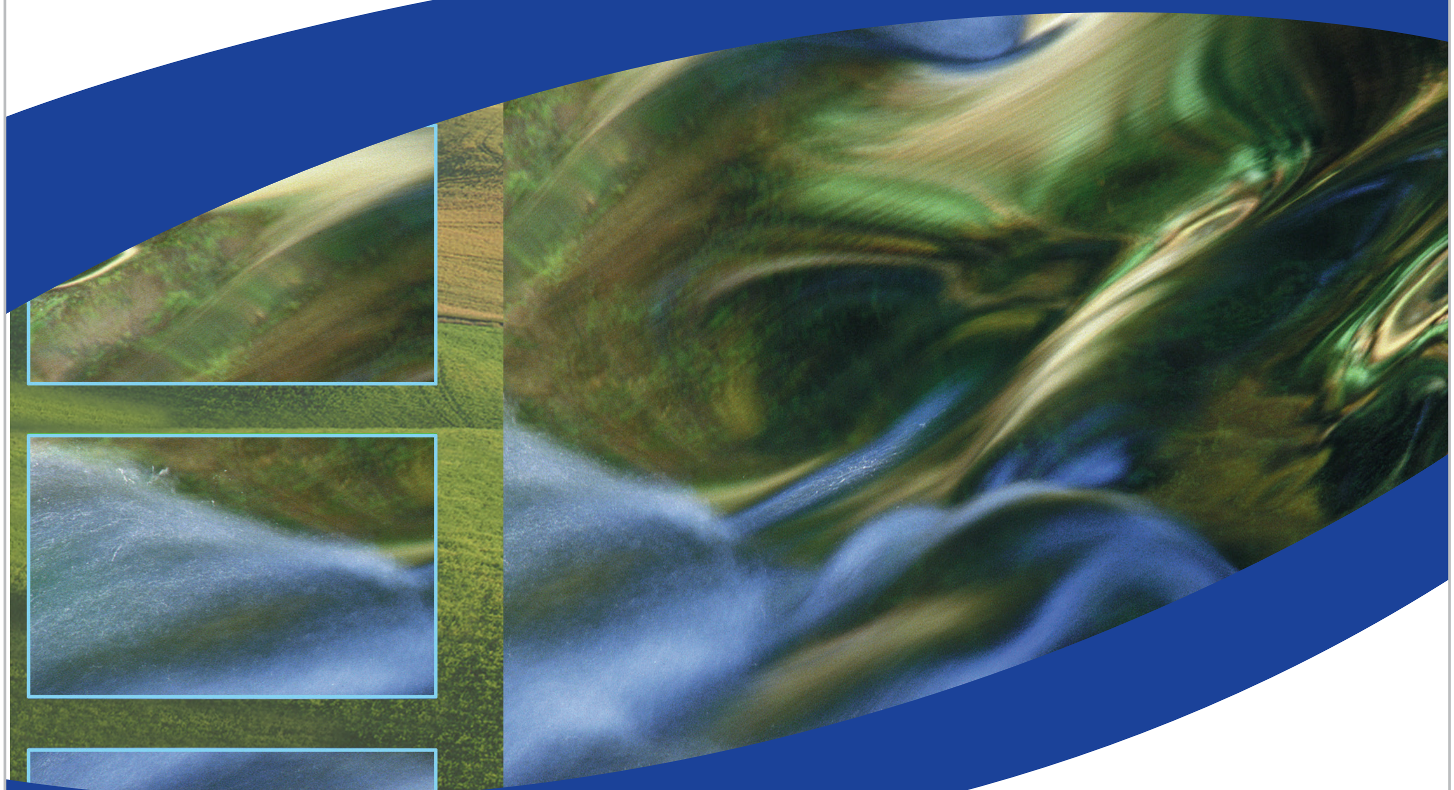
2021 TECHNICAL REPORT

Feasibility Assessment for Water Quality Trading in Lake Winnipeg, Canada

Phase 1

Prepared for CIER Centre for Indigenous Environmental Resources



Feasibility Assessment for Water Quality Trading in Lake Winnipeg, Canada

Phase 1

3002023182

Final Report, December 2021

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ABSTRACT

Water quality trading (WQT) has the potential to reduce nutrient loading to receiving waterbodies at lower cost and more effectively than could otherwise be achieved. While prior studies on WQT for Lake Winnipeg date back more than a decade, none have focused on the fundamental factors across social, environmental, economic, and legal realms. Pulling from experience leading and advising many other WQT programs in the United States, the team considers the most critical elements to realistically assess the potential for WQT to reduce nutrients in Lake Winnipeg.

Current supportive watershed and policy conditions and the new existence of a historic collaborative political group – the Collaborative Leadership Initiative (CLI) committed to reconciliation and environmental outcomes – suggest it may be time to proceed with the implementation of a WQT program that benefits Lake Winnipeg. With this assessment complete, it will be important to proceed with the key actions to continue assessing the reality of WQT in Lake Winnipeg.

This analysis is considered Phase 1 of a feasibility assessment for WQT in the Red River Watershed that drains into Lake Winnipeg. This analysis will *not* detail the rules of a Winnipeg WQT program (trading ratios, credit pricing, tracking, verification, etc.) as it is much too early to develop such criteria. Rather, the assessment will carefully consider threshold legal, scientific, and social elements for a WQT program, suggest whether it is indeed a viable option and, if so, how best to proceed.

The effort to proceed with WQT appears worthwhile, with water conditions in Lake Winnipeg predicted to decline, financial costs for alternative approaches approaching $2B for a single discharger, Canada's over multi-billion dollar green infrastructure commitment to improve watersheds, and the existence of a motivated collaborative leadership group (CLI).

The key next steps for proceeding to another phase of this work are detailed, including developing a full watershed model, proceeding with two specific legal amendments, and confirming participation from the most critical credit buyer (the City of Winnipeg).

WQT is a good way to help meet reduction requirements of the North End Sewage Treatment Plant in lieu of a technology approach that could be a decade away. It may also help mitigate the problem of non-regulated CSO and non-point source loading which are classically intractable issues to tackle.

Finally, WQT for Lake Winnipeg is a "no regrets" strategy that uses natural infrastructure with ancillary benefits including carbon, biodiversity, and landowner support that go well beyond what can be achieved by only a technology-based solution.

Keywords

Water quality
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KEY RESEARCH QUESTION

This analysis is considered Phase 1 of a feasibility assessment for water quality trading (WQT) in Lake Winnipeg, Canada. This report considers threshold legal, scientific, and social elements for a Lake Winnipeg WQT Program, then analyze whether WQT is indeed a viable option and, if so, how best to proceed.

RESEARCH OVERVIEW

Lake Winnipeg – located about 60 km northeast of the province's capital, Winnipeg – is Canada's sixth largest freshwater lake and has the largest watershed of any lake in Canada. Due to excessive phosphorous loading to the lake, it is considered one of the most eutrophied large lakes in the world. The Canadian government has expressed interest in increasing funding for natural infrastructure projects, and the Manitoba province has signaled support for innovative solutions such as water quality trading (WQT). Consideration for WQT in Lake Winnipeg has been ongoing for more than a decade, all with similar agreement regarding potential, but lack of action. Today, several conditions warrant a fresh review of the issue.

KEY FINDINGS

- Watershed conditions, legal construct, and available institutional capacity all indicate viability for development of a WQT program to address a portion of the TP loading to Lake Winnipeg.
- A primary consideration is securing potential credit buyers. The largest discharger of TP into the Lake is the North End Sewage Treatment plant. A Lake Winnipeg WQT Program is a viable way to help meet nutrient reduction requirements of the North End Sewage Treatment Plant in lieu of a technology-only approach, which may still be a decade away.
- WQT may help mitigate the problem of non-regulated combined sewer overflows and non-point source TP and TN loading, which are classically intractable issues to solve.
- WQT for Lake Winnipeg is a "no regrets" strategy that uses natural infrastructure with ancillary benefits including carbon, biodiversity, and landowner support.
- Specific ecological limitations must be acknowledged in order to accurately communicate the potential of WQT to address nutrient loading to the lake, a problem which has developed over decades.

LEARNING AND ENGAGEMENT OPPORTUNITIES

See www.wqt.epri.com for additional information on water quality trading

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PROGRAM: P239

ACRONYMS

BAP	Bioavailable Phosphorus
BMP	Best Management Practice
CIER	Centre for Indigenous Environmental Resources
CLI	Collaborative Leadership Initiative
CDS	Controlled Drainage with Subirrigation
CSA	Critical Source Area
CSO	Combined Sewer Overflow
DP	Dissolved Phosphorus
DRP	Dissolved Reactive Phosphorous
EPRI	Electric Power Research Institute
GIS	Geographic Information System
GROW	Growing Outcomes in Watersheds
IISD	International Institute for Sustainable Development
N	Nitrogen
NNWQT	National Network on Water Quality Trading
NPS	Nonpoint Source
P	Phosphorus
PP	Particulate Phosphorous
SWAT	Soil and Water Assessment Tool
TN	Total Nitrogen
TP	Total Phosphorus
WQT	Water Quality Trading

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BACKGROUND

Lake Winnipeg – located about 60 km northeast of the province's capital, Winnipeg – is Canada's sixth largest freshwater lake and has the largest watershed of any lake in Canada. Due to excessive phosphorous loading to the lake, it is considered one of the most eutrophied large lakes in the world. The Red River, which flows north into Canada from the United States, is the single largest nutrient source to the lake. Recently, the Canadian government has expressed interest in increasing funding for natural infrastructure projects, and the Manitoba government has signaled support for innovative solutions such as water quality trading (WQT). Due to excessive loading of nutrients draining to critical waterbodies in the province, there is interest in water quality trading for phosphorous, with consideration for ancillary benefits for nitrogen, carbon, biodiversity, pollinators, water supply, and flood control.

Consideration for WQT in Lake Winnipeg has been ongoing for more than a decade, all with similar agreement regarding potential and lack of action:

- An International Institute for Sustainable Development (IISD) report in 2009[1] proposed five steps to establish WQT in Lake Winnipeg, concluding that "WQT offers a real potential to remediate the water quality of Lake Winnipeg while allowing farming operations to thrive alongside healthy environments and water bodies that are imperative to long-term sustainability of the basin."
- In 2012, a peer-reviewed paper by Voora et al.[2] concluded, "Further research is required to determine if a viable WQT system could be established within [Lake Winnipeg Basin]. Specifically, establishing a basin-wide shared water quality vision, total nutrient load framework, and effective trading rules and strategies are but a few examples of elements that require further research and coordination."
- In 2017, WQT was included in Manitoba's Climate and Green Plan[3] as an approach for improving water quality in Lake Winnipeg.
- In 2019, IISD issued a second report[4] reviewing existing WQT programs for lessons that may apply to Manitoba, summarizing that "leveraging existing local, provincial and federal resources in a coordinated fashion and using WQT by building on existing programs can enable much-needed water quality improvements in Manitoba." They recommended that further consideration of existing trading programs in the context of Manitoba would help identify institutional and scientific elements for a program that may work in Winnipeg.

Today, several conditions warrant a fresh review of the issue, including the following:

- The Collaborative Leadership Initiative (CLI), a collaboration of First Nations municipal political leaders formed in 2017, spearheaded a new effort to break through inaction and proceed with creation of a WQT program that would lead to ecological, social, and economic benefits.
- More than $5B of support is available for green infrastructure via the Investing in Canada Plan and an additional $200M is available under Canada's Natural Infrastructure Fund (announced June 2021)[5]. Both of these are applicable to a WQT program in Winnipeg.
- The City of Winnipeg, North End Sewage Treatment Plant has seemingly no viable ways to reduce nutrient loading in the next decade, is facing $1.8B in water treatment system upgrades, and is consistently more than five-fold out of compliance with the current phosphorous permit limit of 1mg/L.
- Ongoing severely degraded water conditions in the Lake primarily are caused by excess nutrients.
- Provincial law supports WQT.
- WQT is mentioned in Manitoba's Climate and Green Plan as a possible way to address eutrophication

These conditions suggest it may be time to proceed with the implementation of a WQT program in Lake Winnipeg.

Note: This research was complete in December 2021. Changes in political, economic, and ecological conditions since December 2021 are not reflected in this analysis.

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OBJECTIVE

This analysis is considered Phase 1 of a feasibility assessment for WQT in Lake Winnipeg. The authors form an expert team that has worked on successful WQT projects throughout the United States. This report will not propose how to address the 11 common elements of WQT, including trading ratios, credit pricing, tracking, and verification, as it is much too early to develop such criteria (Box 1). Rather, threshold legal, scientific, and social elements for a Lake Winnipeg WQT Program will be carefully considered towards suggesting whether WQT is indeed a viable option and, if so, how best to proceed.

BOX 1: Common Elements of Water Quality Trading Programs

The National Network on Water Quality Trading – a collaboration of U.S.-based organizations (including two primary authors of this report) – identified 11 common elements to consider when designing and implementing a WQT program. Regarding each element, no "one size fits all" solution exists, and the approach needs to be informed by the specific social, economic, and ecological conditions of the new project. The common elements identified in 2015 follow:

1. Identifying and establishing regulatory instruments to support trading
2. Defining who is eligible to trade, where trading can occur, and what is being traded
3. Determining eligibility for participants in the trading program
4. Quantifying water quality benefits
5. Managing risk and uncertainty in the trading program
6. Defining credit characteristics
7. Establishing project implementation and assurance guidelines
8. Establishing procedures for project review, certification, and tracking
9. Ensuring compliance and enforcement
10. Establishing adaptive management guidelines for ongoing program improvement and performance tracking
11. Defining roles, responsibilities, transaction models, and stakeholder engagement processes

Source: *Building a Water Quality Trading Program: Options and Considerations. National Network on Water Quality Trading*. https://files.wri.org/d8/s3fs-public/buiding-a-water-quality-trading-program-nn-wqt.pdf (June 2015).

3
LEGAL CONSTRUCT

Background

In simplest form, WQT is designed to enable a wastewater treatment facility to achieve required regulatory reductions in pollutant loadings by paying for those reductions elsewhere at lower cost than would be incurred at the facility itself. WQT capitalizes on economies of scale and differences in the costs of reductions among various sources. WQT can take a number of forms, including bilateral agreements between wastewater treatment facilities, bilateral agreements between a wastewater treatment facility and a nonpoint source such as an agricultural operation, and more complex marketplaces involving multiple point and nonpoint source buyers and sellers. As WQT concepts and approaches have matured (especially in the United States), WQT is increasingly viewed as an accelerant to achieve more reductions than minimally required, more quickly, across a broader watershed, through collaborations among multiple stakeholders, and with ancillary benefits beyond specific pollutant reductions (such as flood control, aesthetics, pollinator and wildlife habitat, riparian buffers, carbon reductions, natural infrastructure, and improved agricultural yield).

Scope of Legal Assessment

Although several established WQT programs are in place across Canada, the legal framework for WQT is not as mature as in the United States, especially in Manitoba. To assess the legal viability of WQT for Lake Winnipeg, we reviewed relevant and applicable federal laws (including the *Canada Water Act* and *Fisheries Act*), provincial laws (including the *Manitoba Environment Act* and *Water Protection Act*), provincial regulations (including Manitoba's Water Quality Standards, Objectives, and Guidelines[6]), existing licenses for major dischargers (including the City of Manitoba) and existing incentive programs (including Growing Outcomes in Watersheds, aka GROW). We also reviewed the scope and status of transboundary initiatives such as the International Joint Commission.

Finally, we identified the unique governance opportunity presented by implementation of inherent Aboriginal and treaty rights of Indigenous peoples in the study region. CLI includes First Nations from Treaty 1, 3, and 5, all of which are within the primary study area. Further, recent developments at the federal level on Bill C-15, *An Act respecting the United Nations Declaration on the Rights of Indigenous Peoples*, and *The Path to Reconciliation Act* at the provincial level illustrate the importance and need to build solutions with, and based on, collaborative efforts of multiple authorities including Indigenous jurisdictions. That said, the laws and rights of First Nations in Canada are especially complex and, depending on further study, many of these laws and rights may be implicated in WQT design and implementation. Through active participation, Indigenous nations can ensure that WQT is built to address their needs, that they receive the benefits they seek, and that their jurisdictions can help achieve WQT goals.

