A Water Quality Plan of Study for the Lake of the Woods Basin

International Joint Commission

January 2015

A Report to the Governments of Canada and the United States by the International Joint Commission

For more information about the International Joint Commission and its role in the Rainy-Lake of the Woods please visit the IJC's website: www.ijc.org. Information can also be obtained by contacting any of the following IJC offices:

U.S. Section

2000 L Street, NW
Suite #615
Washington, DC 20440
Phone: 202-736-9024
Fax: 202-632-2007

Canadian Section

234 Laurier Avenue West
22nd Floor
Ottawa, ON K1P 6K6
Phone: 613-995-2984
Fax: 613-993-5583

This Report may be cited as:
International Joint Commission (2015) A Water Quality Plan of Study for the Lake of the Woods Basin.

Cover photos, left to right
Row one: Steep Rock Mine (L. Grim); Kawishiwi River (A. Mast),
Row two: Pine and Curry Islands (K. Saunders); Algae, Lake of the Woods (J. Taylor)

ISBN: E95-2/19-2015E-PDF
978-1-100-25601-6

@ IJCsharedwaters

Facebook.com/internationaljointcommission

Flickr.com/photos/internationaljointcommission

International Joint Commission
Canada and United States

Commission mixte internationale
Canada et États-Unis

January 22nd, 2015

Mr. Christopher Wilkie
Director, U.S Transboundary Affairs Division
Foreign Affairs and International Trade Canada
Lester B Pearson Tower A
125 Sussex Drive
Ottawa, Ontario K1A 0G2

Ms. Susan Saarnio
Director, Office of Canadian Affairs
WHA/CAN
U.S. Department of State
201 C St., NW, Room 3917
Washington, D.C. 20520

Dear Ms. Saarnio and Mr. Wilkie:

The International Joint Commission is pleased to transmit to the governments of Canada and the United States "*A Water Quality Plan of Study for the Lake of the Woods Basin*", January 2015.

The development of a water quality plan of study for the Lake of the Woods Basin was a recommendation in the Commission's January 2012 "*Report to the Governments of the United States and Canada on Bi-national Water Management of the Lake of the Woods and Rainy River Watershed*" to which the two governments agreed in their letters of June 29, 2012 and July 25, 2012.

The Commission commends the two governments for recognizing the importance of developing a water quality plan of study (WQPOS) for this watershed. As you will recall, the 2011 report of the International Lake of the Woods and Rainy River Watershed Task Force, established under the reference of July 13, 2010, identified three priority threats to water quality in these waters: nutrient enrichment and harmful algal blooms; aquatic invasive species; and surface and groundwater contamination. The Commission formed the International Lake of the Woods Basin Water Quality Plan of Study Team, and they developed the attached plan of study dated December 2014 to address these concerns to ensure the improvement and continuing health of the waters of the Lake of the Woods.

After thoroughly reviewing the report, and providing the public and others a 30 day comment period, the Commission is confident in strongly recommending that governments undertake all thirty two projects in the report contained and described in option B. The Commission notes the overall $8.4 million cost is modest considering that over three-quarters of a million people draw their source drinking water from the Lake of the Woods Basin and that good water quality in these waters is important to many other communities in north-western Ontario, Manitoba, and northern Minnesota.

The *Lake of the Woods and Rainy River State of the Basin Report, 2nd Edition* 2014 (attached), an International Watershed Initiative project undertaken by the International Rainy-Lake of the Wood Watershed Board as a first step for developing a water quality plan of study, provides a comprehensive review of environmental conditions and existing data including key ecosystem concerns, the gaps in knowledge to better understand those concerns, and recommended approaches for addressing these gaps. We recommend that this report be reviewed in conjunction with the WQPOS.

A Draft Plan of Study was released for public review and comment in July 2014. The Study Team convened a series of meetings and webinars throughout the Basin in mid-August 2014 to meet with technical experts, the International Rainy-Lake of the Woods Watershed Board (IRLWWB) and its Community and Industry Advisory Groups, indigenous communities, the public and other interests to review the draft report and receive feedback prior to its publication.

During the Commission's public comment period, the Commission heard strong support for undertaking all thirty two projects. The Commission in particular notes the importance and timely need to undertake the foundational monitoring project (project #1). As the report notes:

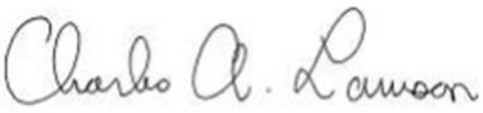
> "A primary challenge to strengthened binational watershed management and improved ecosystem health in the Basin is the limited availability of long-term, consistent data. Without such data, resource agencies cannot track trends in nutrients, contaminants and aquatic invasive species".

The Commission stands ready to provide governments with any additional information they might need in responding to the Study Team's recommended Plan of Study. Given the importance of the study for addressing the serious water quality concerns identified in the Plan, the Commission encourages the governments to respond in a timely manner.

The Commission would like to recognize the excellent work of the Plan of Study Team, and thank them, and the many government and non-government scientists, experts and members of the public who contributed to the content, participated in the workshops, public meetings, and commented on the drafts of the report.

Finally the Commission would like to recognize the valuable contributions of the International Rainy-Lake of the Woods Watershed Board and its Community and Industry Advisory Groups

Sincerely,



Camille Mageau
Secretary
Canadian Section

Dr. Charles A. Lawson
Secretary
U.S. Section

Attachments

- A Water Quality Plan of Study for the Lake of the Woods Basin, January 2015
- Lake of the Woods and Rainy River State of the Basin Report, 2nd Edition 2014

c.c. : Jenna Purl, U.S Department of State
Dan Mejia, U.S Department of State
Sing-En Tam, Foreign Affairs, Trade and Development Canada

International Lake of the Woods Basin Water Quality Plan of Study

Covering the Rainy-Lake of the Woods Watershed

Final Report

December 2014

Prepared by the International Lake of the Woods Basin Water Quality Plan of Study Team

Acknowledgements

The International Lake of the Woods Basin Water Quality Plan of Study Team expresses its sincere appreciation to the following for their contributions in support of development of this Plan of Study:

- members of the International Rainy-Lake of the Woods Watershed Board, including the Board's Community Advisory Group and the Industry Advisory Group;
- members of the International Multi-Agency Arrangement Work Group and Technical Advisory Committee;
- authors of the Rainy-Lake of the Woods 2014 State of the Basin Report;
- staff with government agencies and non-governmental organizations in Canada and the United States;
- representatives from Tribes, First Nations and Métis communities in the Basin;
- participants at the Plan of Study workshops held in International Falls, MN and Fort Frances, ON;
- the many individuals who participated in various public engagement activities to provide information and express their views and concerns; and
- workshop leads and Basin experts who functioned as extended members of the Plan of Study Team, namely:
    - Nolan Baratono, Minnesota Pollution Control Agency
    - Cheryl Becker, Grand Council Treaty 3
    - Bev Clark, Author - State of the Basin Report Update
    - Brenda Hann, University of Manitoba
    - Ryan Maki, Voyageurs National Park
    - Andrew Paterson, Ontario Ministry of Environment and Climate Change
    - Michael Paterson, International Institute for Sustainable Development
    - Todd Sellers, Lake of the Woods Water Sustainability Foundation.

Glenn Benoy, Canadian Co-chair (International Joint Commission)
Mark Brigham, U.S. Co-chair (United States Geological Survey)
Kelli Saunders, Secretariat (Lake of the Woods Water Sustainability Foundation)

Executive Summary

Straddling the international border between Canada and the United States, the International Lake of the Woods Basin is an important natural, economic and recreational resource. Over the past decade, the attention of governments, researchers, local residents and indigenous peoples has increasingly focused on the ecosystem health of the Basin and on the need for cooperative, binational action to address complex water quality challenges.

The International Lake of the Woods Basin Water Quality Plan of Study has been prepared to guide the International Joint Commission (IJC) in making recommendations to the Governments of Canada and the United States regarding a water quality study for the Basin. The IJC was created by Canada and the United States under the *Boundary Waters Treaty of 1909*. Under the Treaty, the IJC has two main responsibilities: regulating shared water uses and investigating transboundary issues and recommending solutions to the two governments.

This is the first Plan of Study for transboundary waters undertaken at the direction of the IJC to specifically address water quality concerns.

The Plan has been prepared by a binational Study Team, and builds upon considerable cooperative work and planning that has been undertaken in the Basin in recent years. This includes the ongoing assessment and reporting work of the International Rainy-Lake of the Woods Watershed Board (IRLWWB) and the work of the International Multi-Agency Arrangement (IMA), which works to foster trans-jurisdictional coordination and collaboration on science and management activities to enhance and restore water quality in the Lake of the Woods Basin.

The preparation of the Plan of Study involved extensive engagement with public agencies in Canada and the United States, scientific and technical experts, First Nations, Métis and Tribes, and the general public.

Recommended Projects and Activities

The Plan of Study identifies 32 projects and activities under five major challenge areas needed to improve understanding of the ecosystem health of the Basin and support a balanced, international approach to water quality management (see summary table, pg. vi)). For each recommended project, the Plan of Study outlines the objectives, description of work, possible lead and participating organizations, and timing and cost considerations.

Monitoring Challenges

A primary challenge to strengthened binational watershed management and improved ecosystem health in the Basin is the limited availability of long-term, consistent data. Without such data, resource agencies cannot track trends in nutrients, contaminants and aquatic invasive species.

- *The Plan of Study recommends a single comprehensive project to address this challenge. The project will address gaps in the existing monitoring and data acquisition work currently supported by agencies in the Basin, make recommendations for new monitoring locations and equipment, and establish more effective ways to share data within the Basin.*

Nutrient Enrichment and Harmful Algal Blooms Challenges

Harmful algal blooms, triggered by a variety of climatic, physical, chemical and biological factors, continue to occur in the Basin, particularly in the southern portion of Lake of the Woods and in other lakes upstream from Rainy River. These blooms can: affect recreational usage of lakes for sport fishing, boating and swimming; alter population densities of commercial and subsistence fisheries; cause undesirable taste and odor of drinking water; and compromise water treatment facilities. As well, the blooms sometimes release algal toxins, which can threaten drinking water supplies, human health and animal welfare.

- *The Plan of Study identifies 11 projects that will improve understanding of what contributes to the occurrence of these blooms and develop better communication tools for alerting the public of risks when blooms occur. Information from these projects will be critical to improved management of algal blooms, reducing their severity and frequency and the risks associated with algal toxins.*

Aquatic Invasive Species Challenges

Over the last 30 years, the Lake of the Woods Basin has been invaded by many non-native species, including the zebra mussel, hybrid cattail, spiny waterflea, rusty crayfish and rainbow smelt. These species have the potential to permanently alter aquatic ecosystems, leading to the loss of native species, reductions in game fish populations, and costly damage to water infrastructure.

- *The Plan of Study recommends seven projects that will strengthen ongoing prevention efforts and pursue control efforts in some cases where invasive species have infested waters in the Basin.*

Surface and Groundwater Contamination Challenges

In recent years, the impacts of contaminants in the Basin have been greatly reduced through reductions of pollutant inputs into the Rainy River. However, important concerns remain. There are areas in the Basin listed as contaminated sites from past mining activities. There is atmospheric contamination of lakes and fish by mercury, and growing concerns over potential contamination from new mining activities and from the transport of petroleum through the Basin by pipeline and rail.

- *The Plan of Study recommends seven projects that will provide a comprehensive assessment of the existing and potential contaminant issues in the Basin. The goals are to improve understanding about potential sources of contamination, assess vulnerability of water resources, and ensure protection measures are in place to minimize risks.*

Capacity Building Challenges

Current water management in the Basin is characterized by a diversity of approaches, driven by different legislative frameworks and policies, and with limited ability to coordinate management efforts across the international boundary. This diversity can be a major road block to any coordinated effort between the two countries. In addition, there are challenges with respect to public awareness and access to information, and the capacity of indigenous peoples to engage on water quality issues.

- *The Plan of Study recommends six projects that will help build greater capacity across the Basin for engaging all Basin interests on water quality management. The projects will help share critical water quality information among natural resource managers, the public, First Nations, Tribes and Métis, and help promote greater cooperation among institutions and agencies active in the Basin.*

Study Options

The Plan of Study recognizes that a number of critical factors impose constraints on project funding and timing, reducing the feasibility that all of the 32 proposed projects can proceed at the same time. Therefore, the Plan of Study proposes for consideration three options for proceeding on a coordinated effort to address the major water quality challenges in the Basin.

The Plan also outlines two funding options for consideration:

- *Option A* proposes that 21 priority projects be funded for a total estimated cost of $5,980,000. These projects will focus on providing core data and knowledge, but will allow for only a limited response to the full scope of current and emerging water quality challenges in the Basin.

- *Option B* proposes all 32 projects – the projects under Option A, as well as 11 additional important projects – for a total estimated cost of $8,398,000. This option would support a broadly-based coordinated effort to improve understanding of the Basin's ecosystem and strengthen water quality management.

Recommendations for Immediate Action

The Study Team identified four projects or activities that are in need of immediate attention, either because they are a critical component of determining ecosystem health in the Basin, are crucial to the successful implementation of the Plan of Study and future binational management opportunities, or because they address a significant, immediate risk to the ecosystem health of the Basin and cannot wait for Plan of Study approval. These are:

- *Project 27: International Platform for Implementation.* This project is crucial to the successful implementation of the Plan of Study and future binational management opportunities.

- *Project 14: Rapid Evaluation and Implementation of Options to Manage Recent Zebra Mussel Infestation in Headwaters Areas in Minnesota.* Zebra mussels pose a significant, immediate risk to the ecosystem health of the Basin.

- *Component of Project 1: Long-term Funding of Wheeler's Point Gage and Designation as a Gage of Binational Significance.* This is a critical component for determining ecosystem health in the Basin.

- *Components of Projects 5 and 7: Implementation of Proven BMPs and Removal of Solids from Effluent.* Where BMPs have been identified as effective at reducing nutrient loads from agricultural lands, they should be implemented immediately. Effluent from sewage and wastewater treatment facilities is an important source of nutrients that can impact lakes and rivers. An immediate action to reduce nutrients would be to enhance the capacity of treatment facilities to reduce solids.

Beyond the Plan of Study: Additional Observations

Throughout the course of developing the Plan of Study, the Study Team heard a range of concerns and ideas regarding water quality in the Basin – how it is under threat today and how it could be better managed in the future. The projects recommended in the Plan of Study deal directly with many of these concerns.

However, there are important issues affecting the Basin and its future ecosystem health that cannot be addressed within the context of this water quality Plan of Study. These concerns, too, will continue to be part of the dialogue on the future of the Basin. They include: the need to review water level regulation on Lake of the Woods; the capacity of indigenous communities in the Basin to participate in water quality management initiatives; the need for a long-term binational strategy for balancing mining activities in the Basin with watershed protection; the need for coordination with water quality management initiatives in neighboring watersheds to the west and east of the Basin; possible health effects related to methylmercury exposure through consumption of fish; and support for the national AIS recording systems in Canada and the U.S..

Summary Table
Lake of the Woods Basin Water Quality Plan of Study
Recommended Projects and Activities

(Note: The projects are listed numerically, under the five themes. The numbering does not relate to any proposed ranking of importance or priority.)

Priority Theme	Plan of Study Projects and Activities
Monitoring	1. International Monitoring Program for the Lake of the Woods Basin
Nutrient Enrichment and Harmful Algal Blooms	2. Mass-Balance Models for Phosphorus and Nitrogen in the Lake of the Woods Basin 3. Internal Loads and Hypoxia in Lake of the Woods 4. Assessment of Iron Fluxes from Sediments on Cyanobacteria Bloom Formation in Lake of the Woods 5. Assessment of Nutrient Subsidies from Shorelines Due to Erosion from High Water Levels in Lakes and High Flows in Rivers 6. Application of Water Quality Models at Watershed and Basin-wide Scales to Apportion Nutrient Sources 7. Implementation of Nutrient Load-Reduction Strategies in Lake of the Woods Basin 8. Application of Satellite Imagery and Remote Sensing Tools to Map and Characterize Water Quality and Algal Blooms 9. Development of Predictive Models of Algal Blooms from Hydrological and Meteorological Processes 10. Influence of Altered Food-Web Structure on Production of Harmful Algal Blooms 11. Taxonomic Characterization of Algal Communities and Algal Toxins 12. Public Health and Animal Welfare Risks: State of Knowledge and the Need for Alerting Mechanisms
Aquatic Invasive Species	13. Binational Aquatic Invasive Species Management Team and Prevention Strategy for the Lake of the Woods Basin 14. Evaluation and Implementation of Options to Manage Recent Zebra Mussel Infestation in Headwaters Areas in Minnesota 15. Ecological Impact of the Spiny Waterflea in Infested Boundary Lakes

Priority Theme	Plan of Study Projects and Activities
	16. Pilot Studies on Adaptive Control Measures for Hybrid Cattail and Rusty Crayfish in Infested Wild Rice Habitat 17. Comprehensive Assessment of Potential Invasion Risks to and within the Lake of the Woods Basin 18. Water Quality Risk Assessment for Zebra Mussels and Quagga Mussels 19. Climate Risk Assessment for Aquatic Invasive Species
Surface and Groundwater Contamination	20. Assessment of Binational Implementation of Water Quality Objectives for Sulfate, Copper, Nickel, and Mercury 21. Synthesis Report on Contaminants in Water, Aquatic Sediment, and Fish 22. Methylmercury Flux and Bioaccumulation in Large Border Lakes 23. Spatial Survey of Contaminants of Emerging Concern 24. Vulnerability Assessment of Border Waters to Contamination from Mining 25. Vulnerability Assessment of Border Waters to Contamination from Rail and Pipeline Transport of Petroleum and other Chemicals 26. Mining Effects Science Workshop
Capacity Building	27. International Platform for Implementation 28. Review of Data Collection Programs and Monitoring in the Headwaters Regions of the Basin 29. Application of Regional Climate Models for the Basin and Improved Public Education and Engagement on the Issue of Climate Change 30. Development of the Lake of the Woods Basin Geospatial Mapping Framework and Public Communication Tool 31. Indigenous Perspectives on Ecosystem Health 32. Funding Program for Non-governmental Organizations to Promote Watershed Protection

Table of Contents

Acronyms

The following is a list of common acronyms used in the Plan of Study:

AIS	Aquatic invasive species
AR5	Assessment Report 5 (from Intergovernmental Panel on Climate Change)
BMPs	Best (or beneficial) management practices
BWCAW	Boundary Waters Canoe Area Wilderness
CANWET	Canadian Watershed Evaluation Tool
CDOM	Colored Dissolved Organic Matter
CECs	Contaminants of emerging concern
CI	Cyanobacterial index
DEM	Digital Elevation Model
EDDMapS	Early Detection and Distribution Mapping System
ELA	Experimental Lakes Area
ELISA	Enzyme-Linked Immunoassay
ESM	Earth System Model
GIS	Geographic Information System
GCMs	Global Circulation Models
HABs	Harmful algal blooms
HPAB	Health Professionals Advisory Board
HSPF	Hydrological Simulation Program-Fortran
HUC	Hydrologic unit code
IJC	International Joint Commission
ILWCB	International Lake of the Woods Control Board
IMA	International Multi-Agency Arrangement
IMA-TAC	International Multi-Agency Arrangement - Technical Advisory Committee
IRLWWB	International Rainy-Lake of the Woods Watershed Board
IRLBC	International Rainy Lake Board of Control
IRRWPB	International Rainy River Water Pollution Board
IWI	International Watershed Initiative
LOWWSF	Lake of the Woods Water Sustainability Foundation
LWCB	Lake of the Woods Control Board
MDNR	Minnesota Department of Natural Resources
MERIS	Medium Resolution Imaging Spectrometer
MNRF	Ontario Ministry of Natural Resources and Forestry
MODIS	Moderate Resolution Imaging Spectro Radiometer
MOECC	Ontario Ministry of Environment and Climate Change
MPCA	Minnesota Pollution Control Agency
NAS	Nonindigenous Aquatic Species System
NOAA	National Oceanic and Atmospheric Administration
NWHU	Northwestern Health Unit
ORVW	Outstanding Resource Value Waters
RCMs	Regional Climate Models
SOBR	State of the Basin Report
SPARROW	SPAtially-Referenced Regressions On Watershed attributes
TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WRAPS	Watershed Restoration and Protection Strategy

1. The International Lake of the Woods Basin

1.1 Overview

The international Lake of the Woods Basin (the Basin) is an important natural, economic and recreational resource straddling the border between Canada and the United States (Figure 1). The Basin is approximately 400 km (240 mi) east-to-west and 260 km (156 mi) north-to-south. Nearly 60 percent of its drainage area of about 69,750 km^2 (26,930 mi^2) is located in Ontario (ON), with about 40 percent in Minnesota(MN) and a small portion in Manitoba (MB).

The Basin's population is sparsely distributed and concentrated in a few cities, towns, townships, counties, on First Nation, Métis and Tribal lands, and in seasonal residences around the shorelines of major lakes. Overall, total population in the Basin is declining, though the populations of indigenous communities are growing. As well, more than 750,000 people rely on the waters of the Basin as a source of drinking water (including the City of Winnipeg, MB).

The Basin can be divided into 10 main sub-basins: Shoal Lake; Lake of the Woods; Big Turtle River - Rainy Lake; Rainy Lake; Rainy Headwaters; Vermilion River; Little Fork River; Big Fork River; Lower Rainy River; and Rapid River. In the upper sub-basins in the eastern part of the Basin, the boundary area often referred to as the Quetico-Superior makes up a significant portion of the land mass and features boreal forest on shallow soils over bedrock. It is an area dominated by the presence of large national parks (Quetico, Voyageurs), the Superior National Forest and the Boundary Waters Canoe Area Wilderness (BWCAW). In 1978, logging was terminated in the BWCAW and motorboat usage was greatly decreased. Since 1978, land use in this protected area has been limited primarily to backcountry recreational use, and the BWCAW has become the most heavily used wilderness area in the United States. Visitor use has increased threefold since the early 1960s, and more than 100,000 people camp in the backcountry each year (Mast and Turk, 1999). Similarly, Ontario Parks statistics indicate that more than 75,000 visitors came to Quetico Provincial Park in 2010 (Ministry of Natural Resources, 2011).

The central and downstream sub-basins are a mix of boreal forest, bedrock, agricultural land and, in the southern Lake of the Woods region, extensive wetlands and sandy shorelines. Lake of the Woods, the largest lake in the Basin, covers an area of 3,850 km^2 (1,486 mi^2), the northern portion being on Precambrian Shield and home to approximately 14,500 islands, while the southern shores of the lake are located on the prairie topography of the old Glacial Lake Agassiz lakebed. Rainy Lake is also of significant size at 932 km^2 (359 mi^2), with surrounding topography also typical of the Shield.

Historical and current land uses in the Basin include agriculture, urbanization, forestry, mining and recreation. In and around the Rainy River and southern Lake of the Woods, forestry, recreation, tourism, and agriculture are the main land use activities, with a considerable portion of the region used for mixed farming or grazing. Agriculture covers about 6 percent of the land portion of the Basin as cropland or cropland and shrubland/woodland. The Lower Rainy River and the Lake of the Woods sub-basins

contain the highest proportion of cropland, at approximately 10-15 percent of the land-only portion. Forestry and recreation dominate the land uses around Lake of the Woods.

Currently, mining operations on the Canadian side of the Basin are limited to exploration and development. There are new gold exploration properties located to the south (Rainy River) and to the east of Lake of the Woods (Cameron Lake), as well as north of Atikokan, ON (Hammond Reef). Elsewhere in the Basin, other minerals have been mined, notably iron ore near Atikokan (the now-closed Steep Rock Mine that was in operation for 40 years) and in areas of Minnesota including Lake Vermilion, Ely, Tower-Soudan, and on the South Kawishiwi River. There are at least two active iron mine operations in the Minnesota part of the Basin, as well as aggregate mining.

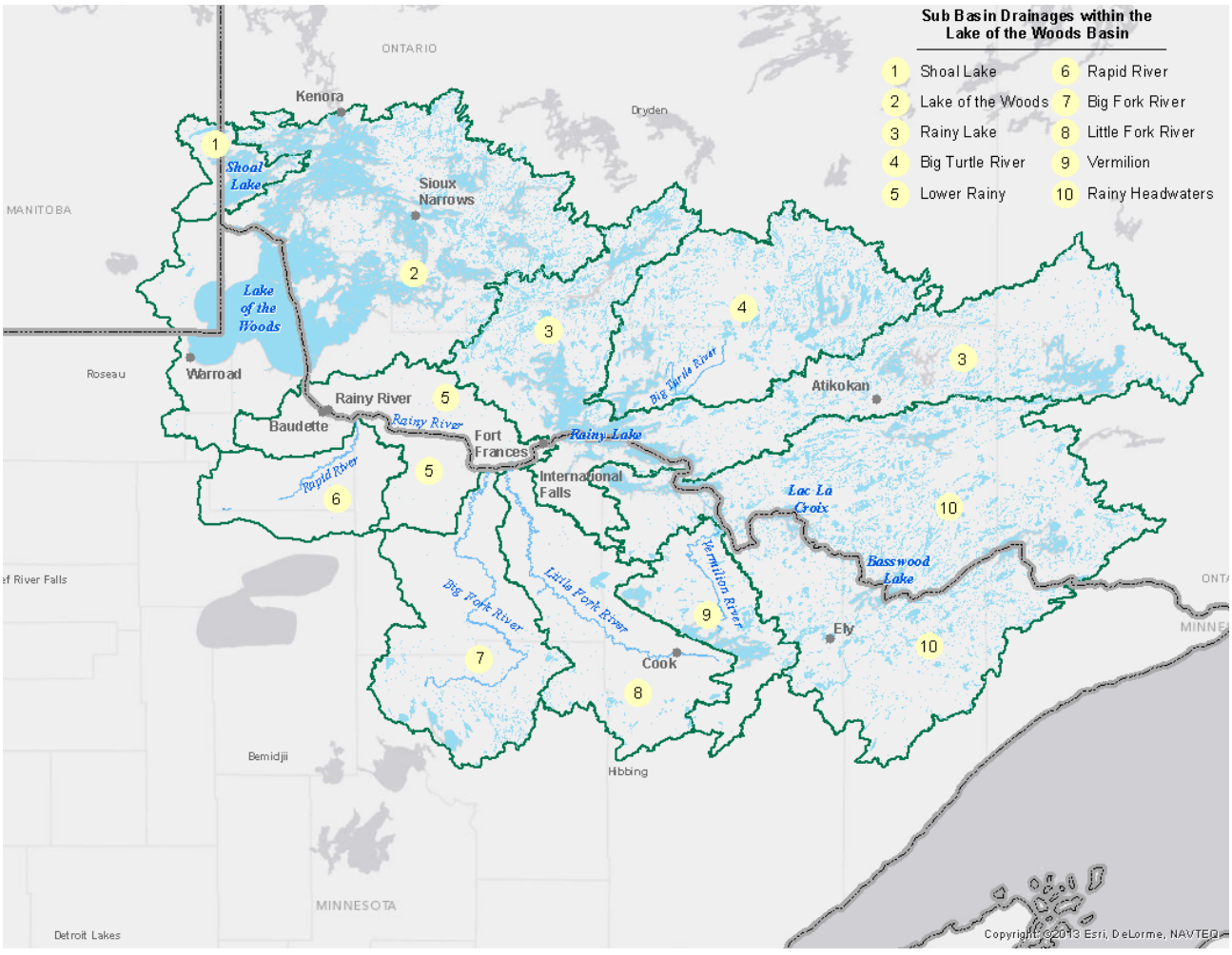


Figure 1 - Lake of the Woods Basin

1.2 Water Quality Concerns in Basin

Over the past decade, the attention of governments, researchers, local residents and indigenous peoples has increasingly focused on the ecosystem health of the Basin and on the need for cooperative, binational action to address complex water quality challenges. These concerns have focused on three key ecosystem health issues. In addition, several important underlying cross-cutting issues have emerged with respect to understanding and addressing these ecosystem health challenges.[1]

1.2.1 Nutrients and Harmful Algal Blooms

In temperate zone freshwater systems, phosphorus is generally considered to be the nutrient that limits aquatic plant growth (Schindler, 2012). Symptoms of excessive loads of phosphorus include harmful algal blooms (HABs) in the water column, attached algae infestations along shorelines and depletion of oxygen in deep-water zones. Historically, the Lake of the Woods has experienced cyanobacterial blooms; however, anecdotal evidence suggests that the lake is deteriorating and that the symptoms are getting worse (Clark and Sellers, 2014). While the Minnesota Pollution Control Agency (MPCA) has found that there is a predominance of high quality lake resources within the U.S. portion of the Basin, the southern portion of Lake of the Woods is considered impaired for aquatic recreational use due to eutrophication, and algal blooms have been observed in other lakes upstream of the Rainy River. A wide variety of climatic, physical, chemical and biological factors are related to the genesis and onset of HABs, their spatial extent and duration, and whether they produce algal toxins.

HABs are undesirable for many reasons: they can prevent recreational usage of lakes for sport-fishing, boating and swimming; alter population densities of commercial and subsistence fisheries; cause undesirable taste and odor of drinking water and compromise water treatment facilities; and release algal toxins. Over the past decade, several species of cyanobacteria that are known to produce toxins have been recorded in the Basin, including *Microcystin, Aphanizomenon* and *Anabaena* in Lake of the Woods, *Aphanizomenon* in Rainy Lake and *Oscillatoria* in lakes in the headwaters watershed. Toxins are of particular concern because they threaten drinking water supplies and human and animal health.

1.2.2 Aquatic Invasive Species

The Lake of the Woods Basin has been invaded by many non-native species that have disrupted ecological communities at all trophic levels (*e.g.*, from algae to fish) (Clark and Sellers, 2014). There is potential for further invasions in the Basin. Aquatic invasive species (AIS) include species that are not indigenous to the Lake of the Woods Basin (including fish species) that may occur naturally in some

[1] For more information on environmental conditions and key ecosystem concerns in the Basin, see the recently released *Lake of the Woods and Rainy River State of the Basin Report, 2nd Edition* (SOBR) (Clark, B.J., and Sellers, T.J., 2014, Rainy-Lake of the Woods State of the Basin Report, 2nd Edition: Lake of the Woods Water Sustainability Foundation http://www.lowwsf.com/component/docman/doc_download/35-complete-rainy-lake-of-the-woods-state-of-the-basin-report-second-edition-2014.html).

basin waters, but which have been transported into Basin lakes where they were not been present historically.

Non-native flora and fauna that have invaded parts of Lake of the Woods and the Rainy River over the last 30 years include: the hybrid cattail (*Typha xglauca*); spiny waterflea (*Bythotrephes longimanus*); the water flea (*Eubosmina coregoni*); rusty crayfish (*Orconectes rusticus*); papershell crayfish (*Orconectes immunis*); clearwater crayfish (*Orconectes propinquus*); and rainbow smelt (*Osmerus mordax*) (Clark and Sellers, 2014).

Of particular concern is the potential for the spiny waterflea, an invasive predatory zooplankton, to substantially disrupt ecosystems in the Basin. Possible effects include limiting fish production and limiting consumption of algae through food web disruption, which in turn could exacerbate HABs. Spiny waterflea prey upon other zooplankton, including *Daphnia spp*., which are common food sources for juvenile and small native fish. In lakes in south-central Ontario on the Precambrian Shield, they have been implicated in the decline in some species of zooplankton and the alteration of zooplankton communities (Yan *et al.*, 2001; Boudreau and Yan, 2003; Jacques *et al.*, 2005; Strecker *et al.*, 2006).

As well, the presence of zebra mussels (*Dreissena polymorpha*) has been confirmed in the headwaters of the Big Fork River, a tributary to the Rainy River (Clark and Sellers, 2014; Minnesota Department of Natural Resources, 2014). Given the potential for the spread of zebra mussels in the Basin, this issue is of utmost importance to the ecological health of the Basin.

1.2.3 Surface and Groundwater Contamination

The impacts of contaminants in the Basin have been greatly reduced through reductions of pollutant inputs into the Rainy River over the years. There are generally fewer or lower concentrations of contaminants entering the Basin than in more densely populated and industrialized areas, such as areas in the Great Lakes watershed. There are, however, areas currently listed as being contaminated sites, legacy contamination from historical mining activities, atmospheric contamination of lakes and fish by mercury, agricultural inputs in the central portions of the Basin, and the potential for mining activities to increase in the Basin (Clark and Sellers, 2014).

Although current contamination from mining and petroleum transport is not thought to be a significant issue for international waters, the larger concern is the potential for contamination due to a large-scale and rapid expansion of these activities, combined with the potential for catastrophic failures such as breaches of mine-tailings basins, pipeline failures or rail accidents. Such failures could exact large costs to ecosystem services and require expensive remediation efforts.

Mining

Numerous historical and current mining sites exist within the Lake of the Woods Basin. As well, there is considerable interest in both Canada and the U.S. in developing new mines to extract the mineral resources in the region. In Canada, a new gold mine in the Basin is in the late stages of environmental

assessment review (New Gold's Rainy River mine). Based on Provincial receiving water criteria and stringent regulatory principles typically applied to effluent discharge into receiving waters, potential downstream impacts are expected to be limited to localized areas.

Disseminated sulfide ore deposits with commercially valuable copper, nickel, and platinum group metals are in the southern portion of the Basin, near the divide that separates the Lake of the Woods and Lake Superior Basins. These deposits have attracted interest from mining companies. An underground mine that would extract copper, nickel and platinum group metals from disseminated sulfide ore deposits is being considered in the Basin near Ely, MN (Twin Metals project). Just over the watershed divide in the Lake Superior drainage basin, a proposed open-pit copper mine (Polymet – Northmet project) is in environmental assessment review. Although each mining project is unique, some aspects of the Polymet – Northmet environmental review may transfer to the Lake of the Woods Basin.

The possibility of mining disseminated sulfide ores in the Basin has resulted in concerns over the potential for serious adverse effects, including: acid mine drainage (thought to be of lower potential severity in this region, due to the low concentration of sulfide in disseminated sulfide ores); impaired wild rice production due to sulfate contamination; elevated methylation of mercury in downstream waters (which would exacerbate the mercury problem); and harmful levels of trace metals that could impair downstream waters. Given these concerns, and the developing efforts to explore and mine metals in the Basin, there is a need to examine the potential for cumulative effects of runoff from past, ongoing, and possible future mining operations to contaminate border waters, and in particular the cumulative effects from operations on both sides of the U.S.-Canada border.

Transport of Petroleum

Substantial amounts of petroleum and other hazardous chemicals are transported through the Basin via rail and pipeline. In recent years, rapid expansion of petroleum extraction from Alberta, Canada and the Bakken formation in North Dakota has resulted in increased rail shipments through the Basin. Other hazardous chemicals are also transported via rail through the Basin. Rail transport necessarily crosses vital water resources, including the Rainy River at Fort Frances, ON/International Falls, MN, Rainy River, ON/Baudette, MN and a pinch point at Kenora, ON. In addition to rail transport, there are proposals to increase pipeline capacity to transport petroleum through the Basin.

Both rail and pipeline transport are subject to large releases of chemicals in the event of derailment or pipeline failures. In recent years, a number of such derailments and pipeline failures have resulted in large releases of petroleum in several locations in Canada and the U.S. Basin residents are concerned that such disasters near waterways in the Lake of the Woods Basin would damage ecosystem services, including contamination of drinking water supplies with toxic chemicals.

Mercury

Although mercury is a natural element, human industrial activities have increased the amount of mercury cycling in the global environment. Unlike some trace metals (copper, selenium, zinc), mercury has no beneficial biological function. In aquatic ecosystems, some portion of inorganic mercury is converted to

methylmercury, a highly toxic form of mercury that magnifies from very low concentrations in water to concentrations of concern in top-predator game fish in many waters. Accordingly, state, provincial, and indigenous natural resource agencies issue fish-consumption advisories that inform anglers about maximum intake of fish from specific water bodies, fish species, and sizes of fish. Although the Basin lacks large sources of mercury pollution, mercury is a global pollutant and is transported long distances in the atmosphere before falling to the earth's surface. Many waters in the Lake of the Woods Basin are sensitive to atmospheric inputs of mercury, and mercury contamination of fish is the most widespread water-quality impairment.[2]

Agricultural Contaminants

Agricultural pesticides, including insecticides, herbicides, fumigants, are widely detected in surface waters in North America. A recent national synthesis report in the U.S. reported that 69 percent of streams in agricultural areas, and 45 percent of streams in mixed land use areas, had one or more pesticides that exceeded aquatic life benchmark levels (Stone *et al.*, 2014). There is concern that agricultural pesticide use, particularly in cultivation of row crops in the southwestern portion of the Basin, could transmit harmful levels of pesticides to international waters.

Contaminants of Emerging Concern

Contaminants of emerging concern (CECs) include different classes of chemicals, such as personal care products, drugs, antibiotics, flame retardants and other classes of synthetic organic chemicals. Laboratory analyses have shown that many of these chemicals reduce species resilience and change behavior (food consumption, boldness and shoaling) (Brodin *et al.*, 2013) at concentrations typically observed in surface water. Many of these chemicals disrupt normal biological functions, even at low concentrations, and traditional water treatment technologies do not remove them from drinking water. In addition to human effects, these compounds can disrupt reproduction of aquatic organisms.

CECs have been detected in both the heavily used lakes (for example, Kabetogama) and in more remote lakes within Voyageurs National Park. In addition to direct input through inflows, aerial deposition of some of these compounds is suspected.

1.2.4 Cross-Cutting Challenges

Underlying the direct bio-physical challenges to the ecosystem health of the international Lake of the Woods Basin are important water management gaps with respect to monitoring and capacity building.

[2] For further information on mercury, seeWentz, D.A., Brigham, M.E., Chasar, L.C., Lutz, M.A., and Krabbenhoft, D.P., 2014, The Quality of Our Nation's Waters: Mercury in the Nation's streams—levels, trends, and implications: U.S. Geological Survey Circular 1395 http://dx.doi.org/10.3133/cir1395.

These gaps have emerged as foundational, cross-cutting challenges to any effort to protect and enhance water quality in the Basin.

Monitoring

A key challenge to strengthened, binational watershed management and improved ecosystem health in the Basin is the limited availability of long-term, consistent data sets for the Basin as a whole, making the tracking of trends in nutrients, contaminants and AIS difficult. Due to the expanded water quality mandate of the new International Rainy-Lake of the Woods Watershed Board (IRLWWB), consistent, strategic monitoring and consideration of objectives against which to measure monitoring data become more critical.

The past two decades have produced a significant amount of project-specific data from a variety of sources (see Figure 2, which illustrates some of the water quality monitoring) and, in some cases, coordinated monitoring with quality assurance/control protocols aligned across the border. However, there are still considerable differences between the two countries in the amount of research and monitoring done of the priority issues and in the protection strategies in place.

Existing Monitoring Activities

United States

In the fall of 2008, Minnesota passed *The Clean Water, Land and Legacy Act*, an amendment to the state's constitution that created a three-eighths of a percent sales tax to fund, among other things, the protection and preservation of Minnesota's freshwater. The amendment has the potential to raise more than $275 million a year, of which about one third, or $85 million a year, will go toward protecting and preserving Minnesota's surface and ground water. For the period 2009 through 2013, Minnesota invested over $2 million for the Lake of the Woods/Rainy Basin Watershed Restoration and Protection Strategy or WRAPS (see http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/watershed-approach/index.html) and the Lake of the Woods total maximum daily load (TMDL) study. These are both part of Minnesota's watershed-based approach to assessing, restoring and protecting water quality. Under this approach, research is being undertaken in each of the watersheds in the Lake of the Woods Basin over the next 10 years. The research done on the U.S. portion of Lake of the Woods resulted in the designation of the lake as an "impaired" waterbody for aquatic recreational use due to eutrophication in 2008. In response, a TMDL study has been underway in Minnesota to determine load allocations that will help remove this waterbody from the impaired waters list. Canada and Ontario are partnering on research initiatives and communicating with Minnesota to support the study, most notably through the initiation of monitoring of Canadian tributaries by the Ontario Ministry of the Environment and Climate Change (MOECC) for concentrations of key water quality parameters and a lake and tributary sampling program by Environment Canada (EC) (see below). The data from Minnesota, Ontario and Canada have been used together in recent modeling efforts to assess nutrient loads to Lake of the Woods. However, loads have had to be estimated on the Canadian side in many cases due to a lack of monitoring sites and the collection of concentration data rather than loading data.

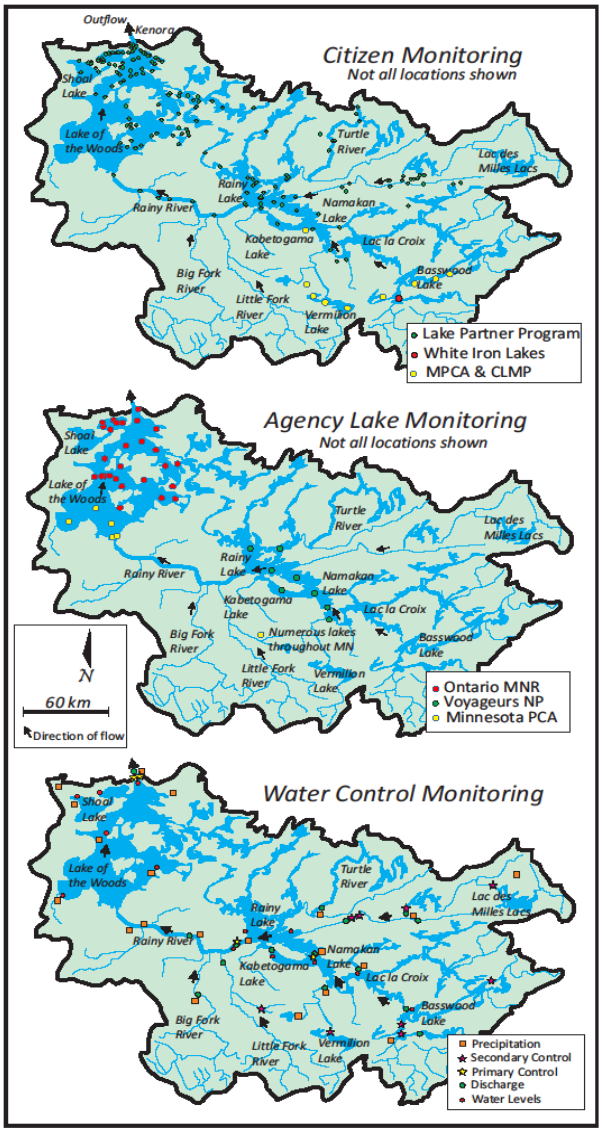


Figure 2
Sampling of Monitoring Sites in the Lake of the Woods Basin
(Source: SOBR Overview, Clark and Sellers, 2014)

Elsewhere in the Basin, the lower reach of the Little Fork River mainstream was added to the Impaired Waters List for turbidity in 2006. Watershed assessment work in the Big Fork watershed (Lueck *et al.*, 2013) found that the most widespread impairment in both streams and lakes was mercury contamination, which has resulted in fish consumption advisories to limit human exposure to mercury through the consumption of fish. Other impairments were due to natural causes. Numerous other water bodies also

are impaired due to mercury contamination of fish.[3] For the Rainy Headwaters, the WRAPS process began in 2014, with plans to assess the Vermilion sub-basin beginning in 2015, the Rainy River/Rainy Lake sub-basin beginning in 2016, and the Black River, Rapid River and Baudette River sub-basins in 2017. In 2011, the White Iron Chain of Lakes Association in partnership with the Lake County Soil and Water Conservation District implemented the Kawishiwi Watershed Protection Project (also in the headwaters), a three-year project designed to develop a Watershed Management and Protection Plan (www.kawishiwiwatershed.com). The program included lake and stream monitoring, and identification of protection and restoration needs along with the analysis of threats from AIS and failing septic systems. The plan was completed in 2013, but monitoring continues, including sampling for heavy metals and E coli; testing wells in areas found to have possible problems; and carrying out extensive trapping of rusty crayfish in an effort to reduce the population and to determine if other lakes nearby are infested.

