Comparing and Evaluating Phosphorus Offsetting Programs in Ontario

Literature Review

Prepared for

Ontario Ministry of the Environment, Conservation and Parks

Waterways Protection Office

February 10, 2023

by

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Suggested citation: Weatherson, W., Johns, C., and Wellen, C. (2023). Comparing and Evaluating Phosphorus Offsetting Programs in Ontario: Literature Review. Prepared for Ontario Ministry of the Environment, Conservation and Parks Waterways Protection Office.

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Nutrient Management Policy: Literature Review

Nutrient management is a major environmental challenge in jurisdictions around the world. In the Great Lakes basin, it has been a recognized problem for almost 50 years that has grown in significance from the 1972 Great Lakes Water Quality Agreement was signed by the Canadian and US federal governments to address water pollution in the region. It has also been a long-standing concern for state governments and the Province of Ontario.

To characterize the enduring challenges and policy landscape related to excess nutrients in the Great Lakes basin (GLB) and Ontario, this document presents a review of relevant policy, economic and management literature describing the challenges, policy goals and generally accepted policy instruments and regulatory strategies for addressing excess nutrients, specifically phosphorus (P) in freshwater ecosystems. Spanning approximately 40 years of nutrient management and water policy in North America, this report summarizes finding from the scholarly and practitioner literature and outlines the various approaches to nutrient abatement in freshwater ecosystems which have been adopted and are currently or were previously in use in the watersheds of the GLB.

While there are several direct regulatory instruments which can be used to meet objectives relating to water quality, these instruments are most typically applied to point-source pollution which is easily measured and therefore regulatory compliance enforcement is feasible (Vandenbergh, 2001). Of these policy instruments, the most highly adopted are those which are implemented on a voluntary basis, such as BMPs or tax incentives, however, most require a mandatory participation component: these include instruments such as command-and-control regulations, for which non-compliance can result in fines or legal consequences (Johns, 2002; Vanderbergh, 2001; Moran, 2003; Gunningham et al., 1998). Though the management of point sources, which are easily monitored and attributed to discrete sources, is straightforward, often accomplished with command-and-control regulatory instruments, non-point sources are difficult to measure or attribute to any one particular source and thus require more flexibility in the regulatory instruments used to control their discharge into the environment (Shortle & Dunn, 1986; Wu & Babcock, 2001). In each case, nutrient management programs must take into consideration the socio-economic, regulatory, and environmental challenges which make watersheds unique or otherwise distinct from each other, necessitating adaptable solutions for nutrient management (International Institute for Sustainable Development (IISD), 2019).

There are also a range of voluntary and market-based instruments used to address non-point sources. Management of point and non-point sources of P in watersheds via Best Management Practices (BMPs), pollution prevention, tax incentive programs, command-and-control regulatory frameworks and market-based instruments are reviewed. The literature related to nutrient management and offsetting programs is reviewed in detail with a specific focus on policy and evaluation criteria to inform the development of a methodology to analyze and evaluate nutrient offsetting programs in Ontario.

Nutrient Management Policy Instruments and Strategies

Jurisdictions across the US and Canada have used a range and mix of policy instruments to address nutrient pollution (Johns, 2000). This section reviews some of the most common policy instruments used to address the negative environmental and economic consequences of excess nutrient loading and nutrient pollution.

Best Management Practices (BMPs)

Best management practices (BMPs) such as those listed in Table 1 are practical approaches that have been recognized in the professional networks of industrial sectors (typically by a government agency) to maximize desirable outputs while minimizing input costs and undesirable outputs (Davey, 1977; Jain & Singh, 2019). In the case of agriculture BMPs, these are affordable solutions to conserving agricultural soil and water resources by reducing the amount of pollution from farm activities such that they are in line with environmental regulations (Davey, 1977; OMAFRA, 2021a). In addition to providing flexibility to growers, BMPs, particularly subsidized BMPs, are preferred by growers because they allow growers to avoid direct regulatory instruments such as command and control (Johns, 2002).

Ontario's application of agricultural BMPs dates back to the 1990s, with Environmental Farm Plans (EFP), voluntary assessments to improve grower awareness of 23 different aspects of their agricultural practices, which use workshops to educate growers in identifying strengths and developing plans to address environmental concerns on their farms (OMAFRA, 2021b). These plans encourage applications of BMPs, with additional support from OMAFRA available to farmers in the form of free factsheets detailing agricultural BMPs for a variety of agricultural businesses (OMAFRA, 2021a). The EFP was originally developed with extensive input from Ontario farmers through the Ontario Farm Environmental Coalition which has participants from major agricultural groups such as the Ontario Federation of Agriculture (OFA), Christian Farmers Federation of Ontario, and Farm & Food Care Ontario; it is members of these organizations who review locally submitted EFPs to support fellow growers in achieving environmental goals (OMAFRA, 2021b). Funding for this program has come from a number of government agencies over its nearly 30-year history; primary partners have been OMAFRA and Agriculture and Agri-Food Canada (AAFC), allowing the program to reach 35,000 participants since 1993 (OMAFRA, 2021b).

There are a range of agricultural BMPs employed to offset nutrient inputs to streams and lakes (Table 2), however the range of uncertainty in amounts of N and P that each of these strategies can successfully offset requires that a range of offsetting ratios are applied to offsetting projects (Voora et al., 2012). These ratios, which can range from 2:1 to 4:1, require that 2 (or 4) kg of a given nutrient be removed for every 1 kg discharged into the watershed, and are designed to compensate for the variability in transportation, uptake and measurement of non-point nutrient sources (Voora et al., 2012; Hutchinson Environmental Sciences Ltd., 2022). These ratios are often prescribed by a central regulator, such as the Ministry of Environment, Conservation and Parks, in the case of Ontario's offsetting programs, and are typically dependent on the individual goals of the program, and characteristics of the sites where abatement features are constructed (T. Krsul, personal communication).

Table 1: Examples of Agricultural Best Management Practices for offsetting non-point sources of pollution

Best Management Practice	Description
Wetland/Riparian Zone Restoration	Restoring existing wetland/riparian buffer zones which slow field run-off, improve infiltration to groundwater, and prevent nutrients from being flushed to receiving waters (Palmer et al., 2021)
Timing/Placement of Fertilizers	Timing nutrient applications to avoid precipitation events and minimize leaching and run-off (Palmer et al., 2021)
Cover Crops	Crops planted to store soil nutrients for future years and prevent run-off, leaching and erosion (Palmer et al., 2021)
Edge-of-Field Practices	Saturated buffers, woodchip bioreactors and drainage water management to control the amount and quality of run-off (Palmer et al., 2021)
Constructed Wetlands	Engineered treatment/retention systems which store nutrients to improve downstream water quality (Palmer et al., 2021)
In-field Structural Practices	Engineered sediment control basins/terraces and grassed waterways to prevent erosion and improve in-field nutrient retention (Palmer et al., 2021)
Clean Water Diversion	Diversion of clean water from barnyard runoff away from areas of manure storage, and anywhere else manure might fall (i.e., over feedlots) minimizes nutrient loading in precipitation event runoff (SNC, 2003)
Manure Storage	Covered storage of manure prevents runoff following precipitation events and regular removal from uncovered surfaces where they would be subjected to transport by surface runoff (SNC, 2003; SNC & Kassirer, 2004).
Septic System Repair/Replacement	Preventing the discharge of septic effluent to groundwater and subsequently to streams from damaged septic systems by repairing septic tanks and pipes on the property and regularly maintaining the septic system based on design specifications (SNC, 2003)
Milkhouse Washwater	Washwater from milk house equipment should be kept separate from manure to minimize TP load in washwater, with treatment in wastewater lagoons (SNC, 2003; SNC & Kassirer, 2004).

Sources: Palmer et al., 2021; SNC, 2003; SNC & Kassirer, 2004

The costs associated with each of these BMPs is dependent on a range of factors beyond materials/labour costs, such as growers' aversion to certain strategies; this aversion typically relates to growers' to fears of legal or financial liability, or the loss of income from decreased crop yields (Stephenson et al., 2010). The financial cost of the incentives for adopting BMPs are wide-ranging, depending on the complexity of the BMP; while offsetting costs for cover crops is relatively inexpensive, land-use conversion from agriculture to forest can be extraordinarily expensive (Table 2). Though these costs can be equalized slightly when considering the annual cost per unit of nutrients offset, selecting the right mix of BMPs can be a very site- and case-specific process (Table 2; Stephenson et al., 2010; Hutchinson Environmental Sciences, Ltd., 2022; Dinnes, 2004, Gitau et al., 2005; Smith et al., 1992).

In Canadian cases such as the South Nation River watershed's phosphorus offsetting program, the modelled offsets and nutrient loads for BMPs were computed based on results from both Canadian and U.S. studies (e.g., Hayman, 1989; Newman et al., 2000), as well as some western European and Oceanic studies (e.g., Macgregor et al., 1982; Sundahl, 1985) (SNC, 2003)

Table 2: Examples of different nitrogen offsetting BMPs in the Chesapeake Bay region

BMP	Incentives paid to farmers (USD, 2007)	Annual Cost per lb Offset
Early Cover Crops	$14-57 per acre	$26 – >$1,000
Reduced fertilizer application	$17 per acre (when offsetting cost of decreased crop yield) Up to (and above) $30 due to farmer hesitancy to adopt	$8 – $54
Continuous no-till	$20 per acre (5-year contracts)	Potential for negative cost (Diaz-Zorita et al., 2004; Pendell et al., 2006).
Crop to forest conversion	$1,000-10,000 per acre (often over multi-year contracts)	$26 – $470

Source: Stephenson et al., 2010

Note: associated costs to incentivize farmers to adopt BMPs, and the total cost of nutrient reductions per pound of N, based on previous studies of economic feasibility of these BMPs in the United States.