Core Principles and Regulatory Climate

Like the United States, "federalism" is a foundational principle in Canada, with basic legal authorities divided between Indigenous, federal, provincial, territorial, and municipal governments. Under the Canadian Constitution, the federal government has the general power to make laws for "peace, order and good government" and, in the environmental context, has done so through laws such as the *Canadian Environmental Protection Act* that regulate contaminants. The federal government also regulates fish and fish habitat under the *Fisheries Act*, has jurisdiction over all federal lands (which include parks, military lands, and First Nations reserve lands), sets Canada-wide water quality guidelines, and supports collaborative governmental agreements on water under the *Canada Water Act*. Provinces have broad powers, given their jurisdiction over "property and civil rights," and play the primary role in regulating water quality on provincial lands and waters (which include First Nations and Métis treaty lands and traditional territories). First Nations have inherent jurisdictions that preexisted colonization and continue today, treaty and Aboriginal rights guaranteed under the Canadian constitution, and legislative rights under the *Indian Act*, *First Nations Land Management Act*, and other federal laws.

In Manitoba, the *Environment Act* serves as the source of authority for licensing wastewater treatment facilities on provincial lands, while the *Water Protection Act* serves as the source of authority for developing water quality standards and effluent limitations that must be implemented through those licenses. Taken together, these laws reflect a commitment to the protection and stewardship of Manitoba's water resources, recognizing the importance of comprehensive planning, the need for stringent levels of protection, the critical role of science in informing policy, and the benefits of incentive programs to enhance environmental protection.

Importantly, there is no explicit source of authority for WQT at the First Nations, federal, provincial, or municipal levels in Manitoba, nor is there any explicit prohibition. However, the core structural elements for WQT are all in place, including the following:

- Comprehensive, if not explicit, legal authority (especially at the provincial, First Nations and municipal levels), for example, the Manitoba *Water Protection Act*, with its holistic approach to watershed management plans for the purpose of preventing, controlling, and abating water pollution from both point and nonpoint sources
- Existing licensing program for wastewater treatment facilities, including licensing for each of the City of Winnipeg's main treatment facilities
- Various incentive programs for agriculture and other nonpoint sources to promote the use of beneficial management practices (such as various sustainable agriculture incentives programs for on-farm practices and the Growing Outcomes in Watersheds (GROW) Initiative, which is being implemented by the local watershed districts through their integrated watershed management plans)
- A mature scientific understanding of the critical need for nutrient reductions to restore water quality in Lake Winnipeg (as most recently documented in the proposed Manitoba Nutrient Targets Regulation[7] under the *Water Protection Act*, described in more detail below)
- Existing and proposed regulatory "drivers" for nutrient reductions

First Nation governments in southern Manitoba have expressed a strong desire to improve the management of waters on their reserve and traditional territories and to do so, where relevant and applicable, in partnership with other governments. No Indigenous government has specifically articulated market mechanisms related to water in any of their authorities, but they have expressed interest in so doing.

There appears to be compelling political and societal support for collaborative multi-jurisdictional approaches to water quality restoration, including WQT. By way of illustration, both the Made-in-Manitoba Climate and Green Plan[8,1] and the proposed Manitoba Nutrient Targets Regulation[9,2] specifically contemplate WQT. When finalized, the Nutrient Targets Regulation will set loading caps for each major tributary into Lake Winnipeg as well as concentration limits within the lake itself. These caps and limits are designed to serve as benchmarks to guide nutrient reductions but are not directly binding or enforceable. In this way, they are very similar to the load and waste load allocations assigned through total maximum daily loads (TMDLs) in the United States.

As noted above, provinces play the primary role in regulating water quality on provincial lands and waters (which include First Nations and Metis treaty lands and traditional territories). As a result, this analysis focused primarily on provincial authorities.

Comparative Programs

As part of the assessment, we reviewed other existing WQT programs in Canada, including the first Canadian Point/Nonpoint Source Trading Initiative for the South Nation River Watershed in Ontario and the Lake Simcoe Region WQT Initiative[10]. In particular, we reviewed the laws, policies, and permit provisions that govern the South Nation WQT program and spoke to program administrators within the South Nation Conservation Authority. Although program administrators described less involvement (and perhaps less opportunities for involvement) with First Nations governments or Indigenous peoples in their program (and in the Province of Ontario more generally), we believe that South Nation serves as an important point of comparison for Lake Winnipeg for each of the following reasons.

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[1] The Green Plan states as follows: "An innovative method to improve water quality is through water quality trading. This applies a market-based approach that works alongside water quality regulation to improve water quality. Generally, a regulator sets an overall limit and allocates amounts of pollution or excess nutrient sources so the limit is not violated. The exceeding entities can then trade amongst themselves to meet the overall limits in the most effective manner. This means that a facility facing high related treatment costs can purchase equivalent reduction requirements from other sources at lower costs. For example, municipalities that are facing wastewater plant treatment upgrade costs to limit nutrient discharge could purchase credits from landowners who are willing to hold nutrients on their land through programs like GROW."

[2] The public consultation document that was released with the proposed regulation in December 2020 states as follows: "One of the tools being considered to reduce nutrients and improve water quality is Water Quality Trading (WQT). Water Quality Trading, a market-based approach that works alongside wastewater regulation, may provide a framework that allows trading of water quality credits (such as limits or caps on nutrient discharges) to reduce nutrients from both point and nonpoint sources. Under this approach, wastewater treatment facilities in non-compliance (that is, exceeding nutrient discharge limits) can purchase environmentally equivalent (or superior) pollution reductions from an alternate source (such as another point or nonpoint source), often at a lower cost. Water quality targets would be required to establish a water quality trading program in Manitoba."

First, South Nation began with a clear regulatory driver. In the 1990s, the Province imposed a "zero discharge" policy on new and expanding wastewater treatment facilities in an effort to address water quality problems under the province's antidegradation regulation. Under that policy, an affected facility was required to either achieve zero phosphorus (P) addition or offset its loading at a 4:1 ratio. This offset option led to the development of WQT. The "zero discharge" policy was derived from the province's water quality standards, which include a provision stating, "Water quality which presently does not meet the Provincial Water Quality Objectives shall not be degraded further and all practical measures shall be undertaken to upgrade the water quality…."[11] Although Manitoba's water quality standards lack an identical "antidegradation" provision, they are similarly broad and could be interpreted by the Province to compel further reductions from treatment facilities (especially those that are new or expanding or are affirmatively revised to explicitly prohibit degradation).

Second, as the program matured, the Province amended the law to explicitly authorize WQT (rather than continue to rely on its interpretation of the antidegradation regulation). We were unable to determine precisely what motivated the Province to do so after-the-fact, but doing so appears to have had the effect of reinforcing the durability and defensibility of the program. The *Ontario Water Resources Act* now makes the following provisions:

The Lieutenant Governor in Council may make regulations establishing and governing water quality trading, including:

- Prescribing areas of Ontario to which water quality trading applies
- Prescribing water quality parameters to which water quality trading applies
- Prescribing persons or classes of persons to whom water quality trading applies
- Governing the creation, retirement, and trading of water quality instruments such as allowances, credits, or offsets
- Prescribing requirements that must be met by persons to whom water quality trading applies, including requirements related to the discharge, monitoring, and reporting of water quality parameters
- Designating a person or body to administer water quality trading
- Governing any other matter necessary for the administration of water quality trading

Third, the program is administered through a conservation authority that is well-funded and has ample capacity, enabling approximately 17 wastewater treatment facilities to use WQT as a compliance option. The funding from these facilities to meet their 4:1 offset ratios is deployed by the authority to nonpoint source projects throughout the watershed, facilitating a robust cash-credit cycle.

Conservation authorities were first authorized in the Province of Ontario in the 1940s for the conservation, restoration, and management of the province's water resources, and their capacity appears to be based on their maturity. Manitoba had a similar source of authorization for conservation authorities but renamed them as watershed districts in 2008. Nomenclature aside, it does not appear that Manitoba watershed districts have the same level of funding as their counterpart conservation authorities in Ontario. In addition, for the purposes of restoring Lake Winnipeg, no single watershed district encompasses the full contributing watershed.

Nonetheless, districts are allowed to work outside their boundaries if the work benefits the district. For that purpose, a district may enter into agreements with others, including First Nations. As a result, any effort similar to South Nation would likely need to involve collaboration among multiple watershed districts as well as other governments and interested stakeholders.

Regulatory Drivers for WQT in Manitoba

Manitoba's existing Water Quality Standards, Objectives, and Guidelines[12] include technology-based standards of 1 mg/l total phosphorus (TP) and 15 mg/l total nitrogen (TN) for industrial and municipal dischargers in Manitoba (subject to certain size and expansion thresholds for applicability/implementation)[3]. These standards, discussed in Box 2, must be applied through the licensing process. However, based on our review of existing licenses, it appears that many have not yet been revised and reissued to impose TP or TN limitations. For example, the licenses for the single largest point source dischargers into Lake Winnipeg, City of Winnipeg's North End and South End sewage treatment plants, were last revised/reissued in 2009 and 2012, respectively, and do not contain such limitations.

As noted above, Manitoba has also proposed a Nutrient Targets Regulation that would set loading caps for each major tributary to Lake Winnipeg, including the Red, Winnipeg, Saskatchewan, and Dauphin Rivers, as well as concentration limits within the lake itself. The loading caps for the Red River (at Selkirk) are 2,800 tons/year TP and 19,050 tons/year TN. The concentration limits within the lake are 0.05 TP and 0.75 mg/L TN. Although not directly binding or enforceable on individual dischargers, the Province anticipates that these caps and limits will help to inform the development of WQT in the watershed by setting overall targets that can then be allocated to individual contributors based on their relative contributions (using watershed modeling to account for the fate and transport of nutrients from each tributary river into the lake).

It is important to note that Indigenous territories do not yet appear to have any regulatory or inherent rights-based concentration or loading limits for nutrients in water that flows through their reserves or traditional territories.

[3] The 1 mg/L TP standard applies to "[a]ll facilities discharging more than 820 kg total phosphorus per year (that is, communities with a population greater than 2,000 or equivalent due to industrial contributions)" as well as "[n]ew or expanding facilities discharging less than 820 kg total phosphorus per year (that is, communities with a population less than 2,000 or equivalent due to industrial contributions)." The 15 mg/L TN standard applies to "new and expanding wastewater treatment facilities discharging more than 33,000 kg of total nitrogen per year (that is, serving more than 10,000 people or equivalent due to industrial loading)" as well as certain food processing facilities.

BOX 2: Technology-Based & Water Quality-Based Standards in Relation to WQT Opportunities

As a general principle of water regulation, technology-based standards focus on the available (or best available) technology that can be applied to wastewater before it is discharged and thus are inherently dependent on factors such as the type of facility, age of infrastructure, nature and characteristics of the wastewater, available treatment technologies, and incremental costs of different treatment options. By contrast, water quality-based standards focus on the conditions in the receiving waterbody and the controls that are needed to attain and maintain applicable water quality standards.

Most WQT programs are designed to address water quality-based standards on a watershed scale, rather than technology-based standards (since those are often facility-specific). In addition, as described above, in the United States at least, the Environmental Protection Agency (EPA) and opponents of WQT maintain that WQT is not permissible to achieve compliance with technology-based limits (unless the technology-based regulations explicitly authorize it). Water quality based effluent limits (WQBELs) can use water quality credits for compliance. Therefore, if a permit is structured as a technology-based limit, as is currently the case for the City of Winnipeg, usually WQT is precluded. For this reason, we are identifying a key action to amend the Manitoba Water Protection Act to explicitly allow WQT to meet a technology-based standard.

Potential Legal Impediments to WQT

While the existing legal framework appears to be generally supportive of WQT approaches, the absence of explicit legal authorization could become problematic if opponents emerge for three reasons. First, as explained above, the fact that Ontario changed its law to explicitly authorize WQT years after the South Nation WQT program began is both cautionary and instructive: cautionary because it suggests the need for statutory authorization (not yet in existence), and instructive because it provides insight into WQT in the Manitoba region. To maximize legal support for WQT in Lake Winnipeg, a targeted amendment to the Manitoba *Water Protection Act* similar to the *Ontario Water Resources Act* would be helpful.

Second, the technology-based standards (see Box 2) in Manitoba's Water Quality Standards, Objectives, and Guidelines appear to require source-specific controls. Indeed, the regulation states, "There is little or no opportunity to modify the technology-based standards at any site except where specifically indicated."[13] If interpreted narrowly, the regulation does not appear to allow a facility to meet the technology-based standards by investing in off-site reductions from another source. In the United States, opponents of WQT have made similar arguments about the need for facilities to achieve their own reductions. To avoid these kinds of arguments in Manitoba, it may be necessary to amend the Water Quality Standards, Objectives, and Guidelines to clarify whether and to what extent WQT may be used to achieve compliance. This could be done in concert with any amendments to the Manitoba *Water Protection Act*, further reinforcing the other explicit statements in support of WQT in the Climate and Green Plan and proposed Nutrient Targets Regulation.

Third, one or more entities will need to administer the WQT program for Lake Winnipeg. This could be done at the provincial level, through local collaboration among affected municipalities and Indigenous groups/councils, or through a stand-alone organization such as the one in place for the South Nation WQT program (the South Nation Conservation Authority). The watershed districts appear to possess the requisite authority; however, the more practical issues are whether they possess the resources to be effective administrators and whether the narrower district jurisdictional lines create inefficiencies to managing a regional WQT program. Depending on the scope and structure of the Lake Winnipeg program, additional legal work may be needed to ensure that the administering entity has the necessary authority (and resources) to achieve the desired outcome.

Legal Summary

Based on our assessment, WQT appears to be a viable legal option to help address water quality problems in Lake Winnipeg. In the absence of explicit legal authorization for (or prohibition of) WQT, Manitoba's existing laws and regulations provide broad support for collaborative approaches such as WQT, and it is clear from the Climate and Green Plan and proposed Nutrient Targets Regulation that the Province is interested in pursuing WQT. The existing regulations appear to serve as a solid initial driver for WQT-based reductions, and the proposed tributary caps and in-lake limits further inform the scope and extent of reductions that will be needed to restore water quality. Finally, it is apparent any of the potential limitations discussed above can be overcome given the level of political and societal support for WQT.

As noted above, we recognize the unique governance opportunity presented by implementation of inherent, treaty, and Aboriginal rights of Indigenous peoples personally and through their governments in the study region. Through a collaborative approach to designing the WQT program, Indigenous nations can ensure that the program is built to address their needs, that they receive the benefits they seek, and that their jurisdictions can help achieve WQT goals.

4

WATER CONDITIONS

Limitation: For efficiency, the initial watershed loading analysis for this report was completed using a simple geographic information system (GIS)-based review. Estimates from this GIS-based analysis need to be refined with full modeling.

The Red River Basin contributes to the vast majority of TP loading into Lake Winnipeg and is therefore the focus of this Phase 1 feasibility assessment. The other contributing basins can also reduce nutrients, but without addressing the loading from the Red River Basin, the water quality issues in the lake will continue. Notably, the largest single point source of TP, the City of Winnipeg North End Sewage Treatment Plant is located on the northern tip of Red River Basin just before the point of discharge into the lake. The location of this discharger is relevant as it may be an important credit buyer in a future WQT program as nutrient reduction practices typically occur upstream (south, in this case) of the credit buyer.

