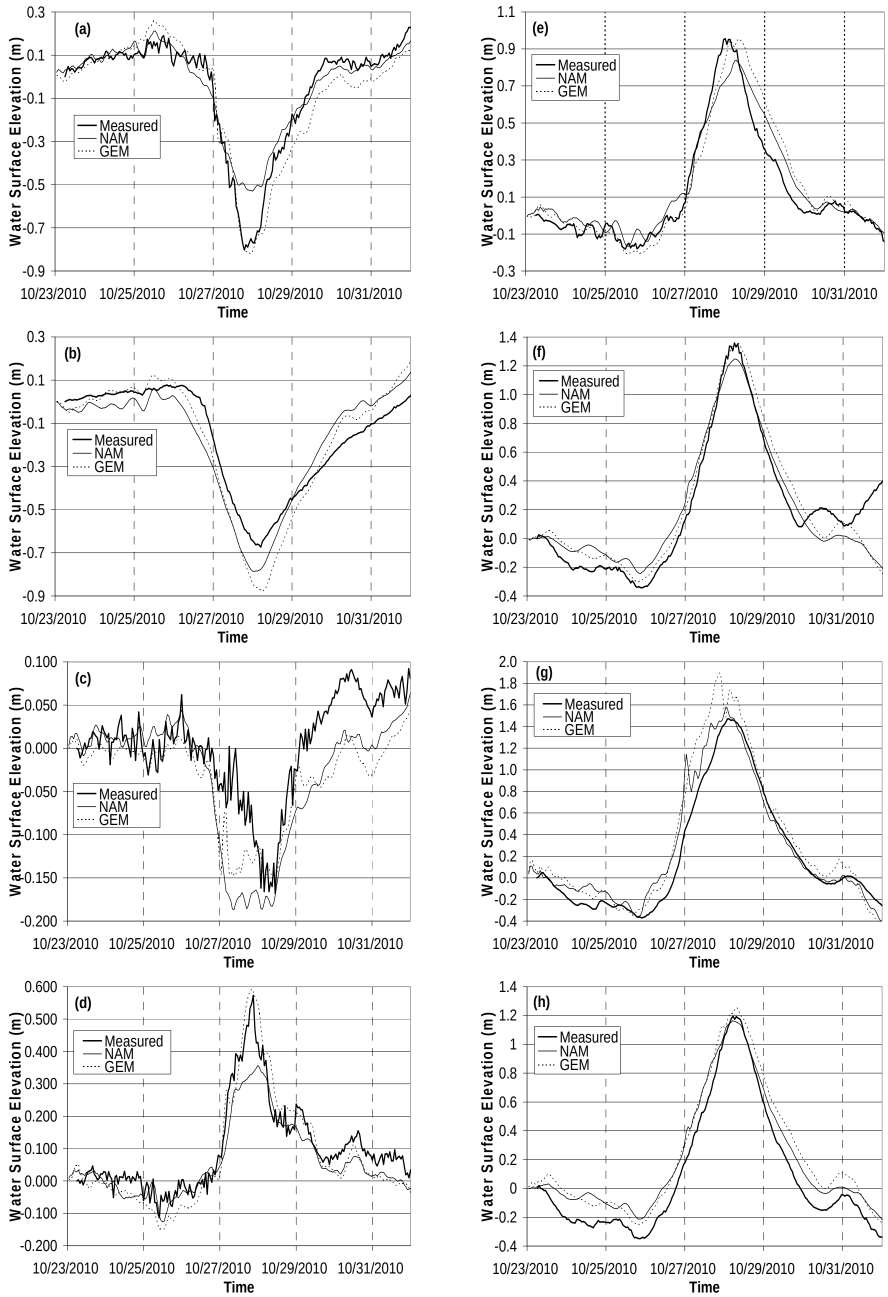


Figure 5: Time series of observed and modelled water level deviations from 23 October level at (a) Mission Point (b) Play Green Lake (c) George Island (d) Berens River (e) Pine Dock (f) Victoria Beach (g) Breezy Point (h) Gimli.

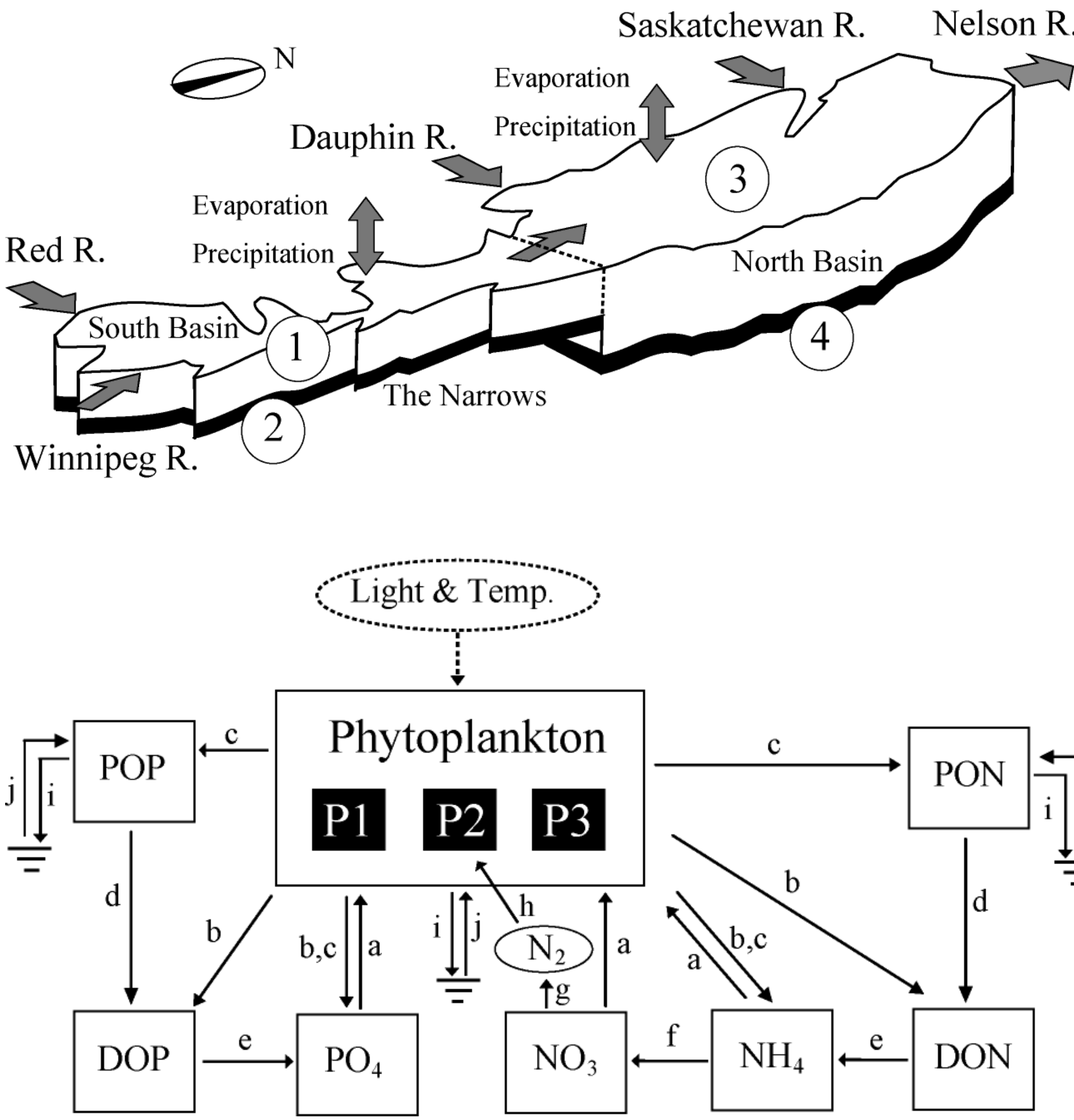


Figure 6: Schematic of Lake Winnipeg model segmentation and the phosphorus and nitrogen cycles of the Lake Winnipeg WASP model.

Deliverable 1: Stable isotope assessment and food web structure and function

Project Team: Leonard Wassenaar, Keith Hobson, Amy Ofukany, David Soto, Bernhard Mayer; Environment Canada

Partners: Manitoba Water Stewardship, Manitoba Fisheries, Lake Winnipeg Research Consortium

Researchers use naturally occurring stable isotopes of elements such as hydrogen, carbon, nitrogen, oxygen, etc as forensic "fingerprints" to determine the origin and follow the fate of these elements in the environment. This project involved stable isotope fingerprinting of nutrients to help identify the various point and non-point sources of nutrients into Lake Winnipeg, analyze the cycling of organic matter and impacts on the food web, the processes that lead to algal formation and enhanced biological oxygen demand, and the factors that affect dissolved oxygen levels in the lake. The project had two major elements as indicated below and was intended to inform and assist in decision making for lake restoration and nutrient management strategies. Work under this project was fully integrated with additional research described in this report under "Spatio-temporal dynamics of dissolved oxygen and phosphorus in Lake Winnipeg".

Food Web Structure and Function – This work involved establishing current carbon and nitrogen isotopic baselines for fishes in Lake Winnipeg in order to describe fish community structure and identify dietary nutrient sources. The lake supports a dynamic aquatic food web, including an extensive freshwater fishery. Only if the current food web structure is well understood can predictions be made regarding the negative impacts of eutrophication on the food web, or on the effectiveness of remediation strategies.

Riverine Nitrate Sources and Cycling - This work focused on temporal concentration trends and stable isotope assays of nutrients (nitrates, phosphates) in the Red River at three locations; Emerson, the Winnipeg River and Saskatchewan River. Stable isotope assays of nitrate were conducted to evaluate seasonality in sources and in-stream nitrate cycling, with emphasis on the impact of nutrients from the Red River to Lake Winnipeg. The purpose was to reveal which sources of nitrogen dominate the nutrient fluxes into Lake Winnipeg, in order to help inform and target control strategies.

Progress and Achievements

- Intensive annual seasonal sampling was implemented across the lake and watershed. Sixty stations in the lake were sampled three times annually on the MV Namao. Dedicated onboard scientific instrumentation (rosette, CDT) was installed on the Namao to facilitate water quality and depth sampling profiles.

- Winter under-ice sampling was conducted by snowmobile and helicopter at 24 stations.

- Stable isotope analysis of fish was conducted to determine sources of water and nutrient inputs into the Lake Winnipeg food web and develop a baseline aquatic food web structure. Gill netting and station trawls resulted in over 600 fish samples collected. Trace metal concentrations in fish were examined to see how food web isotope patterns can provide information about the transport of these contaminants from fish to piscivorous birds such as Double-crested Cormorants.

- Enhanced focus on food web data collections with extensions to cormorants was also undertaken. Over 40 cormorant samples were collected from stations in the north and south basins.

- Sampling and analysis of stable isotope assays of nutrients in major rivers was undertaken at 12 sites on a monthly and quarterly basis to reveal the sources dominating nutrient fluxes into Lake Winnipeg.

- A database of research and sampling results was established for Lake Winnipeg, major tributaries and wastewater treatment plants.

- Three scientific papers were published (water quality, nutrient sources, isotope hydrology).

Research Results

- The research indicated that dissolved nitrate drives the nitrogen flow in the aquatic food webs of Lake Winnipeg. The three main rivers had distinctive nitrate isotopic values, providing an isotopic label for tracing the fate of the nitrates into Lake Winnipeg. The composition of nitrate in Lake Winnipeg appeared to be partly controlled by composition of the riverine nitrate, dominated in the south basin (SB) from the Red River. However, nitrate assimilation and late-season decay of phytoplankton were identified as potential internal lake processes modifying the isotopic composition of nitrates. In the SB, elevated nitrate values in spring changing to lower values by summer suggested short residence times of nitrates either due to rapid flushing, mixing, or rapid assimilation.

- The study indicated that animal waste is a primary source of nitrogen to Lake Winnipeg; however, this anthropogenic nitrogen is fully sequestered in the SB. North basin (NB) nitrate appears to be solely derived from decay of nitrogen fixers, meaning each basin requires a separate nutrient process model. This stands in contrast to traditional in/out mass balance loading models currently used.

- The research also provided an isotopic baseline to monitor changes in fish community structure and nutrient transfer to upper-level organisms. The fish communities in the north and south basins are different and walleye, in particular, may be influenced by the presence of invasive rainbow smelt in the NB. The well-mixed nature of the lake removes any benthic-pelagic coupling. Fish isotope values reflect those in the inorganic nutrients in the lake and these show spatial structure. This means that the isotope technique can be used to trace fish movements.

- A two trophic-level system corresponding to planktivorous fish and predators was observed for both basins. The NB food web was depleted in 15N and enriched in 13C compared to the SB. Smelt did not differ isotopically from other forage fish, while smelt consuming walleye in the NB were more enriched in 15N than SB walleye. This suggested that either smelt differ nutritionally from native forage species, or that SB walleye feed more on zooplankton. Strong correlations between fish tissue isotope values and dissolved bicarbonate and nitrate revealed that inorganic spatial patterns in each basin label the base of the food web isotopically and these signals or fingerprints are passed on to higher-order consumers like fish that are apparently not moving significantly between basins.

Conclusions

Isotope measurements of nitrate provided new information regarding nutrient sources in the Red River Basin. The Red, Winnipeg and Saskatchewan rivers had distinctive nitrate values, providing an isotopic “label” to trace the fate of the nitrates into Lake Winnipeg. Differences in nitrate sources in the north and south basins of Lake Winnipeg were pronounced and indicate that each requires separate nutrient process models.

Stable isotope measurements of fish can be used to trace fish movements, and will assist in tracing any future changes to the lake’s fishery and food web as a result of introduced species and eutrophication, as well as providing a benchmark to assess the effectiveness of remediation measures.

Deliverable 1: The spatio-temporal dynamics of dissolved oxygen and phosphorus in Lake Winnipeg assessed through the oxygen isotopic composition

Project Team: Véronique Hiriart-Baer, Leonard Wassenaar; Environment Canada

The goal of this study was to obtain a better understanding of the sources and in-lake processing of phosphorus in Lake Winnipeg. Research included establishing a database of oxygen stable isotopes associated with dissolved inorganic phosphates in Lake Winnipeg in order to obtain an understanding of the variability of phosphate fingerprints and identify sources of nutrients and the cycling of phosphorus on seasonal and spatial scales.

In addition, research was also undertaken to determine the status, dynamics and threats to dissolved oxygen in Lake Winnipeg. Dissolved oxygen is crucial to the survival of aquatic ecosystems. Excessive algal growth and associated demands in oxygen consumption can depress oxygen levels in the water column.

This work was integrated with research described in this report under "Stable isotope assessment and food web structure and function".

Progress and Achievements

- Water samples were collected and vertical water quality depth profiling was conducted at over 50 stations in the north and south basins of Lake Winnipeg to determine seasonal dissolved oxygen patterns and to apply phosphate oxygen stable isotope analysis to measure productivity patterns.

- All water samples were processed and analyzed for phosphate oxygen isotopes. Potential hypoxic zones were identified.

- One paper was published. Preliminary information on sources and cycling will be available by March 2012; reviewed publications will be forthcoming in March 2013.

Research Results

- Preliminary analysis of the data supports the hypothesis that there is variation over space and time in the sources of phosphorus in Lake Winnipeg. In the south basin (SB), the stations between Gimli and Traverse Bay showed distinct isotopic signatures from that in the rest of the basin. In particular, the isotopic signature in and around Traverse Bay was lower in spring and summer than many of the other stations, including the Red River samples. This suggests that another phosphorus source with a lower isotopic signature exists in this area. Internal sediment phosphorus release is a potential source in this area as well as for the stations across the SB towards Gimli. Further information on the isotopic signature of inorganic phosphorus in surface sediment will be needed to provide the necessary evidence to test this hypothesis.

- In the north basin (NB), the phosphate isotopic signature was lower in both spring and summer, suggesting a different source than the SB. However, by the fall, the isotopic signature resembles that from the SB from the previous months, suggesting waters from the SB are moving north and carrying a supply of phosphorus.

- The data suggest that there are at least two isotopic sources of phosphate in Lake Winnipeg (Figure 7). In the SB, both sources are supplied during the spring and summer, however, in the fall the heavier isotopic source dominates. In the NB, it appears that one source dominates in the summer (and possibly the spring) while a second source is introduced into the basin in the fall. It is hypothesized that during the spring and summer, phosphorus from the sediment in the SB is released and transported north to the NB. This likely occurs through sediment release and re-suspension events (storms, etc.) It is further hypothesized that this phosphorus source reaches the NB in the fall and provides additional nutrients for biological production. This phosphorus source then either makes its way out of the system through the outflow or accumulates in the NB sediments.

- Both tributaries and wastewater effluent sources show some degree of seasonal variability with lower values in the summer. The current evidence needs to be further examined in the context of changing isotopic signatures from the known sources of phosphorus (Figure 8).

- The phosphate isotopic signatures suggest that the supply of phosphorus exceeds the demand from the biological community. Only a few samples showed phosphate isotope values close to or at equilibrium. The retention of the isotopic signatures of the sources is evidence that phosphorus is entering the system faster than it is recycled through the biomass.

Challenges and Lessons Learned

Throughout the process, researchers realized that the method developed for marine systems was difficult to apply in freshwater ecosystems. The higher dissolved organic matter content of freshwater systems led to the contamination of the final product analyzed by mass spectrometry thereby casting doubt on some of the data collected. Careful vetting of each individual data point is required in order to reliably interpret the data and make appropriate inferences. In 2011, a methodological 'fix' for the organic matter contamination was published and is currently being tested on lake sediment. Should this method reliably remove all interfering organic matter, it will be applied to archived Lake Winnipeg samples of surface sediments and phytoplankton biomass.

Conclusions

Preliminary evidence suggests that distinct sources of phosphorus can be identified in Lake Winnipeg. There are seasonally distinct sources in both basins, and the SB is an important source to the NB. Further analysis is required to get a better understanding of the relative importance of the tributary and wastewater phosphorus sources to the lake.

Despite high nutrient loadings and ongoing algal blooms in Lake Winnipeg, surface water oxygen supersaturation and depressed oxygen levels in bottom waters were greatly tempered due to the shallow, well-mixed, and highly turbid nature of the lake. The data further revealed the NB was generally more productive than the SB. Transient bottom water oxygen depletion occurred only in deeper parts of the NB in summer or winter. Evidence suggests that several weeks of prolonged hot weather with little wind are the most favorable conditions for oxygen depletion in the NB. However, the extent and impact of potential bottom water oxygen depletion in the NB requires further study.

The combined use of oxygen mapping over space and time, along with oxygen isotopic assays, has provided a multi-year snapshot of dissolved oxygen and metabolic status of Lake Winnipeg, and a productivity benchmark by which to compare outcomes of future nutrient management development in the lake and its watershed. The oxygen isotope method can be used in future to quantify changes due to nutrient management initiatives.

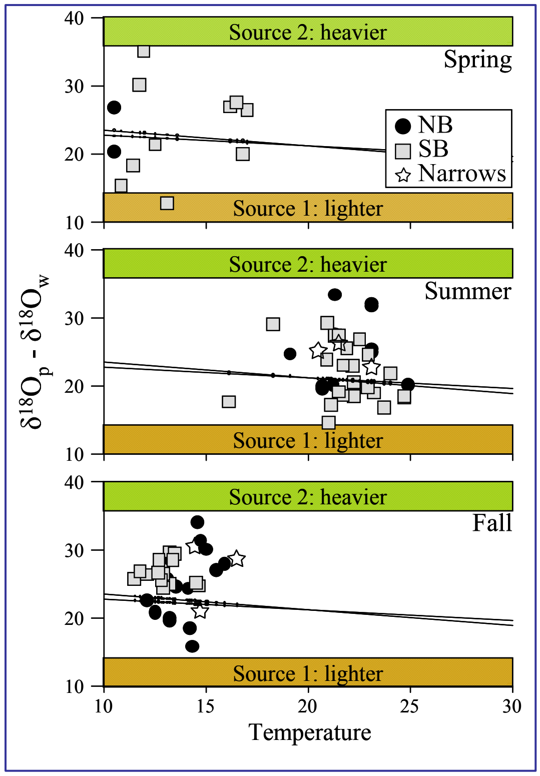


Figure 7: Phosphate isotope signature of lake water samples only relative to the expected equilibrium values. Values are expressed as the difference between the δ18O of phosphates and δ18O of water.

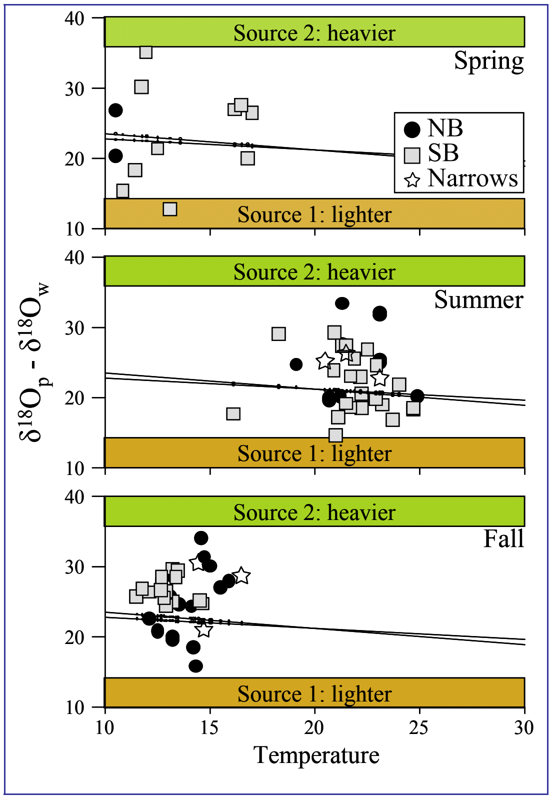


Figure 8: Isotopic signature of the phosphates in the tributaries (top panel) and wastewater effluent (bottom panel) samples as a function of season. Spring: filled circles; Summer: squares; Fall: stars.

Deliverable 1: Developing and improving remote sensing technologies to assess algal blooms

Project Team: Caren Binding, Robert Bukata, Tracie Greenberg; Environment Canada

The goal of this project was to develop and implement aquatic colour remote sensing methods for use with satellite observations of algal blooms, in order to provide an insight into algal bloom dynamics on Lake of the Woods and Lake Winnipeg and enable prompt monitoring and assessments of bloom timing, intensity and extent.

Progress and Achievements

- *In situ* observations of water quality parameters and their associated optical properties were obtained during field surveys on both Lake of the Woods (LoW) and Lake Winnipeg (LW). These measurements were needed to determine the main water colouring parameters of interest and the optimal methods/models for deriving information on algal blooms from the colour signal.

- Two comprehensive research cruises were conducted on LoW in September 2009 and 2010 during which *in situ* optics and water quality measurements were obtained. These cruises provided the necessary information to validate appropriate techniques to detect and monitor algal blooms on the lake using the Medium Resolution Imaging Spectrometer (MERIS), on board the European Space Agency's Envisat satellite.

- Water quality and *in situ* optics measurements were also obtained during LW cruises in 2010 and 2011, which in combination with historical water quality data enabled the testing and validation of the same methods for LW.

- Acquisition, analysis, validation, and interpretation of suitable remote sensing data for the LW/LoW Basin was undertaken, and remote sensing products incorporated into the current near-real-time image processing capacity at Environment Canada's National Water Research Institute.

- Satellite imagery was validated for LoW and image analysis was extended over several years to study longer term variability in bloom dynamics, in light of concerns about increasing occurrence and intensity of algal blooms on the lake.

- Methods developed for LoW are being fully validated for LW. Similar analysis of LW imagery is still underway to monitor recent trends in the timing, intensity and aerial extent of algal blooms on the lake, with a focus on the South Basin in the vicinity of the Red River. Water quality and optical data from 2003 to 2011 is being analyzed to validate MERIS imagery and determine trends in bloom conditions on LW in relation to physical and climatic and watershed variables, in order to further understand the factors driving algal blooms on LW. Extensive image analysis is anticipated to be complete in 2012.

- More than 600 images were produced using archive MERIS imagery, from 2005 to 2011. Satellite imagery for both LoW and LW is being processed routinely both in True Colour composite format and an algal bloom indicator, and posted to the Lake Winnipeg web portal. Work is underway to extend the archive back to 2003. Current plans are to process and provide imagery through the portal in near-real-time for the 2012 bloom season.

Research Results

- *In situ* measurements confirmed LoW to be optically complex; waters are shallow and highly turbid, with very high dissolved organic matter resulting in strong light attenuation and intense cyanobacteria blooms causing surface scum accumulations.

- Cloud-free true colour images compiled from MERIS satellite imagery clearly captured the onset and progress of an intense algal bloom in September 2009 in the surface waters of LoW, accurately depicting the location and extent of the bloom and showed a strong correlation with *in situ* chlorophyll concentrations. Differences in the MERIS maximum chlorophyll index (MCI) imagery within various areas of the lake were analyzed in order to study the progression of the bloom in the lake (Fig. 12 and 13). Results showed a progression in bloom activity from an early, intense and prolonged bloom in the southern, western and central zones, and a later, less intense and shorter bloom in the northern portions of the lake, with eastern sections exhibiting no notable bloom activity for the entire period. These observations are consistent with the pattern of nutrient loadings to the lake, predominantly from the Rainy River, leading to high phosphorus and nitrogen concentrations throughout the southern part of the lake, with moderate concentrations in the north-central zones and low concentrations at sites away from the main south-north flow of water.

- The bloom was highly dynamic, with much variability over short timescales and seemingly disappearing from the lake between one day and the next. This prompted an assessment of meteorological forcing on LoW and its effects on bloom dynamics. Hourly wind data suggested a close correlation between lake-wide MCI and wind speeds (Fig. 14); peaks in MCI coincided with periods of reduced wind speeds and reduced MCI coincided with periods of elevated wind speeds. It is suggested that during wind-events, algal cells were dispersed through the water column, thus decreasing the surface biomass seen by the satellite sensor. During calm conditions, the cells rose to the surface creating an intense bloom which was clearly seen from space.

- Analysis of the LoW bloom cycle since 2003 (Figure 15) indicated variability in bloom intensity between years, but did not show any recent increases in intensity. Rather, the analysis was suggestive of a decrease in intensity (although with the limited data available there is no statistically significant trend). Analysis of climatology data shows that the most intense bloom year in 2006 coincided with both the warmest and driest conditions. The imagery analysis also suggested that the bloom on LoW is peaking later each year - as much as four weeks later in 2009 than in 2003.

Challenges and Lessons Learned

Obtaining sufficient *in situ* optical information to allow adequate model validation for both LoW and LW was difficult to achieve in the timeframe of this project. Archive water quality data from LW was used to validate imagery but it would be beneficial to extend *in situ* optical surveys to LW in order to further develop remote sensing tools for bloom distinction.

The project met some challenges in developing a means of disseminating satellite images in near-real-time on the Environment Canada departmental website; therefore the imagery is being posted to the LW web portal where it can be loaded in near-real-time to enable prompt water quality monitoring and assessment.

Parallel work carried out on Lake Erie has discovered the potential for detecting ice-blooms of winter diatoms using MERIS imagery. It is recommended that further work be carried out to determine the value of applying this approach in the Lake Winnipeg Basin for monitoring bloom activity over the winter months.

Conclusions

The technology and science exists to acquire and process aquatic colour remote sensing data over Canadian inland waters in near-real-time, producing daily snapshots of inland water conditions on a routine, fully automated basis. This project aimed to extend the capacity of current image processing techniques to include lakes within the Lake Winnipeg Basin.

Field observations of aquatic colour and optical properties, in conjunction with water quality information, enabled the development of remote sensing techniques to assist in recognizing and monitoring the onset and progress of algal blooms. Imagery was used to identify and track the progress of an intense cyanobacteria bloom on LoW during September 2009, highlighting the dynamic nature of the bloom, with mixing and resurfacing in response to wind events. Time series analysis identified the seasonal bloom cycle on the lake, with significant variability in bloom evolution throughout the lake. Multi-year image analysis identified evidence of intense bloom activity during dry, warm years, with a suggestion of blooms occurring later each year.

Several investigators (Moreno-Ostos et al., 2009) have stressed the importance of conducting *in situ* algal bloom monitoring on short time scales in order to adequately characterize dynamic algal bloom processes. However, this would be difficult to undertake in some areas of the Lake Winnipeg Basin. Remote sensing offers a cost-effective approach for providing spatial and temporal scales of observation not obtainable with ground based monitoring.

Satellite imagery proved to be a useful tool in determining the timing, extent, and spatial and temporal trends in algal blooms on LoW and LW. This project presented a method that effectively distinguishes surface blooms on the lakes, using the European Space Agency's MERIS aquatic colour sensor. Satellite imagery for both LoW and LW is now being processed and posted in near-real- time to the Lake Winnipeg web portal.

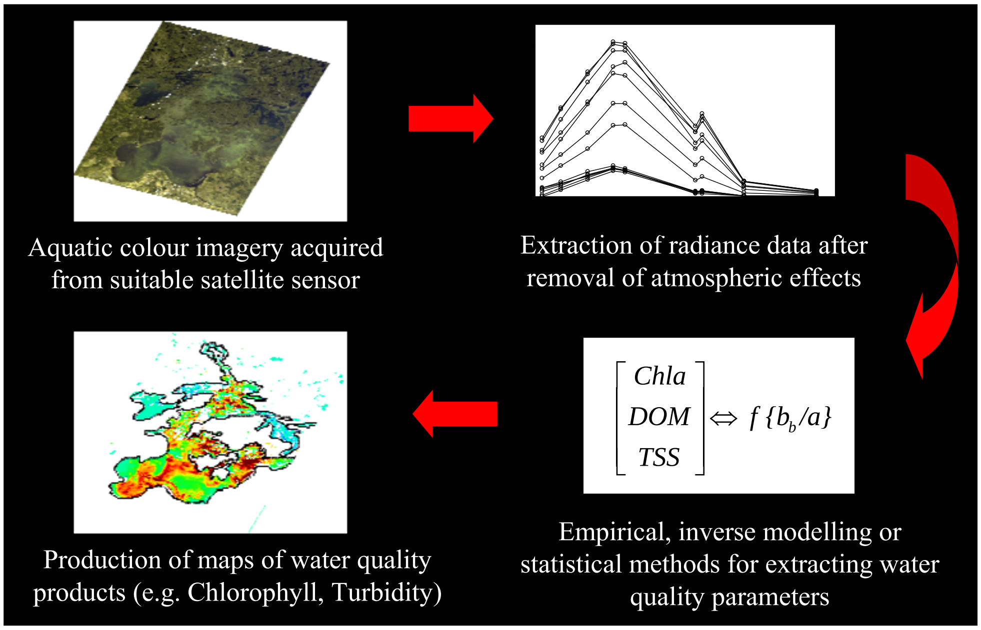


Figure 9(a): Schematic describing the process of deriving satellite estimates of algal blooms from remotely sensed aquatic colour.

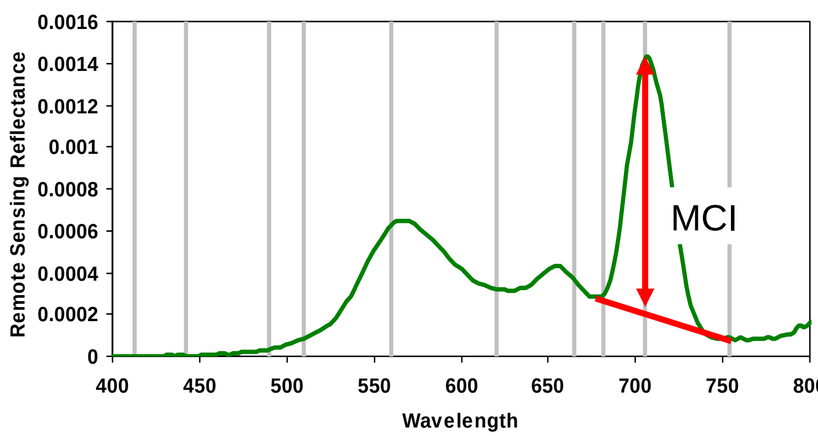


Figure 9(b): Example reflectance spectra from Lake of the Woods describing the Maximum Chlorophyll Index used to quantify bloom intensity.

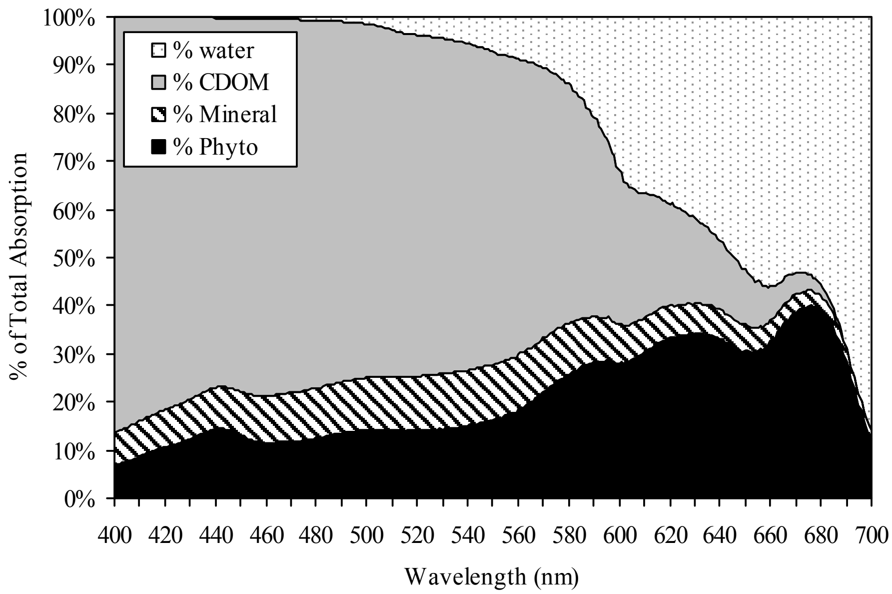


Figure 10: Percentage contribution to total absorption from colour producing parameters in Lake of the Woods, combined into coloured dissolved organic matter (CDOM), mineral suspended minerals (Mineral), and algal cells (Phyto).

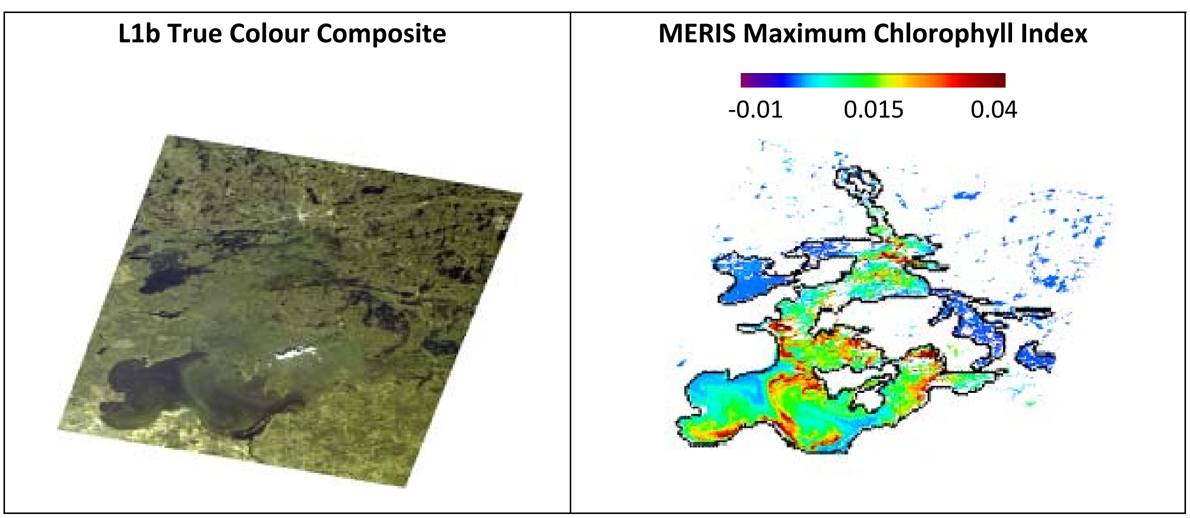


Figure 11: MERIS True Colour Image of Lake of the Woods on September 25th 2009 and derived MERIS Maximum Chlorophyll Index.

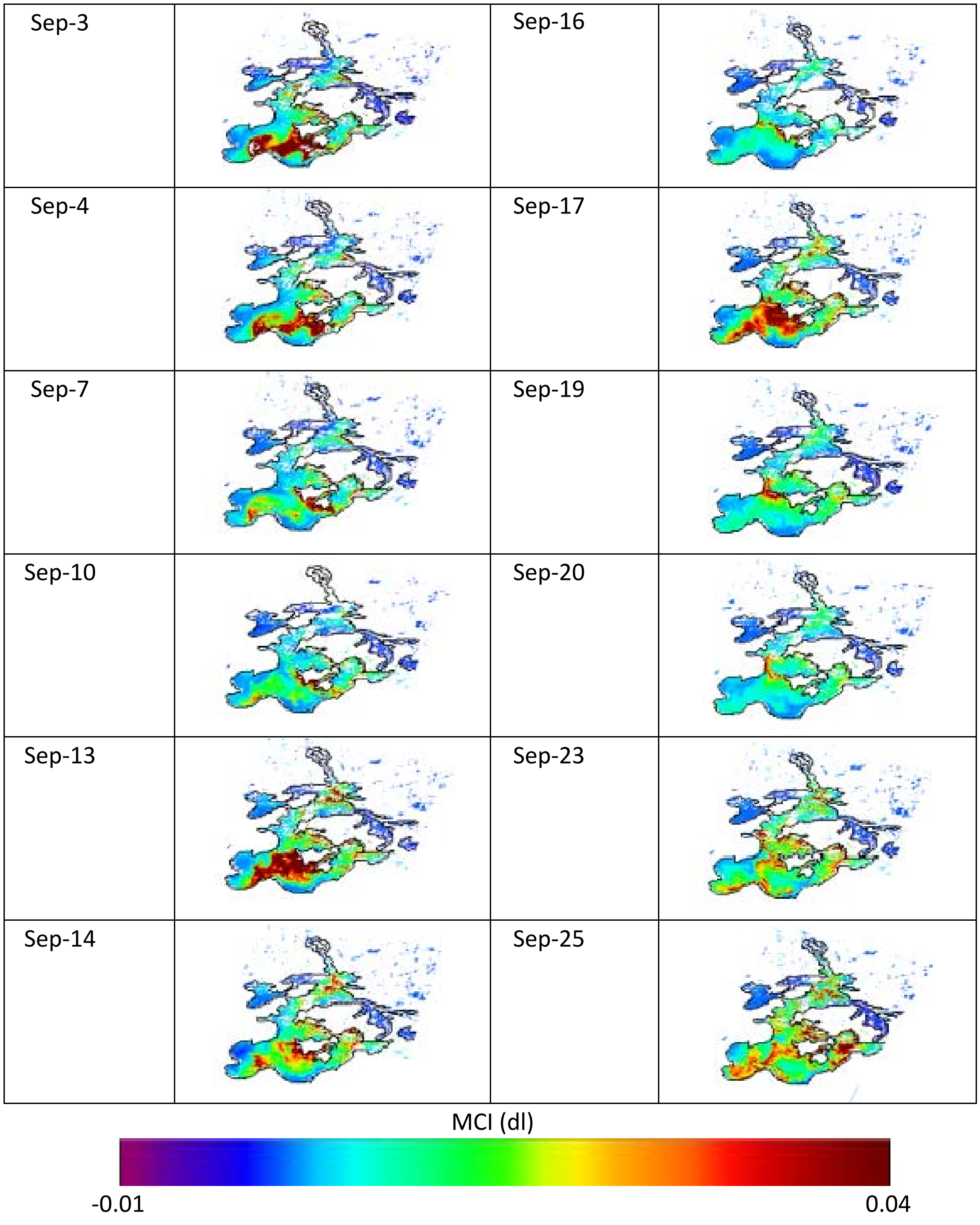


Figure 12: Time series of MERIS Maximum Chlorophyll Index for September 2009 tracking progress of a cyanobacteria bloom on Lake of the Woods.