Command-and-Control Regulation of Point Source Pollution

Command-and-control regulations set a guideline or objective concentration (command) to which polluters are held to through legislated penalties for non-compliance (control), establishing a predictable obligation on the part of polluters (Moran 2003; Gunningham et al., 1998). Such instruments are not effective for non-point sources due to their inability to be easily monitored, however point sources of pollution such as wastewater treatment plants are easy to enforce effluent concentration limitations on; thus, point sources are most commonly regulated using two instruments in particular: investment in public infrastructure to remove nutrients at the wastewater treatment stage, and regulation of large point sources (Johns, 2002). Regulatory instruments are most commonly subject to either ambient standards, established in the context of the receiving water body's capacity to safely absorb nutrients, or effluent standards, which limit the concentration of pollutants in effluents released into receiving waters (Johns, 2002; Waite, 1984).

Command and control regulations have been successful following their implementation in the 1970-1980s, increasing the number of streams and lakes in compliance with clean water standards between 1972 and 1990 and proving effective in reducing air pollution as well following the Clean Air Act (1970) (Vandenbergh, 2001; United States Environmental Protection Agency (US EPA), 2000; Spofford, 1984; Atkinson & Lewis, 1974). For example, following the implementation of the Clean Water Act (1972) in the United States, as of 2000, Lake Michigan's water quality status had improved from mesotrophic/eutrophic in the 1970s to oligotrophic (US EPA, 2000). Additionally, significant investment in wastewater treatment following the 1970s reduced organic wastes and increased the number of households serviced by secondary or better wastewater treatment (Keiser & Shapiro, 2018), and reduced discharges of various priority substances by 99% (Alder et al., 1993). In spite of this, command and control policies have historically been viewed as restrictive and costly to those being regulated, and generally less favourable than more flexible market based regulatory instruments, and yet, despite this perception, has proven to yield benefits to the public which are greater than their cost, particularly in the case of air quality improvement following the 1970s (Cole & Grossman, 1999).

Pollution Prevention through Subsidies and Tax Incentives

In the context of manufacturing firms, King & Lennox (2002) find that pollution prevention is underused as a pollution reduction strategy. For a private firm, managers typically seek to implement pollution reduction strategies which result in maximum profit, ensuring all pollution reduction strategies provide similar productivity to each other (King & Lennox, 2002). Given that it can be costly to identify new methods to preventing pollution, environmental managers are more likely to be biased towards pollution reduction strategies they are already familiar with, unless new information is provided to inform on how alternative strategies might improve the cost effectiveness of pollution reduction (Arrow, 1974; Jensen, 1982; King & Lennox, 2002). The benefits of pollution prevention are considered difficult to quantify, due to their distributive nature, and thus the overall cost effectiveness is not that well understood, resulting in preventative strategies being underutilized by polluting firms (Klassen & Whybark, 1999; Russo & Fouts, 1997; King & Lennox, 2002; Hart, 1995).

King & Lennox (2002) measured financial performance of pollution management strategies based on their return on assets (ROA, calculated by dividing earnings before interest by mean total assets) and Tobin's q (dividing a firm's sum of equity value, long-term debt, and net liabilities by total assets) which indicates expected gains in the future (Chung & Pruitt, 1995; Dowell et al., 2000). Their analysis of manufacturing firms confirmed that many firms uniquely underestimate the potential ability of addressing pollutants at their source, but not other pollution reduction measures (King & Lennox, 2002), however in the case of nutrient management, there may no longer be as many "low-hanging fruit" (i.e., easily executed practices such as proper manure storage and removal prior to cleaning) which can be easily implemented; pollution prevention at WWTPs for example could have significant capital costs, in some cases exceeding $1 billion CAD (Hart, 1995; Hutchinson Environmental Sciences Ltd., 2017; IISD, 2019).

Management of nutrients in systems with an inherent lack of transparency, such as those lacking public reporting of costs, funding sources, or sources and quantities of nutrients applied, are often difficult due to the fact that the information necessary to inform policy instruments is not readily available to decision makers, which can justify the use of economic instruments such as subsidies, taxes and tax incentives to make this information available to regulators (Wu & Babcock, 2001; Johns, 2002). These economic instruments have a range of coerciveness; however, the end goal is to apply pressure to would-be polluters to be properly educated in the best methods to reduce the environmental impacts and increase the sustainability of their operations (Johns, 2002).

Cost-sharing through subsidies is the most common of these economic instruments, and often seek to reduce the costs for polluters to reduce pollution outputs, and protect environmentally sensitive areas in adjacent lands (Johns, 2002; Vedung, 1998 in Bemelmans-Videc, 1998). The efforts to manage nutrients in the Chesapeake Bay is one example of these subsidized BMPs in practice (Stephenson et al., 2010). As of 2022, states such as Virginia, USA are running incentive programs for dozens of BMPs, ranging from structural BMPs such as vegetated buffer strips (paid by linear foot), to nutrient management planning ($2 USD per acre for imported fertilizers, $4 for on-farm manure), sustainable farming practices including no-till planning ($5 per acre) and harvestable crop cover ($20 per acre), and construction animal waste management systems (up to 75% of eligible costs) (Virginia Department of Conservation and Recreation, 2022). Despite these substantial subsidies, however, nutrient loadings from agricultural non-point sources in the state have increased from ~2.21×10^6 kg/year over the period of 2009-2014 to ~3.4×10^6 kg/year between 2020-2021 (Virginia Department of Environmental Quality, 2016; Virginia Department of Environmental Quality, 2022). This change could be partially associated with updates to the nutrient loading calculations for the 2022 publication, which included updates to the land uses, primary crop type, manure spreading periods, number and distribution of farm animals and their corresponding manure production, and updated data on BMP installations, however, reduced retention in major rivers (i.e., the Susquehanna River) is a major contributor to this increase (Virginia Department of Environmental Quality, 2016; Virginia Department of Environmental Quality, 2022; Ator et al., 2019; 2020).

Tax incentives, typically issued by land trusts which ultimately cede various landowner property rights, such as the right to develop land, apply pesticides or undertake various agricultural activities, to the trust in exchange for tax benefits (Johns, 2002; Attridge, 1997). Though tax incentives are popular in the U.S., they have been under-utilized in Canada (Attridge, 1997; Johns, 2002).

Market-Based Nutrient Management

A market-based approach to nutrient management is a program which facilitates trading of pollution credits between individual polluters, such that negotiations take place between individuals who agree to pollute less in exchange for financial compensation from those who are seeking to pollute more than an established guideline threshold or cap for a given region (Woodward et al., 2002; Tietenberg, 2000). This system seeks to ensure that pollution is mitigated where it is easiest and most cost effective to do so, however highly variable costs and difficulties in obtaining complete cost information make precise quantification of costs challenging for comparative studies (Stephenson et al., 2010); though it remains unclear whether these alternative abatement practices are successful in reducing nutrient loadings as intended, concerns relating to capital expenditure on large WWTP upgrades for incremental improvements in nutrient loads have nonetheless encouraged the pursuit of alternative solutions (Woodward et al., 2002). This particular framework is generally referred to as a cap-and-trade system, and while other systems with various differences can be implemented, they share the common goal of reducing nutrient concentrations and loads while allowing polluters some autonomy in how those reductions are made (Woodward et al., 2002). The attributes of various market-based approaches to nutrient management are described in Table 3.

The high costs associated with abating the various point sources of nutrients such as WWTPs is commonly avoided within nutrient trading programs using non-point source offsetting

(Woodward et al., 2002). One such framework for nutrient trading is bilateral negotiations, during which individual water users (i.e., point/non-point source polluters) communicate directly with each other to negotiate the terms of the trade, with the relationship between the involved parties lasting beyond the original contract, however the extensive communications between parties drives up transaction costs (Woodward et al., 2002; Voora et al., 2012). Examples of bilateral negotiations exist in numerous subwatersheds around the United States (e.g., Fox River, Wisconsin, ca. 1981; Lake Dillon, Colorado, ca. 1984; Kalamazoo River, Michigan, ca. 1998), representing the oldest nutrient trading programs, including trading between point sources, point and non-point sources, and non-point sources (Woodward et al., 2002).

Table 3: Different Types of Nutrient Trading Markets

Market Type	Attributes
Exchange	Prominent characteristics are open information structure and fluid transactions between buyers and sellers. Characterized as having the highest initial set-up costs, lowest transaction costs, the highest degree of uniformity and no possibility of establishing buyer liability.
Clearinghouse	Legally authorized by the oversight agency to buy and sell pollution reduction credits, clearinghouses are well suited for Water Quality Trading (WQT) between point and non-point sources. Characterized as having high initial setup costs, low transaction costs, a high degree of uniformity and no buyer liability (the clearinghouse can assume liability).
Bilateral Negotiations	The buyer and seller negotiate terms of trade directly. It is well suited to WQT as it can accommodate detailed information exchange and monitoring negotiations under buyer liability. It is characterized as having low initial set-up costs, highest transaction cost, low degree of uniformity and the possibility of establishing buyer liability
Composite	Composite market disaggregates permit transactions into two primary markets and one secondary market by combining characteristics of an exchange and clearinghouse structures. The two primary markets serve as a clearinghouse for sellers and buyers of discharge permits. It is characterized as having the attributes of all three market types, composite markets reduce transaction costs for individual sources

Source: Voora et al., 2012

Evaluation of Nutrient Management/Trading Programs

Nutrient trading programs have been advocated for by economists since the 1970s for their ability to reduce pollution at lower costs than traditional command-and-control regulations (Hasan et al., 2022). They have existed in various forms within North America for several decades, as early as the 1980s in the United States (Woodward et al., 2002). One challenge that pollution trading programs face is high costs of transactions, due in part to the restrictions placed on credit trading frameworks which require that projects to reduce nutrients to meet environmental objectives; given that market participants inherently seek the most cost-effective nutrient mitigation actions, market structure and environmental efficacy of nutrient trading programs are inherently linked (Woodward et al., 2002).