In the United States, the U.S. Geological Survey and U.S. Forest Service are monitoring areas of potential new mining. The goal of these monitoring efforts is to establish baseline concentrations of metals, sulfate and other constituents prior to any new copper-nickel-platinum group metal mining that may be developed in the region. These monitoring efforts are temporary, not ongoing programs. Additional data from this region were collected in the late 1970s, and summarized in the Minnesota Environmental Quality Board's Regional Copper-Nickel Study.[4]

Canada

In February 2008, Environment Canada launched a four-year $17.7 million initiative, the Lake Winnipeg Basin Initiative, which included support for monitoring and research activities in the Lake of the Woods (the lake) as well as on the Rainy River. The initiative was developed partly in response to Manitoba's request for federal support in meeting research, information and monitoring needs, and to facilitate governance and cooperation throughout the vast, trans-boundary Lake Winnipeg Basin. As part of this initiative, Environment Canada has done hydrological modeling, water quality monitoring (including pesticides, mercury, phosphorus and trace metals), satellite monitoring of algal blooms, and benthic monitoring. Additionally, data were collected from precipitation samplers and a meteorological station for the Basin. In 2014, the Lake Winnipeg Basin initiative was renewed for a further five years. Environment Canada has completed its initial benthic monitoring for Lake of the Woods in 2014 and will be developing a plan to reassess the benthic status on a rotational cycle. Continued monitoring of the nutrient and trace metal inputs from the Rainy River is expected to continue after 2014 pending future levels of funding. Future in-lake monitoring on Lake of the Woods will be assessed in accordance with information needs arising from this Plan of Study and could be undertaken pending available resources.

In 2009, the MOECC established a tributary monitoring program for Lake of the Woods and the Rainy River. The main objective is to contribute data to nutrient loading estimates. Tributaries to the Rainy River include the LaVallee River, the Sturgeon River and the Pinewood River. Under the monitoring

[3] http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/maps-of-minnesotas-impaired-waters-and-tmdls.html
[4] http://www.leg.state.mn.us/edocs/edocs.aspx?oclcnumber=05579755
http://www.leg.state.mn.us/lrl/issues/issues.aspx?issue=coppernickel)

program, samples are analyzed for phosphorus, nitrogen, pH, alkalinity, specific conductance, total and dissolved solids, dissolved organic and inorganic carbon, and reactive silicate. Results to date have shown that concentrations in tributaries to the Rainy River are higher than they are in tributaries elsewhere around Lake of the Woods: only spot loading data have been collected on these tributaries. In addition, analysis of metals in localized tributary sampling is being done to ensure adequate baseline data are available. MOECC provides oversight into baseline assessment data collection for proposed development activities within the Province.

The Lake Partner Program is Ontario's volunteer-based, water-quality monitoring program, operated through the MOECC. Since 2002, the MOECC has coordinated this lake monitoring program in which, each year, more than 60 volunteers within the Lake of the Woods Basin monitor total phosphorus and water clarity in almost 30 inland lakes at over 60 sampling locations. Volunteers collect lake water samples to be analyzed by MOECC for total phosphorus and record monthly water clarity observations during the summer months.

Key Gaps

While these ongoing monitoring efforts on both sides of the border are important, key gaps remain. The International Multi-Agency Arrangement (IMA) group of agencies (see Section 2.3.4) has, for many years, indicated the need for a strategic, long-term, coordinated monitoring program that can identify the status of the water resources at consistent locations, identify drivers of change and identify the management actions that are needed and where, and their effectiveness over time. In discussions with Basin experts and IMA members and in a review of research initiatives in the Basin, the Plan of Study team identified other key gaps in monitoring, related to the priority issues, including:

- the ability to refine nutrient loading estimates;
- the ability to determine nearshore loading from lakeshore development in smaller bays;
- the lack of monitoring of cyanobacterial toxins;
- the availability of data to characterize the benthic invertebrate communities and detect impairments to those communities;
- adequate, reliable monitoring of aquatic invasive species;
- knowledge of contaminant levels in the Basin;
- the ability to assess the performance of a future Basin Management Plan;
- monitoring to detect novel, emerging stressors; and,
- long-term monitoring required to assess cumulative effects of multiple stressors.

Capacity Challenges

Existing Water Protection Mechanisms

The responsibility for regulation and management of Basin resources lies with the more than 25 agencies and organizations on both sides of the border at the federal, state/provincial, and municipal levels. In addition, Métis, First Nations and Tribes also have governance responsibilities over their land and water resources.

United States

The constitutional amendment in Minnesota that provides funding for comprehensive monitoring and watershed assessment work in the state is difficult to replicate elsewhere. As well, the Minnesota watershed assessments are based on federal and state water quality standards in statute. Minnesota's WRAP process, referred to earlier, is a process whereby sub-basins are monitored and assessed (against state standards) for impairments; where impairments are found, implementation and restoration are initiated.

In spring 2009, the Minnesota legislature took the first step in investing the money generated through the constitutional amendment, appropriating $750,000 to the University of Minnesota's Water Resources Center to create a comprehensive, 25-year framework for the sustainable management of Minnesota's water resources. There are several governmental structures and legislative initiatives in Minnesota that address water management issues in the watershed. For example, all lands are under government oversight as part of counties, Soil and Water Conservation Districts, cities, Tribal lands, parks, forests; all are included in the new state-wide, comprehensive watershed planning process.

Canada

In Ontario, the MOECC is responsible for regulating the volumes of water taken from any water body in the province and the quality of any effluent discharged into any waterbody in the province. Regarding nutrient levels, Ontario's Provincial Water Quality Objective for phosphorus for lakes on the Precambrian Shield allows for a 50 percent increase in phosphorus concentration from a modeled baseline of water quality in the absence of human influence. The modeled objective is specific to each lake on the Precambrian Shield, but it is only an objective with no legislative force (Ontario Ministry of Environment, 2010) .

There is no similar program to Minnesota's TMDL study or WRAP process for monitoring, mitigating and managing a water quality objective in current Ontario legislation. Water management plans exist in areas for flow and water level management and there are attempts to consider cumulative effects of industrial/municipal discharges through the application of receiving water criteria, which accounts for background contaminant concentrations. Cumulative impacts are also assessed through the environmental assessment process.

Although there are several municipalities and numerous First Nation reserves on the Ontario side of the Basin, the majority of the land in the watershed is unorganized or unincorporated territory and is managed as Crown land by the Province. Crown land use is guided by policy and legislation of the Ontario Ministry of Natural Resources and Forestry (MNRF). With respect to water quality protection, MNRF reviews subdivision applications on waterbodies with an eye on protection of sensitive habitat and resource values while controlling activities on shorelands (public and private) through work permits under the *Public Lands Act*. In unincorporated areas, private land planning applications, such as consents, subdivisions and condominiums, are reviewed by the Ministry of Municipal Affairs and Housing. This same ministry implements the Provincial Policy Statement, established to help guide development with environmental protection in mind. Within the Basin, MNRF has established the Clearwater Bay

Restricted Development Area Order and the Shoal Lake Restricted Area to protect water quality and improve lake trout habitat. Much of the south and central portions of the province have Conservation Authorities who are responsible for watershed management, flood protection, water sampling and stewardship, but there is no Conservation Authority in northwestern Ontario (*i.e.*, not in the Basin).

Key Gaps

Overall, current water management is characterized by a diversity of approaches, driven by very different legislative frameworks and policies, and with limited ability to coordinate management efforts internationally. This is often the major road block to any coordinated effort between two countries.

Addressing the Monitoring and Water Management Gaps

This section has demonstrated the differences and the gaps that exist in monitoring and water management mechanisms within the various jurisdictions that make up the Lake of the Woods Basin. The Plan of Study projects discussed in Section 3 target many of these gaps, either through the recommendations for scientific research or immediate action items and management projects that initiate solutions. The large gap in monitoring that is of significant concern in the Basin will be handled through a recommended key foundational project to build a strategic, long-term tiered monitoring program for the Basin that is balanced across the border. From this initiative, recommendations to better inform Basin water quality objectives and alert levels and aquatic ecosystem health objectives can be developed. As noted in the State of the Basin Report (SOBR), "it would be prudent to examine the need for specific International Water Quality Objectives for certain areas within the basin, furthermore the objectives should be considered for all parameters of concern."

The remaining issue of differential water management strategies across the border is still a challenge, but significant progress has been made in this regard. The ongoing work of the IMA, the establishment of the IRLWWB and initiation of the International Watershed Coordination Program (see Section 2.3) are important improvements in addressing this gap by establishing a platform for future discussions and decisions around streamlining water management as necessary. In an effort to highlight this important gap and make recommendations towards an effort to find a solution, the Plan of Study has recommended a project that looks to optimize the current institutions in place and support shared water management in the future (Project 27).

2. The International Lake of the Woods Basin Water Quality Plan of Study

The International Lake of the Woods Basin Water Quality Plan of Study has been prepared to guide the International Joint Commission (IJC) in making recommendations to the Governments of Canada and the United States regarding launching a water quality study for the Basin. The IJC was created by Canada and the United States under the *Boundary Waters Treaty of 1909*. Under the Treaty, the IJC has two main responsibilities: regulating shared water uses, and investigating transboundary issues and recommending solutions to the two governments. The IJC's recommendations and decisions take into account the needs of a wide range of water uses, including drinking water, commercial shipping, hydroelectric power generation, agriculture, industry, fishing, recreational boating and shoreline property.

The Plan of Study identifies the projects and activities needed to improve understanding of the ecosystem health of the Basin and support a balanced, international approach to addressing current and emerging challenges and strengthening water quality management in the Basin. The Plan has been prepared by a binational Plan of Study Team (the Study Team), at the direction of the IJC. Study Team members were selected on the basis of their extensive experience with water quality issues in the Lake of the Woods Basin and elsewhere, and did not formally represent their own organizations.

This is the first Plan of Study for transboundary waters undertaken at the direction of the IJC to specifically address *water quality* concerns.

The Plan represents a significant milestone in the evolution of shared water management of the Lake of the Woods Basin between Canada and the United States. It reflects the concerns of the many interests in the Basin and presents a proposal for work that is driven by both science and action. The shared desire among Basin interests for governments to protect water quality in the Lake of the Woods Basin was a clear and consistent message throughout the process of developing this Plan of Study.

2.1 Background

In 2010, the federal governments of Canada and the United States of America issued a Reference to the IJC to conduct a review of binational management of water quantity and quality in this Basin and make recommendations for improvement. To undertake this work, the IJC appointed the International Lake of the Woods and Rainy River Watershed Task Force to prepare the review and recommendations. After extensive consultation with its Community Advisory Group, resource agencies, First Nations, Tribes, Métis and the general public, the Task Force submitted its report to the IJC in July 2011. The report identified the main ecosystem health issues in the Basin as well as the key barriers to watershed-wide management based on regulatory and governance gaps across the international border. There was also recognition of the lack of indigenous representation at the IJC Board level.

The IJC submitted the Task Force’s recommendations to the Governments in January 2012, along with suggested actions, including the need to conduct a Water Quality Plan of Study to better understand the main water quality issues in the Basin.

In 2012, the Governments recognized the importance of having a sound understanding of water quality issues through a Water Quality Plan of Study to inform subsequent actions by the Governments and the IRLWWB. The Governments also agreed with the need for indigenous representation and the need to structure the IJC's water management boards on the basis of the full watershed, rather than have separate boards dealing with separate water bodies within the same watershed. A number of improvements were addressed immediately, including:

- the amalgamation of the two previous IJC boards in the Basin (the Rainy Lake Board of Control and the Rainy River Water Pollution Board) into the current IRLWWB with an expanded geographic jurisdiction based on the "basin" boundaries; and,
- the establishment of three seats on the new Board, one each for a Canadian First Nation member, a Canadian Métis member and a U.S. Tribal member.

This new Board was given the mandate to monitor ecosystem health in the Basin. It was recognized that, given its new mandate, the Board would require a better understanding of the Basin's health.

The Plan of Study builds on a number of recent important initiatives focusing on the ecosystem health of the Basin and on the need for cooperative, binational action to address complex water quality challenges. This work includes:

- the previously noted 2011 Task Force report, *Bi-national Management of Lake of the Woods and Rainy River Watershed*, which presented extensive information and analysis on the accomplishments around water quality and quantity, responsibilities of agencies and organizations with water quality mandates, binational management challenges and key water quality priority issues;

- the recently released *Lake of the Woods and Rainy River State of the Basin Report, 2nd Edition* (SOBR) (Clark and Sellers, 2014), which provides a comprehensive review of environmental conditions and existing data for this Basin, including key ecosystem concerns, the gaps in knowledge to better understand those concerns, and recommended approaches for addressing these gaps;

- the draft *Five Year Workplan* of the IMA Work Group, which presents a thorough overview of completed, ongoing and proposed research on water quality on Lake of the Woods and immediate upstream waters. Driving much of this research is the MPCA's TMDL study for the U.S. portion of Lake of the Woods and the intensive watershed assessment work on other U.S. sub-basins to identify impairments; and,

- the *IJC's Rule Curve Review Studies for the Rainy and Namakan Chain of Lakes* (in progress), which includes projects providing key potential rule curve impact linkages to the Plan of Study.

2.2 Plan of Study Approach

2.2.1 Study Directive and Terms of Reference

The IJC's Directive and Terms of Reference for the Study[5] instructed the Study Team to undertake a Plan of Study to:

- identify needed scientific research to understand the underlying causes of current water quality concerns and establish what remedial actions might be most appropriate to addressing the priority issues;
- provide an analysis of what work is being done in these areas, its timing, as well as what work is still needed;
- assess the costs of any actions and the role of governments and the public in this regard; and,
- provide a basis for the IJC to report to the governments of Canada and the United States on recommended actions.

From the outset, the Plan of Study recognized that watershed assessment and protection is at widely varying stages throughout the Basin, and that working towards Basin-wide solutions requires common goals and a balanced, binational commitment to research and management. The Plan also recognizes the importance of adaptive management in an ever-changing Basin. The recommended projects include immediate, short-term and long-term initiatives, all of which will help resource agencies and their partners fulfill their mandates individually and collectively, but will necessitate commitments from governments.

2.2.2 Guiding Principles

The Lake of the Woods Basin Water Quality Plan of Study has adhered to the following principles:

- The Plan of Study will consider the needs of all the interests, including citizens and grass-roots advisory groups; Tribes, First Nations, and Métis communities; the business community; and governments in the Lake of the Woods Basin and, in doing so, will strive to provide a balanced, science-based Plan of Study.
- The Plan of Study process will be transparent, with opportunities for input and review by all interests.
- Citizen and indigenous knowledge will be given a voice in defining science and management needs for the Basin.
- The Plan of Study will strive for credible, peer-reviewed science using accepted methodologies.
- Potential resource management options that commit public (government) resources will be based on credible, peer-reviewed science.
- The Plan of Study will consider the most cost effective means to conduct recommended studies.

[5] Available at http://ijc.org/en_/LWBWQPOS

- The Plan of Study will strive to prioritize projects based on what is best for the Basin and propose options accordingly.

2.2.3 Geographic Scope

The Plan of Study recognizes the connectivity between the boundary waters and the entire upstream basin draining into those boundary waters and eventually feeding into Lake of the Woods. Therefore, the geographic scope of the Study, the Lake of the Woods Basin, refers to all land and water from the Rainy Headwaters in the east to the outlet where the system drains into the Winnipeg River in Kenora, ON to the northwest. Note that the Plan of Study also makes reference to the "Lake of the Woods sub-basin", which is one of 10 sub-basins that constitute the larger Lake of the Woods Basin (see Figure 1). Where the term "Lake of the Woods" is used on its own, this refers to the lake only.

The geographic scope draws from the IJC's authorities under the *1909 Boundary Waters Treaty* and the Directives issued by the IJC to the IRLWWB. Under the Treaty, the IJC may make recommendations to Governments with regards to water quality objectives for boundary waters in the Lake of the Woods Basin. These waters include, but are not limited to, Lake of the Woods, Rainy River, Rainy Lake and Namakan Lake, Sand Point, Little Vermilion, Lac La Croix, Crooked, Basswood, Sucker, Knife, Saganaga, Gunflint, and North Lakes. As a result, the scope of the Plan of Study focuses on the boundary waters of the Basin, though consideration for scientific analysis and/or activities has been given to upstream waters outside the defined boundary waters where there is justification to believe that activities upstream will affect receiving boundary waters. (This flexibility is provided for in the IRLWWB Directive.)

2.2.4 Scope of Issues

The scope of the Plan of Study includes each of the priority issues and factors related to water quality specifically identified in the IJC's report to the Governments in January 2012. These priority issues are:

- nutrient enrichment and HABs;
- AIS; and,
- surface and groundwater contamination, including heavy metals and other contaminants.

Other important factors identified as priorities by the IJC for understanding water quality include climate change and related development of indicators and adaptation measures, as well as hydrology and hydrologic regulation. These factors have been considered within the Plan of Study insofar as they relate directly to the priority issues.

The Terms of Reference for the Plan of Study identified several additional cross-cutting areas to be considered, including consideration of current organizational and institutional arrangements and programs, and the importance of incorporating traditional/indigenous knowledge into the Study's analysis.

2.2.5 Plan of Study Milestones

The Terms of Reference identify a number of milestones for the Plan of Study, including significant deliverables. The first five milestones of the Plan of Study were achieved through the development of the State of the Basin Report Update and a series of targeted meetings, workshops and webinars with experts convened in early 2014. Specifically, these activities included the following steps:

1. Identify existing research, data, regulatory and other relevant information available on the priority issues and factors.

2. Identify current activities and projects occurring in the watershed to address the priority issues and factors.

3. Identify key science and/or policy questions to be answered within the priority areas of concern and identify gaps in knowledge that, if filled, would provide answers to those key questions. As part of this component, it is critical to:

   a. Develop an approach for engaging key scientists, resource managers, policy personnel, First Nations, Tribes, Métis, the public and the Board's Community Advisory Group and Industry Advisory Group in this key component throughout the watershed. It is recommended that a technical session of experts (including traditional knowledge sharing) occur at the start of the process and a second technical session be held to review the output of the first session prior to finalizing a first draft; and,
   b. Ensure that discussions around key science and/or policy questions not only focus on the priority issues and factors of concern themselves, but also on the gaps that may exist within the regulatory environment (*e.g.*, land use regulation in unorganized territory, watershed planning capabilities, existing and/or differing standards).

4. Define the studies, research, and other activities necessary to fill the identified knowledge gaps and answer the key questions, including:

   a. Articulating and recommending the methodology for conducting all studies and activities to be performed and level of detail anticipated for each;
   b. Making recommendations for building upon existing monitoring programs to ensure long-term data are available to conduct the research, monitor trends and anticipate ecosystem pressures, as well as the effectiveness of activities and adaptive management strategies; and,
   c. Identifying the sources of, or means of obtaining, needed information (scientific and historical/traditional knowledge).

5. Define and articulate the additional activities and projects necessary to address the priority issues and factors.

The remaining milestones have been met through further discussions with Basin experts, meetings with IJC Commissioners and advisors, public meetings and meetings with First Nations, Tribes and Métis and through the ongoing work of the Plan of Study Team:

6. Produce a preliminary draft version of the Plan of Study to be submitted for discussion at the International Rainy – Lake of the Woods Watershed Forum in March, 2014.

7. Recommend the agencies or organizations with the knowledge or expertise (scientific and historical/traditional) to conduct aspects of each study or activity, including the defined additional activities and projects.

8. Establish the priority, duration and timing of each study or activity.

9. Estimate the human and financial resources, including expertise, required to conduct each individual study or activity:

   a. Provide a selection of options that range from a full suite of recommended studies/activities and higher-end costing to scaled-down options with only priority studies and lesser cost; and
   b. Identify potential funding sources available in both Canada and the U.S. to conduct this work and/or anticipated future funding constraints that could compromise the outcome of this study.

10. Produce a Draft Plan of Study to be submitted for comments to the IJC, the IRLWWB and its Community and Industry Advisory Groups at the April 2014 semi-annual meeting.

11. Produce a Final Draft Plan of Study to be made available in late July 2014 for a 30-day public comment period before the IRLWWB annual meeting.

12. Submit a Final Plan of Study to the IJC by October 2014.

2.2.6 Logic Models

The projects and activities proposed in the Plan of Study address clear objectives and direct the studies and analyses towards articulated outcomes. These outcomes will be the basis for the future development of international strategies to manage nutrients, prevent/control AIS, and address surface and groundwater contamination.

The logical progression for this work, linking projects to outcomes, is presented in a series of logic models for each of the Plan of Study's ecosystem priority and cross-cutting issues (Appendix A).

2.2.7 Public Outreach and Engagement

The preparation of the Plan of Study involved extensive outreach and engagement with public agencies in Canada and the United States, scientific and technical experts, First Nations, Métis and Tribes, and the general public. The Study Team convened workshops and made presentations to explain the objectives of the Study and to seek information and feedback.

A Draft Plan of Study was released for public review and comment in July 2014. The Study Team convened a series of meetings and webinars throughout the Basin in mid-August 2014 to meet with technical experts, the IRLWWB and its Community and Industry Advisory Groups, indigenous communities, the public and other interests to review the draft report and receive feedback prior to development of the final report (see text box).[6] The results of these engagement activities were taken into account during the preparation of the final version of the Plan of Study.

What We Heard:

Messages from the Public Review and Comment Phase for the Draft Plan of Study

The Water Quality Plan of Study Team held eight public meetings, as well as a technical meeting, in August 2014. Two of these meetings were held on First Nation and Tribal lands. The meetings were attended by about 220 people. The Team received 10 written submissions and about 80 comments. Public comments received during the 30-day comment period focused on several themes:

- *Algal blooms* in the Basin, which are seen as changing in type, size and frequency, as well as location; while it is important to determine the causes, proper management actions are equally important;
- The need to look at the *cumulative impacts* of mining in the basin – not only contamination from heavy metals, but impacts of additional associated power generation, roadways and other support infrastructure, storage, spills, and long-term leaching from the mines themselves, as well as mine closing plans;
- The significance of *oil shipments* – and the differing oil content - by railway, given a few significant "choke" points close to and crossing boundary waters;
- Management o*f aquatic invasive species* requires both targeted research and immediate action focusing on containment and eradication plans, communication of the risks and prevention; and,
- The need for *monitoring and establishing baseline data* for water quality now throughout the Basin, so that the effects, positive and negative, can be measured.

In addition, there were many specific comments on the Draft Plan of Study and the proposed projects. The Study Team considered each of the comments received and in many cases incorporated the suggestions in the final report.

The Study Team also met with and/or received comments from federal and state/provincial agencies, the International Rainy-Lake of the Woods Watershed Board and its Industry and Community Advisory Groups, the International Multi-Agency Arrangement Work Group, representatives of Grand Council Treaty 3, and municipalities.

[6] For a listing of Plan of Study engagement activities and workshop participants, please see: http://www.ijc.org/en_/LWBWQPOS/Activities.
For a listing of comments received on the draft Plan of Study, please see: http://www.ijc.org/en_/LWBWQPOS/Draft_Plan_of_Study_Comments .

2.3 Basin Interests

This section presents an overview of the key groups and organizations that contributed to the development of the Plan of Study. Their work has set the stage for future international cooperation of water quality management, and their future participation will be critically important in any coordinated approach to address water quality challenges in the Basin.[7]

2.3.1 International Partnerships

The past decade has seen an impressive increase in collaborative research and communication between the U.S. and Canada, especially with regard to understanding what drives algal blooms on Lake of the Woods and caused the state of Minnesota to list the southern basin of Lake of the Woods as "impaired" in 2008. Where there was a gap in IJC Board mandate in the Basin before, the establishment of the IRLWWB in 2013 now provides an international approach for collaborative surveillance of ecosystem health throughout the Basin. The work of the IRLWWB and the development and subsequent implementation of this Plan of Study can draw from the synergies in this Basin; the success of the implementation of the Plan of Study projects and the effectiveness of binational management in the future will depend on the continuation of these synergies, which include:

- the partnership between the Lake of the Woods Water Sustainability Foundation (LOWWSF) and the IJC to fund the SOBR as a prelude to the Plan of Study has provided baseline information required to make informed decisions on gaps and future activities/research to better understand the priority issues;

- the Rainy-Lake of the Woods Watershed Forums, held since 2004, have provided the common ground where researchers share research findings, develop joint project plans and goals and discuss collaborative management options. The themes for the 2014 Forum mirrored the priority issues in this Plan of Study, ensuring that discussions were focused on the topics of greatest concern at this time. The Forum has become known as the hub for scientific knowledge in this Basin and provided the most relevant venue for hosting the March 2014 Plan of Study Expert Assessment Workshop to seek input on the Draft Plan of Study;

- the commitment of the members of the IMA (see 2.3.4 below) over the years to fund research projects within their draft workplan (in particular, the contributions from Minnesota), the contribution those projects now make to the robustness of the Plan of Study and the advisory role this IMA has played in developing the Plan of Study. The close ties between the objectives of the IMA and the outcome of

[7] More detailed information on the interests in the Basin, including those involved in water quality research and management, are available in both the State of the Basin Report Clark, B.J., and Sellers, T.J., 2014, Rainy-Lake of the Woods State of the Basin Report, 2nd Edition: Lake of the Woods Water Sustainability Foundation http://www.lowwsf.com/component/docman/doc_download/35-complete-rainy-lake-of-the-woods-state-of-the-basin-report-second-edition-2014.html and the 2011 Task Force Report.

the Plan of Study will undoubtedly identify studies and activities of benefit to the IMA and the IRLWWB in general as well as to individual resource agencies with a mandate for water quality monitoring and management; and,

- the commitment of partners (currently the IJC, MPCA, LOWWSF, Province of Manitoba) to the provision of catalytic funding for the development of the International Watershed Coordination Program since October 2012. This program has enhanced the capacity within the Basin, through a dedicated Coordinator position, to provide secretariat support to this Plan of Study, to facilitate the draft workplan and actions of the IMA, and to promote civic engagement activities across the border to build support for stewardship and watershed protection from the grassroots level.

2.3.2 International Rainy-Lake of the Woods Watershed Board

Five years ago, there was an effort by citizen groups and local governments to encourage the IJC to create a water pollution board for Lake of the Woods and to create an ad hoc task force to coordinate complementary research and phosphorus management plans for Lake of the Woods. This goal has been considerably fulfilled and, in fact, expanded upon as a result of:

- the creation in 2013 of the IRLWWB (the name "watershed board" goes beyond the original call for a board for only Lake of the Woods); and,
- the ongoing collaborative work of the IMA.

The IRLWWB combines the former International Rainy Lake Board of Control (IRLBC) and the International Rainy River Water Pollution Board (IRRWPB).

The mandate of the IRLWWB is to:

- fulfill the obligations of the Rainy Lake convention to manage water levels on Rainy Lake and other boundary waters in the Rainy Lake watershed, and act as technical adviser to the Commission on this matter;
- report on existing water quality objectives in boundary waters;
- recommend new water quality and/or aquatic ecosystem health objectives in boundary waters, as required; and,
- establish and report on water quality and aquatic ecosystem health alert levels throughout the Basin.

The Board, as referenced in its Directive, has established a Community Advisory Group and an Industry Advisory Group to ensure that community members and industry representatives can provide input into Board activities and decisions and bring the perspectives of these groups to the Board table, via their co-chairs.

This Plan of Study identifies the research needs and activities required to support the Board's mandate as it relates to water quality in particular.

2.3.3 Lake of the Woods Water Sustainability Foundation

The LOWWSF is a central player in the coordination of science and research in the Basin together with the timely dissemination of results among international researchers. Formed in 2005, the Foundation's goal is to support the long-term viability of the Lake of the Woods basin by encouraging and providing financial support for research focused on understanding water quality issues and developing binational community and government support for cooperative action to protect and sustain Lake of the Woods.

As noted previously, the Foundation, together with its partners, initiated the International Watershed Coordination Program, which has allowed for a mechanism to continue and enhance communication across the border, not only at the local level, but regionally and internationally. The Foundation also facilitates the Rainy-Lake of the Woods Watershed Forum each year in International Falls, MN, allowing extensive binational sharing of basin research and monitoring data relating to fisheries, wildlife, in-lake/river chemistry and biota, contaminants, external ecosystem drivers and historical reconstructions using paleoecology.

2.3.4 International Multi-Agency Arrangement

Formed in 2009, the IMA Work Group and its Technical Advisory Committee have moved forward a significant amount of research, especially on Lake of the Woods, have identified priority projects in need of funding, and have developed a comprehensive five-year draft workplan to which all signatories may contribute. Signatories include the key federal and provincial resource agencies and other partners with mandates for water quality: Environment Canada; LOWWSF; Minnesota Department of Natural Resources; Minnesota Pollution Control Agency; Ontario Ministry of the Environment and Climate Change; Ontario Ministry of Natural Resources and Forestry; Manitoba Water Stewardship; Red Lake Band of Chippewa Indians; United States Environmental Protection Agency; and Koochiching Soil and Water Conservation District.[8]

The purpose of the IMA is "to foster trans-jurisdictional coordination and collaboration on science and/or management activities to enhance/restore water quality in the Lake of the Woods Watershed."[9] The IMA's 2014-2019 draft workplan includes ongoing and proposed projects that have been developed collaboratively among Canadian and United States partners to focus on understanding nutrients, algal blooms, erosion and management needs for the Lake of the Woods and Rainy River watershed. The IMA also has begun discussions on the need to address AIS in the Basin and struck a subcommittee with representation from Minnesota, Ontario and Manitoba. While the IMA draft workplan has a vision to eventually incorporate the research needs in the upper basin, the majority of projects currently focus on Lake of the Woods (in particular, the southern portion of the lake) and the immediate upstream areas. The draft workplan also has a vision to incorporate management strategies for dealing with the issues

[8] At the time of signing of the Agreement, the Ontario Ministry of the Environment and Climate Change and the Ontario Ministry of Natural Resources and Forestry were called the Ontario Ministry of the Environment and the Ontario Ministry of Natural Resources, respectively.
[9] This refers to the Lake of the Woods and Rainy River Basins together.

identified through the research undertaken, but this phase of work has not yet been developed. It is worth noting that recruitment of new members is ongoing to ensure that the Basin is well represented by the interested groups working with a water quality mandate within its boundaries.

The initiatives of this draft workplan, together with the protection and implementation work of the resource agencies, municipalities and community groups, provide important insights into how issues currently are being managed and what is still needed for a more binational approach to water management.

2.3.5 Control Boards

The Lake of the Woods Control Board (LWCB) is a Canadian board responsible for regulating the water levels of Lake of the Woods and Lac Seul, and the flows in the Winnipeg and English Rivers downstream of these lakes to their junction, for the benefit of all users and interests. It was established in 1919 and operates under Canadian federal and provincial legislation and a Canada-United States Treaty.

Distinct from the LWCB, the International Lake of the Woods Control Board (ILWCB) was established by a 1925 Canada-United States of America Treaty (Convention and Protocol for Regulating the Level of the Lake of the Woods). This Board approves the outflow from Lake of the Woods whenever the level of the lake rises above or falls below the elevations specified in the Treaty and regulated by the LWCB.

2.3.6 Local Governments, Organizations and Associations

Local entities in the Basin play an important role in moving watershed management issues forward by way of their own planning and project initiatives. In Minnesota, for example, Soil and Water Conservation Districts are local units of government that direct natural resource management programs at the local level in conjunction with landowners and other units of government to carry out programs for conservation use and development of soil, water and related resources.

On the Canadian side of the border, local municipalities are playing a stewardship role through development and implementation of their Official Plans. These plans direct land use planning and stipulate environmental protection measures where necessary. The large tracts of unorganized land surrounding the municipalities are managed by provincial agencies (see section 1.2.4).

On both sides of the border, local lake associations play a significant role in supporting watershed protection programs, research, outreach and education. In Canada, the Lake of the Woods District Property Owners Association has more than 3,500 members and takes an active role in educating its members on stewardship through its educational website, its LakeSmart program, *Kids in the Wild*, and the work of its Environmental Committee.

In the U.S., organizations such as the Cook County Coalition of Lake Associations, the Friends of the Boundary Waters Area Wilderness, the binational Rainy Lake Conservancy, and numerous lake

associations promote conservation, water monitoring and protection and stewardship education at the grassroots level.

2.3.7 First Nations, Métis and Tribes

The Canadian portion of the Lake of the Woods Basin lies within lands of the Anishinaabe Nation of Treaty 3. There are 28 communities that belong to Treaty 3, most of them within the Basin boundaries, including Buffalo Point First Nation in Manitoba.

Responsibility for environmental protection and management of natural resources is transitioning to First Nations. The Rainy River First Nation's Watershed Program and the Seine River First Nation water quality monitoring, as well as the resource management work of Grand Council Treaty 3, are examples of important water quality initiatives by First Nations within the Basin.

Local Métis Nation communities are organized by community councils, of which four are in and around the Lake of the Woods Basin from Kenora east to Atikokan. The Métis have harvesting rights to natural resources, including activities such as hunting and fishing within their traditional territory. They have a self-governed management regime that includes the responsibility to preserve and protect those resources for future generations and have traditional territory-based consultation protocols for any projects or actions that would impact their rights.

Tribes in the United States have sovereignty over their own trust resources and lands. Programs for fisheries monitoring and stocking, wildlife research and management planning are conducted by the Tribes and supported by the U.S. Department of Bureau of Indian Affairs. The Red Lake Band of Chippewa Indians and the Bois Fort Band have lands within the Basin boundaries, the latter as part of an 1854 Treaty. The Red Lake Band Department of Natural Resources has been an active member on the IMA and has contributed water quality monitoring data from the Northwest Angle and its tributaries to the MPCA's TMDL study for Lake of the Woods. Tribes within the 1854 Treaty area are involved in water quality monitoring and AIS monitoring, education and outreach.

3. Plan of Study Projects and Activities

This section outlines the 32 recommended projects and activities designed to address the current and emerging challenges to the water quality of the international Lake of the Woods Basin (the Basin). The projects and activities presented here are grouped into five major themes that include the three priority issues, corresponding to the key challenges facing the Basin (Table 1):

1. *monitoring*;
2. *nutrient enrichment and harmful algal blooms (HABs)*;
3. *aquatic invasive species (AIS)*;
4. *surface and groundwater contamination*; and,
5. *capacity building*.

Note that the projects are listed numerically in Table 1 under the five themes. The numbering does not relate to any proposed ranking of importance or priority. Priorities are conveyed in Section 4, Study Options and Recommendations

The description of each recommended project or activity includes:

- a statement of the *objective*;
- an *overview description*;
- a summary of *methodology*;
- *possible lead and participating organizations and key linkages*, identifying the institutions and organizations that likely would be involved with the project, as well as key linkages to other work in the Basin or other recommended Plan of Study projects; and,
- *cost and timing* considerations.

All of the recommended projects will be completed within one to four years. However, the success of some projects will require ongoing support beyond the timeline of the Plan of Study. Estimated costs are provided for the major tasks involved in undertaking each project.

Table 1
Lake of the Woods Basin Water Quality Plan of Study
Recommended Projects and Activities

Priority Theme	Plan of Study Projects and Activities
Monitoring	1. International Monitoring Program for the Lake of the Woods Basin
Nutrient Enrichment and Harmful Algal Blooms	2. Mass-Balance Models for Phosphorus and Nitrogen in the Lake of the Woods Basin 3. Internal Loads and Hypoxia in Lake of the Woods 4. Assessment of Iron Fluxes from Sediments on Cyanobacteria Bloom Formation in Lake of the Woods 5. Assessment of Nutrient Subsidies from Shorelines Due to Erosion from High Water Levels in Lakes and High Flows in Rivers 6. Application of Water Quality Models at Watershed and Basin-Wide Scales to Apportion Nutrient Sources 7. Implementation of Nutrient Load-Reduction Strategies in Lake of the Woods Basin 8. Application of Satellite Imagery and Remote Sensing Tools to Map and Characterize Water Quality and Algal Blooms 9. Development of Predictive Models of Algal Blooms from Hydrological and Meteorological Processes 10. Influence of Altered Food-Web Structure on Production of Harmful Algal Blooms 11. Taxonomic Characterization of Algal Communities and Algal Toxins 12. Public Health and Animal Welfare Risks: State of Knowledge and the Need for Alerting Mechanisms
Aquatic Invasive Species	13. Binational Aquatic Invasive Species Management Team and Prevention Strategy for the Lake of the Woods Basin 14. Evaluation and Implementation of Options to Manage Recent Zebra Mussel Infestation in Headwaters Areas in Minnesota 15. Ecological Impact of the Spiny Waterflea in Infested Boundary Lakes 16. Pilot Studies on Adaptive Control Measures for Hybrid Cattail and Rusty Crayfish in Infested Wild Rice Habitat

Priority Theme	Plan of Study Projects and Activities
	17. Comprehensive Assessment of Potential Invasion Risks to and within the Lake of the Woods Basin 18. Water Quality Risk Assessment for Zebra Mussels and Quagga Mussels 19. Climate Risk Assessment for Aquatic Invasive Species
Surface and Groundwater Contamination	20. Assessment of Binational Implementation of Water Quality Objectives for Sulfate, Copper, Nickel, and Mercury 21. Synthesis Report on Contaminants in Water, Aquatic Sediment, and Fish 22. Methylmercury Flux and Bioaccumulation in Large Border Lakes 23. Spatial Survey of Contaminants of Emerging Concern 24. Vulnerability Assessment of Border Waters to Contamination from Mining 25. Vulnerability Assessment of Border Waters to Contamination from Rail and Pipeline Transport of Petroleum and other Chemicals 26. Mining Effects Science Workshop
Capacity Building	27. International Platform for Implementation 28. Review of Data Collection Programs and Monitoring in the Headwaters Regions of the Basin 29. Application of Regional Climate Models for the Basin and Improved Public Education and Engagement on the Issue of Climate Change 30. Development of the Lake of the Woods Basin Geospatial Mapping Framework and Public Communication Tool 31. Indigenous Perspectives on Ecosystem Health 32. Funding Program for Non-governmental Organizations to Promote Watershed Protection

3.1 Monitoring in the Basin

The single project recommended in this section focuses on the need for a comprehensive and strategic monitoring and data acquisition system that targets critical aquatic and atmospheric parameters needed to understand and adapt management of the priority water quality issues. It is meant to build on and fill gaps in the existing aquatic monitoring and data acquisition infrastructure currently supported by agencies in the Basin, identify deficiencies in atmospheric monitoring networks, prioritize recommendations for new monitoring locations and measurement equipment, and establish a way to communicate findings within the context of the IJC's harmonized geospatial platform.

Benefits

Direct outcomes of the project will be: *robust and accessible data that can facilitate understanding and resolution of priority issues.*

Over the long-term, the project will contribute to: *improved water quality through a basin-wide monitoring system that supports scientific study, trend analysis of environmental conditions and evaluation of policy options through adaptive management.*

Project 1
International Monitoring Program for the Lake of the Woods Basin

Objective

To establish a strategic international monitoring program that will:

- provide data for the entire Lake of the Woods Basin to support ongoing study and assessment of transboundary lake and river systems; and,
- enable development and evaluation of effective, binational management actions to protect or improve water quality and ecosystem health.

Description

This is the most comprehensive project in the Plan of Study, calling for a more balanced system for water quality monitoring binationally. By utilizing existing monitoring gages and programs in place and adding selected stations in strategic locations, this project promotes a way to establish a consistent, dependable long-term database that will paint a clear picture of ecosystem conditions in the entire Basin.

The monitoring will focus on the priority issues, by ensuring that a key set of monitoring stations will monitor nutrients, AIS and contaminants. Consideration also will be given to the monitoring of key atmospheric constituents. This project includes recommended activities, such as the establishment of long-term gaging and sampling at key locations, and recommended studies to assess the adequacy of existing atmospheric/meteorological monitoring systems and to identify critical data gaps. The rest of the

Plan of Study is dependent on the acquisition and availability of data and information collected through implementation of this strategic international monitoring program. It directly serves the needs of the three priority issues – nutrient enrichment and HABs, AIS, and surface and groundwater contamination – as well as the cross-cutting thematic areas of hydrology and hydrological alteration and climate change.

The strategic international monitoring program for the Lake of the Woods Basin includes and builds on the Tiered Monitoring Program outlined in the Proposal submitted to the International Multi-Agency Arrangement (IMA) by its Core Monitoring Subcommittee. The Subcommittee specified that the program should allow for seamless coverage from the subregion/basin scale down to the subwatershed scale, be statistically sound and accommodate new subject areas and special studies as necessary. While monitoring in the Basin is fairly extensive, especially in Minnesota, there is a need to establish a set of strategic, long-term monitoring sites that utilizes existing sites where possible, allows for a more balanced monitoring system on both sides of the border and provides for consistent locations for sampling of priority issues parameters. The major components of this project are as follows:

- Tiered monitoring of river networks: three tiers are defined that range from coarse to fine spatial scales; as well as a river-based special studies subcomponent that is meant to focus on specific issues or problems;
- Monitoring of transboundary lake systems: the multi-basin Lake of the Woods and other large lakes along the border including, but not necessarily limited to, Gunflint Lake, Basswood Lake, Lac La Croix, Rainy Lake and Namakan Lake, as well as a lake-based special studies subcomponent that is meant to focus on specific issues or problems; and,
- Monitoring of hydrometeorological conditions and the deposition of airborne constituents.

For tiered monitoring of river networks and monitoring of transboundary lake systems, it is important that a common primary set of hydrologic, water quality and chemical parameters that focus on the priority issues are measured to ensure continuity of like data across the system. Similarly, any biological sampling that is undertaken must use the same field sampling techniques (for example, mesh size), lab-processing techniques (such as subsampling) and identification conventions. In addition to parameters that are routinely measured using multi-probe sondes, grab sampling or autosampling is essential to permit measurements of phosphorus fractions, nitrogen species, and suspended solids, among others through laboratory analyses. A suggested starting point for protocols and methodologies would be Minnesota's approach to major watershed/subwatershed loading studies, lake assessments and intensive watershed monitoring studies as part of the WRAPS. Measurements necessary under river-based and lake-based special studies will vary by issue, but may include specialized biotic assessments, scans of chemicals of emerging concern, agricultural contaminants, and focused studies on a critical contaminant such as methylmercury, among others.

The Plan of Study recommends that all tiers be funded and implemented.

Component 1: Tiered monitoring of river networks

This component comprises tiered monitoring of river networks and river-based special studies. Tiered monitoring of river networks starts with monitoring of rivers that serve as the border between Canada and the United States and all major tributaries that discharge into transboundary lakes and rivers in the Lake of the Woods Basin (Tier 1). Following a blend of Canadian and American naming conventions, subsequent tiers (Tier 2 and Tier 3) involve monitoring and sampling at finer scales. River-based special studies address specific issues or problems identified in any of the monitoring tiers.

The approach is iterative and provides a viable framework that allows for:

- interpretation of water quality and ecosystem health in transboundary waters from an international perspective;
- expansion or decrease in monitoring as budgets dictate;
- provision of data that are useful at the subwatershed, watershed and basin scale as necessary;
- determination of cumulative effects; and,
- determination of how effective projects are in meeting goals.

The monitoring approach recommended in this project component is similar to Minnesota's watershed approach (WRAPS), which is based on Hydrologic Unit Code (HUC) 8 watersheds with annual load monitoring (HUC 8s and smaller) and every 10 years an intensive four-year study of individual HUC 8 watersheds that includes monitoring (biological, chemical and physical), modeling and detailed protection and problem investigation and implementation planning at a subwatershed level. By establishing the core sites, sampling and monitoring of Canadian sub-basins (and shared sub-basins) becomes part of the strategic international dataset.

The IJC's Harmonized Boundary Waters Dataset provides the details necessary to initially lay out the spatial scale and scope for the river-based monitoring program. Watershed monitoring sites should provide data for a discrete area upstream of the site and, wherever possible, provide data about downstream effects. Watershed outlets or pour points at different spatial scales provide ready delineation of upstream areas and are often co-located with flow/discharge or water level gages. Component 2 of this project completes monitoring of the entire basin system, by establishing a core set of monitoring sites for Lake of the Woods itself and other large lakes along the border including, but not necessarily limited to, Gunflint Lake, Basswood Lake, Lac La Croix, Rainy Lake and Namakan Lake.