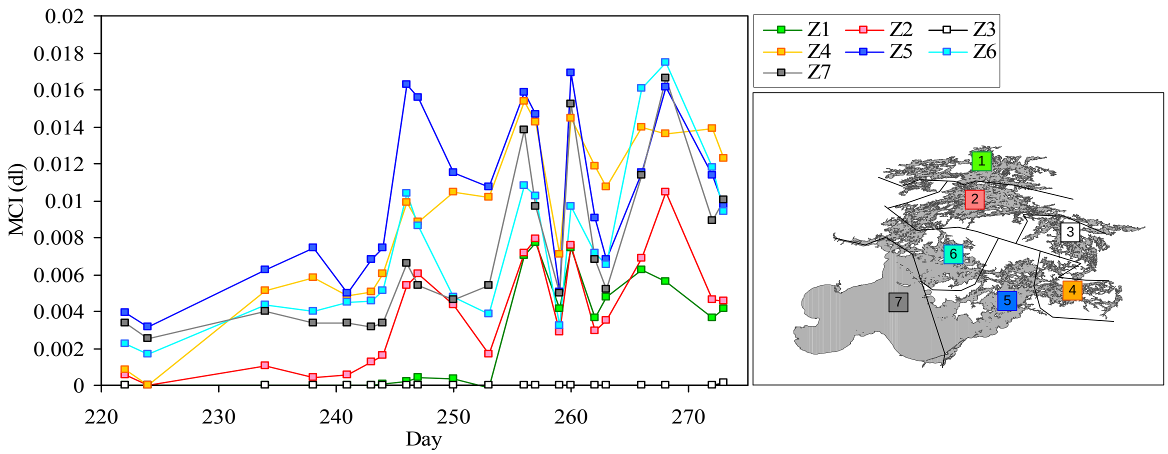


Figure 13: Progression of bloom intensity with day of year as determined by the MERIS MCI for each of the seven Lake of the Woods monitoring zones.

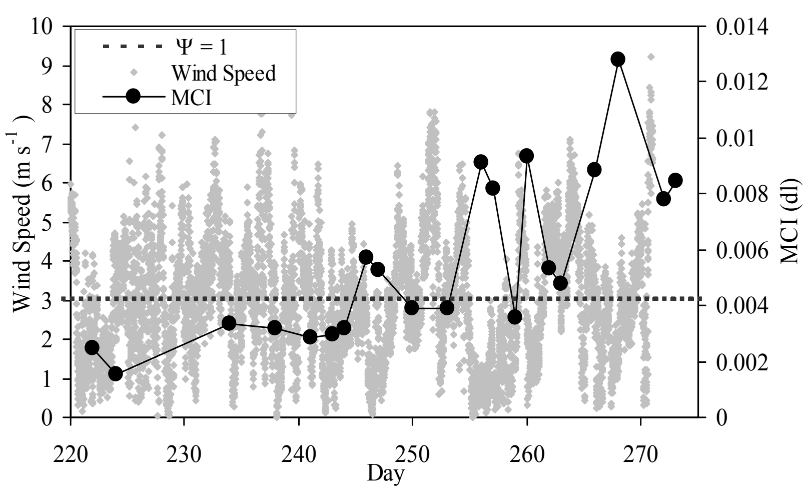


Figure 14: Lake-wide average MCI product with hourly wind speeds showing episodic mixing and re-surfacing of algal cells.

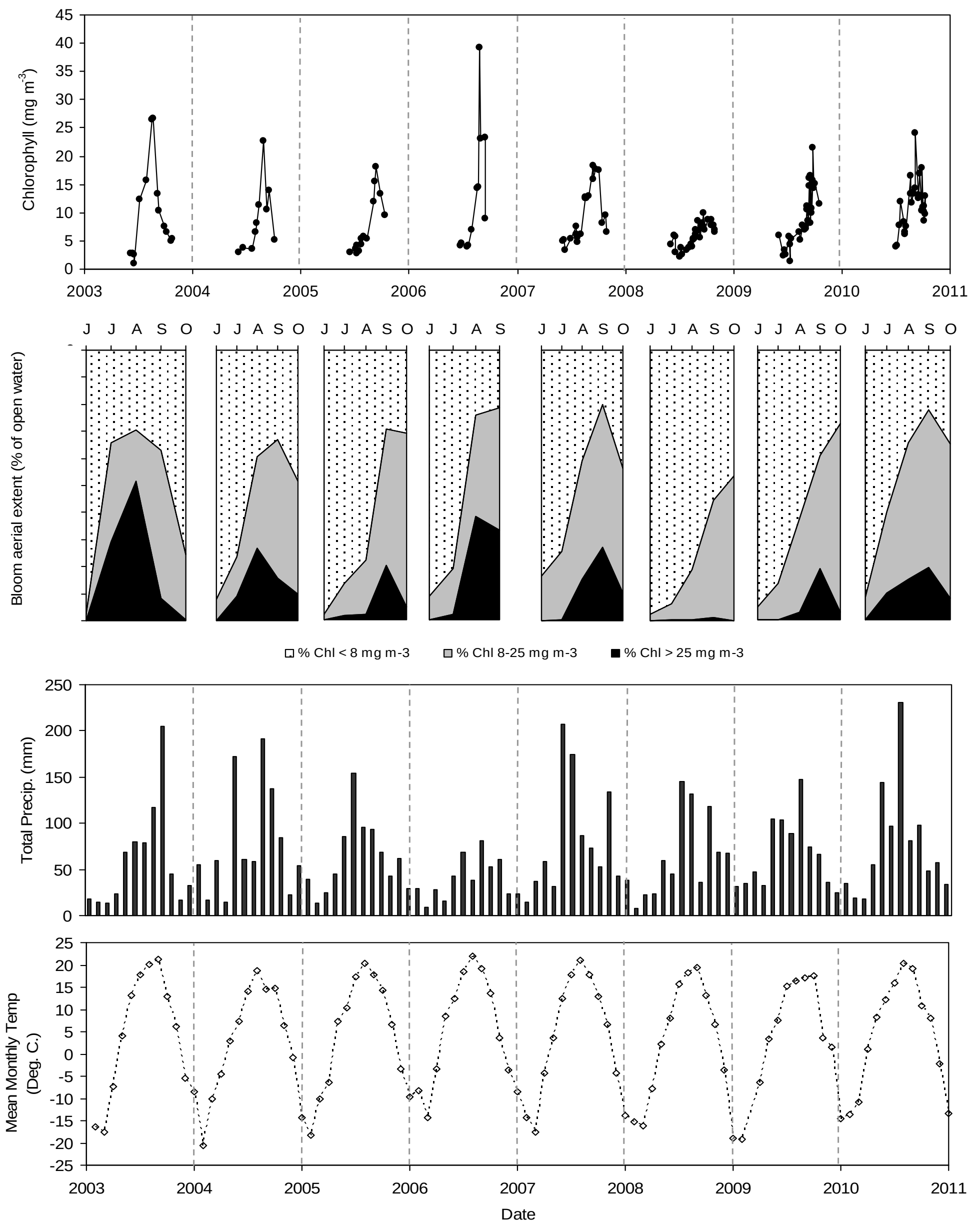


Figure 15: Time-series of (a) lake-wide median MCI-derived chlorophyll concentrations, (b) average bloom aerial extent according to trophic status as a fraction of open water, (c) monthly total precipitation (mm) at Kenora, and (d) monthly mean air temperature (°C) at Kenora.

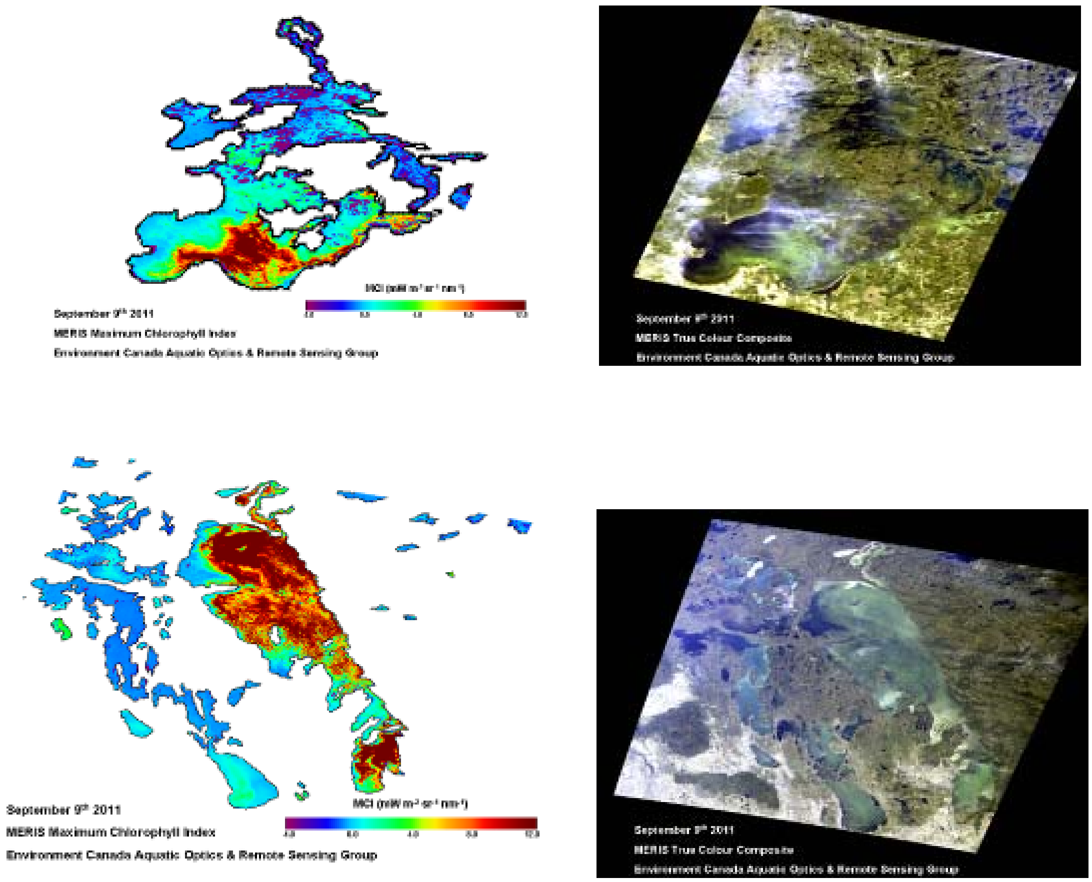


Figure 16: Example of products posted to the Lake Winnipeg web portal from Lake Winnipeg and Lake of the Woods showing on the left the algal bloom index, and on the right a true colour composite image from September 9th 2011.

Deliverable 2: CABIN bio-monitoring in tributaries to the Red River, and in sub-basins of the Lake Winnipeg Basin

Project Team: Nancy Glozier and Emily McIvor; Environment Canada

Partners: Saskatchewan Watershed Authority and Manitoba Water Stewardship

The purpose of this project was to monitor, report, and assess the status of aquatic biological communities as an indicator of water quality within tributaries of the Red River, and within relevant aquatic habitats in the Lake Winnipeg Basin. Within the basin, there are multiple aquatic habitats and ecoregions. In addition, there are several jurisdictions with biomonitoring programs underway or under development. The focus was to evaluate the compatibility of differing field approaches and protocols for assessing aquatic ecosystems, establish reference or background conditions and current biological status conditions in streams and tributaries to the Red River. The goal, in part, was to establish a "network of networks" within the basin for which biomonitoring information could be pooled. This would increase the overall ability to perform assessments.

Progress and Achievements

- Coordination and collaboration with partners involved in biomonitoring activities in the Red River Basin was undertaken in order to develop a network of networks to share information and assess approaches.
- Over 30 site visits were completed to erosional habitats of tributaries of the Red River.
- Using national Canadian Aquatic Biomonitoring Network (CABIN) protocols, stream macroinvertebrate communities were sampled in order to establish current conditions within the riffle habitats in Red River tributaries.
- Consistent macroinvertebrate monitoring protocols are currently lacking for slower flowing habitats in Prairie rivers, which are key aquatic habitats in many Red River tributaries. Therefore, a pilot study was also conducted to evaluate the comparability of two of the sampling techniques which are currently being used for slow flowing riverine habitats in the watershed.
- Fifteen sites were sampled jointly with the Saskatchewan Watershed Authority (SWA), using two field collection techniques. Some sites were located in gravel cobble substrates and some in slower flowing soft bottom sites. Five sites were established and sampled to compare the technique used by North Dakota.
- Preliminary results suggest that only minor differences in benthic invertebrate community composition are detectable between the SWA Point Transect Technique and the modified CABIN traveling kick technique. Once these comparisons are completed with all available data, the dialogue will continue through collaborative relationships that have been established with partners.

- Using the National Canadian Aquatic Biomonitoring Network (CABIN) protocols, stream macroinvertebrate communities were sampled in order to establish reference conditions within the Boreal Ecozone.
- Biological communities were assessed within the Boreal Ecozone with an emphasis on additional watershed and stream orders which will allow model completion. Over 100 site visits to collect CABIN biomonitoring samples were completed in the Boreal Ecoregion.
- A preliminary model was examined with a subset of these sites and a boreal model will be completed for use during site assessments within the Boreal Upland Ecoregion upon completion of the required quality control and assurance checks.
- Some results are pending, awaiting the finalization of several contracts but are projected to include a draft Boreal Ecoregion Reference Condition Model and a final Prairie wetland biomonitoring protocol. Once these are completed, dialogue will continue through relationships already established regarding collaboration and establishment of a Prairie biomonitoring network.

Challenges and Lessons Learned

The large size of the basin creates a logistical challenge when attempting to establish a diverse network of sites within a reasonable time frame. Significant additional staffing resources would be required to further this work. A “network of networks” to share all existing data would be the most appropriate approach to establish reference conditions and continue biomonitoring in the Red River Basin.

Conclusions

A Boreal Reference Condition Model, when finalized, could be used by community groups and government agencies to assess sites of concern. There appears to be interest amongst partners in establishing both a standardized wetland biomonitoring program, and a slow flowing riverine biomonitoring program. Once model development and final protocol reviews are completed, the methods and results obtained in both streams of the Boreal Ecoregion and the prairie wetlands should be amenable to many partners using the approaches for assessment of sites of interest. With the establishment of a protocol and implementation of training, a “network of networks” would be available across the Prairies for all partners and would greatly enhance biomonitoring data for future projects and needs.

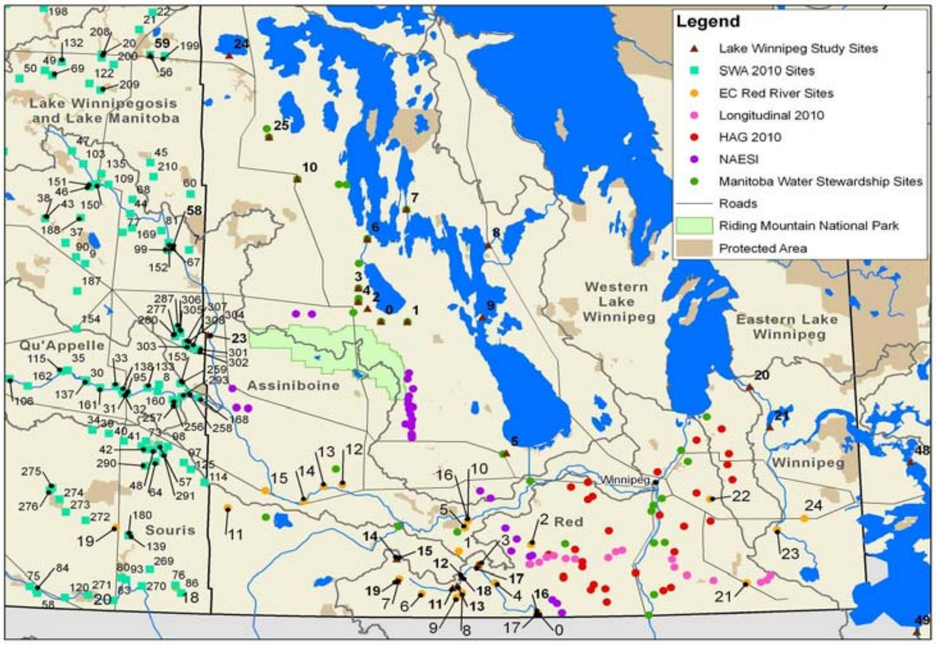


Figure 17: Biomonitoring sites in the Lake Winnipeg/Red River Basin

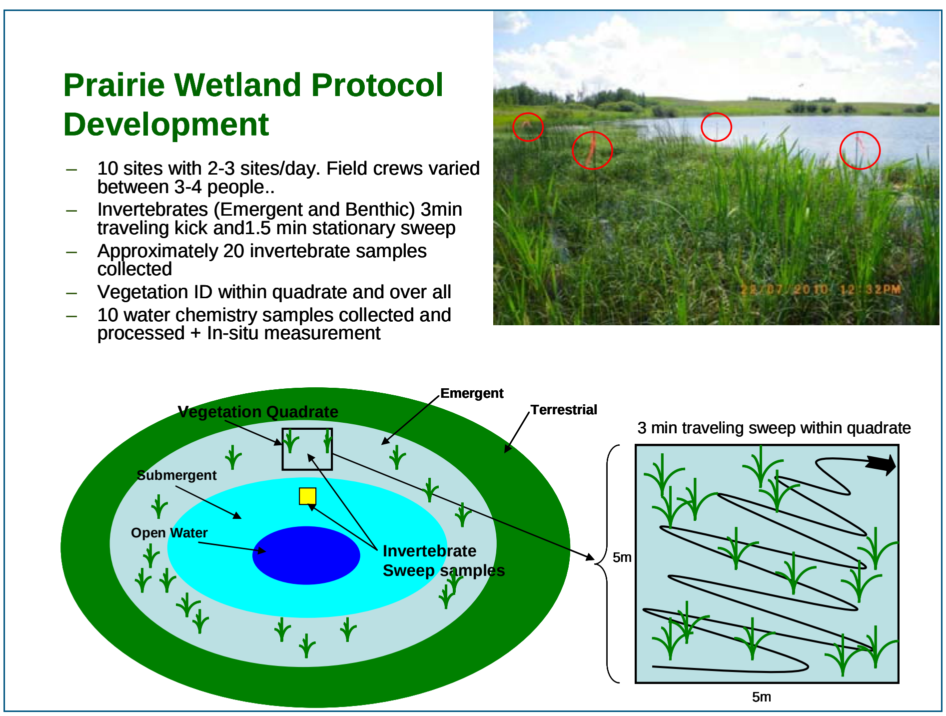


Figure 18: Schematic of Prairie Wetland Protocol

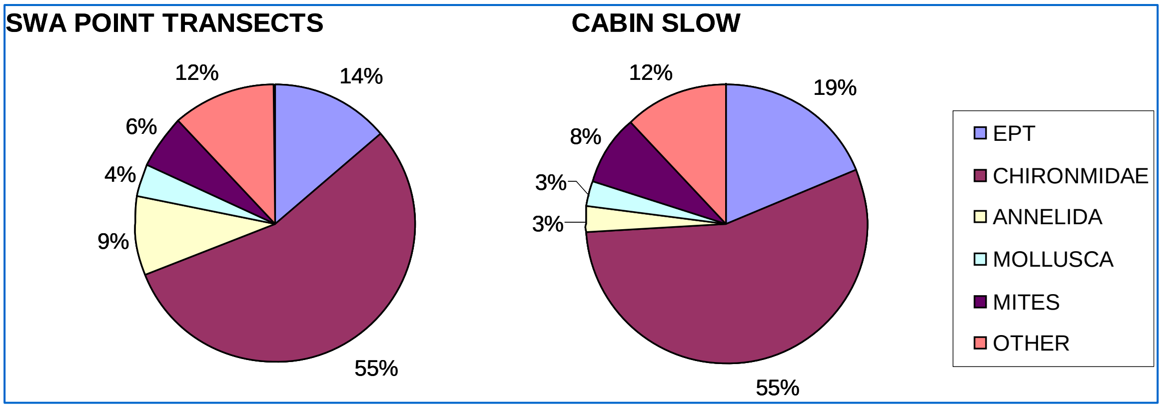


Figure 19: Proportion of key macroinvertebrate taxa in samples obtained from two techniques evaluated

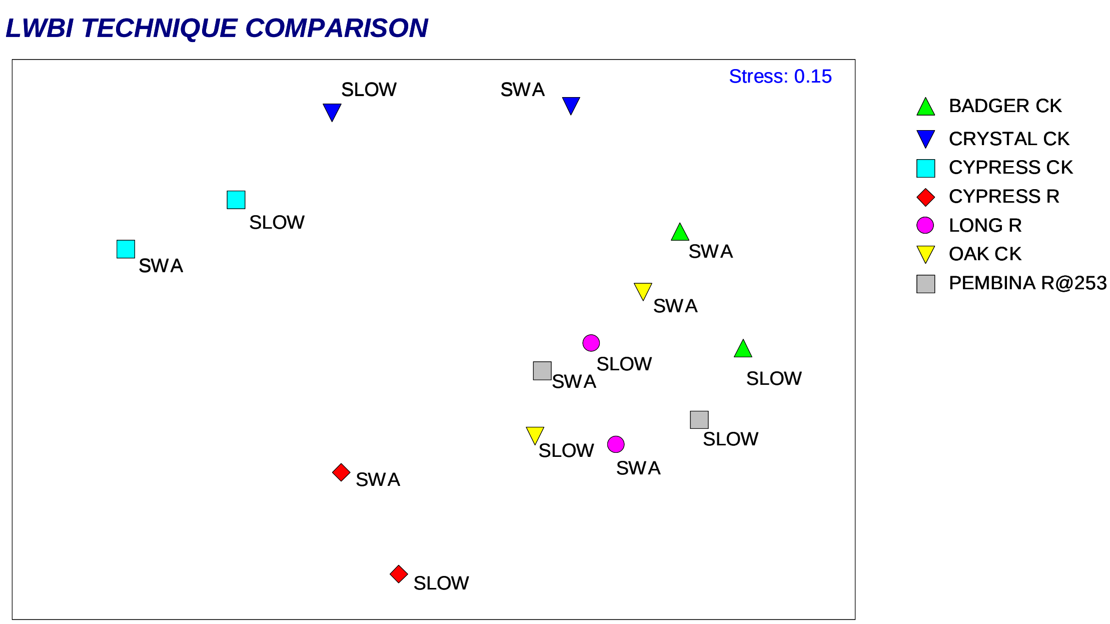


Figure 20: Multi-dimensional Scaling (MDS) plot of benthic invertebrate communities collected with two techniques at the same location. Communities from the same site are most similar and not different overall for all seven sites evaluated in this preliminary analysis.

Deliverable 2: CABIN-based diagnostic indicators development

Project Team: Donald Baird, David Armanini, Nancy Glozier, Wendy Monk; Environment Canada

The purpose of this project was to develop a protoype indicator of local nutrient enrichment, based on biomonitoring data collected using Environment Canada's Canadian Aquatic Biomonitoring Network (CABIN) methodology. This project builds on techniques developed as part of the National Agri-Environmental Standards Initiative (NAESI) which seeks to permit separation and quantification of effect strength for individual land-use drivers (e.g nutrients versus sediments versus water abstraction/instream flow) using riverine invertebrate community structure as a diagnostic information source. By developing driver-gradient sensitivity profiles for common taxa, the aim was to analyze and explore the possibility of teasing apart interactions between landscape-scale drivers in terms of the presence and abundance of sensitive and insensitive organisms collected in biomonitoring samples.

Progress and Achievements

- Relevant data was collated on physical-chemical and biological characteristics of agricultural watersheds of Canada, including the Red and Assiniboine rivers.
- An initial data set of biological samples with associated water chemistry and habitat data (n=4833 unique observations) was compiled using CABIN and other sources, and was used to explore nutrient-biota patterns.
- The project subsequently shifted to focus on a much smaller data set from within the Lake Winnipeg Basin, in which nutrient status was estimated from seasonal observations of water chemistry.
- Candidate diagnostics were developed, focusing on response of biological community structure to specific nutrient drivers versus other drivers (e.g. flow alteration, sedimentation).
- Candidate diagnostics were tested using biological and physical-chemical data generated through the LWBI, focusing on response of biological community structure to specific nutrient drivers versus other land-use drivers (e.g. flow alteration, sedimentation).
- This project did not collect primary data, therefore principal output to date has been the compilation of a data set to extract diagnostic signal information for nutrient status.
- A draft publication and report was prepared on the development of biomonitoring diagnostics for nutrient enrichment in riverine benthic communities, and anticipated to be peer reviewed and completed in 2012.

Challenges and Lessons Learned

A shortcoming in the data sources related to description of nutrient status. Most biomonitoring samples are 'snapshot' samples of sites which are visited only once. It was not possible to determine an accurate nutrient status of sites with only a single associated nutrient value (for either nitrogen or phosphorus). This was further complicated by the fact that within the CABIN database, for example, there was no consistent method to estimate concentrations of nitrogen or phosphorus

In addition, water quality and biomonitoring sites are not often co-located. This means that it is often difficult to associate high-quality observations on water chemistry with ecological condition as observed from biomonitoring samples collected in programs such as CABIN. In future, co-location of sites should be encouraged, as it would greatly enhance not only the ability to develop new tools, but would also permit more direct comparison of site quality measures based on chemistry to be validated by observations on site biology.

Conclusions

Work to develop a nutrient diagnostic based on observations on the taxonomic composition of biomonitoring samples is still ongoing. The lack of a large enough validation data set (preferably n>100 sites spanning a range of nutrient conditions) of co-located high-quality nutrient and biological observations has impeded testing of the approach, but data generated within the LWBI program and also from other outside studies is likely to ameliorate this situation.

Deliverable 2: Water quality monitoring site comparisons and federal/provincial data quality assessments

Project Team: Malcolm Conly, Elise Watchorn, Brian Parker; Environment Canada

The objective of this project was to provide the basis for optimizing the placement of the water quality monitoring network, as well as the frequency and timing of monitoring, in order to detect changes and help to identify the most appropriate performance indicators for meeting future water quality management objectives. This project also involved assessing the comparability of data collected by Manitoba Water Stewardship (MWS) and Environment Canada (EC), to determine if differences in field handling of samples results in any observed differences. Results of this work will determine if federal and provincial datasets can be interwoven or if remedial actions are required to ensure comparability of data.

Progress and Achievements

- In 2009/10, an assessment of the current monitoring activities in Lake Winnipeg was undertaken, in conjunction with Andre St Hilaire, at L'Universite INRS, to assess the ability of the current network of water quality monitoring stations to detect change.
- One-time EC-MWS joint sampling from 18 flowing waters across southern Manitoba was conducted in 2010 and statistical comparisons of the data initiated to determine the comparability of data.
- In addition, paired field and laboratory filtered samples were collected at the same sites to determine if differences in filtration processes and timing of filtration significantly affect analytical results.
- Joint water quality sampling was conducted at 14 sites on Lake Winnipeg during the summer of 2011.
- Joint quarterly sampling was initiated and is being conducted on an ongoing basis between Environment Canada and Manitoba, at the Selkirk Bridge on the Red River.
- A preliminary interpretive report on data comparisons from flowing water collections was prepared in June 2011. A final interpretive report on all available data is anticipated for September 2012.

Conclusions

Conclusions stemming from this project will be available upon completion of a final interpretive report, anticipated for September 2012.

Deliverable 2: Lake Winnipeg Basin water quality network station expansion and operations

Project Team: Brian Parker, Elise Watchorn, Lindsay Wazny, Gordon Chamberlain; Environment Canada

This project was intended to improve databases and modelling efforts that support management decisions made for Lake Winnipeg. Activities included physical-chemical and bio-monitoring of Lake Winnipeg foreshore marshes and the Red River delta to provide baseline data on the biological communities and water quality of the foreshore marshes prior to planned marsh restoration and nutrient management activities. Monitoring was also undertaken to improve data resources for nutrient budget estimation for Lake Winnipeg, by determining nutrient concentrations in the Manigotagan, Bloodvein, Pigeon, Berens and Poplar Rivers, all at their outfalls to Lake Winnipeg, and the Lake Winnipeg Outlet. Gaps in the monitoring program for Lake Winnipeg were filled by incorporating biological and chemical sampling of littoral and inshore waters of the south basin of Lake Winnipeg, improving monitoring of the deepwater benthic fish community and ensuring continued delivery of the offshore collection of lake physical and chemical data.

Progress and Achievements

- Protocols were developed and the physical-chemical and biological characteristics of Netley/Libau Marshes (the Red River Delta) were monitored annually to assess the status of the Red River Delta site. Prior to this work there was no chemical or bio-monitoring of the Red River Delta or foreshore marshes of Lake Winnipeg, despite the capacity of this region to remove nutrients from local drains and Red River waters before they reach and contribute to the eutrophication of Lake Winnipeg. Sampling began in 2009 and concluded in 2010.
- Sampling was conducted at Manigotagan, Bloodvein, Pigeon, Berens and Poplar Rivers at their outfalls to Lake Winnipeg and at the Lake Winnipeg outlet on 4-5 dates between May and October 2010.
- Biological and physical-chemical monitoring was conducted of shoreline and littoral habitats around the south basin of Lake Winnipeg. Water chemistry and communities of phytoplankton, zooplankton, benthic invertebrates and fishes were monitored at five shoreline and five littoral sites. Testing of shoreline and littoral sampling protocols was conducted and completed in 2009 and the full shoreline/littoral sampling program was implemented and concluded in 2010.
- Contribution funding was provided annually to the Lake Winnipeg Research Consortium, to support their activities in education and outreach about Lake Winnipeg, and in coordinating research and monitoring through the operations of the *MV Namao* - the only research platform currently operating on Lake Winnipeg.

- Environment Canada also enhanced the research capabilities of the *MV Namao* by designing and supplying a new combined control room and lab addition to its upper deck. Maintenance and calibration services were provided for an integrated water quality parameter data sonde and multiple depth water sampling rosette.
- An improved fish monitoring program was developed and implemented for use on the MV Namao by testing and applying new monitoring protocols for fishes, including the use of bottom trawling at three sites in the south basin of Lake Winnipeg. Testing of otter trawling from the Namao was completed in July 2010. Bottom trawling work concluded in October 2010.
- Physical monitoring of pelagic waters, including collection of thermal, conductivity and light profiles was conducted and completed in 2011.
- Enhanced tributary monitoring was conducted in co-operation with MWS, to improve estimates of nutrient flux into the Red River between Emerson and Lake Winnipeg. In addition, sampling was conducted on the Red River at Ste. Agathe in 2011 to allow better delineation of regional nutrient loads to the Red River.
- Capacity support was provided by the National Laboratory for Environmental Testing (NLET) in Saskatoon and Burlington for analysis of nutrients, major ions, metals and physical parameters in samples collected through the LWBI research and monitoring program. Technical Operations and Engineering Support staff from the Research Support Section in Burlington provided support to a number of LWBI research projects for sample collection, and field support for preparing, shipping, deploying and recovering scientific moorings on both Lake Winnipeg and Lake of the Woods.
- Data and sampling protocols have been uploaded to the Lake Winnipeg web information portal.

Challenges and Lessons Learned

An alternate bottom trawl design may be required for operation on the MV Namao. The forward tow point on the ship makes deployment of otter-type trawls difficult.

Staffing constraints prevented continuation of most monitoring into 2011, and precluded interpretion of monitoring data gathered throughout the LWBI. As a result, no interpretation of data has been conducted to date.

Conclusions

Interpretation of data has not yet been done, however raw data and sampling protocols have been uploaded to the Lake Winnipeg web information portal.

Deliverable 2: Reservoir nutrient sequestration studies

Project Team: Brian Parker, Elise Watchorn, Lindsay Wazny, Gordon Chamberlain; Environment Canada

This surveillance project evaluated the role of natural lakes and man-made reservoirs in reducing nutrient transfer from the watershed to Lake Winnipeg. Objectives included determining the effect of reservoir/lake size and water renewal rate on nutrient retention, if reservoirs and lakes exhibit different patterns of nutrient sequestration and release, and the effects of windspeed and wind direction on nutrient export/sequestration for shallow lakes. This work complemented research efforts conducted by the University of Manitoba in examining the role of small headwater reservoirs in sequestering nutrients in the Tobacco Creek watershed.

Progress and Achievements

- Sequestration was determined for about 30 larger lakes and reservoirs in the Lake Winnipeg Basin by measuring nutrient fluxes in lake/reservoir inflows and outflows and determining the types and amounts of nutrient retained within the waterbodies.
- Sampling began in September 2008 and field work was completed in 2011. A draft manuscript of the first two years of the study is being prepared and a final report anticipated by March 31, 2013.

Research Results

- Preliminary results indicate that single lakes and reservoirs in the Lake Winnipeg Basin sequester a variable but often high proportion of inflowing nutrients - up to 80% in some cases. For the Dauphin River watershed as a whole, large waterbodies sequester 70% or more of all inflowing nutrient from headwater sources and thereby substantially reduce nutrient loading to Lake Winnipeg.
- Nutrient sequestration, as a percent of inflowing nutrient, is proportional to the water residence time of the receiving water body, with basins of longer water retention time retaining a higher proportion of nutrients.

Challenges and Lessons Learned

The high spring runoff sampling frequencies required to calculate accurate estimates of nutrient loads, coupled with ongoing long-term monitoring requirements, is labor intensive and impacted capacity to meet workloads and scheduling of field visits.

This study and the Tobacco Creek study cover large (>2 km^2) and small waterbodies (<5 ha) respectively. There is an ongoing research need to examine nutrient sequestration in the numerous intermediate size waterbodies in the prairies.

Conclusions

Large lakes and large reservoirs, particularly those with long water retention times, play an important role in reducing downstream nutrient flux to Lake Winnipeg and thereby reduce eutrophication of Lake Winnipeg.

Due to the considerable retention of nutrients in large waterbodies, nutrient reduction efforts above these lakes and reservoirs would be less cost-effective with respect to controlling nutrient input to Lake Winnipeg, than those efforts directed to subwatersheds below these sites, or to watersheds lacking large lakes and reservoirs.

Deliverable 2: Lake of the Woods nutrient surveys and nutrient dynamics

Project Team: Tim Pascoe, Melanie Nielson, Paul Klawunn, Tana McDaniel, Sue Watson, Ram Yerubandi, Jun Zhao & Jay Guo; Environment Canada

Partners: Canadian Coast Guard, Ontario Ministry of the Environment, Minnesota Pollution Control Agency, Rainy River First Nations, Red Lake Band of Chippewa Indians, AETI - Hedy Kling, University of Manitoba, and members of the Lake of the Woods International Multi Agency Working Arrangement (IMA).

Lake of the Woods (LoW), spanning portions of Ontario, Minnesota and Manitoba, is a major component of the Lake Winnipeg Basin. Under the LWBI, a research and monitoring program was initiated for LoW. The LoW science plan included a scientific assessment of existing LoW hydrologic and water quality and nutrient databases, and system scoping; work to estimate LoW nutrient loading and nutrient budgets; improved characterization of hydrological loading and physical limnology of LoW and lake modelling; and characterization of biological community and assessment of risk and impairment by algal blooms.

Progress and Achievements

Scientific assessment of existing LoW hydrologic and water quality/nutrient databases; system scoping:

- Existing data on algal blooms, water quality and flows were amalgamated.
- A water quality monitoring field program was developed for Rainy River and LoW including the establishment of new water quality monitoring stations on LoW and Rainy River.
- An inter-lab comparison study for key water chemistry components was conducted to assess the accuracy and comparability of data from the LoW International Multi Agency Working Arrangement (IMA) laboratory analysis using the Environment Canada Proficiency Testing Program.
- PCBs and PAHs were sampled in a sub-set of LoW sediments while current use pesticides (CUPS) in water were measured at selected sites. In addition, mercury concentrations in water were monitored in the Rainy River throughout the ice free months.

Characterization of hydrological loading and physical limnology and lake modelling:

- Three precipitation samplers were installed to estimate atmospheric nutrient loads to LoW from wet deposition.
- A meteorological station and fixed moorings throughout the lake were established to obtain time series measurements of meteorology and water quality and sediment traps.

- Digital bathymetry was produced by digitizing existing raster-based Canadian Hydrographic Charts, for use in hydrodynamic models.
- A nutrient balance model was developed using information from hydrodynamic model and measurements.
- A high resolution three dimensional hydrodynamic model and a mass-balance model for total phosphorus (TP) was constructed and applied to LoW to model eutrophication and nutrient transport. The model was successful in simulating spatial and temporal patterns in phytoplankton biomass and nutrient concentrations throughout the lake.

Estimation of LoW nutrient loading and nutrient budgets:

- More than thirty new water quality monitoring stations were established in key Basins on LoW and four stations on the Rainy River. Water quality, precipitation and sediment data were collected for LoW and the Rainy River for 2008-2011.
- Lake wide cruises were conducted for water quality using YSI profiling, discreet depth (surface, bottom-1m), and euphotic zone integrated samples
- Surficial sediments on LoW were analyzed for P, total and organic N and C and particle size analysis.
- Data from surveys incorporated into 3D hydrodynamic nutrient transport and loading model for LoW.

Characterization of biological community and assessment of risk and impairment by algal blooms:

- The phytoplankton community was sampled at selected sampling sites and samples analyzed for biomass, taxonomic structure, and pigments.
- An annual spatial survey was conducted during the late summer (high risk period for cyanobacteria blooms). Surface water samples were analyzed for algal biomass, taxonomic structure, pigments, and toxins (microcystins - among the most common and persistent cyanotoxins), and where relevant, other toxins (anatoxin-a, cylindrospermospin, saxitoxin).
- Benthic invertebrates were collected at offshore sites in selected LoW basins to establish a reference baseline for LoW.