The primary costs relating to pollutant credit transactions are a) search and information (i.e., between parties and/or an administrator to determine the number and type of credits available to be bought/traded), b) bargaining and decision (i.e., costs associated with identifying and negotiating compensation to the offset seller for use of their land and/or investing in improved agricultural nutrient management practices), c) monitoring and enforcement (i.e., costs to monitor for nutrient reduction from a particular abatement feature, and to ensure compliance with contracts and/or regulations; Stavins, 1995), and transportation and set up (i.e., administrative oversight costs; Dahlman, 1979; Woodward et al., 2002). These transaction costs can be a single payment at the beginning of market operations or present in every trade as determined by the body responsible for marketplace administration and governance; in most instances, these are government agencies (Woodward et al., 2002).

One significant challenge to the evaluation of the effectiveness of nutrient trading and offsetting programs is the availability of water quality data in watersheds where nutrient trading and offsetting programs are operational. Water quality monitoring programs are not all created equal, and are generally designed with unique goals; similarly, while some watersheds have continuous records of a wide range of parameters (including total phosphorus), many of these records do not span the full range of pre-1970 to present. Though many subwatersheds are not subject to nutrient offsetting programs, several subwatersheds have had the number of water quality monitoring sites along the channel reduced with stations being set to inactive (1699 of 2138 water quality monitoring stations in Ontario are inactive, many of which have not been active since the 1970s) (Ontario Ministry of Environment, Conservation and Parks (OMECP), 2021a). This often results in a loss of upstream or downstream monitoring (e.g., Uxbridge Brook, Beeton Creek) reducing the opportunities to make inferences about the sources and mass of nutrients being discharged from watersheds with publicly available data.

Moreover, there is little research into the appropriate data records necessary to quantify improvement in nutrient concentrations from offsetting projects (Wellen et al., 2020; Melland et al., 2018). While Melland et al. (2018) identified positive effects on water quality in 1-10 years, they noted that it would require up to 20 years of data to detect improvements with confidence. Similarly, Wellen et al. (2020) assessed the statistical power necessary to verify that results are not driven by a lack of data, seeking to achieve the statistical power level of 0.8; the requisite time periods datasets must span significant time periods to determine if significant nutrient reductions have been made (as detailed in Table 4). This suggests that it will be difficult to accurately assess the effects of any nutrient offsetting programs in Ontario in the near future, given that comprehensive assessment requires longitudinal data records are collected and analyzed over an average of 23 years in watersheds where there are nutrient offsetting programs. A greater challenge still, relates to the monitoring dataset design, which must be designed specifically to take into consideration the spatial distribution and hydrologic characteristics of the contaminant sources within the context of the target watershed to be useful in evaluating a nutrient offsetting program that relies on numerous abatement practices.

Table 4: Summary of minimum dataset length necessary to detect improvements in nutrient load and flow-weighted mean concentration (FWMC)

% Reduction	Metric	Analyte	Data Record Required
20%	Load	Nutrients	50-250 years
	FWMC		10-120 years
40%	Load		8-50 years
80%	Load		2-7 years
	FWMC		2-4 years

40%	FWMC	Soluble Reactive Phosphorus (SRP)	5-25 years

Source: Wellen et al., 2020

Evaluation Criteria from the Literature:

There have been numerous evaluation studies to assess effectiveness of water quality and nutrient offsetting programs (summarized in Appendix I). The studies considered span the western hemisphere with particular focus on North America. The studies that include evaluative criteria or design considerations are compared in Table 5.

Table 5: Comparison of the evaluative criteria used to assess WQT programs.

	Stephenson et al., 2010	**Voora et al., 2012**	**Fleming et al., 2022**	**IISD, 2019**
Pollutant characteristics		✔	✔	✔
Transport mechanism	✔	✔		✔
Receiving medium		✔	✔	✔
Modeling		✔	✔	✔
Ecological Objectives	✔	✔		✔
Upstream/ Downstream Mechanics		✔		✔
Emission and Ambient Based-Credits		✔		✔
Trading Ratios	✔	✔		✔
Government Responsibility	✔	✔		✔
Permit Allocations		✔	✔	✔
Monitoring and Enforcement		✔	✔	✔
Sanctions for Non-Compliance		✔		
Trade and Market Type		✔		
Cost Effectiveness		✔	✔	✔
Transaction Costs	✔	✔	✔	✔
Dynamic Efficiency		✔		
Market Distortions		✔		
Credit Stacking				✔
Baseline for Credit Generation				✔
Economic Incentives				✔
Program Administrator				✔

The Virginia offsetting program was developed to reduce nutrient concentrations in the Chesapeake Bay, by limiting annual mass loads using a total maximum daily load (TMDL) target in four main tributaries of the Bay, with fees for excess N or P not offset by other abatement practices (Stephenson et al., 2010; Cappiella et al., 2013). Stephenson et al. (2010) evaluated the performance of a non-point nutrient offsetting program in Virginia with four evaluative criteria, for agricultural and urban non-point sources of pollution, highlighting four central evaluative criteria (Table 6). Due to the lack of offsetting programs, the range of costs for various abatement practices are highly variable and are associated with high levels of uncertainty (Stephenson et al., 2010).

Table 6: Evaluative criteria for Virginia's Nutrient Offsetting Program

Evaluative Criteria	Description
Cost	Total cost (the sum of capital and operating costs, in addition to risk and transaction costs) to implement nutrient abatement activity; compensation must cover costs associated with implementation (capital and operational), risk and transaction costs of nutrient abatement activities.
Technical Feasibility	Reasonableness of options are determined by the level of activity to achieve a nutrient offset of a new or expanded point source, as measured by the number of acres needed to meet a reference offset (i.e., a particular nutrient load).
Certainty in Achieving Claimed Reductions	The degree of uncertainty associated with nutrient abatement strategies is highly variable; though some practices are conducive to direct monitoring, many, especially those for mitigating non-point sources, can be difficult to accurately measure, model, and therefore require higher offsetting ratios.
Administrative Risk	Abatement practices are chosen based on their likelihood of meeting the regulatory requirements; should an abatement practice fail to offset the requisite amount over the year, shortfalls count as a violation of agreements by point-source polluters to meet water quality targets, potentially resulting in civil and financial penalties. As a result, point-source polluters may seek to employ offsetting practices which are under their direct control to minimize regulatory risk, rather than non-point offsets managed by third parties.

Source: Stephenson et al., 2010.

The data used by Stephenson et al. (2010) relating to the cost of abatement practices was limited to the cost of physically implementing/constructing the nutrient abatement measure, though failed to consider transaction costs or the risk associated with abatement measures which fail to meet water quality objectives due to the lack of availability of this information. Stephenson et al. (2010) also noted that the studies referenced represented a broad average cost that failed to properly reflect the changing costs associated with different scales of implementation (i.e., in small or large watersheds). Feasibility of the offset selection was assessed based on the number of acres necessary to offset 43.8 L/s of wastewater effluent based on a 2:1 offsetting ratio (Stephenson et al., 2010). For each of the abatement practices, costs were derived from existing literature, with most data covering a national scale.

Findings from the Virginia offsetting program suggest that the assumption that nutrient trading programs will be able to make favourable transactions between point-source polluters and agricultural nutrient offset traders is misguided: first, agricultural land uses may not make up enough area to apply BMPs at the scale necessary to offset point source pollution; second, growth in point source pollution in the future may significantly exceed the capacity of non-point source offsets; finally, the regulatory risk of failing to meet non-point source offset targets could increase costs for point-source polluters such that it is impractical to participate in non-point source offsetting in the first place (Stephenson et al., 2010). Cappiella et al. (2013) indicate that there is a tendency for some developers to avoid controlling urban pollution on their properties, instead seeking out offsets from the beginning of the project, a practice which should be avoided at all costs to ensure that developments are designed with the intention of minimizing environmental impacts.

Despite the favoured status of market-based instruments in addressing growing concerns relating to the emissions of pollutants such as phosphorus, current research continues to highlight a lack of monitoring data as one of the largest obstacles to measuring the success of nutrient trading or offsetting programs (Fleming et al., 2022). For example, Fox et al. (2021) assess 16 agricultural sub-watersheds in the Chesapeake Bay watershed, however only one of the watersheds has a dataset meeting any criteria necessary to assess for changes in water quality (spanning 1970-2014), but lacks the required frequency and event sampling, and found an increasing trend in TP. This issue can be particularly difficult to address given that watershed boundaries do not correspond to jurisdictional boundaries. In the case of the Chesapeake Bay, 7 states fall within its watershed, each with their own regulatory frameworks for stormwater and agricultural nutrient offsetting permits (Cappiella et al., 2013). While a large number of studies find that there have been improvements in water quality, these tend to be disproportionately focused on modelling changes, rather than actually observing them; when relying on field monitoring data, challenges such as lagged response times and poor distribution of BMPs throughout the watershed made it difficult to identify clear changes in water quality (Lintern et al., 2020).