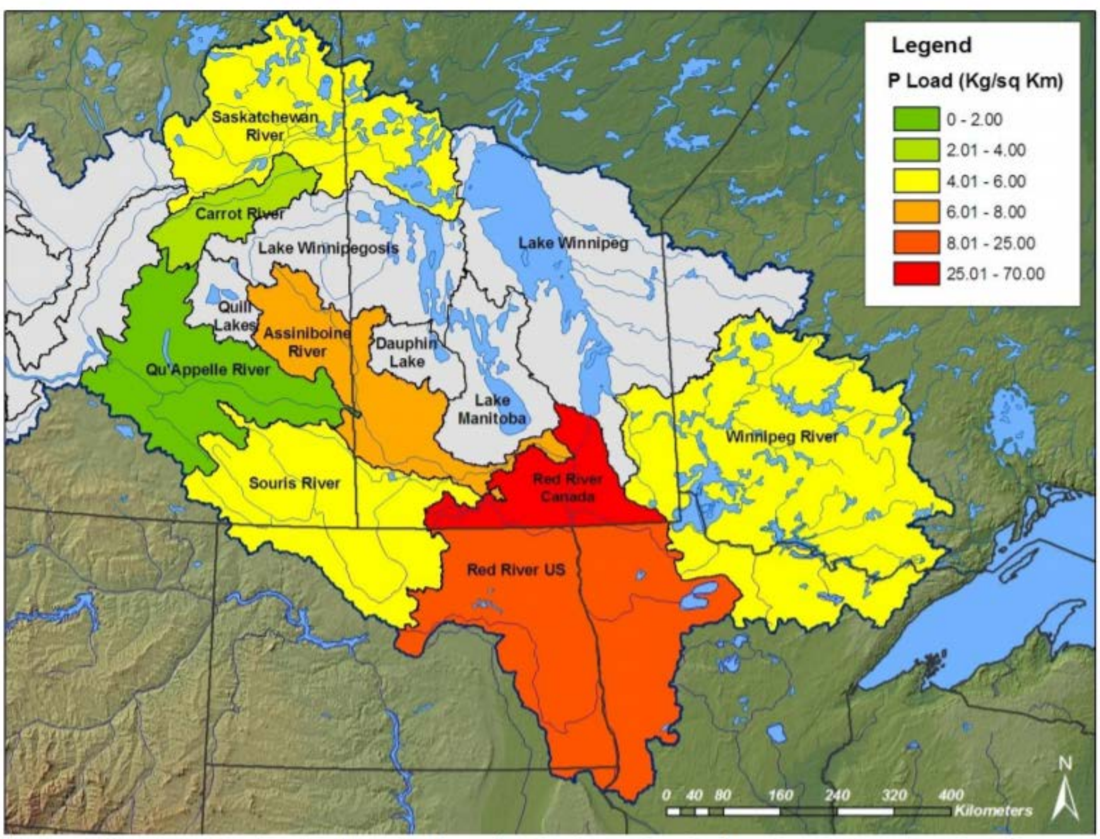


Figure 4-1
P load ranges in tonnes/yr flowing into Lake Winnipeg based on average total annual P loads measured from 1994–2001 at long-term monitoring stations (Bourne et al.[14]).

Summary of Literature Review of Nutrient Loads to Lake Winnipeg

A literature review was conducted to ensure comprehensive understanding of water conditions. The full writeup is provided in Appendix A, with the key points provided in this summary section.

Due in part to its latitude and continentality, the climate around Lake Winnipeg has been warming at twice the global average.[15] Future climate scenarios for the Red River Basin predict that temperature and precipitation will increase over the next century.[16,17] Temperatures are projected to increase by 3°C more than the average under a low-carbon scenario and 4–5°C more under a high carbon scenario by 2080.[18] The winter, spring, and fall seasons are all projected to become wetter, while summers are projected to become slightly drier.[19,20] The area is expected to experience successively shorter snow cover duration, slower snowmelt, smaller monthly snow water equivalent, and a transition from a snow-dominated to a rain-snow hybrid regime.[21]

Major nutrient sources include synthetic fertilizers, crop residue, and livestock waste. Wastewater effluent is the only significant point source in the region.[22,23] For example, the City of Winnipeg treats more than 300 million liters of wastewater per day[24], which results in a daily discharge of hundreds of kilograms of TN and TP to Lake Winnipeg. Diffuse (i.e., nonpoint) sources represent 59% of the TN and 73% of the TP load in the Red River Basin, most of which comes from agricultural regions.[25,26] A load apportionment model (LAM) from Rattan et al. (2020) showed that as much as 70–100% of annual TP load comes from nonpoint sources, depending on the subwatershed.[27]

In addition to inflowing nutrients, Lake Winnipeg has significant internal loading of N and P as a legacy of past nutrient inflows and sediment resuspension.[28] The majority of this load is transported during snowmelt in late winter and early spring from south of the US/Canada border.[29,30,31,32] Most of the loading enters tributaries in the dissolved form.[33,34]

Climate and agricultural practices have been shown to be major factors of TP load in the region.[35,36] With approximately 72% of the land area used for agricultural production, agricultural practices are the single biggest driver of water quality across the basin, and previous modeling efforts show that fertilizer and crops contribute significantly to variations in TP load.[37] Projected climate change is expected to increase sediment oxygen demand, P release rates, and cyanobacterial proliferation.[38]

A fundamental management requirement for watersheds is gaining a basic understanding of external loading sources and how a watershed processes nutrients in upstream lakes and reservoirs thereby impacting downstream water quality.[39] Reducing nutrient loads to Lake Winnipeg starts by reducing stream loads. An efficient strategy for this requires understanding where the nutrients are coming from to better target reduction efforts to prioritize downstream benefit.[40] Because of the variability of instream flows and nutrient loads in the Red River Basin, monitoring results of load reduction based on annual loads from year to year can be misleading because large reductions or increases occur naturally from climate variability (e.g., snowfall, timing of snowmelt).[41] Although in some areas there is a considerable amount of TP from historic fertilizer application (legacy P), better agricultural practices, such as measuring P levels in soils to adjust fertilizer application and timing, can reduce the loading to receiving water bodies. Thus, a long-term view is necessary. It is clear from the research that the Red River and its catchments should be of primary importance for nutrient management strategies and targeted best management practices (BMPs) for nutrient reduction efforts.[42]

Summary of Natural Infrastructure for WQT

Given the funding available for natural infrastructure projects (see Box 3), it is useful to consider the application of these approaches to WQT. The full discussion of natural infrastructure for P load reduction is provided in Appendix B. The key points are provided in this summary section.

Natural infrastructure is defined as a strategically planned and managed network of natural lands, such as forests, wetlands, and other open spaces, which conserve or enhance ecosystem functions and provide associated benefits to human populations.[43,44] Many common agricultural BMPs, such as bioswales, cover crops, and riparian reforestation, fall within the natural infrastructure approach.

Nutrient reduction efficiencies for BMPs fluctuate greatly due to regional variability, design methods, implementation, and maintenance frequency.[45] For example, previously reported TP reduction efficiencies for BMPs such as cover crops can range from 7–63%, contour farming from 30–75%, livestock exclusion from 32–76%, and riparian buffers from 40–93%.[46,47] Such variability results from inherent heterogeneity of landscape topography, hydrology, climate, and prior land use, which influences soil P concentrations.[48,49] Consequently, a thorough understanding of the management mechanisms in nutrient control and uncertainty in efficacy are needed to help prioritize BMP selection.[50,51] Placement in the watershed plays a vital role in nutrient reduction, as the contribution of nutrients varies across watersheds and determines BMP efficiency, efficacy, and cost.[52,53,54,55]

While there are numerous studies on the efficacy of land cover/use and management for reducing nutrient loads, few studies thus far have considered spatially targeted efforts, particularly in the region.[56] Timing is also an important consideration, as shown in a multi-model study by Scavia et al. (2016), which revealed that reducing TP loading in the Maumee River was most effective when the focus was on high-flow events between March and July.[57]

Selecting the natural infrastructure BMPs, prioritizing BMP location(s), and considering BMP timing can all determine the efficacy of nutrient management in a watershed. Cost considerations and land use requirements both impact the likelihood of adoption at the farm level and should be considered as part of the prioritization process along with perceived efficacy, which are the best predictors of whether a BMP will be adopted.[58] Another point to keep in mind is that, under climate change, the optimum BMP location may change should climate shift the origin of the nutrient load or if water or land use management changes occur in response to climate change.[59]

BOX 3: Canadian Government Funding for Natural and Green Infrastructure

Through the Investing in Canada Plan, over $33B in funding is being delivered through bilateral agreements between Infrastructure Canada and each of the provinces and territories. Of this, $5B is allocated for green infrastructure, with $2B of this flowing through Canada's Clean Water and Wastewater Fund. Through three targeted sub-streams of the Investing in Canada Infrastructure Program, investments under the Green Infrastructure stream will support green infrastructure projects with outcomes across three crucial areas, although continued availability of these funds needs to be assessed.

Climate Change Mitigation:

Better capacity to manage more renewable energy

Improved access to clean energy transportation

More energy-efficient buildings

Improved production of clean energy

Adaptation, Resilience, and Disaster Mitigation:

Increased structural or natural capacity to adapt to climate change impacts, natural disasters, or extreme weather events

Environmental Quality:

Upgraded wastewater treatment or collection infrastructure

Upgraded drinking water treatment and distribution infrastructure

Better capacity to reduce or address soil or air pollutants

On June 25, 2021, the Government of Canada announced a new $200M Natural Infrastructure Fund. Under this new program, the first of its kind at the federal level, up to $120M will be invested in large natural infrastructure projects. The new program will support projects that use natural or hybrid approaches to protect the environment, support healthy and resilient communities, contribute to economic growth, and improve access to nature for Canadians.

Sources:

Investing in Canada Plan Funding Streams: Green Infrastructure. Government of Canada (2020). https://www.infrastructure.gc.ca/plan/gi-iv-eng.html

Government of Canada Announces New Natural Infrastructure Fund. Government of Canada Press Release, June 25, 2021. https://www.canada.ca/en/office-infrastructure/news/2021/06/government-of-canada-announces-new-natural-infrastructure-fund.html

Priority Analysis for Nonpoint WQT Credit Generation

Analysis was completed using Arc GIS and available landcover and water quality data. In order to identify farms and nonpoint sources that have conditions most suitable for implementing P load reductions, three key characteristics were identified: type of crops planted, soil drainage, and farm slope. Farms used for crops (e.g., wheat, corn, soybean) are more likely to receive significant amounts of P fertilizer per hectare, relative to pasturelands and other crops, and those in forested or residential use are likely to receive the least amount of loading. Soils with poor drainage are more likely to lead to significant runoff, which is the main transport pathway for P, whether it is dissolved or adsorbed onto soil particles. Well-drained soils (e.g., sandy soils) allow for infiltration of snowmelt and rainfall and are less likely to result in runoff for most storms. Steep slopes accelerate runoff towards receiving waters (rivers, lakes, streams, drainage ditches), while flatter lands minimize runoff.

The Red River region was evaluated using the scoring criteria in Table 4-1. For example, a score of 1 was given to grains and other fertilized crops; soils classified with Poor (P) or Very Poor

(VP) drainage; and lands with a slope >7%. Slope was divided into four categories to identify a broader range of possible locations. The total score is the average of land use, soil drainage, and slope scores for a particular location.

Table 4-1
Criteria for scoring land use, soils, and slope

Land use	Score	US Soil Drainage (equivalent)	Score	Canadian Soil Drainage	Score	Slope	Score
Grains and crops	1	SP, P, VP	1	P, VP	1	>7%	1
Pasture	2	W, MW	2	W, MW, I	2	4-7%	2
Other land use	3	VR, R, ES	3	VR, R	3	2-4%	3
						<2%	4

Abbreviations:

W = Well Drained
MW = Moderately Well Drained
I = Imperfect
SP = Somewhat Poorly Drained
VP = Very Poorly Drained

VR = Very Rapid
R = Rapid
ES = Excessively Drained
P = Poor

Figure 4-2 presents the spatial distribution of the scoring of land use. A significant fraction of the land is used for fertilized crops, particularly in the central and western regions of the watershed. The areas in gray are either urban areas (e.g., City of Winnipeg), water, or natural forest. Although they may have some P fertilizer applied, it is generally much less than for grains and other crops. Most of the land in the Red River Basin watershed has a slope <2%, as shown in blue in Figure 4-3, although there are a number of fields with larger slopes, particularly in the eastern region (Canada and US) and the southwestern region (US). In particular, the long valley through which most of the Red River flows from south to north has a slope generally below 2%. Soil drainage was available at different levels of resolution, with a coarser scale for the Canadian region (Figure 4-4). There are differences in the categorization of drainage between Canada and the United States. Many soils, particularly on the Canadian side, are classified as medium in terms of drainage, while a substantial part of the US side has poor drainage. In some cases, this may reflect actual physical differences in soil characteristics. In other cases, the classification indicates a clear difference in the approach and level of spatial resolution for the classification. The final prioritization (Figure 4-5) encompasses numerous farms within categories 2 and 3, which means that many farms could be good TP credit generators by implementing various BMPs.