Research Results

- Phosphorus (P) inputs from wet atmospheric deposition vary and are 2-3 three times higher at north and west stations than in the east (Sioux Narrows), possibly reflecting an elevated P content of prairie-based air borne dust. Nitrogen (N) inputs are similar in magnitude but vary in chemistry amongst sites, with a greater predominance of nitrates/nitrites in the eastern (Sioux Narrows) area, again possibly reflecting basin influences (agricultural and industrial) on airborne materials.

- Summer thermal stratification is established in some of the deeper basins, particularly in northern areas, and can be associated with low concentrations of dissolved oxygen and elevated levels of nutrients in the bottom waters, indicative of internal P and N loading, and potentially posing a threat to benthic biota.
- There are clear gradients in transparency, suspended material and nutrients across LoW. In general, the shallow wind-swept basins have lower transparency levels and a higher proportion of inorganic content in the suspended material, indicative of re-suspended sediments.
- Phosphorus (P) concentrations in LoW are typical of a meso-eutrophic system and vary with season, basin and depth. Circulation and mixing regimes have a strong influence. During the summer in the well-mixed southern basins, P is fairly uniform in concentration from top to bottom and mostly present in particulate form reflecting a high abundance of phytoplankton cells (predominantly cyanobacteria). In the deeper stratified northern basins, surface P levels are lower (and associated with lower algal biomass), but levels can increase towards the bottom and are evidence of P release from sediments. Surveys near shoreline septic sites indicated that these waste systems may also be a source of local P.
- Nitrogen shows less distinct spatial patterns in chemistry and concentrations. The high abundance of large, nitrogen-fixing cyanobacteria in the summer blooms is indicative of short-term N deficiency but overall, productivity is predominantly controlled by P.
- Chlorophyll-a, used as a general measure of algal abundance, shows clear differences amongst basins with the highest levels in the surface layers during the extensive summer blooms in the southern basins.
- While most attention is focused on the mid-summer blooms dominated by cyanobacteria, diatoms are also important throughout the basins, likely due to the relatively cool water temperatures and low light regimes of the lake, and play an important role in foodweb nutrition.
- As with nutrients, wind and circulation play a major role in transport and vertical mixing /surface formation of blooms, resulting in high spatial and temporal variance in concentrations and associated risk at shorelines.
- During the peak summer period, open water stations often show toxin levels well below drinking water guidelines, but concentrated material can show much elevated toxin levels. Where tested, other toxins have been below detectable levels. Cyanobacteria are likely present but are not dominating these blooms, which are largely caused by non toxic species. However, the risk of toxins increases dramatically in the dense surface or shoreline scums which commonly occur.
- Preliminary analysis of off-shore benthic communities noted a reduction in diversity in deep northern basins where dissolved oxygen was low and concentrations of metals and nutrients in the sediments were elevated.

Challenges and Lessons Learned

Staffing and resource constraints in 2011 led to a significant reduction in the number of benthic samples, impairing ability to properly assess this community.
Currently, nutrient models rely on data from the Experimental Lakes Area, rather than from within the LoW Basin itself, to estimate aerial deposition. Continued monitoring of the aerial deposition of nutrients in within the LoW Basin is needed to characterize this important input more effectively.

While preliminary modelling of the lake behavior has been conducted, additional data exploration and final modelling will require continued support. Temporal analysis of the basin needs to be expanded to further understand nutrient cycling and its effect on phytoplankton species in the lake.

Enhanced spatial coverage of the lake is needed, particularly in the highly productive littoral zone, in order to sufficiently characterize the benthic community of the lake. In addition, nutrient loads in the sediments should be further characterized to address the issue of internal loading as a driver for algal blooms.

Conclusions

The Rainy River is the dominant source of nutrients into Lake of the Woods, although current concentrations of total phosphorus from the river are lower, on average, than in the late 1970s and early ‘80s.

Currently there is a prevailing belief that algal blooms originate in the south end of the lake and move up towards the north basins. However there is evidence to suggest that separate bloom populations may also arise independently in response to local nutrient input and lake wide processes.

Although not significant to the overall nutrient budget for the lake, there is some evidence of localized effects of inshore nutrient loading as a result of cottages and other development. The effects of near shore inputs should be explored further, particularly in bays with extensive cottage development.

The LoW International Multi Agency Working Arrangement Task Force members are working to establish nutrient loading targets for LoW. Currently, the monitoring program can supply information on in-lake concentrations, wet deposition loadings, and internal sediment loads through both direct measures, as well as through advanced modelling and assessment. Efforts to provide a more complete picture of nutrient issues, refine the nutrient budget and reduce nutrient loadings will be reliant on continued monitoring.

The LoW monitoring initiative was initially guided by a need to address knowledge gaps which had been identified as limitations to understanding the nutrient issues in the watershed area. Since work began, the program has begun to provide information for several key issues. Currently, information from LoW is contributing to a better understanding of nutrient loadings to the Winnipeg River, the main outflow of the lake. Nutrient related issues in LoW are also very similar to Lake Winnipeg, and knowledge learned in one location should be directly transferable to the other.

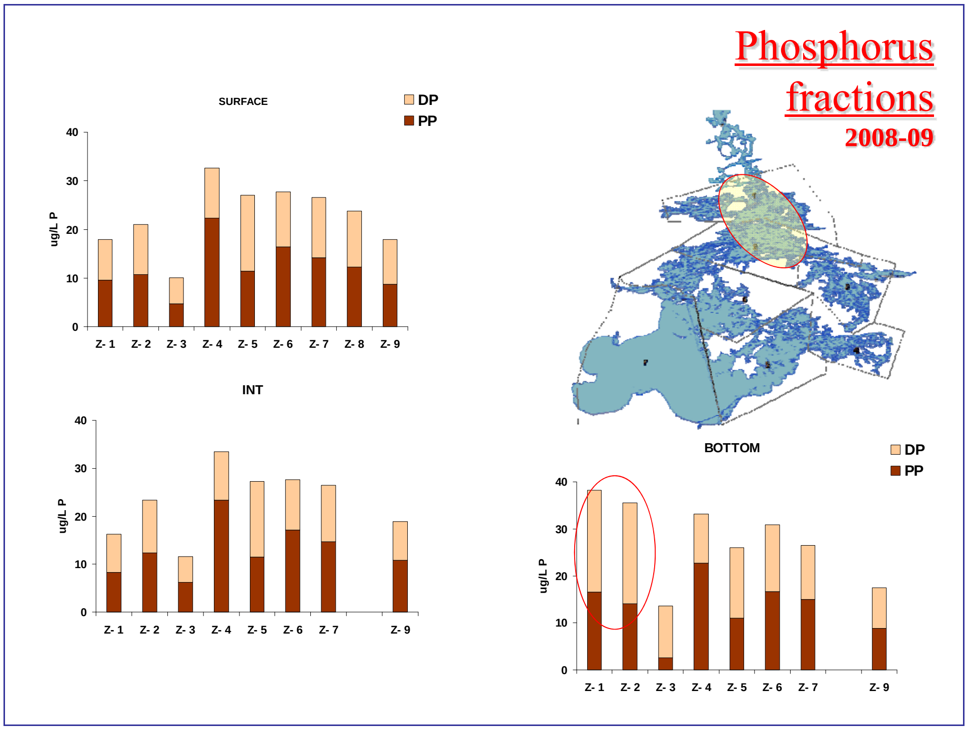


Figure 21: Phosphorus Fractions 2008-09 Lake of the Woods

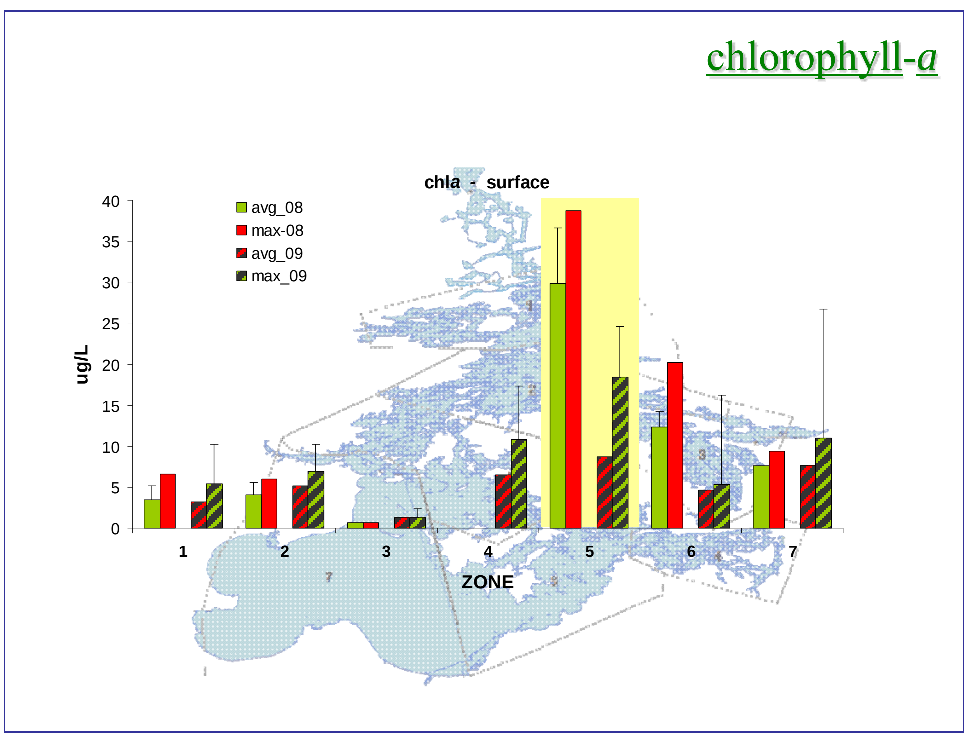


Figure 22: Chlorophyll-a Lake of the Woods

Deliverable 3: Transport of nutrients from agricultural watersheds through tributaries in the Lake Winnipeg Basin

Project Team: Patricia Chambers, Julie Corriveau, Adam Yates, Joseph Culp, Glenn Benoy, Jane Elliott; Environment Canada

Partners: Agriculture and Agri-Food Canada, Manitoba Water Stewardship, Manitoba Agricultural Services Corporation, Deerwood Conservation District, rural landowners and agricultural producers in the Red River Valley

Agriculturally-dominated watersheds in the Red River Valley have been thought to be important sources of nutrient inputs to Lake Winnipeg. This project included three activities: quantifying nutrient loads from land-based sources; determining the transport and storage of nutrients in test watersheds, and applying the results from these field-based studies to model the transport, storage and delivery of nutrients in agricultural watersheds.

Progress and Achievements

- Ten subcatchments draining the western side of the Red River Valley were sampled to determine nutrient export along gradients of human activity. In addition, data from three mainstem sites in the Seine, LaSalle and Little Morris watersheds were analyzed to determine spatial and seasonal patterns in nutrient release.

- Nutrient samples and flow data were collected at bi-weekly intervals, from snowmelt into the autumn season, and analyzed.

- GIS based models were applied to determine critical areas of agricultural influence in nine agriculturally-dominated, prairie subcatchments. The relationships between human activity gradients, the location of agricultural lands, and concentrations of total nitrogen and phosphorus were explored under different seasonal and flow conditions.

- Three publications outlining research results have been prepared and published in peer-reviewed science journals.

Research Results

- Annual patterns in all three prairie rivers were dominated by the snowmelt period: 34-94% of the total annual river volume, 40-97% of the total annual TP load, and 54-97% of the total annual TN load were delivered during snowmelt.

- Concentrations of TP and TN varied amongst seasons (snowmelt, summer, fall and winter), but showed more variability and larger values during winter and snowmelt, with peak values reaching 1.960 mg TP L^{-1} and 16.07 mg TN L^{-1} (Figure 23).

- Elevated concentrations of TP and TN were observed in the ten agricultural subwatersheds during snowmelt peak, with maximum concentrations reaching 3.23 mg TP L^{-1} and 18.50 mg TN L^{-1}.

- Dissolved P and N dominated the total nutrient pool throughout snowmelt, likely due to reduced erosion and sediment transport resulting from the combination of the flat topography, frozen soil and stream banks, and gradual snow cover melt.

- Significant correlations were observed between snowmelt N load and both agricultural land cover and fertilizer usage, with a weaker correlation between snowmelt P load and agricultural area.

- Discharge, nutrient loads and nutrient export increased along the three river gradients. In contrast, TP or TN concentrations showed no significant longitudinal change for the two agriculturally-dominated watersheds yet increased along the forested stream.

- The models indicated that critical areas of influence varied seasonally with areas of influence expanding with individual rainfall events. Inclusion of natural vegetated areas on the landscape resulted in substantial increases in model power for only one scenario.

- Agriculture in areas within approximately 100 m of the stream channel appeared to be the most critical driver of in-stream nutrient conditions during most seasons and under most flow conditions. Within the stream corridor, the presence and position of low lying areas where overland flows became concentrated were especially important predictors of in-stream nutrient concentrations, particularly during drier seasons.

Challenges and Lessons Learned

Despite significant progress, findings were limited by two major challenges. Extensive sampling of nutrient species was limited by resource constraints, and there was a lack of extensive historical data of this nature. This impacted the ability to make stronger conclusions and better understand the associations between in-stream nutrient levels and human activities.

In addition, environmental conditions in the Red River Valley are extremely variable across time and space, and the short-term, four year nature of research under the LWBI reflected only a snapshot of environmental conditions. Applicability of the findings is thus limited because samples on which the findings are based do not reflect the considerable seasonal and inter-annual range of climatic and hydrologic conditions that occur in the region. Spatially extensive and temporally repetitive sampling is required to fully discern patterns and trends in ecological conditions and nutrient uptake. Longer range data is required to capture the annual and seasonal variability that exists and likely effects nutrient transport and delivery, and their relationships to human activity.

Conclusions

The results of this project demonstrated that TP and TN exports in rivers within the Lake Winnipeg Basin are strongly influenced by seasonal hydrology. Snowmelt plays a key role in nutrient export to prairie aquatic ecosystems, and this may have serious impacts on downstream ecosystems. Further analyses are on-going to assess relationships between land-based sources and nutrient loads in different seasons.

Agriculture in areas within approximately 100 m of the stream channel appears to be the most critical driver of in-stream nutrient conditions, especially phosphorus, during most seasons and under most flow conditions. Increasing the amount of natural vegetation within the stream corridor may therefore be effective in controlling nutrient losses to southern Manitoba streams. Constructing and restoring wetlands in areas of concentrated flow may also be an effective strategy for mitigating nutrient losses via transport through areas of concentrated flow within the stream corridor.

Findings suggesting that TP and TN exports in prairie rivers are strongly influenced by seasonal hydrology, with snowmelt being a critical period for nutrient export, have implications for design and implementation of appropriate management practices to minimize nutrient export to local and downstream aquatic ecosystems. Land use management practices need to consider the snowmelt period to control nutrient loads to Lake Winnipeg and other water-bodies in the Lake Winnipeg watershed.

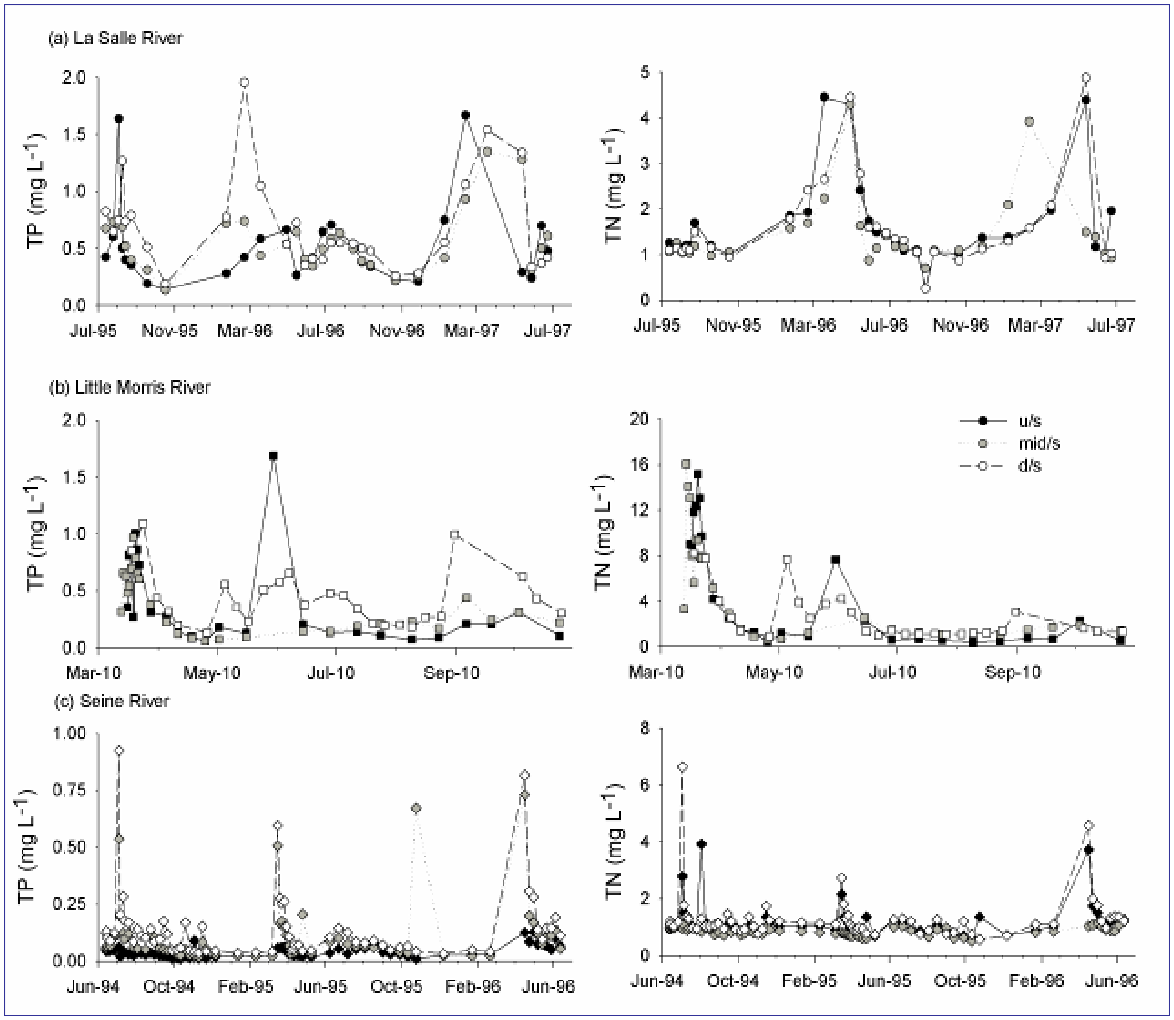


Figure 23: Concentrations of TP and TN along the longitudinal gradients of the (a) La Salle, (b) Little Morris and (c) Seine rivers.

Deliverable 3: Removal of nutrients by biota in agricultural tributaries in the Lake Winnipeg Basin

Project Team: Joseph Culp, Adam Yates, Patricia Chambers, Glenn Benoy, Leonard Wassenaar, Lee Grapentine; Environment Canada

Partners: Agriculture and Agri-Food Canada, Manitoba Water Stewardship, Manitoba Agricultural Services Corporation, Deerwood Conservation District, rural landowners and agricutlural producers in the Red River Valley

The objective of this project was to evaluate whether ecological conditions in tributaries of the Red River were associated with the removal of non-point sources of nutrients. These subcatchments are heavily used for agriculture and have been hypothesized to be important sources of nutrient input to Lake Winnipeg. Research was conducted through integrated analysis of historical biological and nutrient information, GIS data and results of contemporary field sampling.

Progress and Achievements

- Historical data was collated and assessed on ecological condition (community structure and abundance, ecosystem processes) of candidate watersheds of the Red and Assiniboine rivers.

- Two sampling networks were established: a series of sampling stations along the longitudinal profiles of the Tobacco Creek and Rat River systems; and an extensive network of sites in subcatchments of the Red River that represent gradients of nutrient-producing human activities (i.e., human wastewater treatment, livestock production, crop cultivation).

- Sampling was conducted along the longitudinal profiles during the spring, summer and fall seasons of 2009 and 2010, and in the extensive network noted above during the summer of 2010. At all sites the isotopic signatures of aquatic organisms were measured to verify assimilation of nitrogen into tissues of stream biota and to relate land use patterns to food web incorporation of nitrogen. Indicators of nutrient uptake (e.g., ecosystem metabolism and its corollaries) were measured at the longitudinal sites to infer downstream patterns in nutrient uptake. Environmental parameters hypothesized to control stream metabolism were sampled across three spatial scales (i.e., stream reach, stream segment and stream system).

- Reference samples were collected from major nitrogen sources (human wastewater, inorganic fertilizer, livestock manure) in the region.

- Tissue samples from macroinvertebrates and riparian and aquatic plants were collected at 40 sites, with seasonal and inter-annual samples at 18 sites.

- Several key structural and functional indicators of the aquatic system, such as invertebrate community biodiversity, ecosystem metabolism and plant biomass were measured to evaluate the relationship of stream ecological condition to gradients of agricultural land use and human wastewater treatment activities. Based on the established relationships, indicators of ecological condition sensitive to changes in exposure to nutrient-producing human activities were selected for use in future monitoring programs.

- All resultant data is being analyzed with the goal of identifying critical sources and comparing to sources identified in Lake Winnipeg. Relationships between environmental drivers and ecosystem metabolism have been determined. Structural and functional indicators of aquatic ecosystem condition sensitive to nutrient exposure have also been identified.
- A series of primary reports was produced for a number of peer reviewed journals and publications.

Research Results

- Analyses of nitrogen isotopes from tissue samples of aquatic macroinvertebrates and plants, as well as riparian plants, suggested that nitrogen originating from human activities is being assimilated into biota. In particular, nitrogen isotope signatures of aquatic and riparian plants were found to reflect the signatures of nitrogen sources within 22 subcatchments of the Red River. The effect was particularly strong for plants accessing stream water directly, such as arrowhead (*Sagittaria spp,* Figure 24).

- A strong degree of correlation was also found between the amounts of nitrogen calculated to be produced by rural wastewater treatment facilities and livestock production. This indicates that these sources are most likely responsible for the amount of biologically available nitrogen in streams in the Red River Valley. Further analyses are on-going to establish direct links between specific sources of nitrogen and biotic tissues, determine patterns of nitrogen assimilation within aquatic food webs, and compare sources of assimilated nitrogen from stream and lake studies.

- Conditions were starkly different between the Tobacco Creek and Rat River systems in relation to landscape character and water chemistry. Initial analyses suggest that these differences in natural environmental conditions play a large role in nutrient uptake rates as inferred from measurements of stream metabolism. It also appears that the presence of dams on the river system, particularly within Tobacco Creek, are having an influence on indicators of nutrient uptake rates, potentially through the reduction of nutrients being transported downstream. Further analyses are on-going to develop statistical relationships between environmental conditions within the catchments of the two river systems and indicators of nutrient uptake.

- Estimates of nutrient production indicated that agricultural activities, particularly through synthetic fertilizer application, were by far the largest producers of anthropogenic nutrients in most subcatchments (Figure 25). This generalization applies to nitrogen (N) and phosphorus (P). Residential sources in these subcatchments contributed less than 1% of the total amount of nutrients produced.

- Assessment of spatial variation in nutrient production demonstrated that estimated nutrient production from fertilizer application in subcatchments on the west side of the Red River Valley was up to two times higher than that found in subcatchments on the east side. In contrast, high livestock densities in several eastern subcatchments of the Red River Valley produced more than five times the annual area mass of nitrogen and phosphorus of most western subcatchments.

- Estimated rates of stream metabolism were within the range of past studies of metabolism in prairie streams and most streams exhibited a heterotrophic status. Results suggest strong top-down control of stream metabolism by human activities in these prairie ecosystems, a finding consistent with current hierarchically structured riverine paradigms. These results also indicate that measures of stream metabolism may be useful as a monitoring and assessment tool for prairie streams in Canada and elsewhere and should be explored further.

- Building on the results of the study of drivers of metabolism, a series of indicators of ecological condition were assessed, in order to identify indicators that could be used to monitor the effectiveness of nutrient management strategies. Several indicators were identified that appear to be sensitive to major land use categories and specific nutrient producing human activities (Table 1). However, agricultural beneficial management practices (BMPs) were not significantly associated with most indicators. Structural and functional indicators demonstrated clear differences in the types of anthropogenic landscape development types they were associated with. Structural indicators were related to crop production while functional indicators were mostly associated to wastewater treatment and livestock production activities. These findings demonstrate the importance of evaluating indicators against human activities described at the appropriate scale. Furthermore, these results indicate that monitoring programs are more likely to provide an integrated and holistic depiction of the ecological conditions of an ecosystem exposed to multiple activities if both structural and functional indicators are utilized. Based on these conclusions, a framework was developed for conceptualizing the different scales at which anthropogenic landscape development occurs, to better enable evaluation and selection of ecological indicators.

Challenges and Lessons Learned

Despite significant progress, this project was limited by two major challenges. First, the short-term nature of the project reflects only a short, temporal snapshot of environmental conditions. Applicability of findings is limited because sampling and data collection do not reflect the considerable seasonal and inter-annual range of climatic and hydrologic conditions that occur in the region. Spatially extensive and repetitive sampling effort is required to better discern patterns and trends in ecological conditions and nutrient uptake, and to incorporate annual and seasonal variability, which likely affects ecological conditions, their relationships to human activity and the effects of biota on nutrient uptake. Quantifying the potential sources of nutrients to river tributaries is also important to ensure that future sampling sites include catchments where different nutrient-producing activities are most extensive. In addition, human activities exhibit extensive variability throughout the region. This variation needs to be accounted for in future study designs.

The second challenge is related in that there was almost no pre-existing historical ecological data for these streams, making it difficult to validate conclusions with independent data either across space or different time periods. Further sampling is needed to provide more extensive data and increase confidence in the research assumptions and conclusions.

Conclusions

Environmental conditions in the Red River Valley are extremely variable across time and space. Nutrient uptake varies along the longitudinal profile of rivers. Uptake rates appear to be controlled by both natural and anthropogenic environmental conditions.

Dams appear to play an important role in modifying nutrient uptake rates, potentially through reduction in nutrient availability. Agricultural activities, particularly synthetic fertilizer application, were by far the largest producer of anthropogenic nutrients (both N and P) to aquatic ecosystems in most subcatchments. Nitrogen from human activities in the Red River Valley is being assimilated into aquatic biota. Human wastewater appears to be the biologically preferred source of nitrogen to aquatic food webs.

Stream metabolism is increasingly being used for monitoring and assessment of the condition of aquatic ecosystems, in large part because it is connected to nutrient cycling and uptake. Strong top-down control of stream metabolism by human activities in Red River Valley streams is evident. Measures of stream metabolism for prairie streams in Canada and elsewhere should be further explored as a monitoring and assessment tool. Enhanced knowledge of the hierarchical structure of drivers of stream metabolism will help to ensure that assessment results can be used to effectively inform management strategies in prairie ecosystems.

Finally, indicators of ecological condition are strongly associated with nutrient-producing human activities in the Red River Valley. Both structural and functional indicators are required in order to accurately depict the ecological conditions of an ecosystem that is exposed to multiple activities, and to enable effective monitoring of the effectiveness of nutrient management strategies.

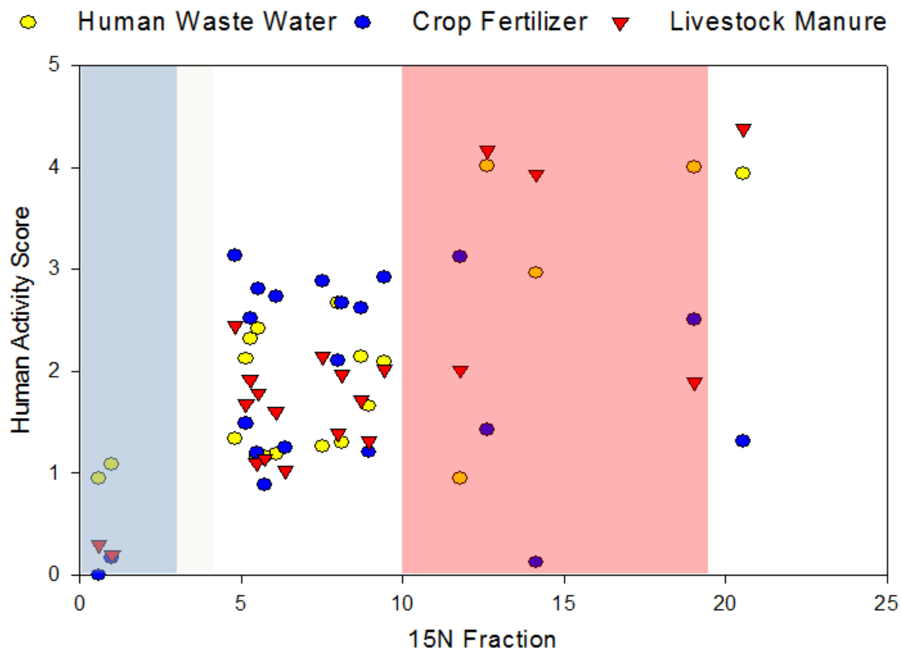


Figure 24: Relationship between the nitrogen isotopic signatures of arrowhead (Sagittaria spp) plants collected at 22 sites with varying amounts and intensities of nutrient- producing human activities. Coloured areas represent nitrogen isotopic signatures of reference samples of inorganic fertilizer (blue) and human wastewater and livestock manure (red).

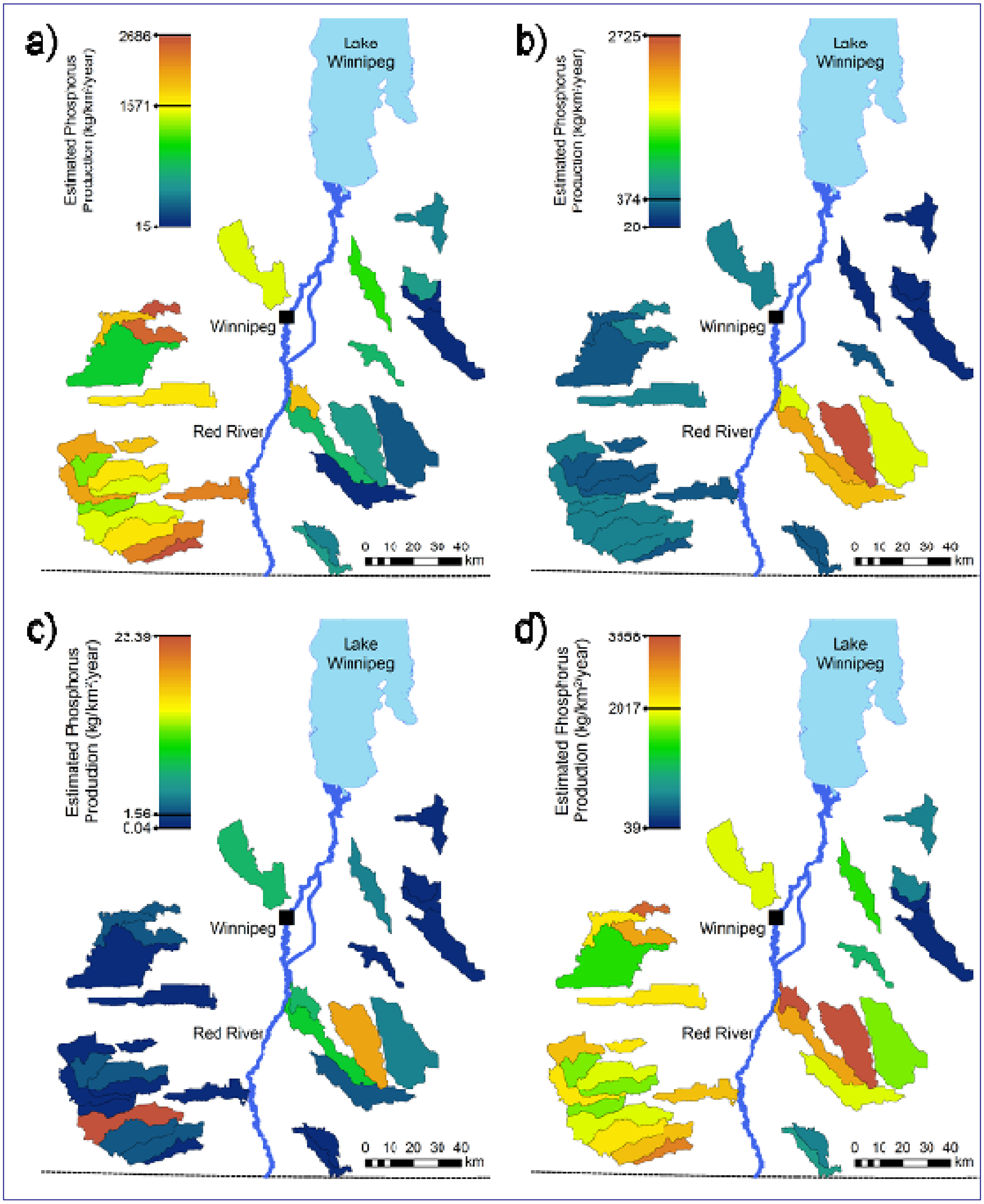


Figure 25: Variation in the estimated annual mass of phosphorus per square kilometer produced from (a) fertilizer applied to cropland, (b) livestock production, (c) wastewater treatment facilities, and (d) all sources combined for 31 subcatchments across the Red River Valley of southern Manitoba. Max, min and median rates are denoted on color ramp.

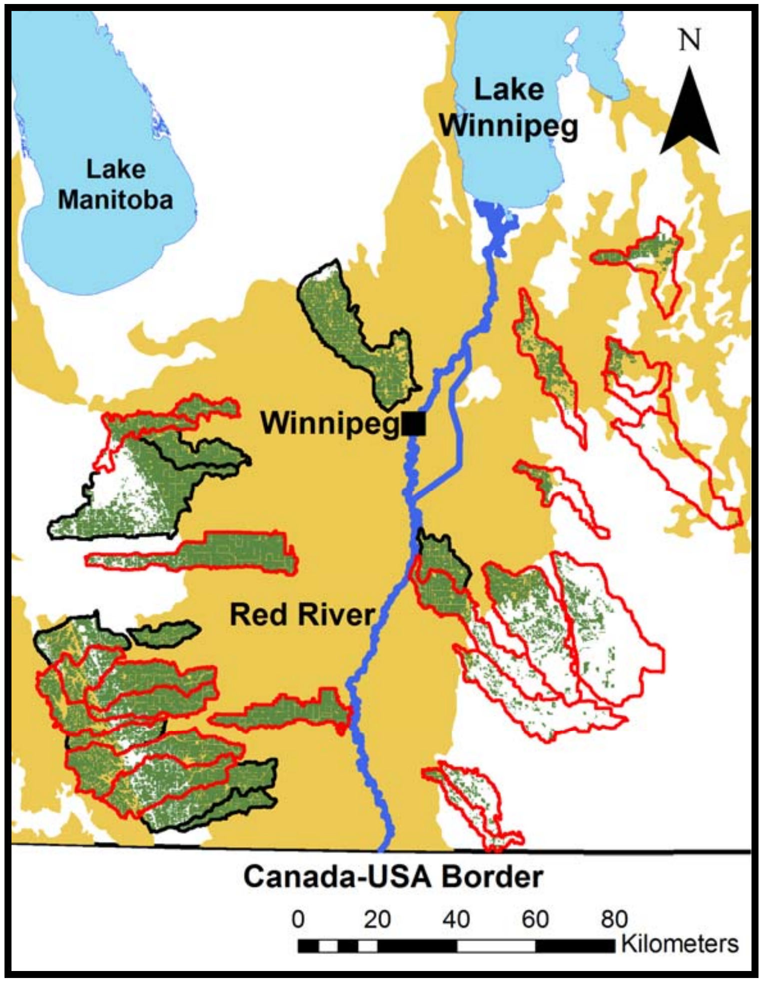


Figure 26: 22 subcatchments selected to represent the described range of variability in human activity gradients from the described 31 subcatchments and sampled for ecological and physic-chemical conditions.

Table 1: Results of linear regression analyses relating 20 ecological indicators to land use descriptors (i.e., % agricultural and % urban), gradients of nutrient-producing human activity (i.e., wastewater treatment, crop production and livestock production) and beneficial management practice gradients (i.e., conservation practices, tillage practices and manure application practices) for 19 subcatchments in the Red River Valley of southern Manitoba, Canada. Strength (r^2) and direction (slope) of tests meeting $p < 0.10$ criteria are presented. Bold type denotes tests with p-values below the Bonferroni adjusted value of $p = 0.003$.

Indicators	Land Use Categories				Human Activities						Management Practices					
	% Agric		% Urban		WWT		Crop		Livestock		Conserv		Tillage		Manure	
	r^2	slope	r^2	slope	r^2	slope	r^2	slope	r^2	slope	r^2	slope	r^2	slope	r^2	slope
FBI	0.24	+	----	----	----	----	0.29	+	----	----	----	----	----	----	0.17	+
% EPT	0.25	-	----	----	----	----	0.37	-	----	----	----	----	----	----	0.25	-
Total Taxa	0.21	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----
% Diptera	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
% Dominant	----	----	0.17	-	----	----	----	----	----	----	----	----	----	----	----	----
NMDS Axis 1	0.23	+	----	----	----	----	0.31	+	----	----	----	----	----	----	0.21	+
NMDS Axis 2	----	----	----	----	----	----	----	----	0.15	-	----	----	0.24	-	----	----
Suspended Chl *a*	0.36	+	----	----	----	----	0.25	+	0.26	+	----	----	----	----	0.18	+
Benthic Chl a	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
GPP	0.17	+	**0.57**	**+**	0.22	+	----	----	----	----	----	----	----	----	----	----
ER	0.18	+	**0.80**	**+**	----	----	----	----	----	----	----	----	----	----	----	----
NEM	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
P/R	----	----	----	----	0.19	+	----	----	----	----	----	----	----	----	----	----
$\delta^{15}N$ BOM	----	----	----	----	----	----	0.16	-	----	----	----	----	----	----	0.25	-
$\delta^{15}N$ Arrowhead	----	----	0.17	+	**0.48**	**+**	----	----	**0.57**	**+**	0.29	+	----	----	----	----
$\delta^{15}N$ Canary	----	----	0.26	+	----	----	----	----	----	----	----	----	----	----	----	----
$\delta^{15}N$ Willow	----	----	**0.58**	**+**	**0.72**	**+**	----	----	0.49	+	----	----	----	----	----	----
$\delta^{15}N$ Elmidae	----	----	----	----	0.52	+	----	----	0.48	+	----	----	----	----	----	----
$\delta^{15}N$ Hyallelidae	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
$\delta^{15}N$ Physidae	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

Deliverable 3: Contemporary hydrology of the Lake Winnipeg Basin: Implications to non-point source contribution of nutrients to Lake Winnipeg

Project Team: Phil Marsh; Barry Bonsal; Chris Spence; Garth van der Kamp, Charles Cuell, Eghbal Ehsansadeh, Terry Prowse, Yonas Dibike; Environment Canada

Partners: Drought Research Initiative (DRI), Agriculture and Agri-Food Canada

This project examined the nature and variability of contributing flow to Lake Winnipeg from all of its major tributaries. The contributing flow of waters is dynamic and variable. Certain areas of the Basin do not contribute flow at all, while other areas only contribute water to the rivers during extreme wet years. Advanced knowledge of this dynamic and the variation is essential for understanding non-point source inputs of nutrients to the major tributaries and to Lake Winnipeg.