A comparison of the different principles and considerations of successful water quality trading programs included in the following Voora et al. (2012) outlined the steps to implementing a WQT program for the Lake Winnipeg Basin, a transboundary watershed between Canada and the United States (Table 7). These considerations might be used as the basis by which the performance, or predicted performance, of water quality trading/offsetting practices could be qualitatively assessed (Voora et al., 2012). These considerations may inform whether it is reasonable to believe that a trading program would yield noticeable benefits to water quality, even if data to accurately measure the performance is not yet available (Voora et al., 2012). While Voora et al., (2012) make recommendations on key elements for the operation of a program which *should* be effective in reducing nutrient loads, based on the best available data at the time, proactive ecosystem managers should seek to test all assumptions with relevant monitoring programs prior to implementing any widespread policy decisions, rather than relying solely on modelling results.

Voora et al. (2012) recommend a multi-level model to facilitate trading throughout the individual sub-watershed basins and across the entire Lake Winnipeg watershed. Intra-watershed trading within the sub-watersheds would be done by identifying point and non-point sources and applying a trading ratio (unclear how much) to trades between these sources in the sub-watershed, whereas inter-watershed trades would be between point sources using a modified trading ratio model, such that non-point and point sources are aggregated at the sub-watershed scale (Voora et al., 2012).

Table 7: General WQT system design elements to assess potential benefits of water quality trading programs.

Consideration	Description of Consideration
Emissions Considerations	

Pollutant characteristics	The nature of the pollutant (toxicity, breakdown and mixing) dictates if it is suitable for trading.
Transport mechanism	Point sources (direct or indirect discharge) are defined water emission sources. Non-point sources are diffuse and difficult to monitor but often less costly to mitigate.
Receiving medium	Background pollution levels, hydromorphology and aquatic biology will impact pollution dispersion assimilation and its ambient concentration.
Modeling	Provides a means to assess pollutant transport and assimilation required to set adequate caps and allocate credits.
Environmental Considerations	
Ecological Objectives	Setting ecological objectives for receiving water bodies instead of flowing streams and rivers can capture cumulative impacts.
Upstream/ Downstream Mechanics	The upstream-downstream dynamic of the pollution sources will influence the pollution concentration at various points in the watershed.
Emission and Ambient Based-Credits	Emission-based credits focus on allowable pollution levels at the source. Ambient-based credits link emissions to pollution levels within water bodies.
Trading Ratios	Impact trading ratios are set exogenously or endogenously to maintain the credit homogeneity. Uncertainty trading ratios are applied to non-point sources to minimize risks and ensure ecological effectiveness
Legal and institutional considerations	
Government Responsibility	A shift is required from regulator to market designer and trading rules enforcer.
Permit Allocations	Auctions or grandfathering can be used to allocate emission credits to emitters participating in the WQT system.
Monitoring and Enforcement	Monitoring and enforcement is required to ensure that the WQT system is improving water quality and that trading rules are being respected.
Sanctions for Non-Compliance	Penalties, which can range from notifications to fines and criminal charges, need to be in place to encourage compliance with trading rules.
Economic Considerations	
Trade and Market Type	WQT allows for Point-to-Point, Point-to-Non-point and Non-point-to-Non-point source trading. Market types include bilateral, clearinghouses, exchanges and composites.
Cost Effectiveness	A wide range of marginal abatement costs is required to achieve cost effectiveness defined as achieving an ecological objective at least costs. This may be difficult to achieve if the market is “thin” or if there is not the right supply and demand balance for water discharge credits, and thus larger, multi-tiered programs may help to lower transaction costs.
Transaction Costs	Transaction costs are greatly influenced by the nature of the water discharge credit that is being traded. High transaction costs can stifle trading activity and they originate from market structures, government oversight, monitoring and enforcement.
Dynamic Efficiency	Advances in abatement technologies must be considered so that innovation will not be hampered.
Market Distortions	WQT systems must be designed to avoid market power, price fixing, intended pollution inflation and free riding.

Source: Voora et al., (2012)

Similar to Voora et al. (2012), the International Institute for Sustainable Development, which prepared a report for the Province of Manitoba, highlighted 10 key components to successful water quality trading/offsetting programs, the importance of stacking of credits/offsets and thus incentives, such as for BMPs which provide reductions in both nutrients and CO_2, or improvements in water retention of the watershed (IISD, 2019; Table 8). Specifically, administrators of voluntary programs, such as nutrient, carbon or stormwater offsetting programs, can support offset sellers by communicating whether certain BMPs qualify for funding under a number of different programs, allowing for the offset sellers to reduce costs of adopting BMPs which may otherwise be prohibitively expensive. The IISD also highlights the importance of accounting for future uncertainty in the TP loading as a result of extreme weather events, either by establishing a "Credit Reserve" of some offsets which are not to be sold, or by increasing the nutrient offsetting ratio, such as in the case of the SNC (IISD, 2019).

Table 8: Key elements of successful international offsetting and water quality trading programs

Element	Description
Regulatory Framework	Successful offset program design and implementation requires moving from concentration-based to load-based caps for dischargers. Explicit regulatory limits are more appropriate for point sources, for which loads are more easily quantified.
Economic Incentives	Given a wide range of transaction costs associated with offset/WQT program setup, implementation and operation, only significant variations in pollution abatement costs would make offsetting/trading a feasible strategy for the watershed.
Credit	A credit is the unit of pollution reduction—the commodity traded in the WQT market. The unit of pollution selected for trading needs to be measurable and cannot create hotspots or accumulation of impacts in the watershed. Some programs restrict trading to credits generated upstream of the point of compliance to prevent localized impacts.
Geographical Considerations	A well-defined geographic area is one of the key elements of success of an offset/trading program and can help ensure that an adequate number of potential buyers and sellers is in place.
Baseline for Credit Generation	The baseline takes account of all pre-existing regulatory requirements in the relevant trading area. It considers all federal, provincial/state and local programs applied before the trading program as the base condition, so that only additional conservation practices, and thus additional benefits, count toward credit generation.
Offset Ratios	Trading ratios and their rationale vary from program to program. More commonly, they incorporate some combination of the following variables: 1. Form of the pollutant 2. Geography of polluters (i.e., the location of buyer in relation to seller)

	3. Uncertainty associated with the quantification of NPS load and BMP performance (different BMPs perform differently in geographically different contexts and at different times) 4. Credit retirement to ensure a net reduction in water pollution 5. Attenuation of a water quality benefit between the location where credit generation occurs (BMPs are installed) and the point of use 6. Lag in time between BMP installation and BMP producing a full water quality benefit Offset ratios ensure equivalency of pollution reductions across trading partners in the watershed. Reliable scientific evidence and consultations with relevant stakeholders are required to support the choice of an offset ratio for the program.
Credit Price	The price is determined by using a cost-based pricing model, such that the sum of all cost inputs that go into generating a credit (direct costs of constructing a BMP and indirect costs of project administration). Therefore, the price of a unit of pollution reduction is not a competitive price, but often set by a program administrator.
Credit Stacking	Some BMPs can result in multiple ecological benefits, so landowners can receive multiple payments for the ecosystem services they provide. In the case of a nutrient trading program, the coexistence of carbon offset markets makes converting lands from livestock farming to forestry more attractive to landowners, since they become eligible for combined benefits of both reduced nutrient discharge and carbon reduction payments.
Program Administrator	Using a trusted intermediary/program administrator to manage the program is important. Organizations that are independent from government, that work with farmers on a daily basis or that are led by farmers are best suited for marketing and managing the rural part of a PS–NPS program.
Verification and Monitoring	In programs involving NPSs, it is important that the verifier has working knowledge of farm operations and systems. Ongoing monitoring frequency can be the same for all NPSs (PS– NPS offsetting), or a priority system for monitoring can be established so that farmers who farm intensively are monitored more often and more closely.

Source: IISD, 2019.

Nutrient management in the EU began around the same time as in the U.S. but took until the 1990s to become coordinated across member states of the European Union, culminating in the Water Frameworks Directive (WFD) in 2000 (Drevno, 2016; European Commission, 2014). This legislation required the implementation of river basin management plans (RMBPs) with updates every 6 years, outlining how water quality and environmental standards were to be met in the basin (Drevno, 2016; Moss, 2004). Though the EU adopted a comprehensive approach to managing water quality, the vast number of different approaches to managing water quality have resulted in inconsistent outcomes across watersheds and gaps in coverage (Drevno, 2016; Environmental Law Institute (ELI), 1998).

A Danish case study suggests that while non-participation rates among growers can result in less-than-optimal nutrient reduction, if participation in the program is high among the farms responsible for the most non-point source pollution, the negative impact of low participation amongst less-polluting farms is minimal (Hasan et al., 2022). At just 24% participation out of a community of 6504 farms (average area of 76 hectares), a nutrient trading program in the Limfjorden catchment in Denmark yielded a 21.5% reduction in N from the baseline load, with 70% efficiency and a total savings of 56% as compared to command-and-control regulations (Hasan et al., 2022). The remaining 76% of farms only account for a total of 30% of maximum nutrient reductions (Hasan et al., 2022). Studies within Switzerland and New York state identify the shortcomings of various BMPs, particularly when used inefficiently (i.e., buffer strips in areas where there is minimal surface runoff, small wetlands with short residence times) (Reinhardt et al., 2005; James, 2005). Together, this suggests that participation rate alone is not necessary to achieve nutrient reductions, rather, that participation rate should be considered in the context of the type and scale of agricultural practices at various farms. A successful nutrient offsetting program would therefore seek not just to achieve wide-ranging adoption of BMPs throughout the watershed but work to prioritize adoption of offsetting practices specifically in areas of the watershed where they will have the most direct impact, and by the most significant polluters (Diebel et al., 2008; Sharpley et al., 2009).