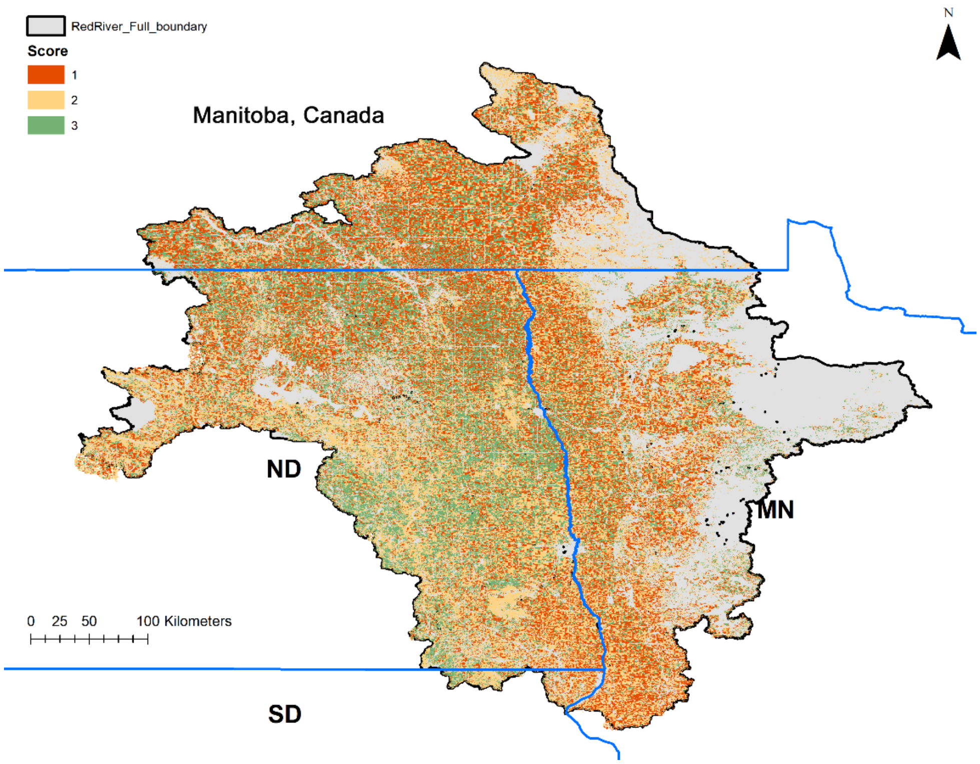


Figure 4-2
Agricultural land classification

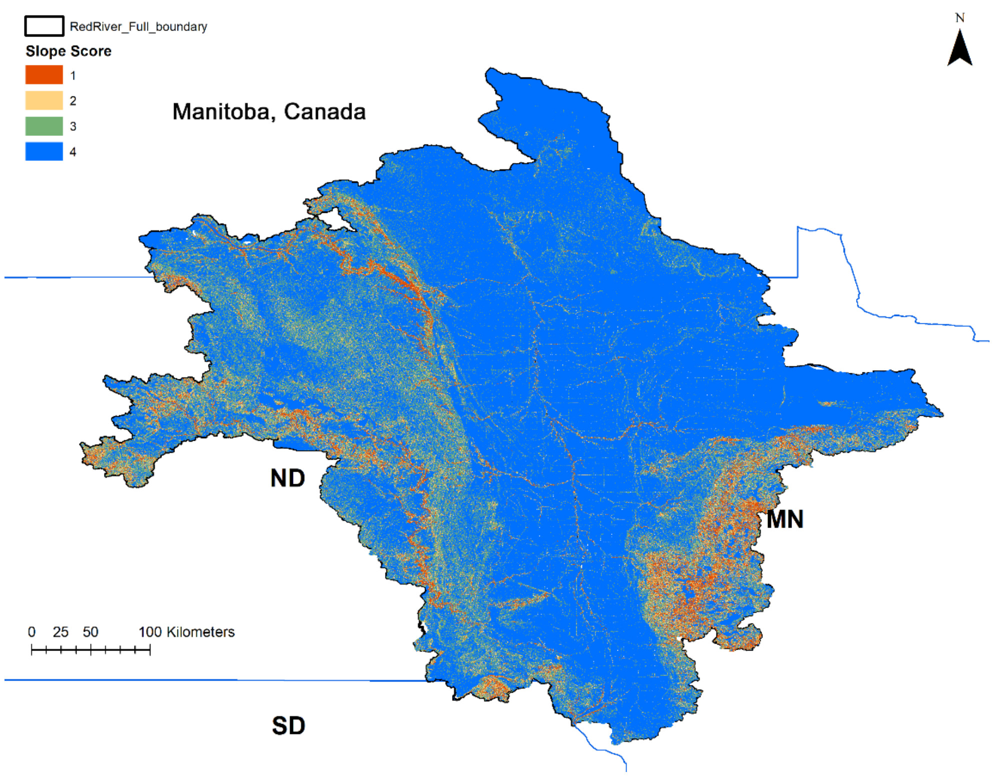


Figure 4-3
Slope classification

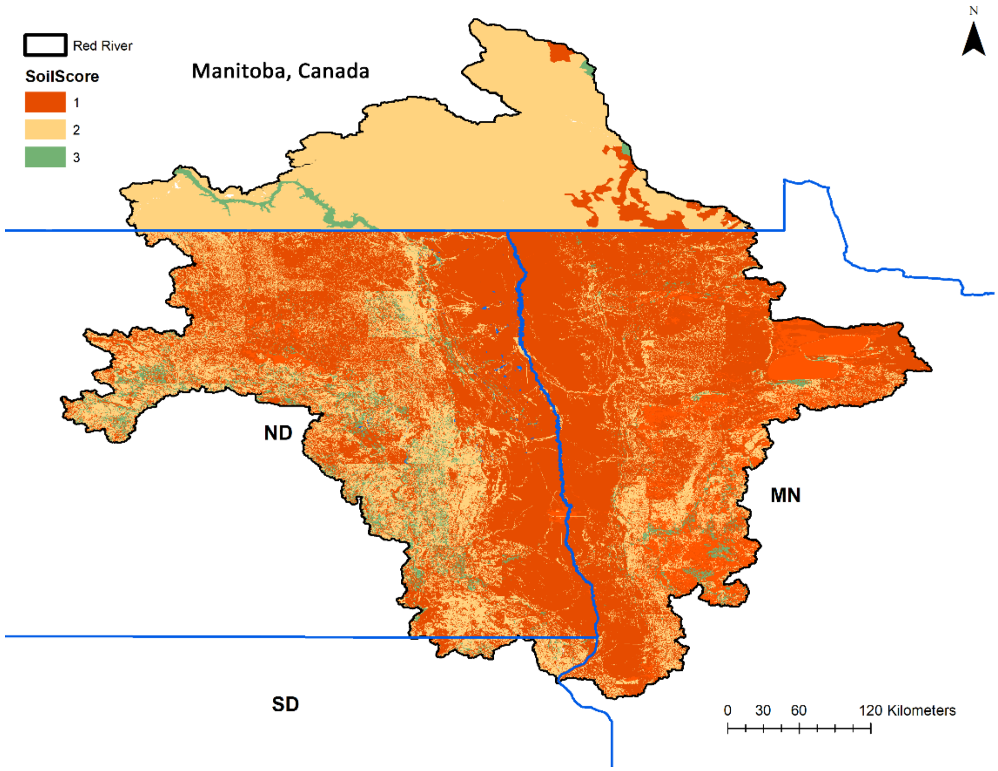


Figure 4-4
Soil classification

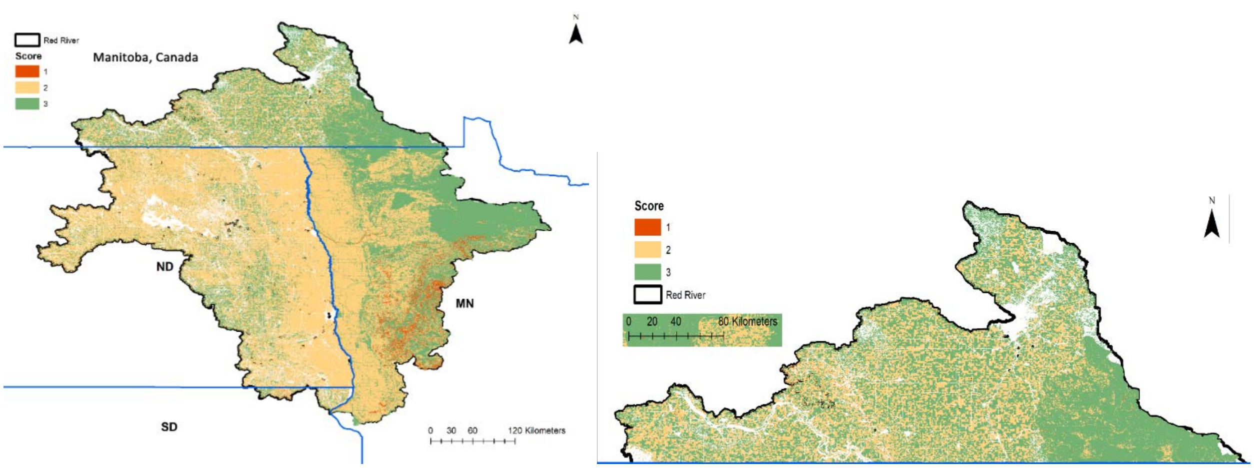


Figure 4-5
Prioritization for BMP implementation (Left: Full Red River Basin. Right: Canadian portion only)

Water Condition Summary

Current P load to Lake Winnipeg is estimated to be around 7,900 tons/yr TP. The nutrient target is 2,800 tons/year. Therefore, a reduction of 5,100 tons/yr from current loading is needed to reach the target. The City of Winnipeg North End Sewage Treatment Plant contributes around 300 tons/yr (about 4% of total TP loading to the lake) and therefore is a key potential credit buyer.

Legacy TP in soils contributes more than 75% of loading into Lake Winnipeg. This legacy P is bound to sediment and can take many years to reach the lake, primarily released during disruptive events, such as rain and snowmelt. WQT can tackle a portion of this legacy P with BMPs such as cover crops and other approaches to stabilize legacy P in the soils and store it in vegetative growth. The specific amounts of legacy P could be estimated using more sophisticated modeling than was done in this Phase 1 feasibility assessment; however, the large amount of legacy P in rivers would be very hard to address with the BMPs implemented in WQT.

New P comprises approximately 25% of the annual P contribution to the lake. This new load is the primary focus of a WQT program. Of this new load, the vast majority of new P is from nonpoint sources rather than point source dischargers. It is notable, however, that the City of Winnipeg contributes the majority of this new P loading and is therefore an obvious buyer of TP credits.

Canada contributes 40% of TP into the Red River loading, with 60% of TP coming from the United States. Following are some key points regarding only the Canadian TP loading to the Red River:

- Agriculture represents >72% of land use.[60]
- Nonpoint sources contribute 70–100% of TP loading, depending on the subwatershed.[61]
- P loads are around 6–110 kg/km^2-yr.[62]
- Around 62% of TP load occurs in a 2–3 week snowmelt period.[63] Throughout the year, 40% of the TP load is distributed.
- In township areas, the point source is 5% of TP loading, while the nonpoint source is 95% of TP loading.
- In city areas, the point source is 70% of TP loading, while the nonpoint source is 30% of TP loading. (The City of Winnipeg North End Sewage Treatment Plant is 5% of total TP loading into the lake.)
- In terms of topography, the landscape is relatively homogeneous, leading to equitable landowner opportunities for participating in TP load reductions.
- Hog farms may be a significant source of loading, but that would need to be verified with an expanded watershed modeling analysis.
- This analysis did not differentiate loading from First Nations, municipal, and provincial lands. Rather, we looked at generalized point source vs. nonpoint source nutrient contributions to the waterway. In general, however, with the vast majority of TP loading coming from nonpoint sources, there will most certainly be a mix of First Nations, municipal, and provincial contributions to the overall water quality. More analysis on the relative proportions can be completed in the next phase of research.

The unique watershed characteristics, nutrient sources, and seasonal dynamics will be important to consider during program development. For example, selecting conservation practices that can mitigate TP loading during the intense snowmelt periods will be advisable.

BOX 4: Purpose and Outcomes of Watershed Modeling

For the next phase of analysis, it is useful to develop a calibrated watershed model for the Canadian side of the Red River Basin and to provide an assessment of the magnitude of agricultural loads from the Red River to Lake Winnipeg in the Manitoba province. The calibrated model will be used to evaluate scenarios for the implementation of various Best Management Practices (BMPs), including those based on natural infrastructure, to estimate nutrient load reductions. This will serve to provide an assessment of the location, number, and type of BMPs needed to generate credits. Point source information will be used to estimate their contribution to nutrient loads in the river and assess the need to buy credits. Within the assessment, the specific TP loading for First Nations and the Province lands will be estimated, based on available information.

After consideration of various modeling capabilities, the suggested approach is to calibrate the Watershed Analysis Risk Management Framework (WARMF). WARMF is a watershed model and decision support system which simulates the physical, chemical, and biological processes in a watershed and provides scientific information to stakeholders. WARMF is used to address a wide range of water quantity and quality issues including determining the source of water quality impairment and potential solutions, understanding climate change impacts, watershed stewardship, and real-time management. WARMF has a comprehensive simulation engine which simulates watershed physical processes on a daily or shorter time step. WARMF has advanced tools in its graphical user interface to identify the contributions of pollutant loading from geographic areas and land uses so stakeholders can identify problems, formulate alternatives, and reach consensus on an alternative that is scientifically sound and politically acceptable.

The WARMF model will require spatial and temporal datasets, as well as an assessment of the potential load reductions from various BMPs using the Nutrient Tracking Tool (NTT) or its underlying model, APEX. This approach has been successful and well-documented by the Ohio River Basin Water Quality Trading Project and peer-reviewed scientific papers.

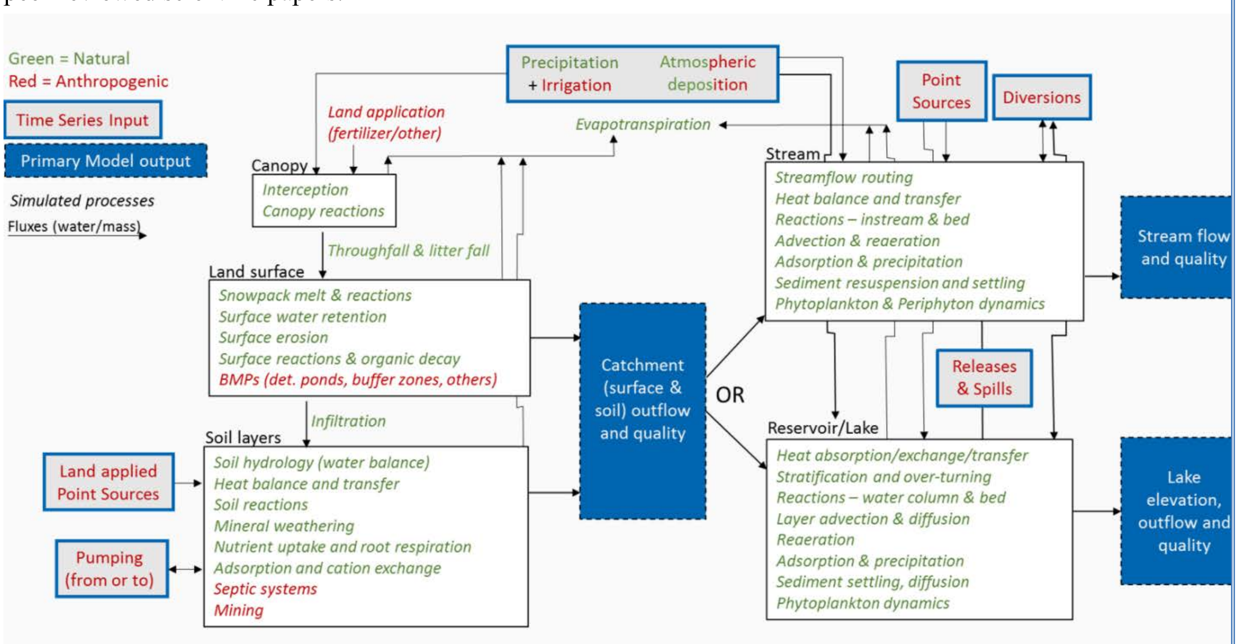


Figure: WARMF Model Simulation Processes. Source http://systechwater.com/warmf_software/

5
CREDIT BUYERS AND SELLERS

Potential Credit Buyers

The report does not attempt to complete a detailed assessment of potential buyers and sellers, which is needed. However, it is possible to do an initial "reality check" on the viability of sources of credits and the potential purchasers of the TP and TN reductions.

We know that there are many potential sources of credit generators based on the initial watershed analysis. On the buyer side, is important to consider the following categories:

- **Corporate Stewardship.** There are organizations that may have an inherent interest in supporting Lake Winnipeg and the surrounding community, even without a regulatory driver. Winners of 2021 Canada's Greenest Employers[64] in the Manitoba region, include Manitoba College, Assiniboine Credit Union, Manitoba Hydro, and Pacific Blue Cross. These organizations generally have broader sustainability commitments that go beyond regulatory obligations and may be interested in purchasing verified water quality credits and associated ecosystem services (carbon, biodiversity, First Nations, etc). In addition, there are several large corporations based in Manitoba, particularly in the agricultural sector, that rely on clean, accessible water and therefore have a vested interest in supporting water quality improvements. This concept is discussed further in Box 5.
- **Hog farms.** There appears to be a heavy presence of hog farms that may be a significant source of loading. These farms could be either buyers or sellers of credits, depending on their requirements and incentives for reducing TN and TP loading.
- **Combined Sewer Overflows (CSOs).** The CSOs throughout the region likely account for significant nutrient loading. These will continue to be a source of TN and TP to the waterway. While they do not hold enforceable permit limits, they could still be a source of credit buyers if paired with attractive incentives.
- **Sewage Treatment Plants.** The City of Winnipeg operates several water treatment plants with permit limits and general sustainability expectations that could be met with WQT credits. The North End Sewage Treatment plant warrants specific consideration, as discussed below.

North End Sewage Treatment Plant

The North End Sewage Treatment Plant is the City of Winnipeg's oldest and largest sewage treatment plant. First commissioned in 1937, it provides 70 percent of the city's wastewater treatment[65]. Of the three plants within the City of Winnipeg jurisdiction, the North End plant is the one discharging the most significant loading of TP and is the single largest point source of TP in the region (Figure 5-1). The plant is discharging 4–5 times their permit limit of 1 mg/L.

The September 2020 Monitoring Data Report shows a discharge of 3.9–5 mg/L TP, License 2684 RRR.[66] There is an opportunity for the plant to adopt a combined nutrient management approach that includes both technology and WQT approaches. By including WQT in the overall nutrient management approach, TP reductions can be achieved more quickly with greater ancillary ecological and social benefits.