Progress and Achievements

- A literature review and data search was undertaken, including analysis of discharge and precipitation data across a range of catchment sizes within the Lake Winnipeg Basin to develop a methodology to discern the frequency with which key areas contribute to streamflow.
- Areas contributing flows to the major river systems were characterized with new modelling schemes.
- The inter-annual variability in the past/present climate and hydrology was assessed, along with the impacts of hydrology on BMPs.
- A series of publications on the discharge regime of the major and minor tributaries of Lake Winnipeg were completed.

Conclusions

Areas of the Lake Winnipeg Basin were investigated to determine the possible presence of trends and shifts in variables that may influence streamflow regimes and water quality of Lake Winnipeg. The total annual streamflow, precipitation, runoff ratio and daily maximum streamflow in the two major tributaries of the Assiniboine River and Red River were analyzed.

Although there was no evidence of statistically significant trends in precipitation and streamflow in the Assiniboine River watershed, a sequence of wet and dry spells has occurred there in the last century. Furthermore, there has been a statistically significant linear decrease in cold season precipitation in the Saskatchewan River Basin, and an increase in warm season precipitation in the Winnipeg and Red River Basins.

Precipitation and runoff in the U.S. areas of the Red River watershed have experienced an increasing rate of streamflow beyond that of increasing precipitation. Variability of precipitation appeared to be the main driver of changes in streamflow. This is attributed to the dynamic nature of contributing areas that, together with a semi-arid climate, leads to sudden changes of streamflow due to major, or even some times minor, changes in climate inputs. Streamflow in the watershed area appears to be sensitive and vulnerable to even minor climate variability and change. Effects of physical changes in the landscape, including wetland drainage and changes of cultivation practices, could not be identified. An increase in contributing area permits more frequent opportunity for the transport of nutrients from hill slopes to streams.

Deliverable 3: Climate impacts on the landscape hydrology and nutrient transport of the Lake Winnipeg watershed

Project Team: Terry Prowse, Yonas Dibike, Barrie Bonsal, Rajesh Shrestha; Environment Canada

The objective of this project was to investigate the impact of climate variability and change on landscape hydrology and non-point source nutrient transport. There were few comprehensive studies quantifying landscape response to future climate change, especially the effects of changes of precipitation and snowmelt regimes on nutrient transport. The project included an analysis of historic trends in precipitation and temperature in the different regions of the lake Winnipeg watershed; setup and calibration/validation of a landscape hydrology/nutrient transport model for application in representative catchments; selection and preparation of a suite of global and regional climate models to drive the hydrologic/nutrient transport model; and identifying changes in landscape hydrology and nutrient production using the hydrologic model and an ensemble of the climate models.

Progress and Achievements

- Climatological data and landscape hydrology/nutrient transport models were compiled and evaluated.
- The Soil and Water Assessment Tool (SWAT) was used to set up hydrologic and nutrient transport models on two representative catchments (upper Assiniboine and Morris).
- An evaluation of different climate change scenarios and analysis of impacts was conducted.
- Validation and coupling of hydrologic/transport models was undertaken with a selected set of global and regional climate modelling data, and simulation and analysis of changes in landscape hydrology and nutrient production were completed
- A series of publications was produced on historical trends in climate and possible future impacts of climate variability and change on the landscape hydrology of Lake Winnipeg watershed, and implications for nutrient transport.

Research Results

- Trend analysis on the annual and seasonal precipitation and temperatures for the 1961-2003 time period reveal no significant trend in total annual precipitation or summer, spring and autumn seasonal precipitation, while a significantly decreasing trend is observed in winter precipitation (~5% per decade).
- The analysis also shows a significantly increasing trend in annual mean maximum temperature (T_{max}) (~ 0.32 ^{o}C per decade) and winter mean T_{max} (~0.85 ^{o}C per decade), while the spring, summer and autumn T_{max} do not show any significant trend.

- There is also a significantly increasing trend in annual mean minimum temperatures (T_{min}) (~0.41 ^{o}C per decade). While winter, spring and summer mean T_{min} exhibit significantly increasing trends (~0.95, 0.58 and 0.25 ^{o}C per decade, respectively), no trends were observed for the autumn season. The analysis also showed higher increasing trends of daily minimum temperatures compared to daily maximum temperatures.
- Evaluation of global and regional climate model (GCM and RCM) based climate change projections between the baseline (1971-2000) and future (2041-2070) time periods revealed that the annual precipitation may increase by 5.5 - 7.7% with the three RCM models averaging 6.5 %. Two of the three models projected the highest increase in future precipitation in spring (11-15 %) while the third model projected the highest increase in autumn (~14.5%). While two models projected a slight decrease in the future summer precipitation (0.6 - 1.6 %), a third model projected an increase of 7.5%.
- All models projected increases in both annual and seasonal T_{max} and T_{min} in the future. Most models indicate that winter and summer temperatures will experience the highest increases (~ 2.7 - 3.8 °C), while spring may see a modest increase of 1.5 - 2.5°C. During this period, annual mean T_{max} and T_{min} in the region are projected to increase by 2.5 - 2.8 °C and 2.8 - 2.9 °C, respectively.
- SWAT modelling revealed that future changes in the climatic regime are likely to produce appreciable changes to the hydrologic and nutrient transport regimes of the upper Assiniboine and Morris catchments. Based on multiple regional climate model (RCM) projections, for precipitation increases of 11 to 18%, and temperature increases of 2.1-2.8°C, simulated increases in catchment runoff range between 16 and 60%. Based on the ensemble RCM projection, a ~30% runoff volume increase in the catchment produced ~5% and ~33% increase in total phosphorus (TP) and total nitrogen (TN) loads, respectively. Of particular note, an earlier start of flushing of nutrient loads related to earlier snowmelt and runoff in the future scenarios. While both begin to rapidly increase in late winter rather than early spring, TP peaks prior to the peak of the spring freshet during the most active snowmelt period, whereas TN peaks later with the discharge peak. The future simulations also show a relatively smaller increase in the TP load than the TN load, reflecting variability in hydrologic response between the two types of nutrients.

Challenges and Lessons Learned

While hydrologic modelling can readily be achieved at a daily time step, nutrient sampling is usually conducted at a much coarser time step; weekly data being the best currently available. Obtaining nutrient source data, such as fertilizer applications was also challenging. Despite these challenges, the transport model was calibrated and validated to simulate total phosphorus and total nitrogen loading from the two catchments, and the potential impact of climate change on the hydrology and transport of these nutrients was simulated based on future climate inputs from multiple RCMs.

Conclusions

Modelling conducted through this project has revealed that future changes in the climatic regime are likely to produce appreciable changes to the hydrologic and nutrient transport regimes of the upper Assiniboine and Morris catchments.

Although the analysis on observed records did not show any significantly increasing trend in precipitation in the Lake Winnipeg watershed in the recent past, future model projections with multiple regional climate models suggest a significant increase in future precipitation. In the case of temperature, both the recently observed records and future projections with the different regional climate models indicate a generally increasing trend.

In accordance with projected increases in runoff, future loadings of total nitrogen (TN) and phosphorus (TP) are also expected to increase. The simulated nutrient loads closely match the dynamics of the future runoff for both nitrogen and phosphorus, in terms of earlier timing of peak loads and higher total loads, related to earlier snowmelt and runoff. While both begin to rapidly increase in late winter rather than early spring, TP peaks prior to the peak of the spring freshet during the most active snowmelt period, whereas TN peaks later with the discharge peak. On an annual basis, the modeled results show smaller percentage increases in nitrogen and phosphorus loadings in comparison to discharge increase. The future simulations also show a smaller increase in the TP load than the TN load, reflecting hydrologic-response variability between the two types of nutrients.

Overall, the effects of climatic changes on the nutrient transport regime need to be considered together with possible future changes in land use, crop type, fertilizer application, and transformation processes in the receiving water bodies.

The ultimate downstream supply of nutrients to Lake Winnipeg is likely to play a key role in the future productivity and trophic state of the lake. From a climate-change perspective, the magnitude of the effect will also depend on changes that might occur in other internal lake climate-controlled processes (e.g., thermal mixing and stratification, dissolved oxygen production), which affect nutrient cycling, use and storage.

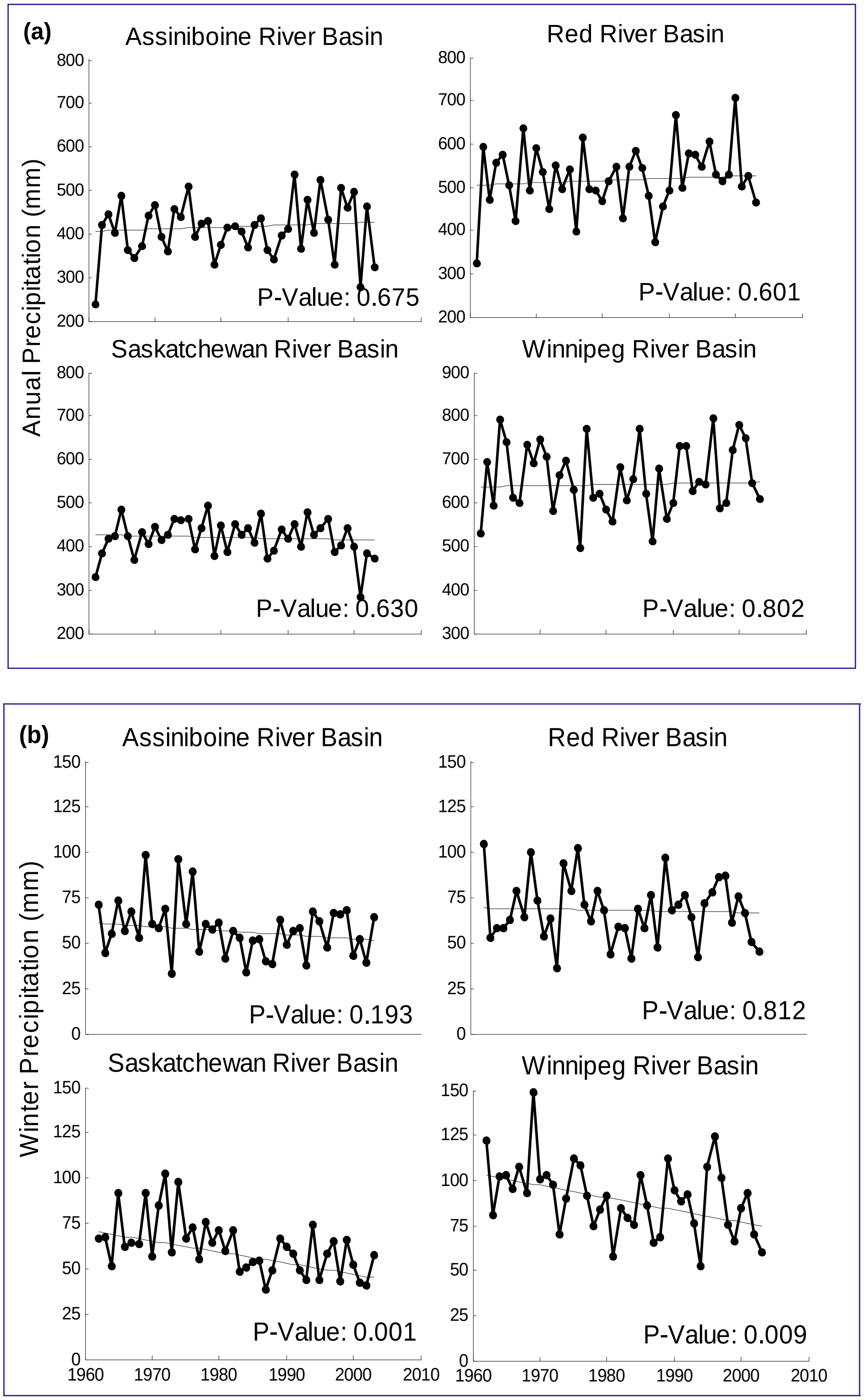


Figure 27: Trends in mean annual (a) and winter (b) total precipitation during 1961 - 2003 in the major tributary river basins of the Lake Winnipeg watershed.

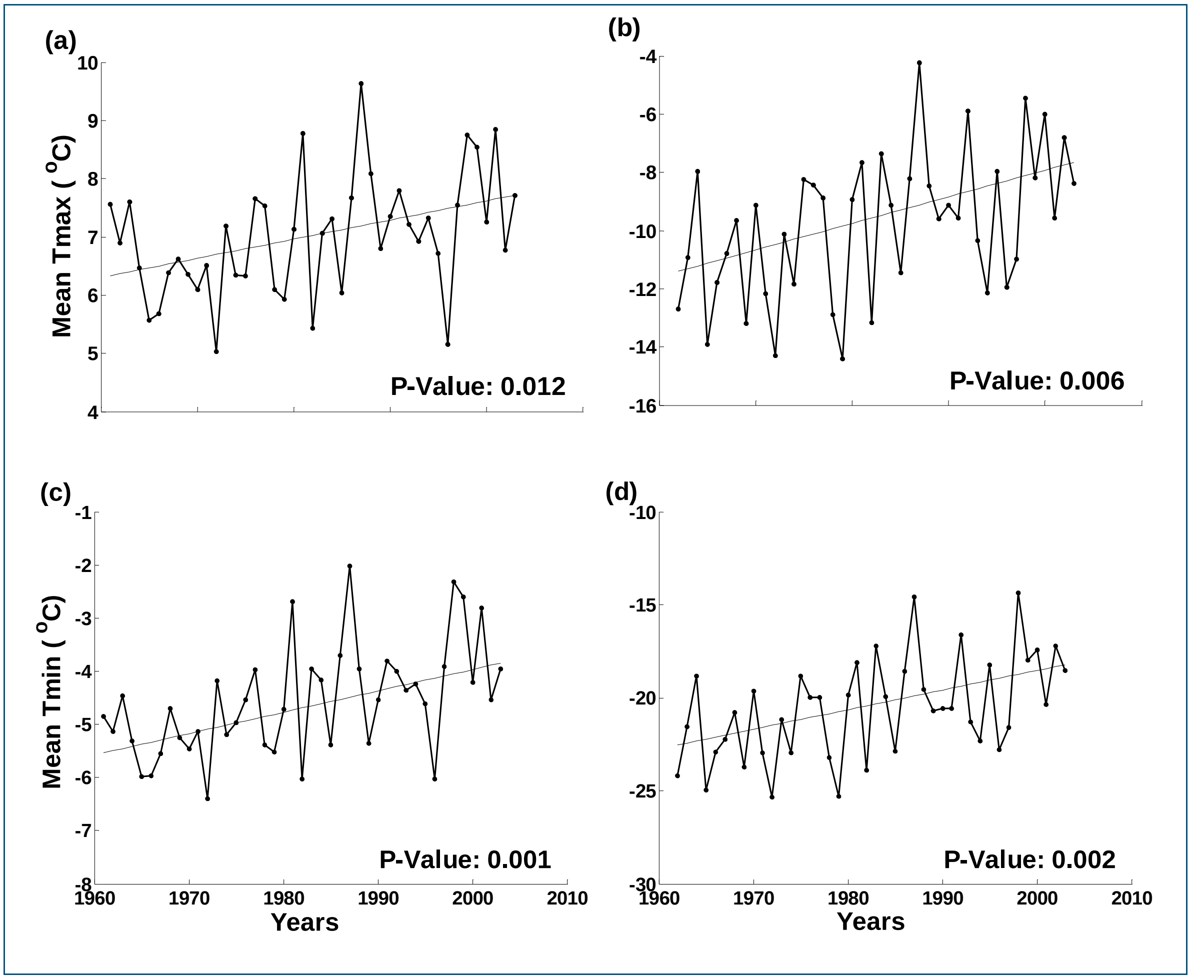


Figure 28: Trends in mean annual and winter T_{max} (a & b) and T_{min} (c & d) during 1961 - 2003 in the Lake Winnipeg watershed.

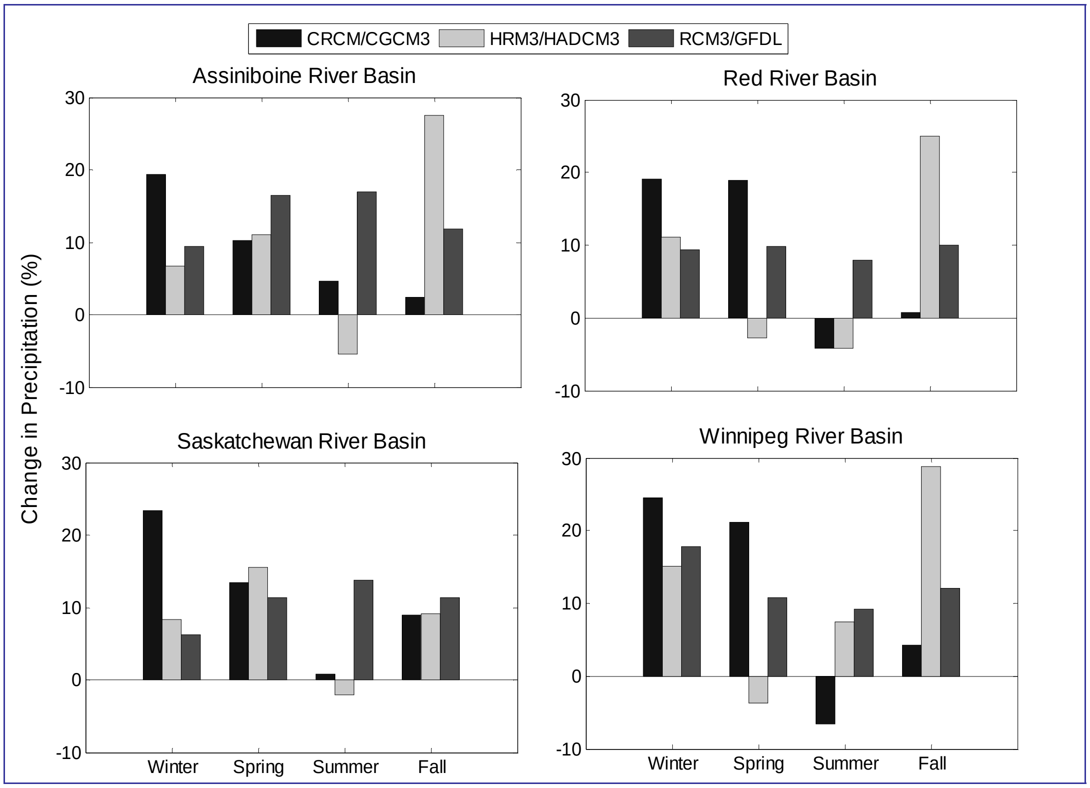


Figure 29: Comparison of changes in mean seasonal precipitation between the future (2040-2071) and baseline (1971-2000) periods in the major tributary river basins of the Lake Winnipeg watershed corresponding to each of the three GCM/RCM projections.

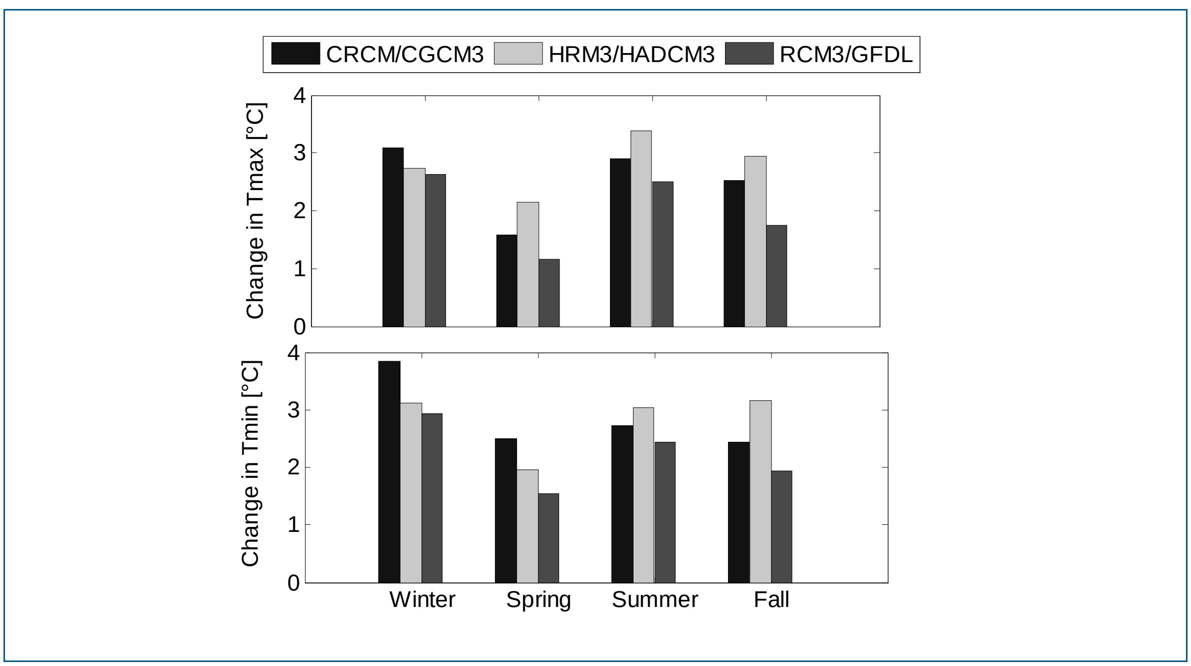


Figure 30: Comparison of projected changes in regional mean T_{max} and T_{min} in the Lake Winnipeg watershed between the future (2042-2070) and baseline (1971-200) periods based on the three GCM/RCMs.

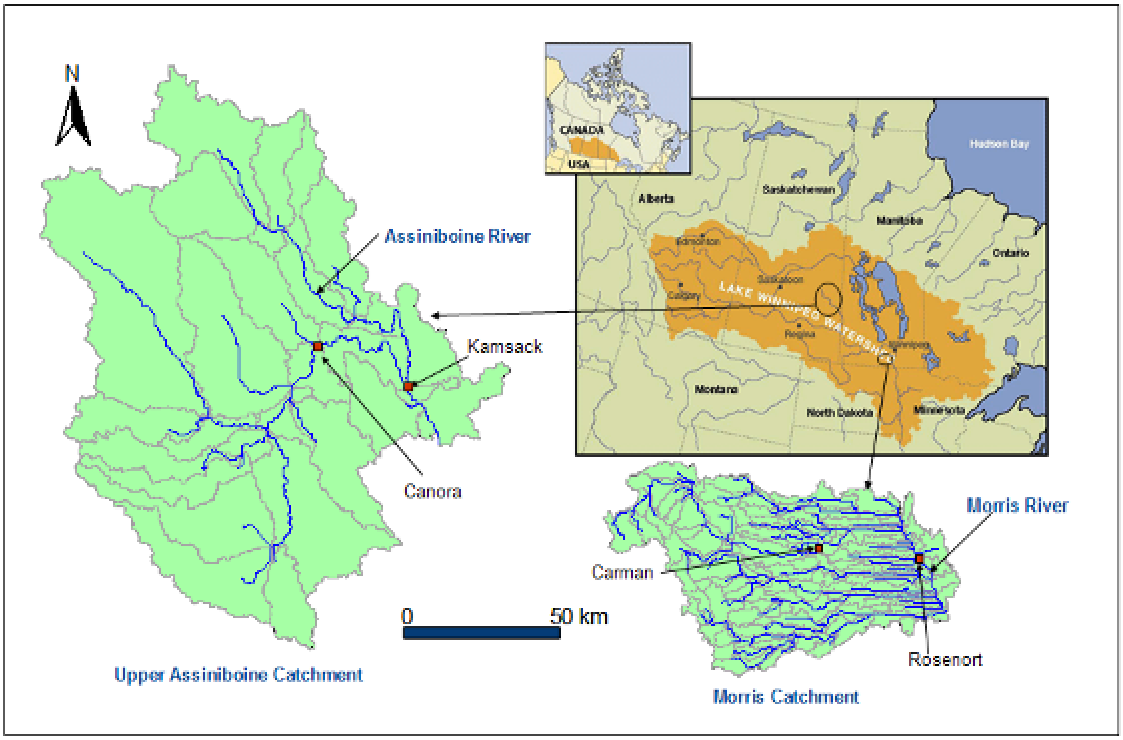


Figure 31: The two representative catchments (Upper Assiniboine and Morris) used in the hydrologic and nutrient transport modelling study.

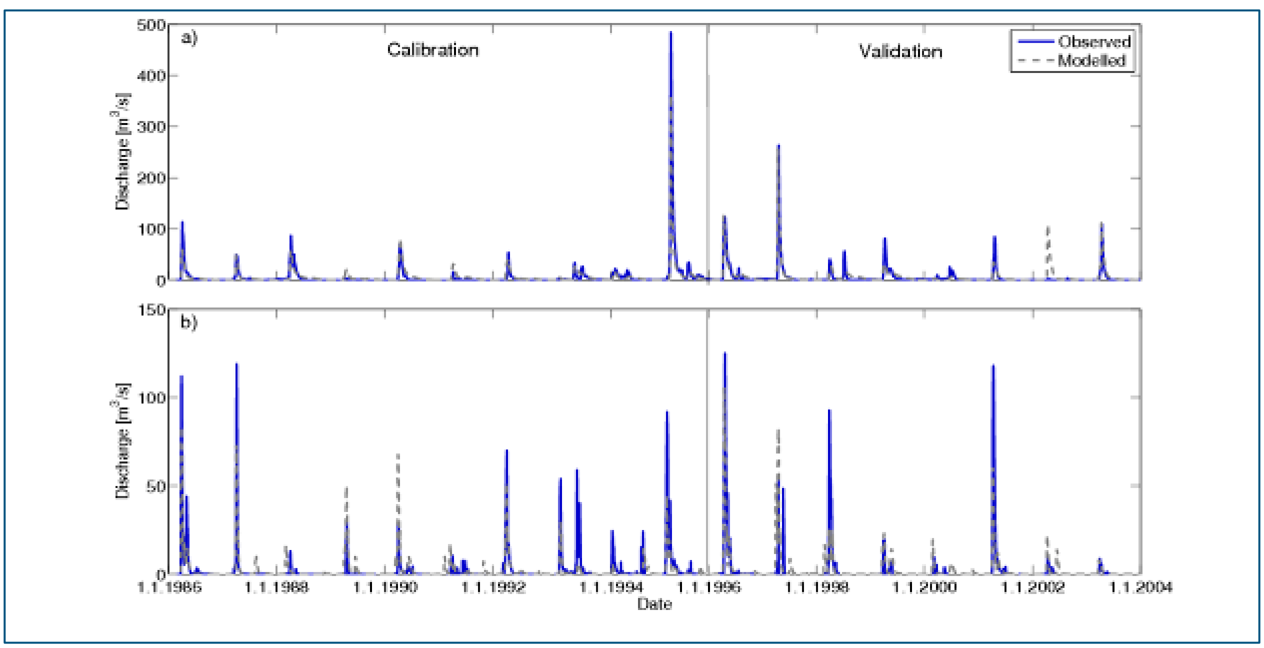


Figure 32: Comparison of observed and simulated discharge for: a) Kamsack hydrometric station in Assiniboine River and b) Rosenort hydrometric station in Morris River, using climate inputs from NARR and GCDC datasets.

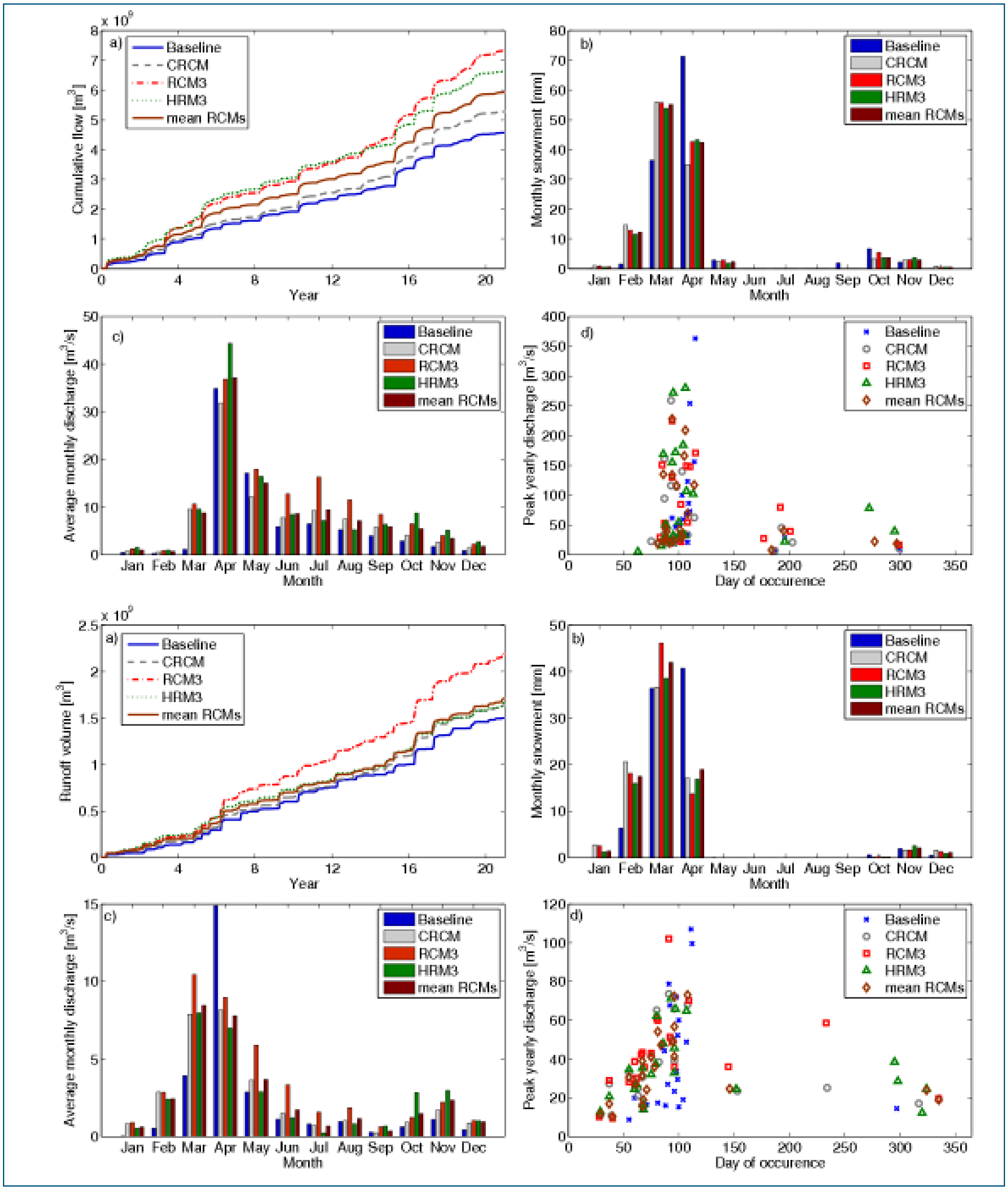


Figure 33: Comparison of simulated future (2042-2062) and baseline (1980-2000) hydrologic regimes for the Upper Assiniboine (top) and Morris (bottom) catchment using the delta-change method. Illustrated are changes in: a) cumulative flow, b) monthly total snowmelt, c) monthly average discharge, and d) magnitude and Julian day of occurrence of annual peak discharge.

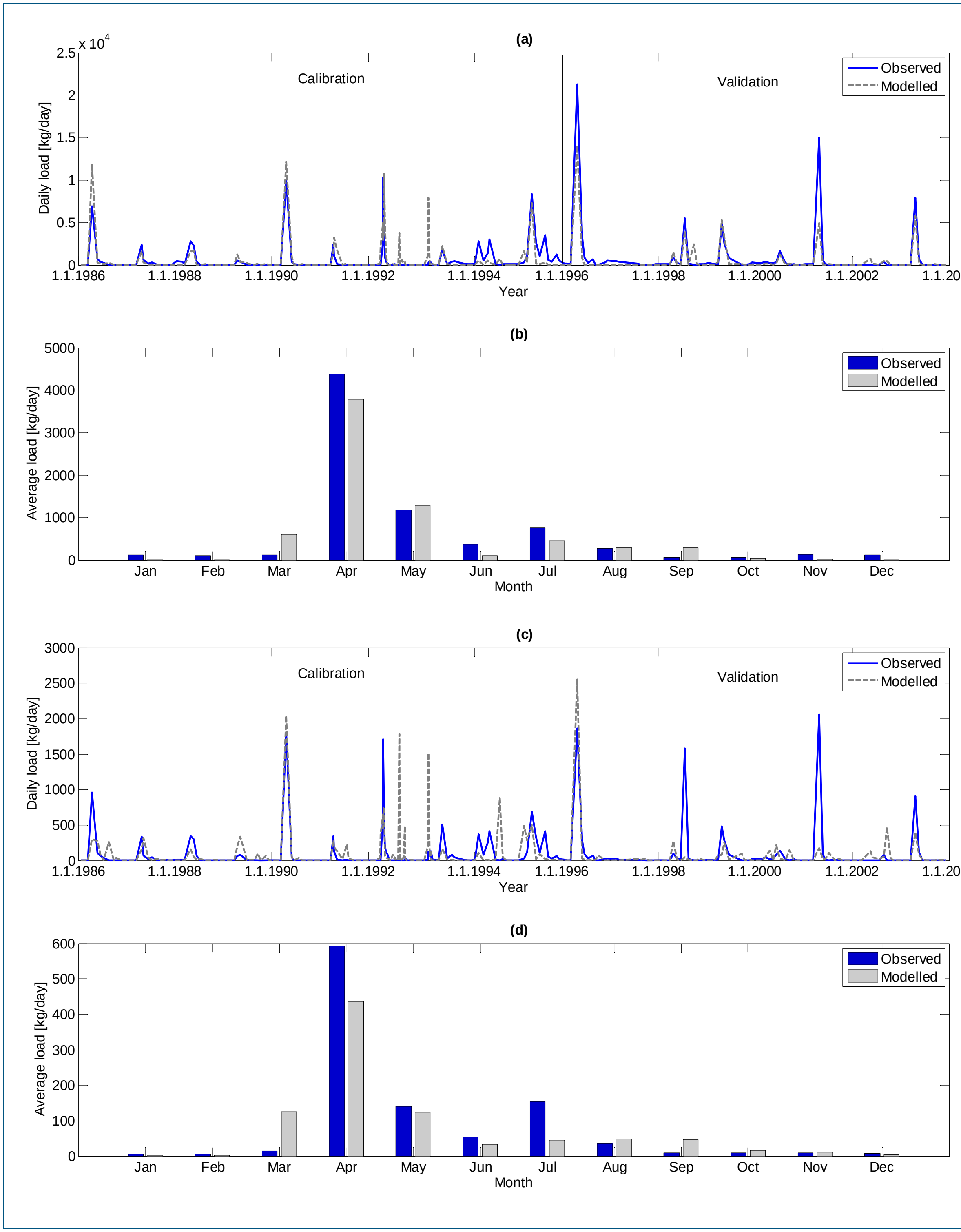


Figure 34: Comparison of observed and modelled nutrient loads for the Upper Assiniboine catchment near Kamsack for: (a) daily total nitrogen loads for calibration (1986-1995) and validation (1996-2003) periods, (b) average monthly total nitrogen loads (1986-2003), c) daily total phosphorus loads for calibration (1986-1995) and validation (1996-2003) periods, and (b) average monthly total phosphorus loads (1986-2003).

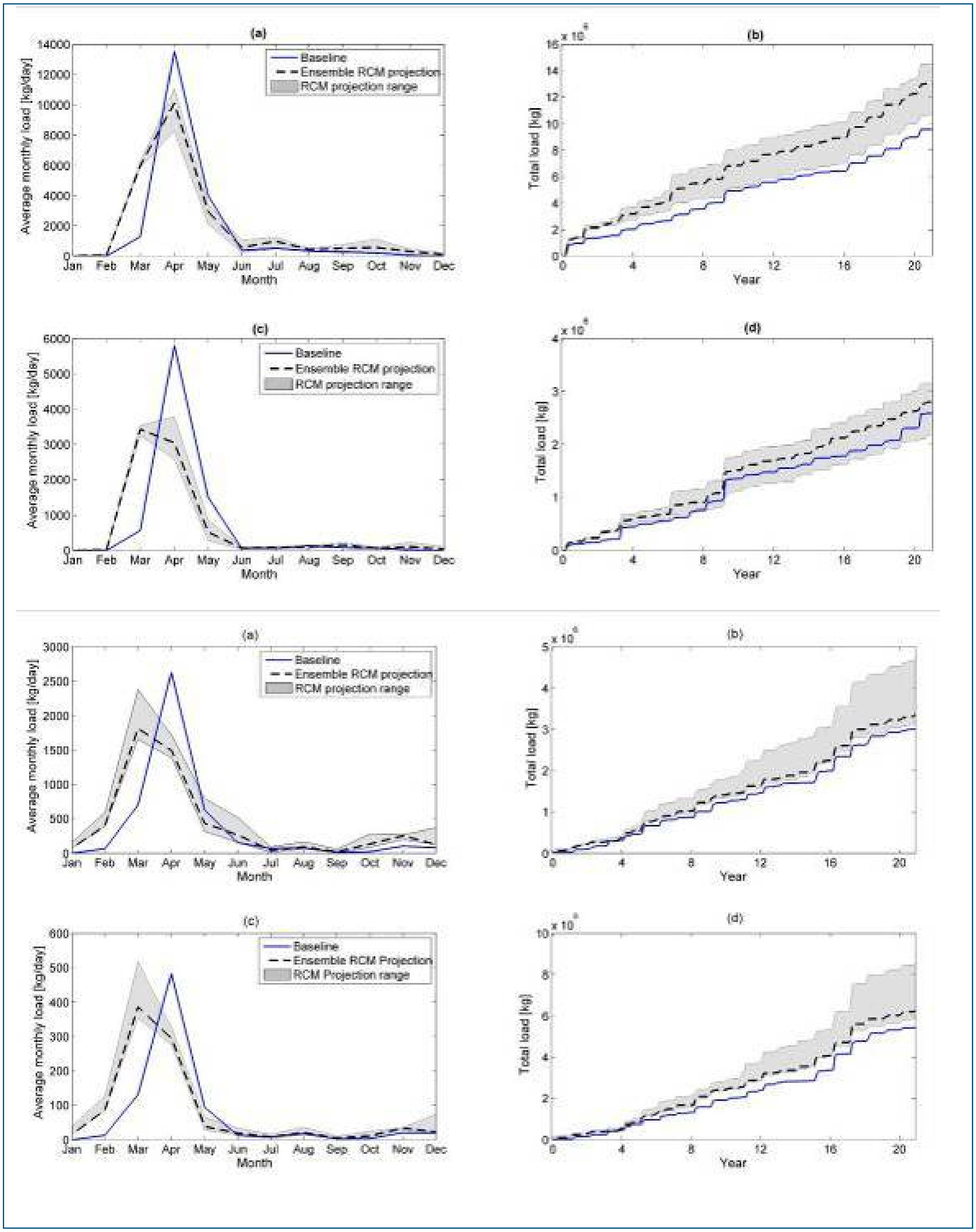


Figure 35: Comparison of nutrient load for a simulated future (2042-2062) and baseline (1980-2000) period in Upper Assiniboine (top) and Morris (bottom) catchments. Illustrated are changes in: a) average monthly total nitrogen load, d) cumulative total nitrogen load, a) average monthly phosphorus load, and d) cumulative total phosphorus load.