Though most TP offsetting programs rely on modelling to inform environmental managers of the benefits of offsetting practices, uncertainty in the factors influencing phosphorus concentrations in tile drainage systems must be overcome to accurately model the benefits of various BMPs (Palm-Forster et al., 2016). Additional uncertainty from climate change is also an under-considered complicating factor, which must be included in future models of nutrient offsetting efficiency (Xie et al., 2015). Biological indicators, such as macroinvertebrate and diatom population densities, can be used to evaluate nutrient reductions, however, requires specific knowledge of dominant taxa in the watershed and understanding of the other dominant contaminants which might be negatively impacting habitat quality (Kroll et al., 2021).

Fleming et al. (2022) also developed a framework for evaluating nutrient target program designs (Table 9). Their research applied the framework from Table 9 to five watersheds across the United States, finding a lack of evidence to support the generalization that nutrient targets can yield measurable water quality improvements relative to non-point source management strategies. Moreover, they highlight the importance of better monitoring data, both in terms of the spatial and temporal coverage, to properly assess whether these nutrient reductions are maintained following the end of pilot projects (Fleming et al., 2022). While some other studies did find some improvements in water quality, they were often offset in the target receiving waterbody by increased discharge due to reduced retention (such as in the Susquehanna River; Ator et al., 2019; 2020). It is suggested that even while there are some BMPs which have shown to be effective, this is dependent on a range of site-specific conditions that are not always met (Kay et al., 2009).

Table 9: Framework for Assessing Design Options

Question	**Range of Potential Answers**
Q1. What is the spatial scale being targeted? At	Broad spatial scale (e.g. particular watersheds or sub-watershed);
	Refined spatial scale (e.g. particular fields or stream reaches)

what spatial scale is the placement of BMPs targeted?		
Q2. How are NPS source areas identified prior to program intervention?	Modeling tools such as SWAT, APEX, CAST, etc. (potentially supplemented with other models related to terrain, land use);	
	Indirect measurement tools (e.g. aerial LiDAR imagery, soil phosphorus levels);	
	Direct measurement tools (e.g. edge-of-field water quality monitoring, USGS monitoring stations)	
Q3. How is BMP pollutant removal effectiveness quantified?	Same options available as Question 2; though a given targeting program may use different tools for Question 2 and Question 3	
Q4. How is the amount of compensation to land managers determined? *(**assumes a voluntary framework for NPS reduction)*	Pay-for-effort: Financial compensation based on cost of installation of a practice (cost-share)	
	Pay-for-performance: Financial compensation based on quantity of service provided or outcome achieved; Service provision linked to the modeling tool or measurement protocol chosen to define "performance" (see Questions 3 and 4 above); Price per unit may be fixed, or negotiated between a buyer and seller	
	Bonus/Reward Payments: Fixed reward payment for achieving a specific benchmark outcome	
Q5. How are people or projects selected?	First-come first-serve among interested land managers;	
	A ranking process among land managers who apply for funds (e.g. using a benefits index);	
	Targeted outreach to land managers at hotspots;	
	A competitive market process in pay-for-performance programs with negotiated prices	
Q6. How is contract compliance determined? How is service provision verified?	Practice implementation: Site visit to verify.	
	Indirect observable outcome: Depends on the measurement tools chosen	
	Water quality outcome: Depends on the measurement tools chosen above	
	In pay-for-performance programs, outcome must be trusted by buyer to indicate service provision	

Source: Fleming et al., 2022.

Summary of Findings and Evaluation Criteria from the Literature

Based on the literature reviewed, a list of key components has been identified as being important for successful nutrient trading/offsetting programs. While this list is not exhaustive, it provides a guide for ecosystem and agricultural managers seeking to develop and implement robust plans for reducing nutrient loads to waterbodies.

1) Identification of Pollutant Sources within the watershed
  - Identification of the source and its loading to receiving waters is necessary to identify critical areas where offsetting should be prioritized; helps to inform offset ratios.
    - Should be done as a component of a subwatershed study (e.g. as part of an Environmental Assessment).

2) Modelling of the system and nutrient sources
- Important for informing selection of appropriate nutrient abatement practices by calculating nutrient loss prior to implementation.
- Potentially useful in follow up assessments of abatement practice effectiveness, in the absence of monitoring; can be used to assess pollutant pathways.
- Also to be done as part of an Environmental Assessment of the subwatershed.

3) Oversight in TP Offsetting Technology Design, Installation, Operation and Maintenance
- Assumptions involved in the design and construction of TP offsetting features, including BMPs and urban SWM improvements should be verified to be applicable within the context of the target watershed.
- Clauses for regular review cycles in a TP offsetting program agreement could improve the program's adaptive capacity by identifying opportunities, challenges and next steps, enabling program administrators to address potential program underperformance or non-compliance.

4) Geographic Prioritization of Offsetting Measure Placement within the Watershed
- In order to meet targets such as the 40% TP reduction goals set for Lake Erie, a combination of 1-4 are important precursors to geographically prioritizing the implementation of offsetting measures, such as BMPs, to areas that are proximal to primary nutrient sources.
- Sources of TP and their respective offsetting measures should be close within the watershed to maximize nutrient abatement effectiveness. This helps to reduce uncertainty, mitigate local impacts to the watershed (i.e., would-be hotspots of high TP/low DO/poor overall ecosystem health from excess algal mass) and simplify monitoring to assess the effectiveness of offsetting measures.

5) Types of Credits/Permit Allocations
- Types of credits (emission- or ambient-based, or hybrid) and their allocation (through auctions, grandfathering, etc.) is clearly articulated to market participants such that individual participant obligations are clear and predictable and can be incorporated into long-term business planning.
- Additional credit types (i.e., carbon, stormwater retention, water balance and thermal mitigation) eligible for incentives should be communicated to participants and allow for "stacking" of credits/incentives, reducing financial burden for offset sellers and recognizing multiple benefits of certain nutrient abatement strategies such as BMPs.
  - It may be possible to amalgamate different programs to where these different types of credits are addressable using the same features (i.e., constructed wetlands), thus allowing for a reduction in total costs, increasing the cost effectiveness of these abatement features.

6) Risk Management (such as through nutrient offset ratios)
- Related to modelling and identification of pollutant sources.
- Program should take into consideration the technical feasibility of the proposed nutrient abatement features within the context of their historical performance to

ensure that program goals and nutrient management targets are achievable with the proposed actions.
  - It is necessary for a nutrient ratio to take into consideration differences in effectiveness of different nutrient abatement practices, and their effectiveness across different locations in the context of their direct impacts to streams (i.e., BMPs are generally more effective at reducing stream TP loads if they are implemented directly adjacent to a stream, rather than 5 km away).
  - Must establish who bears the responsibility/cost of nutrient abatement practices which are identified to be underperforming relative to their assessed and contractually agreed upon offsetting capacity (i.e., who bore initial planning and construction costs, and who bears responsibility for the taxes/fines for excess nutrient loss to streams).

7) Participation/Ownership by Water Users
  - Necessary to ensure adoption and support of the program and its goals by the key water users and the public; nutrient producers will be more inclined to support a program that they understand and have participated in the development.

8) Cost/Cost Effectiveness
  - Relating to the construction, operation, maintenance and administration of nutrient abatement practices and the cost of the nutrient offset transaction; should be quantified in terms of cost per kilogram TP offset.
  - Ideally, costs should be minimized per mass of pollutant removed to help justify the use of a market-based instrument over other policy instruments (i.e., evidence of cost savings relative to direct offsetting through WWTP upgrades, command-and-control regulation, etc.).
  - While transaction costs must be kept low to prevent exclusion of potential participants that create inequitable outcomes across the watershed for growers and inconsistent/poor offsetting performance in the watershed.
  - Efforts should be made to ensure the majority of offsetting costs do not fall to growers.