There are three tiers in the tiered monitoring of river networks component and a river-based special studies subcomponent (note that geospatial descriptors follow USGS naming conventions):

- Tier 1 – Subregion/Basin scale: Permanent gaging combined with storm-event and calendar-based sampling at five key sites along the international border provides "big picture" water quality and ecological information for the Rainy Headwaters and Vermilion sub-basins, the Rainy Lake sub-basin, Big Turtle River and the Lower Rainy and its tributary sub-basins (Little Fork, Big Fork and Rapid River). Measurements and sampling should focus on hydrology, loading of pollutants, and biotic information relevant to nutrients and HABs, AIS, contaminants and climate

change. Three of the five gages are already in place: Gold Portage, International Falls, and Wheelers Point. A new gage will be needed at the outlet of Namakan Lake. A fifth site, just downstream of Kenora at the outlet of Lake of the Woods towards the Ontario-Manitoba border, would then allow for inclusion of the Lake of the Woods sub-basin and enable measurement of pollutant loads and other priority issues parameters from the entire Basin to the Winnipeg River. The data provided by all five of these gages would provide water quality and loading data for all Rainy River watersheds and the Lake of the Woods Basin as well as parameter monitoring of the other priority issues. Gaging and monitoring stations in transboundary waters should be identified as stations of international importance.

- Tier 2 – Basin/Sub-basin Watershed scale: Permanent gaging along with storm-event and calendar-based sampling provides water quality and pollutant (nutrients, AIS, contaminants) information. To provide adequate coverage for Tier 2, four additional monitoring stations are required, all in the Canadian portion of the Basin.
- Tier 3 – Watershed/Subwatershed scale: Permanent gaging and storm-event sampling at targeted smaller watersheds on both the United States and Canadian sides. Tier 3 monitoring stations should be established on an as needed basis following findings generated through the other tiers. The U.S. portion of the Basin has 20 Tier 3 monitoring stations. This Plan of Study budgets for an initial six Tier 3 monitoring stations, all in the Canadian portion of the Basin that could be paired with select U.S. stations in areas requiring more in-depth analysis. Additional monitoring stations may be necessary.
- River-based special studies: Initiated by issues or problems identified in any of Tier 1, 2, or 3 monitoring activities, or identified by federal, provincial, state and local agencies, or residents and stakeholders. Examples of river-based special studies include bioassessment using benthic macroinvertebrate communities as diagnostics of specific stressors or assessment of monitoring capacity in specific regions within the Basin. Constituents that lack sufficient data for assessment could be added to the tiered monitoring program for short duration. A survey of contaminants of emerging concern that spans different land uses and a survey of pesticides in agricultural portions of the basin are two examples of possible special studies that could readily be added to the tiered monitoring program for a short duration to address an information need.

Under Tier 1 – Subregion/Basin scale, the Wheelers Point gage is considered particularly important because it represents the terminus of the Rainy River and all upstream watersheds that discharge into the Lake of the Woods. Based on 2012 modeling, 89% of the water flowing into Lake of the Woods passes by Wheelers Point, along with 93% of the watershed phosphorus load. In a letter to the IJC (October 22, 2013), International Rainy-Lake of the Woods Watershed Board (IRLWWB) secretaries recommended that the gage (USGS Gage 05137500) be designated a gage of binational significance and encouraged the IJC to commit to providing funding for its continued operation. Given the modest cost of operating this gage (approximately $16K USD/year), an immediate action should be taken by the governments to sustain the three-way cost-sharing arrangement between the USGS, the IJC and MPCA to support the Wheeler's Point gage.

Component 2: Monitoring of transboundary lake systems

To complement river-based monitoring, a core monitoring system should be established for transboundary lakes across the Lake of the Woods Basin. In the assessment of lake-based monitoring systems along the transboundary, complementary monitoring programs already in operation should be reviewed, including Minnesota's sampling of lakes above a certain size threshold two out every 10 years on a monthly basis, Voyageurs National Park's long-term biweekly program, MNRF's lake sampling on a rotating basin and Environment Canada's in-lake monitoring on Lake of the Woods ongoing since 2008. Pending outcome of the assessment of lake-based monitoring systems, new monitoring stations will be established.

- Transboundary Lakes: A core set of monitoring sites for large lakes including, but not limited to, Lake of the Woods, Rainy Lake and Namakan Lake, Gunflint Lake, Basswood Lake, and Lac La Croix. For the Lake of the Woods, given its complex bathymetry, multi-basin sampling would be necessary.
- Lake-based Special Studies: Initiated by issues or problems identified in the Transboundary Lakes monitoring activities (above), or identified by federal, provincial, state and local agencies, or residents and stakeholders.

Component 3: Monitoring of hydrometeorological conditions and the deposition of airborne constituents

Aquatic ecosystems of the Lake of the Woods Basin are influenced by external forces that affect meteorological conditions and the deposition of nutrients and contaminants from the atmosphere. This project complements the river- and lake-based tiered monitoring program through the assessment of existing meteorological and atmospheric deposition monitoring stations and networks (see Clark and Sellers, 2014 for tables of existing stations) with the ultimate goal of having a representative core set of strategic, long-term monitoring stations in the Basin. New stations should be established in areas that will improve characterization of gradients across the Basin Optimally, each HUC 8 watershed should have a station; this should provide sufficient coverage to ensure that most storm events are tracked. Information gathered through these networks can be used to support numerous other projects identified in the Plan of Study involving hydrologic budgets, phosphorus budgets and mercury accumulation rates, among others.

For many nutrients and contaminants, the atmosphere is an important pathway for the importation of external sources. A significant fraction of phosphorus is derived from atmospheric sources, particularly in less-developed areas where point and non-point sources are relatively small (Hargan *et al.*, 2011). Though domestic rates of mercury emissions have decreased in Canada and the United States, there is strong evidence that most mercury is from overseas, the result of long-distance travel through global circulation. Of critical importance is the measurement of wet deposition during rain and snowfall and, if possible, dry deposition.

Meteorological stations both on land and on water should be assessed for adequacy of coverage across the Basin to improve hydrologic budgets. Measurements of evaporation, humidity, wind speed, air

temperature, and rainfall and snowfall amounts and accumulation rates, should be recorded at key locations in the Basin that represent different climatic and physiographic regions.

Where existing atmospheric monitoring stations are already in place, analysis of spatial and temporal coverage is possible to identify data deficiencies. To help with interpretation of data acquired through newer stations, retrospective comparisons may be possible through interpretation of recent and paleolimnological sediment cores.

Study Organization, Costs and Scheduling for all Components

The IMA consists of most of the federal, state and provincial agencies and organizations that have a role in adoption and implementation of this tiered monitoring program. Such a monitoring program is identified as an "unfunded high priority" in the IMA's five-year draft workplan.

The IJC would also be included in the project through its geospatial data harmonization project. Additional partners should include LOWWSF, Tribes, Métis and First Nation communities and organizations. Given the nature of this foundational project, it directly and indirectly supports data needs of most projects listed under all three of the Priority Issues and several other Capacity Building projects and activities.

For the atmospheric monitoring components, participation of provincial, state and federal agencies will be needed to coordinate assessment of monitoring networks. Environment Canada operates a meteorological station in the northwestern section of the Basin (standard meteorological and Canadian Air and Precipitation Monitoring Network site); this station should be maintained and used as a reference and calibration station of other existing and planned stations.

Initial funds are necessary to establish new monitoring stations and to support additional monitoring operations and data analysis during the four-year course of the Plan of Study. However, longer term support for operations and analysis is expected to be covered by the monitoring agencies. Due to differences in monitoring efforts currently underway on either side of the border, new sites would only be required on the Canadian side. Periodic reviews every five to 10 years will be necessary for optimal monitoring and cost effectiveness.

The estimated total cost for completion of this foundational project is $1,020,000. Study of water monitoring networks on either side of the border will take one year and cost $50,000. Installation of new monitoring infrastructure, whether in rivers or lakes, varies widely according to specific locations of monitoring sites and the sophistication of the instrumentation. Most monitoring stations cost between $25,000 and $45,000. Taking an average of $35,000 and assuming that approximately 13 new monitoring locations will need to be established (four for Tier 2 rivers; approximately six for Tier 3 rivers, and approximately three for transboundary lake systems), the total installation cost would be $455,000. All river stations will be on the Canadian side, while lake stations will be in both American and Canadian waters. Siting and installation should also take one year. Maintenance and analytical costs for the first three years of monitoring are estimated at $300,000. These analytical costs are included in the Plan of Study budget because data collected during this time period will directly support many other projects

designed to address the priority issues. Estimated costs for atmospheric deposition monitoring are structured similarly, including costs for two new stations using the upper estimate of $45,000. Evaluation of monitoring of atmospheric deposition in the Basin should take one year and cost $50,000 and three years of sample collection and analysis should cost $75,000 ($25,000 per year).

In an adaptive management framework, sustained monitoring is critical. Cost-sharing arrangements should be pursued to maintain and optimize monitoring systems developed through the plan of Study.

Cost Estimates for Project 1
International Monitoring Program for the Lake of the Woods Basin

Major Tasks	Timeline	Estimated Costs
Tiered monitoring of river networks and monitoring of transboundary lake systems		
Study of current condition and extent of monitoring networks on either side of the border	Year 1	$50,000
Installation of new monitoring infrastructure (@$35,000 per station for 10 river stations and 3 lake stations)	Year 2	$455,000
Sample collection and processing, laboratory analyses and data interpretation (@$100,000 per year for 3 years)	Years 2-4	$300,000
Monitoring of atmospheric deposition		
Evaluation of atmospheric monitoring in the Basin	Year 1	$50,000
Installation of new monitoring stations (@$45,000 per station)	Year 2	$90,000
Sample collection and monitoring of atmospheric deposition (@$25,000 per year for 3 years)	Years 2-4	$75,000
Total estimated costs		**$1,020,000**

Notes: Costs estimated for assessment and evaluation of monitoring networks are unlikely to change. However, costs estimated for installation and monitoring new stations will vary according to the number of stations deemed necessary. Budgeting is based on the addition of 13 new monitoring stations in rivers and lakes and two new atmospheric monitoring stations..

3.2 Nutrients and Harmful Algal Blooms

HABs, triggered by a variety of climatic, physical, chemical and biological factors, continue to occur in the Basin, particularly in the southern portion of Lake of the Woods and in other lakes upstream from Rainy River. These blooms can prevent recreational usage of lakes for sport-fishing, boating and swimming, alter population densities of commercial and subsistence fisheries, cause undesirable taste and odor of drinking water and compromise water treatment facilities, and sometimes release algal toxins. Toxins are of particular concern because they threaten drinking water supplies, human health and animal welfare.

The Plan of Study identifies a series of projects designed to improve understanding of what contributes to the occurrence of these blooms, to provide a platform by which nutrient abatement and bloom control solutions can be developed and evaluated, and to disseminate information about water quality conditions and HABs to the public for safer use of Basin waters.

Benefits

Direct outcomes of the projects under this theme will be:

- *targets and objectives for concentrations and loads in the Basin's transboundary lakes and rivers and reduced loads of nutrients to border waters;*
- *predictive models of HABs linked to nutrient targets and objectives; and,*
- *knowledge of algal toxins in the Basin and a better educated public to minimize risks of HABs.*

Over the long-term, the projects will contribute to:

- *international nutrient management strategy to combat HABs;*
- *integration through adaptive management plan; and,*
- *international algal bloom and toxin reduction strategy.*

3.2.1 Answering the Nutrient Question

Policy recommendations to decrease nutrient loads and reduce the frequency and severity of HABs rely on robust descriptions and models of lake and river systems. Through the IMA, a substantial amount of work has been done towards building nutrient budgets and mass-balance models for Lake of the Woods and the Rainy River. However, Clark and Sellers (2014) and Pascoe *et al.* (2014) have identified several outstanding knowledge and data gaps that compromise a detailed and realistic accounting of phosphorus sources and sinks, not just in Lake of the Woods, but in several other transboundary lakes that also suffer from symptoms of eutrophication.

The projects recommended under this heading will provide the basis for the needed policy recommendations. They include the development of mass-balance nutrient models for Lake of the Woods, Rainy River and key tributaries, the study of processes that appear to contribute to HABs in this Basin (*i.e*., internal loading), and the application of water quality models to evaluate management options, climate change scenarios, and assist with the development of water quality objectives (nutrient concentrations for transboundary lakes and nutrient loads for boundary rivers and key tributaries).

Project 2
Mass-Balance Models for Phosphorus and Nitrogen in the Lake of the Woods Basin

Objectives

To:

- Develop budgets and dynamic mass-balance models that describe trends in concentrations and loads of phosphorus and nitrogen in Lake of the Woods and other transboundary lakes, and the Rainy River and other major tributaries, and

- Develop binational water quality objectives for phosphorus and nitrogen that can be recommended to the governments.

Description

Mass-balance modeling involves integration of inputs and outputs over defined periods of time. A nutrient budget is a way to quantify system compartments of phosphorus and nitrogen within a lake or river and across its catchment. Budgets and mass-balance models depend on observational datasets to ensure that they, as realistically as possible, represent key components of a system and the rates by which nutrients move into, through and out of the system. Studies of nutrient dynamics within Lake of the Woods and in defined watersheds of the Basin, projects focused on developing load and mass-balance datasets, the Rainy River load monitoring from 2010, load and lake mass-balance modeling for TMDL and lake-based models, and Minnesota's storm event-based watershed monitoring have all demonstrated the utility of nutrient budgets and mass-balance models for improved understanding of nutrient sinks and sources (Hargan *et al.*, 2011; Anderson *et al.*, 2013).

In development of budgets for phosphorus and nitrogen, data gaps are likely to be encountered that hamper budget completeness. For example, within-lake budgets, especially for phosphorus, will depend on a greater understanding of internal loading (recycling of phosphorus from lake-bottom sediment back into the water column) as well as quantification of inputs from streams and rivers and the atmosphere derived from point (e.g. wastewater and sewer discharges) and non-point (e.g. agricultural or forest) sources. As well, estimates of nutrient loads in rivers are sometimes compromised by incomplete time-series of observations. Total forms of phosphorus (TP) and nitrogen (TN) represent the most common measures of nutrients; however, special attention will also be dedicated to the feasibility and utility of budgets for dissolved or bioavailable phosphorus since they are the forms that most readily stimulate algal blooms. For these reasons, this project depends on robust water quality monitoring networks. Paleolimnological work completed through the IMA should be considered as it will provide a picture of how loading rates and algal communities have changed over the recent past.

This multi-component project aims to build on previous IMA-organized efforts by broadening the spatial extent of the budgets and mass-balance models to include all remaining watersheds not already covered by MPCA to develop basin-wide nutrient models. Once completed, phosphorus and nitrogen budgets can be used to set binational targets and objectives for concentrations in the water column of Lake of the Woods and other transboundary lakes and for annual or seasonal loads of nutrients entering the lakes. Targets and loads should be developed in consideration of approaches adopted in other systems confronted with eutrophication. For the western basin of Lake Erie, a cyanobacterial index (CI), a measure of algal bloom severity, is strongly related with discharge and phosphorus from key tributaries in the basin (Stumpf *et al.*, 2012; International Joint Commission, 2014; Scavia *et al.*, 2014). The resulting load-response curves can be used to set policies according to desirable levels of algal blooms compared to current conditions.

In addition, this project is critical to the evaluation of land use and land cover changes, conservation practices and best /beneficial management practices (BMPs) intended to reduce excessive nutrient loading to basin waters (Project 7).

Methodology

The project will be undertaken in five components:

- **Component 1**: Development of nutrient budgets for watersheds in the Basin not already covered. For portions of the Basin that have robust water quality data, such as watersheds in Minnesota, this will be more straightforward than for areas that are data-deficient, including some in northwestern Ontario. Estimates of historical P loads from Rainy River to Lake of the Woods and associated burial rates will be used to improve interpretation of budgets.

- **Component 2**: Development of lake-wide (Lake of the Woods) and Basin-wide coupled mass-balance models that quantify nutrient sinks and sources. Models will consider annual periods, seasonal periods and storm events. This component should build on load and lake mass-balance modeling for Minnesota's TMDL program for impaired areas (for example, Big Traverse Bay) as described in the IMA draft workplan.

- **Component 3**: Interpretation of nutrient budgets mass-balance models to make recommendations for binational water quality objectives for phosphorus and nitrogen; concentrations objectives for open water zones of lakes and load objectives for rivers and inputs to lakes.

- **Component 4**: Development of relationships for transboundary lakes between indices of algal bloom severity, such as the Cyanobacterial index (CI) and forcing factors such as discharge or phosphorus loads from key tributaries.

- **Component 5**: Phased-in aspect of the project, which involves updating of the budgets and models on a periodic basis as new sources of monitoring data and information and new statistical interpretation techniques are made available.

Study Organization, Costs and Scheduling

Major participants in the IMA (such as Environment Canada, MPCA, MOECC) and USGS, are well-positioned to lead this project.

Estimates of nutrient sinks and sources developed through this project will serve as critical information for recommendations of water quality objectives for nutrient concentrations and loads. The Great Lakes Water Quality Agreement has objectives for concentrations and loads; processes used to develop these objectives may be transferable to the Lake of the Woods Basin.

Minnesota's currently funded project, as described in the IMA "Storm-event based load monitoring", should be used to improve event-based phases of models. Similarly, results from the IMA accomplished project "Estimating TP loads from Shoreline Erosion" will be applied.

Nutrient concentrations and loads should be georeferenced to binational stream networks, under development through the IJC, and to land-use maps through IMA collaborations with the University of Minnesota and the University of Manitoba.

Estimates of internal loading as a subsidy of phosphorus will depend on development of monitoring and measuring tools described in internal load and hypoxia projects elsewhere in the Plan of Study.

Components 1 and 2 of this project are estimated to cost $75,000 each. Components 3 and 4, recommendations of binational water quality objectives and development of algal bloom indices, are estimated to cost $25,000 each year. Once nutrient budgets and mass-balance models have been developed, periodic updates, recommended on a five-year basis, are estimated to cost $50,000 per update and would represent an ongoing funding requirement. Not including the periodic updates, this project is estimated to cost $250,000 over a four-year period.

Components 1 and 2 should each take approximately three years. Components 3, 4 and 5 would involve a longer term commitment to support analysis and interpretation of water quality datasets.

Cost Estimates for Project 2
Mass-Balance Models for Phosphorus and Nitrogen in the Lake of the Woods Basin

Major Tasks	Timeline	Estimated Costs
Nutrient budgets for outstanding watersheds	Years 1-3	$75,000
Lake-wide and basin-wide mass-balance models	Years 1-3	$75,000
Development of water quality objectives for nutrients	Years 3-4	$50,000
Application of cyanobacterial index (CI) to Lake of the Woods	Years 3-4	$50,000
Total estimated costs		**$250,000**

Note: Model updating should occur on an ongoing basis as new data are generated.

Project 3
Internal Loads and Hypoxia in Lake of the Woods

Objective

To improve understanding of internal nutrient loads and hypoxia towards better prediction of HABs.

Description

A consistent message from Basin experts and highlighted in both Clark and Sellers (2014) and the IMA draft workplan is that there is insufficient knowledge about the role of internal loading and hypoxia in the development of algal blooms in the Basin. More than 90 percent of the phosphorus entering Lake of the Woods comes from the Rainy River. Although the annual loads of phosphorus to Lake of the Woods

have been decreasing from Rainy River, the frequency and severity of algal blooms has not and may be increasing. There is speculation that the accumulated reservoir in lake-bottom sediments is supplying phosphorus for algal growth. The subsidy of phosphorus from lake-bottom sediments is thought to be particularly important in the Lake of the Woods Basin. However, improved methodologies and monitoring systems for quantifying internal loads and hypoxia are needed and they need to be adapted to climatic and hydrologic conditions that typify transboundary lakes in the Basin. Once internal loads of phosphorus are estimated and incorporated into phosphorus nutrient budgets, a variety of other ecological questions can be addressed, such as the impacts of hypoxia on habitat for fish such as lake trout, walleye and sturgeon.

This multi-component project builds on existing research projects recently completed in the Basin that have focused on targeted areas of internal loads and hypoxia. Internal loads are believed to be a major source of phosphorus to the water column and a factor in the development and duration of HABs in Lake of the Woods (especially Big Traverse Bay) as well as other transboundary lakes such as Kabetogama and eutrophic bays of Rainy Lake. Recent work by Edlund *et al*. (2014) has shown that phosphorus is released from lake-bottom sediments in Lake of the Woods, indicating the importance of remobilization. In addition, phosphorus derived from internal loads is primarily in a dissolved form, which is more bioavailable for uptake by primary producers, including algae. Other dynamics at play at the sediment-water interface include sediment resuspension, particularly in areas of lakes prone to large open-water stretches (fetches). This project will develop methods to monitor, estimate and model internal loads. Such methods will need to be applicable not just during the open-water season, but also during winter to quantify under-ice dynamics since lakes can be covered by ice for many months of the year. Complete year accounts of internal loading would be subjected to interpretation as a function of climate change scenarios from existing regional climate models that may affect lake stratification, thermal regimes and ice phenology.

Hypoxia is related to internal loads through oxygen depletion. An understanding of the drivers of hypoxia, which includes inputs of phosphorus, organic matter and nitrogen, will improve quantification of internal loading and provide insight into conditions that may impair ecological condition through HABs or fishkills. This project will develop relationships between oxygen consumption and physical drivers, such as temperature, water circulation and lake bathymetry, and sediment chemistry. Research will be carried out in concert with the other projects listed in this subsection and will involve a combination of field studies and geospatial modeling. Another output from this project would be a mapping application that shows the location, size and duration of hypoxic areas. This application can be combined with other mapping applications, such as HAB extent, to assess overlaps in space and time.

The Lake of the Woods Basin is famous for its fisheries; its sport fishery and its subsistence fishery for First Nations, Tribes and Metis. Lake trout, walleye and sturgeon are emblematic of the watershed. Healthy fish populations are due to well-oxygenated waters and the availability of suitable habitat for spawning. This project will involve summer surveys of lakes across the Basin to quantify and characterize habitat for lake trout, walleye and sturgeon and the collection of sediment cores to reconstruct hypolimnetic oxygen concentrations and historical water quality. Indigenous knowledge will form an additional and novel source of information on the history of fish communities and catch rates.

Methodology

The project will be undertaken in four components:

- **Component 1**: Estimation of phosphorus loading from sediments will be improved by the development of better measurement techniques and enhancement of monitoring. A particular challenge that needs to be overcome through this component is consideration of seasonality. Winter conditions, specifically under ice dynamics, may play a key role in setting up conditions for internal loads and hypoxia; however, this portion of the year is typically difficult to monitor and often overlooked.

- **Component 2**: Associated with monitoring is mapping of spatial extents of internal load and hypoxia. Both are temporally dynamic in that spatial extents vary from year to year. For this reason, mapping layers will be linked to bathymetry. Variation in water levels, as a function of hydrologic regulation or weather-related flooding, will be incorporated into the model to improve their utility under future conditions. In addition, vulnerability areas will be identified that may include specific zones of lakes and relatively protected bays.

- **Component** 3: Information derived from monitoring and mapping will be integrated into a modeling system that could be used to predict internal loads and hypoxia and serve as a visualization tool of conditions that are likely to lead to the development of HABs.

- **Component 4**: Mapping and modeling tools developed to describe hypoxic areas should then be applied to Lake of the Woods and other selected transboundary lakes to predict impacts of hypoxic variation on key fish species such as lake trout, walleye and sturgeon.

Study Organization, Costs and Scheduling

Internal load data will be useful in the development of nutrient budgets and geospatial data layers of hypoxia will contribute to the suite of mapping tools that can describe the condition of Lake of the Woods and other transboundary lakes.

Technique development for measuring and monitoring of internal loads and spatial extent of hypoxia should be led by partnerships between government agencies already involved with Basin studies and universities that have the expertise to develop and evaluate suitable technologies.

Mapping tools and applications developed through this project will need to be housed and maintained by an agency or organization, such as one or more already part of the IMA.

This project is estimated to cost $400,000 over a four-year period. For the internal loads component of this project, preliminary research in Big Traverse Bay cost $150,000. A reasonably complete study of the Lake of the Woods will cost another $150,000 and if other transboundary lakes are to be studied for internal loads (*e.g.*, Rainy Lake and some of the lakes in Voyageurs National Park) an additional $50,000 is necessary. Complementary work on hypoxia is expected to cost $75,000 for Lake of the Woods and

another $50,000 for other select transboundary lakes. Development of a mapping tool will build on other Plan of Study projects involving mapping tools, and is estimated to cost $25,000. The fish habitat modeling component will cost $50,000 per year.

Components 1, 2 and 4 of this project are research-oriented and should take three years to complete; though additional years may be necessary to characterize interannual variability. Component 3 will require a start-up period to ensure data are translated into mapping tools, and then an ongoing commitment to mapping support.

Cost Estimates for Project 3
Internal Loads and Hypoxia in Lake of the Woods

Major Tasks	Timeline	Estimated Costs
Estimation of phosphorus loading from sediments for Lake of the Woods and other transboundary lakes	Years 1-3	$200,000
Mapping of hypoxia in the same set of lakes	Years 1-3	$125,000
Development of a mapping tool	Year 3	$25,000
Modeling of fish habitat	Years 3-4	$50,000
Total estimated costs		**$400,000**

Project 4
Assessment of Iron Fluxes from Sediments on Cyanobacteria Bloom Formation in Lake of the Woods

Objective

To determine whether anoxia and phosphorus-iron dynamics at the sediment-water interface are precursors to internal loading and the formation of algal blooms.

Description

This project focuses on iron at the sediment-water interface as it may play a specific biogeochemical role in the release and availability of internally loaded phosphorus. Recent research from a survey of Canadian lakes suggests that iron plays a specific role in the stimulation of algal blooms.

Molot *et al.* (2014) provided evidence from several Canadian lakes spanning a trophic gradient that, while phosphorus controls productivity, blue-green algal dominance of phytoplankton communities is dependent on access to ferrous iron in anoxic waters diffusing from anoxic sediments below. Experimental evidence from the Experimental Lakes Area (ELA) (Molot *et al.*, 2010) showed that denial of access to ferrous iron prevents bloom formation even if productivity does not decrease. This suggests that bloom formation could be prevented in Lake of the Woods by maintaining oxidized sediments to prevent formation of ferrous iron. In turn, this could be accomplished by limiting anthropogenic inputs to

the lake not only of phosphorus but also possibly organic carbon, organic nitrogen and ammonium, all of which lead to microbial consumption of dissolved oxygen. Indeed, the risk of bloom formation (Downing *et al.*, 2001) may be linked to the risk of anoxic sediment formation which increases as P loading increases.

Insight gained through this project will buttress the need for monitoring of internal loads and hypoxia in support of the development of nutrient budgets and mass-balance models. It also will help provide a biogeochemical context for interpretation of contaminant-mediated release of phosphorus, such as that described in the contaminants assessment project for sulfate.

Methodology

This project will involve several field and laboratory research activities. Field activities will be carried out in collaboration with efforts to improve measurement and monitoring of internal loads and hypoxia:

- assess the development of anoxia and internal loading in affected and reference areas of the lake in relation to the timing of blooms;
- map surface sediments for organic carbon, organic nitrogen and ammonium;
- assess the potential of sediments to contribute ferrous iron should sediments become anoxic;
- measure sediment and water column nitrification and respiration rates; and,
- measure release rates of phosphorus and iron from incubating sediment cores.

Once mechanisms for iron-mediated phosphorus release are better understood, options for maintaining oxidized sediments will be reviewed through this project.

Study Organization, Costs and Scheduling

This project will be led by an academic institution in partnership with federal, state and provincial agencies.

Results could be linked to phosphorus mass balances to set effective phosphorus input targets once a dissolved oxygen model becomes available that predicts how sediments will respond to various phosphorus control scenarios. However, mass balances for other oxygen consuming substances may be necessary.

Due to the extensive field and laboratory work required for this project, it is estimated that it will cost $250,000. This is a research-oriented project that will require three years of field work and one year to synthesize results.

Cost Estimates for Project 4
Assessment of Iron Fluxes from Sediments on Cyanobacteria Bloom Formation **in Lake of the Woods**

Major Tasks	Timeline	Estimated Costs
Methods development, field collections and laboratory experiments, and sample processing and analysis	Years 1-3	$150,000
Graduate student support, including report writing	Years 1-4	$100,000
Total estimated costs		**$250,000**

Note: Costs associated with this project are consistent with a doctoral level research program.

Project 5
Assessment of Nutrient Subsidies from Shorelines Due to Erosion from High Water Levels in Lakes and High Flows in Rivers

Objective

To quantify rates of phosphorus loss from existing properties and infrastructure and shoreline erosion so as to improve nutrient budgets and develop a shoreline vulnerability index that considers high water levels in lakes and high flows in rivers due to hydrologic regulation and altered circulation and wind patterns due to climate change.

Description

The 2014 SOBR identified shoreline erosion as one of the main concerns facing the Basin, most significantly in the southern portion of Lake of the Woods along the Minnesota lakeshore and in the Buffalo Point area in Manitoba. These shorelines are particularly vulnerable to the combined forces of high winds and high water levels, resulting in a higher likelihood that the subsidy of phosphorus from shorelines will increase. Elevated water levels and high winds observed during the late spring and early summer of 2014 may be an indicator of future environmental conditions. Discussions with Basin experts and property owners around Lake of the Woods yielded the point that substantial amounts of shoreline and land were lost in 2014.

Erosion was the focus of a detailed investigation on shoreline load contributions from Minnesota to sediment and nutrient budgets (Houston Engineering Inc., 2013). Studies by Hadash (2010), Hargan *et al*. (2011) and Anderson *et al.*, (2013) estimate that approximately 5 percent of the TP load to Lake of the Woods comes from erosion of shoreline properties. Phillips and Rasid (1996), through a study on how shoreline erosion along the U.S. side of the lake contributes to the lake's nutrient issues, generated a historical overview of erosion problems in Lake of the Woods that are associated with water level controls. Results from the study indicated that TP loading to the lake from southern shoreline erosion may be a significant source of nutrients to the lake, on the order of loading from precipitation and local

watershed inputs (estimated by Hargan, *et al*. (2011) at 105 and 89 tonnes/year, respectively). The findings suggest that further study is warranted to generate more robust estimates of shoreline erosion subsidies of phosphorus and how the subsidies relate to water level regimes.

Accurate measurement of water levels is important for tracking changes and modeling potential impacts on shoreline erosion. Water level gage harmonization in the Rainy and Namakan Lakes and the Rainy River was completed in 2014. Similar work should be completed on the remaining portion of the Rainy River and Lake of the Woods to provide a more complete picture. In addition, there are identified "blind spots" on LOW for modeling water levels. Additional gaging and climatology data collected on the southeastern portion of LOW is needed to better understand the wind-driven lake-level oscillations that directly lead to shoreline erosion and nutrient inputs (see Project 9). Additional information and assessment can directly impact water level management decisions that can ultimately reduce nutrient inputs from shoreline erosion. The IMA has recently updated their 5-year draft workplan to include these high priority projects.

Additional risks associated with shoreline erosion include wash-outs of septic systems and associated drain fields, which may result in substantial subsidies of nutrients to adjacent waters.

It is also worth highlighting that the IJC, on behalf of the IRLWWB, is funding ongoing efforts to evaluate the performance of water level management strategies for Rainy and Namakan Lakes and Rainy River (Rule Curve Review). As part of that review, a consultant was retained in 2013 to undertake site visits of shoreline properties on the Rainy, Namakan, Kabetogama, Sand Point, Little Vermilion, and Crane Lakes to help gather the necessary data to assess shoreline vulnerability due to high water levels. The project is expected to be completed in March 2015.

Where applicable, results from these studies will be interpreted for their potential influence on vulnerability of shorelines to erosion and sediment and nutrient loss rates. Many factors can affect rates of shoreline erosion. Some are within the control of structures in the Basin through water level regulation, while others are not, such as alteration of wind and water circulation patterns due to climate change. The high water levels and flows experienced in the Basin during June and July of 2014 due to exceptionally high rainfall rates exacerbate current rates of erosion.

The major challenge of this project will be to estimate changes in nutrient subsidies to rivers and lakes as a function of these factors and how they influence water quality and the occurrence of HABs.

Methodology

Given the work done in support of this area of research through the IMA's "Estimating TP Loads from Shoreline Erosion", this project should focus on the following six components:

- **Component** 1: Add a nearshore sampling program (one option is through river-based and lake-based special studies described in the foundational tiered monitoring project, Project 1) to characterize the distribution and fate of phosphorus from eroded sediments;

- **Component 2**: Incorporate measured TP loads from southern shores and estimates of TP loads from northern shores into nutrient budget models;

- **Component 3**: Harmonize Lake of the Woods lake level gages, assess the distribution of gages, and evaluate the methodology of the mean water level that is used to target lake level management decisions.

- **Component 4**: Develop erosion vulnerability index for shorelines and disseminate it through a mapping tool that would show shoreline zones in a risk framework. The index will include hydrologic conditions such as those observed in 2014 and be used to model shoreline projections (alterations to shorelines) according to more recent trends in hydrologic variability and possibly frequency of extreme events. The index will then be used to estimate future changes to phosphorus loads from shorelines and assist with land-use planning;

- **Component 5:** Review protection strategies and BMPs for erodible shorelines, identify proven actions to protect shorelines that can be implemented immediately in Lake of the Woods, Rainy River and other boundary waters, develop and evaluate new strategies, and initiate demonstration projects; and,

- **Component 6**: Interpret results of projects undertaken through the Rule Curve Review by relating them to risk of increased shoreline erosion.

Study Organization, Costs and Scheduling

Work in support of this project should be undertaken by agencies and institutions in collaboration with MPCA, Soil and Water Conservation Districts, Ontario municipalities and property owners/lake associations who can work directly with owners of shoreline properties.

Activities recommended in this project should be carried out in coordination with current and future rule curve review and regulation plan projects as directed by the IRLWWB.

Based on previous preliminary work through the IMA on shoreline erosion nutrient subsidies, it is estimated that components 1 and 2 will cost $250,000 over a two-year period. The project under Component 3 involving gage harmonization is estimated to cost $65,000 and the assessment of gage distribution and evaluation of mean water level methodology is estimated to cost $40,000. Development of the mapping tools in component 4 will cost $25,000. Components 5 and 6 will cost $50,000 each; the project on protection strategies should be initiated immediately, while the project on interpretation of project results in relation to the Rule Curve Review can be delayed until after the second and third years of research. The cost of this project is $480,000.

Research components of this project will take three years to ensure that adequate interannual variation is covered.

Cost Estimates for Project 5
Assessment of Nutrient Subsidies from Shorelines
Due to Erosion from High Water Levels in Lakes and High Flows in Rivers

Major Tasks	Timeline	Estimated Costs
Nearshore sampling program to quantify shoreline sources of P	Years 1-2	$200,000
Incorporation of P subsidy estimates into nutrient budget models	Years 2-3	$50,000
Lake level gage harmonization, assess distribution of gages and evaluate mean water level methodology	Years 1-2	$105,000
Development of an erosion vulnerability mapping tool	Year 3	$25,000
Review protection strategies and BMPs for erodible shorelines	Year 1	$50,000
Study of how Rule Curve Review project results interact with shoreline erosion	Year 3	$50,000
Total estimated costs		**$480,000**

Project 6
Application of Water Quality Models at Watershed and Basin-wide Scales to Apportion Nutrient Sources

Objective

To calibrate water quality models for specific watersheds and the Lake of the Woods Basin as a whole that can be used to apportion nutrient sources and run management action and climate change scenarios.

Description

Water quality models build on nutrient budgets. They can be used to identify knowledge and data gaps, answer questions about sources of nutrients, and evaluate scenarios that may involve predictions of how climate change or nutrient abatement management actions affect water quality. Successful calibration of water quality models depends on the availability of relevant datasets.

The State of Minnesota has already made great strides in the modeling of watersheds that comprise portions of the Lake of the Woods Basin through the application of Hydrological Simulation Program-Fortran (HSPF), which includes a routine that can provide preliminary mass-balance model evaluations. The current HSPF model under development by MPCA (anticipated completion data of August 2015) includes the Canadian portion of the Basin, which forms the basis of a model for the entire Basin. Watershed modeling efforts recommended in this project complement the HSPF effort as well as the IJC's binational SPARROW application[10] (anticipated completion date December 2015). For example, the CANWET model[11] used to address nutrient enrichment and algal bloom issues in Lake Simcoe may be readily available for application in the Canadian portion of the Basin. Multi-model approaches are

[10] http://wi.water.usgs.gov/nutrients/sparrow/index_modeling_MCSM.html
[11] http://www.grnland.com/index.php?action=display&cat=17

encouraged as individual water quality models have strengths and weaknesses and suitability at different spatial scales.

Calibrated water quality models have several uses in the Basin. First, they can be coupled to lake models (IMA workplan, and Clark and Sellers, 2014) as drivers of water quality, ecological condition and algal blooms (for example, Zhang *et al.*, 2013). Second, they can be used to evaluate hypotheses or policies of land use change, management actions or climate change to estimate their influence on nutrient concentrations and loads. Third, online mapping and decision support system tools of calibrated models afford opportunities for customization to suit local stakeholder needs and for public engagement through visualization of water quality and watershed attributes. Fourth, they can be used to support an adaptive management strategy for the improvement of water quality in the Basin (IJC, 2014).

Methodology

Given the water quality modeling activities already underway in the Basin, the first activity in this project should be organization of a workshop to review water quality modeling completed or under development in the Basin, exchange information and analytical tools, and to identify data gaps. In portions of the Basin for which there is insufficient monitoring data to calibrate a water quality model, regional binational modeling should be advanced to at least provide estimates of nutrient loads and concentrations that can be used to inform policy.

Where necessary, watershed attributes should be developed and harmonized across the Basin to provide robust input data for the models. Such attributes or factors may include elevation models, stream networks, physiography, and land use/land cover maps, wastewater and sewer discharges, among others. A central archive and retrieval website for binational datasets would be of great benefit to model developers and interested organizations and residents of the Basin. Such a website, possibly hosted by the IRLWWB, is recommended as a project in this Plan of Study (Project 30, Geospatial Mapping Framework). Land use/land cover maps, in particular, are useful for describing human activities in the Basin and, when developed on a periodic basis, provide a picture of how the Basin is changing over time.

Calibrated models will be used to forecast changes in concentrations and loads of nutrients in lakes and rivers according to alterations (according to climate change scenarios) on temperature and precipitation regimes and policies and strategies involving land use and land cover change, conservation practices, and BMP implementation. Calibrated models and their supporting datasets will be made available through technical (published) resources and online tools. With changes in human activities in the Basin and the influence of climate change, models should be updated on a periodic basis as new monitoring information becomes available.

Study Organization, Costs and Scheduling

Binational work on water quality modeling will include partnerships with key agencies including MPCA, Environment Canada, MOECC, MNRF, USGS and the IJC. Collaborations with academic institutions, corporations or non-profit organizations may also be beneficial for the advancement of models.

Calibrated water quality models for lakes and rivers will be used to assist with the development of water quality objectives for Lake of the Woods and other transboundary lakes, Rainy River and other major tributaries.

This modeling effort will cost $200,000 over four years. It includes $50,000 for the international modeling workshop and $100,000 for the development of new water quality models. An additional $50,000 will be used to take the calibrated lake, river and watershed models and evaluate a variety of scenarios, which may include climate change, management policies surrounding land use and land cover change and BMPs.

Acquisition of datasets and calibration of new water quality models will take two years. Multi-model integration, model stewardship and adaptive management represent an ongoing commitment.

Cost Estimates for Project 6
Application of Water Quality Models at Watershed and Basin-wide Scales to Apportion Nutrient Sources

Major Tasks	Timeline	Estimated Costs
Binational workshop to review applications of water quality models in the basin, identify data gaps and promote synergies	Year 1	$50,000
Development of new water quality models	Years 1-2	$100,000
Evaluation of climate change, management policy and BMP scenarios through model forecasting	Years 3-4	$50,000
Total estimated costs		**$200,000**

Note: Workshop costs cover the services of a facilitator to administer the workshop as well as travel costs for non-agency invitees.

Project 7
Implementation of Nutrient Load-Reduction Strategies in Lake of the Woods Basin

Objective

To develop, evaluate and implement land use change, conservation practices and BMPs to reduce nutrient loads to surface waters throughout the Lake of the Woods Basin.

Description

With the general understanding that nutrient enrichment, especially phosphorus, is the cause of HABs in Lake of the Woods and in other transboundary lakes, management towards reduction of nutrient loads to surface waters represents a fundamental strategy for improvement in water quality. Several broad categories of management options exist that control nutrients, including change in overall land use and land cover, landscape-scale conservation practices, and targeted BMPs in urban, rural and agricultural areas. With the complex landscape heterogeneity that characterizes the Lake of the Woods Basin, in terms of surficial geology, soils, topography and native vegetation cover, a suite of management options should be reviewed and tailored for specific watersheds. Implementation of nutrient control strategies should be prioritized in those watersheds with the greatest nutrient yields and those that are clearly linked to water quality impairment in particular transboundary water bodies. The intensive watershed monitoring and assessment work already done or ongoing by the MPCA will provide guidance on priority sub-basins upon which to focus and best strategies for dealing with any identified impairments. For example, through total maximum daily load (TMDL) efforts in Minnesota, the Little Fork River has already been identified as the highest single source of phosphorus to the Rainy River. With limited resources to combat excessive nutrient loading, the greatest return on nutrient abatement efforts may be through spatial targeting of those areas identified as the highest contributors.

Land use and land cover changes cover broad-stroke alterations to landscapes. For nutrients, they mainly involve changes in land use to less nutrient intensive activities, which may involve changes in agricultural commodities or changes to cropping systems and livestock, mainly dairy, operations. They may also involve changes in landscape cover whereby marginal lands used for production are returned to native forest cover and restoration or wetlands. Land use and land cover changes should focus on landscape attributes that may result in a net decrease of nutrients applied to the land and also assist with the sequestration of nutrients on the land in soils, sediments, and vegetation before they reach stream networks. Conservation practices are similar to land use and land cover changes except that they tend to be geared towards particular land resource activities. Buffer zones along the edges of agricultural fields and forest harvest patches and riparian zones along the edges of surface water systems may be among the most familiar conservation practices. Measures that are meant to reduce shoreline erosion fall under this heading. The term BMP covers a wide array of targeted actions that are customized for specific practices, depending on the context. In urban and rural environments, some BMPs include storm retention structures, swales, septic system management and green infrastructure.

Regarding sewage and wastewater from facilities that service residents of the Basin, an immediate action that could be taken would be to enhance removal of solids from wastewater treatment plants. Effluent from sewage and wastewater treatment facilities is an important source of nutrients that can impact lakes and rivers. Across the Basin, facilities range widely in terms of age, size and level of treatment. An immediate action to reduce nutrients would be to enhance the capacity of treatment facilities to reduce solids. In Minnesota, the MPCA has identified a number of priority facilities that would benefit most from system upgrades. Implementation of these upgrades would immediately reduce loads of phosphorus and nitrogen to basin waters an improve water quality locally. In addition, it is estimated that there are well over 100,000 backcountry visitors to the Basin each year, most of which choose to visit the

headwater regions that include national, state and provincial parks. Education programs involving proper management of waste in backcountry should be enhanced.

In agricultural environments, BMPs range from improved manure management and fertilizer application rates to controlled tile drainage and precision pesticide application techniques. While many of these options have been developed, evaluated and implemented in regions that differ in significant ways from the Lake of the Woods Basin (*i.e.*, U.S. Midwest, Eastern Seaboard), research and development into land use and land cover options, conservation practices and BMPs (geographically or by sector) needs to be initiated so that resource managers have tools at their disposal to recommend to government agencies, non-governmental organizations and individuals to decrease the flow of nutrients to shared waters.