Table 2: Projected changes in regional mean annual and seasonal T_{max}, T_{min} and Precipitation in the Lake Winnipeg watershed.

	T_{max} (°C)			T_{min} (°C)			Precipitation (mm)		
	1971-2000	**2041-2070**	**Difference (°C)**	**1971-2000**	**2041-2070**	**Difference (°C)**	**1971-2000**	**2041-2070**	**Difference (%)**
CRCM/CGCM3									
Annual (°C)	**6.8**	**9.3**	**2.5**	**-6.4**	**-3.5**	**2.9**	**605.3**	**644.1**	**6.4%**
Seasonal (°C)									
Winter	-7.8	-4.7	3.1	-19.9	-16.1	3.8	109.4	123.7	13.1%
Spring	7.0	8.6	1.6	-8.0	-5.5	2.5	133.4	153.6	15.2%
Summer	20.3	23.2	2.9	6.4	9.1	2.7	229.2	227.6	-0.7%
Autumn	7.3	9.8	2.5	-4.1	-1.7	2.4	133.2	140.0	5.1%
HRM3/HadCM3									
Annual (°C)	**9.9**	**12.7**	**2.8**	**-0.3**	**2.5**	**2.8**	**667.1**	**703.9**	**5.5%**
Seasonal (°C)									
Winter	-5.6	-2.9	2.7	-13.1	-10.0	3.1	120.7	131.1	8.6%
Spring	9.9	12.0	2.1	-1.0	1.0	2.0	199.6	209.6	5.0%
Summer	24.9	28.3	3.4	12.8	15.9	3.1	208.4	205.0	-1.7%
Autumn	9.4	12.2	2.8	-0.2	2.9	3.1	138.3	158.3	14.5%
RCM3/GFDL									
Annual (°C)	**4.1**	**6.1**	**2.0**	**-3.4**	**-1.2**	**2.2**	**768.1**	**827.3**	**7.7%**
Seasonal (°C)									
Winter	-9.6	-6.8	2.8	-16.1	-13.0	3.1	121.4	129.2	6.4%
Spring	3.5	4.5	1.0	-4.5	-3.1	1.4	175.4	195.2	11.3%
Summer	17.7	20.3	2.6	8.9	11.4	2.5	293.9	316.1	7.6%
Autumn	4.4	6.0	1.6	-2.3	-0.4	1.9	177.4	187.3	5.6%

Table 3: Comparison of changes in mean annual runoff volume, and magnitude and day of occurrence of average annual peak snowmelt discharge between baseline (1980-2000) and future (2042-2062) periods using delta-change method.

	Upper Assiniboine			Morris		
	Mean runoff vol. change (%)	Av. annual peak discharge [m^3/s]	Av. day of occurrence	Mean runoff vol. change (%)	Av. annual peak discharge [m^3/s]	Av. day of occurrence
Baseline	-	76	104	-	42	92
CRCM	15.4	60	93	9.2	34	71
RCM3	60.3	72	96	46.1	41	70
HRM3	45.0	88	95	11.0	35	74
Mean RCMs	29.6	71	96	14.1	35	72

Table 4: Comparison of changes in precipitation, runoff and nutrient loads between the baseline (1980-2000) and future (2042-2062) periods.

	Precipitation	Runoff		Nutrients	
	Mean annual prec. changes [%]	Timing of peak runoff [Julian day]	Runoff vol. change [%]	Total nitrogen (TN) load change [%]	Total phosphorus (TP) load change [%]
Baseline	-	104	-	-	-
CRCM	11.0	93	15.4	10.3	-18.1
RCM3	17.5	96	60.3	49.6	18.5
HRM3	16.0	95	45.0	44.4	16.8
Ensemble RCM mean	14.8	96	29.6	32.8	5.2

Deliverable 3: Nutrient transfer from agricultural lands in the Red River Basin during spring freshet

Project Team: Jane Elliott, Environment Canada; Jason Vanrobaeys, Agriculture and Agri-Food Canada

Many agricultural conservation practices or beneficial management practices (BMPs) use ground cover to protect soil and water, however vegetation may be a greater source of dissolved nutrients in snowmelt than soil contact. Since snowmelt is the most important source of surface water recharge in prairie landscapes, conservation practices must be effective during snowmelt. This project sought to gain an understanding of the role of vegetation as a source of nutrients in snowmelt.

Progress and Achievements

- Edge-of-field (EOF) and drainage runoff data for the flood plain was identified as a major information gap. To provide a link between agriculture practice and the scale of environmental monitoring, an assessment of EOF and in-stream nutrient contributions on the flood plain was initiated as a first step in integration to the larger watershed scales where monitoring data are available.

- Two EOF sites were established on producers' fields in the La Salle watershed. Flow and water quality were monitored at these sites during snowmelt and summer runoff events. The data obtained for these sites were compared with the extensive South Tobacco Creek (STC) database to assess the transferability of data collected in the headwaters to the flood plain situation. All of the EOF monitoring data were processed and nutrient fluxes and flow-weighted mean concentrations calculated.

- In-stream monitoring sites were also established to provide knowledge of nutrient transport in the flood plain drainage network. As with the flood plain EOF sites, the data from the in-stream sites were assessed relative to long-term data from similar stream orders in the STC network. Processing of these data is still underway but is expected to be complete by spring 2012. The in-stream data from the drains will be compared to similarly sized watersheds in STC to provide a preliminary assessment of flood plain transport.

- Methodology was developed for simulating snowmelt under laboratory conditions, and the potential for a range of different residues to contribute nutrients to snowmelt was assessed. Residues that were tested included cereals, oilseeds and pulse crops, forages and riparian vegetation. The relative contributions of soils and residues and soil-residue interactions were also studied using snowmelt simulations. A manuscript was submitted to a special issue of the *Canadian Journal of Soil Science*.

- Laboratory snowmelt simulations were manipulated to identify environmental conditions that impact the contribution from residues. The effect of freeze-thaw cycles and the presence of ponded water on nutrient release from plant residues were evaluated and the results used to refine the snowmelt simulation methodology for EOF comparisons.

- The flood plain EOF sites were used along with STC EOF sites and pasture EOF sites to verify results from the laboratory snowmelt simulations.

Research Results

- Winter cereals, riparian vegetation and forage crops were identified as potential major contributors of nutrients. The potential release from these residues was many times greater than from soil. In fact, soil acts as a buffer for release of some nutrients and could be used to mitigate nutrient release from the vegetation types that are major contributors of nutrients to snowmelt.

- The number of freeze thaw cycles had little effect on the release of nutrients by residues. In freely draining samples, nutrient release from residues was generally less than in samples where the water was allowed to pond. However, the effect was dependent on the type or residue. Nutrient release from residues which generally released large amounts of nutrients was reduced by 40 to 60% when the water was not allowed to pond. Nutrient release from less productive residues was more stable and for some nutrients actually increased in the absence of ponding.

- There were considerable differences in nutrient concentration and flow data between the two EOF sites on the flood plain. Data from both sites are largely in the range of data collected on EOF sites in the STC watershed since 1993, but fluxes tended to be among the highest and lowest losses measured in STC. At both sites, nutrients are transported primarily in dissolved forms, especially during snowmelt, when more than 80% of phosphorus transported is dissolved.

- Snowmelt simulations were performed for 16 site-years of EOF data. For each year and location, the snowmelt simulations reflected differences between treatments observed in the EOF runoff. However, because variations in climatic conditions are controlled in the snowmelt simulations but not in the EOF data, a consistent relationship that is applicable to all sites and years has yet to be established. It is hoped that the investigation of climatic controls and indicators underway using long-term STC data will allow the development of a transfer function that can be used to establish a relationship that is valid for all sites and years. As the 2011 STC data become available, a full assessment of the flood plain data will be performed and a manuscript detailing the methodology used in the comparison will be prepared.

Challenges and Lessons Learned

The use of snowmelt simulations has provided a means of assessing nutrient sources independently of climatic fluctuations. However to verify the results of simulations with field data, methodology needs to be developed to standardize the field data for climate. Analysis of long term STC data that may lead to this methodology is underway.

Conclusions

This research has demonstrated that vegetation is a significant source of nutrients to snowmelt runoff. This has important implications for the development of BMPs in the Lake Winnipeg watershed. Most BMPs have been designed to remove sediments from runoff and often use vegetation to prevent soil erosion and trap dislodged particles. However, the soil may actually buffer dissolved nutrients that are released from residues.

Field monitoring methodologies and sites have been established on the Red River flood plain are providing the first data measurements of nutrient fluxes from flood plain fields, and nutrient transport in the flood plain drainage network. Continued monitoring at these sites will provide a long-term record and further understanding of nutrient fluxes that is independent of hydrology and climatic variability.

Deliverable 3: Water quality modelling to evaluate scenarios of land use change and BMP implementation and forecast impacts on nutrients loads to surface waters

Project Team: Glenn Benoy, William Booty, Isaac Wong, Qi Yang (NSERC), Luis Leon, Craig McCrimmon, Phil Fong; Environment Canada

Partners: Agriculture and Agri-Food Canada, Manitoba Water Stewardship, University of Manitoba

This project examined the impacts of land use change and beneficial management practice (BMP) implementation on nutrient loading and water quality of streams in targeted watersheds of the Red-Assiniboine Basin, including the La Salle River, the Boyne River, and the Little Saskatchewan River. Goals included demonstrating the utility of non-point source water quality modelling as an effective tool for the evaluation of agricultural management scenarios; devising land use change and BMP implementation scenarios that address both downstream water quality issues and the realities of farming in southern Manitoba, and generating a decision support system (DSS) tool that can be transferred to government and stakeholder agencies. This will enable decision makers to prioritize land and agricultural management actions that will most effectively reduce nutrient loading.

Progress and Achievements

- Core datasets were acquired, including time-series of precipitation, stream discharge and water chemistry, and GIS layers of digital elevation models, soils, and land use and land cover.
- Classes of scenarios were determined and potential contributing BMPs and land use changes for each of the watersheds were identified. This was done through literature search and review, consultations with farmers through workshops in each of the watersheds, and expert opinion provided by collaborators and colleagues.
- Non-point source water quality models including the Soil and Water Assessment Tool (SWAT) were parameterized and calibrated for scenario investigations of land use changes and BMP implementation for each watershed.
- Following successful execution of a wetland restoration scenario, scenarios of annual cropland conversion (including wetland restoration), nutrient management and riparian areas were run in the LaSalle and Boyne watersheds and compared to current conditions. Results of scenario evaluations for the Little Saskatchewan watershed are pending.

- A Decision Support System (DSS) was developed, based on the National Agri-Environmental Standards Initiative (NAESI) platform for the Land-Water Integration Project (Wong et al. 2008). Critical input and source datasets were included in the DSS; users are able to customize land use changes and BMP implementation according to their needs and constraints.

Research Results

The SWAT model research results reported for the LaSalle and Boyne river simulations are preliminary and subject to further improvements in model coefficient parameterization and sophistication of land use change and BMP scenarios. Indicated changes in flow rates and sediment and nutrient loads should be interpreted with caution. Consequently, only qualitative forecast changes are summarized at this point.

LaSalle River

- Compared to the baseline annual average flow scenario for the La Salle watershed, if all croplands were converted into hayland, the flow would be reduced by approximately one-third. Wetland conversion would marginally increase flow. All other practices including improving commercial fertilizer and manure, 100% incorporation of manure, and filter strips would have negligible impact on flow. For average annual sediment load, if all croplands were converted into hayland, the load would be reduced by almost half and wetland conversion would reduce sediment only slightly. All other practices would have a negligible impact on sediment reduction.

- For annual average total nitrogen (TN) load, if all croplands were converted into hayland, TN would be reduced by approximately one-third, followed by a small reduction through wetland conversion. Application of all manure and commercial fertilizer in spring, and 100% incorporation of manure would not have any discernable impact on TN. In contrast, addition of filter strips to all croplands would result in approximately one-quarter reduction of TN.

- The predicted annual average total phosphorus (TP) load was 50 tonnes in the baseline scenario. If all croplands were converted into hayland, TP would be reduced by about half, followed by a modest reduction due to wetland conversion. Improving timing of manure and commercial fertilizer and 100% incorporation of manure would have no impact on TP. Addition of filter strips to all croplands would result in a TP reduction of approximately one-third.

- The model coefficients used are most appropriate for rainfall-induced runoff, but may not reflect the effectiveness of the practices during snowmelt runoff which frequently accounts for a substantial percentage of annual runoff (greater than 50%). This consideration is especially relevant for interpretation of the nutrient reduction efficacy of filter strips. Therefore, the actual reduction in transport will likely be less than the percentages reported above, especially in a low-relief watershed, such as the LaSalle. The model will be updated with coefficients that are suitable for the snowmelt period as they become available.

Boyne Watershed

- If all croplands were converted into hayland, flow would be reduced by almost two-thirds. All other practices would not have any impact on flow, including wetland conversion, improving timing of commercial fertilizer and manure, 100% incorporation of manure, and filter strips. For annual average sediment, if all croplands were converted into hayland, the annual sediment load would be reduced by up to almost 90%. No other practices had an impact on sediment reduction.

- Compared to the baseline scenario, if all croplands were converted into hayland, TN would be reduced by approximately one-quarter. Wetland conversion would have a negligible effect. If all commercial fertilizer were applied in spring, TN would increase by about one-quarter. Application of all manure in spring and 100% incorporation of manure would not have any impact on TN. Filter strips on all croplands would result in a TN reduction of almost half.

- For average TP load, if all croplands were converted into hayland, the TP would be reduced by up to 90%. Wetlands conversion would have a minor impact on TP reduction. Improving timing of commercial fertilizer and manure and 100% incorporation of manure would have no impact on TP. Application of filter strips on all croplands may achieve a reduction in TP greater than half.

- The same caveats as stated for the LaSalle watershed apply to the Boyne watershed. Improvements in some water quality parameters, such as TN and TP, reflect differences in baseline conditions relative to differences imposed by forecast scenarios and physiographic differences between watersheds that are slightly more favourable for the Boyne (relatively greater relief).

Challenges and Lessons Learned

A lack of gauging station flow data and water quality monitoring data resulted in very few integrating locations for calibration and validation of model output and scenario forecasts. The flow and water quality time series data that does exist was often truncated (i.e. historical periods or constrained to periods of time within the year) or of insufficient frequency. The more comprehensive datasets tend to be located along the main rivers that drain into Lake Winnipeg. For meaningful scenario development and evaluation, smaller scale systems need to be modelled. The monitoring system established in the South Tobacco Creek watershed is an example of a system that generates robust time series data. Such systems are not feasible across southern Manitoba, due to cost and labour constraints, however, monitoring stations in targeted watersheds would greatly enhance the power of scenario-based modelling and output.

The SWAT model, although commonly used around the world, was not specifically developed for northern Great Plains/prairie environments. An ongoing challenge was developing SWAT to be more responsive to critical landscape features such as snow redistribution, frozen soils, and snowmelt-driven (rather than rainfall-driven) hydrology. There are significant challenges to modelling flow and water quality parameters in the Red and Assiniboine basins, including development of a stream network in extraordinarily flat landscapes with an abundance of engineered water management structures and diversions, capturing the critical snowmelt period when water and nutrient management problems are most acute, and modelling the timing and extent of frozen soils. Modelers working in South Tobacco Creek and elsewhere in Canada have begun to adapt SWAT and introduce new models to better represent these critical features of prairie hydrology and agriculture.

Selection of BMPs and land use changes to populate scenarios is relatively straightforward; however the challenge was to define levels of BMP implementation and land use change within a much more constrained realm of possibilities. Through stakeholder engagement, subsets of BMPs and land use changes and their respective levels of implementation were identified as "realistic" scenarios. In this way, a suite of scenarios was developed for each of the watersheds that could be used to prioritize and recommend management responses to excessive nutrient losses from fields and operations to nutrient loads to water courses.

Scenarios were developed and evaluated according to their forecast impacts on nutrient losses and loading. This is essential for a basic understanding of the overall system; however, socio-economic considerations and social dynamics need to be integrated. In addition, developing a decision support system that generalizes BMP scenarios that can be used in different watersheds is difficult because some of the BMPs may only be appropriate for specific areas of the watershed.

Conclusions

SWAT model parameterization and calibration for each of the watersheds was hampered by flow and water quality data availability. As a result, caution must be exercised when interpreting model output. More emphasis should be given to relative differences in nutrient loading output than absolute differences.

Water quality modelling at the scale of the LaSalle, Boyne and Little Saskatchewan watersheds enabled examination and evaluation of land-use change and BMP implementation scenarios between fine-scale evaluation of specific processes that affect BMP efficacy and coarse-scale evaluation of major drivers and trends in the agricultural sector. At this intermediate scale, "what if" scenarios that ranged from optimal land use change and BMP implementation through continuation of current trends were modeled. These scenarios are considered relevant for land use planners and conservation districts in the region because they map out changes that may occur as a function of policies developed at provincial and municipal levels. Forecast changes in nutrient loading to streams and rivers in these modeled watersheds varied according to the "intensity" by which practices were implemented. The decision support system played a critical role in the evaluation of scenarios as it enabled hypothetical changes in land use and BMP extent to be modeled.

Water quality modelling in agricultural landscapes is a multidisciplinary endeavour that requires collaboration and partnerships with a variety of stakeholders, ranging from federal and provincial departments, to producer agencies and landowners. Cultivating effective partnerships with collaborating agencies and researchers, along with stakeholder and landowner engagement through activities such as presentations and workshops, is essential for improved nutrient management in the agricultural sector, and achieving improvements in the water quality of Lake Winnipeg and its major tributaries.

Table 5: Land use changes and beneficial management practices (BMP) modelling in the Lake Winnipeg Basin Initiative (EC) and Sustainable Agriculture Environment Systems (AAFC) Red-Assiniboine water quality modelling project.

Category	Practice	Practice Code	Priority	Modelled Results Expected 2011-2012	Modelled Results Expected 2012-2013	Water shed
Annual cropland conversion	Hayland - entire fields to grass for hay	AC3	1	Y		All
	High runoff and depressional areas to grass for hay	AC2	3	N	?	All
	Wetlands - to wetlands	AC1	1	Y		All
	To other cropping systems (e.g. from "more intense" to "less intense", e.g. forage rotation or fall cereal rotation)	AC4	2	N	Y	All
Nutrient management	Timing - improved timing of nutrient applications (manure and commercial fertilizer)	NM1	1	Y		All
	Placement - manure injection/incorporation	NM2	1	Y		All
	Rate - zone management (not a blanket application) of nutrients (reduced application in critical areas, i.e. high runoff, water ponding areas of low crop yields)	NM3	1	N	Y	TBD
Riparian areas	Grass riparian buffer strip - grass buffers that are harvested	RA1	1	Y		La Salle - sub
	Improved riparian health - improved health through natural vegetation establishment	RA2	1	N	Y	La Salle
	Treed riparian buffer strip - willow plantings for harvest	RA3	1	Y		La Salle - sub
Drainage Water Management	Tile drainage with biofilters (constructed wetlands for tile discharge treatment)	DW1	1	N	Y	Boyne
	Small dam network	DW2	1	N	Y	Boyne - sub
Municipal wastewater	Improved treatment techniques	MW1	1	Y		All

Table 6: Scenarios of wetland restoration (AC3) in the LaSalle watershed.

Scenario	% wetland	Code	Description & data sources
Current	0.1%	Current	2001 landcover data derived from LANDSAT imagery
Historic wetland cover	6.1%	W1870	Original Dominion Land Survey township maps (Hanuta 2006, Bossenmaier and Vogel 1974)
¼ restoration of 1870s cover	1.5%	QWR	Restoration at *historic* locations
¼ restoration at mouths of subwatersheds	1.5%	QWRsuboutlet	Restored wetlands positioned at *mouths of subwatersheds*
¼ restoration at whole watershed outlet	1.5%	QWRoutlet	Restored wetlands positioned *entirely at watershed outlet*

Table 7: Beneficial management practice (BMP) categories used in the initial set of scenario evaluations for the LaSalle and Boyne watersheds.

BMP categories	Practice code	Practice	Notes
Annual cropland conversion	AC1	Wetland restoration	Restoration to historic levels
	AC3	Conversion to grass	Conversion of entire fields to grass for hay
Nutrient management	NM1.1	Improved timing of commercial fertilizer (N) application	Current scenario: La Salle watershed: 50% fall, 50% spring; Boyne watershed: 70% fall, 30% spring; water quality improvement: 100% in spring
	NM1.2	Improve timing of manure application	Current scenario: 80% fall, 15% winter, 5% spring; water quality improvement: 100% spring
	NM2	Placement-manure injection/incorporation	Current scenario: 80% incorporation; water quality improvement: 100% incorporation
Riparian areas	RA1	Grassed riparian buffer strips	5-m wide applied on all cropland

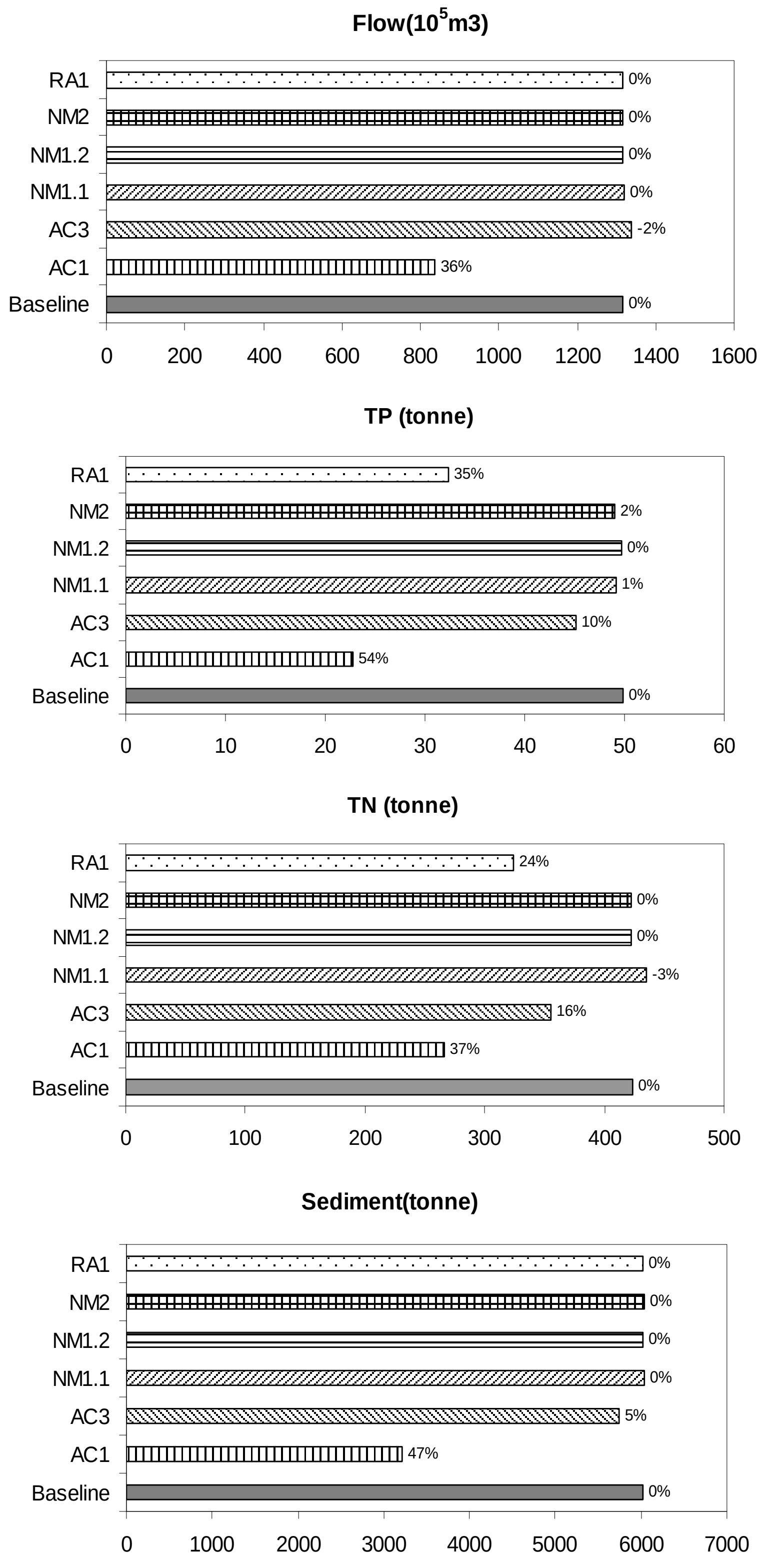


Figure 36: Results of preliminary BMP scenario evaluations for the La Salle watershed.

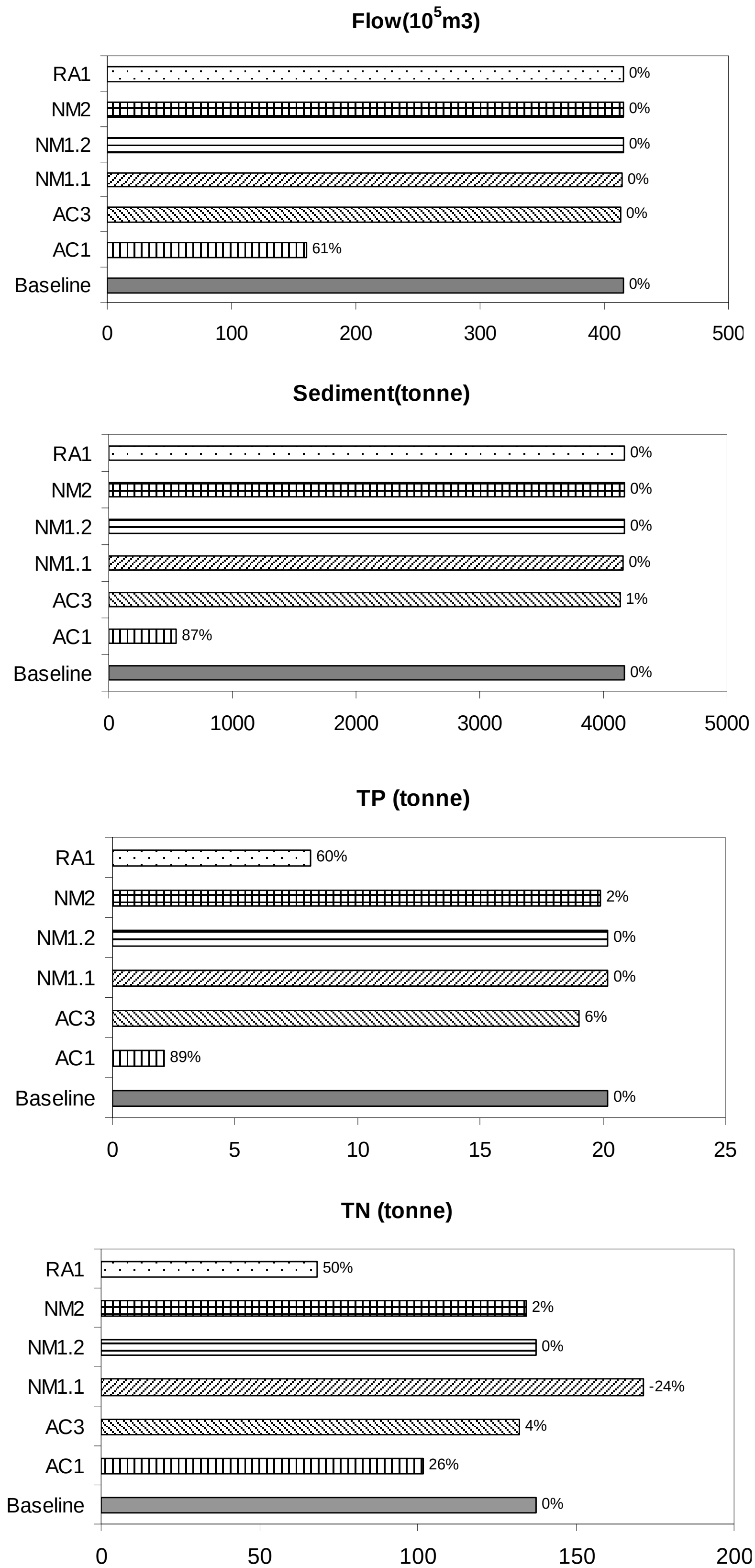


Figure 37: Results of preliminary BMP scenario evaluations for the Boyne watershed.

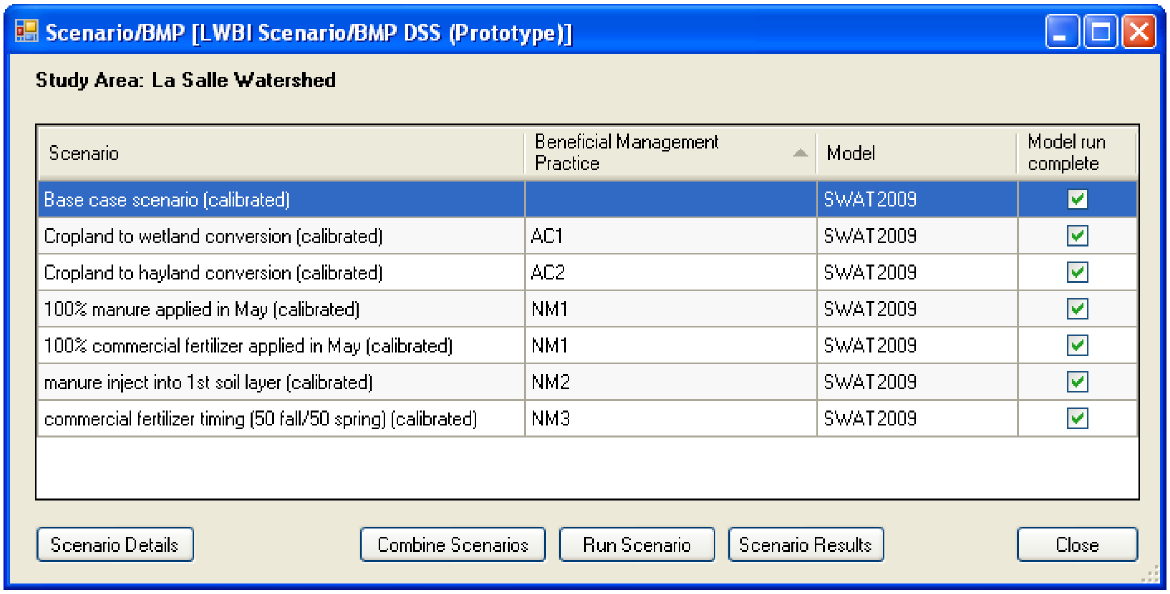


Figure 38: Scenario Decision Support System interface

Deliverable 4: Costs and benefits of instruments to reduce nutrients using an ecological goods and services approach

Project Team: Luis Leigh, Valerie Sexton, Monika Drozdz; Environment Canada

Excess nutrients in Lake Winnipeg not only pose a threat to water quality, but also result in economic costs. In order to choose the most effective and efficient nutrient reduction activities, decision-makers require information about the costs and benefits of various potential policy measures. Different policy measures can result in varying amounts of ecological goods and services (EG&S), which have value for both our economies and human well-being. The objective of this project was to assess the effectiveness of policy options and instruments to manage or reduce nutrient loads in Lake Winnipeg, and consider their effects on other EG&S.

Progress and Achievements

- A literature review was undertaken to review the work that has been done to identify, quantify and value EG&S in Canada. The review, by Wilson (2009), reported on the types of EG&S that have been studied, the frameworks and methods used to value EG&S, and the outcomes and values reported in those studies. The review found that there is growing interest in defining and valuing EG&S in Canada, and provided methodological examples helpful for this project.

- An *Analytical Framework for Decision Involving Ecological Goods and Services* was developed by Environment Canada. The framework outlined a step-by-step approach for incorporating values of EG&S in the decision-making process, including: defining the policy scenario or proposed management change; establishing the physical baseline and estimating the physical changes; applying a monetary value to changes in EG&S; incorporating those values in a cost-benefit Analysis (CBA); and using the economic tradeoffs to inform decisions.

- The analytical framework was applied to two case studies in the Lake Winnipeg Basin. The first, by Thomsen et al. (2010), examined various agricultural beneficial management practices (BMPs) to improve nutrient loading in the watershed and provide additional EG&S. BMPs included nutrient management, crop selection, vegetative filter strips, conservation tillage, and surface water control structures. EG&S benefits included the value of pollination, wildlife habitat, greenhouse gas reduction, water regulation, and erosion control. These values, along with the estimated costs of implementing the BMPs, were used to carry out cost-benefit analyses.

- The second case study concerned the impact of wastewater treatment strategies in reducing nutrient loading in small to medium-sized communities in Manitoba (ICF Marbek et al., 2011). Wastewater strategies included Biological Nutrient Removal (BNR), Sequencing Batch Reactors (SBR), land application of pre-treated wastewater effluent; free water surface wetlands, and chemical precipitation.

- The synthesis report (ICF Marbek et al., 2012) was the final deliverable in the project. It serves to summarize the overall project and compare the results of the nutrient reduction strategies examined in the case studies using a common metric. However, due to deficiencies in available data, and difficulties in estimating values of water quality improvements due to decreased phosphorus concentrations in Lake Winnipeg, the synthesis report adopted a social cost effectiveness approach, rather than a cost-benefit analysis. As a result, the impacts of the various nutrient-reducing measures were presented as net costs per tonne of phosphorus reduced, rather than an overall net cost (or net benefit) of the measure.

- Information about this project was presented at the 2011 AD Latornell Conservation Symposium as well as several other workshops, and reports will be posted on the LWBI web portal.

Research Results

- Once the results of the case studies were calculated in a common metric, it was found that the Biological Nutrient Removal (BNR)/Sequencing Batch Reactors (SBR) plant strategy had by far the highest annualized net cost per tonne of phosphorus removed, followed by the pivot system strategy for land application.
- Vegetated filter strips and crop selection strategies had a net benefit (i.e., had improvements in EG&S that are greater than their costs), and had the highest positive impact of all the policies studied.
- For wastewater strategies, the wetland low cost and land application via traveling gun strategies both exhibited an annualized net cost per tonne of phosphorus removed that was lower than that of chemical precipitation.
- Various sensitivity analyses were conducted to demonstrate how results would change under different assumptions on the amount of phosphorus removed by the agricultural BMP strategies, and under different assumptions of the values of pollination services, nitrogen, and carbon. The impact of the choice of discount rate on the results was also examined.
- The sensitivity analyses showed that the results observed for the various nutrient reduction strategies were fairly robust, with the rank ordering of the cost-effectiveness of the strategies remaining largely unchanged. For example, with the agricultural BMPs, the rank order of the cost-effectiveness of the strategies did not change across assumptions on the amount of phosphorus reduced or the assumed value of pollination services.

Challenges and Lessons Learned

The synthesis report findings considered co-benefits for only a limited number of EG&S. This limitation relates to the difficulty in quantifying and/or costing some EG&S. For example, this report does not assign a monetary value to the benefits of less phosphorus in Lake Winnipeg, such as improved water quality and fewer algal blooms.

Further research is required in a number of areas in order to improve the analysis of costs and benefits of instruments to reduce nutrients, not only in Manitoba, but other jurisdictions experiencing eutrophication problems. While nutrient transport rates from Manitoba studies were used, the possible range of values was the largest driver of uncertainty in the final results. Limited data existed on the effectiveness of some BMPs at reducing/removing phosphorus and nitrogen over time as did data on the quantity of EG&S improvement resulting from BMPs. It was difficult to obtain data on the private costs of adopting certain BMPs in Manitoba (marginal costs). There was a lack of values for use in benefit transfer that are related to the improvement in water quality in Lake Winnipeg (marginal values), specifically due to reduction in phosphorus and nitrogen. Finally, the availability of marginal values of EG&S co-benefits derived from adoption of BMPs (e.g., wild pollination, flood control) is limited and sometimes difficult to transfer from other study sites.

Conclusions

In general this report found that adopting an EG&S approach to inform policy decisions is important as some options for nutrient reduction were associated with substantial co-benefits resulting from EG&S. While some challenges, such as data availability, exist, adopting this approach for the analysis of policy options likely to involve EG&S can be worthwhile in terms of improving the quality of information about policy impacts.

Some recommendations can be made for selection of nutrient reduction strategies for Lake Winnipeg, based on the cost-effectiveness of each strategy for removing a tonne of phosphorus. Results of this research indicate that wastewater treatment strategies are generally less cost-effective than agricultural BMP strategies, when the annualized cost per tonne of phosphorus removed is considered. In contrast, two of the four agricultural BMPs (vegetated filter strips and crop selection) actually have a negative annualized net cost per tonne of phosphorus due to the fact that the improvements in EG&S resulting from these strategies are greater than the cost to implement them. However, it should be noted that the vegetated filter strips and crop selection scenarios have a limited overall potential to reduce phosphorus loading in the watershed compared to other scenarios.

The value of the improvements in EG&S provided by nutrient reduction strategies would point to an increased need for municipal, provincial and conservation and watershed authorities to identify, measure, and monitor EG&S.

Data limitations currently hamper the ability of researchers to measure and value EG&S. This largely stems from a lack of ecological and economic information, such as changes in the current levels of provision of EG&S and how this provision might change under different land use scenarios. The data gaps highlight the importance of using applied EG&S research to support policy decision-making. For example, there is a need for studies that look at changes in marginal values (rather than total values), and the impacts that various policies have on the provision of EG&S. Increased research in this area would improve the accuracy of analyses of the costs and benefits of policy alternatives, and would thus help decision-makers choose between competing policies or resource uses.

The focus of this study examined Manitoba sources of nutrient loading. There may be opportunities for nutrient reduction and EG&S activities in other jurisdictions that may be more cost-effective than implementing further measures in Manitoba.