9) Government Responsibility
  - Necessary for the government to facilitate efficient trading and enforce the terms and conditions of the marketplace and transactions
  - Scope of government responsibility could also include continued education of participants and the public regarding best practices and innovative methods/technology (such as offering subsidies to participate in piloting experimental methods)
  - Enforcement of market rules (deadlines to begin offsetting, minimum pollutant targets such as load/concentration, etc.) to ensure program goals can be met

10) Compliance Enforcement
  - Related to monitoring and government responsibility

- Ideally mitigated by strong educational opportunities to ensure offset buyers/sellers understand their responsibilities to each other, the environment and all who rely on their local water resources
- Enforcement might be informed by scheduled monitoring (i.e., pre-/post-implementation and at regular intervals), with dialogue between participants to encourage/facilitate positive outcomes, while still appropriately disincentivizing repeated non-compliance (i.e., by applying strict penalties for repeated offences or failure to communicate)

11) Monitoring of environmental indicators
    - Minimum of 20 years of daily monitoring data (with particular emphasis on event monitoring) to have confidence in detection of trends (improving or not), unless very large improvements are made
        - Very costly to implement and maintain over a long period of time, generally not feasible at scale
    - Monitoring of these parameters is not commonly done at such high frequency, let alone with respect to TP offsetting programs; pre- and post-implementation monitoring at program-specific sites necessary to be able to detect these changes; PWQMN is not designed to be sufficient for evaluating offsetting programs
    - Site-specific monitoring may be necessary to verify effectiveness of individual abatement practices if programs are failing to meet goals for watershed WQ; in the absence of >20 years of watershed scale data, direct monitoring of abatement practices is best way to verify performance
12) Accountability
    - Public records of water quality, public reporting of program goals and progress/performance metrics
    - Regulator/government support to market participants in the form of efficient compliance, enforcement and appeals processes focused
        - Compliance, enforcement, and appeals activities ideally undertaken with supervision by grower volunteers with specific familiarity with practical applications of farm BMPs (in line with #7 Ownership by Participants and #13 Engagement)
13) Engagement
    - Engagement of a diverse set of stakeholders is a key factor related to successful nutrient trading/offsetting programs
    - Though not a component of any existing framework, in the context of Canadian nutrient management programs, engagement and partnership with Indigenous communities and groups in watersheds could provide important insights relating to sustainable agricultural practices and managing nutrients, improve outcomes and also represents a step toward the broader goal of truth and reconciliation.

Nutrient Management Challenges in the Great Lakes Basin

Following successful efforts to reduce phosphorus concentrations in the Great Lakes during the 1970s and 1980s with the implementation of the 1972 Great Lakes Water Quality Agreement (GLWQA), phosphorus loads in the Great Lakes had fallen below objectives by 1985 (Environment Canada and the Ontario Ministry of the Environment and Climate Change (EC & OMOECC), 2014; Nelligan et al., 2021). As a result of the transition to low-phosphate detergents, algal blooms subsided between the 1980s-1990s, with most drastic improvements in Lake Erie (Nelligan et al., 2021).

Part of the issue driving the resurgence of algal blooms in the Great Lakes lies in the distinction between sources of pollution: point sources are identifiable source of pollution which can be readily monitored, such as wastewater treatment plants (WWTPs), while non-point sources are those which are difficult to quantify due to originating from a large area (i.e., farms, urban runoff from lawns and golf courses) make up large portions of the total phosphorus and nitrogen in the Great Lakes basin (Voora et al., 2012; Nelligan et al., 2021; Palmer et al., 2021). Though non-point sources of pollution were identified as an important source of nutrients in need of management during the late-1970s, efforts to manage non-point sources have not been well-documented (Nelligan et al., 2021) and there are a range of policy instruments and implementation arrangements in Canada and the US (Johns, 2002). As a result of the significant influence of non-point sources, algal blooms have since experienced a resurgence, particularly in Lakes Erie, Ontario and Huron (EC & OMOECC, 2014; Mohammed et al., 2019). Though this is partially due to an increase in the bioavailable P from soils, changes in the way nutrients are processed in lakes due to the presence of mussels which concentrate nutrients in their fecal waste while simultaneously increasing water clarity allowing for algal growth at greater depths (i.e., nearshore shunt) also exacerbate algal bloom occurrences (Hecky et al., 2004; Lake Erie Nutrient Science Task Group, 2015).

While the previous algal blooms were controlled by only a few simple factors, more recent algal blooms are resultant of a combination of factors including invasive species (i.e., zebra and quagga mussels, round gobies), changes in agricultural production, increased urbanization and climate change (EC & OMOECC, 2014). Future reduction strategies must address each of these factors, rather than just require blanket reductions (EC & OMOECC, 2014). This includes implementation of initiatives to manage nearshore water quality, aquatic ecosystem health, as well as algal blooms in all the Great Lakes (EC & OMOECC, 2014). The frequency and severity of harmful algal blooms (HABs) in Lake Erie has increased since the mid- to late-2000s, driving a growing concern from local and federal governments in the U.S. and in Canada (Great Lakes Water Quality Agreement (GLWQA) Nutrients Annex Subcommittee, 2019). Due to its physical characteristics, Lake Erie is especially susceptible to HABs, due to its shallow western basin making it especially warm and biologically productive, particularly given that it receives as much as 61% of the total annual phosphorus load to the Lake (GLWQA Nutrients Annex Subcommittee, 2019). These HABs have led to closures of drinking water treatment plants in Toledo, OH, in 2014, with residents of Pelee Island, Ontario unable to safely use their private water systems due to contamination of microcystin (GLWQA Nutrients Annex Subcommittee, 2019). With a large and growing proportion of the phosphorus entering the Great Lakes being in the dissolved form, rather than particulate form, more of the nutrient is readily available for uptake by algae (GLWQA Nutrients Annex Subcommittee, 2019).

Domestic action plans have been prepared by Canada and the United States, with cooperation from the province of Ontario, Lake Erie states, Tribes, First Nations, and other relevant stakeholders, with nutrient management plans in place in Indiana, Ohio, Michigan, and Pennsylvania (GLWQA Nutrients Annex Subcommittee, 2019). These plans outline the steps to be taken to manage nutrients in each jurisdiction to meet binational nutrients targets (GLWQA Nutrients Annex Subcommittee, 2019). The primary focus of these plans is to reduce nutrients in agricultural sources; though some jurisdictions may be able to achieve sufficient reductions by targeting certain polluters exclusively (Hasan et al., 2022), in many agriculturally dominated watersheds in the United States, it is important that participation rates are high amongst all polluters, with new approaches necessary to achieve these targets (GLWQA Nutrients Annex Subcommittee, 2019). In addition to improving community/stakeholder engagement and education relating to BMPs and the effects of poor nutrient management practices, improved BMP demonstration capabilities and research to understand confounding factors relating to HABs in the Great Lakes (i.e., what role does nitrogen play in their severity) are needed (GLWQA Nutrients Annex Subcommittee, 2019).

Nutrient Management Policies/Programs in Great Lakes Region

This section describes the nutrient management policies and frameworks of the United States and Canada, as well as the transboundary and intergovernmental agreements made to meet the goals outlined in their respective jurisdictions within the Great Lakes region.

Regulation of the Great Lakes water quality is supported first by the Boundary Waters Treaty, which was established by Canada and the United States of America in 1909 and outlines the principles guiding the usage of transboundary waters between the two countries (International Joint Commission, 1909). To mitigate the impacts of point source pollution, the United States and Canada have both implemented similar instruments: first, public investment in nutrient reduction infrastructure at WWTPs and second, monitoring and regulation of large point sources (Johns, 2002). On the other hand, non-point sources of pollution are primarily managed through incentivized adoption of agricultural best management practices (Johns, 2002). Though the approaches of Canadian and U.S. management strategies are generally similar, previous work has found that Canada and Ontario are lacking in their jurisdictional capacity to manage non-point source water pollution relative to the United States federal and state governments (Johns, 2002).

Canadian Federal Policy and Regulatory Framework

There are several pieces of Canadian legislation which are responsible for outlining the objectives and requirements of federal agencies and the provinces in regulating water quality in Canadian waterbodies, including the Great Lakes. The first of these is the Canadian Environmental Protection Act (1999), which facilitates coordination between provinces and the federal government to develop water quality objectives (Voora et al., 2012). This indirectly controls nutrients through the application of the Canadian Water Quality Guidelines. However, the federal Minister of the Environment has the authority to establish water quality guidelines and programs to implement various economic instruments to meet objectives, exerting a direct influence over nutrient management where necessary (Voora et al., 2012). In accordance with section 330 of the Act, these instruments can be used in conjunction with prescribed limits to the minimum, maximum or average concentration of a given pollutant, as well as a standardized method to calculating that concentration (Voora et al., 2012).

The second piece of federal legislation, the Canada Water Act (1985) exists to regulate pollution discharge in areas which have already been designated as “prescribed water quality management areas” and allows for areas to be designated as such where additional regulations are required in order to protect water quality (Voora et al., 2012; Canada Water Act, 1985). As per section 13, subsection 2, the Act establishes that water quality management programs for transboundary waters may become of critical national importance, such that the Governor in Council, with recommendation from the Minister of the Environment, designate waters as water quality management areas, authorizing the Government of Canada to implement water quality management activities (Canada Water Act, 1985; Voora et al., 2012).

For those seeking to undertake development or other activities which would impact the water quality of Canadian waters regulated by the federal government, the Canadian Environmental Assessment Act may be triggered, requiring evaluation of the impacts of proposed developments, however, has minimal impact on the functionality of a water quality trading program (Canadian Environmental Assessment Act, 2012; Voora et al., 2012). Conversely, the Fisheries Act (1985), which protects fish, fisheries, and fish habitat, prohibits activities which would lead to harmful alteration of fish habitat, through deposition of harmful substances or other polluting activities, which would disrupt the natural life cycle processes of fish.

US Federal & State Regulatory Framework

Agricultural sediment runoff, nutrient loading, and pathogens from livestock and human waste represent the largest contributors of non-point source pollution in the United States (Johns, 2002; US EPA, 1995). The U.S. Clean Water Act (1972) seeks to maintain the chemical, physical and biological integrity of the waters of the USA. In addition to defining point and non-point sources of pollution, the act implemented the National Pollutant Discharge Elimination System (NPDES), which requires permits to limit discharges of nutrients into the environment (Clean Water Act, 1972). These discharges are limited by the total maximum daily load (TDML), which is required to be established separately for the relevant pollutant in every lake, river, stream, or other waterbody that fails to meet the federal water quality standards (Clean Water Act, 1972; Voora et al., 2012). Though these limits are used to define permits for point source polluters, it is up to the states to implement plans to meet water quality objectives for various waterbodies, and non-point sources are not directly regulated by the CWA (Palmer et al., 2021). Instead, grants are awarded to states through the Section 319 program, which requires states to develop and submit non-point source pollution management plans to the US EPA to be eligible for funding (Palmer et al., 2021). Funding is subsequently used according to the initiatives outlined in the NPSP management plans (Palmer et al., 2021).