Several nutrient control options are proven to reduce nutrient loads to surface waters and are suitable for the climatic and physiographic conditions in the Lake of the Woods Basin. Programs should be enhanced or established immediately to implement these options in tributary watersheds known to contribute significant loads of nutrients to Lake of the Woods and other transboundary lakes. Success will depend on government action as well as support to local non-government organizations with the mandate for water stewardship. As noted, Minnesota's WRAPS is a comprehensive template for assessing and, where needed, restoring and protecting water quality on a watershed by watershed basis.[12] Soil and Water Conservation Districts in Minnesota implement conservation practices and BMPs based on their own knowledge and the findings of the WRAPS in their local sub-basin. In northwestern Ontario, BMPs are promoted and/or implemented through stewardship councils, non-governmental organizations such as lake associations and by municipalities through their Official Plans. In unorganized territory, which comprises the bulk of the Basin in Canada, there are provincial and federal park plans and the Ontario Municipal Affairs and Housing provincial policy statement that provides high level guidance to other ministries regarding environmental protection around development. Citizen-based actions should also be encouraged; for example, fertilizers for residential lawn and garden use are now available that are free of phosphorus (IJC, 2014).

Methodology

The first step under this project will be to review the state of knowledge surrounding land use and land cover changes, conservation practices and BMPs in the Lake of the Woods Basin. This review will identify those actions and measures that have been proven to be effective in the Basin and make recommendations as to how they can best be immediately implemented. It will also identify those actions that have been proven successful in reducing nutrient loads and should be implemented immediately. A binational workshop in support of this review will serve to galvanize interest and participation.

In the IMA draft workplan, one of the management objectives is to reduce nutrient loading to the Rainy River and its tributaries from permitted facilities. For these facilities, several strategies have been identified that would reduce P effluent concentrations to 1.0 mg/l or less during permit renewals,

[12] http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/watershed-approach/index.html

prevention of nutrient loading from non-sewered areas and new facilities, improvement of the condition of facilities around the boundary waters, and workshops to discuss nutrient loadings and future permit limits. Strategies such as these will be the focus of discussion at the workshop.

Where knowledge of effectiveness is lacking in any of these areas, research and development programs in Canada and the United States should be enhanced or initiated to evaluate nutrient control options most likely to be effective in the Lake of the Woods Basin. Actions and measures developed elsewhere in temperate regions in North America and around the world may have potential for suitability in the region. The research and development programs should be located within the Basin as local conditions have a major influence on the effectiveness of nutrient control techniques. For example, field-based models of agricultural systems for such research and development programs exist in both Canada *(i.e.,* Agriculture and Agri-Food Canada, Ontario Ministry of Agriculture, Food and Rural Affairs) and the United States (*i.e.,* United States Dept. of Agriculture, Natural Resource Conservation Service, Minnesota Department of Agriculture). Field-based model systems for evaluation will be co-located with monitoring sites identified in the tiered monitoring project (Project 1) to optimize use of monitoring data and to permit "scaling up" scenarios of nutrient control measures across larger geographic regions of the Basin.

Study Organization, Costs and Scheduling

A wide variety of participants should be involved with all aspects of this project, including members of the IMA. The IMA, in Part II of its draft workplan, identified similar objectives of working towards adaptive management planning as a way to begin implementation of the science in Part I of their draft workplan. The state-of-knowledge review workshop should include broad representation from agencies at all levels of government, non-profit organizations and interested citizens.

Research and development programs and projects should be carried out through innovative partnerships between organizations that represent specific sectors (for example, agricultural, forest, urban infrastructure) and provide practical contexts of nutrient management issues and academic institutions that can provide technical expertise and a forum for rigorous review and debate of novel techniques.

The binational workshop on mitigation measures and a review of current practices will cost $50,000. Land use and land cover scenarios, conservation practices and BMP implementation scenarios will be evaluated through scenario modeling, based on calibrated water quality models. In addition, owing to the particular climatic and physiographic conditions that characterize the Basin, targeted development and evaluation of BMPs for both agricultural and urban/rural lands in the basin will require a multi-year field study. The total cost of this project is $425,000.

The review of current practices workshop can be completed within a year. Results of innovative mitigation measures will take at least four years, followed by ongoing water quality monitoring as there is typically a lag-time between implementation and the observation of effects.

Cost Estimates for Project 7
Implementation of Nutrient Load-Reduction Strategies in Lake of the Woods Basin

Major Tasks	Timeline	Estimated Costs
Binational workshop on mitigation measures to review state of implementation, outcomes and effectiveness, and research needs	Year 1	$50,000
Development of land use and land cover, conservation practice and BMP scenarios for evaluation using water quality models	Years 3-4	$50,000
Field-based development and evaluation of BMPs	Years 1-4	$325,000
Total estimated costs		**$425,000**

Notes:

1. For the scenario evaluation component, preliminary water quality models available after two years will be used to begin the evaluation phase.

2. For the field-based BMP evaluation component, an initial $175,000 is required to augment monitoring as described in the tiered monitoring project with additional instrumentation suitable for specific quantification of BMP effectiveness, followed by an additional three years of monitoring; however, monitoring should continue beyond the formal duration of the Plan of Study due to anticipated lag effects.

3.2.2 Drivers of Harmful Algal Blooms and Development of Predictive Models and Tools

The generation of a predictive model for the timing, spatial extent and duration of HABs represents an ambitious goal. The projects under this subheading involve identification of drivers or forcing factors that may result in HABs and characterization of HABs through satellite imagery and remote-sensed data to facilitate visualization and interpretation.

A component of the first two projects is application of the approach adopted for the western basin of Lake Erie involving development of relationships between a cyanobacterial index (CI) based on satellite imagery and phosphorus loads from a major contributing tributary. The return of severe HABs at Lake Erie and the response of governments, stakeholders and citizens in that basin provide an example of how to frame and address eutrophication in an international context.

The last project in this section addresses how food web variation may increase or decrease the likelihood of algal blooms. Ecological properties of trophic structure may exert control on processes such as grazing pressure on algae and may help explain why lakes behave differently. Similarly, the introduction and establishment of AIS can have a major influence on food web dynamics, such as spiny waterflea on zooplankton communities and zebra and quagga mussels on nearshore habitats and communities (see section 3.3, below).

Project 8
Application of Satellite Imagery and Remote Sensing Tools to Map and Characterize Water Quality and Algal Blooms

Objective

To apply satellite imagery and remote sensing tools to develop mapping and interpretation tools of water quality and HABs and to develop an index of bloom severity.

Description

Research using satellite imagery and remote sensing data has shown a promising capacity to map water quality variables such as chlorophyll, non-algal suspended sediment, Colored Dissolved Organic Matter (CDOM) and water clarity on a regional basis throughout the Basin and to characterize algal bloom timing, extent and severity in near-real time and on a historical basis. This project would build on and accelerate research into water quality mapping in the Basin (Olmanson *et al.*, 2008; Olmanson *et al.*, 2011, 2013; Brezonik *et al.*, 2014) and algal bloom characterization (Binding *et al.*, 2011a; Binding *et al.*, 2011b; Pascoe *et al.*, 2014). The maps would be created by developing relationships between satellite imagery and water quality variables. These maps will be used to help develop predictors of algal blooms in collaboration with field-based measures of water temperature, dissolved oxygen profiles, turbidity, concentrations of chlorophyll, and rates of inflow and phosphorus loads into lakes, among others. In addition, images and interactive maps can serve as powerful tools for resource managers and for public education and awareness, as specifically noted in the IMA draft workplan.

The experience of understanding HABs in the western basin of Lake Erie suggests that predictive relationships of algal bloom spatial extent and duration can be developed using key forcing variables such as discharge or phosphorus loads from major tributaries (International Joint Commission, 2014). Satellite imagery collected through this project should be evaluated for interpretation as a CI (as described in Stumpf *et al.*, 2012; Michalak *et al.*, 2013) which can then be used towards setting phosphorus load targets and objectives for algal bloom frequency and severity.

Methodology

The complex geomorphology and bathymetry and highly dynamic nature of algal blooms on Lake of the Woods necessitates frequent monitoring to adequately characterize bloom evolution, intensity and aerial extent. However, for the isolated and hydrologically complex waters of Lake of the Woods this would be logistically and financially challenging by *in situ* sampling alone. Fortunately there are numerous historic, current and forthcoming satellite-based images and datasets that are or will be available at low or no cost that will greatly enhance the water quality information that can be gathered at a lake-wide to a Basin-wide scale. The main data limitation for this project will be having adequate observational data that can be used to validate images and calibrate models. However, to best utilize available remote sensing imagery, some *in situ* data collection will be required for this project. Selection of specific zones, bays or regions of Lake of the Woods and other transboundary lakes prone to water quality issues and HABs in particular may be necessary for expedient development of mapping and interpretation tools. Much of the field data

collection necessary for this project is covered in other proposed projects. However, to get the most out of these efforts, field data collection should be targeted during satellite overpass. This project has four complementary components:

- **Component 1:** Regional basin-wide remote sensing assessment of lake water quality that can be used to assess spatial and temporal patterns and can be posted through online tools such as the University of Minnesota Lake Browser (water.umn.edu). This component will utilize water quality information from MNRF (more than 100 lakes in the Ontario portion of the Basin) and Minnesota Pollution Control Agency water quality monitoring program (hundreds of lakes in the Minnesota portion of the Basin) for calibration of the imagery. The improved spectral, temporal and spatial characteristics of the forthcoming Sentinel-2 satellite that is scheduled for launch in April 2015 will allow for chlorophyll, non-algal suspended sediment and CDOM to be mapped independently in complex optical waters in the Basin. This will allow for a more comprehensive assessment than is currently possible with Landsat imagery. Landsat imagery available since 1972 can be used to assess historical and current water clarity. The improved radiometric characteristics of the newly launched Landsat 8 (Feb 2013) also allows for CDOM measurements. Such a tool has been proven to be an important resource for lake managers and very useful for public education and awareness.

- **Component 2:** To capture the highly dynamic nature of algal blooms on Lake of the Woods, near-real time monitoring will be developed using MODIS and the forthcoming Sentinel-3 satellite data. The high frequency of imagery should be adequate to characterize bloom evolution, intensity and aerial extent during the open-water season. To develop a better understanding of the dynamic nature of algal blooms and quantify bloom intensity change, a retrospective analysis of available open water clear imagery back to 2003 using MODIS/MERIS will be used to create a historical water quality database of chlorophyll and other-related variables within LOW. Similar to the tool for mapping water quality, this tool would also serve an important resource for lake managers and public education and awareness.

- **Component 3:** To better understand the algal distribution, abundance and algal species within Lake of the Woods, research will be conducted utilizing the improved spectral characteristics of the forthcoming Sentinel-3 satellite. This project will develop protocols specific to the lake and characteristics of the Sentinel-3 satellite to map algal distribution, abundance and algal species composition within LOW. Protocols developed by the USGS to utilize fixed-station data to validate and calibrate Sentinel-3 imagery will be investigated and potentially utilized. Similar to the tool for mapping water quality, this tool would also serve an important resource for lake managers and public education and awareness.

- **Component 4:** Imagery and spatial datasets generated through this project should be assessed for suitability as an index of algal bloom extent and duration, such as the CI developed for the western basin of Lake Erie. The National Oceanic and Atmospheric Administration (NOAA)

communications product, the Lake Erie Harmful Algal Bloom Update[13], could be considered for application in the Lake of the Woods Basin.

Study Organization, Costs and Scheduling

The core group for this project should include IMA agencies and organizations such as EC and the USEPA in partnership with the Canadian Space Agency, NOAA and academic institutions involved with the development of interpretation tools.

Geospatial data products developed through this project would be accessible and made available through the geospatial mapping project (Project 30).

The project is estimated to cost $285,000. Interpretation tasks including database compilation and georeferenced maps and dissemination of processed images (in coordination with the Geospatial Mapping Project, Project 30) will cost $215,000 and the remaining $70,000 will be used for partnering with Environment Canada to carry out *in situ* monitoring studies for model validation.

Research in support of this project should take four years, as it will mainly focus on processing imagery and data. A longer timeframe may be required to capture interannual variability.

Cost Estimates for Project 8
Application of Satellite Imagery and Remote Sensing Tools to Map and Characterize Water Quality and Algal Blooms

Major Tasks	Timeline	Estimated Costs
Compilation of Landsat databases and development of georeferenced maps	Years 1-3	$70,000
Development of water quality maps and monitoring of algal and particulate conditions using MODIS	Years 1-4	$120,000
Build on the IRLWWB website to host processed images on an ongoing basis	Years 1-4	$25,000
In situ annual monitoring surveys for model validation	Years 1-4	$70,000
Total estimated costs		**$285,000**

[13] http://www2.nccos.noaa.gov/coast/lakeerie/bulletin/

Project 9
Development of Predictive Models of Algal Blooms from Hydrological and Meteorological Processes

Objective

To improve understanding of how hydrological and meteorological processes in the Basin, including hydrological forcing, wind dynamics and water circulation affect the onset, extent and duration of algal blooms.

Description

Prediction of the location, timing and extent of HABs in Lake of the Woods would be of great benefit to government agencies, regional stakeholders and residents of the Basin. However, the great variety of interacting factors suggests that undertaking multiple approaches is likely the best option for making sense of such a complex system. In addition to the biogeochemical processes referred to in the Plan of Study, there are physical or hydrometeorological processes, such as hydrological forcing, wind patterns and dynamics and water circulation and flows, that influence the distribution of nutrients in water bodies and the dynamics of algal blooms (McCullough *et al.*, 2012; Zhang *et al.*, 2013). Through Environment Canada's Water Science and Technology Directorate, an effort is underway to parameterize a HABs model for Lake of the Woods. Remaining knowledge and data gaps will be identified as a result of this effort.

This project should be coordinated with other projects that focus on development and use of topographic digital elevations models (DEMs) and bathymetric maps. Detailed bathymetric mapping of select littoral zone locations in Rainy Lake and Namakan Reservoir is a planned study associated with the Rainy and Namakan Lakes Rule Curve Review studies, and will support development of a more precise digital elevation model for Rainy Lake and Namakan Reservoir which allows researchers to improve their data analyses by improved quantification of areas inundated and dried under various hydrologic regimes. This is important for nutrient loading (and HABS) as well as for production of methylmercury (contaminants). Creation of detailed DEM for the Rainy Lake and Namakan Reservoir area, as part of the habitat modeling project for these waterbodies, can be used in combination with the hydrologic models referenced above to investigate the relative influence of various hydrologic regimes (rule curves and state of nature) on nutrient loading, methylmercury production, and habitat for fish and wildlife.

Methodology

The project involves analysis of historical and contemporary hydrometeorological data to develop time-series of hydrological forcing, wind patterns and water circulation. The components are:

- **Component 1**: Evidence from some other lakes suffering from eutrophication suggests that increases in loads alone are not sufficient to explain the recent proliferation of algal blooms, but that hydrological forcing as a result of increases in runoff is accelerating the transfer of phosphorus from land to receiving waters. This component involves relating phosphorus loads from Rainy River to

estimates of runoff and discharge to separate the relative contributions of both factors. It will be linked to the nutrient budgets and mass-balance models project.

- **Component 2**: Changing wind patterns may have an impact on thermal stability with Lake of the Woods, which in turn may influence internal loading and algal abundance and composition. Environment Canada embarked on a study that involved development of a wind simulation, but wind data were only available for one season. Multiple years of data are needed to parameterize a model of wind patterns. Additional wind data may be available through the atmospheric component of the tiered monitoring project. Wind measurements would need to be coupled to simultaneous measurements of internal loading.

- **Component 3**: The circulation and flows of water within Lake of the Woods has an impact on the lateral and vertical transfer of nutrients and the spatial distribution of algal blooms. A circulation model for the lake exists (Zhang *et al.*, 2013; Pascoe *et al.*, 2014), but it would benefit from further refinement. In addition, water level variation, as a function of hydrologic regulation or climate change, should be considered when developing and modeling water circulation through the system. To support consideration of water level regimes, a lake level gage should be established and maintained on the southeastern shore of LOW with a meteorological station for four years (see Project 5). This will assist with lake level management decisions to reduce impacts from shoreline erosion and phosphorus loading. Meteorological station data will provide needed meteorological data to assess the wind effects on the southern shore.

- **Component 4**: All models should be made available through mapping tools and versions of the models should be applied to other transboundary lakes.

Study Organization, Costs and Scheduling

IMA agencies involved with the collection of information on wind direction and speed and water movements will be involved, as well as NOAA.

It is estimated that this project will cost $300,000 and take four years to ensure sufficient time to capture interannual variability in hydrological and meteorological conditions. Component 1 requires a study that can be completed within a year. Component 2, the project involving characterization of wind patterns, will require additional field work to capture interannual variability in hydrological and meteorological conditions, so it is a multi-year project. Component 3 aims to build on existing understanding of circulation patterns in the lake and water level variation; additional field work may be required. Output from these components, including datasets and images, will be incorporated into the Geospatial Mapping Framework (Project 30).

Cost Estimates for Project 9
Development of Predictive Models of Algal Blooms from Hydrological and Meteorological Processes

Major Tasks	Timeline	Estimated Costs
Study to characterize and quantify relationships between loads from Rainy River to Lake of the Woods and hydrologic factors	Year 1	$50,000
Interpretation of wind data as a factor that may predict blooms in Lake of the Woods	Years 1-4	$125,000
Southeastern portion of the Lake of the Woods meteorological station	Years 1-4	$75,000
Refinement of circulation models in Lake of the Woods	Years 2-3	$50,000
Total estimated costs		**$300,000**

Project 10
Influence of Altered Food-Web Structure on Production of Harmful Algal Blooms

Objective

To understand and quantify the role of zooplankton communities and aquatic trophic structure in the development of HABs.

Description

Trophic interactions in aquatic ecosystems can exert a strong influence on energy flow. Algal population growth and community structure are controlled by the availability of bioavailable nutrients and by grazing pressure, primarily by invertebrates called zooplankton. In most lakes, aquatic community structure is relatively stable, meaning that the composition and abundance of organisms at different trophic levels (that is, primary producers, such as algae and macrophytes; herbivores, such as zooplankton; consumers, such as forage fish; and top-level predators, such salmonids) are relatively unchanged from year to year. It is a testament to the resilience of most natural communities that they persist in this way.

This project is focused on understanding and quantifying how alteration to components of transboundary lake food webs may influence the occurrence and severity of HABs. One of the major perturbations to aquatic food webs in the Basin is the introduction of the invasive species spiny waterflea. It may affect algal growth and biomass through alteration of herbivorous zooplankton communities (Yan *et al.*, 2002; Barbiero and Tuchman, 2004). Trophic structure as a whole may also affect the likelihood that algal blooms occur through phenomena called trophic cascades (Carpenter and Kitchell, 1996). Another major perturbation to aquatic food webs can occur as a result of invasion of zebra mussels. Though zebra mussel habitat is primarily along shorelines, their filtration capacity has been observed to dramatically alter water clarity and distribution of nutrients across the nearshore zone to the open water zone (Hecky *et al.*, 2004).

With the complex bathymetry and density of islands that exist in the Lake of the Woods in particular, there is the potential for widespread infestation.

Methodology

This project relies on coordinated biotic sampling in selected parts of Lake of the Woods and across a series of transboundary lakes. Sampling locations should occur as part of the tiered monitoring program to optimize resources and take advantage of ancillary datasets. Construction of food web models will include identification of predatory-prey relationships through field observations and gut contents analyses, as well as through the application of stable isotope analyses. Food web models should then be interpreted and, if possible, coupled to other models developed through the Plan of Study to develop a more comprehensive picture of what factors may control HABs.

Study Organization, Costs and Scheduling

Selection of study locations should follow the foundational tiered monitoring program, particularly the river-based and lake-based special studies.

This project should be operated as a partnership between agencies in the Basin, which can assist with monitoring and sampling, and key academic institutions, which can assist with analyses and interpretation.

Other Plan of Study projects addressing the spiny waterflea will be linked to this effort.

The data collection component of this project will cost $150,000 and the model development component will cost another $150,000, for a total of $300,000.

As a field-based research project, a minimum of four years should be undertaken for biotic monitoring and sampling.

Cost Estimates for Project 10
Influence of Altered Food-Web Structure on Production of Harmful Algal Blooms

Major Tasks	Timeline	Estimated Costs
Data collection in coordination with monitoring and sampling efforts in the tiered monitoring program	Years 1-4	$150,000
Development of ecological models	Years 1-4	$150,000
Total estimated costs		**$300,000**

Note: This project would be suitable as a graduate student project, which would benefit from cost-saving through agency-university partnerships.

3.2.3 Improved Understanding of Risks Associated with Toxic Algae and Enhancement of Public Education

One of the more hazardous by-products of HABs is the potential release of algal toxins. There is limited knowledge about the taxonomy of algal species in HABs and even less about algal toxins. The first project under this group involves a synoptic survey of nearshore waters and targeted sampling of algal blooms to improve understanding of specific risks in the Lake of the Woods Basin transboundary lakes and boundary rivers. This information will be useful for generation of accurate public health advisories regarding water uses.

The second project focuses on a review of public health and animal welfare risks as a result of algal toxins. It builds on previous work in the Basin by the IJC's Health Professionals Advisory Board (HPAB) and involves development of communication tools such as websites, social media alerts and traditional print media to inform the public of current conditions.

Project 11
Taxonomic Characterization of Algal Communities and Algal Toxins

Objective

To provide the public with accurate and up-to-date information about water quality conditions in transboundary lakes that experience HABs, through detailed characterization of algal communities and algal toxins.

Description

HABs are undesirable in the Basin because they impair water quality, ecological condition and human uses of water resources. HABs can also lead to the release of algal toxins that threaten human health and animal welfare (such as pets and livestock). Perhaps the most commonly known algal toxin is microcycstin. To properly appreciate risks associated with toxins, improved resolution of composition is critical as there are different strains of microcystin that vary in toxicity and persistence, as well as other toxins such anatoxin-a, among others.

There is insufficient understanding of the composition and structure of phytoplankton communities in both offshore and nearshore zones of Lake of the Woods and other transboundary lakes (Kotak and Zurawell, 2007). Over the past decade, there have been several reports of cyanobacterial bloom toxins, including microcystin, in Lake of the Woods (Chen *et al.*, 2009; Orihel *et al.*, 2012). In particular, it should be noted that anatoxin-a, a neurotoxin, has been detected in HABs, and was responsible for the death of a dog recently at Caliper Lake, ON (adjacent to Lake of the Woods, and in the Basin). Recent high-profile contamination incidences of drinking water supplies in the Lake Erie basin (Carroll Township, Ohio, in 2013 and Toledo, Ohio, in 2014) indicate that drinking water treatment plants need monitoring for algal toxins.

Findings from this project will be used to inform the projects devised to help predict the occurrence of HABs. It is not a given that the same sets of factors that give rise to algal blooms also contribute to the release of algal toxins. Separate predictive models may need to be developed. Predictive models for various algal toxins should be developed, but given the paucity of data on anatoxins in the basin waters, it is likely more realistic to generate one first for microcystin.

Methodology

This project will involve a series of biotic and biochemical sampling programs in transboundary lakes which will occur during the open-water season over at least three years to capture within-season and inter-annual variation. Sampling will be stratified in two ways and locations will be selected in consideration of lake-based monitoring programs to optimize research resources and provide additional information for interpretation of findings. First, samples will be collected from key pelagic (open-water) zones at fixed depths to collect algae settling out of the water column. Second, samples will be collected from nearshore zones along transects perpendicular to the shore and from areas adjacent to water treatment facilities. There are a limited number of sampling protocols for algal communities and toxins in nearshore environments, so they may need to be developed for this project. Samples will also be collected from sediments at sample locations to evaluate toxin risk. All samples will be identified for algal community composition and algal toxins (for example, microcystin).

In addition, the project would greatly benefit from *in situ* continuous sensor measurements of chlorophyll-*a* and blue-green pigments. The project would start with a pilot study to develop and test sampling strategies, processing techniques and methods of toxin analysis. Relationships would be developed between algal communities and water quality parameters and satellite imagery. Further, results from paleolimnological analyses, as anticipated from the IMA project entitled "Southern Basins Paleolimnology Project", will be used to provide historical context for contemporary observations.

Study Organization, Costs and Scheduling

This project should be supported through partnerships of agencies, academic institutions and other specialized organizations that can identify algal species and toxins.

Information collected through this project on algal toxins will be useful for other Plan of Study projects involving review of public health implications of HABs, as possibly being carried out by the IJC's HPAB, and public education.

Characterization of algal communities will be cross-validated with satellite imagery and remote-sensed data.

The field component of this project will be carried out in conjunction with other open water and nearshore sampling programs. It will cost $40,000 a year for four years. Sample analysis represents the largest allocation of funds in support of this project, $60,000 a year for four years. The total cost of this project is estimated to be $425,000.

This project will require three years of study to adequately cover interannual variation in algal communities and the occurrence and extent of algal blooms. The first year of the project will be dedicated to refinement of sampling protocols and analytical methods and identification of optimal sampling locations.

Cost Estimates for Project 11
Taxonomic Characterization of Algal Communities and Algal Toxins

Major Tasks	Timeline	Estimated Costs
Field sampling component	Years 1-4	$160,000
Sample analysis costs for algal toxins	Years 1-4	$240,000
Analysis, interpretation and recommendations	Year 4	$25,000
Total estimated costs		**$425,000**

Project 12
Public Health and Animal Welfare Risks: State of Knowledge and the Need for Alerting Mechanisms

Objective

To assess the risks of HABs to public health and animal welfare and develop communication tools to alert the public of possible risks.

Description

When HABs occur, there is an increased risk that algal toxins may be released, putting human health and animal welfare at risk. This project will support efforts by government agencies, stakeholders and non-government organizations to keep the public informed about when and where HABs occur and the associated composition of algal toxins. It also will form the basis of a HAB and algal toxin early warning system that could be linked to other geospatial applications in the Basin.

This project has two components. The first is to determine the risks to human health and animal welfare associated with occurrences of microcystin and other toxins such as anatoxins by conducting a literature review and producing a discussion paper.

The second component is to develop an effective communication tool to notify the public of the risks, based on enhancing current communication efforts in both Canada and the United States. This project would involve an inventory of actions taken within each jurisdiction regarding alerting the public of HABs. In Ontario, the MOECC and the Northwestern Health Unit (NWHU) have partnered in the past to produce posters with information on blue-green algae, the need to avoid them if seen and numbers to call

if the blooms are spotted. However, there is no ongoing information on algae blooms offered on the websites of either the Ministry or the NWHU website[14], though beach closure notifications (as they relate to *E. coli*) are noted on the NWHU website. Regular monitoring of microsystins does not occur as a part of the weekly beach sampling program done by the NWHU. The Ontario government recommends contacting their Spills Action Centre if an algae bloom is seen. In Minnesota, the Department of Environmental Health website has information on microcystins for the public to read, as does the MPCA website.

Methodology

The first component of the project involves development of a discussion paper that will draw from existing algal toxin data from the Basin and include a review of toxicity incidents to humans and animals, worldwide. It will document types of toxins, exposure routes, toxicity and conduct a risk assessment. It could also feed into the planned update of the 2009 Health of Rainy-Lake of the Woods report by the IJC's HPAB that may be addressing/suggesting the analysis of water samples collected at beaches for microcystins in addition to the regular analyses for *Escherichia coli*.

The second component is needed to ensure that communication of HABs and algal toxins reaches the general public, medical community (doctors, veterinarians), government agencies and others in the Basin. The geography of this Basin makes it difficult to reach the communities that can be affected and different communication tools will work better for different communities. A concerted effort needs to be placed on communicating health risks, as well as previous and new results of algal toxin monitoring. A communications strategy needs to be developed that should include:

- review of provincial/state communication tools for HABs;
- identification of target audiences;
- messaging; and,
- types of communications media (for example, pamphlets/fact sheets, posting on websites, newspaper articles, Facebook, regular update in the Lake of the Woods State of the Basin Report, lake association websites and email contact lists).

Working with the IJC, provincial/state/federal government agencies and other experts, a draft communication plan will be developed. Based on the communication plan, communication products and avenues of communication will be subsequently implemented and supported by relevant agencies.

Study Organization, Costs and Scheduling

Many organizations will be consulted through the course of this project including NWHU, Minnesota Department of Environmental Health, MPCA, MOECC, indigenous communities, Grand Council Treaty 3. The two components of this project will each cost $25,000 for a total of $50,000 and require one year to complete.

[14] www.nwhu.on.ca

Cost Estimates for Project 12
Public Health and Animal Welfare Risks:
State of Knowledge and the Need for Alerting Mechanisms

Major Tasks	Timeline	Estimated Costs
White paper on algal toxin issues in the Basin: state of knowledge	Year 1	$25,000
Development of a communication and outreach strategy for algal toxins	Year 1	$25,000
Total estimated costs		**$50,000**

3.3 Aquatic Invasive Species

AIS include species that are not indigenous to the Lake of the Woods Basin (including fish species) that may occur naturally in some basin waters, but which have been transported into Basin lakes where they were not present historically. Over the last 30 years, the Basin has been invaded by many non-native species that have disrupted ecological communities in all trophic levels (*e.g.,* from algae up to fish). These invasive species include the hybrid cattail, spiny waterflea, rusty crayfish and rainbow smelt. The spiny waterflea, an invasive predatory zooplankton, poses a significant challenge, as it preys upon other zooplankton, a common food source for juvenile and small fish species. As well, zebra mussels have been reported in the headwater lakes of the Big Fork River, a tributary to the Rainy River.

There is considerable potential for these invasive species to expand their ranges in the Basin, carried downstream by rivers or inadvertently transported to other waterways by recreational boaters and other "human vectors." These threats require assessment, rapid response and a coordinated prevention plan.

The rapid expansion of zebra mussel infestations in Minnesota, including entry into the Lake of the Woods Basin, highlights the need for redoubling of efforts aimed at preventing costly, ecologically disruptive infestation. Key gaps addressed by the projects in this section include:

- the need to implement control measures to restore waters and ecological functions that have been disrupted by AIS, including a rapid response and control plan related to the recent entry of zebra mussels into several water bodies in the Basin;
- the need to implement strategies to prevent introduction of AIS into the Basin, or spread of AIS within the Basin;
- the need to better understand entry points and vulnerabilities of Basin waters to the introduction of AIS; and,
- the need to better understand ecological disruptions, particularly those that affect fish production and algal blooms.

Benefits

Direct outcomes of the projects under this theme will be:

- *prevention programs and rapid response efforts to contain and eradicate infestations;*
- *establishment of strategies to prevent spread and improved understanding of the ecology of invasive species; and,*
- *improved understanding of AIS vectors and risks of infestation.*

Over the long-term, the projects will contribute to: *a coordinated international prevention program for AIS.*

3.3.1 Comprehensive Aquatic Invasive Species Prevention Strategy

Large-scale ecological and economic disruptions often occur when invasive species enter water bodies (Ricciardi, 2001; Pimentel *et al.*, 2005). Given that the most cost-effective approach to management of invasive species is preventing them from invading ecosystems (Figure 3), the highest priorities for the Basin are to develop and implement effective prevention strategies and improve upon existing strategies. Manitoba, Ontario and Minnesota, as well as federal agencies, each have their own prevention initiatives, legislation, and strategies and these will need to be coordinated so as to be most effective for the Basin.

In 2013, an Aquatic Invasive Species Subcommittee of the IMA-TAC was struck to begin this effort. However, the subcommittee has not yet been able to advance its goals and objectives. The subcommittee drew up a draft mission statement and plan for cooperative prevention among the three jurisdictions. This provides a good starting point, but there needs to be resources and capacity for this group to be successful as well as expansion of its membership to include the parks and protected areas in the Basin. The project in this section outlines a mechanism for developing a coordinated, comprehensive prevention strategy for the Basin and the more specific pieces required to better understand the threats and options for implementation.

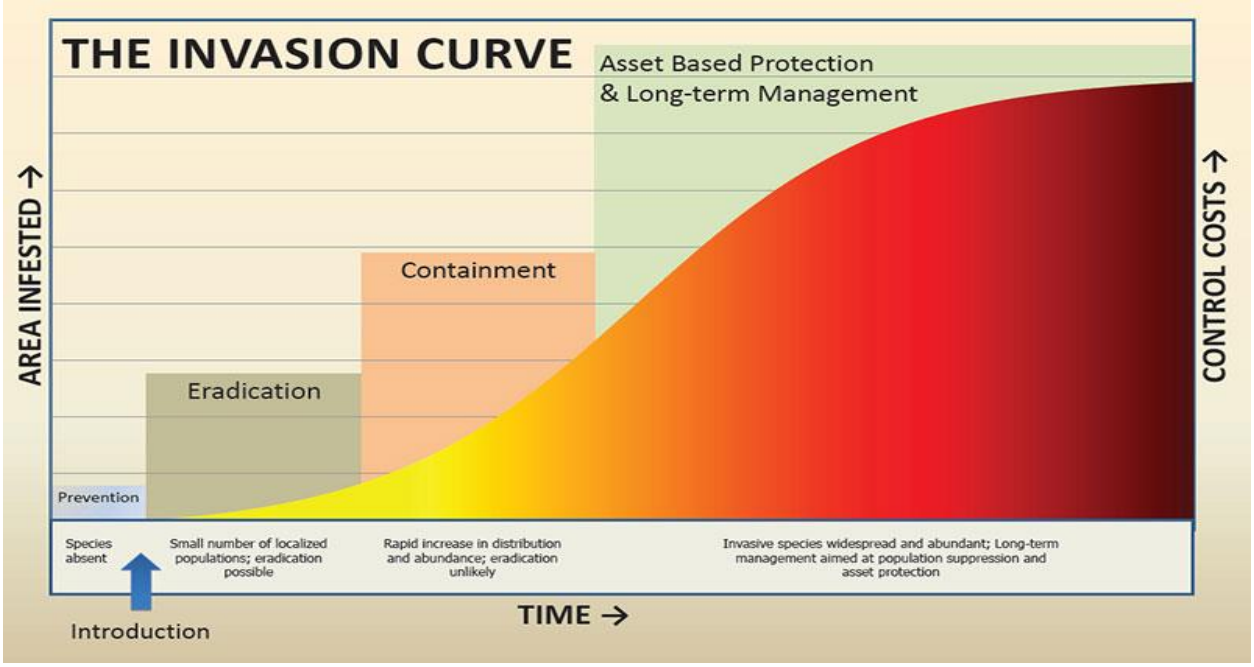


Figure 3
Addressing Aquatic Invasive Species: The Invasion Curve

The invasion curve conceptual diagram suggests that prevention costs are small, compared with management of invasions after they occur; and that cost progressively increases as the area of infestation increases and invasive species become widespread and abundant.

(Figure and concepts from LeRoy Rodgers, South Florida Water Management District, http://www.naisn.org/generalinformation.html)

Project 13
Binational Aquatic Invasive Species Management Team and Prevention Strategy for the Lake of the Woods Basin

Objectives

To:

- Strengthen the leadership and capacity of the IMA-TAC AIS Subcommittee to become the Binational Management Team; and,
- Establish the mission of the Team to be:
  - To develop a binational strategy (program) to prevent AIS in the Basin, respond rapidly to new and emerging AIS threats, and, where possible, contain or eradicate, AIS already in the Basin;
  - To develop a binational public engagement and education campaign; and,

- To ensure robust procedures are in place to track movement and abundance of important AIS, while ensuring that confirmed field data are entered into appropriate federal, state, and provincial data bases.

Description

This activity will ensure that membership on the IMA-TAC Subcommittee is supported with representation from Ontario, Manitoba, Minnesota and other appropriate entities and that the resources are provided to develop a coordinated, multi-jurisdictional plan to improve efforts to prevent the introduction of AIS from nearby basins. The level of effort varies considerably between the jurisdictions and it will be important to balance these efforts more. Minnesota has an extensive prevention strategy and Ontario and Manitoba have already worked alongside AIS leaders in Minnesota to develop and enhance their own programs. Manitoba has a well-defined border inspection program that has proven to be effective. Ontario implements its invasive species program through the Ontario Federation of Anglers and Hunters and, at times, has partnered locally with the local Lake of the Woods and District Property Owners Association to ensure a student is monitoring and undertaking outreach activities on the topic. In the past few years, the association has provided this service independently.

While the framework will largely be developed and implemented with input from resource agencies with this mandate in the Basin, it is important that it be done in partnership with indigenous communities and the general public and provide for educational opportunities on prevention.

The prevention framework should include:

- Harmonization and implementation of regulations and actions across borders and political jurisdictions, aimed at prevention of the intentional and unintentional spread of invasive species. For example, consistent approaches to managing spread of bait, bait water, and invasive species on aquatic equipment and gear are needed; common messaging and signage throughout the Basin is another example.
- An emphasis on managing the pathways or vectors through which AIS enter or move within the Basin, and managing those vectors to prevent the spread of all invasive species, rather than a species by species strategy (for example, see page 25 of Rosenberg *et al.*, 2010). Building on the inspection programs in place within the three jurisdictions and handling them cooperatively, especially at provincial and federal borders will be important.
- Ongoing research, review, and adaptive management of current actions related to AIS prevention and control measures (monitoring, regulations, chemical and biological controls, educational activities, civic engagement, and other relevant activities), to assess efficacy of approaches.
- Development of a Rapid Response Plan for the most ecologically and economically threatening species.

With regard to the Public Engagement and Education component, civic engagement for many ecosystem stewardship activities is underway as part of the International Watershed Coordination Program as well as through the current AIS prevention strategies in each jurisdiction. Basin scientists and stakeholders have expressed a need to expand efforts to engage and educate the public on a number of interrelated issues

regarding AIS. This needs to be done more consistently on both sides of the border. These efforts include: information on the ecological, aesthetic, and economic damage caused by invasive species in the Basin; threats if regionally important AIS invade the Lake of the Woods Basin; best practices for reducing or preventing further spread of invasive species into and within the Basin; and, engaging the public in the collection and flow of information, including the links to data bases and decision support systems.

Developing effective outreach materials and strategies was deemed a high priority by Basin experts. One example of a useful education/outreach activity could be development of a "10 most unwanted species" information campaign (brochure, web site, media campaign) highlighting species of high risk for introduction or spread within the Basin and including information on prevention. The Kawishiwi Watershed Protection Project also has developed AIS outreach materials, including a survey of residents of that basin (http://kawishiwiwatershed.com/ais).

Methodology

This project will build upon the AIS prevention efforts and public engagement/education campaigns underway by agencies and organizations in Minnesota, Manitoba, and Ontario. It would complement and strengthen ongoing activities, and therefore strengthen AIS prevention efforts across the entire Lake of the Woods Basin.

Due to the ongoing threat of AIS infestation, particularly in light of expanding ranges of many AIS in the region, this will necessarily be a long-term, sustained effort, and is a high priority for the Basin. This is a major effort that requires commitment and support from local, state, provincial, and federal agencies, as well as non-government organizations.

A useful model to consider for adaptation to the Lake of the Woods Basin is the framework developed by the IJC for the Lake Huron/Lake Erie Corridor as a pilot project for international basins (Donahue, 2012). It addresses the following key objectives: early detection and reporting process; rapid risk assessment methodology; decision making and response protocol; prompt, efficient and effective response actions; and, continuous plan assessment and adaptive management. Although a primary objective of the plan is rapid response, numerous aspects of the plan establish a sound framework for binational management of AIS, including monitoring, research, prevention, rapid response, and ongoing adaptive management. In addition, there is currently an effort to develop an Invasive Mussel Control Collaborative among federal, state, provincial, tribal and First Nations, academic, and local agencies. This collaborative will likely yield research and control strategies that could be applied to the Lake of the Woods Basin. It will be important to adapt any model for the much more rural and seasonal nature of the Basin and its landowners, compared to the Great Lakes Basin.

The framework would be facilitated by annual meetings of the binational team, timed in conjunction with the annual Rainy-Lake of the Woods Watershed Forum.

Study Organization, Costs and Scheduling

This project will draw from strategies being developed elsewhere (for example, Donahue, 2012; Ontario Ministry of Natural Resources, 2012; Lake Superior Binational Program, 2014) and will build upon the work already started by the AIS Subcommittee of the IMA-TAC. Partnering with the IRLWWB will be important to ensure the information flow to the Board is seamless for its work in monitoring ecosystem health.

The overarching structure through the IJC and the IMA is in place to develop and facilitate a comprehensive approach by all jurisdictions in the Basin. Key linkages include: the MDNR Invasive Species Program; Ontario Federation of Anglers and Hunters Invading Species Awareness Program[15]; Ontario's Invasive Plant Council; lake associations throughout the Basin; Minnesota Sea Grant; Voyageurs National Park; MNRF (Lake of the Woods Fisheries Assessment Unit, regional MNRF science staff); Manitoba Conservation and Water Stewardship; U.S. Fish and Wildlife Service; Quetico Provincial Park, U.S. Forest Service, the Great Lakes Aquatic Nuisance Species Panel[16]; and other agencies and independent experts. The Minnesota Invasive Species Advisory Council (which includes several of the above agencies) organizes conferences, assists with public outreach, and facilitates communication among agencies on invasive species issues and would be a key contact for this work.[17]

The work should connect with ongoing focused research, such as that done by at Lakehead University on models to predict angler movement based on fish population characteristics and access points. Outreach messages will draw from existing economic impact studies of AIS invasion.

This project should be started immediately. The framework for an international prevention strategy should be developed within one to two years, and will require ongoing, adaptive management thereafter.

Much of the cost of this project will be in-kind (*e.g.*, agency staff salaries). It is estimated that $200,000 is needed for the first four years, to cover expenses related to workshops, professional services (facilitation, writing and editing) and travel expenses for representatives from small or under-represented organizations. Following completion of the project, ongoing funding for adaptive management and implementation will be needed.

[15] www.invadingspecies.com
[16] http://glc.org/projects/invasive/panel/
[17] http://www.mda.state.mn.us/misac/

Cost Estimates for Project 13
Binational Aquatic Invasive Species Management Team and
Prevention Strategy for the Lake of the Woods Basin

Major Tasks	Timeline	Estimated Costs
Organize two to four annual AIS prevention expert workshops	Years 1-4	$50,000
Travel for small or under-represented organizations	Years 1-4	$10,000
Draft prevention strategy: professional services (facilitation, writing, editing)	Years 1-4	$135,000
Publication and outreach materials	Years 1-4	$5,000
Total estimated costs		**$200,000**

Note: First four years of activity are estimated here; ongoing adaptive implementation will be needed thereafter

3.3.2 Assessing and Controlling Impacts of Aquatic Invasive Species

The most cost-effective and highest priority work related to invasive species is focused on preventing the introduction of additional invasive species. However, to protect and maintain natural resources and prevent economic harm, it is critically important to assess the impacts of and assess methods for controlling established populations of invasive species.

Questions remain regarding the extent of demonstrated impacts of a variety of species in the Basin and future anticipated impacts. Better understanding of impacts is important to allow resource managers to avoid collapses in populations of economically vital gamefish populations as well as in populations of culturally important resources such as wild rice. This understanding is also important so that preventive measures may be placed into a cost-benefits construct; that is, to ensure that appropriate resources are allocated to prevent potentially costly spread of AIS into currently uninfested waters.

AIS such as the spiny waterflea, rusty crayfish, rainbow smelt, and hybrid cattail already have caused some ecological disruptions and have the potential to cause substantial additional ecological disruptions in boundary waters. There is a need to better understand these disruptions, their impact on economically and culturally important resources, and, where possible, to control AIS to minimize damage.

Project 14
Evaluation and Implementation of Options to Manage Recent Zebra Mussel Infestation in Headwaters Areas in Minnesota

Objectives

To:

- Contain or eradicate (if possible) zebra mussels from new invasion fronts in Lake of the Woods Basin; and,
- Prevent further introductions of zebra mussels from nearby waters.

Description

In 2013, zebra mussels were reported in Sand Lake, Little Sand Lake, and the Bowstring River in Itasca County, MN; as of 2014, three additional lakes in the same area have had zebra mussels detected (Minnesota Department of Natural Resources, 2014). These water bodies are all in the same sub-basin, and drain into the Big Fork River, a tributary to the Rainy River—the border river that flows into Lake of the Woods. Zebra mussels are also reported to be in waters of adjacent river basins, very near the Lake of the Woods Basin. These include Lake Winnibigoshish (Itasca County, MN) and Gilbert Pit Lake (a former mine pit, now used for scuba diving) in St. Louis County, MN (Minnesota Department of Natural Resources, 2014).

Given the potential for large-scale ecological disruption in border waters, including Rainy River and Lake of the Woods, which are downstream, high priority should be given for immediate action to prevent further spread of zebra mussels within the basin; reduce or eradicate zebra mussels from currently infested lakes; and prevent further introductions of zebra mussels from nearby waters.