The development of a standard approach for the measurement and valuation of EG&S for Canada would greatly improve EG&S research and valuation. A more comprehensive study of EG&S could also potentially be applied towards efforts with other jurisdictions to develop nutrient reduction targets and measures.

Table 8: Annualized Net Cost per Tonne of Phosphorus Removed of Nutrient Reduction Strategies

Nutrient Reduction Strategy	Annualized Net Cost - 3% Discounting	Annual Tonnes of Phosphorus Removed	Annualized Net Cost per Tonne of Phosphorus Removed - 3% Discounting
Biological Nutrient Removal / Sequencing Batch Reactor Plant	$192,473,856	114	$1,688,367
Wetland - High	$41,767,621	114	$366,383
Wetland - Low	$5,538,355	114	$48,582
Land Application - Pivot System	$110,894,779	140	$792,106
Land Application - Traveling Gun	$6,699,316	140	$47,852
Chemical Precipitation	$26,479,236	114	$232,274
Nutrient Management	$16,891,992	96.9	$174,324
Vegetated Filter Strips	-$625,408	1	-$625,408
Crop Selection	-$2,495,595	3.9	-$639,896
Surface Water Control Structures	$683,930	2.4	$284,971

Source: ICF Marbek (2012)

Deliverable 5: Lake Wpg Basin physiography & geo-spatial data management

Project Team: Malcolm Conly, Emily Ritson-Bennett; Environment Canada

The objective of this project was to compile, manage and map geo-spatial data for Lake Winnipeg and its basin, to support LWBI projects and ensure consistency and comparability of products and data. Activities included compiling and managing geo-spatial data at Basin scales; development of basin maps; integration and assimilation of geo-spatial data layers from multiple provincial and international jurisdictions; and Geographic Information System (GIS) and mapping support for monitoring and research in support of the LWBI.

Progress and Achievements

- The LWBI science program has generated a large amount of spatial data. In collaboration with scientists, interpretive geospatial products have been generated using Canadian Geospatial Data Infrastructure (CGDI) standards, and have facilitated the production of a number of reports and publications.

- The data is also used for the LWBI web information portal, providing access to both public and secure data, information, models and other tools.
- GIS support was provided for the *State of Lake Winnipeg 1999-2007* report. Chemical, physical and biological data was analyzed using GIS interpolation techniques.
- Lake station data was also analyzed and used in production of articles for the Lake Winnipeg special edition of the *Journal of Great Lakes Research*.

Challenges and Lessons Learned

Consistency and ongoing communication were essential to the successful accumulation and use of spatial data. A watershed of Lake Winnipeg's vast size and scale (almost one million km^2), combined with a large number of interprovincial and international stakeholders, and differences in data classification and descriptions, etc., presented challenges for spatial data collection. For example, data from the Canadian Geological Survey has 18 classes, and North Dakota and U.S. Geological Survey data contains 30 classes. A technique called manual generalization was used to remove detail from, and combine datasets, so they could be displayed at the same scale. As a result, some small-scale maps were rendered with less detail.

Conclusions

A thorough collection of spatial data was acquired for the Lake Winnipeg Basin. It has been managed at a central location with proper quality control and assurance procedures to supply users with the maps and data they require. The maps that have been produced have supported a variety of research projects, and are expected to continue to support future efforts.

Deliverable 5: Development and implementation of an information and decision support web portal for the Lake Winnipeg Basin

Project Team: Malcolm Conly, Sarah Hall, William Booty, Isaac Wong, Phil Fong, Craig McCrimmon and Luis Leon; Environment Canada

Partners: Agriculture and Agri-Food Canada (AAFC), Algal Taxonomy and Ecology Inc. (AETI), City of Winnipeg, Ducks Unlimited Canada, Fisheries and Oceans Canada, Natural Resources Canada, Government of Saskatchewan, International Institute for Sustainable Development, Lake Winnipeg Research Consortium, Manitoba Water Stewardship, Red River Basin Commission, Salki Consultants Inc., University of Guelph, University of Manitoba

This project involved the development of a Lake Winnipeg web-based information portal, to gather and facilitate access to relevant scientific data, models, information and tools leveraged through the research activities of Environment Canada and stakeholders.

Progress and Achievements

- Environment Canada worked with partners to develop and obtain data, and provide guidance on modelling standards for the portal. Three major workshops were organized with partners and stakeholders, focusing on user needs, data sources, and modelling. A prototype of the portal was developed based on workshop discussions.

- Funding was provided to stakeholder groups to enhance capacity in developing and acquiring/migrating datasets for the portal.
- Data, tools, and online modelling capacity were gathered and developed, to further refine the portal to meet the needs of stakeholders and users.
- The portal made use of international standards in the delivery of its data and information to ensure interoperability with other computer systems.
- Dataset and model community pages were created to allow users to freely upload their data and information and model results to the portal for sharing with others. More than ten models and studies have been added to date. Data mining and

mapping components were developed to provide users with functionality for analyzing and visualizing data.

- All existing relevant datasets were added to the portal, including Environment Canada shoreline survey water quality, benthos and zooplankton, chlorophyll image maps, phytoplankton and some base GIS layers of Lake Winnipeg watersheds. Data sets on the portal currently number about 137. General information including the Lake Winnipeg Basin Stewardship Fund and projects, science conducted under the LWBI and reports such as the *State of Lake Winnipeg 1999-2007* are also available on the portal.
- Portal participants and users currently number 109 users and 20 different groups and organizations.
- A portal hosting agreement was reached with the University of Manitoba and the portal was transferred to the university in the spring of 2012, where it will continue over the longer term as a comprehensive source of information and a resource for students, scientists and the public.

Challenges and Lessons Learned

Early stakeholder input and involvement in the design of the portal was essential to ensure development of a tool that met user needs and expectations. In addition, data consistency concerns arise with data obtained from various different sources. It is recommended to develop some technology or protocol to transfer data from the source into a uniform format for the user. Collaboration and compromise between different parties was required to be able to do this in a way that is both desirable to the user and accepted by data providers.

Migrating or importing disparate datasets into the portal and ensuring consistency was expedited by developing a dataset community area where users are able to share their data in a format of their own choosing. There were also some technical challenges with respect to geospatial tools and technologies that can be used on all browsers, operating systems and networks.

The timing of LWBI science project results coincided with the completion of the portal development, which has impacted the amount of integrative products and information currently available on the portal.

Conclusions

The LWBI web information portal and project deliverables were completed successfully. Strategic capacity development by partners in government and non-government stakeholder organizations was initiated, fostering long-term information sharing and capacity for the portal. Capacity building exercises and annual workshops were implemented throughout the project, enabling ongoing user input and adaptations, based on user feedback and recommendations.

Feedback for the portal has generally been quite positive in regards to its usefulness, particularly in providing access to data about the Lake Winnipeg Basin. It provides access to previously unavailable data, and integrates a diverse set of scientific information, including water quality and quantity measurements, phytoplankton, zooplankton, spatial data such as soil, land cover and satellite images of chlorophyll, and lake and watershed models.

The portal's accessibility and the ease with which data can be shared with other portal users, such as the dataset and model community pages, will help ensure the portal continues as a valuable tool for scientists, stakeholders and the public in the future.

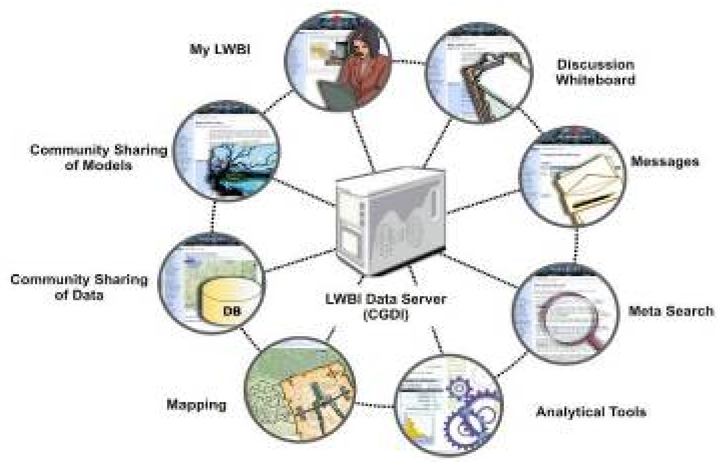


Figure 39: LWBI web information portal schematic

Deliverable 5: Integrated watershed/lake modelling and decision support systems

Project Team: William Booty, Luis Leon, Isaac Wong, Glenn Benoy, Qi Yang (NSERC), Craig McCrimmon, Phil Fong; Environment Canada

Partners: University of Manitoba, Manitoba Water Stewardship, Agriculture and Agri-Food Canada (AAFC)

This project applied watershed modelling tools to evaluate scenarios of land use change and implementation of best management practices (BMPs), and assess impacts of nutrient loads to surface waters. Lake models were also developed to determine the dynamics of nutrients sediments and phytoplankton in Lake Winnipeg. The watershed and lake models were then integrated to simulate water quality. A suite of decision support systems (DSSs) were used to assess modelling uncertainty, particularly within the integrated modelling framework.

Progress and Achievements

- In conjunction with AAFC, three pilot watersheds (La Salle, Boyne and Little Saskatchewan) were identified for non-point source modelling and BMP scenario development.
- Three modelling workshops were held and resulting recommendations were used to improve and fine-tune project deliverables.
- All three pilot watersheds were calibrated in the Soil and Water Assessment Tool (SWAT) model, using the best available input (climate, physiography, land use/land cover, etc) and calibration data (flow rate, water quality parameters, etc). Inventories of BMPs in each of the watersheds were continuously updated to identify current or baseline conditions. Calibrated results were applied to BMP scenario development.
- A number of datasets were acquired and integrated into the models, including time-series of precipitation, stream discharge and water chemistry, and GIS layers of digital elevation models, soils and land cover. These base case modelling results were also applied to the LWBI BMP scenario development project.
- Lake modelling simulations were conducted using the Estuary and Lake Computer Model/Computational Aquatic Ecosystem Dynamics Model (ELCOM/CAEDYM) model and OneLay and PolTra models.
- These models simulate suspended sediments and nutrients in Lake Winnipeg. In addition, the ELCOM/CAEDYM model simulates phytoplankton dynamics. Inputs to the model included the nutrient contributions of the main tributaries. Initialization and calibration were performed using about 60 sites in the Lake from May-Oct of 2007.

- Final calibration of the OneLay/PolTra and ELCOM/CAEDYM lake models was completed. Two-way calibration of the integrated modelling work was also completed. Integrated modelling results were used to assess exceedances of both watershed and lake water quality objectives.
- A set of decision support system tools (DSS) was developed, based on OpenMI (Open Modelling Integration) and CGDI (Canadian Geospatial Data Initiative) standards, to evaluate models and BMP scenarios.
- Two papers on the SWAT modelling and the two-way calibration of the integrated modelling of the SWAT and OneLay/PolTra were prepared. Watershed non-point source, lake and integrated modelling results were also provided to the LWBI web portal.

Challenges and Lessons Learned

For both watershed and lake modelling, temporal and spatial data challenges existed. The biggest challenge was a lack of gauging station flow data and water quality monitoring data. More monitoring data would greatly enhance the power of scenario-based modelling and the interpretability of model output.

The data issue was a particular problem for the ELCOM/CAEDYM model as it requires extensive observation data. This is also a computationally intensive model and the complexity of the inputs and outputs makes it difficult to apply automated calibration techniques. In order to better compare the dynamics at the end of the growth season, it would be useful to extend the simulation period to late October and/or include additional years. Lack of data made the validation of Chl_a dynamics difficult. Similarly, the lack of observations for river loadings impacted the OneLay/PolTra model inputs. More frequent observations at appropriate locations would improve calibration. It was also found that automated calibration greatly improves model fitness and accuracy over manual calibration.

Another challenge was in developing SWAT models to be more responsive to critical landscape features such as snow redistribution, frozen soils, and snowmelt-driven (rather than rainfall-driven) hydrology. Partnerships were developed with SWAT model developers at the University of Guelph and elsewhere, who have begun to adapt SWAT and introduce new models to better represent critical features of prairie hydrology and agriculture.

A challenge for integrated modelling was estimating the uncertainty of observations. More data would reduce uncertainty and improve calibrations. It was also learned that backwater could be affecting the observations in the La Salle watershed. This factor should be considered for other future pilot watersheds. However, the integrated modelling results can be used as a relative comparison tool for BMP scenario comparisons.

Conclusions

Simulation models at the watershed level were applied to aid in the understanding and management of surface runoff, nutrients and sediment transport processes. Similarly, models with different degrees of complexity were used to simulate the aquatic ecology and water quality in the lake. The models proved capable of simulating the values of environmental variables most relevant to nutrient and sediment dynamics with sufficient accuracy to make it useful for addressing project objectives. The SWAT model was capable of calibrating a base case for each of the three pilot watersheds on a monthly basis with reasonably good modelling statistics. This has allowed the SWAT model base case results to be used to carry out the evaluation of the BMP scenario development. This work is also being used as part of the AAFC SAGES program.

The results of the ELCOM/CAEDYM model captured the major patterns of seasonal, inter-annual and depth related variability. The OneLay/PolTra model was successfully calibrated for the lake for the 2002 period and should be a valuable tool for simulating other years and for evaluation of the effects of BMP scenarios.

Simulated total phosphorus (TP) concentrations were consistent with measured averaged values. TP values are higher for the south basin (SB) and Narrows in contrast with the north basin (NB, due in part to high nutrient concentrations in the Red River. Also, the narrows serve as a natural blockage for transport of material from the SB and limit inter-basin transfers. Total nitrogen (TN) was also highest in the SB compared to the NB following the same rationale as for TP. The spatial and temporal variability in phytoplankton in Lake Winnipeg represented by Chlorophyll_a concentrations is consistent with recent studies of the plankton community in the lake, indicating that warmer and drier years, such as the conditions in 2007, are dominated by blooms of the N fixing bluegreens (Cyanophytes), mostly in the NB. Chlorophyll_a concentrations were higher in the NB compared to the SB.

Decision support systems (DSS) designed for modelling and scenario development proved to be effective. Since these tools use OpenMI and CGDI standards, they become of greater value when the models themselves are more complex or are linked to one another such as in two-way calibration. However, due to their complexity, web-based DSS may not be best suited for all applications or in all situations.

Two-way range calibration between the SWAT pilot watershed model and the lake OneLay/PolTra model can be used to improve the overall fitness of the models and ultimately be useful for analyzing the effects of BMP scenarios on Lake Winnipeg. With improved monitoring data, the uncertainty of the integrated models should be reduced. The successful implementation of this integrated modelling approach could be applied to other watersheds in the future.

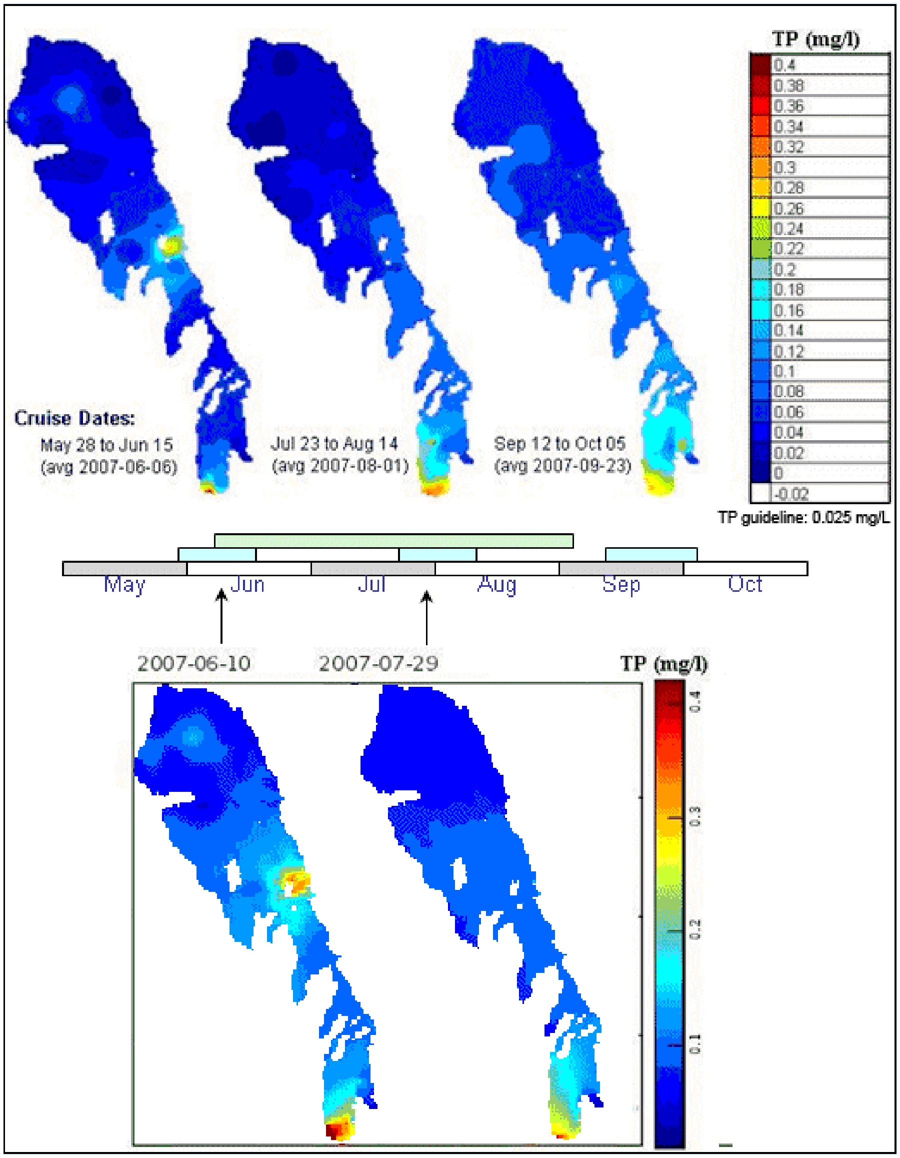


Figure 40: Spatial distribution of TP measured (top) and simulated (bottom). The calendar boxes show the simulation period (green) and the survey dates (blue). The maps do not represent an exact picture in time as values were sampled through almost 4 weeks during the cruise survey.

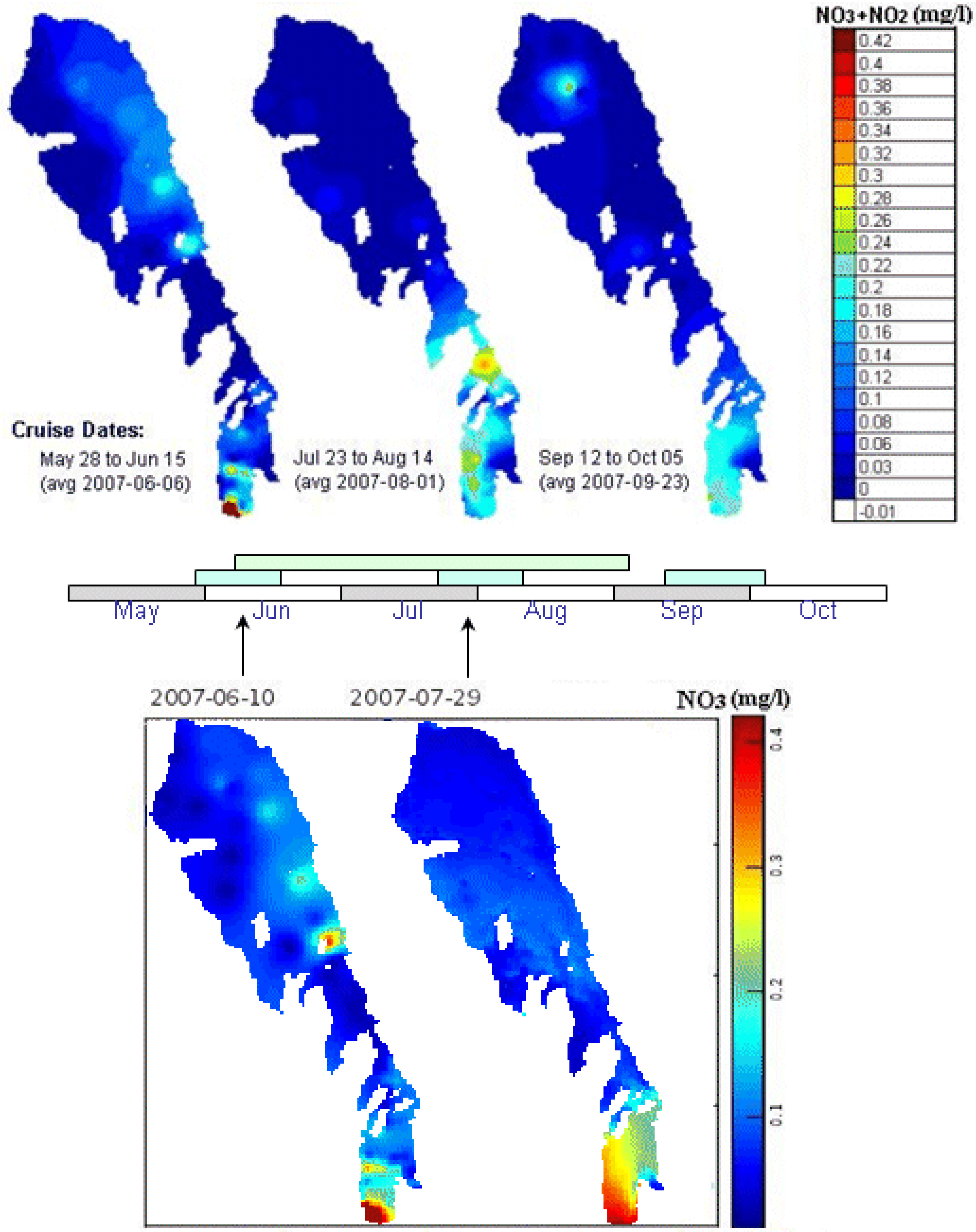


Figure 41: Spatial distribution of Nitrate measured (top) and simulated (bottom). The calendar boxes show the simulation period (green) and the survey dates (blue).

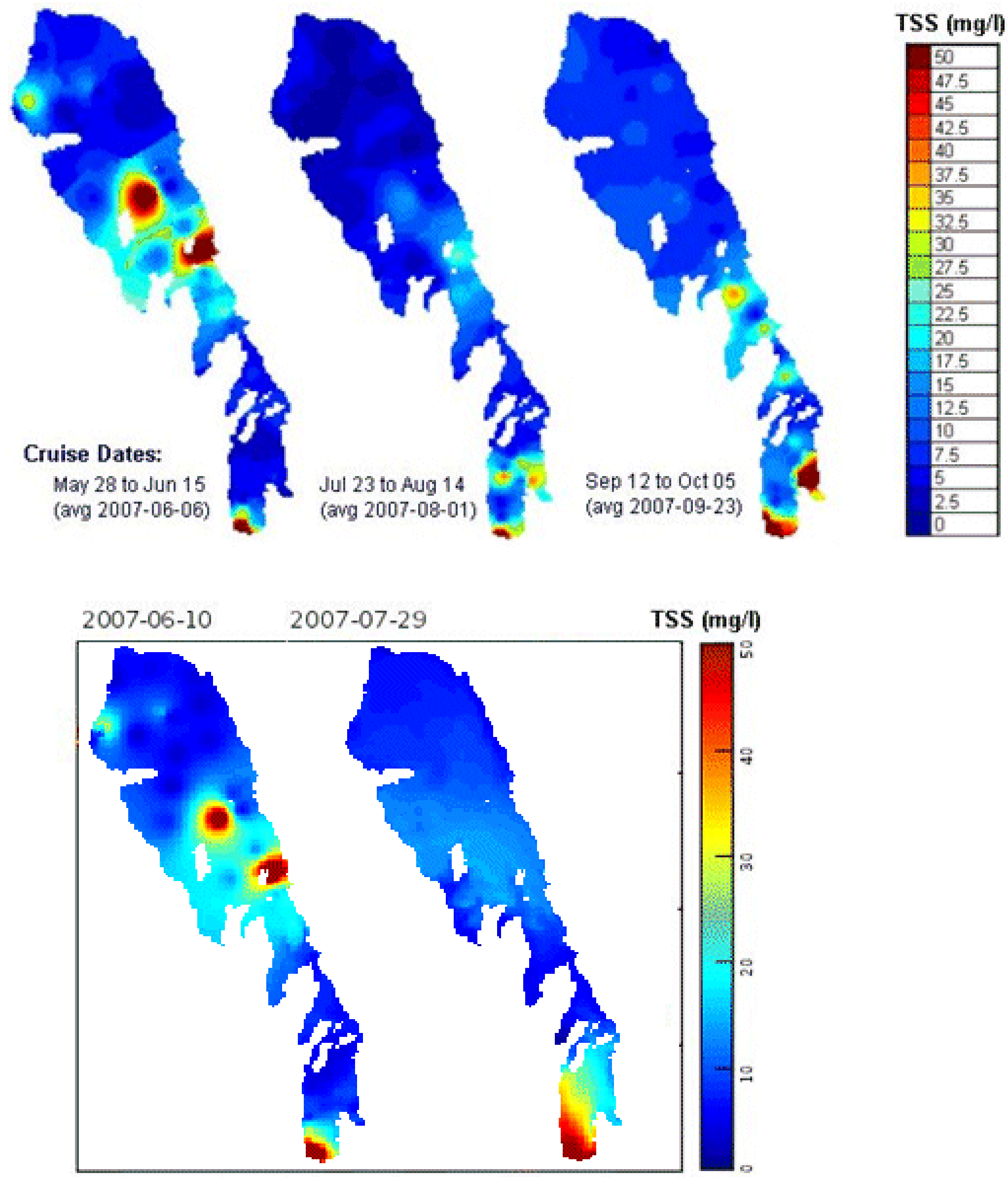


Figure 42: Spatial distribution of TSS measured (top) and simulated (bottom).

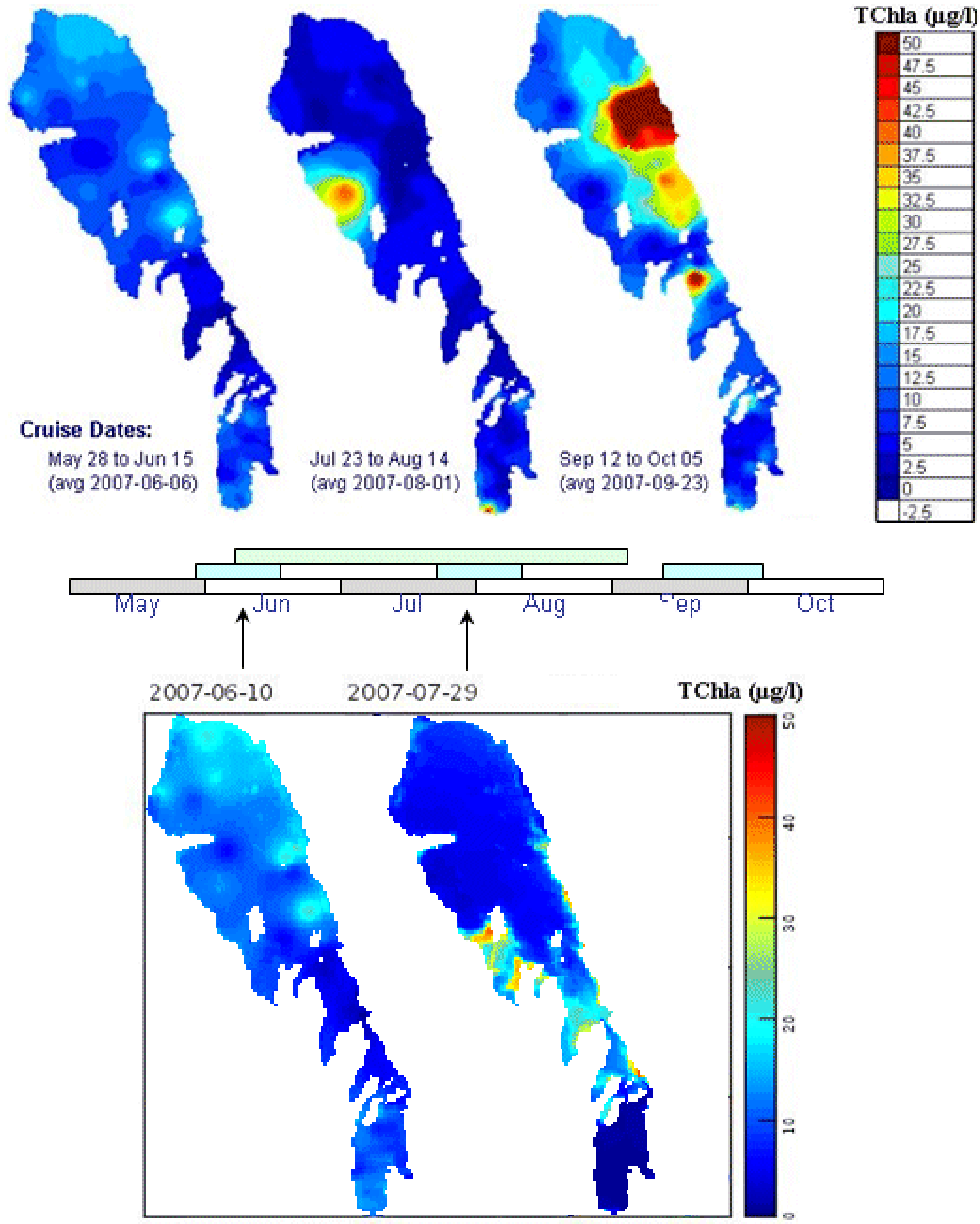


Figure 43: Spatial distribution of Chl_a measured (top) and simulated (bottom). The calendar boxes show the simulation period (green) and the survey dates (blue).