The U.S. Great Lakes states have also developed their own nutrient management plans and legislation relating to freshwater protection, including the Illinois Nutrient Trading Initiative, Phosphorus Trading Exchange in Wisconsin (Palmer et al., 2021), and Pennsylvania Nutrient Management Act (2005).

Great Lakes Water Quality Agreement – 2012

The Great Lakes Water Quality Agreement (GLWQA) between the United States and Canada exists to ensure the long-term viability of the Great Lakes as a source of drinking water, but more generally ensure that the Great Lakes are supported by healthy, productive aquatic ecosystems (i.e., streams, groundwater, wetlands) (US EPA and ECCC, 2012). This agreement's main objectives pertain primarily to maintaining ecosystem health by preventing the deposition of excess nutrients and contaminants and the proliferation of invasive species in the waterways of the Great Lakes basin (GLB), and are supported by the specific lake ecosystem and substance objectives (US EPA and ECCC, 2012). The objectives established in the GLWQA are intended to be accomplished through their jurisdiction-specific environmental programs, with each jurisdiction responsible for monitoring and reporting the environmental conditions of their sub-watersheds to assess progress toward meeting the general and specific objectives of the GLWQA (US EPA and ECCC, 2012).

The GLWQA has several annexes which are relevant to the management of excess nutrients in the sub-watersheds of the Great Lakes Basin, each of which have their own subcommittee within the International Joint Commission, with members including government and non-government environmental and agricultural organizations, with the Annex 9 (Climate change) subcommittee including the Oneida Tribe of Indians of Wisconsin (US EPA and ECCC, n.d.).

Over the period of 2020-2022, there have been several achievements with respect to the Great Lakes WQA Annex 4 relating to Nutrients. These relate to increased actions to reduce P loads to Lake Erie, improved communication between conservation groups about use of modelling to assess and report on hypoxia in Lake Erie, and the commencement of a binational approach to managing harmful algal blooms in Lake Erie (GLEC, 2022). Current priorities relating to nutrient management science include a review of the interim TP guidelines (currently set at 0.03 mg/L) in Lake Ontario, which will be used as a gauge of their effectiveness to ultimately help improve nutrient management in the other Great Lakes (GLEC, 2022).

With respect to the 7th annex on habitat conservation, Canada has made a number of promises relating to establishing land trusts and conserve coastal properties along the Great Lakes, however most activities are still in the community education and support gathering phase, with only small percentages of the anticipated lands being acquired (GLEC, 2022). Similarly, Canada has yet to make significant progress in addressing the environmental impacts from climate change on our natural environments as required by the 9th annex on climate change; to date, most of Canada's achievements relate to the production of reports outlining current research on climate change and facilitating discussions among the climate change modelling community to improve our predictions of potential outcomes from 2000-2100 (GLEC, 2022).

Annex 4: Nutrients

Annex 4 relates to the management of nutrients, specifically P, with the mandate to help achieve suitable P loading and concentrations in the waters of the Great Lakes through coordination of binational management programs. The ecosystem objectives of this Annex seek to ensure that algal blooms are consistent in size and species composition with those of healthy aquatic ecosystems, and that any HABs are maintained at levels such that they do not produce cyanotoxin concentrations high enough to impact human or ecosystem health (US EPA and ECCC, 2012). This includes maintaining an oligotrophic state in the open waters of Lakes

Superior, Michigan, Huron, Ontario, and the eastern basin of Lake Erie, while maintaining a mesotrophic state in the open waters of the western and central basins of Lake Erie (US EPA and ECCC, 2012).

The substance objectives of Annex 4 have been identified as necessary milestones by which to ensure that the ecosystem objectives are being met and seek to establish objective concentrations and loading targets for P, shown in Table 10 (US EPA and ECCC, 2012). These objectives for the open waters of the Great Lakes are to be reviewed and adjusted as necessary, with the GLWQA parties responsible for determining P loading allocations necessary to achieve the Agreement's objectives in each country (US EPA and ECCC, 2012). Additional responsibilities pertain to establishing concentration and loading objectives for nearshore waters of the Great Lakes (i.e., embayments and tributary discharge) (US EPA and ECCC, 2012).

Table 10: Phosphorus loading and concentration objectives for waterbodies within the Great Lakes basin

<table>
<tr><th colspan="2">Waterbody</th><th>Spring mean [P] Objective</th><th>Annual Loading Target (metric tonnes P)</th></tr>
<tr><td colspan="2">Lake Ontario</td><td>10 ug/L</td><td>7,000</td></tr>
<tr><td rowspan="2">Lake Erie</td><td>Central and Eastern Basins</td><td>10 ug/L</td><td rowspan="2">11,000</td></tr>
<tr><td>Western Basin</td><td>15 ug/L</td></tr>
<tr><td colspan="2">Lake Superior</td><td>5 ug/L</td><td>3,400</td></tr>
<tr><td colspan="2">Lake Michigan</td><td>7 ug/L</td><td>5,600</td></tr>
<tr><td colspan="2">Lake Huron</td><td>5 ug/L</td><td>2,800</td></tr>
<tr><td colspan="2">Georgian Bay</td><td>--</td><td>600</td></tr>
<tr><td colspan="2">North Channel</td><td>--</td><td>520</td></tr>
<tr><td colspan="2">Saginaw Bay</td><td>--</td><td>440</td></tr>
</table>

Source: US EPA and ECCC 2012.

In each case, P concentration and loading targets are required to take into consideration the concentrations of each bioavailable species of phosphorus and nitrogen in the watersheds, in the context of ecosystem productivity and fisheries productivity requirements, seasonality, climate change, invasive species and downstream effects as necessary (US EPA and ECCC, 2015). These objectives are periodically reviewed (last reviewed in 2012, and to be reviewed again in 2022) and revised as needed, with additional nutrients to be regulated via future objectives as needed based on periodic reviews (US EPA and ECCC, 2012; GLEC, 2022). Though most of the watersheds did not have a specific timeline to meet these objectives, this work was required to be completed in Lake Erie within 3 years of the GLWQA (US EPA and ECCC, 2012). In each case, the Lake Erie states and Ontario have developed nutrient management plans in most, if not all, of their sub-watersheds (GLEC, 2022).

Annex 4 also requires that the Agreement's parties develop regulatory and non-regulatory programs to address and reduce excess P loading from urban sources, including optimization of wastewater treatment plants and modernization to improve P reductions (US EPA and ECCC, 2012). Daily effluent nutrient concentrations from municipal wastewater treatment plants are to be limited at 1 mg/L in Lakes Superior, Michigan and Huron, and 0.5 mg/L in Lakes Ontario and Erie, with potential for more stringent requirements as necessary (US EPA and ECCC, 2012).

Regulatory and non-regulatory programs should also be established to minimize P loadings from agricultural and rural non-farm sources, in addition to working to reduce P from household cleaning agents to 0.5% by weight (US EPA and ECCC, 2012).

Additional measures must be taken to identify priority watersheds requiring nutrient management and implementation of monitoring environmental quality to help identify further areas of improvement and future binational research initiatives (US EPA and ECCC, 2012). This research is mandated by Annex 4 to focus on nutrient distribution and transportation through the GLB, improved understanding of the causes of HABs, the sources, forms and proportions of nutrients such as P, the biological response of the Great Lakes to various nutrients and what subsequent adverse effects occur, with particular consideration for how climate change will impact various methods of controlling nutrients (US EPA and ECCC, 2012).

Reporting on the progress of implementing the requirements of this Annex are to be published every three years, documenting progress towards meeting lake ecosystem and substance objectives, and changes in P loads and concentrations (US EPA and ECCC, 2012).

Annex 7: Habitats and Species

This Annex seeks to establish objectives which support the conservation and restoration of native species in their environments by supporting ecosystem health and function (US EPA and ECCC, 2012). To this end, the parties have agreed to conduct baseline studies against which to compare future Great Lakes ecosystem health and measure progress towards achieving the GLQWQA's general ecosystem and substance goals (US EPA and ECCC, 2012). Additionally, Annex 7 requires that the parties implement broadscale protective and restorative conservation strategies based on adaptive management to begin addressing the most significant stressors to the Great Lakes ecosystem and assess gaps in binational and domestic programs to develop a framework for prioritizing conservation activities (US EPA and ECCC, 2012). Using a collaborative binational approach to reduce biodiversity loss in the Great Lakes, the parties must identify and increase awareness of protected environments, easements, and other conservation mechanisms necessary to facilitate sensitive species recovery and habitat gains, supporting the longevity of native species in the Great Lakes (US EPA and ECCC, 2012).

Lake-wide management plans are the primary mechanism by which the parties are to coordinate the development of habitat and species protections, with regular reporting on a 3-year basis similarly to Annex 4 (US EPA and ECCC, 2012).