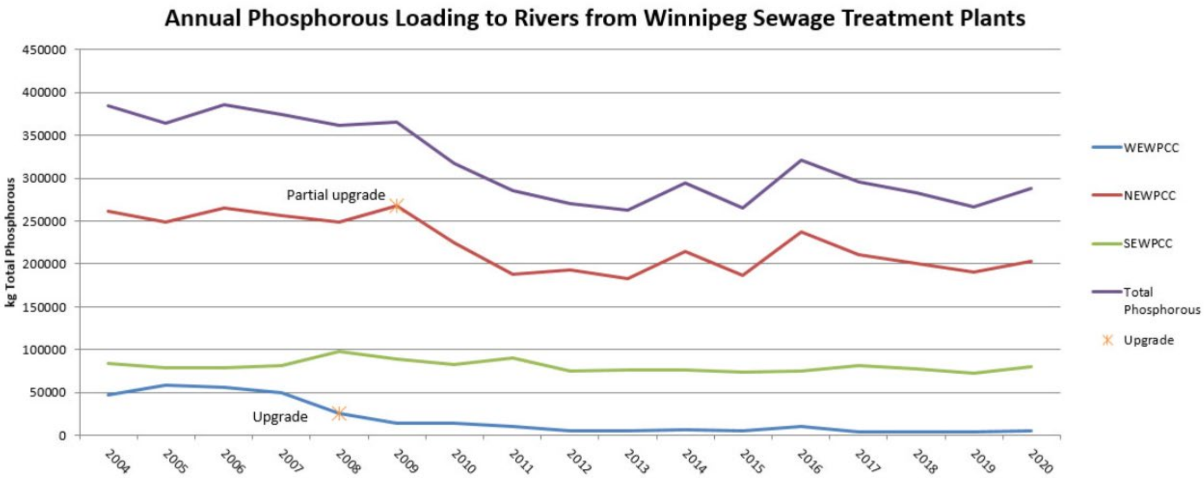


Figure 5-1
TP loading of Winnipeg Sewage Treatment Plants (Source: https://winnipeg.ca/waterandwaste/sewage/ProtectingOurWaterways/index.stm)

As part of the Winnipeg Sewage Treatment Program, the plant is undergoing one of the largest, most complicated upgrade projects in North America in order to meet the requirements of the Environment Act Licence[67] requiring treatment for TN and TP. The three capital projects and cost estimates (including interest charges) to complete the North End Treatment Plant upgrade are estimated at[68]:

1. Power Supply and Headworks Facilities - $408 million;
2. Biosolids Facilities - $553 million; and
3. Nutrient Removal Facilities - $828 million

In July 2021, the phase 1 for the Power Supply and Headworks was finally funded after a series of delays over nearly a decade[69]. Phase 2 and 3 are not funded, not approved, nor scheduled. According to the city, the biosolids effort (Phase 2) might be funded in 2023 and the nutrient removal upgrade (Phase 3) could be funded sometime in 2035, although the schedule is nebulous (see Figure 5-2). It is not clear if all the TP issue will be addressed after the Nutrient Removal Facility upgrade is complete and limited nutrient reductions will occur prior to that upgrade. At the current moment, it appears that the nutrient discharge will continue at pace (or increase) through 2035. WQT can begin much sooner to reduce TP loading while the technology is pursued.

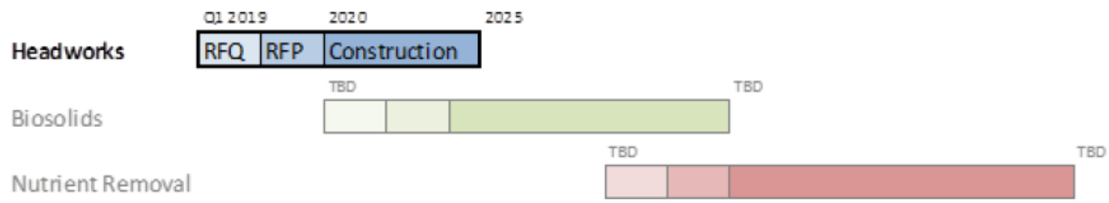


Figure 5-2
North End Sewage Treatment Plant Upgrade Schedule

Watershed Influence on Buyers and Sellers

In general, credits are generated upstream of where credits are applied (Figure 5-3). This prevents degradation of the waterway between buyers and sellers. If a point-source discharger were to release water into the watershed upstream of where reductions were realized, there is a risk of “hot spots” and temporal degradation of the waterway for the distance between the buyer and seller (Figure 5-3B). This practice of requiring credits to be generated upstream of the applicable buyer is referred to as “upstream trading” and prevents unintended degradation of water (Figure 5-3C). In the United States, the Clean Water Act prohibits the creation of “hot spots” or degradation of a waterway as a result of WQT. This prohibition has guided most WQT programs to require only upstream trading. However, as illustrated in Figure 5-3, despite the potential to create localized “hot spots,” downstream trading can provide benefits to a receiving waterbody compared to “Business as Usual” (no trading), which appears to be the circumstance for Winnipeg.

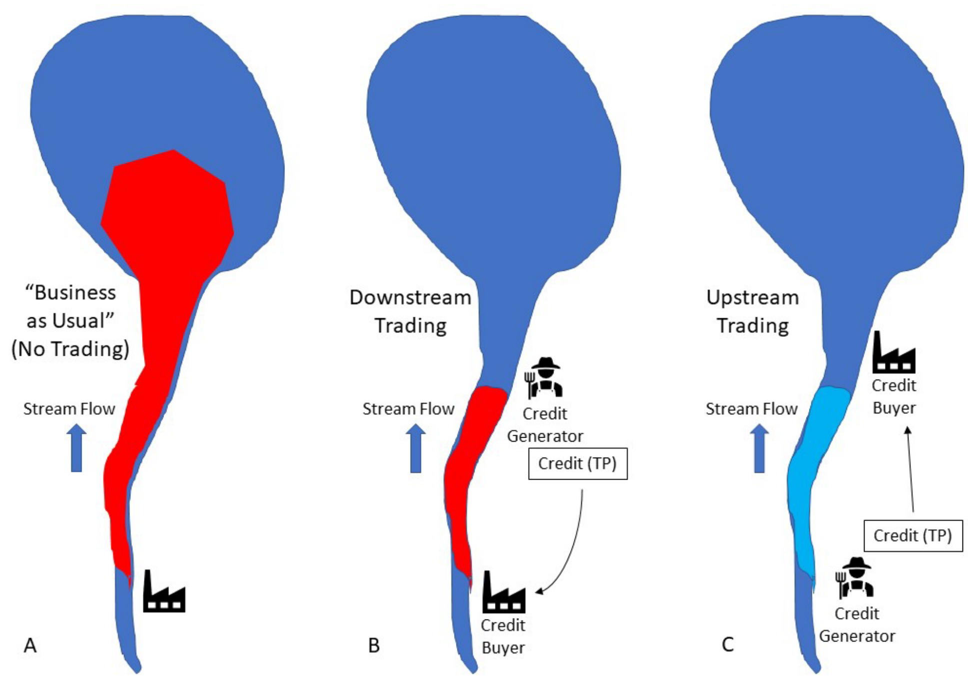


Figure 5-3
TP levels in a waterbody illustrating (A) no WQT, (B) downstream trading, and (C) upstream trading. Red shows areas of elevated TP levels, while light blue shows areas of improved water (TP less than background) provided by credit generation.

The issue of upstream trading is particularly relevant for Lake Winnipeg due to the location of the anticipated large credit buyer, North End Sewage Treatment Plant. The plant is located very near the lake and downstream of nearly all potential credit generators. Nearly all potential nutrient reductions will occur upstream of the plant, which is ideal for a WQT program and results in water quality improvements before the primary credit buyer discharges into the waterway.

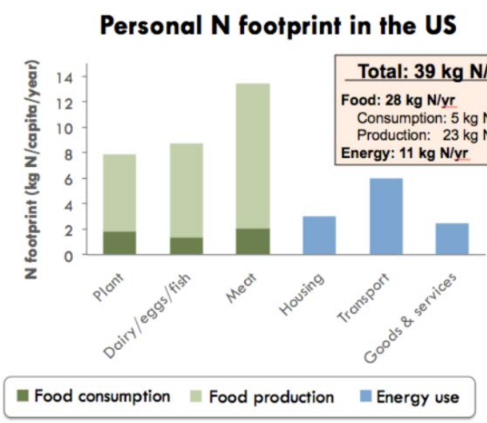
Given that 60% of TP loading comes from the United States portion of the Red River Basin, it is useful to consider a future international trading program. The issue of upstream trading arises under a scenario of a potential cross-boundary US-Canada WQT Program for Lake Winnipeg. With the US loading all occurring upstream of Canada, US landowners have many opportunities for generating credits and being credits sellers, but few opportunities for purchasing credits from Canadians. Unless water and program conditions allowed for downstream trading (i.e. there are no impaired waters that might be further degraded), there will be limitations to specific buyer-seller scenarios across the region. This can be further considered in a future phase of the analysis.

Finally, the relatively homogeneous nature of the watershed, as indicated by the priority analysis for BMP installation, points to opportunities for land managers throughout the watershed area to reduce nutrients and participate in the WQT program. Hence, the execution of a WQT project in the Red River Basin will not require explanation of complex biogeochemistry conditions that cause preferences for a particular landowner receiving funding. Indeed, it would have been difficult on a social level to implement a program if the watershed dictated preference to First Nations and/or provincial lands; however, this is *not* the case.

BOX 5: Beyond Compliance: Personal and Corporate Credit Buyers

The EPRI Ohio River Basin WQT Project markets credits to personal and corporate stewardship buyers, widening the reach of the market.

The Ohio River Basin Water Quality Trading Project is a market-based approach to reducing water pollution through a first-of-its-kind credit trading program and was recognized for its innovation by winning the US Water Prize in 2015. Working with small farmers, the water quality credits protect watersheds that support agriculture operations by providing a science-based option for those seeking to mitigate supply chain impacts, satisfy personal environmental footprint goals, and meet larger corporate sustainability targets. The credits align with various sustainability programs and disclosures, including GRI, CDP, United National Sustainable Development Goals, and CEO Water Mandate. EPRI's collaborators at First Climate can arrange for purchases of 1 to 100,000 credits.



Source: Ohio River Basin Trading Project. EPRI. http://wqt.epri.com

6

GOVERNANCE STRUCTURE FOR LAKE WINNIPEG WQT PROGRAM

Given the number of potential partners and interested parties, taking a collaborative approach to developing a Lake Winnipeg WQT Program is advisable. A collaborative approach can allow for input from many groups, although it can take more time develop a program that is responsive to input. The resulting effort, however, can carry more support and participation than a "going at it alone" approach. Even for the collaborative model, it is useful to have one organization act as the program manager and accountable party to keep the effort proceeding. It is important for this program manager to have institutional capacity, fiduciary stability, and experience facilitating discussions that result in decision making (not just brainstorming). An example of a collaborative approach with an accountable and invested overseeing program manager is the EPRI Ohio River Basin Water Quality Trading Program, described in Box 5.

CLI appears to be a viable option for acting as the program manager, although not the only option, for leading the WQT project (see Box 6). Given their intrinsic approach to collaboration and reconciliation to address shared land and water challenges, CLI offers an existing table for facilitating agreement on the structure and rules of WQT for Lake Winnipeg. In fact, CLI has already spearheaded conversations regarding the creation of a WQT program for Lake Winnipeg for ecological, social, and economic benefits. One participant in CLI is the City of Winnipeg managing the North End Sewage Treatment Plant (the largest single contributor of TP to Lake Winnipeg), which will give them an active position to inform program development. This may prove important as their role in purchasing credits will be critical to program success. As a novel collaboration that includes participation from many leaders, CLI seems to provide a strong platform for facilitating decisions on the specific rules of a WQT program (see Box 1 for summary of WQT key elements).

BOX 6: Collaborative Leadership Initiative (CLI)

CLI, a collaboration of First Nations municipal political leaders, was formed in 2017 when 28 elected leaders in the Winnipeg Metropolitan Region and Indigenous First Nations Chiefs met and agreed there needed to be a better way to work together and that the status quo was insufficient. They agreed to pursue a collaborative approach to allow them to address shared social issues, create good jobs and a strong economy, and pursue the complex issues of protecting land, water, and air. The elected leaders committed to clearly defining common interests, identifying obstacles to progress, and dispelling mutual myths with the fact-based dialogue of mutual respect.

On March 1, 2019, Municipal leaders of the Winnipeg METRO Region (WMR) and the Chiefs of the Southern Chiefs' Organization (SCO) made history at Lower Fort Garry National Historic Site in St. Andrews, Manitoba – the location of the historic signing of Treaty 1 in 1871, 150 years ago. The 25 elected leaders working together in the CLI signed a Memorandum of Understanding recognizing the considerable value of First Nations and municipal governments formally agreeing to work together on common goals and interests.

Source: Collaborative Leadership Initiative (2021). https://www.collaborativeleaders.ca/

Another approach would be for the City of Winnipeg to lead the project unilaterally, as the primary purchaser of credits in the program. The city could release a payment program for land-based projects that reduce TP loading, establish contracts directly with landowners for installing conservation practices, pay for those contracts, and use the resulting credits towards their permit limit with provincial approval. This approach limits participation to only one buyer and gives full authority and responsibility for the effort to the city. While the authority is clear with this approach and it could be implemented relatively quickly compared to a deliberative process via CLI, the approach does not leverage collaboration or reconciliation. Fundraising under this approach may be limited and the city would likely be responsible for all costs. However, as the City of Winnipeg would be the primary buyer of credits regardless of governance structure, this approach could reduce loading to the lake and create new funding streams for landowners for conservation practices. All details would, of course, be driven by city preferences as the sole source credit buyer. An example of this approach is the Alpine Cheese Factory WQT Program in Ohio (coordinated by Ohio State University) where one buyer, the cheese factory, purchases credits from various farmers.

Additional approaches may be identified in Phase 2 of this feasibility assessment; thus, it is prudent to remain open and flexible to alternative approaches.

Further Contemplating CLI as WQT Program Coordinator

In further contemplating CLI as a program manager, below is consideration of some initial actions and milestones. CLI could act as the initial coordinator for all steps leading towards a functioning WQT project. This allows for all CLI signatories to participate in the early development of the trading program, including the City of Winnipeg and the North End Sewage Treatment Plant. CLI could drive actions and meetings to realize its organizational purpose by leading this effort. This effort could create funding opportunities for the project and CLI.

CLI will need to establish a clear budget and designate a project manager. Once the rules of the program are determined via collaborative discussions with CLI leaders, capacity and organizational infrastructure needs can be defined and acquired. As a benefiting organization, the City of Winnipeg and/or the province may be willing to make an enabling funding commitment to allow early work to proceed.

Possible Milestones Include:

- Month 1: CLI leaders sign commitment statement for working together to consider and determine the rules of the WQT program.
- Month 2-8: Facilitate agreement on program design and rules and develop a governing “Trading Plan”.
- Month 12: The Trading Plan for Lake Winnipeg WQT Project is signed by appropriate signatories and enabling parties.
- Month 13+: Implement Winnipeg WQT project per Trading Plan.

Collaborating Organizations

An effective program will need to consider the participation and roles these various organizations, all of which have their own expertise and perspectives. A partial list is below:

Governance Partners

- Treaty One Development Corporation
- Southern Chiefs' Organization
- Winnipeg Metropolitan Region
- Watershed Districts

Agriculture Partnerships

- ALUS Canada
- Keystone Agricultural Producers

Capacity and Expertise

- International Institute for Sustainable Development
- Lake Winnipeg Research Consortium

International Partnerships

- Red River Basin Commission
- International Joint Commission

7
SUMMARY

Watershed conditions, legal construct, and available institutional capacity all indicate viability for development of a WQT program to address a portion of the TP loading to Lake Winnipeg. This leaves the primary consideration of securing potential credit buyers; an entire program could be built, but without credit buyers committed, the program will not succeed. The number one discharger of TP into the Lake is the North End Sewage Treatment plant, which is immediately the focus of the credit buyers.

Under intense social pressure, the City of Winnipeg is facing a scenario of spending $1.8B on upgrades at the North End Sewage Treatment Plant[70] and the nutrient treatment technology has no apparent viability of being installed for about a decade or longer. The Province and community may be willing to offer flexibility in approaches for the City of Winnipeg to mitigate nutrient loading in the interim, while the technology solution is funded, approved, and installed (possibly not until 2035). As this is the single largest contributor of TP to the lake and there are no comparable regulated dischargers, the North End Sewage Treatment Plant offers the most obvious purchaser of credits and likely the best chance of success for a WQT program. Similarly, WQT can offer a real solution for the city.