Methodology

This project should include several complementary activities:

- vulnerability assessment for spread of zebra mussels in the Bowstring / Big Fork River sub-basin;
- assessment of the extent of infestation (infestations limited to a small area, such as a dock or boat ramp, may be easy to eradicate; infestation of a whole lake are difficult to impossible to eradicate);
- assessment of containment or eradication options for Sand, Little Sand Lakes, Bowstring River and other infested waters.
- immediate ramp-up of inspections, enforcement actions, and related strategies to prevent further unintentional spread of zebra mussels within or into the Lake of the Woods Basin by movement of watercraft or other means.

The U.S. Geological Survey's Upper Midwest Environmental Sciences Center in LaCrosse, Wisconsin has been testing the use of Zequinox (a product that is toxic to zebra mussels) as a means of eradicating zebra mussels from lakes in Minnesota. Chemical controls (using potash and copper sulfate) have also

been attempted. Mussel control experts should assess options for rapid implementation, depending on extent of mussel infestation.

Study Organization, Costs and Scheduling

This would be a multi-investigator, multi-institutional study, with partnerships between MDNR, Itasca County (MN), Minnesota's Aquatic Invasive Species Prevention Aid grants[18], U.S. Geological Survey's Upper Midwest Environmental Sciences Center, conservation groups, and other agencies.

Although the information base is incomplete, waiting for further studies is not desirable because zebra mussel populations rapidly expand in number and extent. Therefore, this project is recommended for immediate start. Given the expanding distribution of zebra mussels in the region, it likely will require ongoing management to prevent infestation of international waters.

It is not possible to provide precise cost estimates, because the areal extent of infestation is unknown. Accordingly, the extent of needed physical, biological or chemical controls are unknown. The Plan of Study proposes an approximate budget of $500,000 for the first two years (to be leveraged with additional County and State funds). Funding for the project should proceed sequentially, in phases. The first phase will be rapid assessment of extent of infestation of zebra mussels in currently infested waters in Itasca County, MN. The next phase will be expert evaluation of implementation options and risk for further spreading. The third phase will be implementation of control or eradication measures (likely the most costly part of this project).

Final control or eradication costs may be considerably higher. Alternatively, if the Water Quality Risk Assessment for Zebra and Quagga Mussels (Project 18) concludes that international border waters (in particular, Rainy River and Lake of the Woods) cannot support zebra mussels (due to low levels of calcium and other constituents), then the IJC may consider pulling back from control and eradication efforts.

Cost Estimates for Project 14
Evaluation and Implementation of Options
to Manage Recent Zebra Mussel Infestation in Headwaters Areas in Minnesota

Major Tasks	Timeline	Estimated Costs
Rapid evaluation of extent of zebra mussel infestation within six known, infested water bodies in Itasca County, MN	Year 1	$24,500
Rapid evaluation of control strategies	Year 1	$24,500
Implementation of chemical or biological controls to eradicate zebra mussels, and/or deployment of physical barriers to prevent further spread.	Years 1-2	$450,000
Outreach	Years 1-2	$1,000
Total estimated costs		**$500,000**

[18] http://www.dnr.state.mn.us/grants/aquatic_invasive/aq_inv_prevention_public_awareness.html

Notes: Given present information, the estimates are provisional. If zebra mussel infestations are limited to a single access point within each water body, the funding identified may be sufficient to successfully eradicate. Lake-wide treatments may be costlier, or entirely not feasible. Some State and County level funding may be available for leveraging.

Project 15
Ecological Impact of the Spiny Waterflea in Infested Boundary Lakes

Objective

To characterize ecological disruptions that have resulted from spiny waterflea infestation in large boundary lakes, including effects on gamefish production.

Description

Basin scientists called for a comprehensive analysis and assessment of the ecological impacts of spiny waterflea in the Lake of the Woods Basin. They identified a need to better understand the effects of spiny waterflea on energy flow, fish recruitment and possibly phytoplankton dynamics in Lake of the Woods, Rainy Lake, and Namakan Reservoir and other lakes in the Basin. Substantial changes in lake ecology are caused by the spiny waterflea (Yan *et al.*, 2001; Rennie *et al.*, 2011; Yan *et al.*, 2011). There is evidence that native zooplankton populations have been reduced by as much as 40 percent in Lake of the Woods and that native zooplankton biomass has been reduced by 40 to 60 percent in Rainy Lake and the Namakan Reservoir (Hobmeier *et al.*, 2013), likely as a result of the spiny waterflea invasion.

Based on the substantial reductions in zooplankton biomass measured in these lakes after the invasion, resource managers and researchers expect to see a decrease in fish production in these lakes (based on a decrease in energy flow and possibly due to a developmental bottleneck for young of the year fish). Such a decrease in zooplankton abundance may disrupt aquatic food webs in two important ways: First, abundance of important game fish species (including walleye, lake trout, cisco, and northern pike) may be limited due to reduced biomass lower in the food web. Secondly, the algal blooms may be exacerbated because fewer zooplankton are consuming algae. Yet researchers lack quantified estimates of these effects in the Basin.

This project would use existing and new data from Lake of the Woods, Rainy Lake, and the Namakan Reservoir Lakes. It would implement modeling to assist in adaptive management of fishery resources in the watershed and make use of stable isotopes to track food web linkages. The project would benefit from ongoing assessment and modeling work being performed by the MDNR, the USGS, and universities on other large lakes in Minnesota (especially on Mille Lacs, where current efforts are focused on the effects of spiny waterflea and zebra mussels on the walleye population). Consideration would also be given to reference lakes from other datasets, for example, the MDNR's Shallow Lakes Program[19] and Sustaining Lakes in a Changing Environment program.[20]

[19] http://www.dnr.state.mn.us/wildlife/shallowlakes/index.html
[20] http://www.dnr.state.mn.us/fisheries/slice/index.html

Methodology

For this project, water bodies to be assessed include Lake of the Woods, Rainy Lake, and Namakan Reservoir, mainly because these lakes have zooplankton data pre- and post-invasion. The focus will be on assessing the effects of an established population of spiny waterflea on energy flow and developmental bottlenecks affecting gamefish populations in these three waterbodies. Due to pronounced decreases in biomass of lower trophic level prey in these lakes, fisheries managers and Voyageurs National Park would benefit from this assessment in order to manage for sustainable gamefish populations, including the economically vital walleye populations. This project came out as the top priority study of the AIS breakout session at the March 2014 expert workshop.

Past research and monitoring investments on Lake of the Woods, Rainy Lake, and Namakan Reservoir have generated good data sets on pre- and post- spiny waterflea invasion zooplankton (identifications, densities, biomass). These before-and-after data make this project possible. New data collected through this Plan of Study on linkages in energy flow will allow assessment of whether fish production is being affected through a decrease in forage biomass and/or through a developmental bottleneck for young fish that are unable to efficiently consume spiny waterflea (Kerfoot *et al.*, 2011; LeDuc, 2012) and fail to develop due to a lack of available zooplankton forage.

The project will produce a peer-reviewed scientific report or paper that incorporates analysis of existing and new data.

Study Organization, Costs and Scheduling

This would be a multi-investigator, multi-institutional study, with partnerships between the U.S. National Park Service, MDNR, MNRF, the University of Manitoba, and the USGS.

The U.S. National Park Service, the MDNR and Michigan Technological University are collaborating on a study of spiny water flea effects on four units of the U.S. National Park Service, including Voyageurs National Park. This research has shown major effects of the exotic species spiny water flea on native zooplankton of these lakes (Kerfoot *et al.*, 2011) and provides a foundation for a Lake of the Woods study.

It is recommended that this project be started immediately and run for four years.

The cost estimate for this study is $300,000, over the four years. This includes about $68,000 for technician services for Rainy and Namakan lakes, with the remainder covering equipment, supplies, and staff salaries (for staff not associated with the following three institutions). The National Park Service (Voyageurs), Minnesota DNR, and the University of Manitoba would provide approximately an equivalent amount of in-kind support for ecological expertise needed for this study.

Cost Estimates for Project 15
Ecological Impact of the Spiny Waterflea in Infested Boundary Lakes

Major Tasks	Timeline	Estimated Costs
Sample collection (salary, field technicians)	Years 1-2	$68,000
Sample collection (equipment and supplies)	Years 1-2	$10,000
Data analysis, interpretation, report preparation (salary)	Year 3	$217,000
Publication and outreach	Years 3-4	$5,000
Total estimated costs		**$300,000**

Note: Cost estimates from likely study participants; three collaborating agencies will contribute additional in-kind salary to this project at a level roughly equivalent to new funding.

Project 16
Pilot Studies on Adaptive Control Measures for Hybrid Cattail and Rusty Crayfish in Infested Wild Rice Habitat

Objective

To eradicate or control invasive hybrid cattail and rusty crayfish populations from Basin waters, especially in wild rice habitat.

Description

Hybrid (non-native) cattails have invaded some waters in the Basin and are displacing native wild rice plants, an important plant species to Basin residents, particularly the First Nations and Native American communities. Rusty crayfish occupy similar habitats and disrupt aquatic vegetation, such as nearshore aquatic plants (macrophytes), in important zones of fish reproduction. There is an identified need to:

- corroborate the impact of hybrid cattail and rusty crayfish on aquatic vegetation, including wild rice;
- assess effects of changes in water level, growing season relative to climate change; and,
- develop measures to control the abundance or spread of these species, and restore desired ecologic functions, particularly wild rice production and fisheries.

Although eradication of either species in infested waters is thought to be difficult, it is important to attempt to control their distribution to prevent further spread of these species. In addition, in areas where important wild rice habitat is being impaired by invasive hybrid cattails, there is a desire to attempt eradication measures.

Methodology

A multi-phased approach is envisioned. A pilot project is ongoing (supported by the International Watershed Initiative (IWI) funding of the IJC) that is attempting to eradicate hybrid cattails and re-establish wild rice in selected infested waters in the Seine River First Nation territory in Ontario. However, given that complete eradication is extremely difficult, subsequent phases should focus on assessing the effectiveness of pilot management efforts, and continue adaptive management strategies to control hybrid cattails.

A parallel effort to assess and implement methods for controlling rusty crayfish should be piloted in selected portions of the Basin where rusty crayfish have infested wild rice beds.

Numerous other ecological disruptions have been attributed to hybrid cattails and rusty crayfish within the Basin. However, aquatic invasive species experts advised the Plan of Study Team against attempting to engage in large-scale eradication efforts due to the high cost and low probability of success. Therefore, it is emphasized that this project should focus on pilot control or eradication efforts in selected areas where hybrid cattails and/or rusty crayfish are causing damage to native wild rice beds. It is hoped that research piloted in selected areas may yield successful strategies that could be applied on a broader scale in the future.

Study Organization, Costs and Scheduling

This activity closely relates to the IWI-approved study that is evaluating control strategies for invasive hybrid cattails.

Linkages will be needed with the Seine River First Nation, 1854 Treaty Authority, Grand Council Treaty 3, First Nations, Tribes, Métis, USFS, MNRF, MDNR and Experimental Lakes Area scientists, the Minnesota Aquatic Invasive Species Research Center, and academic institutions including Lakehead University. The initial pilot project will require an estimated $300,000 over four years to support pilot implementation efforts and associated data collection and analysis; partner agencies will provide in-kind support (field logistics; technician support).

The need for control and adaptive management will be ongoing. Adaptive management should be based on new, ongoing research within the Basin, and research from other areas that holds promise for implementation within the Basin. New sources of funding will be needed to implement ongoing, adaptive control strategies.

Cost Estimates for Project 16
Pilot Studies on Adaptive Control Measures for Hybrid Cattail and Rusty Crayfish in Infested Wild Rice Habitat

Major Tasks	Timeline	Estimated Costs
Implementation of pilot control strategies	Years 1-2	$200,000
Data collection to evaluate effectiveness (graduate research assistant, supplies, equipment, and travel)	Years 1-3	$75,000
Data analysis, interpretation, report preparation	Year 3	$20,000
Publication and outreach	Years 3-4	$5,000
Total estimated costs		**$300,000**

Note: Collaborating agencies will contribute additional in-kind salary to this project.

3.3.3 Aquatic Invasive Species Vulnerability Assessments

Assessing vulnerability of waters within the Basin to AIS is an important component to developing effective prevention strategies and, in fact, can play a role in the prioritization of introduction prevention efforts; this was done in California for dreissenid introduction (Claudi and Prescott, 2011).

Consideration of how vulnerable boundary lakes are to new infestations of AIS is important. Zebra mussels, for example, have already infested several waters within the Basin, and are in adjacent basins. Also, boundary lakes that are currently infested by AIS need to be considered as potential sources of AIS to upstream and downstream lakes and tributary streams. Does water chemistry preclude a large-scale invasion? How is vulnerability impacted by climate change and what are the effects of climate on AIS habitat barriers?

Project 17
Comprehensive Assessment of Potential Invasion Risks to and within the Lake of the Woods Basin

Objective

To assess risks of invasion from nearby basins and spread of AIS from current infestations within the Lake of the Woods Basin.

Description

A comprehensive assessment of invasion risks is critically important to developing an effective binational prevention strategy (see Project 13). This assessment will include the following components:

- assessment of the distribution of AIS within the Lake of the Woods Basin (closely tied to geospatial mapping project, Project 30), and neighboring basins. The analysis will cover current state of knowledge of key species of concern and include information on history (timing) of infestation; routes of entry into the Basin; information related to ecological and economic disruptions;
- assessment of vulnerability of the Lake of the Woods Basin waters to infestation of AIS, which includes the following two sub-components:
    - identification of invasion vectors, or routes of entry, both for current infestations and for potential infestations from neighboring basins; and,
    - assessment of habitat suitability; suitable habitat would allow newly introduced species to become established within Basin waters, and lead to an infestation;
- assessment of likely ecological and economic disruptions that would result from infestation;
- identification and binational agreement of high-priority aquatic invasive species (species that should be tracked and aggressively managed);
- assessment of management options in-place, and options needed to prevent further introductions into, or spreading of AIS within the Basin; and,
- assessment of adequacy of current monitoring programs to document all AIS infestations, to inform management decisions and prevention efforts.

The components of this activity are complementary. Zebra mussels, which have invaded many natural waters in the midcontinent, are a useful example. Tracking their migration within the region is important to increase prevention measures once their introduction becomes likely due to close proximity or frequent movement of watercraft from infested waters to the area of interest. Understanding how zebra mussels are transported (for example, by recreational boats) is important in developing prevention strategies. Assessing suitability of habitat is important to establish whether (or where) zebra mussels could survive. Some waters in the basin may be unsuitable habitat for zebra mussels due to low calcium concentrations, whereas other waters may be suitable. Therefore, a complete assessment of invasion risk for zebra mussels includes understanding its presence regionally, understanding routes of invasion, and assessing whether water bodies are capable of supporting a viable population.

Mapping the information on potential vectors of AIS invasion and vulnerability of water bodies to various invasive species will aid resource managers in more effectively understanding, managing and communicating the threats. This concept has been discussed by the IMA and IJC as a useful project to pursue to demonstrate the utility of the mapping platform for the Basin.

Methodology

A group of experts will prepare a report or scientific paper describing current state of knowledge of AIS infestations in neighboring basins, invasion vectors, suitability of habitat to high-risk invasive species, and likely disruptions that would result from key AIS infestations. The experts group will communicate with the Binational AIS Management Team proposed in Project 13.

Study Organization, Costs and Scheduling

This vulnerability assessment will require one or two experts from both Canada and the U.S. to collaborate on analysis, interpretation, and reporting of findings. Experts would likely be drawn from: state and provincial agencies; U.S. Fish and Wildlife Service; U.S. Geological Survey; Quetico Provincial Park; the MDNR Invasive Species Program; and, Voyageurs National Park; Ontario Federation of Anglers and Hunters; MNRF and academic institutions.

This project is relevant to the Binational Prevention Strategy (Project 13) and climate risk assessment for AIS (Project 19).

While the water-quality risk assessment for zebra and quagga mussels (Project 18) is somewhat redundant in theme, that project is intended to be a short-duration, rapid assessment focused on suitability (survivability) of Basin waters, given the requirements of zebra dreissenid mussels for adequate levels of calcium, pH, and other constituents. This comprehensive assessment is broader in scope, considering a greater range of species and a greater range of conditions for infestation to occur.

An estimated $300,000 is needed to fund up to four individuals part-time for three years to complete the study. It is anticipated that these funds would leverage additional agency in-kind support and state and provincial grant monies.

Cost Estimates for Project 17
Comprehensive Assessment of Potential Invasion Risks to and within the Lake of the Woods Basin

Major Tasks	Timeline	Estimated Costs
Compile and review literature on vulnerabilities to priority AIS; review data on distribution of AIS in Lake of the Woods region. Analysis, interpretation, report preparation.	Years 1-2	$290,000
Travel	Years 1-2	$5,000
Publication and outreach	Years 2-3	$5,000
Total estimated costs		**$300,000**

Note: Funding largely for salaries for expert team; it is anticipated that additional in-kind contributions from participating agencies may be available.

Project 18
Water Quality Risk Assessment for Zebra Mussels and Quagga Mussels

Objective

To assess which Basin waters have suitable water chemistry to allow dreissenid mussels (zebra mussels, quagga mussels) and other high-risk AIS to survive.

Description

Basin experts expressed a need for an assessment of water quality suitability of lakes and rivers within the Basin for the establishment of zebra mussels and quagga mussels, two species of invasive dreissenid mussel. Adult zebra mussels do not survive in waters with low calcium (less than 8 milligrams per liter), low pH (less than 7), low alkalinity (less than 30 milligrams per liter as calcium carbonate), and low-conductivity (<30 µS/cm) (Mackie and Claudi, 2010). Waters with constituents slightly above these levels (8-15 mg/L calcium; pH 7.0-7.8; alkalinity 30-55 mg/L as calcium carbonate; and conductivity of 30-60 µS/cm) may be marginally suitable for survival of adult zebra mussels, but hold little potential for larval development and are, therefore, unlikely to become infested on a large scale. Additional water-chemistry and temperature requirements for these species have also been compiled (Mackie and Claudi, 2010). An assessment of suitability of water chemistry for zebra mussel and quagga mussel infestations against such criteria would help Basin managers focus control strategies on water bodies at risk for infestation.

Although many lakes in the Basin have calcium, pH, and/or alkalinity levels that currently are too low to support zebra mussels, there is concern that conditions could change and make water chemistry suitable for infestation. For example, calcium chloride in runoff from road salt could elevate calcium levels in some locations. Also, lake-water pH and alkalinity are recovering from historical acid rain pollution. Although the recovery is generally thought to be beneficial, lakes that might reach pH above 7.8 may become susceptible to zebra mussel infestation if other habitat suitability requirements are also met.

For the above reasons, it is critically important to:

- assess existing water quality data (both chemical and physical measures) in relation to suitability (survivability) for AIS infestation;
- examine trends in water quality data that may indicate lakes and rivers that are not currently suitable but may soon be as water quality changes; and,
- examine forcing functions (for example, calcium chloride road salt use) that may be managed to prevent reaching a tipping point in AIS survivability in certain waters in the Basin.

Two large-scale risk assessments have been done in Canada, but given the 2013 entry of zebra mussels into the Lake of the Woods Basin, it is critically important to provide an updated, spatially detailed assessment for the Lake of the Woods Basin. A Canada-wide risk assessment for dreissenid mussels (zebra mussels; quagga mussels) was conducted by Therriault *et al.* (2013). This assessment considers probability of invasion to be a function of probability of arrival (that is, accidental introduction of an AIS into a water body) and probability of survival (that is, whether water quality and habitat conditions are suitable for survival of the species). This analysis found that while the probability of arrival was high for both zebra mussel and quagga mussel in Lake of the Woods Basin (cited in the study as eastern Lake Winnipeg drainage), the probability of survival (and hence invasion) was low. However, Therriault *et al.*, (2013) provide the following caution:

> *Given the spatial scale of this assessment (i.e., sub-drainages) and limited site-specific data, we did not determine explicitly the probability of secondary spread within each sub-drainage. The rapid expansion of these species across North America and Europe indicates that human-mediated activities are highly likely to re-distribute dreissenids within sub-drainages after their initial arrival. Further, by employing the 75th percentile in available calcium concentrations per sub-drainage this approach suggests within sub-drainages multiple locations of suitable habitats exist for secondary survival.*

An earlier risk assessment for the Province of Ontario indicates that the invasion into the southern portion of Lake of the Woods was "very probable" based on water chemistry, although much of the rest of the Ontario portion of the Basin was of "unlikely" probability for invasion (Neary and Leach, 1992).

In Minnesota's Northern Lakes and Forests ecoregion (which intersects the Lake of the Woods Basin), potential for zebra mussel colonization was high to moderate based on alkalinity, pH, and conductivity levels of lake water; and was moderate to low based on calcium levels (G. Montz, Minnesota Department of Natural Resources, written communication, April 2010). Depending on which calcium benchmarks were used, approximately one-quarter to two-thirds of the lakes in the Northern Lakes and Forests ecoregion in Minnesota would have calcium levels too low to support zebra mussel populations, with the remaining lakes being vulnerable.

This study would build on the national, provincial and state-level work described above, and provide a more spatially detailed analysis for the Lake of the Woods Basin, using data from state, provincial, and federal agencies, as well as from Indian Tribes, First Nations and Métis communities. The goal is to identify specific water bodies within the Basin that are at risk for invasion and quantify the risk (low, medium, and high) so that prevention efforts can be targeted accordingly. The regional analyses referenced above are useful starting points, but with zebra mussels now in several water bodies in the Basin, detailed, lake-specific information on zebra mussel colonization potential is critically important to target management strategies.

Methodology

A peer-reviewed report or paper will be published on suitability of water chemistry for high-risk AIS zebra and quagga mussels, using existing water quality data sets from agency monitoring programs and other published water quality data. No new data would be collected, but the paper would include assessment of water bodies where data are not complete or sufficient to assess vulnerability to dreissenid infestation.

Study Organization, Costs and Scheduling

This research project would be led by a university or agency. Participants could include the U.S. National Park Service, USGS, MDNR, MPCA, Ontario, and Manitoba water-quality monitoring agencies. This activity would inform the Comprehensive Assessment, described above (Project 17), and is critical to informing a rapid response plan to manage the recent infestation of zebra mussels in some headwaters lakes.

Costs are estimated to be $125,000, entirely for salary and publication costs. It is recommended that this project be started immediately and be completed within two years.

Cost Estimates for Project 18
Water Quality Risk Assessment for Zebra Mussels and Quagga Mussels

Major Tasks	Timeline	Estimated Costs
Review literature on water quality conditions suitable to dreissenid mussels; compile and review water quality data within Lake of the Woods region. Analysis, interpretation, report preparation.	Year 1	$120,000
Publication and outreach	Years 1-2	$5,000
Total estimated costs		**$125,000**

Note: Funding largely for salaries for expert team; it is anticipated that additional in-kind contributions from participating agencies may be available.

Project 19
Climate Risk Assessment for Aquatic Invasive Species

Objective

To prepare a climate-based risk assessment for key AIS that are likely to invade the Lake of the Woods Basin.

Description

This project will develop a prioritized list of AIS that are known to be present within the region (but not yet in the Lake of the Woods Basin), that are known to be of high adverse economic impact, and for which survivability in the Basin is currently limited by temperature or other climate-related parameters, including dissolved oxygen (which is partly controlled in lakes by temperature regimes and eutrophication).

Develop models to predict climate-driven changes in border waters, and assess the effects of these changes on survivability of key AIS species. This activity should consider various modeled climate change scenarios considered likely by the generally accepted climate models. This would form the necessary information on which to base the comprehensive strategy to prevent AIS invasion of these lakes.

A comparable analysis, using climate change scenarios, has been done for lake thermal and dissolved oxygen regimes to assess potential changes in cold-water fish habitat and warm-water fish habitat under warming scenarios (Stefan *et al.*, 2001) and to assess changes in fish habitat in U.S. streams (Mohseni *et al.*, 2003).

This study should make clear connections between research findings (for example, projected changes in vulnerability to high-priority AIS based on climate-driven changes to lake ecosystems) and state and provincial AIS management plans, and make general recommendations regarding how AIS management plans can be made more resilient. This topic has been explored by the U.S. Environmental Protection Agency (2007).

Methodology:

This project will involve a research study and peer-reviewed paper, by experts on AIS and lake-modeling. Researchers should consider changes in physical and chemical parameters that may be associated with climate change (for example, greater water level fluctuations, longer open ice season, warmer water, more oxygen stressed lakes) and how these changes will affect suitability of habitat and changes in risk of infestation of priority AIS.

Study Organization, Costs and Scheduling

This activity depends on the Comprehensive Assessment (Project 17) to identify priority AIS for consideration, and it depends on the regional climate model study (Project 29) for climate scenarios. After these activities are completed, this project will be three years in duration, and involve modeling but no new data collection. It is well suited to a research university project by a Ph.D. candidate or postdoctoral researcher.

Estimated cost for this project is $185,000.

Cost Estimates for Project 19
Climate Risk Assessment for Aquatic Invasive Species

Major Tasks	Timeline	Estimated Costs
Review and analysis of regional climate model scenarios, with respect to AIS vulnerability and state and provincial management plans. Analysis, interpretation, report preparation.	Years 1-3	$180,000
Publication and outreach	Years 2-3	$5,000
Total estimated costs		**$185,000**

Note: Funding largely for salaries for expert (or expert team); it is anticipated that additional in-kind contributions from participating agencies may be available.

3.4 Surface and Groundwater Contamination, including Heavy Metals and other Contaminants

The contaminant studies recommended in this section seek to fill several key gaps in protection and in the information on which to assess risks and base management decisions.

The impacts of contaminants in the Basin have been greatly reduced through reductions of pollutant inputs into the Rainy River over the years. There are however, areas listed as federal contaminated sites, legacy contamination from past mining activity, atmospheric contamination of lakes and fish by mercury, and agricultural inputs in the central portions of the Basin. There also are concerns within the Basin over potential contamination from new mining activities including mining of low-grade metal sulfide ores in northeastern Minnesota and gold mining in Canada. Finally, contaminants of emerging concern, which include personal care products, drugs, antibiotics, and other classes of synthetic organic chemicals, have been detected in lakes within Voyageurs National Park.

In response to these concerns, the Plan of Study identifies the need for a more complete assessment of the various contaminant issues in the Basin. The goals are to improve the knowledge base about potential sources of contamination, assess vulnerability of water resources, and ensure protection measures are in place to minimize risks associated with contamination from various sources.

Benefits

Direct outcomes of the projects under this theme will be:

- *improved understanding of the extent of contamination and risks associated with contamination; and,*
- *identification of risks and gaps in protections and vulnerabilities, and engagement strategies.*

Over the long-term, the projects will contribute to: *a strategy for addressing contaminant issues and mitigating risk in the Basin.*

3.4.1 Inventory of Surface and Groundwater Contamination Issues and Prioritization of Threats to Ecosystems and Human Health

Although numerous studies and monitoring programs may have collected data on contaminants in the Lake of the Woods Basin, this information has not been rigorously summarized. While the State of the Basin Report (Clark and Sellers, 2014) provides an overview of contaminant issues within the Basin, it recognizes "…there is not a complete inventory that can be examined." Therefore, Basin experts agreed on the need for a more complete assessment of the various contaminant issues in the Basin, including detailed assessments of contaminant concentrations against established levels of concern; compilation of information on contaminant data collected by various monitoring efforts; and compilation of information on potential new contamination sources from proposed mining, petroleum transport, and other activities.

Project 20
Assessment of Binational Implementation of Water Quality Objectives for Sulfate, Copper, Nickel, and Mercury

Objective

To develop recommendations on binational water quality objectives for priority contaminants to protect ecological and human health in border waters in the Lake of the Woods Basin.

Description

There is a need for enforceable water quality objectives to protect ecological functions and human health. Objectives for several key water quality constituents should be considered.

The Plan of Study recommends formation of advisory groups for each of four (or five) constituents, as described below. The advisory groups would assess past analyses that were used in Canada and the U.S. to establish standards in each country; assess recent and ongoing research that will be completed in the near future (we identify key research below); and recommend establishment of new basin-wide standards (or objectives) for these constituents.

1. Sulfate standard

Wild rice plants, a nutritionally and culturally important resource in the Basin, may be sensitive to elevated sulfate. The mechanism for sensitivity involves conversion of sulfate to sulfide by sulfate-reducing bacteria that occur naturally in aquatic sediment. Elevated sulfate concentrations can lead to elevated sulfide, which can be toxic to wild rice and other sensitive plants that grow in aquatic sediment.

The State of Minnesota currently has a 10 mg/L standard for sulfate that reads "*10 mg/L sulfate applicable to water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels."* This standard is currently undergoing extensive review (Minnesota Pollution Control Agency, 2014b). New research to evaluate the specific mechanisms, and interactions with other geochemical parameters, is a core part of Minnesota's sulfate standard review. Preliminary analysis (Minnesota Pollution Control Agency, 2014a) supports the hypothesis that elevated sulfide is toxic to wild rice plants, although specific revisions to the 10 mg/L sulfate standard have not yet been proposed. One tentative finding of the MPCA research is that wild rice growing in aquatic sediment with relatively high iron concentrations and low organic matter content seem more tolerant of high sulfate in the surface water. Therefore, as part of a revision of the 10 mg/L sulfate standard, it is possible that the MPCA may account for site conditions that mitigate the negative effects of elevated sulfate on wild rice.

The Province of Ontario currently uses British Columbia's Ambient Water Quality Guideline for Sulphate of 100 mg/L, based on toxicity studies on striped bass, an amphipod, and aquatic mosses (British Columbia Ministry of Environment, 2000). This criterion may not be protective of wild rice.

Sulfate concentrations in Basin waters tend to be fairly low, which would apparently allow for the growth of wild rice, although there are other variables that can control wild rice distribution, such as water transparency, water depth, benthic fish activity, and competing aquatic macrophytes. However, sulfate in most samples from the Rainy River at Manitou Rapids are in the 4-8 mg/L range (U.S. Geological Survey, 2014a). Thus, increases in sulfate loading from municipal, industrial or mine-water discharges could elevate sulfate levels above Minnesota's current standard, and potentially inhibit wild rice growth.

The sulfate / sulfide issue also relates to the other priority issues the Basin:

- *Nutrient enrichment and harmful algal blooms:* Sulfate can enhance phosphorus release from aquatic sediments, which may play a role in internal loading of phosphorus (Caraco *et al.*, 1989) and generation of harmful algal blooms.
- *AIS:* Phragmites (*Phragmites australis*) and cattails (*Typha spp.*) are tolerant of high sulfide concentrations in aquatic sediment (Lamers *et al.*, 2013). Elevated sulfate and sulfide could contribute not only to displacement of native wild rice, but also establishment of invasive phragmites and hybrid cattails in the Basin.
- *Mercury:* Natural populations of sulfate-reducing bacteria, which produce sulfide from sulfate, also convert inorganic mercury to methylmercury, the form that bioaccumulates in fish (Gilmour *et al.*, 1992). An addition of sulfate to sulfate-limited sites of mercury methylation, therefore, has the potential to increase the mercury concentration of fish in hydrologically connected waters. However, the role of sulfate in controlling fish contamination in any given water is difficult to model with any accuracy and is the subject of ongoing research by the MPCA and others. For instance, sulfate additions may not increase fish contamination if added to a system where the bacteria are not limited by sulfate availability, or if the major loading of methylmercury is not affected by changes in sulfate loading. Modeling efforts are further challenged by the prevailing hypothesis that high levels of sulfate can inhibit the methylation of mercury.

Therefore, a basin-wide sulfate standard that is protective of wild rice may also provide some level of protection against other impairments in the Basin.

Upon completion of Minnesota's analysis of the effect of sulfate on wild rice and potential revision of the associated sulfate standard, the International Rainy-Lake of the Woods Watershed Board should review the Minnesota research and consider adopting Minnesota's standard as a water-quality objective for the Lake of the Woods Basin in order to protect native wild rice and other native, sulfide-sensitive aquatic plants in the Basin. When Minnesota's assessment is completed, the information may be sufficient to recommend a basin-wide objective without the need for further study.

Key linkages for a sulfate water quality objective: MPCA (individual contacts identified at Minnesota Pollution Control Agency, 2014b); IWI wild rice study researchers; Mine Water Research and Assessment Program[21], MOECC, First Nation, Tribes, Métis.

[21] See heading "Sulfate released from mining regions (MWRAP)" at the MDNR web site: http://dnr.state.mn.us/lands_minerals/mineland_reclamation/research.html

2. Copper and nickel

High concentrations of copper and nickel are toxic to aquatic organisms. Due to the potential for new copper and nickel mining operations in the Basin, especially northeastern Minnesota, a review of existing standards and implementation of a binational objective that protects aquatic organisms is important.

Minnesota Water Quality Standards for copper and nickel depend on the hardness of the water. For simplicity, this discussion focuses on the standards at hardness of 50 mg/L as calcium carbonate. Minnesota's chronic (4-day) standard for the protection of aquatic life for copper is 6.4 µg/L; (micrograms per liter); the maximum concentration standard (1-day) is 9.2 µg/L; and the acute standard is 18 µg/L (State of Minnesota, 2014). Ontario's Provincial Water Quality Objective for copper is 5 µg/L (Ontario Ministry of Environment and Energy, 1994), and Environment Canada's chronic standard for copper is 2 µg/L (30 day average where hardness is less than 90 mg/L $CaCO_3$) (Environment Canada, 2011). Both Canadian standards are lower and potentially more protective of aquatic life than Minnesota's standard.

Minnesota's chronic (4-day) standard for the protection of aquatic life for nickel is 88 µg/L; the maximum (1-day) standard is 789 µg/L; and the acute standard is 1,578 µg/L (again, all at hardness of 50 mg/L as calcium carbonate). Ontario's Provincial Water Quality Objective for nickel is 25 µg/L , and Environment Canada's standard is a function of hardness; at 50 mg/L hardness, the chronic standard is 10.5 µg/L (based on the formula on page 27 of Environment Canada, 2011). Both Canadian standards are lower and potentially more protective of aquatic life than Minnesota's standard.

A review of copper and nickel standards should consider newer analysis by the U.S. Environmental Protection Agency, which incorporates the Biotic Ligand Model to develop standards that are specific to local water-quality conditions. Revision of Minnesota's copper standard, currently under review, has considered the Biotic Ligand Model in its analysis (Monson and Monson, 2010).

Key linkages for copper and nickel standards include: MPCA, Mine Water Research and Assessment Program, MOECC, Environment Canada, U.S. Environmental Protection Agency, First Nation, Tribes, Métis.

3. Mercury

Mercury is a vexing contaminant to effectively manage, given the many anthropogenic and natural sources to the global atmosphere; long-range transport and deposition; and the many factors that affect it's accumulation in aquatic food webs to levels of concern for humans and piscivorous (fish-eating) wildlife. Given the pervasiveness of impaired waters in the Basin due to mercury in fish, it is important to implement measures to reduce mercury contamination, or at a minimum, avoid exacerbating the mercury problem.

Minnesota has a Statewide water quality criterion for total mercury in water of 6.9 ng/L, and in fish of 0.2 parts per million (ppm). These criteria are meant to be protective of human health from consumption of fish that inhabit the State's waters. Minnesota also has a Statewide Mercury Total Maximum Daily Load plan designed to reduce contamination in Minnesota's waters. Within the Lake Superior Basin, a more

protective water quality criterion of 1.3 ng/L has been established; this standard is intended to be protective of wildlife.[22]

Ontario has a Provincial Water Quality Objective of 0.2 µg/L mercury in a filtered water sample. This is equivalent to 200 ng/L (Ontario Ministry of Environment and Energy, 1994), which is about 30 times less protective than Minnesota's statewide criterion, and about 150 times less protective than the Lake Superior Basin binational criterion. Based on the scientific understanding that has developed over the past 20 years regarding mercury methylation and bioaccumulation in aquatic food webs (Wiener *et al.*, 2003; Wentz *et al.*, 2014) the Study team concludes that Ontario's Provincial Water Quality Objective for mercury is not protective of human or wildlife health, and that a more protective objective for the Basin is needed. A similar examination of criteria for fish mercury levels should be undertaken with the goal of establishing a binational objective that is protective of both human health and wildlife health in the Basin.

A review of the above standards, and their applicability within the Lake of the Woods Basin, is needed to reduce mercury contamination from within the Basin or prevent any increases.

Given that much of the atmospheric load of mercury to the Lake of the Woods Basin is from outside of the Basin (and beyond direct pollution controls that could be applied within the Basin), the Study team also recommends development of mercury objectives that specifically address land and water management activities that exacerbate the mercury problem by increasing methylation of mercury. Specific examples include:

- Large water-level fluctuations in managed lakes, reservoirs, and other impoundments are known to exacerbate mercury methylation, making higher concentrations of methylmercury available for accumulation in aquatic food webs (Sorensen *et al.*, 2005; Larson *et al.*, 2014).
- Newly flooded terrestrial soils, such as when new reservoirs or impoundments are created, also exacerbate mercury methylation and bioaccumulation (Bodaly *et al.*, 1997; Paterson *et al.*, 2003).
- Methylmercury production (and hence bioaccumulation) aquatic environments increases with increased atmospheric deposition of both mercury (Harris *et al.*, 2007; Orihel *et al.*, 2007) and sulfate (Jeremiason *et al.*, 2006). Although substantial progress has been made in recent decades in controlling emissions of both mercury and sulfur oxides (precursors to sulfate), continued vigilance is important to prevent regional increases in mercury and sulfate deposition. Permitting of industrial activities needs to consider potential effects of increased mercury and sulfate emissions on atmospheric deposition of these constituents, regionally.

The Lake of the Woods Basin should consider implementation of a Binational Persistent Toxics Virtual Elimination Strategy, similar to the agreement in the Great Lakes Basin. This strategy seeks zero discharge of mercury and other persistent toxic chemicals to the environment of the Great Lakes Basin.

[22] http://www.epa.gov/r5water/wshednps/pdf/min_merc_final%20dec%20doc%203-27-07.pdf

Linkages for mercury objectives include MPCA, MOECC, MNRF, National Park Service, and other state, provincial, federal, and First Nations, Tribal and Métis natural resource agencies.

Study Organization, Costs and Scheduling

Key participating organizations would include state and provincial agencies, the U.S. EPA, Environment Canada, and academic institutions as well as those listed above as key linkages.

A provisional budget estimate of $75,000 would be for technical assistance in compiling existing criteria and drafting basin-wide water quality objectives for these constituents. For copper, nickel, and mercury the work can commence immediately. For sulfate, work should commence upon completion of Minnesota's revision of the sulfate criterion in waters that support native stands of wild rice.
This is a four-year study. The sulfate component depends on the completion of the Minnesota studies, described above.

Cost Estimates for Project 20
Assessment of Binational Implementation of Water Quality Objectives for Sulfate, Copper, Nickel, and Mercury

Major Tasks	Timeline	Estimated Costs
Review established criteria for copper, nickel, and mercury; prepare report recommending binational water quality objectives for Lake of the Woods basin	Years 1	$50,000
Review Minnesota's sulfate standard; prepare report recommending binational water quality objective for Lake of the Woods basin (pending completion of MPCA's sulfate standard revision)	Years 2-4	$20,000
Publication and outreach	Years 1-4	$5,000
Total estimated costs		**$75,000**

Note: Funding largely for salaries for expert or expert team.

Project 21
Synthesis Report on Contaminants in Water, Aquatic Sediment, and Fish

Objective

To summarize information on monitored contaminants in water, aquatic sediment and fish in the Lake of the Woods Basin.

Description

While various monitoring and research data sets exist for contaminants in the Lake of the Woods Basin, Basin experts indicated a need for an assessment report that pulls the information together and assesses

contaminant levels and risks. This project would provide for a binationally coordinated assessment of contaminants in water and fish. The assessment should:

- review existing data on contaminants in the Basin, summarizing published reports and papers, and publicly accessible data bases from agencies, academic institutions, and companies (for example, existing Environmental Effects Monitoring data sets);
- compare contaminant concentrations to available levels of concern, including water quality standards, human-health-based screening levels or advisory levels, and levels of ecotoxicological concern;
- prioritize contaminants based on prevalence, exceedances of established levels of concern, and other indicators of the severity of threat;
- assess adequacy of current monitoring efforts for priority contaminants, including coverage of key land uses where risk of contamination is greatest (depending on contaminant class); and,
- assess trends over past 10 to 30 years in concentrations of priority contaminants in surface water and sediment, for all boundary waters and principal tributaries to the boundary waters. (Such an assessment has been termed a *longitudinal base line study* by some basin experts.)

Methodology

Prepare a peer-reviewed scientific report that examines literature and public data sets on contaminants in the Basin and evaluates ongoing monitoring programs. The scope is on boundary waters and major tributaries to the boundary waters (including key potential contaminant sources), and should focus primarily on contaminant data collected over the past 10 years. Longer time frames may be considered for specific priority contaminants, where sufficient data exist, so that contaminant concentration trends can be placed within the context of pollution control efforts.

The assessment should include: contaminants that are primarily water-borne; contaminants, such as mercury, which are primarily associated with edible fish tissues, and sediment-associated contaminants of concern either because the contaminants may leach into water, or may be toxic to organisms that spend part of their life cycle in benthic environments. An assessment of trace metals, sulfate, total dissolved solids (conductance), and other potential mining-related contaminants, relative to water-quality standards and objectives, should be a part of this study; a more detailed analysis of the potential for past, ongoing, and potential future mining operations to contaminate border waters will be conducted in a separate set of studies.

The 2014 State of the Basin Report (Clark and Sellers, 2014) provides a summary of contamination issues, which should be used to guide the more comprehensive report. These issues include: known high-priority contamination sites tracked by U.S. and Canadian governments; mining-related contaminants (including acidity, metals, and sulfate which can harm wild rice production); mercury contamination of fish (largely resulting from atmospheric deposition from sources outside the Basin); organochlorines, including pesticides and PCBs. This report should ascribe priority contaminants to source type (point source, diffuse source within Basin, atmospheric source), and make recommendations for more quantitative assessment of sources. Where information on source type is lacking, provisional source-type attribution will help guide future inventories of point, diffuse, and atmospheric inputs.

In the expert workshop, it was noted that historical mining operations within the Basin have contaminated sediment in some locations with heavy metals. Where sediment surveys establish that contaminated sediments are present near such locations, there should be an effort to assess and delineate these areas and possibly have them listed as federal contaminated sites. This activity should avoid duplication of effort for current federally listed sites in Canada. The State of the Basin Report (Table 29, page 139; Clark and Sellers, 2014) lists known soil and sediment contamination sites for areas under federal jurisdiction in Canada that are both High and Medium priority for remediation. The Government of Canada is developing remedial action plans and/or conducting further testing to address these priority contamination sites. This project would be complementary in that areas outside of federal jurisdiction would be included in the assessment.

Mercury-related fish consumption advisories are prevalent throughout the Basin. Furthermore, there is considerable potential for trends in fish-mercury concentrations. In recent decades, both Canada and the United States have reduced anthropogenic mercury emissions to the atmosphere—the primary route of contamination of remote waters—and further reductions are anticipated as controls on emissions from coal-fired power plants are enacted. However, counter to North American reductions, mercury emissions continue to increase globally due largely to rapidly industrializing countries in Asia.

In addition to changing mercury emissions in North America and globally, mercury bioaccumulation to game fish may be affected by other environmental changes. Reductions in acid rain pollutants (sulfate and hydrogen ion) likely reduce the amount of mercury methylation within aquatic ecosystems, thus potentially less methylmercury is available for bioaccumulation in the food web (Coleman Wasik *et al.*, 2012; Brigham *et al.*, 2014). In addition, changes in food web structure may affect the amount of methylmercury transferred to top predators (Kelly *et al.*, 2006; Lepak *et al.*, 2009). Such changes may result in Basin waters as a result of fishing pressure, AIS, or other disturbances. Lastly, hydrological and climatic fluctuations may also affect the mercury cycle. An example of this is the increased mercury bioaccumulation in perch with increased water-level fluctuation in lakes and reservoirs of northern Minnesota (Sorensen *et al.*, 2005).