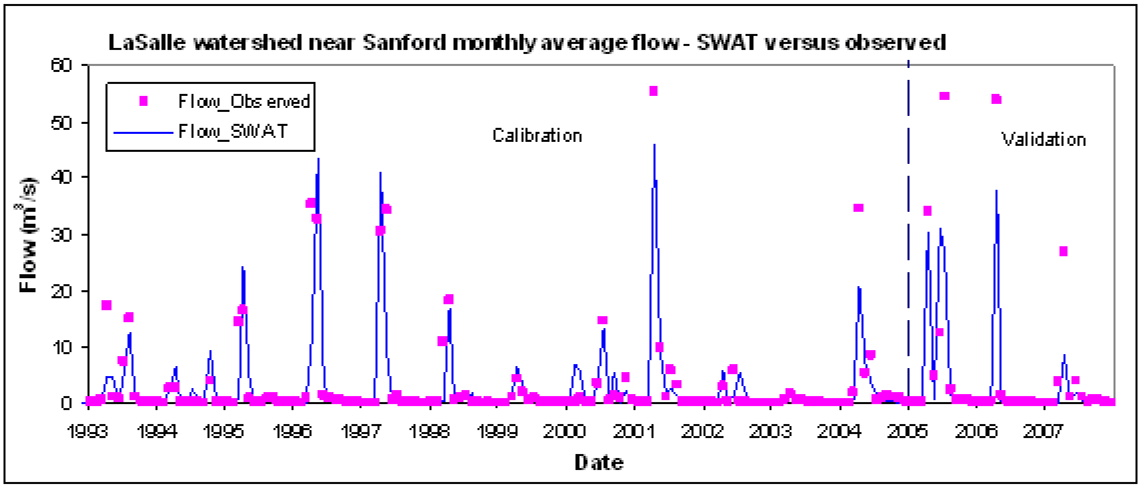


Figure 44: La Salle monthly average flow

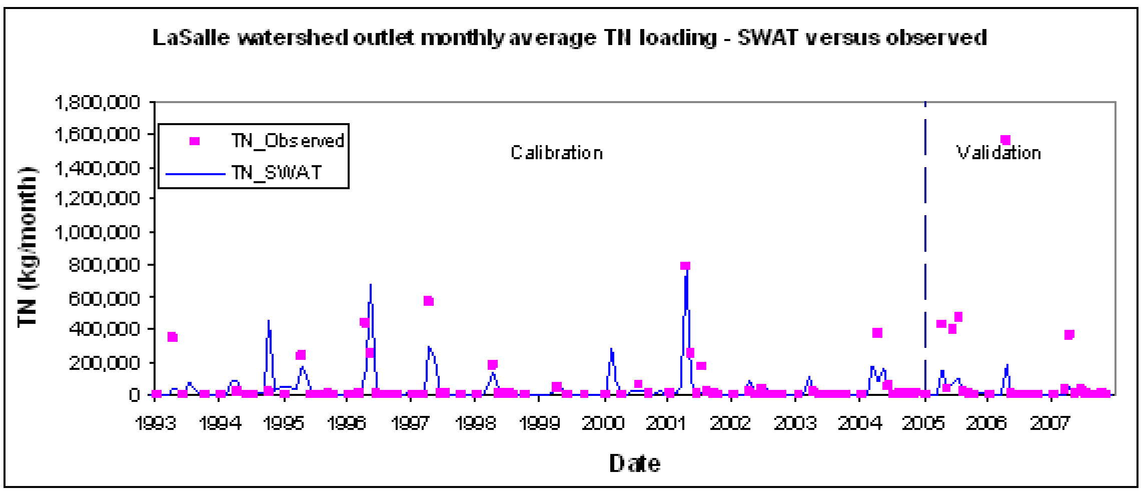


Figure 45: La Salle monthly average TN loading

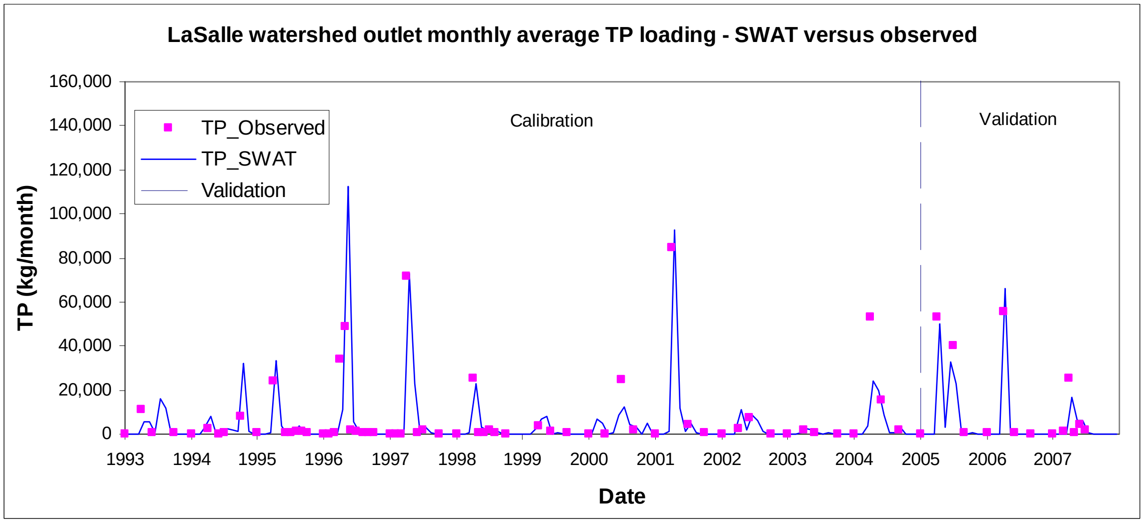


Figure 46: La Salle monthly average TP loadings

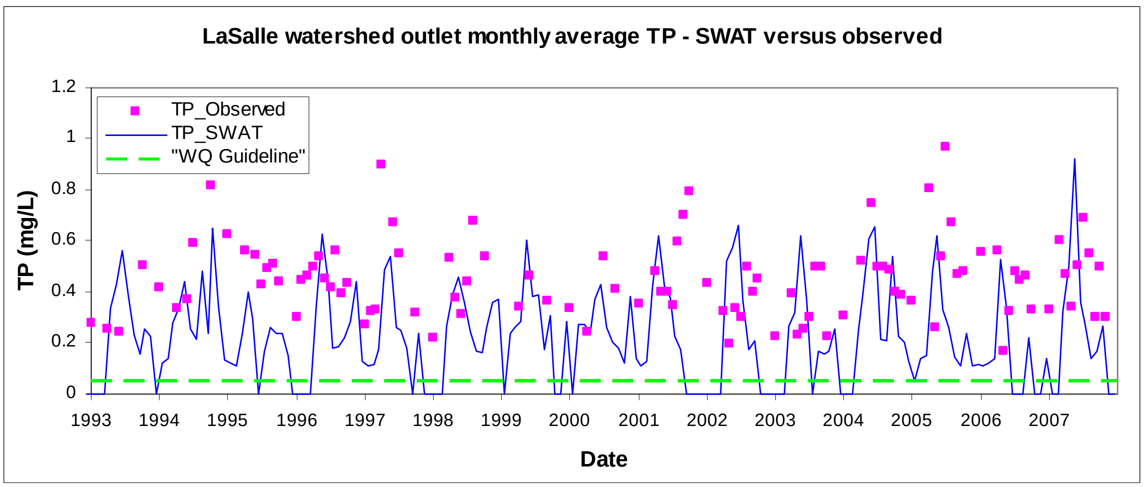


Figure 47: LaSalle monthly average TP concentration

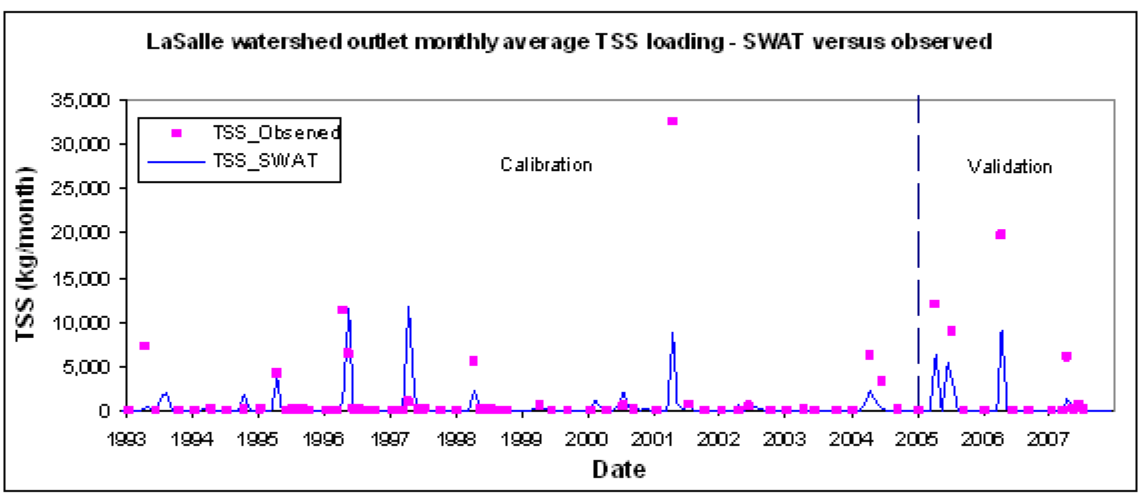


Figure 48: La Salle monthly average TSS loading

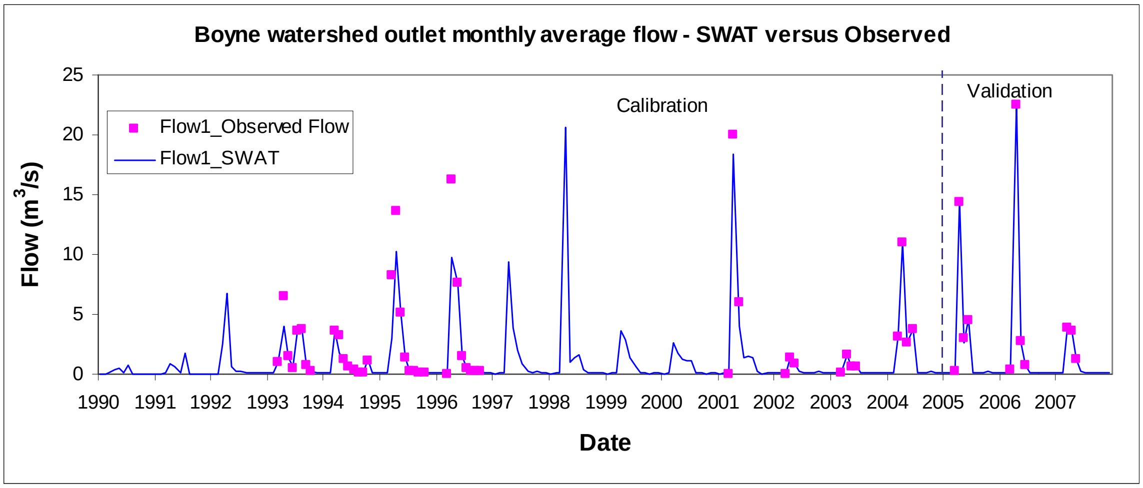


Figure 49: Boyne monthly average flow

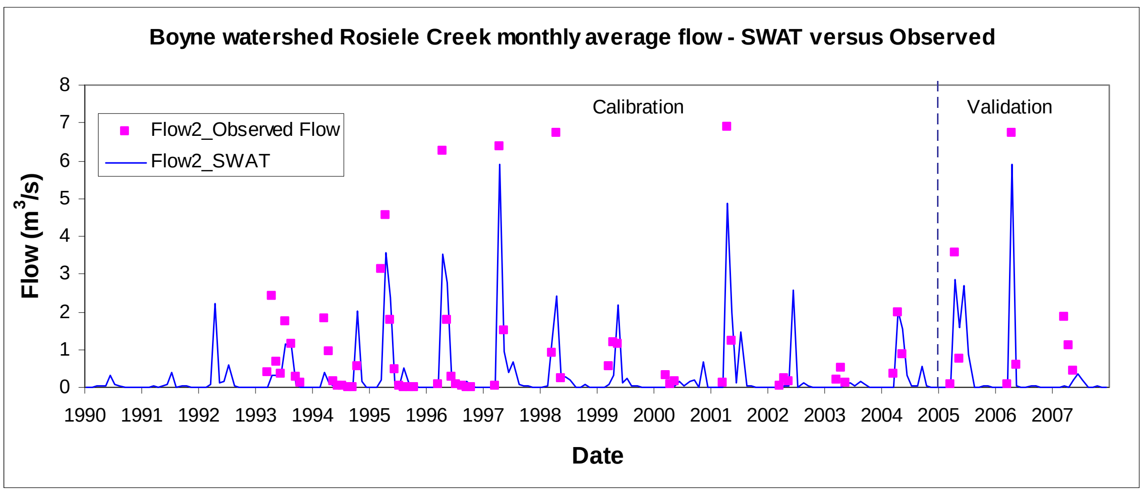


Figure 50: Boyne (Roseisle Creek) monthly average flow

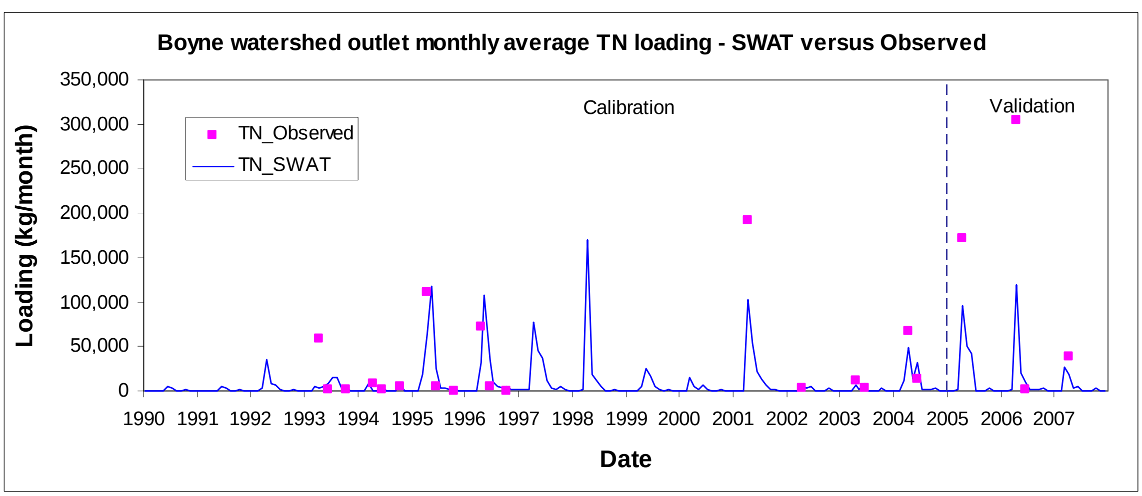


Figure 51: Boyne monthly average TN loading

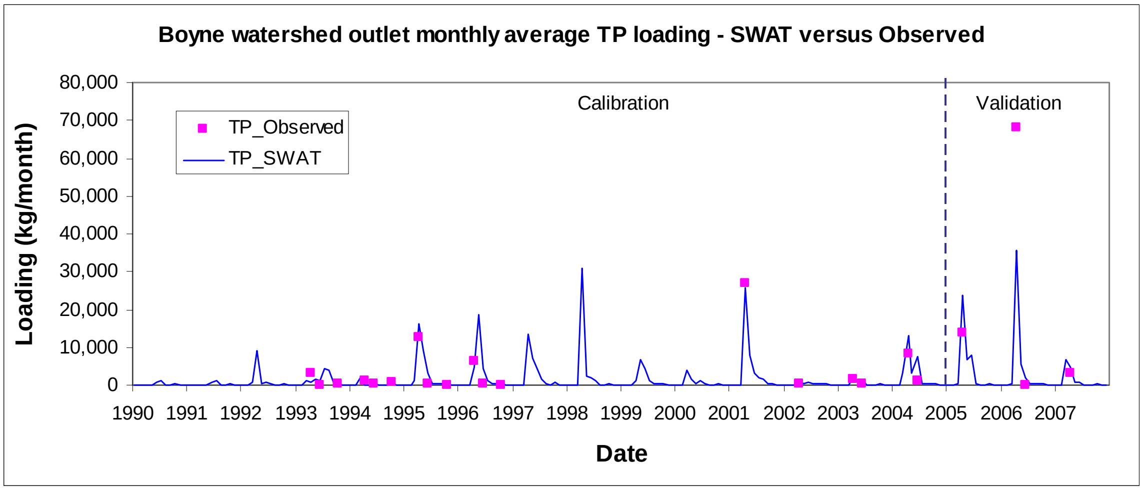


Figure 52: Boyne monthly average TP loading

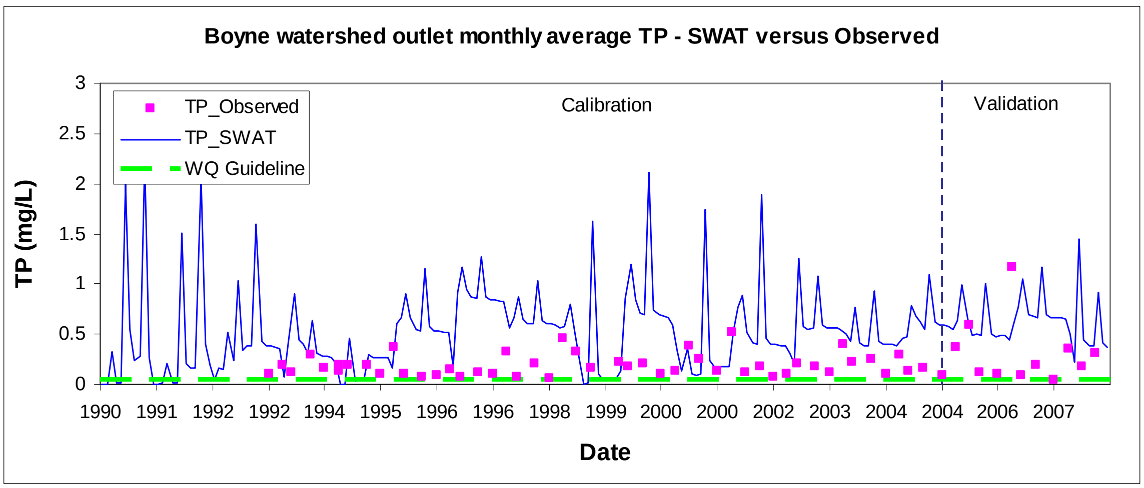


Figure 53: Boyne monthly average TP concentration

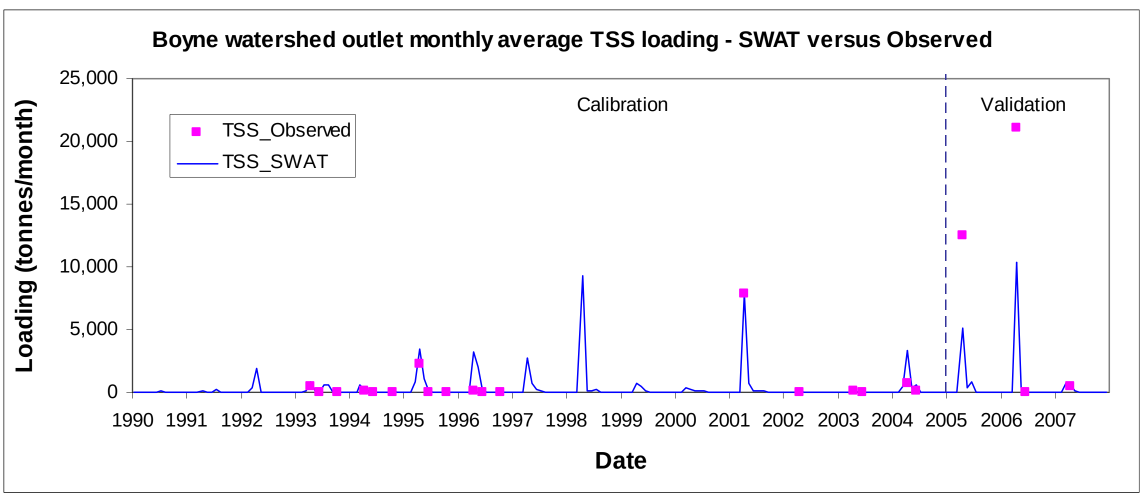


Figure 54: Boyne monthly average TSS loading

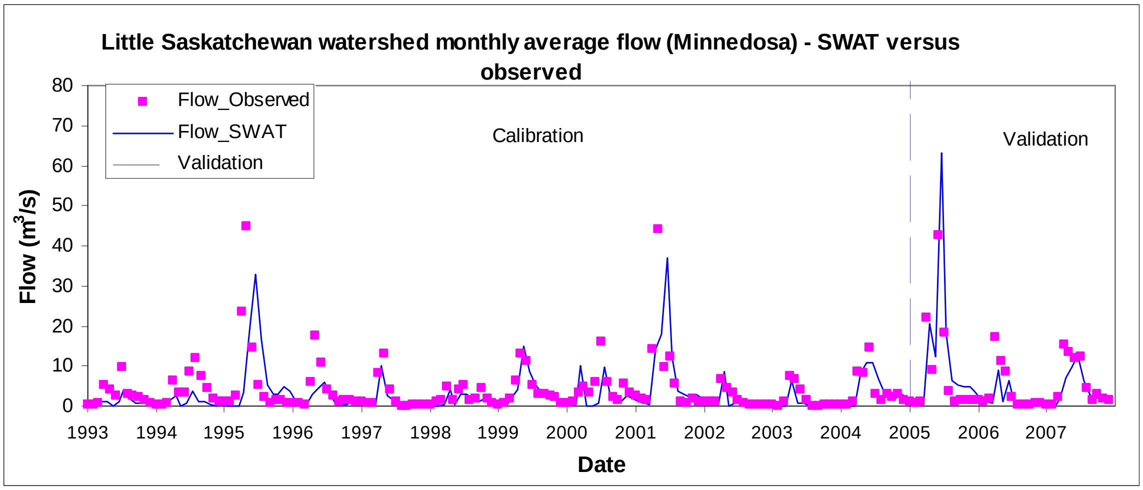


Figure 55: Little Saskatchewan monthly average flow (Minnedosa)

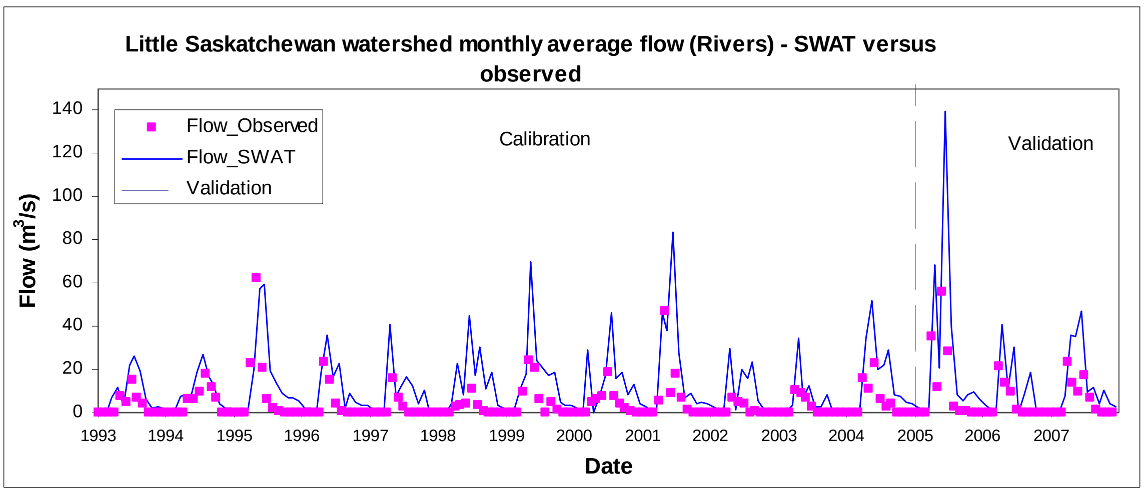


Figure 56: Little Saskatchewan monthly average flow (Rivers Reservoir)

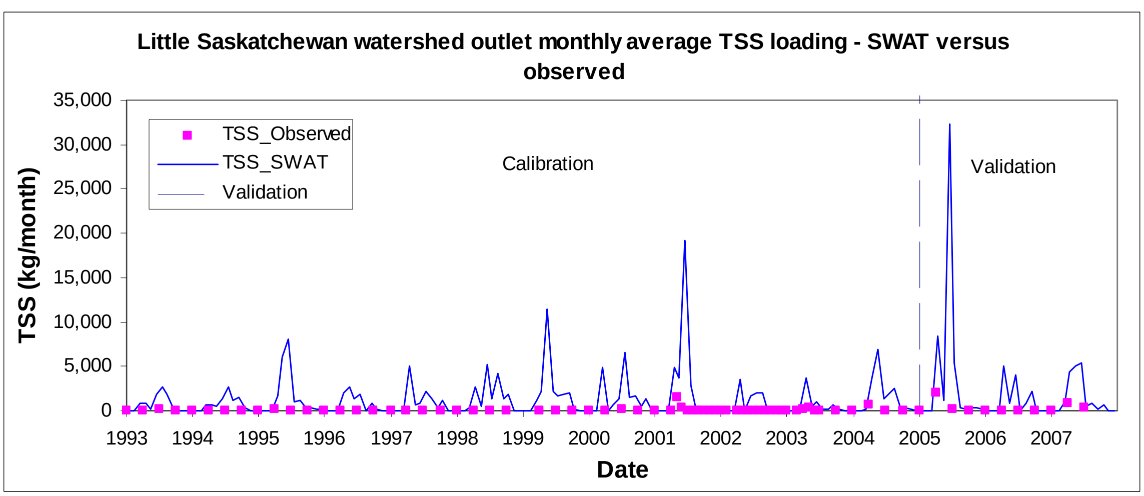


Figure 57: Little Saskatchewan monthly average TSS loading

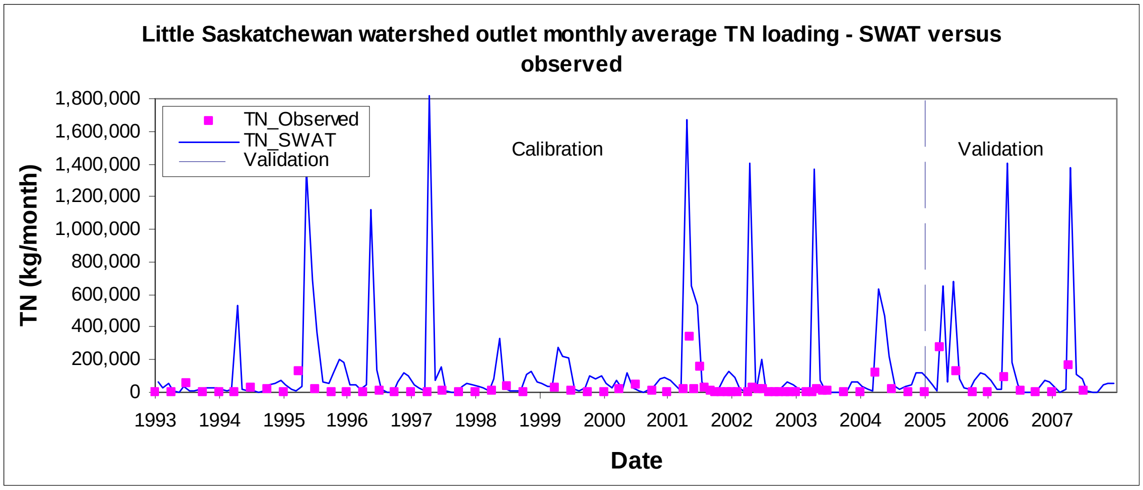


Figure 58: Little Saskatchewan monthly average TN loading

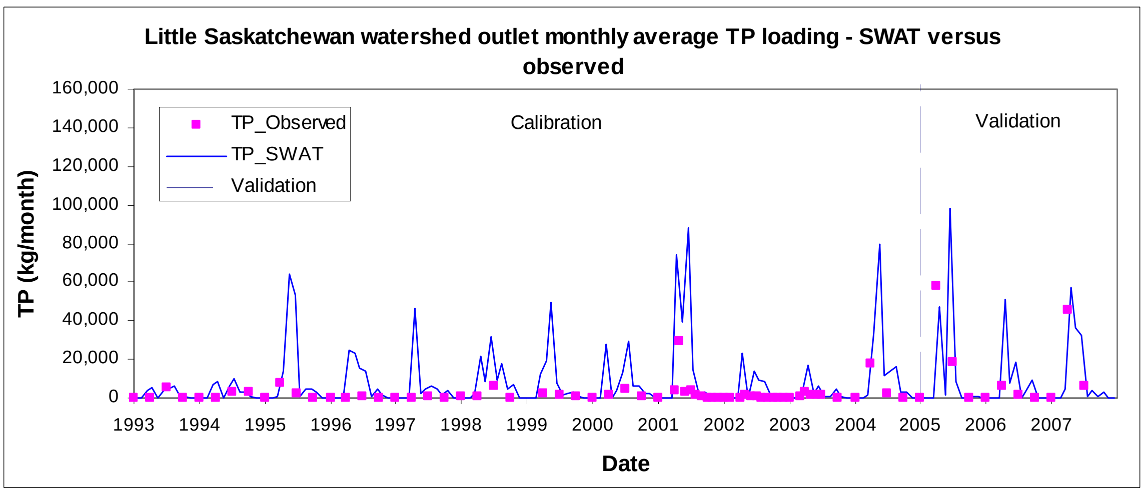


Figure 59: Little Saskatchewan monthly average TP loading

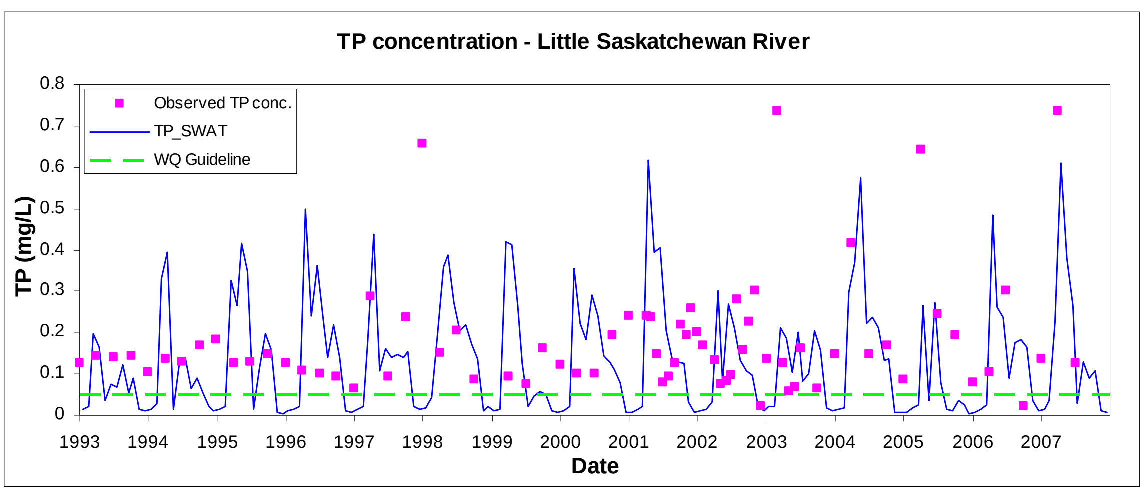
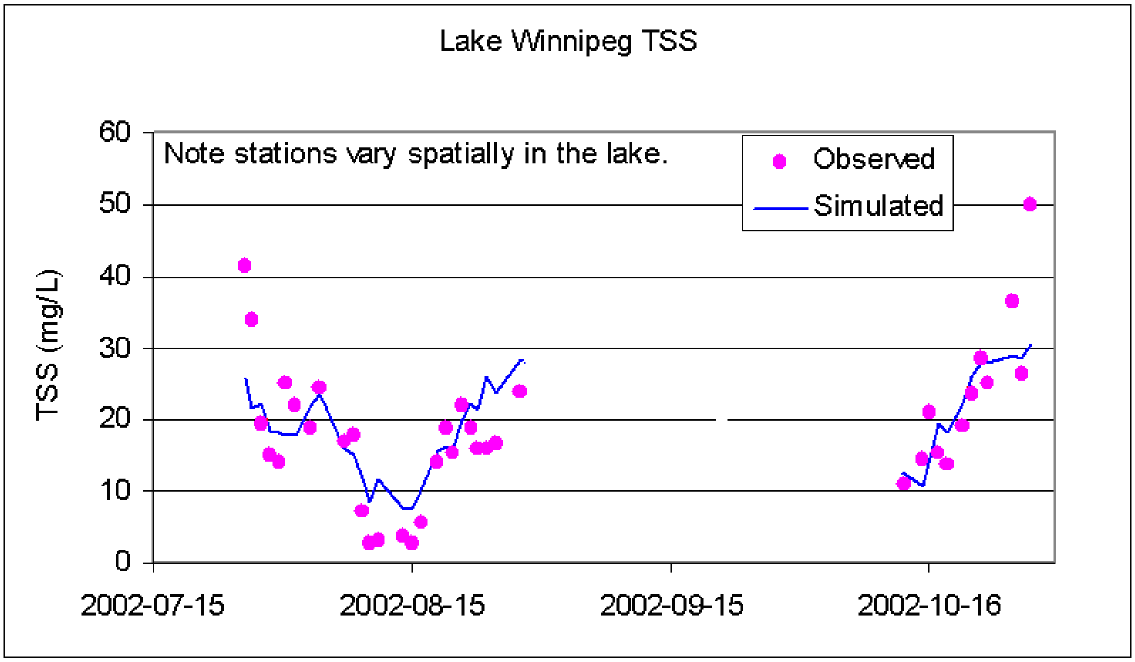


Figure 60: Little Saskatchewan TP concentration



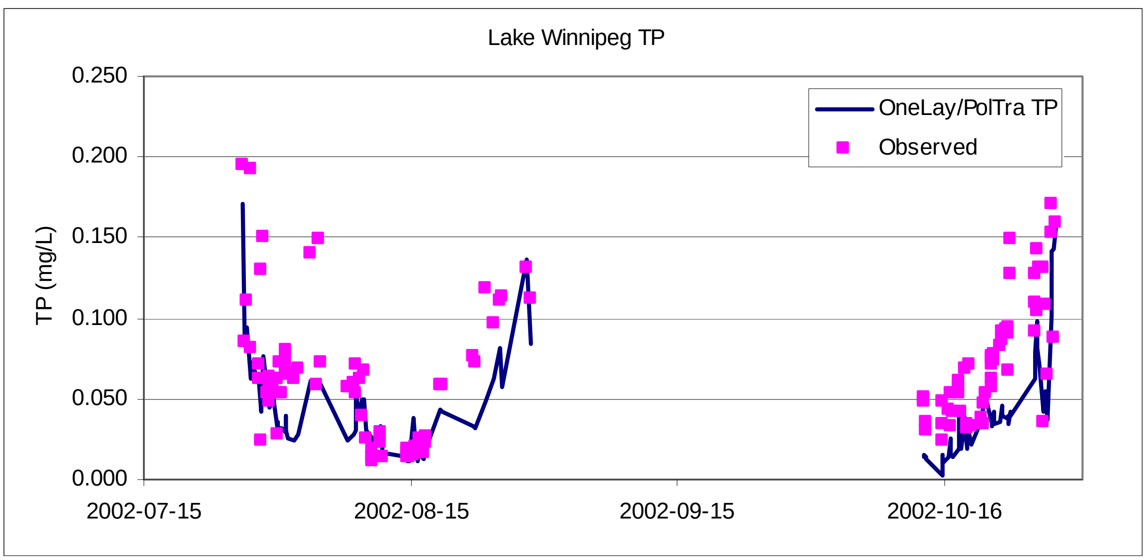


Figure 61: OneLay/PolTra Simulated and Observed Time Series (a) TSS (b) TP

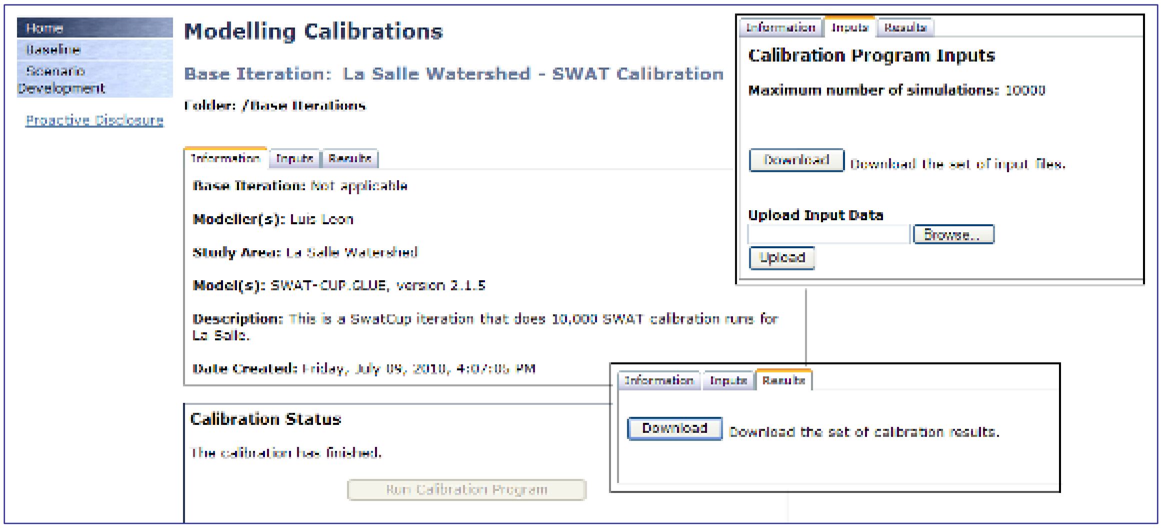


Figure 62: The web-based DSS for performing SWAT calibrations.

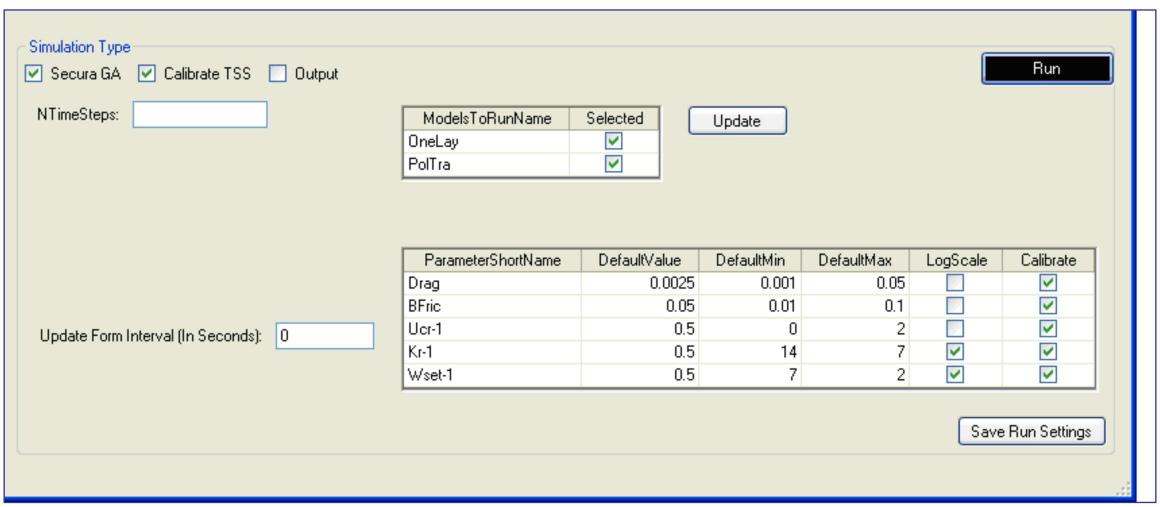


Figure 63: An interface for setting up the calibration for the calibration for the OneLay/Poltra model.

Deliverable 6: Baseline science and data assessment for the Lake Winnipeg Basin

Project Team: Malcolm Conly, Sarah Hall, Lucie Levesque, John Lawrence, Leonard Wassenaar, Brian Parker, Ram Yerubandi, Emily Ritson Bennett, Sarah Ross, Vincent Mercier, Genevieve Tardiff; Environment Canada

Partners: Manitoba Water Stewardship, Partners for the Saskatchewan River Basin, Agriculture and AgriFood Canada, Fisheries and Oceans Canada

Progress and Achievements

- Environment Canada worked with the Manitoba government and other partners to draft a report assessing Lake Winnipeg's physical, chemical and biological characteristics from 1999-2007. The report compiled historic data for Lake Winnipeg, highlighted recent research on the lake, explored current and emerging issues of concern to the health and integrity of Lake Winnipeg, and provided a baseline against which the results of current research and monitoring activities can be compared. The Canada/Manitoba *State of Lake Winnipeg 1999-2007* report was issued in 2010.
- Support was provided through the LWBI to the Partners for the Saskatchewan River Basin for production of the *State of the Saskatchewan River Basin* report, published in 2009.
- The *Journal of Great Lakes Research* special edition on Lake Winnipeg was coordinated by EC scientists as a deliverable under the LWBI for publication in early 2012. Eighteen articles and papers from various government and non government authors are contained in the Journal's special edition, which is a peer-reviewed publication of the International Association for Great Lakes Research.
- Environment Canada worked with Manitoba to develop a science framework for developing long term, ecologically sensitive nutrient objectives for Lake Winnipeg and tributaries. Workshops were held with partners and stakeholders to obtain input into the framework.

Deliverable 6: Geo-spatial assessment and optimization of sampling networks to measure the health of Lake Winnipeg

Project Team: Malcolm Conly, Leonard Wassenaar, Sue Watson, Ram Yerubandi; Environment Canada

Partners: Manitoba Water Stewardship, Fisheries and Oceans Canada, University of Quebec

The federal and provincial monitoring/sampling network on Lake Winnipeg was assessed to determine the efficacy of the network to detect water quality changes within the lake, and geo-statistical analysis was undertaken to determine optimization of placement of the sampling network as well as frequency and duration of sampling. The purpose was to increase efficiency and assist in the future design of network and monitoring operations in support of water quality monitoring on Lake Winnipeg. This project was linked to the CA/MB *State of Lake Winnipeg 1999-2007* report, as data compiled as part of the retrospective assessment for the report formed the foundation for assessing the monitoring program.

Progress and Achievements

- An initial feasibility assessment was completed in March 2009 to determine whether there was sufficient data to undertake a geostatistical analysis of monitoring networks. The assessment concluded that there was sufficient data from the various networks to undertake such an analysis. This initial feasibility assessment also provided a description of the various statistical approaches to be employed in the analysis.
- During 2009-10 a first statistical assessment of the current applied monitoring activities in Lake Winnipeg was undertaken, focusing on isotope sampling data, and various conservative water quality parameters including pH, conductivity, total suspended solids, water temperature, chloride, alkalinity, hardness, etc. Results from this analysis indicated that for most of the water quality variables tested, monthly sampling would allow acceptable estimation of the mean values for most of the variables. High variability in some parameters, however, suggested that more samples may be required for more accurate estimation of the mean values of these variables.
- Results of this initial assessment also revealed that of the parameters tested, there is no set of stations that should unambiguously be removed from, or retained from the network.

- Results also suggested that due to the irregularly applied sampling frequency of the parameters tested, autocorrelation analysis and seasonal characteristics of the water quality variable cannot be adequately assessed. In order to provide some further insight on autocorrelation and seasonal characteristics, it was recommended that intensive sampling be applied at a few sampling sites that represent the three main regions (the narrows, the south and north basins) in Lake Winnipeg.

Challenges and Lessons Learned

The variety of sampling networks operated by the various agencies, at times following different field protocols, created challenges in assimilating a consistent series of data that could be used for the statistical analysis. The preparation of the *State of Lake Winnipeg 1999-2007* report, which used the data from the various networks for assessing the status of the lake, was the key to advancing this project.

Data for the lake came from three primary sources - Fisheries and Oceans Canada, Manitoba Water Stewardship, and Environment Canada. Through the process of sorting through the data, many of the issues associated with comparability issues with variable sampling techniques and analytical methodologies were discovered and highlighted, prior to undertaking the more complex geo-spatial analysis of the data.

As part of this project, as well as within the context of the overall LWBI, working closely with the team of scientists preparing the *State of Lake Winnipeg* report, and centralized management of geo-spatial data for LWBI proved to be very beneficial.

Conclusions

This project was a necessary step in assessing the efficacy of the current network of monitoring stations within Lake Winnipeg to detect change. Moreover, and once water quality objectives have been established for the lake, the geo-statistical analysis will provide a basis for optimizing the sampling network both spatially and temporally relative to frequency of sampling and will help to inform the required duration of operation for the network, in order to detect change.

Much remains to be done in the context of the Lake Winnipeg water quality monitoring network. Network design will require careful consideration of monitoring objectives. These objectives need to be reviewed and precisely defined for Lake Winnipeg. Moreover, the objectives will need to be defined relative to the specific indicators (parameters or variables) that will be used to measure the nutrient changes and the changes in the ecology of the system, before the final networks can be designed or existing networks optimized.

Periodic analysis of the monitoring network will also be required in the future, in part due to the potential regime changes in lake water quality resulting from hydrologic or climatic change, but also due to changes in other factors that could impact on the lake (e.g., invasive species). More broadly, it is also important in an adaptive management framework to periodically evaluate a monitoring system in the context of its objectives.

Implementation of an appropriate water quality monitoring network post 2012, informed by the results of this study, will be imperative in tracking the change in the nutrient regime of Lake Winnipeg.

Deliverable 6: Performance indicators to assess the health of Lake Winnipeg and the watershed

Project Team: Malcolm Conly, Vincent Mercier, Sarah Hall, Genevieve Tardif; Environment Canada

Partners: Manitoba Water Stewardship

The goal of this project was to identify, assess and prioritize a list of measurable and informative indicators most relevant to detecting change in the status of eutrophication in Lake Winnipeg. The indicators could be used to direct future monitoring and research activities in and around the lake, and complement the development of ecologically relevant nutrient objectives.

Progress and Achievements

- An advisory committee consisting of water quality experts from Manitoba Water Stewardship, Environment Canada, and academia, collectively developed a list of potential eutrophication indicators for Lake Winnipeg. Selection was based on experience gained from conducting monitoring and research in the Basin and on collective knowledge of both historical and recent literature. As a result of this process, eighteen indicators were chosen for more extensive review and assessment.
- Literature reviews were conducted for each indicator, to complete a profile on how the indicator could best be reported, whether the data needed for that indicator was available or easily attainable, if the indicator was particularly suited to Lake Winnipeg, how frequently it should be reported, if the indicator was already in use for the Great Lakes, and a variety of other attributes. Concrete map based, chart based, and text driven examples illustrating how the indicator could best be reported to diverse audiences was also included within each of the profiles.
- Applying some of the indicator selection and assessment methods adopted for the Great Lakes, a DPSIR (driver-pressure-state-impact-response) model was used to categorize the various indicators and understand the relationships between indicators and their inter-dependencies.
- A list of assessment criteria was also developed so that each indicator could be evaluated in a systematic way and without bias. The indicators were assessed and prioritized using these criteria, and eighteen indicator profiles developed. A draft report on the indicators and assessment methodology was produced.
- A review process which included an indicator assessment survey was developed for distribution to experts, to enable feedback for each indicator. Ongoing characterization, refinement and validation of the indicators is expected to continue as the peer review process unfolds.

Challenges and Lessons Learned

Some delays in the delivery of this product resulted from staffing constraints in 2011, as well as from challenges in identifying the most appropriate indicators for Lake Winnipeg from an extensive list currently in use for the Great Lakes. Compared to the Great Lakes, there is limited research available for Lake Winnipeg. In some cases, entirely new indicators had to be identified. Highly effective and useful indicators often rely on data that currently does not exist, or which is difficult or costly to obtain.

Many indicators are correlated and it is difficult to quantify the extent of that correlation without supporting scientific literature. As one example, the near shore environment is frequently mentioned as a critical area for monitoring and for the development of specific indicators, but studies in this area ended before any meaningful results could be obtained.