The City of Winnipeg could engage to establish a WQT program and in parallel pursue funding, approval, and installation of the nutrient treatment system at the North End Sewage Treatment Plant. This will show action and commitment to the lake and community through a creative and collaborative approach. WQT does not need to provide the entire TP loading reduction solution for the plant, but it can be a viable interim approach to achieving reductions over the next 10 years while a technology upgrade is pending. The WQT credits are also excellent for nutrient reduction shortfalls that may occur even after the technology approach installed.

Other options for credit buyers, such as organizations interested in investing in corporate stewardship initiatives, should be explored concurrently.

Primary Factors Supporting/Limiting Lake Winnipeg

The following factors support a Lake Winnipeg WQT Program:

- Water quality issues are not subsiding, and nutrient loading has increased significantly over the last 10 years. Province, First Nations, municipalities, local residents, and the ecosystem are anxious for a viable solution.
- There are no legal prohibitions against a WQT program, and there is existing expressed support, as detailed above.
- While there is heavy TP loading from nonpoint sources, numerous nonpoint source conservation practice options are available to reduce loading, indicating strong potential supply of WQT credits. Equitable opportunity exists for landowners to create credits due to

homogeneous watershed conditions and the downstream location of the primary buyer. This avoids potential complications associated with "ranking" landowners and explaining complex scientific modeling as the basis for individual landowner engagement.

- Funding opportunities may be available via the Government of Canada (Box 3), Province of Manitoba, City of Winnipeg, and others interested in adopting a "no regrets" approach to protecting the lake in the immediate future.
- The CLI has initiated discussions on WQT with leaders and has confirmed general interest and support at a conceptual level.

Two underlying ecological realities limit the application of WQT for Lake Winnipeg, as follows:

- Legacy TP will limit WQT as *the only* solution for nutrient management – other approaches are advisable to fully address excessive nutrient loading, particularly approaches to mitigate legacy TP.
- The lake may not experience benefits for at least 3–5 years after SIGNIFICANT conservation practices are installed. The exact number and types of conservation practices necessary to show demonstrable changes can be assessed using a calibrated watershed model (suggested in the Next Steps section). Expectations regarding when the average person will see changes in the lake's water conditions should be managed.

The specific contributions of First Nations to TP loading were not assessed but could be done in the next phase of the work. Clearly, there is an important role for treaty landowners in installing BMPs that create TP credits in the Red River Basin.

Next Steps

The following are steps to proceed in developing a Lake Winnipeg WQT program:

1. Develop a calibrated watershed model to perform detailed analyses of land use, soil, slope, and nutrient loading. The modeling will allow for a scientifically based assessment of nutrient attenuation and therefore credit trading ratios. Modeling can help target specific areas in the watershed for various BMP types, consider installation of natural infrastructure types, and determine whether infrastructure improvements will result in the necessary TN and TP outcomes. It is critical to structure a WQT program with detailed consideration of the watershed flows and dynamics. Otherwise, the risk is that the program will not help realize the intended ecological and nutrient reduction outcomes.
2. A calibrated watershed model along with social-economic analysis is needed to advance an assessment of potential buyers and sellers. On the buyer side, it is important to review corporate stewardship buyers, hog farms, CSOs, and nonpoint source credit buyers. This includes assessing the specific TP loading, financial motivations, and willingness to participate of First Nations, municipalities, and the Province. This will determine the number of credits that can be created and the potential to sell those credits.
3. To maximize legal support for WQT in Lake Winnipeg, a targeted amendment to the Manitoba *Water Protection Act* similar to the *Ontario Water Resources Act* would be helpful.
4. Amend the Water Quality Standards, Objectives, and Guidelines to clarify whether and to what extent WQT may be used to achieve compliance. This could be done in concert with

any amendments to the Manitoba *Water Protection Act*, further reinforcing the other explicit statements in support of WQT in the Climate and Green Plan and proposed Nutrient Targets Regulation.

5. Advance discussions to understand the City of Winnipeg's commitment to the WQT program. Is the city able to make an upfront credit purchase contracts to create certainty and stability for a new program? Analysis of the viable path for North End Sewage Treatment Plant to engage is important. As the single largest discharger into the lake, the city's buy-in is important to ensure a viable path forward for WQT in the Red River Basin.
6. Engage with local organizations and corporations to gauge interest in the use of water quality credits to meet corporate stewardship objectives.

Conclusion

While previous WQT studies for Lake Winnipeg date back more than a decade, none have focused on the fundamental threshold factors across social, environmental, economic, and legal realms. With this initial phase 1 assessment is complete, it will be important to proceed with the noted next steps to continue assessing the reality of the program.

Water conditions in the lake are predicted to decline, financial costs for alternative technologies approach $2B for the largest single discharger with no clear path to reduce TP loading in the next decade, large amounts of funding is available from the Government of Canada to implement natural infrastructure projects, and there is the existence of a motivated collaborative leadership group (CLI) that has the potential to advance the effort.

A Lake Winnipeg WQT Program is a good way to help meet nutrient reduction requirements of the North End Sewage Treatment Plant in lieu of a technology-only approach, which may still be a decade away. It may also help mitigate the problem of non-regulated CSO and non-point source TP and TN loading which are classically intractable issues to solve. Finally, WQT for Lake Winnipeg is a "no regrets" strategy that uses natural infrastructure with ancillary benefits including carbon, biodiversity, and landowner support that go well beyond what can be achieved by only a technology-based solution.

A
LITERATURE REVIEW OF NUTRIENT LOADS TO LAKE WINNIPEG

By Kendra Garner and Arturo A. Keller

Introduction

Lake Winnipeg is the sixth largest freshwater lake in Canada, with an area of about 23,750 km^2.[71,72] The lake is an important resource for fisheries, hydroelectric power, and tourism. Historically, the region was dominated by grassland prairies and wetlands.[73] More recently, it is a major agricultural area with significant human activity, though a sparse population.[74] The agricultural modification has resulted in a loss of wetlands and significant alteration to the streams and river channels.[75] Lake Winnipeg is a shallow, well-mixed lake with a turbid Southern Basin and a deeper North Basin, separated by a narrow and hydrologically complex channel, called the Narrows.[72] The depth ranges from 9 m in the Southern Basin to 13.3 m in the Northern Basin, with the deepest points found in the Narrows.[72] Residence time is relatively short, ranging from at 3–5 years on average, but with significant annual variability (2.5–8 years).[71,72]

Historically, the basin was mesotrophic, with total phosphorus (TP) ranging from 15–20 ug/L and naturally occurring algal blooms.[76] However, the frequency, severity, and extent of the blooms have increased over the last several decades, largely due to increased nutrient loadings.[72] Water quality in the region is a complex international issue, due in part to the fact that Lake Winnipeg has become a eutrophic and hypereutrophic lake over the last 30 years, with TP concentrations exceeding 0.1 mg/L and more than doubling since the 1990s.[71,77,78] Riverine inputs to Lake Winnipeg largely come from the Red River (16%), the Winnipeg River (49%), and the Saskatchewan River and smaller watersheds around the lake, primarily around the South Basin (25%).[72] The Red River, despite its lower contribution to flow, is the primary source of nutrients to Lake Winnipeg, contributing as much as 68% of the annual TP load.[72,78] The majority of inputs are from nonpoint rather than point sources.[6] Given its importance in terms of TP loads, this review will focus on the Red River Valley (RRV), which is a transboundary watershed covering nearly one million km^2 stretching from the United States to Canada across Minnesota, North Dakota, and Manitoba (Figure 1). The Nelson River starts at the outlet of Lake Winnipeg and is not a tributary.

The increase in eutrophication can be tied directly to livestock and agriculture, rather than the effects of climate change.[76,79] The average annual TP loads from anthropogenic and natural sources are estimated at around 6,000–8,000 tons per year, while total nitrogen (TN) loads exceed 40,000 tons per year.[79,80,81,82] Knowledge of the timing of nutrient release (seasonal or episodic vs. year-round), mode of delivery (point vs. nonpoint), and within-river transformations are critical to predicting the magnitude of nutrient export and, thus water quality implications including eutrophication, algal blooms, and biodiversity.[80] A 2020 *State of Lake Winnipeg* report points to climate change, invasive species, land use change, fishing pressures, and land and water management changes as significant challenges to maintaining a healthy aquatic ecosystem in Lake Winnipeg and, in particular, the RRV.[71]

Climate

The region experiences a cold, continental climate typical of the Canadian Prairie.[75] Average annual temperature in the RRV is 4°C, and the region receives about 500 mm of precipitation annually, with greater precipitation occurring above the Manitoba escarpment on the western edge and drier conditions below.[75,83] Air temperatures vary considerably, with mean annual temperatures ranging from -0.7°C in the north to 1.6°C in the south, and from to 1.1°C in the west to 0.6°C in the east.[71] Most precipitation in the region falls as rain from April to October (~75%), with a lesser amount falling as snow (~25%) in the winter months.[71,75,83,84]

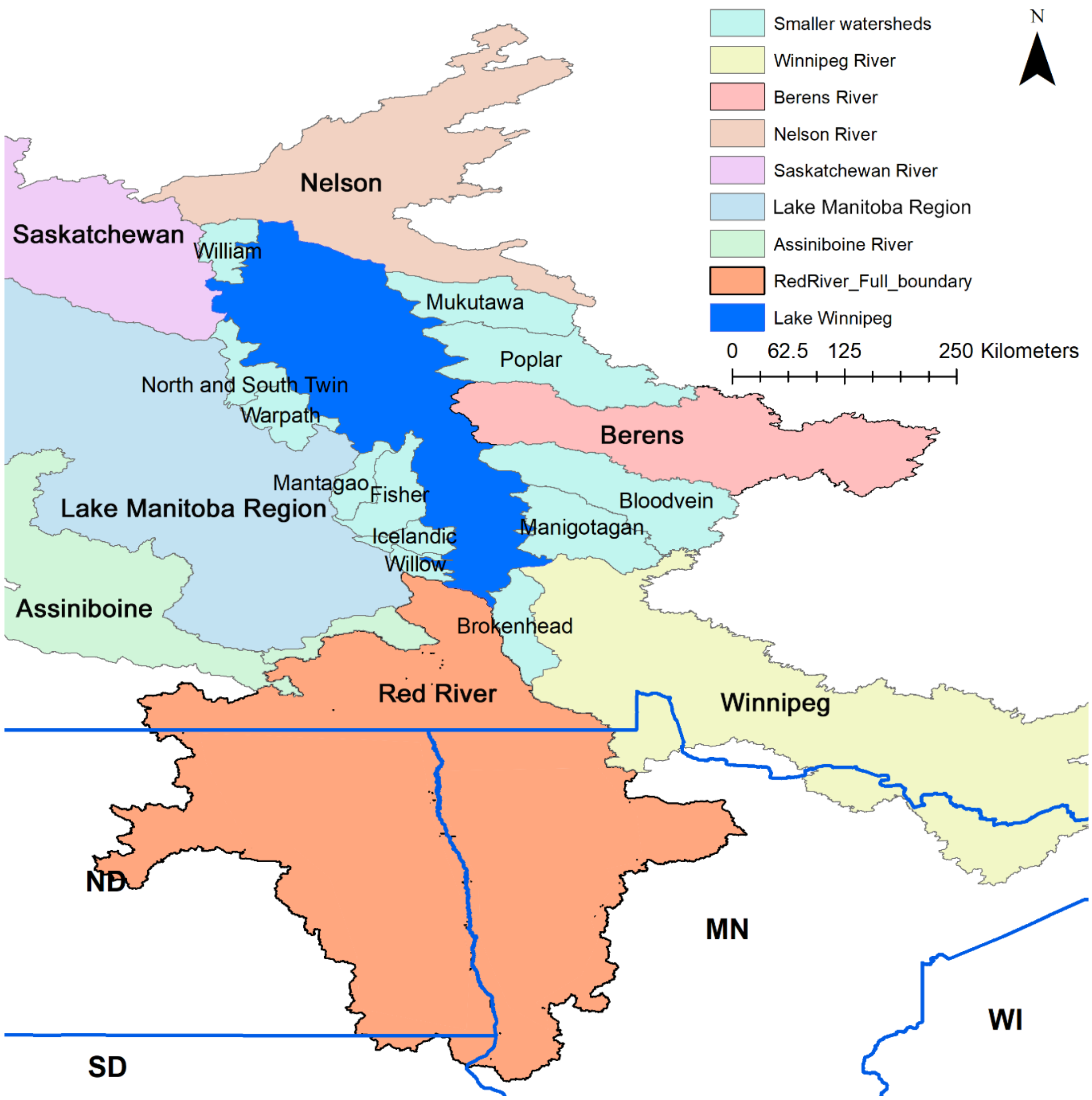


Figure A-1
Watersheds draining into Lake Winnipeg. The Nelson River starts at the outlet of Lake Winnipeg and is not a tributary.

Due in part to its latitude and continentality, the climate around Lake Winnipeg has been warming at twice the global average.[71] Future climate scenarios for the RRV predict that temperature and precipitation will increase over the next century.[84,85] Temperatures are projected to increase by 3°C more than the average under a low-carbon scenario and 4–5 °C more under a high-carbon scenario by 2080.[71] The winter, spring, and fall seasons are all projected to become wetter, while summers are projected to become slightly drier.[71,86] The area is expected to experience successively shorter snow cover duration, slower snowmelt, smaller monthly snow water equivalent, and a transition from a snow-dominated to a rain-snow hybrid regime.[86]

Hydrology

The RRV has complex geology with numerous pothole depressions into which surface runoff typically drains, forming small wetlands that retain water until their capacity is exceeded along with many channelized streams and rivers.[87,88] For much of the year, 95% of the stream channels are hydrologically inactive and remain disconnected from the main rivers because of low or no-flows, high temperatures, limited precipitation, high evaporation in summer and fall, and frozen channels in winter.[74,77] During snowmelt, however, these regions become hydrologically connected and significant flows occur.[74,85,87] As a result, inflow into Lake Winnipeg varies significantly by season and year.[89] For example, between 1999 and 2007, total annual river inflow ranged from as little as 537 m^3/s to as much as 6,854 m^3/s.[89] The bulk of the river inflow, and thus the external nutrient input, is delivered first to the South Basin before being distributed through the Narrows to the North Basin.[89]

Differences in the nutrient load from rivers create variations in water quality between the South and North Basins of the lake.[71,90] Water chemistry in the South Basin and Narrows is largely controlled by the water chemistry of the Red and Winnipeg rivers.[71] The North Basin water chemistry is controlled to a greater extent by the Saskatchewan and Dauphin rivers.[71] The Dauphin River connects the Lake Manitoba region to Lake Winnipeg.