Owing to the numerous factors related to the source, geochemistry, and bioaccumulation of mercury in aquatic ecosystems, it is likely that fish mercury levels will change over time. Therefore, this project should specifically include an assessment of ongoing monitoring efforts to ensure that fish consumption advisories are based on adequate, up-to-date monitoring data. Current practice is to issue advisories, but not make the data, including sampling dates, publicly available so as to allow quick assessment of how up-to-date the advisories are. Basin scientists and resource managers would like access to the underlying data sets that are used to inform fish consumption advisories. These data should be compiled and shared in a comparable format between the U.S. and Canada and made publicly available.

Study Organization, Costs and Scheduling

Participating agencies would include MPCA, MNRF, MOECC, Manitoba Conservation and Water Stewardship, Lake of the Woods Water Sustainability Foundation, Environment Canada, U.S. EPA, national, state and provincial parks and the U.S. National Park Service.

Minnesota Department of Natural Resources, Minnesota Department of Health, Voyageurs National Park, the USGS, and University of Wisconsin-LaCrosse, and other researchers have been researching and monitoring mercury contamination of Rainy Lake and Namakan Reservoir and upstream lakes for decades, providing a foundation for understanding factors that control mercury concentrations in lakes in the region – they would, therefore, all be key contacts/potential partners for this project.

This project will involve a team of several authors, from agencies in both Canada and the U.S. It will cost an estimated $300,000 and require four years from project initiation to published report.

Cost Estimates for Project 21
Synthesis Report on Contaminants in Water, Aquatic Sediment, and Fish

Major Tasks	Timeline	Estimated Costs
Compilation of agency and researcher contaminants data sets	Year 1	$35,000
Analysis, interpretation, and report preparation	Years 2-3	$260,000
Publication and outreach	Years 3-4	$5,000
Total estimated costs		**$300,000**

Note: Funding largely for salaries for an expert team.

Project 22
Methylmercury Flux and Bioaccumulation in Large Border Lakes

Objective

To assess loading (or flux) and bioaccumulation of mercury and methylmercury in key border waters in the Basin.

Description

This project leverages other recommended Plan of Study activities to accomplish two fundamental objectives.

The first objective is to determine the loading, or flux, of methylmercury key hydrologic nodes, including (a) large water fluxes, and (b) key archetypal landscapes in the basin to assess effects of land use, land cover, and water level fluctuations, to determine whether certain landscapes (or water level regimes) contribute disproportionately to methylmercury levels in the Basin. Assessing methylmercury concentrations and fluxes at large water flux nodes will be important to assess loading to large lakes, including Lake of the Woods. It also will provide critical information on effects of water-level fluctuation within the large lakes on methylmercury production and delivery to downstream waters. Previous studies from the Basin (and some sites extending into the Great Lakes Basin) have shown that during years when large water-level fluctuations occur, methylmercury accumulates to higher concentrations in perch (Sorensen *et al.*, 2005). Assessing methylmercury flux from key landscape settings will allow

identification of basins that contribute a disproportionate amount of methylmercury to the large border lakes. Wetlands are known to be key landscape features that are sensitive to mercury inputs, and abundance of hydrologically connected wetlands has been correlated to methylmercury levels in water and fish in both lakes (Wiener *et al.*, 2006) and rivers (Bradley *et al.*, 2013). To maximize efficiency, all stream monitoring proposed in this study should be conducted at gaged streams that are part of the tiered monitoring program.

The second objective is to determine whether unique food web ecological features exacerbate the accumulation of methylmercury to top predator fish within major border lakes. Methylmercury bioaccumulation (accumulation of methylmercury from water to the base of the food web, *e.g.*, algae) and biomagnification (the tendency for methylmercury concentrations to increase with each successive step in the food chain, reaching highest concentrations in top predators) has been assessed in food webs of many water bodies in North America. Comparing trophic enrichment (slope of methylmercury concentration in biota to trophic position, as determined from nitrogen isotope analyses; Chasar *et al.*, 2009) in important border lakes to trophic enrichment determined from numerous other ecosystems across North America, will allow researchers to identify whether trophic enrichment is unusually high in lakes within the Basin.

This two-pronged assessment will provide insight as to whether the "methylmercury problem" in these lakes is driven more by physical and chemical processes within the Basin that affect mercury methylation, or by in-lake ecological factors that result in abnormally high rates of methylmercury bioaccumulation / biomagnification. Gaining understanding of these issues is important, insofar as certain land and water-level management decisions can be better informed by an understanding of how they contribute to methylmercury levels in fish.

Methodology

This project would leverage other recommended projects in the Plan of Study, including a subset of river and lake sites within the tiered monitoring program, and the food web model project (Project 10). Three data-collection components are envisioned:

- Long-term data collection at a subset of large, gaged rivers in the tiered monitoring program would be sampled for key mercury measures (total mercury, methylmercury, dissolved organic carbon, and other standard chemical measures as part of the core tiered monitoring program). This work would be ongoing at a few key river sites, to assess changes in flux of methylmercury that may be driven by changes in mercury deposition, sulfate deposition (which affects mercury methylation), and water level fluctuation due to reservoir operation or climatic variations.
- Smaller gaged streams that drain a range of land use/land cover settings, including streams that drain regulated reservoirs, would be sampled over a period of 3 years to assess spatial variability among key landscapes.
- In several large border lakes, where food web studies and models are being conducted, key mercury measures will be collected in the water (total mercury, methylmercury, dissolved organic carbon, and other standard chemical measures as part of the core tiered monitoring program). In addition,target organisms in the aquatic food web that are being sampled for the food web model will be assessed for key mercury measures (total mercury, methylmercury, nitrogen and carbon

isotope data specified in the food web model study). Key trophic levels to target include algae and periphyton, zooplankton, benthic invertebrates, young-of-year yellow perch, and game fish. This work would be completed within three years.

An interpretive report would follow the first three years of data collection. Thereafter, lower level mercury monitoring would occur at a small subset of tiered monitoring sites. Specifically, continued monitoring of young-of-year yellow perch from large, regulated border lakes and stream monitoring at large hydrologic flux nodes downstream from large border lakes, will provide critical data to monitor trends due to changing water-level fluctuations and other environmental changes.

Study Organization, Costs and Scheduling

The following agencies have been involved with key mercury monitoring and research efforts in the region, and are likely participants in a Lake of the Woods Basin mercury assessment: U.S. National Park Service (Voyageurs National Park): U.S. Geological Survey (Minnesota Water Science Center and Upper Midwest Environmental Sciences Center); U.S. Forest Service (Marcell Experimental Research Station); university researchers (University of Wisconsin-LaCrosse, Gustavus Adolphus College); MOECC; EC; MPCA; Experimental Lakes Area scientists; state and provincial fish monitoring programs.

Through several agencies, the State of Minnesota currently is assessing mercury flux and bioaccumulation in the St Louis River Basin (a tributary to Lake Superior). It will be conducting a similar assessment on selected tributaries in the Red River of the North Basin. Both of these efforts lie in international basins that are adjacent to the Lake of the Woods Basin. Researchers and agencies should consider bringing data sets together from across the region to provide a more robust assessment of land use/land cover, hydrologic, and food web influences on methylmercury bioaccumulation.

This project will also leverage historical and ongoing data collection in Voyageurs National Park that has focused on assessing mercury levels in young-of-year perch in large lakes. This has been, and continues to be an active area of research with important implications for lake-level management (Sorensen *et al.*, 2005; Larson *et al.*, 2014).

The cost-effectiveness of this project will benefit from: implementation of the tiered monitoring program (for stream flow, streamwater chemistry sampling, lake chemistry sampling, and sampling of aquatic invasive species); implementation of the food web model project and associated sampling; implementation of the geospatial data project (which will provide critical basin-wide data on land use and land cover).

Costs of the project are estimated at $300,000, including approximately $200,000 for data collection for approximately six stream sites and four lake sites, and $100,000 for interpretation and report preparation. The project will involve a three-year field effort, and one year for analysis and report publication, starting upon implementation of the tiered monitoring program and food web model data collection.

Cost Estimates for Project 22
Methylmercury Flux and Bioaccumulation in Large Border Lakes

Major Tasks	Timeline	Estimated Costs
Mercury sampling and analysis at surface water sites (using a subset of tiered monitoring sites, Project 1) and at biological sampling sites (using a subset of food-web study sites, Project 10)	Years 1-3	$200,000
Data analysis, interpretation, and report preparation	Years 4	$95,000
Publication and outreach	Years 3-4	$5,000
Total estimated costs		**$300,000**

Project 23
Spatial Survey of Contaminants of Emerging Concern

Objective

To determine the prevalence and concentrations of contaminants of emerging concern (CECs) on major boundary lakes that span gradients of human influence.

Description

While there are not many studies documenting CECs in the Lake of the Woods Basin, a few sites throughout the watershed including sites in Voyageurs National Park have been sampled as part of other ongoing investigations. Presence of some of these chemicals (hormones, pesticides, personal care products, synthetic musks, surfactants, and pharmaceuticals) has been established in both the heavily used (for example, Kabetogama) and remote lakes within Voyageurs National Park (Writer *et al.*, 2010; Barber *et al.*, 2012; Ferrey *et al.*, 2012; U.S. Geological Survey, 2014b) and throughout the Minnesota side of the Lake of the Woods Basin (Lee *et al.*, 2004; Minnesota Pollution Control Agency, 2010; Lee *et al.*, 2011). In addition to direct inputs through wastewater and industrial discharges and runoff from land surfaces, aerial deposition of some of these compounds is suspected.

This activity would assess the prevalence and concentrations of CECs on major boundary lakes that span gradients of human influence.

Methodology

This will be a multi-agency assessment/research project, involving collection of new data to assess contaminant concentrations along gradients of anthropogenic disturbance. This study should include sites with known sources of CECs such as industrial and wastewater discharges; sites near septic system inputs or other potential groundwater sources; sites near agricultural or urban land for investigation of runoff sources; and pristine sites where little aerial deposition, runoff, or groundwater sources are suspected. CECs are sometimes detected where there are no obvious point sources; therefore, atmospheric transport

should be examined as a possible contributor to CECs. This tiered sampling design will allow detected compounds to be placed into context of likely sources.

The following data-collection components are envisioned:

- Screen a relatively large number of sites during the first sampling season for targeted indicator compounds and biological assays. Collect, extract, and archive samples for follow-up analyses, pending results of the screening survey. The initial screening tests could include analyses of indicator chemicals such as caffeine, synthetic musks, carbamazepine, alkyphenols, and estrogens, that are all available as ELISA (Enzyme-Linked ImmunoasSAy) kits, or a simplified, more cost-effective chemical analysis. For biological screening, bioassays of estrogenicity, androgenicity, carcinogenicity, immune response, and toxicity should be completed.
- Analysis of archived samples and sample extracts for a greater suite of CECs, including hormones, pharmaceuticals, personal care and industrial products. Conduct more detailed analyses only at sites deemed to be priority sites, with significant detections of indicator compounds, and/or biological response to the bioassays.
- Follow-up sampling to assess spatial, temporal, and hydrologic variations in CEC concentrations, for those areas where significant detections occur.
- Specific chemicals and laboratory analyses that have been used to date are covered in references listed in the Description section, above. This background work should be used as the starting point for chemicals to assess under this project.

As appropriate, investigators should leverage sampling efforts with the tiered monitoring program (Project 1) for CEC sampling. Following 1-2 years of new data collection, publish a peer-reviewed report or paper summarizing findings on occurrence of contaminants of emerging concern, as well as human health and ecotoxicological implications.

Study Organization, Costs and Scheduling

Participating agencies could include the U.S. National Park Service, USGS, university researchers, MOECC, Environment Canada, MPCA, Health Professionals Advisory Board and the Great Lakes Work Group on Chemicals of Emerging Concern (Great Lakes Chemicals of Emerging Concern Advisory Work Group to the International Joint Commission (IJC), 2009).

Total costs for this project are estimated at $200,000 over a four-year period, including about $105,000 for data collection and $90,000 for interpretation and report preparation.

Cost Estimates for Project 23
Spatial Survey of Contaminants of Emerging Concern

Major Tasks	Timeline	Estimated Costs
Water sampling and analysis (using a subset of tiered monitoring sites, Project 1)	Years 1-2	$105,000
Data analysis, interpretation, and report preparation	Year 3	$90,000
Publication and outreach	Years 3-4	$5,000
Total estimated costs		**$200,000**

3.4.2 Assessment of Potential Contamination from Mining and Petroleum Transport

Basin experts placed a high priority on improving the knowledge base about potential sources of contamination, assessing vulnerability of water resources, and ensuring protections are in place to minimize risk associated with contamination from these sources. Although current contamination from mining and petroleum transport is not thought to be a significant issue for international waters, the larger concern is the potential for contamination due to a large expansion of these activities.

Both provincial/ state and federal governments impose stringent requirements for proposed mining projects to minimize potential environmental impacts. However, Basin residents remain concerned over the potential for adverse impacts from mining. The Plan of Study Team does not endorse any position on mining. However, given the many concerns over the issue and examples of degraded water from sulfide ore mines, the Team agrees that expert assessment independent of mining interests, permitting agencies, and advocacy groups is a precautionary measure that will inform the public and natural resource agency managers. Potential catastrophic failures such as breaches of mine-tailings basins, or similarly, pipeline failures or rail accidents could exact large costs to ecosystem services and require expensive remediation efforts. Therefore, assessment of risks should include both normal operations, as well as the potential risks and response plans for catastrophic failures.

Project 24
Vulnerability Assessment of Border Waters to Contamination from Mining

Objective

To assess vulnerability of border waters to the cumulative load of contaminants from mining and mineral exploration, in support of management decisions regarding protective measures.

Description

This project will:

- conduct an inventory of locations and, where known, amounts of potential contaminants (for example, mine waste stored on site or proposed to be stored under permit);
- prepare an analysis of key transport pathways to boundary waters, and analysis of dilution potential;
- review recent mining incidents for lessons learned (for example, what contributed to catastrophic releases and are there lessons that are transferrable to potential mining operations in the Basin?);
- conduct an assessment of safeguards in place and recommended new safeguards, including new technologies that can minimize downstream contamination; and,
- assess the risks associated with increased climate variability; (for example, consider whether there are structures such as holding ponds that are designed for 50-year or 100-year precipitation events and if so, assess likelihood of exceedance of events of that magnitude, given shift toward more extreme precipitation events).

Methodology

A team of experts will prepare a series of peer-reviewed reports on vulnerability assessment based on available information on the geology, hydrogeology, and locations of historical, ongoing, proposed, and high-potential new mine sites. In addition to providing an assessment based on the best current information, each report also should identify gaps in data, and make recommendations for future data collection efforts necessary to make a more complete assessment. The following reports are proposed:

- an assessment of metal-sulfide ore mining effects on water quality. This assessment should explicitly include (but not be limited to) a literature review of acidic and high-metal-concentration waters in other areas where disseminated sulfide ores have been mined in North America, include sites where modern pollution control and site mitigation measures have been employed; and an analysis and summary of current concentrations and loads of metals, sulfate, acidic water, and other water quality constituents from historical and ongoing mine operations within the Lake of the Woods Basin;
- an analysis of the potential for new mining operations to elevate contaminant concentrations and loads in Basin waters. New mining operations include newly permitted, in-review, and active mineral leases where there is a strong potential for a mine to be developed. For lease areas where specific mine operation plans have not yet been developed, the assessment should allow for some range of scenarios, using the best professional judgment of scientists conducting the evaluation. Consideration of both surface discharges and contaminant transport via groundwater flow paths should be included. This study should consider a mass-balance framework that incorporates contaminant concentration and load information from the prior two reports. This report will place contaminant concentrations and loads in the context of water quality standards, and the cumulative potential to impact international border waters;
- a review of the vulnerability due to catastrophic infrastructure failures, such as breaches of tailings basins, dams, or mine-waste treatment processes; including an independent assessment of current review processes and protections against water-quality degradation, with an assessment of significant weaknesses in those processes and protections. This assessment should explicitly recognize failures due to large precipitation events, and report on future vulnerability of infrastructure under likely regional climate model scenarios; and,
- a synthesis report, fact sheet, or web-based announcement that summarizes the above assessment reports, for policy makers and the public.

It is emphasized that although this project will examine the cumulative effects of basin-wide mining activities, the focus of the cumulative effects (impairments) will be on international border waters—that is, the large border lakes and Rainy River. Other agencies have jurisdiction over waters contained entirely within one nation's border, and this project will not attempt to assess the potential for impairment of waters that are not international border waters except to the extent that such waters are upstream from large border lakes.

Study Organization, Costs and Scheduling

This effort should be led by earth scientists from non-regulatory agencies and universities. Potential partners include U.S. Geological Survey, Geological Survey of Canada, the Natural Resources Research Institute (NRRI) at the University of Minnesota-Duluth, other university researchers, and Minnesota Geological Survey. Assessment reports should be subject to rigorous peer review, and all potential conflicts of interest (including funding ties to mining industry and/or environmental advocacy groups) should be minimized or clearly identified.

Linkages to agencies with permitting and/or regulatory authority will be critical to obtain necessary information. These agencies include Environment Canada, Ontario Ministry of Northern Development and Mines / Ontario Geology, the MDNR, U.S. Forest Service, U.S. Department of the Interior (Bureau of Land Management and Office of Surface Mining and Reclamation).

This project will benefit from the Contaminant mapping component of Project 30 (geospatial mapping project).

Costs are estimated at $600,000 over a four-year period.

Cost Estimates for Project 24
Vulnerability Assessment of Border Waters to Contamination from Mining

Major Tasks	Timeline	Estimated Costs
Assessment report 1: assessment of metal-sulfide ore mining effects on water quality. Literature review, data analysis and interpretation, and report writing	Years 1-3	$230,000
Assessment report 2: analysis of the potential for new mining operations to elevate contaminant concentrations and loads in Basin waters. Literature review, data analysis and interpretation, and report writing	Years 1-3	$230,000
Assessment report 3: review of the vulnerability due to catastrophic infrastructure failures. Literature review, summarize key vulnerabilities in Lake of the Woods Basin, report writing	Years 1-2	$125,000
Publication and outreach, including synthesis report for lay readers	Years 3-4	$15,000
Total estimated costs		**$600,000**

Project 25
Vulnerability Assessment of Border Waters to Contamination from Rail and Pipeline Transport of Petroleum and other Chemicals

Objective

To assess risks, protective measures, and response plans related to rail and pipeline transport of petroleum and other hazardous chemicals.

Description

Given the large and increasing volume of petroleum transport, including rail transport and proposed expansion of pipeline capacity, and in light of recent train derailments in both Canada and the U.S., there is great interest in assessing vulnerability of transboundary waters within the Basin and relevant response plans.

An assessment of risks associated with rail transport of petroleum should also consider rail transport of other large volume hazardous chemicals (or classes of chemicals). Many chemicals (for example acids, chlorine gas) have very different fate, transport, persistence, and health risks than petroleum, therefore risks to water supplies and response plans will likely be quite different.

Methodology

A team of experts will prepare a report on vulnerability assessment based on available information including location of transport routes (rail and pipeline, including proposed pipelines); operational considerations; infrastructure considerations (for example, age, condition, design, and safety features of critical infrastructure); surface water resources, as well as geologic and hydrogeologic features that affect contaminant transport to surface waters; and response plans, including local capacity to respond to a spill or disaster. In addition to providing an assessment based on the best current information, the report should identify gaps in data and make recommendations for future data collection efforts necessary to make an improved (more complete) assessment. Transport of contaminants by direct spill (discharge) into surface waters, as well as via groundwater flow paths, should be included in the assessment.

The report should consider multiple forms of petroleum that are transported through the Basin, including Bakken shale gas crude (a highly volatile product derived from hydraulic fracturing of shale formations) and diluted bitumen (dilbit, a semi-solid generally shipped by pipelines under high pressure). The different forms likely have different transport characteristics and likely break down at different rates.

The report should identify key risks, vulnerabilities, inadequacies in existing protections (including relevant government laws and regulations to provide environmental protection against the potential threats to water resources from petroleum pipelines) and response plans. It should make recommendations to address inadequacies in protections and response plans, and identify where existing

data are insufficient to adequately evaluate vulnerability. As appropriate, the report also should identify recommendations for improvements in environmental protection.

Study Organization, Costs and Scheduling

This project will likely involve provincial, state, and federal agencies; academic institutions; and private consultants. The diluted bitumen spill report (Government of Canada, 2013) is a useful reference.

The project will involve a three-year study, with an estimated budget of $200,000.

Cost Estimates for Project 25
Vulnerability Assessment of Border Waters to Contamination from Rail and Pipeline Transport of Petroleum and other Chemicals

Major Tasks	Timeline	Estimated Costs
Literature review and data compilation (in collaboration with project 30, geospatial mapping project)	Year 1	$85,000
Analysis, interpretation, and report writing	Year 2	$110,000
Publication and outreach	Years 2-3	$5,000
Total estimated costs		**$200,000**

Project 26
Mining Effects Science Workshop

Objective

Provide a forum for ongoing exchange of scientific information on water quality effects related to mining activities in Lake of the Woods Basin.

Description

Considerable efforts related to mining are underway in the Basin, including mineral exploration, formal applications for mine permits, agency reviews of mine permit applications, advocacy for greater protective assurances such as cumulative impact assessment and programmatic review, and advocacy against any expansion of mining in the region.

Given the considerable interest in mining in the Basin, as well as opposition to expansion or development of new mines, there is a need to provide for improved communication of science information related to mining. In particular, there is a need for communicating the science on: baseline water quality conditions and availability of data; water quality risks associated with mining options and technologies; treatment, mitigation and reclamation technologies; and analysis of infrastructure design criteria *vis-à-vis* future climate uncertainty.

This activity would:

- establish a diverse stakeholder group, including scientists and engineers from the mining industry, permit review authority agencies, non-regulatory earth science agencies, universities, First Nations, Métis and Tribal communities(all bands and First Nations with interests in the Basin, including usufructuary rights in Ceded Territories should be included), environmental advocacy group and interested members of the IRLWWB, its CAG and IAG; and,
- establish a process for periodic (annual or biennial) exchange of science-based information on science issues related to environmental effects of mining within the Basin. The process should include:
    - a workshop (or forum) where relevant science information on environmental effects of mining is presented. The presentations would be drawn from a diverse cross-section of the stakeholders described above;
    - a focus on presenting and communicating scientific information among diverse stakeholder groups and representation of diverse stakeholder interests;
    - robust processes to ensure balance and scientific integrity; objective scientists from non-regulatory, non-advocacy institutions provide research, analysis, and peer review; separate input mechanisms for interest groups, including mining interests and groups interested in protecting water resources. Potential conflicts of interest (including funding ties to mining industry and/or environmental advocacy groups) should be minimized or clearly identified.
    - organized site visits to historical, ongoing, and proposed mining areas to allow all parties to observe conditions "on the ground," and exchange information. This is important to provide a sense of scale of mining operations, relative to surrounding areas;
    - reviews of mining operations in other locales, particularly when similar mining activity is proposed in the Lake of the Woods Basin; and,
    - publish proceedings and summarize key findings presented at each workshop in press releases and other derivative lay-reader materials.

The emphasis should be on science that informs policy-relevant decisions. Policies should be established to ensure that advocacy is kept out of this forum, as alternate venues are available for public input and advocacy on policies and specific permit applications.

The issues differ somewhat between nations, with proposed gold mining in Ontario, and iron mining and proposed nickel and platinum group metal mining of disseminated sulfide ores in Minnesota. A number of mineral deposits and associated mining concerns straddle the watershed divide between the International Lake of the Woods Basin, and the Lake Superior Basin (part of the International Great Lakes Basin) to the east. Therefore, as an IJC boundary waters concern, the IJC should consider mining-effects workshops that encompass both Basins, (Lake of the Woods and Lake Superior), and ensure that mining issues in both Canada and the United States are addressed.

Methodology

Create a mining expert group, representative of diverse and relevant interests and expertise in the Basin. Charge the group with establishing the detailed processes for enhanced communication of scientific issues related to mining effects on water quality, as outlined above.

Study Organization, Costs and Scheduling

Participants could include: MDNR; Mine Water Research Advisory Panel; U.S. Forest Service; U.S. National Park Service; Minnesota Geological Survey; U.S. Geological Survey; Geologic Survey of Canada; Mineralogical Association of Canada; U.S. EPA; Environment Canada; Lake of the Woods Water Sustainability Foundation; IRLWWB and its CAG and IAG; MPCA; Ontario Ministry of Northern Development and Mines, MOECC; MNRF; Manitoba Conservation and Water Stewardship; universities; Tribes, Metis and First Nations; county governments; Watershed Districts; Mining company scientists and engineers; Society for Mining, Metallurgy, and Exploration; science advisors or consultants to clean-water advocacy groups opposed to mining in the Basin (including Northeastern Minnesotans for Wilderness; Minnesota Center for Environmental Advocacy); wilderness groups (Voyageur Outward Bound School, Wilderness Inquiry) and park and wilderness-edge businesses (outfitters, resorts, lodges, fishing guides, dogsledders).

Previous mining-effects themed workshops in the neighboring Lake Superior region include a 2011 workshop "Understanding the Impacts of Mining in the Western Lake Superior region (Minnesota, Wisconsin, and Michigan)" organized by the USGS, Great Lakes Indian Fish and Wildlife Commission, and two Native American bands in the region[23]. In addition, the Sigurd Olsen Environmental Institute at Northland College, Ashland, Wisconsin, has put on several forums that address mining effects issues, and include a variety of perspectives including those from the mining industry, environmental monitoring agencies, and Native American bands in the region[24]. Both of these efforts serve as models for future mining effects science workshops.

An estimated cost for the first four years of workshops is $50,000 (approximately $25,000 per year, every second year) to assist with costs of organizing the workshop; professional services (including facilitation of workshop sessions and expert panels; compilation and web-publication of conference proceedings, and media outreach); and limited travel assistance for representatives from small or under-represented organizations. It is anticipated that this base funding would leverage additional funds including workshop registration fees, agency contributions (including in-kind), and grants.

The workshop should be held biennially.

[23] http://mn.water.usgs.gov/projects/tesnar/2011/TESNAR2011WORKSHOPAgenda.htm
[24] http://www.northland.edu/mining.htm

Cost Estimates for Project 26
Mining Effects Science Workshop

Major Tasks	Timeline	Estimated Costs
Workshop 1 Professional services (organize workshop; facilitate workshop; web publish workshop proceedings; outreach)	Year 1 or 2	$25,000
Workshop 2 Professional services (organize workshop; facilitate workshop; web publish workshop proceedings; outreach)	Year 3 or 4	$25,000
Total estimated costs		**$50,000**

3.5 Capacity Building

Finally, the limited capacity of various organizations and interests to address water quality concerns in a comprehensive, coordinated manner is an underlying challenge in the Basin. For example, as discussed in section 1, current water management in the Basin is characterized by a diversity of approaches, driven by different legislative frameworks and policies, and with limited ability to coordinate management efforts across the international boundary. This diversity can be a major road block to any coordinated effort between the two countries. In addition, there are challenges with respect to public awareness and access to information, and the capacity of indigenous peoples to engage on water quality issues.

The Plan of Study recommends six projects that will help build greater capacity across the Basin for engaging all Basin interests on water quality management. The projects will help share critical water quality information among natural resource managers, the public, First Nations, Tribes and Métis, and help promote greater cooperation among institutions and agencies active in the Basin.

Benefits

Direct outcomes of the projects under this theme will be *a wide variety of information sources and mechanisms to build capacity in the Basin to understand, communicate and implement solutions.*

The projects outlined here will contribute to the following long-term outcome: *improved water quality through basin-wide mapping, communication and an implementation platform to support policy development, decision-making, and adaptive management.*

Project 27
International Platform for Implementation

Objective

To ensure that institutional arrangements and entities are adequately constituted and optimized to implement the Plan of Study projects and management solutions for sustained ecosystem health in this international basin.

Description

The Plan of Study team heard a clear message from the public that the health of the Lake of the Woods Basin should be a priority of governments and that an international commitment to water quality management in the future is critical for this to happen.

This Basin has seen tremendous advances in governance and partnerships that have moved international research and collaboration significantly forward. The establishment of the IMA in 2009 and the appointment in 2013 of the IRLWWB both form a strong basis for future coordination of efforts and implementation of projects recommended in this Plan of Study.
The Plan of Study projects identify the needed research and activities to move from science to solutions and the tools to monitor ecosystem health in the Basin. Implementation will require a commitment from governments and a strong, collaborative body to get the work done, both over the short term and long term. Current successes in the Basin have been based on strong partnerships, a willingness to work together and share information, and multi-agency collaborative work-planning and prioritization of needs. The next step is to assess whether current institutional arrangements are adequately positioned and constituted to effectively conduct research and implement management actions internationally.

Methodology

A facilitated workshop session will be held to review existing institutional arrangements and partnerships in the Basin for their strengths, weaknesses, gaps and impediments to help ensure that the Plan of Study work can proceed. The findings will help determine whether a higher level commitment is needed. The outcome of this project will be a report with clear recommendations on the optimal platform upon which binational implementation of the Plan of Study projects and future water quality management can occur.

The project methodology will respect the existing institutional arrangements but also consider the need for any additional requirements. The IRLWWB is making progress towards international cooperation around ecosystem health through development of a workplan, support and involvement in the Plan of Study development, addressing Basin concerns and developing a public engagement strategy. However, Board capacity and expertise to implement the Plan of Study projects may be a constraint. The IMA is a key resource of local and regional expertise in the basin. It has a track record of collaboration on inter-agency and inter-jurisdictional research to find solutions in the Basin. However, the IMA exists as a discretionary working arrangement, endorsed by its member agencies at differing levels of formal authority and resourcing. Its focus has been on a subset of the issues and geography in the basin. The

IMA likely provides key elements. However, as currently constituted, it may be constrained in its ability to deliver fully on Plan of Study project implementation.

This project will optimize the synergies in the Basin and assess whether the current IMA Arrangement is a strong enough vehicle to handle the next phase of work needed in this Basin. It will also identify the roles and responsibilities required for Plan of Study implementation, guiding principles needed for successful implementation and the capacity required to develop international management strategies into the future. While optimizing the relationship between the current entities (IMA and IRLWWB) will be examined as one possible solution, other options will also be reviewed.

Study Organization, Cost and Scheduling

It is recommended that this project be undertaken immediately. It will require that a facilitator be hired to engage the IMA, the IRLWWB and other key basin interests such as First Nations, Tribes, Métis and resource agencies into this discussion.

Estimated cost is $14,000 to cover facilitation of the workshop, venue costs, travel for participants and report preparation.

Cost Estimates for Project 27
International Platform for Implementation

Major Tasks	Timeline	Estimated Costs
Facilitated workshop: Review with relevant parties the strengths, weaknesses, gaps and impediments to Plan of Study implementation (includes travel, rental space fees, meals)	Year 1	$10,000
Compilation of discussion points from facilitated workshop to develop recommendations	Year 1	$2,000
Review of recommendations with workshop participants; development of final report	Year 1	$2,000
Total estimated costs		**$14,000**

Notes: Costs pertain mainly to hiring of a facilitator to hold workshop sessions with relevant parties and develop recommendations.

Project 28
Review of Data Collection Programs and Monitoring in the Headwaters Regions of the Basin

Objective

The objective of this study would be to improve the capacity to detect water quality changes in headwaters systems that may influence the water quality or ecosystem health of transboundary lakes and rivers.

Description

Data collection in the headwaters across the Basin serves two key functions. First, it provides a means by which localized water quality issues can be readily identified. Secondly, it improves the understanding of how human activities in upstream reaches and lakes can influence priority issues of transboundary waters.

A great deal of the monitoring of water quality in the Basin has focused on Lake of the Woods and waters immediately upstream, though in Minnesota, waters in the headwaters region have and will be monitored through the WRAPS. In the headwaters region, intensive watershed monitoring is underway in the Rainy Headwaters sub-basin and will be done in the Vermilion sub-basin in 2015 and Rainy Lake sub-basin in 2016. Lakes within Voyageurs National Park have been monitored for many years as part of the park's research initiatives and monitoring programs exist within the Superior National Forest, Quetico Park and within the Seine River system by Seine River First Nation. There are considerable headwaters data as part of the Kawishiwi Watershed Protection Project, citizen-based monitoring from a variety of lake associations elsewhere and private industry (such as dam operators and mining companies).

Methodology

This project involves a review of data collection programs in headwaters regions, which should be accomplished through a survey of all agencies and organizations in the Basin for their current and planned monitoring and sampling activities. It also will involve a summit or workshop (possibly in conjunction with the annual Watershed Forum) to enable exchange of technical knowledge and development of a geospatially-referenced map of activities, and to affirm basin-wide involvement in the development of solutions for lakes and rivers along the transboundary. Such information will be made available through the IRLWWB website.

Study Organization, Costs and Scheduling

The project will involve all federal, state and provincial agencies, as well as any non-government organizations, counties and Soil and Water Conservation Districts, First Nations, Tribes and Métis, that are responsible for collecting water quality data or information that may affect water quality.

The review of data collection programs should take less than a year, followed by a summit or workshop to bring participating agencies, organizations and individuals together.

The total cost of this project will be $50,000.

Cost Estimates for Project 28
Review of Data Collection Programs and Monitoring in the Headwaters Regions of the Basin

Major Tasks	Timeline	Estimated Costs
Survey and collection of information on headwaters data collection programs and monitoring	Year 1	$25,000
Workshop to bring relevant agencies, stakeholders, organizations together (perhaps at the same time as annual Watershed Forum (cost refers mainly to workshop lead's time; minimal additional costs if held at time of forum)	Year 1	$15,000
Compilation of workshop proceedings and mapping of data for posting on IRLWWB website	Year 1	$10,000
Total estimated costs		**$50,000**

Project 29
Application of Regional Climate Models for the Basin and Improved Public Education and Engagement on the Issue of Climate Change

Objective

To synthesize and evaluate currently available downscaled climate models and apply outcomes to other Plan of Study projects and to stimulate public engagement opportunities.

Description

Climate change represents an overarching influence on natural processes and human activities throughout the basin. The latest Intergovernmental Panel on Climate Change report (IPCC, 2013) identifies fossil fuel consumption by human societies as the primary cause of global warming through excessive release of greenhouse gases and warming atmospheric temperatures.

Global Circulation Models (GCMs) simulate and forecast changes to temperature and precipitation regimes at a very large scale. Techniques exist to "down-scale" GCMs through integration of finer-scale meteorological data and generate Regional Climate Models (RCMs). Several RCMs are currently available for the Lake of the Woods Basin. There is value in utilizing these available models to apply outcomes to other Plan of Study projects, as well as to the ongoing Rule Curve Review and to stimulate public engagement opportunities.

The Ministry of Natural Resources and Forestry (MNRF) has access to the most up to date climate model data from recently downscaled models. MNRF collaborates with the Canadian Forestry Service, and has been provided this extensive data for MNRF climate change research purposes. The five Earth System Models (ESM) provided are:

- CanESM2 – Canadian Earth System Model version 2;
- MIROC-ESM-CHEM – Model for Interdisciplinary Research – Earth System Model developed by the University of Tokyo;
- CESM1-CAM5 – Community Earth System Model version 1 (CESM1) that includes Community Model Version 5(CAM5);
- HadGEM2-ES - Hadley Global Environment Model 2 - Earth System; and,
- COMPOSITE_AR5 - the average (ensemble) of the four GCMs models listed above.

Methods for developing the five ESMs (Assessment Report 5 or AR5) are described in detail in McKenney *et. al*. (2011).

Methodology

RCMs can be used to describe the likely impacts of climate change (both apparent today and forecast for the future) on water quality and ecosystem health through scenario modeling (Stefan *et al.*, 2001; Novotny and Stefan, 2007). Timely communication of the RCMs to researchers and practitioners involved in other Plan of Study projects will be conducted to inform them of current local projections if the project involves "looking forward" components, such as adaptive management strategies. Interpretations of RCMs can be made available to the public so that citizens can monitor how aspects of the basin, such as phenology, ice cover, water levels and temperature, and storm severity are changing and potentially affecting water quality. In this way, the public can understand local impacts of a more global issue and be informed of adapting lifestyle changes to help mitigate those impacts.

MNRF is currently coordinating a number of research projects on climate change vulnerability of terrestrial and aquatic ecosystems in the Great Lakes Basin from which research on Lake of the Woods Basin could draw. Two key projects with application to this Basin include a climate change/AIS research project that will be expanding beyond the Great Lakes Basin to describe AIS spread risk across the province, including human vector influences. The second, in partnership with the Ontario Ministry of Agriculture, Food and Rural Affairs, is looking at changes not just in agricultural practices to adapt to climate change, but also changes in cropping systems and livestock operations as weather conditions change.

The final project element around promoting citizen actions should include organizations such as municipalities, service boards and lake associations. There are numerous adaptation strategies geared to changing traditional planning and development policies to accommodate future climate that can be done by these organizations and others, including the provincial and state governments.

This project involves several components:

- synthesize and evaluate RCMs that include the Basin: regional interpretation of climate change will enable temperature and precipitation scenarios to be forecast;
- mapping and online availability of forecast changes to temperature and precipitation regimes as a result of RCMs (link to the Geospatial Mapping project);

- generation of a report that describes climate impacts on the priority issues in transboundary lakes and rivers and across the Basin;
- development of information tools for the public to assist with monitoring of water quality-related climate change impacts and with the selection of adaptation measures. Specific emphasis should be on interactions with the appearance and dynamics of HABs and the identification of AIS and their distribution; and,
- development of policies resulting in citizen actions that promote awareness of human activities that contribute to climate change and adaptation practices; municipalities, service boards and lake associations can play a role in leading this charge.

Study Organization, Costs and Scheduling

MNRF, MPCA and MOECC along with other relevant partners including EC and NOAA should lead this initiative. The IRLWWB, the LOWWSF, the IJC and others in the basin should develop guidebooks and factsheets to expand understanding of climate change and encourage public interest and response. Climate change adaptation strategies currently in place by Ontario, Manitoba and Minnesota should be reviewed for inclusion in this project. Close collaboration and cross-referencing with the LWCB website would be beneficial to users who frequently access that website for water level information already.

Hydrologic models for Rainy Lake and Namakan Reservoir allow for investigation of water levels under different hydrologic regimes (1970 and 2000 Rule Curves; Thompson, 2013) and allow researchers to incorporate climate change through variable inflow datasets (variable inflow datasets to investigate climate change effects is proposed as part of Rule Curve Review).

Results of RCMs are of direct benefit to several projects in this Plan of Study, especially those concerned with the improvement of hydrologic budgets and the forecasting of HABs.

Findings from this project will be used to inform the projects devised to help predict the occurrence of HABs. It is not a given that the same sets of factors that give rise to algal blooms also contribute to the release of algal toxins; separate predictive models may need to be developed.

Synthesis and evaluation of the existing RCMs and inclusion in the Basin's geospatial mapping framework would take one year at a cost of $50,000. Development of information tools and a reporting system should also take approximately one year at a cost of $50,000 and then minimal funding would be necessary to manage datasets and share them via the Board's website.

Cost Estimates for Project 29
Application of Regional Climate Models for the Basin and
Improved Public Education and Engagement on the Issue of Climate Change

Major Tasks	Timeline	Estimated Costs
Synthesize and evaluate RCMs that include the Basin	Year 1	$25,000
Map and post online forecast changes to temperature and precipitation regimes as a result of RCMs	Year 1	$13,000
Generate a report that describes climate impacts on the priority issues in transboundary lakes and rivers and across the Basin	Year 1	$12,000
Develop information tools for the public to assist with monitoring of water quality-related climate change impacts and with the selection of adaptation measures	Year 2	$30,000
Develop policies resulting in citizen actions that promote awareness of human activities that contribute to climate change and adaptation practices	Year 2	$20,000
Total estimated costs		**$100,000**

Project 30
Development of the Lake of the Woods Basin Geospatial Mapping Framework and Public Communication Tool

Objective

To provide a common and sustainable geospatial platform upon which the IRLWWB, local non-governmental organizations, First Nations, Tribes, Métis, natural resources agencies and the public can access, supplement and steward geospatial data unique to the shared geography of the Basin. This platform will be created so as to be accessible and user friendly via the current IRLWWB website, thereby promoting the IRLWWB website as a key communication tool in the Basin.

Description

This project is key to providing the IRLWWB with the tools it needs to monitor ecosystem health in the Basin and to inform others of Basin conditions and activities. It will serve as one geospatial reference location for the mapping of priority and emerging issues so that trends can be observed, new data can be added as they become available and information can be accessible when the Board is speaking to the public and partners. In addition, this project is meant to enhance community appreciation for the environmental resources of this international basin via innovative GIS applications and tools while providing access to up to date scientific and social data unique to the Lake of the Woods Basin. This Basin should draw from the unique opportunity it has with the IJC's ongoing development of geospatial products specific to this Basin's geography.

In 2013, the IMA-TAC, along with the IJC, began to develop a draft Geospatial Strategic Plan, recognizing the need to develop a geospatial platform upon which the work of the IMA could be

displayed and utilized by themselves, resource managers, the IRLWWB and others in the Basin. Other binational mapping initiatives in the Basin include Streamstats (online watershed delineation and hydrographic characterization through USGS) and SPARROW[25] water quality modeling through the IJC, USGS and NRC. The modeling efforts have primarily focused on the physical structure of landscapes, including digital elevations models), stream networks and watershed delineations, which comprise the fundamental hydrographic characteristics of the system.

With the data-harmonized structure in place as created by the IJC, the development of the draft Geospatial Strategic Plan began as a way to start thinking about how best to map activities and findings in the Basin and to make them easily accessible. This project supports and builds upon the vision put forth in that draft plan. The geospatial platform and the IRLWWB website will become the "home" to the information derived from the projects proposed in this Plan of Study, most notably the data generated from the strategic tiered monitoring program, as well as the information being collected by the IMA and others in the Basin.

Building upon the stated vision in the draft strategic plan, the key goals of this project are to:

- Bridge the institutional gaps that inhibit the creation, manipulation, visualization, and stewardship of geospatial data and sub sets of geospatial data unique to the Basin; mapping of information has been a challenge for the IMA and this provides the framework for referencing and comparing their work and the work of the other partners in the Basin;
- Deliver valued public service by ensuring responsiveness to communities in the Basin via accessible, user-friendly geospatial and geographic services;
- Evolve and enhance GIS applications and tools to support effective and efficient decision making; this will serve the needs of the IRLWWB and the IMA as they move forward in monitoring ecosystem health and working towards joint water quality protection;
- Encourage local, regional, indigenous and federal engagement in the creation and visualization of geospatial data and media relating to the health and wellbeing of the ecosystem, thereby providing mechanisms for sharing information and enhancing communication.

Methodology

Component 1 – Building the Platform

Some of the initial work required for the first component – building the platform - has already been done. The first task of securing appropriate software and hardware has been achieved and is licensed to the LOWWSF (IMA member). The hiring of an individual to manage initial, key geospatial mapping activities noted below will be needed as well as ongoing funding to manage the mapping initiatives. Identification of pertinent base layers (datasets) and desired operational layers (datasets) would be the next steps.

[25] http://water.usgs.gov/nawqa/sparrow/

There is a need for a wide variety of geospatial data layers to characterize the natural features of the Basin and human activities; some of this will be drawn from the current IMA project that is compiling LandSAT data for the 1990 and 2010 time periods to develop land use maps of the entire Basin (to be complete June 2015). Accurate and updated land-use data are critical in the development of watershed loading models and nutrient budgets. Examples of natural features of particular importance for understanding water quality are vegetation cover (forests, wetlands), soils, surficial geology, and groundwater regions. Examples of human activities important for georeferencing are agricultural systems, municipal and industrial point sources, current and abandoned waste disposal facilities, road and rail transportation networks, and built-up areas. With the unprecedented flooding observed in 2014, another key geospatial data layer is flood extent according to variation in water levels.

Based on priority issue mapping needs, the following focus areas are detailed to illustrate the utility of geospatial mapping and to highlight the recommended activities for initial consideration in this project:

Algal Bloom Mapping

Mapping of algal blooms benefits both the research community and the public. Projects described elsewhere in the Plan of Study, specifically the satellite-imagery and remote-sensed data project, the algal composition project and bloom prediction project, collect georeferenced information that can be visualized as a map layer within this project. When a series of maps are generated, both within years and between years, the timing of onset, duration and spatial extent of algal blooms can be quantified and shared with agencies, non-governmental organizations and the public.