Ideally, the most relevant and critical eutrophication indicators should be identified prior to the development of ecologically relevant objectives and should guide that development. Otherwise, significant effort may be expended on the development of an objective that has little ability to influence the resulting eutrophication challenges.

Finally, an extensive collection of peer-reviewed literature is needed to accurately identify and assess each indicator. Relevant science that contributes to the identification and assessment of priority indicators was still underway when the indicators report was being developed. For example, much of the content for the indicator report relied on science being undertaken concurrently through the LWBI, much of which is still being finalized and only now appearing in publications and journals. As a result, indicators development may have been better timed as a follow-up to the LWBI. Despite this, significant process was made on the development of a potential list of indicators suited to Lake Winnipeg and on a methodology to assess them.

Conclusions

Despite some challenges, significant progress was made on the review of potential indicators for Lake Winnipeg. A variety of partners were engaged throughout the process. Various methods for delivery of the indicators were identified along with gaps in both data and knowledge on those indicators. A priority list of indicators was developed after careful consideration and assessment.

More effort will be required to further validate these indicators in conjunction with the establishment of measurable objectives/targets for these indicators. Moreover, the existing network of monitoring sites will need to be assessed and potentially re-designed, relative to these indicators and the results of the geo-spatial analysis of existing networks on Lake Winnipeg.

It is further recommended that these indicators be considered in the context of the framework on developing ecologically relevant nutrient objectives for Lake Winnipeg, as developed by Manitoba Water Stewardship.

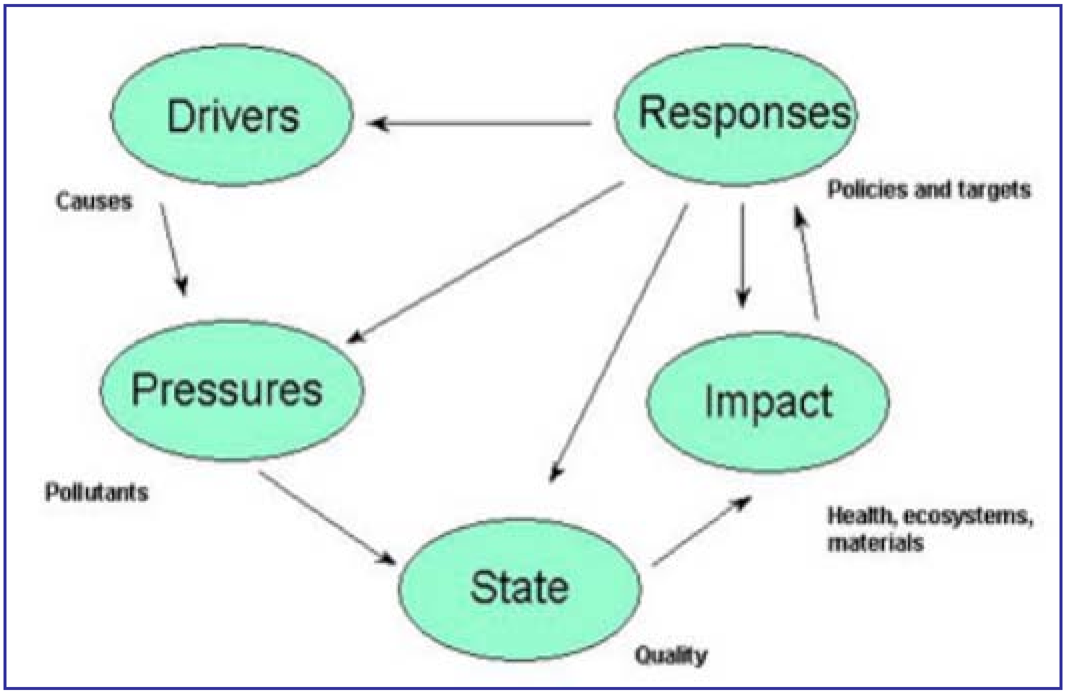


Figure 64: The Driver-Pressure-State-Impact-Response (DPSIR) model being incorporated as part of the Lake Winnipeg indicator development.

Table 9: Indicator Profile Template used to characterize and profile the 18 indicators identified by the experts for Lake Winnipeg.

	Name of the Indicator
What does it measure?	Identify the quantitative or qualitative value provided by the indicator
Issue Represented	What issue does the indicator address? For example does it generally provide information on eutrophication or specifically address a nutrient related challenge?
Recommended Methodology	How will the indicator be calculated and presented for public/decision-maker display and use.
Objectives	Do any specific objectives or targets for the indicator already exist? If not, are there objectives that can be applied or is there a recommended approach to the development of appropriate guidelines/standards/ objectives.
Temporal and Spatial Scales	What is the scope of applicability of the indicator from both a temporal and spatial scale? Is the indicator most suited for application only in one Basin, an area of the watershed or more broadly through space and time?
Reporting Recurrence	What is the recommended temporal reporting frequency?
Limitations	What are the limitations to reporting on the indicator? This may include a lack of necessary data, non-relevance, inability to control for confounding factors like climate change and weather, limitations on measurement precision and accuracy, or lack of an appropriate methodology.
Data Source	Who is/are the provider(s) of the data needed to report on the indicator?
Short term feasibility	How quickly can the indicator be adopted for reporting?
Indicator in use already for the State of Great Lakes Assessment?	Is the same indicator already used for reporting on the State of the Great Lakes?
Driver, Pressure, State, Impact or Response (DPSIR model component)	As part of the DPSIR model, where does this indicator fit?

Table 10: Consolidated list of eighteen indicators relative to the (DPSIR) model

Pressures: As a result of supporting the drivers

1. Risk of contamination by phosphorus from agriculture
2. P loading (from major tributaries)
3. N loading (from major tributaries + atmospheric?)
4. Run-off
5. Invasive species

State: Changes which result from pressures created in an attempt to meet the demands of driving human needs.

1. Dissolved oxygen
2. P concentration
3. N concentration
4. N:P ratio
5. Water Quality Index

Impact: Causal impacts which can be linked to changes in state.

6. Beach closure advisories
7. Algal blooms (frequency, intensity, spatial distribution and duration)
8. Commercial fish catches
9. Wetland extent and change within watershed
10. Benthic Species metrics

Responses: Implementation and adoption of policies or beneficial management practices

1. Area of land currently under a BMP
2. Percent of population with Wastewater Treatment
3. System management

Conclusion

The LWBI accomplished its near-term deliverables and commitments; however, challenges remain.

The water quality and biological monitoring conducted throughout the four years of the LWBI provided a relatively short “snapshot” of environmental conditions in Lake Winnipeg and its watershed. Spatial and temporal gaps in monitoring data imposed limitations on some of the research and modelling results. For example, reasonable calibration of hydrodynamic and eutrophication models was achieved during the LWBI, but additional observations, including winter measurements, would provide more robust validation of the models. Longer-term water quality and biological monitoring is also necessary to reflect the annual and seasonal variability that exists in the watershed and affects nutrient transport and delivery, and for measuring the effectiveness of current and future nutrient reduction measures on the health of Lake Winnipeg.

Additional areas for potential further exploration were identified throughout the course of the LWBI, including the role of flooding on nutrient loading into Lake Winnipeg, the role of internal recycling of nutrients within the lake, impacts of environmental factors (light conditions, wind speeds, etc.), climate change and variability, and the potential impact of invasive species. Nutrient-related issues in Lake Winnipeg also show parallels with those within the Lake Erie West Basin. Comparison and analyses of these two systems may allow further insight into the factors modifying Lake Winnipeg’s response to current and future basin-wide actions.

Work undertaken through the LWBI also points to the need for a standard approach across Canada to measure and value ecological goods and services (EG&S). Applying this concept holds the potential to reveal otherwise-hidden benefits associated with water quality improvement projects.

In order to facilitate transboundary nutrient management, the federal focus going forward should be on the inclusion of the nutrient issue in collaborations with domestic and international mechanisms and partners, in a manner that supports the implementation of a broad bi-national nutrient management strategy across the Red River basin. Opportunities also exist to increase engagement of other provincial and U.S. entities to address nutrient issues in Lake of the Woods and the Winnipeg River system.

Focusing future stewardship efforts and support on sub-watersheds shown to be the significant sources of nutrient loading, along with implementation of long-term water quality monitoring and other evaluation tools, would also enable a more demonstrable assessment of stewardship project impacts on nutrient loading. Targeted initiatives to engage watershed residents in individual and collective behavioural changes would be beneficial in realizing short-term outcomes and garnering support for longer-term systemic solutions. Increased engagement of watershed residents in supporting and participating in potential remedies to address the issues affecting Lake Winnipeg will be important for community-driven stewardship to take hold and grow.

Finally, the role and contributions of partner agencies and stakeholders in contributing to the LWBI cannot be overstated. The expertise, data and advice provided by the Manitoba government, Agriculture and Agri-Food Canada, Fisheries and Oceans Canada, municipal agencies and conservation districts, non-government agencies, landowners and other stakeholders was vital for implementation of all facets of the LWBI. The vast size of the watershed, and the myriad of non-point sources of nutrient loading, makes engagement across a broad spectrum of government and non-government agencies and stakeholders essential for improving the health and sustainability of Lake Winnipeg.

Appendice 1 - List of LWBI Publications and Resources

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Appendice 2 - Lake Winnipeg Basin Stewardship Fund Projects

Round 1 Funded Projects

Project Name: Achieving Successful Wetland Restoration in the Assiniboine River Watershed

Project Proponent: Assiniboine Watershed Stewardship Association Inc.

Environment Canada Contribution: $139,400

Description: Source water quality in the Assiniboine River and its tributaries will be improved. Lake Winnipeg will benefit from better downstream water quality.

Project Name: Advancing Netley-Libau Marsh Restoration Efforts

Project Proponent: International Institute for Sustainable Development

Environment Canada Contribution: $44,000

Description: The project will promote the nutrient reduction benefits of marshland restoration to community stakeholders. This project expands on the International Institute for Sustainable Development's Netley-Libau Marsh Research.

Project Name: Building Capacity for Ecological Infrastructure Investments in the Red River Basin

Project Proponent: Red River Basin Commission

Environment Canada Contribution: $55,000

Description: Canadian municipalities and counties in the U.S. discussed costs and benefits of restoring natural environments to improve interjurisdictional water quality.

Project Name: Development of a Model/Experimental Watershed Representative of the Manitoba Prairie Pothole Region

Project Proponent: Ducks Unlimited Canada

Environment Canada Contribution: $391,464

Description: Ducks Unlimited and partners will establish a watershed monitoring network and water quality modelling that will be used to determine how changes in land use affect water quality. Wetlands will also be restored and monitored as part of this project.

Project Name: Development of a Preliminary Total Phosphorus Budget and Water Quality Modelling for Lake of the Woods

Project Proponent: Lake of the Woods Water Sustainability Foundation

Environment Canada Contribution: $129,911

Description: A phosphorus budget and water quality modelling are being developed to assist decision-making for phosphorus management in the Lake and its watershed. The Lake of the Woods Water Sustainability Foundation and partners are collaborating on this project.

Project Name: Icelandic River and Washow Bay Creek Non-Point Source Nutrient Abatement Program

Project Proponent: East Interlake Conservation District

Environment Canada Contribution: $25,000

Description: Agricultural nutrient runoff will be reduced to the Icelandic River and Washow Bay Creek through the use of fencing, alternate watering sources for cattle and riverbank vegetation zones.

Project Name: Meewasin Valley Authority Riparian Restoration

Project Proponent: Meewasin Valley Authority

Environment Canada Contribution: $21,608

Description: Water quality in the South Saskatchewan River and Lake Winnipeg has improved by restoring natural vegetation to damaged shore lands and by educating the public on the importance of riparian zones in river ecology.

Project Name: Modelling Water Quality in the South Basin of Lake Manitoba

Project Proponent: University of Manitoba

Environment Canada Contribution: $25,000

Description: Understanding of Lake Manitoba water quality has been improved by this study, which also provides a basis for evaluating nitrogen and phosphorus reduction efforts. This research could also be used to measure the impact of Lake Winnipeg stewardship initiatives.

Project Name: Qu'Appelle River Water Quality Mitigation Project

Project Proponent: Upper Assiniboine River Conservation District

Environment Canada Contribution: $4,300

Description: Agricultural nutrient runoff has been reduced to a seasonal oxbow lake in the Upper Assiniboine River through the use of fencing, alternate watering sources for cattle and riverbank vegetation zones

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Project Name: Seine River Riparian Enhancement Program

Project Proponent: Seine-Rat River Conservation District

Environment Canada Contribution: $25,000

Description: Agricultural nutrient runoff to the Seine River has been reduced through the use of fencing, alternate watering sources for cattle and riverbank vegetation zones.

Project Name: Souris River Riparian Enhancement Program

Project Proponent: Turtle Mountain Conservation District

Environment Canada Contribution: $25,000

Description: Agricultural nutrient runoff to the Souris River has been reduced through the use of fencing, alternate watering sources for cattle and riverbank vegetation zones.

Project Name: Wastewater Pond Systems in Cold Climates

Project Proponent: Spectrum Scientific Inc.

Environment Canada Contribution: $132,767

Description: A wastewater pond system will be adapted to Manitoba's climate using a modified greenhouse structure.

Round 2 Funded Projects

Project Name: The Sustainability of Municipal Wastewater Irrigation in the Interlake Region of Manitoba as a Means of Nitrogen and Phosphorus Abatement for Lake Winnipeg

Project Proponent: East Interlake Conservation District

Environment Canada Contribution: $6,257

Description: Wastewater irrigation, as an alternative to discharging wastewater directly to waterways leading to Lake Winnipeg, was assessed. The project involved three short-term field demonstrations of wastewater irrigation, municipal/town council focus groups on wastewater irrigation and a local resident survey to assess perceptions on wastewater re-use within their communities.

Project Name: Morden's Community Lead Environmental Action on Nutrient Elimination and Removal (CLEANER) in Dead Horse Creek

Project Proponent: University of Winnipeg

Environment Canada Contribution: $109,372

Description: This extensive water sampling and analysis program is identifying and monitoring sources of phosphorus and nitrogen along Dead Horse Creek, Plum River and the Red River near Morden, Manitoba. University undergraduate and high school students will contribute research products and practices to potentially reduce phosphorus and nitrogen in these waterways. Students will also lead community-based social marketing efforts to encourage Morden area residents to deposit less phosphorus and nitrogen in the town's storm and sanitary wastewater systems.

Project Name: Moose Mountain Creek Phosphorus Reduction Project

Project Proponent: Cornerstone Regional Economic Development Authority

Environment Canada Contribution: $37,250

Description: Beneficial management practices (BMPs) that reduce agricultural phosphorus loads and improve water quality are being promoted. Perennial forage seeding, exclusion fencing, portable windbreaks and portable water systems are all improving water quality. Stewardship agreements are engaging landowners to convert cropland to perennial forage, restore wetlands and improve both winter site and riparian zone management. BMPs are being promoted across the watershed through outreach activities such as field demonstration days, public newsletters and on-site farm visits by technicians.

Round 3 Funded Projects

Project Name: Down the Drain - A Demonstration Landscape; Using Plants and Natural Systems to Clean Our Water

Project Proponent: Rivers West Red River Corridor Inc.

Environment Canada Contribution: $46,014

Description: Rivers West Red River Corridor Inc. and partners are designing and constructing a "rain garden" or bioretention system that filters storm runoff using landscaping similar to that found in forest ecosystems. The project is also encouraging the community and local schools to participate in the project and learn more about water quality challenges facing Lake Winnipeg

Project Name: Pembina River Watershed – Integrated Watershed Management Plan

Project Proponent: Pembina Valley Conservation District

Environment Canada Contribution: $25,000

Description: The Pembina Valley Conservation District is engaging landowners near Rock Lake and Killarney Lake to reduce nutrient loads and shoreline erosion by restricting cattle access to waterways leading into Lake Winnipeg. In addition, a water retention dam is being constructed above an eroding gully close to Rock Lake, reducing sediment runoff in drinking water sources and larger waterways entering Lake Winnipeg.

Project Name: Lake Friendly Campaign

Project Recipient: Lake Winnipeg South Basin Mayors and Reeves

Environment Canada Contribution: $241,520

Description: The Lake Winnipeg South Basin Mayors and Reeves are reducing nutrient contributions to Lake Winnipeg by informing and educating consumers about products that are the best environmental choice for Lake Winnipeg. The project's "It's Lake Friendly" labelling campaign identifies products that are better environmental choices for reducing nutrients to Lake Winnipeg.

Project Name: Nutrient Management through Livestock Management

Project Recipient: Assiniboine Hills Conservation District

Environment Canada Contribution: $17,580

Description: The Assiniboine Hills Conservation District is working with landowners and cattle operators to develop three riverbank management sites that are reducing nutrient flows to Lake Winnipeg through practices such as: fencing to restrict livestock creek access, alternative watering and overwintering sites located away from the riverbank.

Project Name: Lake Wahtopanah Nutrient Reduction Project

Project Recipient: Little Saskatchewan River Conservation District

Environment Canada Contribution: $25,000

Description: The Little Saskatchewan River Conservation District and landowners are working together to reduce phosphorus loads to Lake Winnipeg by identifying and restoring primary shoreline areas along Lake Wahtopanah. They are improving water quality in these areas through beneficial management practices such as planting riparian buffers zones and grassed waterways, installing offsite watering systems, and constructing retention ponds.

Project Name: Upper Oak River Non-Point Source Nutrient Reduction Project

Project Recipient: Upper Assiniboine River Conservation District

Environment Canada Contribution: $25,000

Description: The Upper Assiniboine River Conservation District and landowners are reducing phosphorus loads to Lake Winnipeg by identifying and restoring primary shoreline areas along the Upper Oak River sub-watershed. They are also re-establishing perennial cover in these areas to reduce erosion and runoff sediment, reduce nutrient loads to Lake Winnipeg and benefit local aquatic ecosystems.

Project Name: Thunder and Silver Creeks Surface Water Management Project

Project Recipient: Birdtail Assiniboine Water Planning Authority

Environment Canada Contribution: $25,000

Description: The Birdtail Assiniboine Water Planning Authority is working with local landowners to select priority restoration areas along Thunder Creek and Silver Creek. Through beneficial management practices such as reconstructing wetlands, building water retention ponds and developing in-stream erosion structures, their efforts are limiting nutrient loads and reducing the impacts of local flooding.

Project Name: Paleolimnological Determination of Water Quality Change in Lake Winnipeg for Use as Management and Remediation Goals

Project Recipient: Dr. Peter Leavitt, University of Regina

Environment Canada Contribution: $126,162.50

Description: Seven researchers from four universities are working together to create a long-term record of historical water quality changes within the north Basin of Lake Winnipeg. This research is documenting past trends and recent changes such as increases in potentially toxic *cyanobacteria* and changes in the lakes nitrogen, phosphorus and carbon levels. This research will help decision-makers to set ecologically-relevant goals for nutrient reduction and the future management and protection of Lake Winnipeg.

Round 4 Funded Projects

Project Name: Establishing a Process for a Wetland Vegetation Rehabilitation and Management program focused on Reed Canarygrass (Phalaris arundinacea): A Parkland Mews Case Study

Project Recipient: The University of Manitoba

Environment Canada Contribution: $13,000

Description: The University of Manitoba is conducting research that will minimize knowledge gaps in the control of the invasive species, Reed Canarygrass. Research results will examine the effectiveness of constructed wetland cells to prevent nutrient loads and will determine the connection between increased nitrogen and phosphorus loads and Reed Canarygrass.

Project Name: Beaver Creek Water Retention Project

Project Recipient: Upper Assiniboine River Conservation District

Environment Canada Contribution: $3,600

Description: The Upper Assiniboine River Conservation District is working with partners to create a dam that will reduce local seasonal flooding and nutrient runoff in the Beaver Creek watershed. The dam will allow water to be captured in early spring and slowly filter into surrounding soils to recharge local ground water and increase flow to important fish habitat downstream.

Project Name: Sustainable Nutrient Removal and Recovery from Wastewater

Project Recipient: The University of Manitoba

Environment Canada Contribution: $36,000

Description: The University of Manitoba is developing a method for treating municipal wastewater through an innovative biological process that reduces nutrient loads to Lake Winnipeg while allowing for the recovery of phosphorus -- a valuable economic resource. The results of this project will be used to carry out a pilot study at the City of Winnipeg's South End wastewater treatment plant.

Project Name: Nutrient Reduction and Habitat Rehabilitation Project

Project Recipient: West Interlake Watershed Conservation District

Environment Canada Contribution: $12,500

Description: The West Interlake Watershed Conservation District is improving local water quality by eliminating cattle access along three creeks through the installation of exclusion fencing, off-site watering systems and cattle crossings, and restoring riverbank vegetation areas.

Project Name: Enhanced Removal of Nutrients, Organic Micropollutants and Toxicity from Sewage Lagoons and Waters of Morden and Winkler by Manipulative Constructed Wetland Microcosms

Project Recipient: The University of Winnipeg

Environment Canada Contribution: $173,761

Description: The University of Winnipeg is researching the benefits of using constructed wetlands to remove nutrients such as phosphorus and nitrogen and other toxic substances from rural wastewaters.

Project Name: Prevent Livestock Nutrient Runoff into the Souris River

Project Recipient: Assiniboine Hills Conservation District

Environment Canada Contribution: $16,300

Description: The Assiniboine Hills Conservation District is setting up fencing and alternative wintering sites for cattle as well as portable wind breaks and swath grazing along the Souris River. These beneficial management practices are significantly reducing the loading of nutrients such as phosphorus and nitrogen into this tributary of Lake Winnipeg.

Project Name: Lake of the Woods Water Quality Improvement Program

Project Recipient: Anishinaabeg of Kabapikotawangag Resource Council Inc

Environment Canada Contribution: $12,050

Description: The Anishinaabeg of Kabapikotawangag Resource Council and partners are identifying and preventing sources of nutrient runoff to the Lake of the Woods. In addition to analyzing and prioritizing sites for future water quality improvements, project leaders are educating the local community on how residents can help to improve local water quality.

Project Name: Assessing the Relationship between Internal Ferrous Iron Loading and Cyanobacteria Bloom Formation in Lake Winnipeg

Project Recipient: Faculty of Environmental Studies – York University

Environment Canada Contribution: $24,800

Description: York University is researching how loading rates and quantities of internal ferrous iron and other sediments can help predict the formation of *cyanobacterial* algae blooms within Lake Winnipeg.

Project Name: Dog River Constructed Wetland Lagoon System

Project Recipient: Moose Jaw River Watershed Stewards Inc.

Environment Canada Contribution: $25,000

Description: The Moose Jaw River Watershed Stewards and partners are creating a wetland lagoon system that will restore native plant communities and provide a healthier aquatic ecosystem downstream.

Round 5 Funded Projects

Project Name: The Forks Riparian Preserve

Project Recipient: Forks Renewal Corporation

Environment Canada Contribution: $40,000

Description: Project leaders with the Forks Renewal Corporation are helping to improve the quality of water entering Lake Winnipeg by restoring a riverbank habitat on approximately two acres along the banks of the Assiniboine River at the Forks Historic site in Winnipeg, Manitoba.

Project Name: Pembina and Long River Riparian Enhancement Program

Project Recipient: Turtle Mountain Conservation District

Environment Canada Contribution: $20,000

Description: The Turtle Mountain Conservation District is encouraging land managers along Manitoba's Pembina River and Long River to implement agricultural practices that will benefit water quality and improve local riverbank integrity. Some of these beneficial agricultural management practices include restrictive cattle fencing and remote watering systems for cattle and the re-establishment of riverbank vegetation as a "buffer" zone to prevent erosion.

Project Name: Peguis First Nation Sustainable Cattle Management Project

Project Recipient: Centre for Indigenous Environmental Resources (CIER)

Environment Canada Contribution: $15,000

Description: To improve water quality in the Peguis First Nation, the Centre for Indigenous Environmental Resources (CIER) is working with a community producer to create a new management system designed to more effectively spread cattle manure. The result will be greater agricultural productivity, reduced overland runoff and fewer nutrients entering the local watershed. CIER is also providing guidance to help the producer to reconstruct farm operations with techniques such as cattle rotation, restrictive fencing and other beneficial agricultural management practices.

Project Name: Innovative Process for Enhanced Phosphorus Recovery from Sludge

Project Recipient: University of Manitoba (Dr. Jan Oleszkiewicz)

Environment Canada Contribution: $26,000

Description: The University of Manitoba is conducting new research on the potential use of water treatment reactors to recover phosphorus from wastewater sludge. The results of this innovative study will be tested in a pilot experiment at the City of Winnipeg's South End wastewater treatment plant.

Project Name: Riparian Enhancement Initiative

Project Recipient: Whitemud Watershed Conservation District

Environment Canada Contribution: $20,000

Description: The Whitemud Watershed Conservation District is protecting Lake Winnipeg water quality by enhancing the health, longevity, and effectiveness of riverbank buffer zones along the Whitemud River. Project leaders are constructing restrictive fencing to keep cattle from damaging the riverbank and polluting the water, re-establishing riverbank buffer zones with natural materials and native plants, and working with landowners to ensure future protection of the riverbank zone and its water quality.

Project Name: Sensitive Habitat Inventory and Mapping of Foreshore Areas of Lake Winnipeg's South Basin

Project Recipient: Lake Winnipeg Foundation

Environment Canada Contribution: $110,950

Description: Foreshore areas are often significantly impacted by human activities and play a key role in the health and vitality of Lake Winnipeg. The Lake Winnipeg Foundation is gathering aerial photos and field research on ecosystems along the south Basin of Lake Winnipeg's foreshore. This information will provide decision makers, planners, developers, landowners, and government agencies with the tools they need to make sustainable shoreline use decisions.

Project Name: Effective Use of Riparian Zones to Filter Sediments and Phosphorus

Project Recipient: University of Manitoba (Dr. David A. Lobb)

Environment Canada Contribution: $99,600

Description: The University of Manitoba will undertake a comprehensive study on the use of riparian areas as filters for sediment and phosphorus that enter waterways from agricultural land. Data from previous studies in the Lake Winnipeg Basin are being analyzed and enhanced through continued field research. The final results will provide decision-makers with the information they need to determine the future use of riverbank areas in preventing nutrients from entering Lake Winnipeg and its watershed.

Project Name: Nutrient Reduction on Continuous Cropped Erodible Soils

Project Recipient: Swan Lake Watershed Conservation District

Environment Canada Contribution: $25,000

Description: The Swan Lake Watershed Conservation District (SLWCD) is working with land owners in southwest Manitoba to prevent topsoil loss and the negative impacts it has on groundwater quality. Together, the SLWCD and landowners are constructing flow-reduction waterways that will re-establish natural vegetated areas in cropland that is vulnerable to erosion and soil loss.

Project Name: Wetland Restoration Preservation Initiative

Project Recipient: East Interlake Conservation District

Environment Canada Contribution: $26,000

Description: The East Interlake Conservation District (EICD) is working with landowners in locations at risk of wetland loss to encourage the establishment of conservation agreements with EICD and the Manitoba Habitat Heritage Corporation. These agreements will protect this land from future development and prevent further agricultural nutrients from entering Lake Winnipeg at these sites.

Appendice 3 - CA/MB MOU and Terms of Reference

Canada-Manitoba Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin

Between

THE GOVERNMENT OF CANADA,
represented herein by the Minister of the Environment,
who is responsible for the Department of the Environment

("Canada")

AND

THE GOVERNMENT OF MANITOBA,
represented herein by the Minister of Water Stewardship,

("Manitoba")

Canada and Manitoba are collectively called "the Parties".

WHEREAS Canada and Manitoba (the Parties) share the vision of a healthy, prosperous and sustainable Lake Winnipeg for present and future generations;

AND WHEREAS, Lake Winnipeg is the 10th largest freshwater lake in the world based upon surface area and the 3rd largest freshwater reservoir;

AND WHEREAS, the Lake Winnipeg Basin encompasses a drainage area of over one million square kilometres, in four Canadian provinces, and four American states, and is impacted by water related decisions and actions taken by governments in those states and by decisions of the Canadian and American federal governments;

AND WHEREAS, the Lake Winnipeg Basin is home to over six million people, and human activities from agriculture, urban and industrial development have resulted in increasing amounts of nutrients and other substances being deposited into Lake Winnipeg;

AND WHEREAS, Lake Winnipeg supports significant economic activity in the region, particularly through fishing and recreation industries;

AND WHEREAS, the Parties recognize the importance of the health of Lake Winnipeg and its Basin to the ecological, social and economic well-being of Manitobans and other residents of the Basin;

AND WHEREAS, the Parties are concerned about environmental degradation of the water quality of Lake Winnipeg and the long-term ecological health of Lake Winnipeg and the Lake Winnipeg Basin;

AND WHEREAS, the federal and provincial governments each have responsibilities relating to water and the Parties thus share mutual interests in cooperating to protect the water quality and ecological health of Lake Winnipeg and the Lake Winnipeg Basin;

AND WHEREAS, the Parties recognize the need to coordinate their respective efforts to develop and implement scientific research and monitoring activities and to promote and undertake governance and management activities aimed at protecting the ecological health of Lake Winnipeg and the Lake Winnipeg Basin;

AND WHEREAS, the *Canada Water Act* encourages federal-provincial cooperation in the examination and resolution of water resource issues and provides for arrangements with provinces respecting water resource management;

AND WHEREAS, the *Water Protection Act* (Manitoba) recognizes the importance of inter-jurisdictional agreements protecting water, and the shared right and responsibility of all jurisdictions in the Hudson Bay Drainage Basin to protect water resources within the Basin;

AND WHEREAS, the Governor General in Council has by Order-in-Council No. xx dated xx, authorized the Minister of the Environment to enter into this Memorandum of Understanding for Canada; and

AND WHEREAS, the Lieutenant-Governor in Council has, by Order-in-Council No. xx dated xx, authorized the Minister of Water Stewardship to enter into this Memorandum of Understanding for Manitoba,

NOW THEREFORE, THE PARTIES COMMIT TO THE FOLLOWING:

SECTION 1 - DEFINITIONS

In this Memorandum of Understanding (MOU):

a) "aquatic ecosystem" means the community of flora and fauna functioning and interacting together within their aquatic habitats and habitats immediately adjacent to and associated with surface waters.

b) "Lake Winnipeg" means the surface waters and shoreline of Lake Winnipeg.

c) “Ministers” means the Minister of the Environment for Canada and the Minister of Water Stewardship for Manitoba.

d) “nutrients” means elements necessary for the development and sustainment of aquatic life.

e) “senior representatives” means for Canada, the Regional Director General for Environment Canada, Prairie Northern Region, and for Manitoba, the Assistant Deputy Minister, Ecological Services Division, for Manitoba Water Stewardship.

SECTION 2 -PURPOSE

The purpose of this MOU is to facilitate a cooperative and coordinated approach between the Parties in their efforts to understand and protect the water quality and ecological health of Lake Winnipeg and its Basin, and achieve a healthy, prosperous and sustainable Lake Winnipeg for present and future generations.

SECTION 3 – PRINCIPLES

The following principles will direct and guide the actions of the Parties under this MOU**:**

a) *Openness and Transparency.* The Parties are concerned with the ecological health and sustainability of the entire Lake Winnipeg Basin insofar as this affects the water quality and aquatic ecosystem health of Lake Winnipeg. Consequently, the Parties agree to the sharing of information with each other, stakeholders and interested parties.

b) *Cooperation and Collaboration*. The Parties wish to work together to identify priorities to achieve the vision of a sustainable Lake Winnipeg. The Parties agree to work together to identify priorities for science activities. Also, the Parties intend to coordinate the activities of their respective departments to ensure comprehensive monitoring, management, communication and governance activities, in order to maximize synergies and avoid duplication.

c) *Maximizing the Benefits of Existing Resources or Mechanisms.* The Parties may rely upon other existing federal-provincial agreements, arrangements and other decision-making mechanisms to support this MOU.

d) *Accountability for Activities.* The Parties are committed to undertaking individual and collaborative efforts in keeping with the principles set out in the MOU. The Parties understand that although this MOU does not commit the transfer of resources between them in the carrying out of projects and initiatives related to this MOU, the Parties may agree to jointly fund projects developed under subsidiary arrangements of this MOU.

SECTION 4 - GEOGRAPHICAL SCOPE OF MEMORANDUM OF UNDERSTANDING

The geographical scope of the MOU is Lake Winnipeg and its Basin and downstream receiving environment, within the Province of Manitoba.

SECTION 5 – SUBSIDIARY ARRANGEMENTS

a) The Parties agree that they may, from time to time, develop subsidiary arrangements to outline the nature and scope of collaborative programs of scientific study, management and governance for the purpose of this MOU that are a priority to the Parties and that will benefit from cooperative and coordinated action.

b) Subsidiary arrangements may be developed at any time and will come into effect upon signing by senior representatives for the Parties. Each subsidiary arrangement will remain in effect for the duration of this MOU unless it specifies an earlier expiry date.

c) Subsidiary arrangements may be amended by the senior representatives for the Parties at any time in the same manner as the subsidiary arrangement was made.

d) Subsidiary arrangements may be terminated by either Party giving the other at least six (6) months written notice. If the Parties terminate this MOU, all subsidiary arrangements are also terminated, unless the Parties agree otherwise in writing.

SECTION 6 - MANAGEMENT AND COORDINATION

a) The Parties will establish a Steering Committee to oversee the implementation of this MOU. The MOU Steering Committee will be co-Chaired by the senior representatives of the Parties who will report to their respective Ministers.

b) The Terms of Reference for the Steering Committee are set out in Appendix 1.

SECTION 7 – COMMITMENT TO NOTIFY

The Parties acknowledge that the actions of one government often have effects on other governments, and therefore commit to providing written notice of change in policies or programs that could have an impact on the achievement of the objectives of this MOU.

SECTION 8 - TRANSPARENCY AND INFORMATION SHARING

a) Subject to applicable access to information, privacy and other relevant legislation, the Parties intend to make available, at no cost to each other, and on a regular basis, all relevant data relating to or arising out of the activities under this MOU.
b) The Parties recognize that all data, research documents, and other materials produced by either of the Parties will remain the property of that Party, and one Party will not use, publish, distribute or disclose any information, data, research documents, or materials produced by the other Party without first obtaining permission from the other Party.
c) This MOU and any activity conducted pursuant to it are not intended to affect or diminish any proprietary rights or interests of the Parties.

SECTION 9 - COMMUNICATIONS

a) The Parties intend to collaborate, where possible, in developing public education and information materials, and in developing and implementing media relation plans with respect to this MOU to ensure consistent messages.

b) The Parties expect that where collaborative efforts do not occur in developing public education and information materials, the Party developing the materials will provide it to the other Party for information, prior to public release.

c) The Parties acknowledge that all communications involving Canada must conform to the requirements of the federal *Official Languages Act* (Canada) as well as all language related policies, guidelines and directions provided by the Treasury Board of Canada.

d) The Parties will treat information related to or generated as a result of this MOU in accordance with the requirements of applicable federal and provincial legislation.

SECTION 10 – AMENDING THE MOU

This MOU may be amended by agreement in writing by both Parties. Any amendment becomes part of this MOU.

SECTION 11 – SETTLEMENT OF DISPUTES

At the onset of a dispute, the Parties, or their senior representatives, agree to meet promptly for the purposes of attempting, in good faith, to resolve this dispute. The Parties are committed to working collaboratively to avoid and resolve any disputes concerning the interpretation or implementation of this MOU.

Any disputes regarding the interpretation or implementation of the MOU will be resolved by consultation between the Parties and will not be referred to a tribunal or other third party for resolution.

SECTION 12 – LANGUAGE OF MOU

This MOU is prepared in the English and French languages, and each version is equally valid.

SECTION 13 - DURATION OF MOU

a) This MOU comes into force on the date of signature by the Ministers and remains in force for a term of five (5) years, unless terminated earlier by one of the Parties in accordance with paragraph 13 c).

b) The Parties may extend this MOU for an additional term of five (5) years. Such an extension will require the mutual written consent of the Parties prior to the expiration of this MOU.

c) Either Party may terminate this MOU upon providing six (6) months written notice to the other Party.

SECTION 14 – REVIEW OF MOU

a) Prior to the expiration of each five (5) year term of this MOU, senior representatives will initiate a review the effectiveness of the MOU to assist the Parties in deciding whether to extend or renew this MOU.

b) The process to assess the effectiveness of this MOU will be coordinated by both senior representatives.

SECTION 15 – COMPLIANCE WITH LAW

a) Nothing in this MOU alters the legislative or other authorities of each of the Parties with respect to the exercise of their legislative or other authorities under the Constitution of Canada.

b) The Parties acknowledge that this MOU is governed by the applicable laws of Canada and Manitoba.

Terms of Reference for the Steering Committee for the Canada-Manitoba Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin

1) The MOU Steering Committee will be responsible for:

   a) Overseeing the implementation of the *Canada-Manitoba Memorandum of Understanding Respecting Lake Winnipeg and the Lake Winnipeg Basin;*

   b) Designing, developing and overseeing the implementation of subsidiary arrangements under this MOU, and overseeing any activities under the subsidiary arrangements;

   c) Developing a management review process to assess the degree to which implementation of this MOU has been successful, and for conducting ongoing management review prior to the expiration of each term of five years. Management reviews will be undertaken within existing resources;

   d) Establishing and maintaining working relationships with other governmental and non-governmental organizations with a mutual interest in Lake Winnipeg water quality and/or the ecological health of the Lake Winnipeg Basin;

   e) Meeting regularly, and keeping a record of meetings and deliberations with such records to be made public in a manner consistent with the structure of each Party's organization;

   f) Reporting to the respective Ministers;

   g) Creating committees and appointing membership as required to achieve the objectives of the MOU; and

   h) Carrying out such other related duties as the Ministers may request that are consistent with the intent and purpose of this MOU.

2) The composition of the MOU Steering Committee:

   a) Membership of the Steering Committee will strive to consist of an equal number of federal and provincial representatives appointed by each of the federal and provincial governments. The Steering Committee will be co-chaired by a federal representative employed with Environment Canada and a provincial representative employed with Manitoba Water Stewardship.

   b) Members of the Steering Committee will be appointed by the senior representatives of this MOU for Canada and Manitoba and may consist of membership from provincial and federal departments responsible for the management of water, natural resources, environment, aboriginal affairs, health, agriculture and government affairs, or others.

c) Additional members of the Steering Committee may be appointed by joint agreement of the senior representatives of the Parties.

3) Secretariat:

The Parties will share, on an equal basis, the Secretariat support required for the MOU Steering Committee, with no exchange of financial resources.

For More Information

For more information about the Lake Winnipeg Basin Initiative (2008/09 – 2011/2012), please contact:

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905-336-4913

Website: www.ec.gc.ca/doc/eau-water/winnipeg_e.html

Lake Winnipeg Web information portal: http://lwbi.cc.umanitoba.ca