Nutrients

Nitrogen (N) and phosphorus (P) are important nutrients for aquatic organisms, but too much of either will negatively impact an ecosystem.[711] As previously mentioned, the climate change scenarios suggest that the conditions at the lake are not going to get better; human behavior changes will be needed to result in water quality improvements. Greater increases have been observed in TP over TN across the entire valley.[75,91,92,93] Nustad and Vecchia (2020) analyzed trends in nutrient concentrations from 2000–2015 across 34 sites in the RRV and found that while there was no consistent pattern of increase or decrease in nitrogen, there was a distinct pattern of decreasing concentrations for TP in the Sheyenne and Upper Red River subbasins but increasing concentrations in the lower Red River subbasin[94]. Median nitrate plus nitrite concentrations ranged from 0.06–0.81 mg/L, whereas median TP concentrations ranged from 0.07–0.49 mg/L.[94] Major nutrient sources include synthetics fertilizers, crop residue, and livestock.[75,95] Wastewater effluent is the only significant point source in the region.[75,95] Nonpoint sources represent 59% of the TN and 73% of the TP load in the Red River Basin, most of which comes from agricultural lands.[75,81] A load apportionment model (LAM) from Rattan et al. (2020) showed that as much as 70–100% of annual TP load comes from nonpoint sources.[80]

The majority of TN and TP loads is transported during snowmelt in late winter and early spring from South of the US/Canada border.[78,78,92,96] Most of it enters tributaries in the dissolved form.[92,97] Compared to more southern temperate regions, where summer storms are the major source of nutrient runoff,[98] snowmelt in the Canadian prairies contributes as much as 80% of annual TP and TN loads.[77,99,100,101] Mean concentrations during snowmelt season can get as high as 0.57–0.82 mg/L in streams.[96] During snowmelt, stream channels are hydrologically connected along their entire length, but during snowmelt, soils are typically frozen and migration of water through the snowpack is dominated by unsaturated flow.[96,98] The volume of snowmelt runoff and nutrient delivery is affected by weather and vegetation. For example, rapid warming during snowmelt favors more runoff generation and less infiltration, while freezing and thawing of vegetation (either crop residue left after harvest or riparian plants) lyses cells and increases nutrient concentrations in snowmelt runoff.[96] Rattan et al. (2017) conducted a three-year study in the region showing that discharge and nutrient concentrations exhibited a strong seasonal pattern, with high discharge and high nutrient loads during snowmelt and lower discharge and nutrient concentrations the rest of the year that primarily correlated with precipitation events. [82,84,87,96] In fact, 62% of the annual TP load and 67% of the annual TN load occurred during the 2–3 week snowmelt period.[96] We can also expect to see this pattern shift in the future because the snowmelt pattern is changing.

Since the catchment basin is more than 40 times larger than the total lake area, riverine nutrient and sediment loads have an immense influence on water quality.[102 103] Lake Winnipeg receives as much as 96,000 tons of N and 7,900 tons of P annually, though annual loads vary significantly.[71,76] In addition to inflowing nutrients, Lake Winnipeg has significant internal loading of N and P as a legacy of past nutrient inflows and sediment resuspension.[103]

In the South Basin, nutrient concentrations are indicative of hypereutrophic conditions with mean TP and TN concentrations of 0.104 mg/L and 0.85 mg/L, respectively.[90] In the North Basin, nutrient concentrations are indicative of mesotrophic conditions with mean TP and TN concentrations at only 0.039 mg/L and 0.63 mg/L, respectively.[90] Surrounding lakes and reservoirs have the potential to sequester around 8,234 tons TP/yr and 32,108 tons TN/yr preventing their transport to, and the enrichment of, Lake Winnipeg.[104] While the total trophic reduction benefit to Lake Winnipeg is unknown, it is probably substantial, and any change to this sequestration potential could lead to Lake Winnipeg receiving higher loads of nutrients.[104]

Matisoff et al. (2017) studied sediment nutrient concentrations and found that deposition patterns mirror circulation patterns in the lake, with a south to north directional flow.[89] The highest sedimentation rates occur in the deeper portions of both the North and South Basins, suggesting that resuspension of bottom sediments results in the focusing of sediment to deeper waters.[89] TP and bioavailable phosphorus (BAP) in the top sediment layer was generally lower in the North than the South Basin, reflecting inputs from the Assiniboine and Red Rivers to the South Basin.[89] Concentrations of P were thus higher at the bottom vs. the surface of the lake.[71] BAP constitutes ~34% of TP in suspended and bottom sediments, with the remainder present largely as non-hydrolysable apatite P.[89] Research shows that in-lake resuspension remobilizes as much as the top 7 cm of the sediment back into the water column for several decades, allowing for significant continued nutrient exposure. However, because the residence time of resuspended sediment in the water column is relatively short, there are limits to the time available for nutrient assimilation to occur.[89] Projected climate change is expected to increase sediment oxygen demand, P release rates, and cyanobacterial proliferation.[103]

Climate and agricultural practices have been shown to be the major drivers of TP load in the region.[77] With approximately 72% of the land area used for agricultural production, agricultural practices are the single biggest driver of water quality across the basin, and previous modeling efforts show that fertilizer and crops contribute significantly to variations in TP load.[77] In spring and summer, TP concentrations positively correlate with discharge, livestock, and fertilizer applied in spring.[96] In summer, however, precipitation, crop cover, population served by wastewaster treatment plants (WWTPs), livestock density, and applied fertilizer positively correlated with TP load.[96] Point sources typically contribute less, particularly in winter.[80] The broader range in seasonal compared to annual contributions is indicative of changes in P sources among seasons.[80]

Ryberg (2017) used a Structural Equation Model (SEM) to explicitly explain almost 60% of the year-to-year variation in TP load in the Red River. The remaining 40% of the variance that is unexplained may be due to unquantified errors in WWTP effluent data, lack of data related to in-stream processes, generalizations made by the model, lagged factors, and/or unquantified errors in the TP load estimates.[77]

TP concentrations in streams in the RRV range from below detection (< 0.001 mg/L) to 3.27 mg/L.[96] A more recent study found TP concentrations ranging from 0.02–3.5 mg/L.[80,87] Other phosphorous concentrations consistently ranged from 0.02–3.2 mg/L for total dissolved phosphorous (TDP), 0.01–2.9 mg/L for soluble reactive phosphorus (SRP), and 0.01–3.0 mg/L for particulate phosphorus (PP).[80,87] Phosphorus loads and yields ranged from 2.2–31 tons/yr.[80] Estimated TP loads averaged 6–15 tons/yr, respectively, over 2010, 2013, and 2014.[96] Loads and yields appear to be more than proportionally higher for medium to large subwatersheds, meaning those greater than 180 km^2.[80] Estimates of the contribution from the US portion of the RRV range from 70–76% of the annual TP load, and from 70–78% of the annual TN load.[78]

Nürnberg and LaZerte (2016) estimated the internal load of P in Lake Winnipeg between 1999 and 2012 as ranging from 259–467 tons/km^2 per year. External TP inputs vary but are largest in the South Basin and smallest in the North Basin leading to much of the observed variation. Lake TP concentrations generally decrease from the southern stations through the Narrows to the northern stations.[103] Matisoff et al. (2017) estimated TP fluxes to range from 146 tons/km^2 per year in the North Basin to 264 tons/km^2 per year in the South Basin, slightly lower but in the range of estimates provided by Nurnberg and LaZerte (2016).[89,103] This could be because the estimate does not account for any TP released via resuspension, suggesting that internal loading may be an important component of the phosphorus budget in Lake Winnipeg.[89]

Soto et al. (2019) found that N input into Lake Winnipeg from the South Basin rivers can be quite variable, depending on the source river and time period. The main sources of N to Lake Winnipeg are wastewater in the Assiniboine River (62%) and inorganic fertilizers in the Red River (40%).[105] A study by Cormier et al. (2020) confirmed that the primary sources of N to the Red River were: 1) synthetic nitrate fertilizer (0 ± 3%); 2) nitrification processes arising from mineralization of organic matter and ammonium fertilizer (5 ± 5%): and 3) waste sources including livestock manure and human wastewater (15 ± 5%). In spring, the main sources were fertilizer (31 ± 7.5%), nitrification processes (26 ± 5.5%), and waste sources (43 ± 13%). These shift even more towards waste sources in summer.[106] These different source contributions are temporally variable, with a predictable decrease from fertilizer loads following spring snowmelt.[105] In the Assiniboine River specifically, riverine nitrate inputs tend be vary both spatially and temporally with higher contributions during flood events, which is important because of the likelihood of higher frequency flooding under climate change.[105]

Rattan et al. (2017) found that TN concentrations in the Red River varied between below detection limit (<0.007 mg/L) to 18.5 mg/L.[96] A similar study found concentrations ranged from 0.01–12 mg/L TN.[87] Similar to TP, highest TN loads were observed, on average, during snowmelt.[96] However, unlike TP, inter-annual patterns in TN loads did not track the hydrologic regime: annual and snowmelt TN loads were, on average, greatest in 2010 and lowest in 2014, whereas snowmelt discharge and annual discharge volume were greatest in 2013. Other N concentrations ranged from 0.01–12 mg/L for total dissolved nitrogen (TDN), 0.01–9.9 mg/L NO^3+NO^2, 0.01–3.1 mg/L NH^{4-}N, and 0.01–9.6 mg/L particulate nitrogen (PN).[87] Snowmelt concentrations ranged from 0.20–0.80 mg N/L for NH^{4+} and 0.73–3.14 mg N/L for NO^{3-}. Rattan et al. (2017) compared seasonal concentration averages and found that in spring, TN showed negative associations with precipitation and positive associations with sewage. However, in summer, TN was positively associated with precipitation and sewage but negatively associated with applied fertilizer.[96]

Over the last two decades, the types and total amount of phytoplankton present (reported as biomass) have varied considerably in response to changes in lake nutrients, temperature, and light, among other factors. Cyanobacteria account for approximately half of the total biomass in Lake Winnipeg between spring and fall.[71] Many studies have tried to identify which environmental variables promote and regulate algal blooms, with several authors noting the limitations brought about by inadequate spatial and temporal coverage of traditional monitoring.[72,107,108] Binding et al. (2018) found that both the severity and duration of blooms positively correlate with TP loading.[72] Ali and English (2019) found that major blooms in Lake Winnipeg occur when 50% of the smaller rivers become hydrologically connected during snowmelt, which is also when TP loads are highest.[74]

Other Water Quality Issues

In general, concentrations of potassium, total suspended solids, turbidity, total organic carbon, and the majority of trace elements are higher in the South Basin and Narrows compared to the North Basin. In contrast, conductivity, alkalinity, sodium, chloride, total dissolved solids, and total inorganic carbon are higher in the North Basin compared to the South Basin and Narrows. Concentrations of calcium and magnesium as well as pH levels are similar throughout the lake. Concentrations of trace elements in Lake Winnipeg over the last 20 years were low and many were often below detection limits.[71]

Unlike nutrient concentrations, sulfate and chloride concentrations have shown consistent spatial and temporal changes, which are assumed to be more closely tied to human-induced rather than natural changes. Concentrations of sulfate have been increasing in the tributaries and main-stem of the Red River since at least 2000, with median concentrations ranging from 14–510 mg/L. Chloride has similarly increased, with median concentrations ranging from 5.69–75 mg/.[94] Most metals, other than aluminum and iron that have naturally high concentrations in Manitoba freshwaters, rarely exceeded the guidelines for the protection of aquatic life. In fact, concentration of most trace elements in Lake Winnipeg have not increased over the last couple of decades and remain consistent with other Manitoba freshwaters.[71]

Challis et al. (2018) studied the concentrations of pesticides, pharmaceuticals, per- and polyfluoroalkyl substances (PFAS), and microbes bearing antibiotic resistance genes (ARGs) in 2014 and 2015. Pesticide loads ranged from 800 kg per year for atrazine, to 120 kg per year for thiamethoxam and clothianidin, to 40 kg per year of imidacloprid with the greatest concentration seen post-application in June and July. Atrazine did not exceed 500 ng/L during the study period, with much of it coming from south of the US/Canada border. Seven pharmaceuticals, including Carbamazepine, were detected at low ng/L levels downstream from the City of Winnipeg WWTP, with an estimated load of 20 kg per year. Both PFAS and ARGs were observed consistently and ubiquitously, with no indications of a point source origin.[109]

Conclusions

A fundamental management requirement for watersheds is gaining a basic understanding of external loading sources and how a watershed processes nutrients in upstream lakes and reservoirs thereby affecting downstream water quality.[104] Reducing nutrient loads to Lake Winnipeg starts by reducing stream loads. An efficient strategy for this requires understanding where the nutrients are coming from to better target reduction efforts to prioritize downstream benefit.[78] Because of the variability of instream flows and nutrient loads in the RRV, monitoring results of load reduction based on annual loads from year to year can be misleading because large reductions or increases occur naturally from climate variability.[94] Although in some areas there is a considerable amount of TP from historical fertilizer application (legacy P), better agricultural practices, such as measuring P levels in soils to adjust fertilizer application, can reduce the loading to receiving water bodies. Thus, a long-term view is necessary. It is clear from the research that the Red River and its catchments should be of primary importance for nutrient management strategies and targeted best management practices for nutrient reduction efforts.[104]

B

NATURAL INFRASTRUCTURE AND RELATED BEST MANAGEMENT PRACTICES TO REDUCE TOTAL PHOSPHORUS LOADS

By Kendra Garner and Arturo A. Keller

Introduction

With changing climate conditions and intensified human use, the natural infrastructure provided by healthy, functioning watersheds including wetlands, soils, aquifers, and floodplains is currently under threat of loss at an unprecedented global scale. Losing the natural infrastructure associated with watersheds can weaken resilience to rapidly changing climate conditions and hinder economic development and human well-being.[110] That same natural infrastructure is often overlooked when it comes to management solutions; built infrastructure such as dams, reservoirs, and flood barriers tend to be prioritized.[110] Traditionally, infrastructure included only human-made assets, sometimes called grey infrastructure, but more recently, scientists and conservationists have argued that ecosystems and the services they provide should be considered a type of infrastructure.[111],[112] This is because healthy ecosystems provide goods and services to humans, including flood and nutrient management and maintenance of biodiversity.[111]

Natural infrastructure is defined as a strategically planned and managed network of natural lands – such as forests, wetlands, and other open spaces – which conserve or enhance ecosystem functions and provide associated benefits to human populations.[113],[114] Natural infrastructure can be provided through either conservation of existing systems or restoration efforts.[115] A number of key techniques include porous pavement, subsurface storage, tile drains, infiltration trenches, retention ponds, wet and dry detention basins, vegetative buffer strips, and natural or constructed wetlands.[116],[117],[118] Natural infrastructure, sometimes called *green infrastructure*, can be further defined as *fully natural* in the sense that no long-term human intervention or management is required, such as wetlands, or *engineered*, such as a water retention facility.[115,119]

Nonpoint source pollution (NPS) is pollution that comes from many nonpoint sources and generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification. NPS management requires a strategic combination of practices to control source entry into receiving water systems.[120] Best management practices (BMPs) are widely accepted methods that minimize the impact of agricultural activities on both surface water and groundwater and are typically classified as infrastructure based or management based.[120,121122] Infrastructure-based BMPs – including buildings or structures that require one-time construction costs and subsequent maintenance costs – are used to alter hydrologic pathways to reduce flow and/or nutrient loads.[116,121] Management-based BMPs include strategies that are implemented on a continuous basis (cadence can be daily, seasonally, or annually) and are used to redistribute nutrient loads either away from high runoff producing areas or to less frequently saturated areas.[116,121] Non-infrastructure measures include efforts such as reducing use of fertilizers, proper timing of fertilizer application, planting cover crops, no-till farming, and residue management.[117,123,124]

Nutrient reduction efficiencies for BMPs fluctuate greatly due to regional variability, design methods, implementation, and maintenance frequency.[120] For example, previously reported total phosphorus (TP) reduction efficiencies for BMPs such as cover crops can range from 7–63%, contour farming from 30–75%, livestock exclusion from 32–76%, and riparian buffers from 40–93%.[125],[126],[127] Such variability results from inherent heterogeneity of landscape topography, hydrology, climate, and prior land use, which influences soil phosphorus (P) concentrations.[120,128] Consequently, a thorough understanding of the management mechanisms in nutrient control and uncertainty in efficacy are needed to help prioritize BMP selection.[120,125] Placement in the watershed plays a vital role in nutrient reduction, as the contribution of nutrients varies across watersheds and determines the efficiency, efficacy, and cost of a BMP.[118,120,125,126]

While many studies of BMPs to reduce nutrient loads have been conducted, a significant challenge remains in identifying which practices to implement in which locations across a watershed.[128] There are, however, very few field-based and watershed-scale studies of BMP efficacy, and the results are often uncertain.[129] BMP implementation in a dairy farming region of New York was able to reduce nutrient loads across six small watersheds in the region by as much as 35%.[130],[131] In another study, total P losses were reduced by 36% following the implementation of cattle crossings in a creek.[116] A survey of 90% of all farms in two northeastern Wisconsin watersheds found that nutrient management can reduce nutrient loads.[125,132,133,134,135] Another study in central Illinois, however, found no significant changes in nutrient loads after BMP application.[132] Steinman et al. (2018) also found no significant difference in upstream vs. downstream water quality and no significant improvements to water quality from two wetland restoration efforts in the Macatawa Watershed two years after construction. Possible reasons for the lack of improved water quality include the wetlands being too young to retain significant nutrients and too small relative to the total loads, the location being less than optimal, or the overall climate being relatively dry during the study period.[133] Most studies *do* generally conclude that nutrient management is effective.[125,134]