Aquatic Invasive Species Mapping

This application involves development of an international database and GIS layers to show distribution of AIS in the Lake of the Woods Basin, and serve this information to resource managers and the public via the worldwide web. This effort would also establish a monitoring and reporting system to provide resource managers with timely, updated information into the future.

Two web-accessible AIS inventories are already in place: the Early Detection and Distribution Mapping System (EDDMaps) [26] (covers Ontario and Manitoba and portions of the U.S.); and the Nonindigenous Aquatic Species (NAS) system covers invasive animal species (including AIS such as zebra mussels) for the United States (and in Canada, where reported by agencies) [27]. This project would link these two systems to this Geospatial Mapping Project so that an internationally harmonized, web-viewable data base of AIS would be available to Basin managers and the public. This activity would necessarily encompass the entire Basin, as well as neighboring basins to support vulnerability assessments on an ongoing basis. Local, Provincial, and State agencies should endeavor to make full use of these national-scale systems to maximize efficiencies across Basin and political boundaries. As noted in the Recommendations for Immediate Action section, full support of these two national AIS-tracking systems is needed.

[26] http://www.eddmaps.org/
[27] NAS, http://nas.er.usgs.gov/

The project will consist of two main activities: (1) develop an automated system to pull data from national-scale data bases and integrate them with the international Geospatial Mapping project, so that AIS data can be accessed by the public and resource managers in a seamless manner, across the entire Lake of the Woods Basin and neighboring basins; and (2) develop a system for local (Lake of the Woods Basin) information to be uploaded into the respective national-scale data bases. Consideration will need to be given to who will collect data, by what methodology and how it is verified – current AIS monitoring is inconsistent within the Basin.

Potential Contaminant Sources Mapping

This component will provide a publicly accessible, online, up-to-date map of mining (including historical, existing, approved, and permit-pending locations), cultivated agriculture, and petroleum transport activity to inform public and resource managers. Basin scientists saw the need to bring together known data of potential sources of contaminants into an integrated, harmonized GIS map product. There is concern within the Basin that future activities may have the potential to contaminate surface waters directly or indirectly via groundwater transport. Historical (closed), existing, and approved mines are important to map to give resource managers within the Basin a more accurate view of potential for mining-related contaminants that may affect water resources. Agricultural lands also need to be brought into the Basin's GIS. More detailed hydrogeologic mapping is needed where groundwater resources intersect potential areas of contamination; this information will directly support the vulnerability assessment projects proposed (Projects 24 and 25). Much of the information exists in state and provincial databases; assembling the data and providing them publicly via the Basin's web-searchable GIS would provide a valuable information tool.

Wild Rice Inventory Mapping

Wild rice is sensitive to invasive species such as hybrid cattail (which can crowd out native wild rice stocks) and rusty crayfish (which can disturb root zones); sensitive to excessive sulfate and sulfide (which may result from mine-water discharge); and sensitive to water depth and water-level fluctuations. Detailed mapping of wild rice occurrence in the Basin is critical to understanding how the above stressors may impact wild rice over time.

Component 2: Enhancing the IRLWWB Website as a Communication Tool

This second component of the project involves a review of the current information on the IRLWWB website and development of a strategy for effectively getting information back out to the public, agencies and organizations. The website will be a tremendous resource for communicating the progress of Plan of Study project implementation, management actions that are initiated as a result and accessing other Basin resources (*e.g.*, SOBR update). It will also provide the "home" for interactive maps developed as part of this project and story maps to highlight activities and groups at work in the Basin. Suggested additions to the current website that may be of interest include:

- Home Page – description of the watershed, details on what data the gages shown on the map provide; listing of partners involved in binational water management and links to their websites; vision and mission of the Board;
- Members Page – explanation of how Board was formed and importance of having local and designated members seats, map with distribution of membership (Board, community and industry advisory groups);
- Resources Page – links to more partners with indication of the type of work they do; interactive map with sub-basin level information; Board outreach plan; and,
- Links Page – add in other partners such as LOWWSF, Ontario Ministry of Environment and Climate Change (Lake of the Woods page), Environment Canada, MPCA, U.S. Environmental Protection Agency, and MNRF.

The IMA has already discussed with the IJC the idea of geospatially mapping signage for the prevention of AIS in the basin and to begin to record sightings of AIS on this platform through social media. It also has discussed the concept of developing a Basin geospatial narrative (a map service that provides an introduction to the geography and fundamental hydrodynamics of the basin). Both of these initiatives should be included in the scope of this Project as essential public involvement and outreach tools.

Study Organization, Costs and Scheduling

Current partners in this initiative should remain involved (LOWWSF, IJC, IMA) and new partners should be involved in the design and implementation of this project, including the IRLWWB, First Nation, Métis and Tribal natural resource departments, Soil and Water Conservation Districts, counties, municipalities, lake associations, resource managers. Other key participants could be state and provincial agencies (MNRF, MDNR, Manitoba Conservation and Water Stewardship, Minnesota Sea Grant), university experts, Ontario Federation of Anglers and Hunters, Voyageurs National Park, Quetico Park, Superior National Forest.

Public input could be provided via the IRLWWB's Community Advisory Group and Industry Advisory Group to ensure that accessibility issues are considered and developments are user friendly. A GIS specialist is needed to produce the deliverables.

Linkages will be made with the EDDMaps system and the U.S. NAS system.

Two years will be necessary to complete a study on website enhancement and interoperability. Ongoing financial and human resources will be required to ensure that the website is maintained and updated. The cost to develop the geospatial mapping is estimated at $160,000.

Cost Estimates for Project 30
Development of the Lake of the Woods Basin Geospatial Mapping Framework and Public Communication Tool

Major Tasks	Timeline	Estimated Costs
Identification of Base and Operational Layers	Year 1	$40,000
Algal Bloom Mapping: map georeferenced information from Project 8 and Project 11	Year 2	$30,000
AIS Mapping: develop automated system to pull data from national databases and system for local data uploading	Year 2	$20,000
Potential Contaminant Sources Mapping: map known information on potential contaminant sources and hydrogeology	Year 2	$30,000
Wild Rice Inventory Mapping: map wild rice locations	Year 1	$10,000
Review of current information on IRLWWB website and identification of public information needs	Year 1	$10,000
Structural changes to website and addition of communication tools	Year 1	$20,000
Total estimated costs		**$160,000**

Notes: First two years of activity are estimated here with majority of funding being dedicated to a GIS consultant; ongoing financial and human resources will be required to maintain/update website and mapping databases as new information becomes available.

Project 31
Understanding Indigenous Perspectives on Ecosystem Health

Objective

To develop an inventory of existing ecosystem health data collected by First Nation, Métis and Tribal communities in the Basin and host an Elder Gathering to better understand indigenous views of priority issues.

Description

The current conditions of the Basin have been described as they relate solely to the scientific data that have been collected by resource agencies, lake associations and local government organizations. This project aims to enhance the knowledge base of the Basin by developing an inventory of data and information being collected at First Nation, Tribe and Métis communities and organizations on the priority issues. Inclusion of these data with other information that will be collected as a result of Plan of Study projects or ongoing monitoring is important. In addition to this, this project will also support the enhancement of knowledge of this Basin through listening and learning from Elders.

Methodology

This project has two components. The first component is the inventory of data available through communities, Tribal Councils, Métis organizations, Tribes, Grand Council Treaty 3, federal organizations

and others to ensure ecosystem health data being collected are incorporated into the baseline knowledge for this Basin and that communities, in turn, are made aware of the scientific data and results to date being collected by others. Contact with communities and their representative councils and organizations will be done; the opportunity to include their work within the geospatial mapping project proposed will be discussed.

The existence of ecosystem data within communities is not widely known, with the exception of the Red Lake Band who monitors water quality regularly in the Northwest Angle, Rainy River First Nation through their Watershed Program, the 1854 Treaty Authority along with the Fond du Lac Tribe who conduct water testing and AIS monitoring and Seine River First Nation's contaminants study. There are examples of research and consultation elsewhere along the transboundary Lake Superior North Shore (Tobias and Richmond, 2014) but a comprehensive inventory for this Basin would be beneficial.

The second component of this project is based on listening and learning from aboriginal Elders regarding ecosystem health changes, bioindicators and ideas around environmental protection. It will involve the planning of an Elder Gathering and appropriate engagement with the Treaty 3 Women's Council and other similar groups in the U.S. and within the Métis community. In traditional culture, women are the "water-keepers" and it is their responsibility to protect it, therefore this is a key group to work with on this project. Both components will provide for a database of observations, records and narratives to assist with interpretation of Plan of Study results and findings. Intellectual property rights will be respected and will remain vested in the community of origin.

Study Organization, Costs and Scheduling

There are numerous communities and organizations that should be involved in the development and implementation of this project including First Nation communities in Treaty 3, Red Lake Band of Chippewa Indians, Bois Forte Band of Chippewa, Tribal Councils in basin, Fond du Lac Tribe, 1854 Treaty Authority, Grand Council Treaty 3, Métis Nation of Ontario and their local Councils, Health Canada and other federal, state and provincial agencies.

Each component of this project will take approximately four months to complete and could be done simultaneously.

Component 1 cost would be $17,000 and would involve extensive communication with all relevant parties, development of a database and report on ongoing data collection projects, methodologies, status of work and key contacts.

Component 2 cost would be $14,000 to host an Elder Gathering and would involve communication with key individuals to determine attendees and develop the format for the gathering as well as accommodate participants for travel expenses if need be.

Cost Estimates for Project 31
Understanding Indigenous Perspectives on Ecosystem Health

Major Tasks	Timeline	Estimated Costs
Development of database to inventory available ecosystem health data	Year 1	$5,000
Contact with communities and indigenous organizations to gather ecosystem health data	Year 1	$12,000
Development of Recording Tool for Elder Gathering	Year 1	$2,000
Hosting of an Elder Gathering (includes event planning, space rental, travel, opening ceremonies)	Year 1	$12,000
Total estimated costs		**$31,000**

Project 32
Funding Program for Non-governmental Organizations to Promote Watershed Protection

Objective

To establish a Lake of the Woods Basin Guardian Fund to provide funding to groups to carry out stewardship work in the Lake of the Woods Basin.

Description

Establishing such a Guardian Fund is needed given the paucity of funding opportunities available to non-governmental organizations and community groups in the Basin for stewardship work, especially on an international level. This project would review the components of other funding programs and inventory the needs of the Basin to determine the best type of program and its focus. The Great Lakes Guardian Community Fund, for example, has three goals: protect water quality for human and ecological health; improve wetlands, beaches and coastal areas; and, protect habitats and species. Goals such as these could be considered and adapted to best suit the needs of the Basin.

This Plan of Study recognizes the effectiveness of the efforts of lake associations, non-governmental organizations and citizen groups. However, it is critical that these groups have access to funds that will allow them to focus their efforts on stewardship, implementation of BMPs and activities that, collectively, will enhance watershed protection.

Methodology

A committee will be established to review current funding programs and identify gaps and determine, through public consultation, the desired focus of such a program and provide rationale for such a fund. It will be important to link this project to the ongoing outcomes of the watershed assessments being done in

the Basin to identify key stressors and BMPs for watershed protection. In this way, the fund can target the true needs of the basin to promote stewardship that helps to mitigate impacts associated with the priority issues. Consideration should also be given to how funds are distributed and to whom (for example, criteria development, geographic scope for awarding of funds). Current stewardship funding programs such as the Lake Winnipeg Basin Initiative, Trillium Foundation, Bush Foundation, RBC Bluewater, and the Great Lakes Guardian Community Fund will be reviewed to help identify both gaps and opportunities in the Basin. It will be important to make funding accessible to groups of all sizes.

Study Organization, Costs and Scheduling

Key participants include lake associations, non-governmental organizations, the IRLWWB Community Advisory Group and Industry Advisory Group and the public.

This project could be started in the near future based on current knowledge of some of the key stressors in the Basin, known BMPs for both prevention and remediation and existing funding opportunities. However, the funding of more extensive or elaborate projects to reduce nutrients and contaminants would benefit from the findings of many of the Plan of Study projects first. It is recommended that this project be initiated as soon as possible with a focus on BMPs known to be effective, perhaps with a smaller amount of funding; as results come in from studies and the main water quality concerns are better understood and remediation efforts being considered, the fund could be given greater consideration with more funding available for a larger number of projects.

The preliminary budget estimate to review existing programs and conduct consultation with appropriate organizations and the public is $23,000 over one year.

Cost Estimates for Project 32
Funding Program for Non-governmental Organizations to Promote Watershed Protection

Major Tasks	Timeline	Estimated Costs
Review existing funding programs and develop basin needs given funding gaps	Year 1	$5,000
Develop Funding Program Rationale and Structure	Year 1	$5,000
Garner Public and Agency input on Rationale and Structure (includes travel, rental fees for meeting spaces, printing)	Year 1	$7,000
Report Preparation and Outreach (printing, communication)	Year 1	$6,000
Total estimated costs		**$23,000**

Notes: This project could be started immediately based on current information in the Basin; as Plan of Study projects are completed and new/additional BMPs are identified, revision of the program rationale may be required in future years; costs do not include the actual funding pot to which non-governmental organizations would apply nor ongoing costs to continue administering the funding.

4. Study Options and Recommendations

4.1 Summary

Over the past decade, the attention of governments, researchers, local residents and indigenous peoples has increasingly focused on the ecosystem health of the Lake of the Woods Basin and on the need for cooperative, binational action to address complex water quality challenges. These concerns have focused on three key ecosystem health issues:

- nutrient enrichment and harmful algal blooms (HABs);
- aquatic invasive species (AIS); and,
- surface and groundwater contamination, including heavy metals and other contaminants.

The Plan of Study presents a comprehensive and coordinated approach for addressing these water quality challenges in five key areas:

1. This Plan of Study calls for a major focus on strengthening **monitoring** across the Basin. High quality monitoring data will form the basis for improved understanding of ecosystem health through science initiatives and indigenous knowledge, inputs and/or movement of constituents of concern including nutrients and contaminants, and assessment of trends in water quality in response to changing management practices and other environmental changes.

2. Numerous large lakes within the Basin are impaired by **harmful algal blooms**, some of which produce algal toxins of concern for wildlife, and the health of humans and domestic animals. This Plan of Study recommends several projects designed to: better understand sources and movement of nutrients, in particular phosphorus, within the Basin; understand how other environmental factors conspire to produce HABs; understand conditions that lead to production of algal toxins; and, develop better communication tools for alerting the public of risks when blooms occur. This information will be critical to improved management of algal blooms and ultimately to reducing the severity and frequency of HABs and the risks associated with algal toxins.

3. **Aquatic invasive species** have the potential to permanently alter aquatic ecosystems, causing disruptions including nuisance to anglers, loss of high-value native species, reductions in game fish populations and costly degradation of water infrastructure. The projects recommended in this Plan of Study are designed to increase and coordinate ongoing prevention efforts and pursue control efforts in some cases where AIS have infested waters in the Basin. Concerted efforts on prevention and on early control and eradication of AIS, where possible, are essential to protecting the highly valued lakes and rivers in the Basin and the ecosystem services they provide. Studies are also proposed that will provide improved understanding of effects on fisheries, so that populations can be carefully managed.

4. Although the Basin is much less densely populated and less industrialized than other parts of North America, there are concerns over existing **contaminants** and over potential for new contamination

issues to arise through development of new mining and transport of petroleum. This Plan of Study recommends several projects designed to thoroughly assess contaminants within the Basin, including assessment of risks associated with existing contaminants and vulnerabilities to new contaminants. Such information is critical to improved management of contaminants, and improved communication of science-based information related to the potential for resource extraction and transport activities to contaminate lakes and rivers in the Basin.

5. This Plan of Study calls for several **capacity-building projects** designed to make information widely available geospatially, and develop information sources and mechanisms to build capacity in the Basin to understand, communicate and implement solutions. This will enable natural resource managers and the public to better understand conditions within the Basin and have input into the knowledge base, and will improve water quality and water resource management. There is also a focus on supporting binational water management through cooperation among institutions and agencies active in the Basin.

4.2 Study Options

The Plan of Study recognizes that a number of critical factors impose constraints on project funding and timing, reducing the feasibility that all of the proposed projects can proceed at the same time. These factors include: fiscal restraint by all governments; the time required to establish partnerships needed to move some projects forward; and, the linkages among a number of projects, whereby, for example, the data/findings of one project are needed before another can begin.

Therefore, the Plan of Study proposes for consideration two options for proceeding on a coordinated effort to address the major water quality challenges in the Basin. The projects proposed under each option are summarized in Table 2. The cost estimates indicated in the table cover only the four-year timeline of the Plan of Study.

4.2.1 Study Option A

Under Study Option A, 21 projects are funded for a total estimated cost of $5,980,000. These projects include:

- *core projects* that provide foundational data and knowledge improving understanding of water quality in the Basin; and,
- *opportunities for immediate action* by governments, working with appropriate partners, to address urgent water quality concerns in the Basin; on these initiatives, there is broad consensus among researchers and interested parties in the Basin that current levels of knowledge can support immediate action, without the need for further research and analysis (see below).

The Plan of Study considers these projects to be top priority in the Basin, for several reasons:

- they will contribute to improved understanding of the major challenges to the ecosystem health of the Basin through a more strategic, watershed-based approach to the collection and distribution of data;
- they do not require a high level of inter-agency planning and coordination, which could require additional time and resources; and,
- they will promote better communication of research and knowledge throughout the Basin – among agencies and the public – by building on ongoing initiatives that address local concerns.

However, Option A would allow for only a limited response to the Directive issued by the IJC to the Plan of Study Team. Important gaps would remain in all five of the challenge areas.

4.2.2 Study Option B

Under Study Option B, all 32 projects are funded at a total estimated cost of $8,398,000. This option addresses all of the objectives listed in the IJC Directive and supports:

- enhancing understanding of the impacts of climate change and hydrologic regulation on the priority issues in the Basin;
- providing tools for predicting algal blooms and assessing the risks from invasions of AIS;
- providing further refinement of the nutrient issue; and
- implementing additional capacity-building actions.

Table 2
Plan of Study Implementation Options:
"ongoing" identifies projects that require post Plan of Study support

Plan of Study Project	Priority Theme	Timeline	Study Options	
			A	B
1. International Monitoring Program for the Lake of the Woods Basin	Monitoring	4 years; ongoing	$1,020 K	$1,020 K
2. Mass-Balance Models for Phosphorus and Nitrogen in the Lake of the Woods Basin	Nutrient Enrichment and Harmful Algal Blooms	4 years; ongoing	$250 K	$250 K
3. Internal Loads and Hypoxia in Lake of the Woods	Nutrient Enrichment and Harmful Algal Blooms	4 years	$400 K	$400 K
4. Assessment of Iron Fluxes from Sediments on Cyanobacteria Bloom Formation in Lake of the Woods	Nutrient Enrichment and Harmful Algal Blooms	4 years	-	$250 K
5. Assessment of Nutrient Subsidies from Shorelines Due to Erosion from High Water Levels in Lakes and High Flows in Rivers	Nutrient Enrichment and Harmful Algal Blooms	3 years	$480 K	$480 K
6. Application of Water Quality Models at Watershed and Basin-wide Scales to Apportion Nutrient Sources	Nutrient Enrichment and Harmful Algal Blooms	4 years	$200 K	$200 K
7. Implementation of Nutrient Load-Reduction Strategies in Lake of the Woods Basin	Nutrient Enrichment and Harmful Algal Blooms	4 years; ongoing	$425 K	$425 K
8. Application of Satellite Imagery and Remote Sensing Tools to Map and Characterize Water Quality and Algal Blooms	Nutrient Enrichment and Harmful Algal Blooms	4 years	-	$285 K
9. Development of Predictive Models of Algal Blooms from Hydrological and Meteorological Processes	Nutrient Enrichment and Harmful Algal Blooms	4 years	-	$300 K

Plan of Study Project	Priority Theme	Timeline	Study Options	
			A	**B**
10. Influence of Altered Food-Web Structure on Production of Harmful Algal Blooms	Nutrient Enrichment and Harmful Algal Blooms	4 years	-	$300 K
11. Taxonomic Characterization of Algal Communities and Algal Toxins	Nutrient Enrichment and Harmful Algal Blooms	4 years	-	$425 K
12. Public Health and Animal Welfare Risks: State of Knowledge and the Need for Alerting Mechanisms	Nutrient Enrichment and Harmful Algal Blooms	1 year	$50 K	$50 K
13. Binational Aquatic Invasive Species Management Team and Prevention Strategy for the Lake of the Woods Basin	Aquatic Invasive Species	4 years; ongoing	$200 K	$200 K
14. Evaluation and Implementation of Options to Manage Recent Zebra Mussel Infestation in Headwaters Areas in Minnesota	Aquatic Invasive Species	2 years; ongoing	$500 K	$500 K
15. Ecological Impact of the Spiny Waterflea in Infested Boundary Lakes	Aquatic Invasive Species	4 years	$300 K	$300 K
16. Pilot Studies on Adaptive Control Measures for Hybrid Cattail and Rusty Crayfish in Infested Wild Rice Habitat	Aquatic Invasive Species	4-year pilot study; ongoing adaptive mgt	-	$300 K
17. Comprehensive Assessment of Potential Invasion Risks to and within the Lake of the Woods Basin	Aquatic Invasive Species	3 years	$300 K	$300 K
18. Water Quality Risk Assessment for Zebra Mussels and Quagga Mussels	Aquatic Invasive Species	2 years	$125 K	$125 K
19. Climate Risk Assessment for Aquatic Invasive Species	Aquatic Invasive Species	3 years	-	$185 K
20. Assessment of Binational Implementation of Water Quality Objectives for Sulfate, Copper, Nickel, and Mercury	Surface and Groundwater Contamination	4 years	$75 K	$75 K

Plan of Study Project	Priority Theme	Timeline	Study Options	
			A	**B**
21. Synthesis Report on Contaminants in Water, Aquatic Sediment, and Fish	Surface and Groundwater Contamination	4 years	$300 K	$300 K
22. Methylmercury Flux and Bioaccumulation in Large Border Lakes	Surface and Groundwater Contamination	4 years	$300 K	$300 K
23. Spatial Survey of Contaminants of Emerging Concern	Surface and Groundwater Contamination	4 years	-	$200 K
24. Vulnerability Assessment of Border Waters to Contamination from Mining	Surface and Groundwater Contamination	4 years	$600 K	$600 K
25. Vulnerability Assessment of Border Waters to Contamination from Rail and Pipeline Transport of Petroleum and other Chemicals	Surface and Groundwater Contamination	3 years	$200 K	$200 K
26. Mining Effects Science Workshop	Surface and Groundwater Contamination	4 years	$50 K	$50 K
27. International Platform for Implementation	Capacity Building	1 year	$14 K	$14 K
28. Review of Data Collection Programs and Monitoring in the Headwaters Regions of the Basin	Capacity Building	1 year	-	$50 K
29. Application of Regional Climate Models for the Basin and Improved Public Education and Engagement on the Issue of Climate Change	Capacity Building	2 year	-	$100 K
30. Development of the Lake of the Woods Basin Geospatial Mapping Framework and Public Communication Tool	Capacity Building	2 years; ongoing	$160 K	$160 K

Plan of Study Project	Priority Theme	Timeline	Study Options	
			A	**B**
31. Indigenous Perspectives on Ecosystem Health	Capacity Building	1 year	$31 K	$31 K
32. Funding Program for Non-governmental Organizations to Promote Watershed Protection	Capacity Building	1 year	-	$23 K
Total Costs of Study Options			**$5.980 M**	**$8.398 M**

4.3 Recommendations for Immediate Action

The Study Team identified four projects or activities that are in need of immediate attention, either because they are a critical component of determining ecosystem health in the Basin, are crucial to the successful implementation of the Plan of Study and future binational management opportunities or because they address a significant, immediate risk to the ecosystem health of the Basin and cannot wait for Plan of Study approval. These are:

- *Project 27: International Platform for Implementation.* This project is crucial to the successful implementation of the Plan of Study and future binational management opportunities.

- *Project 14: Rapid Evaluation and Implementation of Options to Manage Recent Zebra Mussel Infestation in Headwaters Areas in Minnesota.* Zebra mussels pose a significant, immediate risk to the ecosystem health of the Basin.

- *Component of Project 1 - Long-term Funding of Wheeler's Point Gage and Designation as a Gage of Binational Significance*. This is a critical component for determining ecosystem health in the Basin.

- *Components of Projects 5 and 7: Implementation of Proven BMPs and Removal of Solids from Effluent.* Where BMPs have been identified as effective at reducing nutrient loads from agricultural lands, they should be implemented immediately. Effluent from sewage and wastewater treatment facilities is an important source of nutrients that can impact lakes and rivers. An immediate action to reduce nutrients would be to enhance the capacity of treatment facilities to reduce solids.

4.4 Additional Observations

Throughout the course of developing this Plan of Study, the Team has listened carefully to the public, resource agencies, indigenous communities, the IRLWWB and its Community Advisory Group and Industry Advisory Group. The team has heard a wide variety of concerns and ideas regarding water quality in the Basin – how it is under threat today and how it could be better managed in the future.

Many of the proposed projects in this Plan of Study deal directly with a number of these concerns. However, the Team recognizes that there are important issues affecting this Basin and its future ecosystem health that may not be adequately captured within the context of a recommended project in this Plan of Study. The Team feels compelled to bring these issues to the attention of the IJC and Governments for their consideration, as they affect the success of future, coordinated management of the Basin's important water resources.

1. Water Level Regulation on Lake of the Woods

The IJC, in its 2012 Report on the Binational Water Management of the Lake of the Woods and Rainy River Watershed, recommended a water levels study for Lake of the Woods. The governments responded to that recommendation by indicating their preference to have water quality (and levels to the extent it impacts water quality) considered first, as this was the priority.

This issue was raised once again at the public meetings for the Plan of Study, when numerous individuals expressed concern for the current water level regulation regime on Lake of the Woods, especially in light of the high water levels this past summer. The additional complications of ongoing post-glacial isostatic rebound (the north end of the lake is rebounding at a faster rate than the south end), climate change (increased frequency of large rainfall events), and seiches (wind-driven lake-level oscillations) conspire to exacerbate water level damages in the southern portion of Lake of the Woods, and should be considered in any review of current water regulation regimes. These comments and concerns echo those heard in 2010-2011 by the Task Force when it was also heard from some members of First Nations that a water level study could provide insight into issues around the impacts of regulation on wild rice production, the health of the fisheries, and flooding of First Nations lands. Grand Council Treaty 3's submission at the time directly called for an examination of water levels, not just on Lake of the Woods, but on Rainy Lake, Namakan Lake and Lac Seul as well.

2. Capacity of Indigenous Communities to Participate in Water Quality Management Initiatives

It was made clear in the Team's discussions, and was also pointed out by the Task Force in 2011, that the capacity for indigenous communities to participate in water quality sampling and/or management initiatives and to provide meaningful input into proposals and projects is limited. Many communities do not have the expertise or resources to establish water quality monitoring programs or to participate in the partnership initiatives that have sprung up throughout the Basin over the past few years.

While efforts are being made at the local level to engage citizens, collaborate on research, collect known data for better knowledge of the Basin and enhance communication, these initiatives must include all partners. There are excellent examples within the Métis organizational structure, the Red Lake Band (it has its own Department of Natural Resources) and a number of Canadian First Nation communities where there are well established programs and personnel dedicated to water quality monitoring/management. But these are not the norm throughout the Basin. Of note, as well, is that the IMA currently only has membership from the Red Lake Band.

Governments should implement actions to enable indigenous communities to build technical capacity in natural resource fields. Along with increased technical capacity, there is a need for viable career opportunities for indigenous members both within their communities and within state, provincial, and federal agencies that work in the Lake of the Woods Basin. Ongoing programs meant to build this technical capacity should be examined for their effectiveness, and where appropriate, greater efforts should be made to engage the communities in the process.

3. Concern in Basin regarding Potential Mining Impacts

Many individuals expressed concerns regarding the potential impacts of future mining operations and of historical mines on water quality in the Basin. The Study Team is aware of the letters sent to both the IRLWWB and the IJC requesting an examination and reporting on water related impacts from sulphide mining exploration and development. It is also aware of the Community Advisory Group's request to the IRLWWB that the Board and/or the IJC ask for a comprehensive EIS regarding mining on public lands, prior to additional permitting.

The Team heard of concerns over the integrity of the old Steep Rock Mine near Atikokan and the future potential for leakage or overflow as the old pits fill up with water. It also heard concerns that the New Gold Mine near Rainy River, ON is very close to Lake of the Woods (50 km east of the lake and 25 km north of the Rainy River); similarly it is approximately 48 km by water from the proposed Twin Metals mine to Pipestone Bay on Basswood Lake . Questions arose as to whether there is adequate mitigation in place should an accident occur. The water quality impacts of sulphide mining in the headwaters regions of the Basin are a significant concern to many with whom the Team spoke during the course of developing the Plan of Study. Many written submissions and verbal presentations heard emphasized their strong desire to have sulphide mining prevented in the Basin, citing a history of water contamination from this type of mining and the need to prevent water quality deterioration, especially in already protected boundary waters. The Team is also aware that there is a growing amount of interest in mining on both sides of the border and that there is currently no mechanism to assess the potential cumulative effects of new mines doing exploration and production on either side of the border at the same time.

There is also recognition that a considerable portion of the shared waters in the Basin are located within the Boundary Waters Canoe Area Wilderness (BWCAW), an area that has been given the designation of "Outstanding Resource Value Waters" (ORVW). Under this designation, the BWCAW (and Voyageurs National Park, as well) fall within the category of "prohibited discharge", meaning any potential discharges to waters that flow into ORVW waters need to be controlled to assure no deterioration of ORVWs. The appropriate controls are intended to be determined in the permitting process, however the

inclusivity of all permitted facilities in the application of non-degradation regulations is unknown. In addition, the process whereby degradation is determined may not be sufficient for the more complex hydrological systems in the Basin.

The Plan of Study Team believes that the issue of mining in the Basin is a divisive and emotional one, and that it requires greater collective attention at the international level. It is the Team's intention to provide the needed information within the context of this Plan of Study to determine the potential risks associated with the increased potential for mining in the boundary waters area. However, the much-needed long-term, binational strategy for balancing mining activities with watershed protection is beyond the scope of the Plan of Study.

4. Interaction between the Rainy-Lake of the Woods Watershed Board and its Counterparts in Neighboring Watersheds

Though the Plan of Study is focused on water quality issues in the Lake of the Woods Basin, many comments were received by the Study Team regarding how neighboring watersheds are addressing their water quality issues and what mechanisms are in place to facilitate exchange of information and expertise.

To the west, the International Red River Board is currently involved in the development of a nutrient management strategy for the Red River basin and Red River loads to Lake Winnipeg. Given that the Winnipeg River, flowing out of Lake of the Woods, is a significant tributary to Lake Winnipeg nutrient loads, the determination of nutrient targets and nutrient reduction strategies should be coordinated. If the Rainy-Lake of the Woods Watershed Board is going to be determining the need for water quality objectives for the Basin, the Plan of Study Team feels it is important that these two boards communicate on the progress they are making and discuss research and modeling being done to ensure objectives are compatible given the goals of the two Boards.

During the summer of 2014, many comments were made about the spread of zebra mussels. As noted in the Plan of Study, zebra mussels were identified in several headwater lakes of the Rainy River. They were also found in several locations in Lake Winnipeg. The province of Manitoba carried out an eradication program by applying liquid potash to infested shoreline reaches and embayments. The sentiment from the public and people involved with the development of the Plan of Study was that opportunities for exchanges of "lessons learned" when it comes to the prevention and control of zebra mussels would be valuable.

To the east, Lake Superior and its watershed fall under the Great Lakes Water Quality Agreement. Comments were heard about the lack of consistency in mechanisms that promote binational water quality management along the border and the implications of identifying a threat to water quality from one Basin to another. The ability to respond to a threat binationally in the Lake Superior Basin, for example, is much different than in the Lake of the Woods Basin because of the mechanism in place via the Agreement. There was a voiced desire for coordinated responses to water quality issues across basins along the border.

5. Assessment of Human Exposure and Possible Health Effects Related to Methylmercury Exposure through Fish Consumption

Some Basin residents are concerned about exposures and possible health effects related to methylmercury exposure through consumption of fish. The Plan of Study Team believes that human exposure and effects assessments were beyond the scope of its directive. However, these concerns are related to widespread water quality impairment and are important for Governments to consider. This observation should be passed along to the IJC's Health Professionals Advisory Board for consideration

6. Full Support for National AIS Tracking Systems

Effective management of aquatic invasive species (AIS) requires effective, fully supported systems to track the occurrence of AIS. Because many AIS tend to expand geographic range over time, crossing basin and political boundaries, this tracking is done most efficiently at the national scale. Both the U.S. and Canada have systems in place (NAS in the U.S.; EDDMaps in Canada—see Project 30). The portion of the NAS system for aquatic invasive plant species has been taken offline due to lack of sufficient support; fully supporting this system would benefit the Lake of the Woods Basin and other transboundary basins where invasive plant species exist, such as invasive hybrid cattail and phragmites. Although beyond the scope of the Lake of the Woods Plan of Study, the IJC should consider support of fully functional NAS and EDDMaps systems in both the U.S. and Canada as a high priority that would help meet critical information needs of numerous transboundary basins

4.5 Looking Ahead

Effective management of water quality issues and their complex interactions with environmental, climatic, and human influences requires high quality information gleaned from monitoring, research, modeling, analysis, and public consultation. Furthermore, it requires an adaptive management framework where problems are addressed with the best information available and evaluated using sound science, and where approaches are adapted as new information is learned. Finally, it requires the will and the commitment of governments to dedicate the necessary short and long-term funding and resources to share the responsibilities of managing water quality together across the border and to provide opportunities for public participation.

The projects and activities proposed in this Plan of Study address clear objectives and direct the studies and analyses towards articulated outcomes. These outcomes will be the basis of future development of strategies in the Basin to manage nutrients, prevent/control AIS, and address possible surface and groundwater contamination. Together, these strategies will provide a solid foundation for the future management of shared Basin waters.

References

Anderson, J., Baratono, N., Heiskary, S., and Wilson, B., 2013, Updated Total Phosphorus Budget for Lake of the Woods, in Proceedings of the 2013 International Lake of the Woods Water Quality Forum, International Falls, MN, U.S., Lake of the Woods Water Sustainability Foundation.

Barber, L.B., Writer, J.H., Keefe, S.H., Brown, G.K., Ferrey, M.L., Jahns, N.D., Kiesling, R.L., Lundy, J.R., Poganski, B.H., Rosenberry, D.O., Taylor, H.E., Woodruff, O.P., and Schoenfuss, H.L., 2012, Endocrine disrupting chemicals in Minnesota lakes—Water-quality and hydrological data from 2008 and 2010 U.S. Geological Survey Open-File Report 2012–1124, 53 p. http://pubs.usgs.gov/of/2012/1124/

Barbiero, R.P., and Tuchman, M.L., 2004, Changes in the crustacean communities of Lakes Michigan, Huron, and Erie following the invasion of the predatory cladoceran *Bythotrephes longimanus*: Canadian Journal of Fisheries and Aquatic Sciences, v. 61, no. 11, p. 2111-2125.

Binding, C.E., Greenberg, T.A., and Bukata, R.P., 2011a, Time series analysis of algal blooms in Lake of the Woods using the MERIS maximum chlorophyll index: Journal of Plankton Research, v. 33, no. 12, p. 1847-1852.

Binding, C.E., Greenberg, T.A., Jerome, J.H., Bukata, R.P., and Letourneau, G., 2011b, An assessment of MERIS algal products during an intense bloom in Lake of the Woods: Journal of Plankton Research, v. 33, no. 5, p. 793-806.

Bodaly, R.A., St. Louis, V.L., Paterson, M.J., Fudge, R.J.P., Hall, B.D., Rosenberg, D.M., and Rudd, J.W.M., 1997, Bioaccumulation of mercury in the aquatic food chain in newly flooded areas, *in* Sigel, A., and Sigel, H., eds., Metal ions in biological systems: New York, Marcel Decker, Inc., p. 259-287.

Boudreau, S.A., and Yan, N.D., 2003, The differing crustacean zooplankton communities of Canadian Shield lakes with and without the nonindigenous zooplanktivore Bythotrephes longimanus: Canadian Journal of Fisheries and Aquatic Sciences, v. 60, no. 11, p. 1307-1313.

Bradley, P.M., Journey, C.A., Brigham, M.E., Burns, D.A., Button, D.T., and Riva-Murray, K., 2013, Intra- and inter-basin mercury comparisons--importance of basin scale and time-weighted methylmercury estimates: Environmental Pollution, v. 172, p. 42-52.

Brezonik, P.L., Olmanson, L.G., Finlay, J.C., and Bauer, M.E., 2014, Factors affecting the measurement of CDOM by remote sensing of optically complex inland waters: Remote Sensing of Environment, no. 0.

Brigham, M.E., Sandheinrich, M.B., Gay, D.A., Maki, R.P., Krabbenhoft, D.P., and Wiener, J.G., 2014, Lacustrine responses to decreasing wet mercury deposition rates—results from a case study in northern Minnesota: Environmental Science & Technology, v. 48, no. 11, p. 6115-6123.

British Columbia Ministry of Environment, 2000, Water quality—ambient water quality guidelines for sulphate, http://www.env.gov.bc.ca/wat/wq/BCguidelines/sulphate/sulphate.html, 1 September 2014.

Brodin, T., Fick, J., Jonsson, M., and Klaminder, J., 2013, Dilute Concentrations of a Psychiatric Drug Alter Behavior of Fish from Natural Populations: Science, v. 339, no. 6121, p. 814-815.

Caraco, N.F., Cole, J.J., and Likens, G.E., 1989, Evidence for sulphate-controlled phosphorus release from sediments of aquatic systems: Nature, v. 341, no. 6240, p. 316-318.

Carpenter, S.R., and Kitchell, J.F., 1996, The Trophic Cascade in Lakes: Cambridge Studies in Ecology, Cambridge University Press, Boston, MA, 400 p.

Chasar, L.C., Scudder, B.C., Stewart, A.R., Bell, A.H., and Aiken, G.R., 2009, Mercury cycling in stream ecosystems. 3. Trophic dynamics and methylmercury bioaccumulation: Environmental Science and Technology, v. 43, no. 8, p. 2733–2739.

Chen, J., Zhang, D., Xie, P., Wang, Q., and Ma, Z., 2009, Simultaneous determination of microcystin contaminations in various vertebrates (fish, turtle, duck and water bird) from a large eutrophic Chinese lake, Lake Taihu, with toxic Microcystis blooms: Science of the Total Environment, v. 407, no. 10, p. 3317-3322.

Clark, B.J., and Sellers, T.J., 2014, Rainy-Lake of the Woods State of the Basin Report, 2nd Edition: Lake of the Woods Water Sustainability Foundation http://www.lowwsf.com/component/docman/doc_download/35-complete-rainy-lake-of-the-woods-state-of-the-basin-report-second-edition-2014.html

Claudi, R., and Prescott, K., 2011, Examination of calcium and pH as predictors of dreissenid mussel survival in the California State Water Project RNT Consulting, 74 p. http://www.water.ca.gov/environmentalservices/docs/Claudi_Prescott_2011_Examination_of_Calcium_pH_as_Predictors_of_Dreissenid_Mussel_Survival_in_the_CA_SWP.pdf

Coleman Wasik, J.K., Mitchell, C.P.J., Engstrom, D.R., Swain, E.B., Monson, B.A., Balogh, S.J., Jeremiason, J.D., Branfireun, B.A., Eggert, S.L., Kolka, R.K., and Almendinger, J.E., 2012, Methylmercury declines in a boreal peatland when experimental sulfate deposition decreases: Environmental Science & Technology, v. 46, no. 12, p. 6663-6671.

Donahue, M.J., 2012, Binational AIS rapid response plan for the Great Lakes-St. Lawrence River Basin—A pilot plan for the Lake Huron/ Lake Erie corridor: International Joint Commission, 32+appendices p. http://www.ijc.org/files/publications/2013-AIS-RResponse-PilotPlan-FinalReport-GLRI.pdf

Downing, J.A., Watson, S.B., and McCauley, E., 2001, Predicting cyanobacteria dominance in lakes: Canadian Journal of Fisheries and Aquatic Sciences, v. 58, no. 10, p. 1905-1908.

Edlund, M.B., Reavie, E.D., Schottler, S., Hougardy, D., Wattrus, N., Baratono, N., Paterson, A.M., and Engstrom, D.R., 2014, Reconstructing a historical phosphorus budget for Lake of the Woods: Biogeochemical and diatom records in the southern basin, in Proceedings of the 2014 International Lake of the Woods Water Quality Forum, International Falls, Minnesota.

Environment Canada, 2011, Technical guidance document for Water Quality Indicator practitioners reporting under the Canadian Environmental Sustainability Indicators (CESI) initiative 2008 http://publications.gc.ca/site/eng/381540/publication.html

Ferrey, M., Schoenfuss, H.L., Poganski, B.H., Jahns, N.D., Martinovic, D., Barber, L.B., Writer, J.H., Keefe, S.K., Brown, G.K., Taylor, H.E., Woodruff, O.P., Rosenberry, D.O., Kiesling, R.L., and Lundy, J.R., 2012, Endocrine active compound monitoring in Minnesota lakes, 2009-2011—Lake habitat and land use Minnesota Pollution Control Agency, Legislative Report tdr-g1-08b, 11 p. http://www.pca.state.mn.us/index.php/view-document.html?gid=17685

Gilmour, C.C., Henry, E.A., and Mitchell, R., 1992, Sulfate stimulation of mercury methylation in freshwater sediments: Environmental Science and Technology, v. 26, no. 11, p. 2281-2287.

Government of Canada, 2013, Properties, composition and marine spill behaviour, fate and transport of two diluted bitumen products from the Canadian oil sands, 85 p. http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=D6AB8B67-73F5-48B6-B3D1-AAE1B06FF9A2

Great Lakes Chemicals of Emerging Concern Advisory Work Group to the International Joint Commission (IJC), 2009, Work Group Report on Great Lakes Chemicals of Emerging Concern: IJC Special Publication 2009-01

Hargan, K.E., Paterson, A.M., and Dillon, P.J., 2011, A total phosphorus budget for the Lake of the Woods and the Rainy River catchment: Journal of Great Lakes Research, v. 37, no. 4, p. 753-763.

Harris, R.C., Rudd, J.W.M., Amyot, M., Babiarz, C.L., Beaty, K.G., Blanchfield, P.J., Bodaly, R.A., Branfireun, B.A., Gilmour, C.C., Graydon, J.A., Heyes, A., Hintelmann, H., Hurley, J.P., Kelly, C.A., Krabbenhoft, D.P., Lindberg, S.E., Mason, R.P., Paterson, M.J., Podemski, C.L., Robinson, A., Sandilands, K.A., Southworth, G.R., St. Louis, V.L., and Tate, M.T., 2007, Whole-ecosystem study

shows rapid fish-mercury response to changes in mercury deposition: Proceedings of the National Academy of Sciences, USA, v. 104, no. 42, p. 16586-16591.

Hecky, R.E., Smith, R.E., Barton, D.R., Guildford, S.J., Taylor, W.D., Charlton, M.N., and Howell, T., 2004, The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes: Canadian Journal of Fisheries and Aquatic Sciences, v. 61, no. 7, p. 1285-1293.

Hobmeier, M.M., Hirsch, J.K., Kerfoot, W.C., Yousef, F., LeDuc, J.F., and Maki, R.P., 2013, Spiny Water Flea (Bythotrephes longimanus) Impacts on Zooplankton Communities of Voyageurs National Park, in Lake of the Woods 10th Annual International Water Quality Forum.

International Joint Commission, 2014, A Balanced Diet for Lake Erie—reducing phosphorus loadings and harmful algal blooms Report of the Lake Erie Ecosystem Priority, 96 p. available for download from: http://www.ijc.org/en_/leep/report

IPCC, 2013, Summary for Policymakers., *in* Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P.M., eds., Climate Change 2013—The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press, p. 3-29.