Some natural infrastructure options also have the ability to inadvertently become causes of legacy nutrient loads in agricultural regions.[117] For example, in one study, 18% of tests found that soils with vegetated buffer zones contained surface soil P levels 33% greater than the field soil.[117] Constructed wetlands are effective at trapping particulate bound P from upstream NPS, but summer baseflow can cause leakage of P as increased organic matter in suspended sediment in runoff can change the redox potential to promote reduction.[117,136] Additionally, if the constructed wetlands are not maintained and emptied of sediments, they can also become a source of legacy nutrients.[117]

The range and unpredictability of BMP efficacy can make it difficult to target BMPs in regions lacking long-term monitoring data. Decision-makers must consider the form of and source location from which nutrients are delivered to waterbodies, rather than solely considering the total nutrient load in the region.[123] While there are numerous studies on the efficacy of land cover/use and management for reducing nutrient loads, few studies thus far have considered spatially targeted efforts.[137] Timing is also an important consideration, as shown in a multi-model study by Scavia et al. (2016), which found that reducing TP loading in the Maumee River was most effective when the focus was placed on high-flow events between March and July.[138]

Costs

Natural infrastructure investments do not necessarily replace the need for grey infrastructure, but they can provide a critical complement and potentially multiply the benefits from a healthy, functioning watershed.[110,139] In addition, the costs associated with implementing BMPs have consequences for their efficacy. For example, farmers are less likely to adopt high-cost BMPs even though they may be the most effective management options.[140] Land availability is a common limitation for BMP implementation as many options are often land intensive and not economically feasible in certain regions.[141],[142],[143] In addition, certain BMPs, such as sediment ponds and buffer strips, occupy additional farmland making it highly unlikely that farmers would implement more than one BMP at a site.[144] Implementation costs are equally important at the regulatory level as the goal is to mitigate pollution at the least cost.[140]

A critical element in determining the net present value (NPV) of a BMP is the discount rate used; that is to say that the future costs are considered less expensive than current costs.[145] In Canada, the social time preference rate is estimated at 3%, which can be applied to natural infrastructure projects too.[145] However, this remains controversial because discounting reduces the importance of events in the distant future as well as the welfare of future generations.[115] Most cost-benefit analyses render the benefits and costs associated with a project that occur more than a few decades into the future as negligible, which tends to weight the value of grey over green infrastructure and lead to grey infrastructure as the outcome.[146] A case study of Gavins Point Dam shows that available information on damages due to a lack of sediment management account for 70% of the actual construction cost and would exceed construction costs if all damage information were available; however, the discount rate negates these costs.[146] Natural infrastructure projects often offer solutions to multiple watershed challenges, which while not always accounted for, increase their value proposition relative to traditional grey infrastructure solutions.[115]

Rao et al. (2012) used the Variable Source Loading Function model and NPV to show that converting runoff-prone agricultural land to vegetation buffer zones and installing BMPs are highly effective in decreasing P loss from a single-farm watershed, but are also quite costly.[121] On average, including the BMPs decreases the nutrient loading by about 5.5% compared with only implementing vegetation buffer zones.[121] A study by Strauss et al. (2007) found that identification of critical source areas (CSAs) – small areas of land that are disproportionately large sources for nutrient loads – can substantially mitigate the cost associated with BMP implementation.[140] As with other studies, the spatial location and time frame over which BMPs are implemented determine their efficacy and cost, as shown in the following chart and tables:

Table B-1
Phosphorus reduction potential by BMP type

Region	BMP	Reduction Potential	Cost	Ref.
New York, Dairy Farm Watershed	Buffer zones over 3.2% of land (5.2 ha)	Reduction factor 0.8	Not Disclosed (ND)	116
New York, Dairy Farm Watershed	Culvert crossing	Reduction factor 0.36	ND	116
New York, Dairy Farm Watershed	Filter strips over 5% of crop land use	Reduction factor 0.3	ND	116
Michigan, Saginaw River Watershed	Recharge structures	~1 kg/ha (5–40%) in reach if placed in high-priority area	ND	120
Michigan, Saginaw River Watershed	Conservation tillage	~0 kg/ha (-5–1%) in reach if placed in high-priority area	ND	120
Michigan, Saginaw River Watershed	Native grasses	~ 2 kg/ha (10–50%) in reach if placed in high-priority area	ND	120
Michigan, Saginaw River Watershed	Residue management (2,000 kg/ha)	~0.75 kg/ha (2–20%) in reach if placed in high-priority area	ND	120
Lake Erie Watersheds	Filter strips over 20% of row crop land, 10 m wide with 25% trapping efficiency	0.5–3% decrease in TP (0.2–3 kg P/km^2)	ND	129
Lake Erie Watersheds	No till over 25% of cropland	-3–4% TP reduction (3 kg P/km^2 increase to 3.9 kg P/km^2 decrease)	ND	129
Lake Erie Watersheds	Cover crop over 25% of cropland	0.1–33% decrease in TP (0.1–11 kg P/km^2)	ND	129
Lake Erie Watersheds	Combination of filter strips, no till, and cover crops	0.3–9.5% decrease in TP (0.3–7.7 kg TP/km^2)	ND	129
Wisconsin, Pleasant Valley Watershed	Conversion to grasslands over less than 4% of watershed area	66–80% reduction of P in subwatersheds, 8% reduction of P at watershed outlet	ND	126
Wisconsin, Pleasant Valley Watershed	No till, over less than 4% of watershed area	14–19% reduction of P in subwatersheds, 2% reduction of P at watershed outlet	ND	126
Southwestern Ontario, Canada	Controlled drainage with subirrigation (CDS) with no cover crop over 15-m x 67-m plots	TP increased from 0.75–0.79 mg TP/L-yr	ND	127

Table B-1 (continued)
Phosphorus reduction potential by BMP type

Region	BMP	Reduction Potential	Cost	Ref.
Southwestern Ontario, Canada	CDS with cover crop over 15-m x 67-m plots	TP decreased from 0.75–0.62 mg TP/L-yr	ND	127
Southwestern Ontario, Canada	Cover crop over 15-m x 67-m plots	TP decreased slightly from 0.75–0.74 mg TP/L-yr	ND	127
Upstate New York Dairy Farm Watersheds	Manure spreading schedule	~35% reduction in dissolved phosphorus (DP) contributions from manure, but only ~18% reduction from manure-spread soils	ND	130
South Western Australia	Replanting perennial pasture species	10% P reduction	ND	147
South Western Australia	Replanting riparian vegetation	10% P reduction	ND	147
South Western Australia	Stock exclusion from waterways	30% P reduction	ND	147
South Western Australia	Use of P retentive soil amendments	40% P reduction	ND	147
South Western Australia	Use of low-solubility P fertilizers	30% P reduction	ND	147
South Western Australia	BMP fertilizer management (application only when if as needed)	10% P reduction	ND	147
Manitoba, Pelly's Lake	Water retention wetland system	1,500 kg, $60/kg	$1M + $125K annual operating expenses	115
Manitoba, Broughton's Creek Watershed	Wetlands	0.009 kg P/acre-year	ND	115
Italy, Lake Vico	Conservation tillage 5.2–14% of total land (of 6.1–16.5 acres)	31–46% effective	€377–€1,008	140
Italy, Lake Vico	Grasslands 5.2–14% of total land (of 6.1–16.5 acres)	61–84% effective	€1,111–€2,989	140

Table B-1 (continued)
Phosphorus reduction potential by BMP type

Region	BMP	Reduction Potential	Cost	Ref.
Italy, Lake Vico	Winter cereals instead of spring cereals 5.2–14% of total land (of 6.1–16.5 acres)	44–62% effective	€374–€999	140
New York, Delaware River	75 individual BMPs across 164-acre single farm watershed including barnyard management, nutrient management, crop rotation, filter strips, and cattle crossings	DP loads reduced by 43%, particulate phosphorous (PP) loads reduced by 29%	~$4K/ha	121

Table B-2
Range of BMP reduction factors reported in the literature

BMP	Reduction ranges (%)	References
Buffer	19–99	Gitau et al. (2005, 2004), Novotny (2003), Lee et al. (2000a), Peterjohn and Correll (1984)
NMP	−66–94	Gitau et al. (2005, 2004), Novotny (2003), Osei et al. (2000), Schuman et al. (1973)
Strip cropping	20–93	Gitau et al. (2005, 2004), Novotny (2003), Haith and Loehr (1979)
Crop rotation	30–75	Gitau et al. (2005), Clark et al. (1985), Haith and Loehr (1979)
Filter strips	−56–59	Gitau et al. (2005), Novotny (2003), Eghball et al. (2000), Novotny and Olem (1994), Schmitt et al. (1999)
Culvert crossing	11–38	Flores-Lópes, submitted for publication
Animal waste management	−117–40	Gitau et al. (2005), Brannan et al. (2000), Novotny and Olem (1994), Novotny (2003)
Barnyard management	5–81	Gitau et al. (2005), Brown et al. (1989)

Positive numbers indicate load decreases while negative numbers indicate load increases.

(Rao et al.)

Table B-3
Potential total P reduction efficiencies (percent change) in surface runoff. Estimates are average values for a multiple year basis.

Conservation practice	Total P reduction	Reference
	%	
Source measures		
P rate balanced to crop use vs. above recommended rate	15–47	Dinnes, 2004
Subsurface applied P vs. surface broadcast	8–92	Dinnes, 2004
Adoption of nutrient management plan	0–45	Devlin et al., 2003; Gitau et al., 2005
Transport measures		
No-till vs. conventional tillage	35–70	Devlin et al., 2003; Dinnes, 2004
Cover crops	7–63	Dinnes, 2004
Diverse cropping systems and rotations within row cropping	25–88	Dinnes, 2004
Contour plowing and terracing	30–75	Devlin et al., 2003; Gitau et al., 2005
Conversion to perennials crops	75–95	Smith et al., 1992
Livestock exclusion from streams vs. constant intensive grazing	32–76	Dinnes, 2004; Gitau et al., 2005; Smith et al., 1992
Managed grazing vs. constant intensive grazing	0–78	Dinnes, 2004; Gitau et al., 2005
In-field vegetative buffers	4–67	Devlin et al., 2003; Dinnes, 2004; Gitau et al., 2005
Sedimentation basins	65	Gitau et al., 2005
Riparian buffers	40–93	Dinnes, 2004; Gitau et al., 2005; Smith et al., 1992
Wetlands	0–79	Dinnes, 2004; Gitau et al., 2005; Smith et al., 1992

(Sharpley et al.[125])

Case Studies

A major contributor to excess phosphorus in waterbodies is often poor nutrient management planning, specifically poor timing and over-application of fertilizer, as well as broadcast application without incorporation.[148] In the Great Lakes Region, traditional advice recommends application in spring rather than fall or winter; however, recent studies suggest increased precipitation and runoff in spring can offset the benefits of spring application.[148] Many NPS control programs in the region, such as Maumee and Sandusky, have been effective in reducing nutrient export; however, dissolved reactive phosphorous (DRP) export has increased in some instances.[149],[150],[151] Sheshukov et al. (2016) found that BMPs, including off-stream watering sites and stream or riparian fencing, reduced organic P loads by more than 59%, but were less effective in reducing total suspended solids (TSS) and sediment attached P loads.[152] Thus, agricultural phosphorous load reduction programs should address both DRP and PP.[149]

Bosch et al. (2013) used SWAT to compare the efficacy of various nutrient load reduction strategies in Maumee, Sandusky, Cuyahoga, Raisin, Grand, and Huron watersheds. Cover crops, filter strips, and no-till BMPs, when implemented at levels considered feasible, were minimally effective (<11% reduction), with the greatest reduction seen when all three BMPs were implemented simultaneously. When BMPs were targeted to high source regions, reductions increased from 2% to 9%.[129]

Lamba et al. (2016) used the Soil and Water Assessment Tool (SWAT) to assess the reduction in TP loading after conversion of croplands to grasslands in subwatersheds identified as CSAs in South Central Wisconsin. Load reduction ranged from 66–99% at the subwatershed level. No-till practices alone led to reductions ranging from only 14–25%. At the watershed scale, however, the impact of BMPs was not significant, likely because the BMPs only targeted about 8% of the watershed area, which was not sufficient to reduce TP across the watershed.[126] In terms of BMP implementation, Giri et al. (2012) also found that native grass and terraces were generally the most effective in the Saginaw watershed, while no-till conservation tillage and residue management had limited impact. Multiple spatial prioritization methods were tested and no single method was found to be better or worse, though each method produced different medium- and high-priority areas for BMP placement. Placement in medium-priority areas had limited impact at the watershed outlet and close to 0% reduction in nutrient loads. As with other studies, Giri et al. showed that placement and selection of appropriate BMPs must be carefully considered.[120]

Rivers et al. (2013) found that neither broad implementation of biological BMPs, such as perennial pastures and managed riparian zones, nor chemical BMPs, such as reduced water solubility fertilizers and P-retentive soil amendments, resulted in reductions in P loads in South Western Australia over a 100-year time frame. This study again emphasized the importance of the spatial location of BMPs at either their earliest possible point in the P-transport pathway and/or at the most critical point in the watershed.[147] Engebretsen et al. (2019) simulated the efficacy of BMPs for reducing TP loads to waterways, including a decrease in the amount of P fertilization, establishment of vegetated buffer strips along streams, constructed wetlands, no autumn tilling, and removal of point sources from scattered dwellings. They found that the uncertainty associated with estimating the impact was so large that, at best, they could state with 80% confidence that TP loads would have been 26% higher without any BMPs.[117]

Hogan and Wallbridge (2007) examined two types of stormwater detention basins designed to retain peak stormwater flows – stormwater detention basin–best management practice (SDB-BMP) and stormwater detention basin–flood control (SDB-FC). SDB-BMPs are also designed using basin topography and wetland vegetation to provide water quality improvement through sediment and nutrient removal and retention. The SDB-BMPs had significantly greater surface soil TP concentrations than the SDB-FCs (~800 kg/ha as opposed to ~650 kg/ha respectively) as well as increased soil P sorption capacities, which resulted in increased nutrient removal by the green infrastructure over the grey infrastructure.[118] Similarly, a pilot study in the Arkansas Headwaters Recreation Area in Colorado combined grey infrastructure (i.e., sediment basin, concrete pan, bridges, and culverts) with green infrastructure (i.e., biostabilization and native vegetation plantings) to reduce sediment and nutrient loads and improve reslience.[110]

Culbertson et al. (2016) tested the impact of fertilizer application in the Maumee River under climate change scenarios. They found that if fertilizer application rates can be held at current rates, TP loads will decrease. If application rates continue to increase at the same rate as plant P uptake, TP loading will increase 4.0% (0.9%) in the near-century and 9.9% (24.6%) by the late-century. Soluble reactive phosphorus (SRP) loading will increase by 10.5% (6.1%) in the near-century and 26.7% (42.0%) by the late-century under Representative Concentration Pathway 4.5 (RCP 4.5) (RCP 8.5).[150]

Conclusions

A lack of observed data can make it difficult to reliably predict spatial variation of nutrient loads.[128] In spite of this, selecting the BMP, prioritizing its location, and considering the timing can all determine the efficacy of nutrient management in a watershed. Cost considerations and land use requirements both impact the likelihood of adoption at the farm level and should be considered as part of the prioritization process along with perceived efficacy, which are the best predictors of whether a BMP will be adopted.[148] Another point to keep in mind is that, under climate change, the optimum BMP location may change should climate shift the origin of the nutrient load, or if water or land use management changes occur in response to climate change.[137]

C
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