Jacques, J.M.S., Douglas, M.S.V., Price, N., Drakulic, N., and Gubala, C.P., 2005, The Effect of Fish Introductions on the Diatom and Cladoceran Communities of Lake Opeongo, Ontario, Canada: Hydrobiologia, v. 549, no. 1, p. 99-113.

Jeremiason, J.D., Engstrom, D.R., Swain, E.B., Nater, E.A., Johnson, B.M., Almendinger, J.E., Monson, B.A., and Kolka, R.K., 2006, Sulfate addition increases methylmercury production in an experimental wetland: Environmental Science and Technology, v. 40, no. 12, p. 3800-3806.

Kelly, E.N., Schindler, D.W., St. Louis, V.L., Donald, D.B., and Vladicka, K.E., 2006, Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs: Proceedings of the National Academy of Sciences, USA, v. 103, no. 51, p. 19380-19385.

Kerfoot, W.C., Yousef, F., Hobmeier, M., Maki, R., Jarnagin, S.T., and Churchill, J., 2011, Temperature, recreational fishing and diapause egg connections: dispersal of spiny water fleas (Bythotrephes longimanus): Biological Invasions, v. 13, no. 11, p. 2513-2531.

Kotak, B.G., and Zurawell, R.W., 2007, Cyanobacterial toxins in Canadian freshwaters: A review: Lake and Reservoir Management, v. 23, no. 2, p. 109-122.

Lake Superior Binational Program, 2014, Lake Superior aquatic invasive species complete prevention plan, 71+appendices p. http://www.epa.gov/greatlakes/lakesuperior/lake-superior-ais-prevention-plan-201401.pdf

Lamers, L.P.M., Govers, L.L., Janssen, I.C., Geurts, J.J., Van der Welle, M.E., Van Katwijk, M.M., Van der Heide, T., Roelofs, J.G., and Smolders, A.J., 2013, Sulfide as a soil phytotoxin—a review: Frontiers in Plant Science, v. 4.

Larson, J., Maki, R., Knights, B., and Gray, B., 2014, Can mercury in fish be reduced by water level management? Evaluating the effects of water level fluctuation on mercury accumulation in yellow perch (Perca flavescens): Ecotoxicology, p. 1-9.

LeDuc, J.F., 2012, Predator-prey: Interactions between the spiny waterflea (*Bythotrephes longimanus*) and pumpkinseed sunfish (*Lepomis gibbosus*), Michigan Technological University, 74 p.

Lee, K.E., Barber, L.B., Cahill, J.D., E.T., F., Kolpin, D.W., Meyer, M.T., and Zaugg, S.D., 2004, Presence and distribution of organic wastewater compounds in wastewater, surface, ground, and drinking waters, Minnesota, 2000-02. U.S. Geological Survey Scientific-Investigations Report 2004-5138 http://water.usgs.gov/pubs/sir/2004/5138/

Lee, K.E., Langer, S.K., Barber, L.B., Writer, J.H., Ferrey, M.L., Schoenfuss, H.L., Furlong, E.T., Foreman, W.T., Gray, J.L., ReVello, R.C., Martinovic, D., Woodruff, O.P., Keefe, S.H., Brown, G.K., Taylor,

H.E., Ferrer, I., and Thurman, E.M., 2011, Endocrine active chemicals, pharmaceuticals, and other chemicals of concern in surface water, wastewater-treatment plant effluent, and bed sediment, and biological characteristics in selected streams, Minnesota-design, methods, and data, 2009 U.S. Geological Survey Data Series 575, 54 + appendices p. http://pubs.usgs.gov/ds/575/

Lepak, J., Robinson, J., Kraft, C., and Josephson, D., 2009, Changes in mercury bioaccumulation in an apex predator in response to removal of an introduced competitor: Ecotoxicology, v. 18, no. 5, p. 488-498.

Lueck, A., Anderson, J., Kennedy, M., Baratono, N., Christopherson, D., Duffey, D., Grayson, S., Jasperson, J., Lundeen, B., Monson, B., Nelson, S., Parson, K., and Streitz., A., 2013, Big Fork River Watershed Monitoring and Assessment Report: Minnesota Pollution Control Agency, wq-ws3-09030006b, 139 p. http://www.pca.state.mn.us/index.php/view-document.html?gid=20347

Mackie, G.L., and Claudi, R., 2010, Monitoring and Control of Macrofouling Mollusks in Fresh Water Systems, Second Edition CRC Press, Boca Ratan, FL, 550 p.

Mast, M.A., and Turk, J.T., 1999, Environmental characteristics and water quality of Hydrologic Benchmark Network stations in the Midwestern United States, 1963-95 U.S. Geological Survey Circular 1173-B, 130 p.

McCullough, G.K., Page, S.J., Hesslein, R.H., Stainton, M.P., Kling, H.J., Salki, A.G., and Barber, D.G., 2012, Hydrological forcing of a recent trophic surge in Lake Winnipeg: Journal of Great Lakes Research, v. 38, Supplement 3, no. 0, p. 95-105.

McKenney, D.W., Hutchinson, M.F., Papadopol, P., Lawrence, K., Pedlar, J., Campbell, K., Milewska, E., Hopkinson, R.F., Price, D., and Owen, T., 2011, Customized Spatial Climate Models for North America: Bulletin of the American Meteorological Society, v. 92, no. 12, p. 1611-1622.

Michalak, A.M., Anderson, E.J., Beletsky, D., Boland, S., Bosch, N.S., Bridgeman, T.B., Chaffin, J.D., Cho, K., Confesor, R., Daloğlu, I., DePinto, J.V., Evans, M.A., Fahnenstiel, G.L., He, L., Ho, J.C., Jenkins, L., Johengen, T.H., Kuo, K.C., LaPorte, E., Liu, X., McWilliams, M.R., Moore, M.R., Posselt, D.J., Richards, R.P., Scavia, D., Steiner, A.L., Verhamme, E., Wright, D.M., and Zagorski, M.A., 2013, Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions: Proceedings of the National Academy of Sciences, v. 110, no. 16, p. 6448-6452.

Ministry of Natural Resources, 2011, Ontario Provincial Parks Statistics 2010: Ministry of Natural Resources,, 69 p. http://www.ontarioparks.com/pdf/statistics/2010_park_statistics.pdf

Minnesota Department of Natural Resources, 2014, Department of Natural Resources - Designation of Infested Waters - May 23, 2014, http://files.dnr.state.mn.us/eco/invasives/infested_waters.pdf, 26 June 2014.

Minnesota Pollution Control Agency, 2010, Pharmaceuticals and personal care products in Minnesota's Rivers and Streams—2010 http://www.pca.state.mn.us/index.php/view-document.html?gid=19426, April 4, 2014.

Minnesota Pollution Control Agency, 2014a, Analysis of the wild rice sulfate standard study—draft for scientific peer review wq-s6-42z, 91 p. http://www.pca.state.mn.us/index.php/view-document.html?gid=21244

Minnesota Pollution Control Agency, 2014b, Minnesota's sulfate standard to protect wild rice, http://www.pca.state.mn.us/index.php/water/water-permits-and-rules/water-rulemaking/minnesotas-sulfate-standard-to-protect-wild-rice.html,

Mohseni, O., Stefan, H.G., and Eaton, J.G., 2003, Global warming and potential changes in fish habitat in U.S. streams: Climatic Change, v. 59, p. 389-409.

Molot, L.A., Li, G., Findlay, D.L., and Watson, S.B., 2010, Iron-mediated suppression of bloom-forming cyanobacteria by oxine in a eutrophic lake: Freshwater Biology, v. 55, no. 5, p. 1102-1117.

Molot, L.A., Watson, S.B., Creed, I.F., Trick, C.G., McCabe, S.K., Verschoor, M.J., Sorichetti, R.J., Powe, C., Venkiteswaran, J.J., and Schiff, S.L., 2014, A novel model for cyanobacteria bloom formation: the critical role of anoxia and ferrous iron: Freshwater Biology, v. 59, no. 6, p. 1323-1340.

Monson, B., and Monson, P., 2010, Aquatic Life Water Quality Standards Technical Support Document for Copper Biotic Ligand Model Triennial Water Quality Standard Amendments to Minn. R. chs. 7050 and 7052--DRAFT For External Review, October 14, 2010 Minnesota Pollution Control Agency http://www.pca.state.mn.us/index.php/view-document.html?gid=14924, 2 October 2014.

Neary, B.P., and Leach, J.H., 1992, Mapping the Potential Spread of the Zebra Mussel (*Dreissena polymorpha*) in Ontario: Canadian Journal of Fisheries and Aquatic Sciences, v. 49, no. 2, p. 406-415.

Novotny, E.V., and Stefan, H.G., 2007, Stream flow in Minnesota—indicator of climate change: Journal of Hydrology, v. 334, p. 319-333.

Olmanson, L.G., Bauer, M.E., and Brezonik, P.L., 2008, A 20-year Landsat water clarity census of Minnesota's 10,000 lakes: Remote Sensing of Environment, v. 112, no. 11, p. 4086-4097.

Olmanson, L.G., Brezonik, P.L., and Bauer, M.E., 2011, Evaluation of medium to low resolution satellite imagery for regional lake water quality assessments: Water Resources Research, v. 47, no. 9, p. W09515.

Olmanson, L.G., Brezonik, P.L., and Bauer, M.E., 2013, Airborne hyperspectral remote sensing to assess spatial distribution of water quality characteristics in large rivers: The Mississippi River and its tributaries in Minnesota: Remote Sensing of Environment, v. 130, no. 0, p. 254-265.

Ontario Ministry of Environment, 2010, Lakeshore Capacity Assessment Handbook--Protecting Water Quality in Inland Lakes on Ontario's Precambrian Shield, PIBS 7642e, variously paged p. http://www.ontario.ca/environment-and-energy/lakeshore-capacity-assessment-handbook-protecting-water-quality-inland-lakes

Ontario Ministry of Environment and Energy, 1994, Povincial water quality objectives of the Minstry of Environment and Energy PIBS 3303E, 31 p. http://agrienvarchive.ca/download/water_qual_object94.pdf

Ontario Ministry of Natural Resources, 2012, Ontario invasive species strategic plan: Ontario Ministry of Natural Resources MNR 62788, 58 p. http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@biodiversity/documents/document/stdprod_097634.pdf

Orihel, Diane M., Bird, David F., Brylinsky, M., Chen, H., Donald, Derek B., Huang, Dorothy Y., Giani, A., Kinniburgh, D., Kling, H., Kotak, Brian G., Leavitt, Peter R., Nielsen, Charlene C., Reedyk, S., Rooney, Rebecca C., Watson, Sue B., Zurawell, Ron W., and Vinebrooke, Rolf D., 2012, High microcystin concentrations occur only at low nitrogen-to-phosphorus ratios in nutrient-rich Canadian lakes: Canadian Journal of Fisheries and Aquatic Sciences, v. 69, no. 9, p. 1457-1462.

Orihel, D.M., Paterson, M.J., Blanchfield, P.J., Bodaly, R.A., and Hintelmann, H., 2007, Experimental evidence of a linear relationship between inorganic mercury loading and methylmercury accumulation by aquatic biota: Environmental Science and Technology, v. 41, no. 14, p. 4952-4958.

Pascoe, T., McDaniel, T., Watson, S., Yerubandi, R., Binding, C., Zhang, W., and Greenberg, T.A., 2014, Environment Canada's Lake of the Woods Science Initiative 2008-2011: Environment Canada, Burlington, ON, 166 p.

Paterson, M.J., Bodaly, R.A., Hall, B.D., Majewski, A.R., Peech, K.A., Rolfhus, K.R., and St. Louis, V.L., 2003, Methylmercury in new reservoirs—the flooded uplands dynamics experiment, in American Society of Limnology and Oceanography Aquatic Sciences Meeting, Salt Lake City.

Pimentel, D., Zuniga, R., and Morrison, D., 2005, Update on the environmental and economic costs associated with alien-invasive species in the United States: Ecological Economics, v. 52, no. 3, p. 273-288.

Rennie, M., Strecker, A., and Palmer, M., 2011, Bythotrephes invasion elevates trophic position of zooplankton and fish: implications for contaminant biomagnification: Biological Invasions, v. 13, no. 11, p. 2621-2634.

Ricciardi, A., 2001, Facilitative interactions among aquatic invaders: is an "invasional meltdown" occurring in the Great Lakes?: Canadian Journal of Fisheries and Aquatic Sciences, v. 58, no. 12, p. 2513-2525.

Rosenberg, D.M., Turner, M.A., Jansen, W., Mosindy, T., and Watkinson, D.A., 2010, Threats to Lake of the Woods and the Winnipeg River by the rusty crayfish (*Orconectes rusticus*), an aquatic invader: Ontario Ministry of Natural Resources NWSI Technical Workshop Report TWR-005, 54 p. http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@letsfish/documents/report/stdprod_068102.pdf

Scavia, D., David Allan, J., Arend, K.K., Bartell, S., Beletsky, D., Bosch, N.S., Brandt, S.B., Briland, R.D., Daloğlu, I., DePinto, J.V., Dolan, D.M., Evans, M.A., Farmer, T.M., Goto, D., Han, H., Höök, T.O., Knight, R., Ludsin, S.A., Mason, D., Michalak, A.M., Peter Richards, R., Roberts, J.J., Rucinski, D.K., Rutherford, E., Schwab, D.J., Sesterhenn, T.M., Zhang, H., and Zhou, Y., 2014, Assessing and addressing the re-eutrophication of Lake Erie: Central basin hypoxia: Journal of Great Lakes Research, v. 40, no. 2, p. 226-246.

Schindler, D.W., 2012, The dilemma of controlling cultural eutrophication of lakes: Proceedings of the Royal Society B: Biological Sciences.

Sorensen, J.A., Kallemeyn, L.W., and Sydor, M., 2005, Relationship between mercury accumulation in young-of-the-year yellow perch and water-level fluctuations: Environmental Science and Technology, v. 39, no. 23, p. 9237-9243.

State of Minnesota, O.o.t.R.o.S., 2014, 7050.0222 SPECIFIC WATER QUALITY STANDARDS FOR CLASS 2 WATERS OF THE STATE; AQUATIC LIFE AND RECREATION., https://www.revisor.mn.gov/rules/?id=7050.0222, 2 October 2014.

Stefan, H.G., Fang, X., and Eaton, J.G., 2001, Simulated fish habitat changes in North American Lakes in response to projected climate warming: American Fisheries Society, v. 130, p. 459-477.

Stone, W.W., Gilliom, R.J., and Ryberg, K.R., 2014, Pesticides in U.S. Streams and Rivers: Occurrence and Trends during 1992–2011: Environmental Science & Technology.

Strecker, A.L., Arnott, S.E., Yan, N.D., and Girard, R., 2006, Variation in the response of crustacean zooplankton species richness and composition to the invasive predator Bythotrephes longimanus: Canadian Journal of Fisheries and Aquatic Sciences, v. 63, no. 9, p. 2126-2136.

Stumpf, R.P., Wynne, T.T., Baker, D.B., and Fahnenstiel, G.L., 2012, Interannual variability of cyanobacterial blooms in Lake Erie: PLoS ONE, v. 7, no. 8, p. e42444.

Therriault, T.W., Weise, A.M., Higgins, S.N., Guo, Y., and Duhaime, J., 2013, Risk assessment for three dreissenid dussels (*Dreissena polymorpha*, *Dreissena rostriformis bugensis*, and *Mytilopsis leucophaeata*) Department of Fisheries and Oceans - Canada, Science Advisory Section, 88 p. http://www.dfo-mpo.gc.ca/Csas-sccs/publications/resdocs-docrech/2012/2012_174-eng.pdf

Thompson, A.F., 2013, Rainy and Namakan Hydrologic Response Model Documentation: International Joint Commission Prepared for the Evaluation of the International Joint Commission 2000 Order for Rainy and Namakan Lakes and Rainy River, 31 p.

Tobias, J.K., and Richmond, C.A.M., 2014, "That land means everything to us as Anishinaabe….": Environmental dispossession and resilience on the North Shore of Lake Superior: Health & Place, v. 29, p. 26-33.

U.S. Environmental Protection Agency, 2007, Effects of climate change on aquatic invasive species and implications for management and research, External Review Draft EPA/600/R-07/084 http://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=468482

U.S. Geological Survey, 2014a, National Water Information System, sulfate data for Rainy River and Rainy Lake, northern Minnesota, retrieved on 19 September 2014, http://nwis.waterdata.usgs.gov/mn/nwis/qwdata?search_station_nm=rainy&search_station_nm_match_type=anywhere&multiple_parameter_cds=00945&param_cd_operator=AND&group_key=NONE&sitefile_output_format=html_table&column_name=agency_cd&column_name=site_no&column_name=station_nm&inventory_output=0&rdb_inventory_output=file&begin_date=1992-09-30&end_date=2014-09-01&TZoutput=0&pm_cd_va_search=00945&pm_cd_compare=Greater%20than&radio_parm_cds=previous_parm_cds&qw_attributes=0&format=rdb&qw_sample_wide=0&rdb_qw_attributes=0&date_format=YYYY-MM-DD&rdb_compression=value&list_of_search_criteria=search_station_nm%2Cmultiple_parameter_cds,

U.S. Geological Survey, 2014b, USGS water data for Minnesota — U.S. Geological Survey National Water Information System, http://nwis.waterdata.usgs.gov/mn/nwis.

Wentz, D.A., Brigham, M.E., Chasar, L.C., Lutz, M.A., and Krabbenhoft, D.P., 2014, The Quality of Our Nation's Waters: Mercury in the Nation's streams—levels, trends, and implications: U.S. Geological Survey Circular 1395 http://dx.doi.org/10.3133/cir1395

Wiener, J.G., Knights, B.C., Sandheinrich, M.B., Jeremiason, J.D., Brigham, M.E., Engstrom, D.R., Woodruff, L.G., Cannon, W.F., and Balogh, S.J., 2006, Mercury in soils, lakes, and fish in Voyageurs National Park (Minnesota)—importance of atmospheric deposition and ecosystem factors: Environmental Science and Technology, v. 40, no. 20, p. 6261-6268.

Wiener, J.G., Krabbenhoft, D.P., Heinz, G.H., and Scheuhammer, A.M., 2003, Ecotoxicology of mercury, Chapter 16, *in* Hoffman, D.J., B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr., ed., Handbook of Ecotoxicology, 2nd edition.: Boca Raton, Florida, CRC Press, p. 409-463.

Writer, J.H., Barber, L.B., Brown, G.K., Taylor, H.E., Kiesling, R.L., Ferrey, M.L., Jahns, N.D., Bartell, S.E., and Schoenfuss, H.L., 2010, Anthropogenic tracers, endocrine disrupting chemicals, and endocrine disruption in Minnesota lakes: Science of the Total Environment, v. 409, no. 1, p. 100-111.

Yan, N., Leung, B., Lewis, M., and Peacor, S., 2011, The spread, establishment and impacts of the spiny water flea, Bythotrephes longimanus, in temperate North America: a synopsis of the special issue: Biological Invasions, v. 13, no. 11, p. 2423-2432.

Yan, N.D., Blukacz, A., Sprules, W.G., Kindy, P.K., Hackett, D., Girard, R.E., and Clark, B.J., 2001, Changes in zooplankton and the phenology of the spiny water flea, Bythotrephes, following its invasion of Harp Lake, Ontario, Canada: Canadian Journal of Fisheries and Aquatic Sciences, v. 58, no. 12, p. 2341-2350.

Yan, N.D., Girard, R., and Boudreau, S., 2002, An introduced invertebrate predator (Bythotrephes) reduces zooplankton species richness: Ecology Letters, v. 5, no. 4, p. 481-485.

Zhang, W., Watson, S.B., Rao, Y.R., and Kling, H.J., 2013, A linked hydrodynamic, water quality and algal biomass model for a large, multi-basin lake: A working management tool: Ecological Modelling, v. 269, no. 0, p. 37-50.

Appendix A
Logic Models for the
Lake of the Woods Basin Water Quality Plan of Study

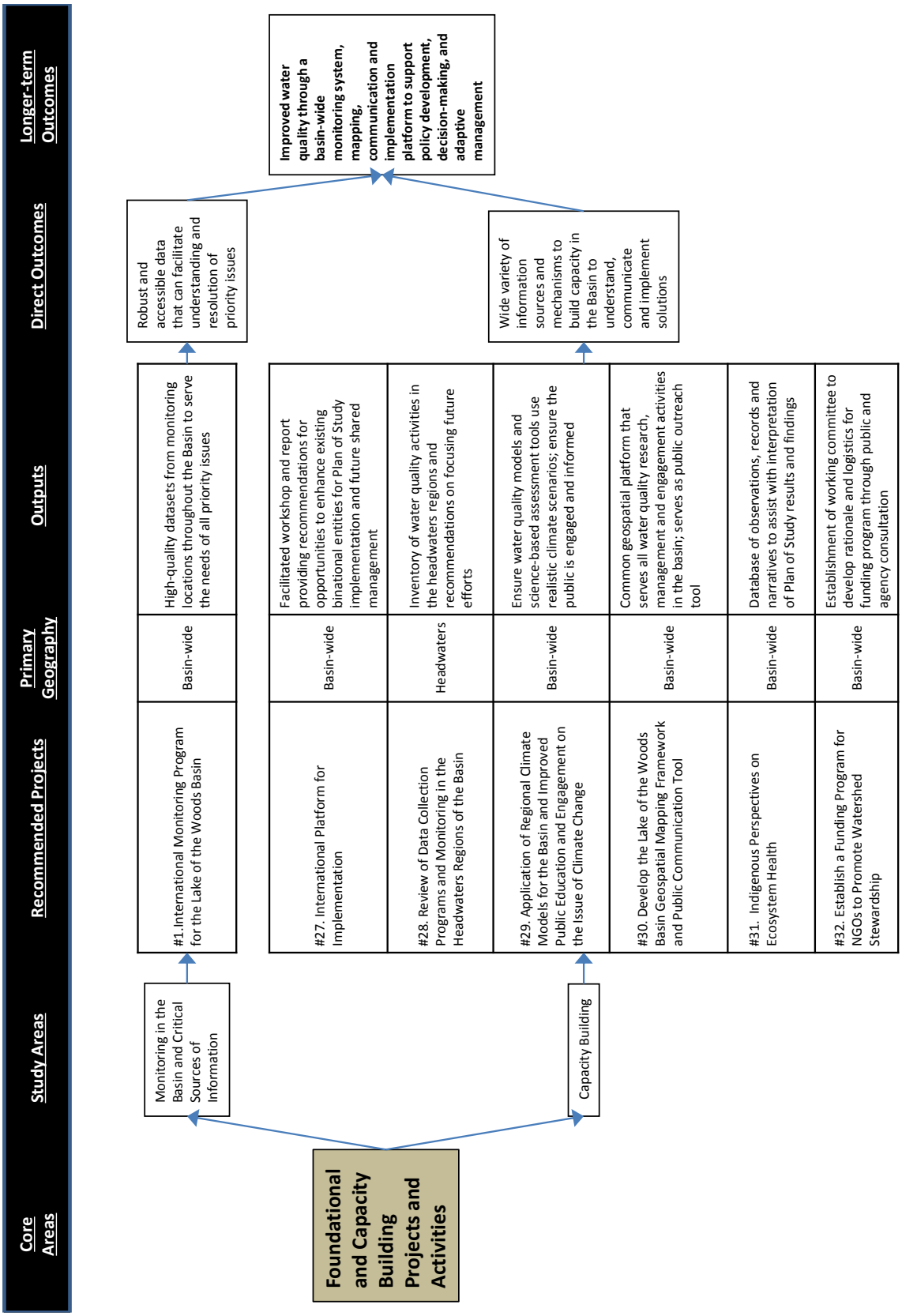
For the Plan of Study projects, a series of logic models were developed to graphically depict linkages between the priority issues and cross-cutting themes as defined in the Directive to the Study Team and overall end-goals expected as a result of support for the POS. Use of logic models assisted with organization of recommended projects and outputs, identification of short-term (direct) outcomes and longer-term outcomes, and visualization of how all the pieces fit together.

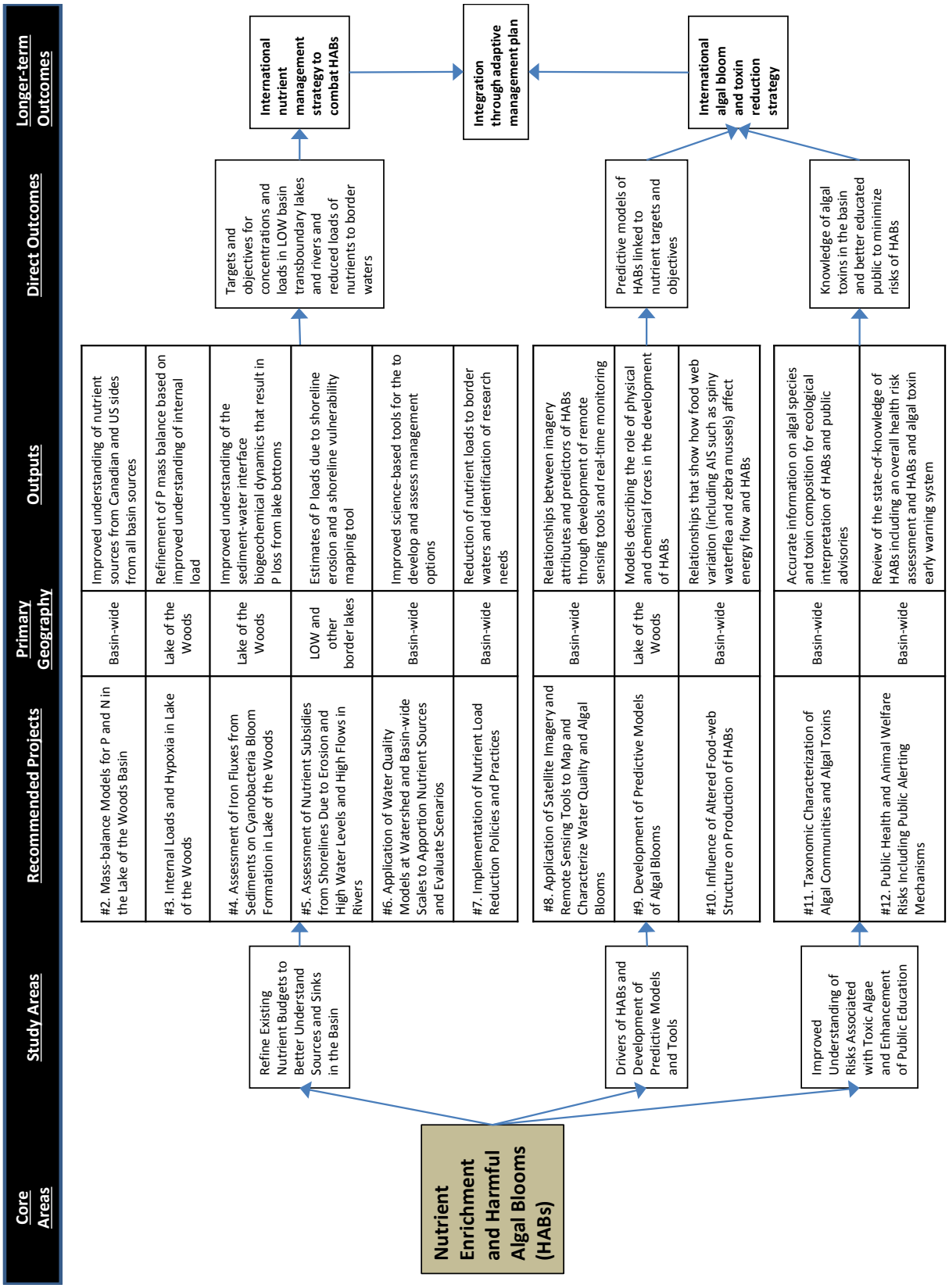
This Appendix has four logic models that match the groups of projects described in the Plan of Study:

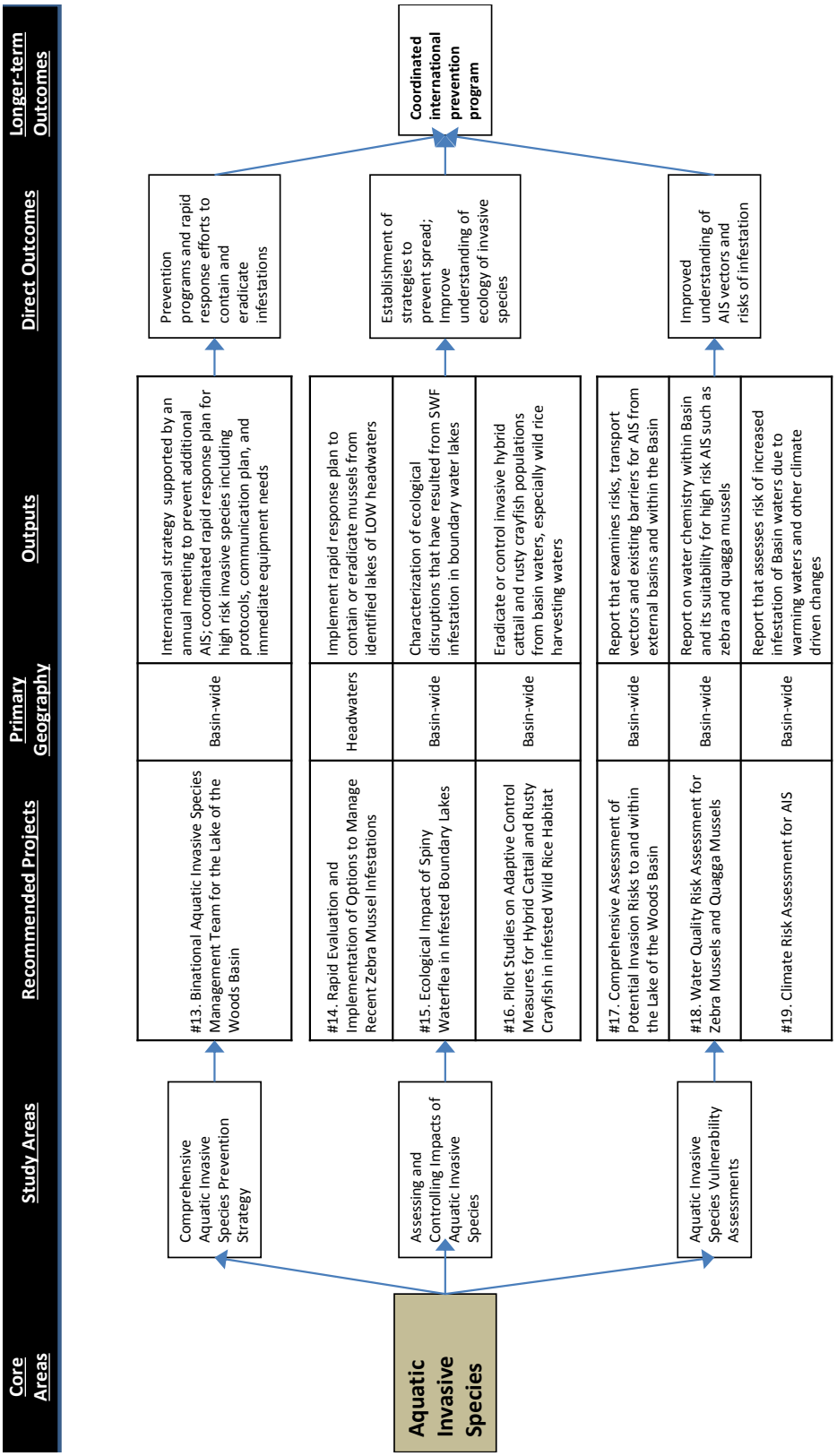
Foundational and Capacity Building Projects and Activities;
Nutrient Enrichment and Harmful Algal Blooms (NE-HABs);
Aquatic Invasive Species (AIS); and,
Surface and Groundwater Contamination.

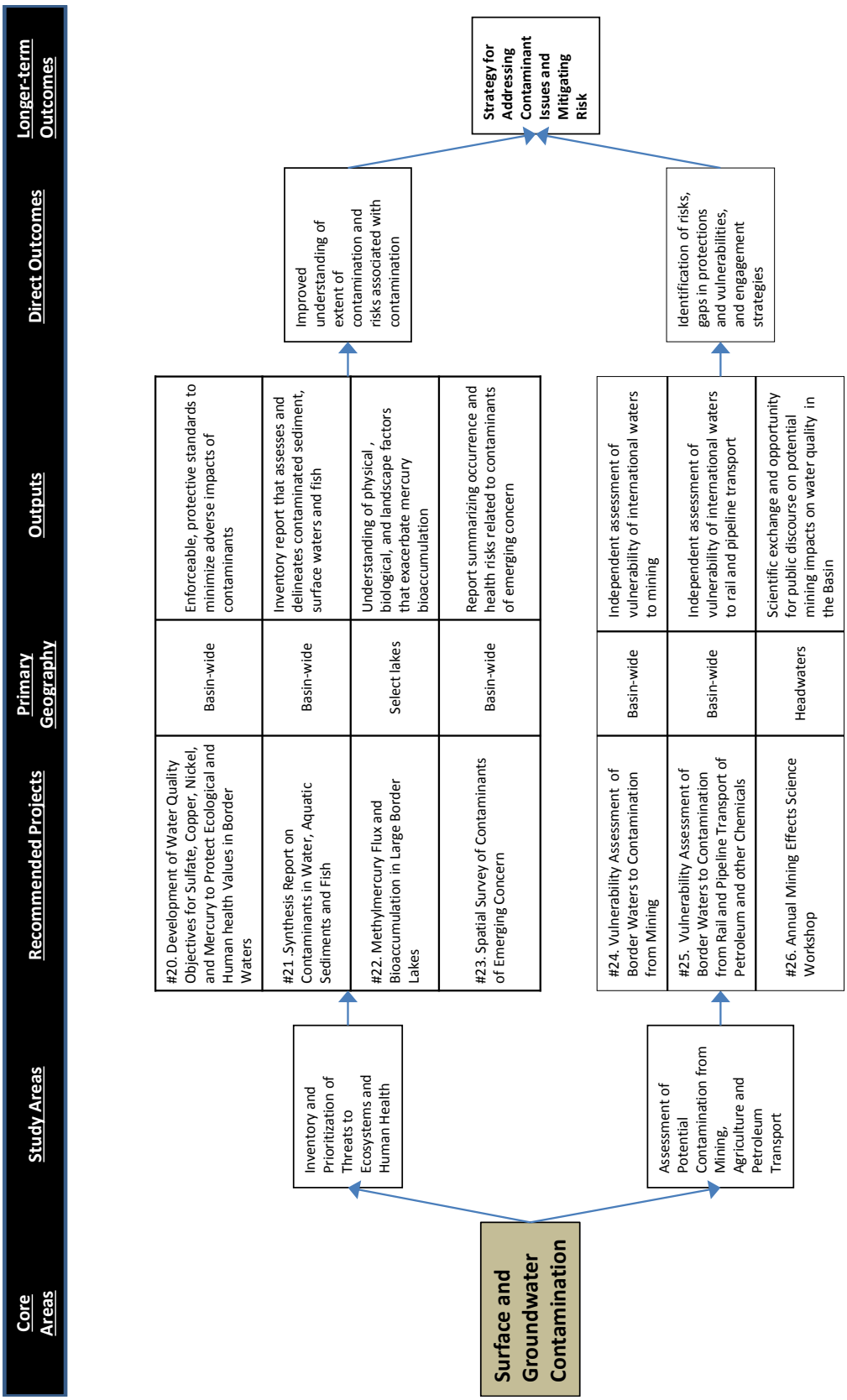
Within each logic model, the same headings are used:

- *Study Areas*, which break down the high-level aggregation of projects under major headings into small groups of projects that address the same study area;
- *Recommended Projects and Outputs*, which show the titles of each project and their specific outputs;
- *Primary Geography*, which indicates the geographic focus of the project (Basin-wide, Lake of the Woods or Headwaters);
- *Direct Outcomes*, which expresses the benefit of a project or projects in addressing a particular study are; and,
- *Longer-term Outcomes*, which identify big picture goals of the Plan of Study and beyond.


Core Areas
Study Areas
Recommended Projects
Primary Geography
Outputs
Direct Outcomes
Longer-term Outcomes
Improved water quality through a basin-wide monitoring system, mapping, communication and implementation platform to support policy development, decision-making, and adaptive management
Robust and accessible data that can facilitate understanding and resolution of priority issues
Wide variety of information sources and mechanisms to build capacity in the Basin to understand, communicate and implement solutions
Foundational and Capacity Building Projects and Activities
Monitoring in the Basin and Critical Sources of Information
Capacity Building
#1. International Monitoring Program for the Lake of the Woods Basin
Basin-wide
High-quality datasets from monitoring locations throughout the Basin to serve the needs of all priority issues
#27. International Platform for Implementation
Basin-wide
Facilitated workshop and report providing recommendations for opportunities to enhance existing binational entities for Plan of Study implementation and future shared management
#28. Review of Data Collection Programs and Monitoring in the Headwaters Regions of the Basin
Headwaters
Inventory of water quality activities in the headwaters regions and recommendations on focusing future efforts
#29. Application of Regional Climate Models for the Basin and Improved Public Education and Engagement on the Issue of Climate Change
Basin-wide
Ensure water quality models and science-based assessment tools use realistic climate scenarios; ensure the public is engaged and informed
#30. Develop the Lake of the Woods Basin Geospatial Mapping Framework and Public Communication Tool
Basin-wide
Common geospatial platform that serves all water quality research, management and engagement activities in the basin; serves as public outreach tool
#31. Indigenous Perspectives on Ecosystem Health
Basin-wide
Database of observations, records and narratives to assist with interpretation of Plan of Study results and findings
#32. Establish a Funding Program for NGOs to Promote Watershed Stewardship
Basin-wide
Establishment of working committee to develop rationale and logistics for funding program through public and agency consultation


Core Areas
Study Areas
Recommended Projects
Primary Geography
Outputs
Direct Outcomes
Longer-term Outcomes
Nutrient Enrichment and Harmful Algal Blooms (HABs)
Refine Existing Nutrient Budgets to Better Understand Sources and Sinks in the Basin
Drivers of HABs and Development of Predictive Models and Tools
Improved Understanding of Risks Associated with Toxic Algae and Enhancement of Public Education
#2. Mass-balance Models for P and N in the Lake of the Woods Basin
Basin-wide
Improved understanding of nutrient sources from Canadian and US sides from all basin sources
#3. Internal Loads and Hypoxia in Lake of the Woods
Lake of the Woods
Refinement of P mass balance based on improved understanding of internal load
#4. Assessment of Iron Fluxes from Sediments on Cyanobacteria Bloom Formation in Lake of the Woods
Lake of the Woods
Improved understanding of the sediment-water interface biogeochemical dynamics that result in P loss from lake bottoms
#5. Assessment of Nutrient Subsidies from Shorelines Due to Erosion and High Water Levels and High Flows in Rivers
LOW and other border lakes
Estimates of P loads due to shoreline erosion and a shoreline vulnerability mapping tool
#6. Application of Water Quality Models at Watershed and Basin-wide Scales to Apportion Nutrient Sources and Evaluate Scenarios
Basin-wide
Improved science-based tools for the to develop and assess management options
#7. Implementation of Nutrient Load Reduction Policies and Practices
Basin-wide
Reduction of nutrient loads to border waters and identification of research needs
#8. Application of Satellite Imagery and Remote Sensing Tools to Map and Characterize Water Quality and Algal Blooms
Basin-wide
Relationships between imagery attributes and predictors of HABs through development of remote sensing tools and real-time monitoring
#9. Development of Predictive Models of Algal Blooms
Lake of the Woods
Models describing the role of physical and chemical forces in the development of HABs
#10. Influence of Altered Food-web Structure on Production of HABs
Basin-wide
Relationships that show how food web variation (including AIS such as spiny waterflea and zebra mussels) affect energy flow and HABs
#11. Taxonomic Characterization of Algal Communities and Algal Toxins
Basin-wide
Accurate information on algal species and toxin composition for ecological interpretation of HABs and public advisories
#12. Public Health and Animal Welfare Risks Including Public Alerting Mechanisms
Basin-wide
Review of the state-of-knowledge of HABs including an overall health risk assessment and HABs and algal toxin early warning system
Targets and objectives for concentrations and loads in LOW basin transboundary lakes and rivers and reduced loads of nutrients to border waters
Predictive models of HABs linked to nutrient targets and objectives
Knowledge of algal toxins in the basin and better educated public to minimize risks of HABs
International nutrient management strategy to combat HABs
International algal bloom and toxin reduction strategy
Integration through adaptive management plan


Core Areas
Study Areas
Recommended Projects
Primary Geography
Outputs
Direct Outcomes
Longer-term Outcomes
Aquatic Invasive Species
Comprehensive Aquatic Invasive Species Prevention Strategy
Assessing and Controlling Impacts of Aquatic Invasive Species
Aquatic Invasive Species Vulnerability Assessments
#13. Binational Aquatic Invasive Species Management Team for the Lake of the Woods Basin
Basin-wide
International strategy supported by an annual meeting to prevent additional AIS; coordinated rapid response plan for high risk invasive species including protocols, communication plan, and immediate equipment needs
Prevention programs and rapid response efforts to contain and eradicate infestations
#14. Rapid Evaluation and Implementation of Options to Manage Recent Zebra Mussel Infestations
Headwaters
Implement rapid response plan to contain or eradicate mussels from identified lakes of LOW headwaters
#15. Ecological Impact of Spiny Waterflea in Infested Boundary Lakes
Basin-wide
Characterization of ecological disruptions that have resulted from SWF infestation in boundary water lakes
Establishment of strategies to prevent spread; Improve understanding of ecology of invasive species
#16. Pilot Studies on Adaptive Control Measures for Hybrid Cattail and Rusty Crayfish in infested Wild Rice Habitat
Basin-wide
Eradicate or control invasive hybrid cattail and rusty crayfish populations from basin waters, especially wild rice harvesting waters
#17. Comprehensive Assessment of Potential Invasion Risks to and within the Lake of the Woods Basin
Basin-wide
Report that examines risks, transport vectors and existing barriers for AIS from external basins and within the Basin
#18. Water Quality Risk Assessment for Zebra Mussels and Quagga Mussels
Basin-wide
Report on water chemistry within Basin and its suitability for high risk AIS such as zebra and quagga mussels
Improved understanding of AIS vectors and risks of infestation
#19. Climate Risk Assessment for AIS
Basin-wide
Report that assesses risk of increased infestation of Basin waters due to warming waters and other climate driven changes
Coordinated international prevention program


Core Areas
Study Areas
Recommended Projects
Primary Geography
Outputs
Direct Outcomes
Longer-term Outcomes
Surface and Groundwater Contamination
Inventory and Prioritization of Threats to Ecosystems and Human Health
Assessment of Potential Contamination from Mining, Agriculture and Petroleum Transport
#20. Development of Water Quality Objectives for Sulfate, Copper, Nickel, and Mercury to Protect Ecological and Human health Values in Border Waters
#21 .Synthesis Report on Contaminants in Water, Aquatic Sediments and Fish
#22. Methylmercury Flux and Bioaccumulation in Large Border Lakes
#23. Spatial Survey of Contaminants of Emerging Concern
#24. Vulnerability Assessment of Border Waters to Contamination from Mining
#25. Vulnerability Assessment of Border Waters to Contamination from Rail and Pipeline Transport of Petroleum and other Chemicals
#26. Annual Mining Effects Science Workshop
Basin-wide
Basin-wide
Select lakes
Basin-wide
Basin-wide
Basin-wide
Headwaters
Enforceable, protective standards to minimize adverse impacts of contaminants
Inventory report that assesses and delineates contaminated sediment, surface waters and fish
Understanding of physical , biological, and landscape factors that exacerbate mercury bioaccumulation
Report summarizing occurrence and health risks related to contaminants of emerging concern
Independent assessment of vulnerability of international waters to mining
Independent assessment of vulnerability of international waters to rail and pipeline transport
Scientific exchange and opportunity for public discourse on potential mining impacts on water quality in the Basin
Improved understanding of extent of contamination and risks associated with contamination
Identification of risks, gaps in protections and vulnerabilities, and engagement strategies
Strategy for Addressing Contaminant Issues and Mitigating Risk