Annex 9: Climate Change

The climate change annex exists with the purpose of coordinating efforts to understand how climate change will impact the quality of waters in the Great Lakes and augment existing challenges to water quality (US EPA and ECCC, 2012). The GLWQA parties agree to consider the effects of climate on chemical, physical and biological parameters, taking climate change into consideration in fulfilling other objectives as outlined in the GLWQA (US EPA and ECCC, 2012). In meeting the objectives of the GLWQA relating to climate change, the parties agree to ensure coordination with the management activities taken by or with the International Joint Commission (US EPA and ECCC, 2012).

The responsibilities of this annex include the development and use of climate models to predict the impacts of potential climate change scenarios on the Great Lakes ecosystem and its component parts; these models are to be compatible and linked to the outputs of other regional models of chemical, biological and physical characteristics, and subsequently used in analytical models to predict specific impacts and risks to future water quality as a result of climate change (US EPA and ECCC, 2012). Binational coordination of climate change research (monitoring, modeling, and analysis) is essential to ensure achievement of water quality objectives across the GLB (US EPA and ECCC, 2012).

Recommended Phosphorus Loading Targets for Lake Erie – 2015

The Recommended Phosphorus Loading Targets for Lake Erie (RPLTLE) was a report jointly released by the Canadian and US governments in May 2015, which identifies the principal cause of eutrophication in Lake Erie to be external sources of phosphorus such as agricultural fertilizers (Mohammed et al., 2019; US EPA & ECCC, 2015). As a result of increasing frequency of HABs within Lake Erie's western basin and the hypoxia experienced in the central basin, a 40% reduction of TP (relative to 2008 loads) was recommended, equal to a total annual TP load of 6000 MT (US EPA & ECCC, 2015). Additionally, a 40% reduction in spring TP and SRP was recommended to control algal blooms in near-shore waters (US EPA & ECCC, 2015). Specific to the United States, a 40% reduction to spring TP and SRP in the Maumee River was also suggested, to a total of 860 MT of TP and 186 MT of SRP (US EPA & ECCC, 2015).

While the 40% reduction target for TP loads to Lake Erie is a necessary component to preserving the health of the Great Lakes, several key challenges exist (Mohammed et al., 2019). First, while the major tributaries such as the Maumee River are well monitored and thus the annual TP loads are well understood, monitoring of the small tributaries is generally quite poor, ultimately resulting in lakewide uncertainty in TP loads to be >20%, confounding an already difficult task brought on by the inter-annual variability of lake loading (20-40% between years in the Great Lakes, ~25% in Lake Erie) (Mohammed et al., 2019; Moatar & Meybeck, 2005; Dolan & Chapra, 2012). Additional challenges exist in the form of lagged responses of TP in watersheds following the implementation of nutrient abatement practices, due to the buildup of legacy pollutants in nutrient sinks such as soils and wetlands which can contribute to TP loads (Mohammed et al., 2019; Sharpley et al., 2009; Parsons et al., 2017).

To address these challenges, the US and Canadian governments seek to implement adaptive management strategies with a suitably robust monitoring program to detect key changes in TP loads and precipitation patterns throughout the year to ensure that nutrient management strategies in the Great Lakes can adapt in response to climate change (US EPA & ECCC, 2015). This improved monitoring is recommended in addition to regularly updated models to facilitate a proactive approach to nutrient management in Lake Erie and the Great Lakes (US EPA & ECCC, 2015).

Implementation of nutrient and phosphorus loading targets since 2015 has primarily been through the intergovernmental efforts of federal, state, and local authorities. In Canada this has primarily been implemented through the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health.

Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health

This Agreement seeks to understand how to better protect the water quality of the Great Lakes from sources within the Canadian portion of the Great Lakes; in particular, the Annexes of the Canada-Ontario Agreement focus on 1) reducing excess nutrients, 2) reducing harmful pollutants, 3) improving wastewater and stormwater management and 4) preventing the discharge from watercraft (EC & OMOECC, 2014).

Annex 1: Nutrients

This annex outlines the steps to be taken to manage nutrients in the Great Lakes, prioritizing Lake Erie due to the severity of nutrient loading, with insights to be applied in the future to Lake Ontario and the remaining Great Lakes as appropriate (EC & OMOECC, 2014).

Both Federal and Provincial governments have invested in nutrient monitoring and research in the Great Lakes with the end goal of reducing harmful algal blooms and hypoxia in the Great Lakes (EC & OMOECC, 2014). These take the form of green infrastructure, wastewater infrastructure and treatment upgrades, and improvement of land use management in rural and urban areas. Specifically, enhanced understanding of nutrient dynamics to develop phosphorus targets and action plans to increase agricultural nutrient efficiency (EC & OMOECC, 2014).

This annex establishes responsibilities and objectives for Canada and Ontario to work towards together and independently, with the goal of meeting P reduction targets in Lake Erie and priority tributaries, managing algal blooms in Lake Ontario to maintain trophic system health and adopting practices which will result in lower P loss from agricultural soils (EC & OMOECC, 2014).

Annex 3: Wastewater and Stormwater

This annex is complementary to that of the Canada-US GLWQA, and similarly serves to support meeting the objectives outlined in the Nutrients annexes of each agreement (EC & OMOECC, 2014). Improvements to wastewater and stormwater management are costly projects which require involvement from a range of organizations, often across federal, provincial and municipal jurisdictions; funding is available through programs such as the Investing in Canada Infrastructure Program, which can support green infrastructure projects which increase stormwater retention and delay transport of contaminants to streams, as well as wastewater treatment facility upgrades which can reduce nutrient concentrations in wastewater effluent (EC & OMOECC, 2014). While much of the funding from these programs tends to be concentrated in areas with high population density, the Ontario Community Infrastructure Fund extends some monetary support to northern and rural communities looking to repair or expand core stormwater and wastewater infrastructure (EC & OMOECC, 2014).

To better protect the Great Lakes from the effects of combined wastewater-stormwater sewer overflows in accordance with the Province of Ontario's Environmental Compliance Approvals, the Province works with municipalities to improve monitoring and reporting of these overflows and to find ways to reduce the presence of pathogens and other contaminants which may impair the health of the Great Lakes (EC & OMOECC, 2014).

The goals outlined in Annex 3 pertain to reductions in excess nutrients and contaminants in stormwater and wastewater facilities of urban and rural communities, with the Federal government providing funding and support for improved infrastructure to mitigate nutrients and contaminants, while the Province of Ontario is responsible for promoting best management practices among municipalities (EC & OMOECC, 2014). Both federal and provincial governments will work to make data available with regular reporting to support regular policy reviews to identify progress and additional necessary steps toward meeting nutrient and contaminant reductions (EC & OMOECC, 2014).

Ontario Great Lakes Strategy – 2012

A main goal of Ontario's Great Lakes Strategy pertains to the protection of water for human and ecological health (Ontario Ministry of the Environment & Climate Change (OMOECC), 2012). This includes reducing concentrations of toxic chemicals, conserving aquatic ecosystems and minimizing the compound effects brought on by climate change, invasive species, urban growth and increasing water diversions on the Great Lakes (OMOECC, 2012).

Algal blooms within the Great Lakes have become increasingly problematic, in part due to the presence of invasive mussels which help to amplify sensitivity to P inputs from land-based sources, with agricultural and urban non-point sources being the most dominant influences on P loading to near-short waters where mussels are present (OMOECC, 2012).

Population growth poses a threat to the Great Lakes, with increasing populations necessitating greater wastewater treatment capacity, leading to greater P loading to watersheds (OMOECC, 2012). With a changing climate resulting in more severe storms, runoff water quality and erosion will result in more frequent and severe high-[P] pulses through watersheds into receiving water bodies, which may be mitigated with green infrastructure, such as constructed wetlands (OMOECC, 2012).

Watershed-based approaches such as those employed in the Lake Simcoe watershed may serve as a strong model for water quality management in watersheds which face the common challenges of excess nutrients and contaminants, proliferation of invasive species, rapid urban growth and a changing climate (OMOECC, 2012). Lake Simcoe combines voluntary environmental stewardship with community engagement and educational activities to drive support for regulatory actions which reduce P and mitigate its effects over the long-term (OMOECC, 2012).

The Great Lakes Strategy seeks to achieve five main objectives. The first is to protect drinking water by taking a collaborative approach to support and implement source water protection plans in the GLB in line with the Clean Water Act (OMOECC, 2012). This objective also requires support for First Nations communities in implementing drinking water source protection strategies which are culturally appropriate (OMOECC, 2012).

The second objective is to reduce impacts from contaminated stormwater and wastewater by facilitating further research, development and engagement with the community about their benefits from green infrastructure and low impact development (LID) techniques in controlling both the volume of water and urban contaminants (OMOECC, 2012). Ontario must also ensure that municipal wastewater policies consider the management of stormwater in the context of emerging management practices and technologies, with a more streamlined approvals process to ensure that these emerging strategies are more easily and affordably adopted (OMOECC, 2012). To do so, continued monitoring of combined sewer overflows is necessary to quantify contaminants for reduction and highlight the importance of promoting alternative stormwater and wastewater controls (OMOECC, 2012). Reducing wastewater impacts is to be accomplished by cooperation between the various levels of government in supporting municipalities in managing infrastructure assets to identify potential areas of improvement, and by providing a "one-window" approach with consistent minimum standards for WWTP discharge (OMOECC, 2012). Collectively, this will require consultation across municipalities, provincial and federal government agencies, the water sector and other stakeholders to implement a municipal water sustainability plan under the promoted sustainable and consistent policies which are founded in regular reporting of performance indicators to protect source waters (OMOECC, 2012).

The third and fourth objectives pertain to reducing excess nutrients and toxic chemical contaminants, respectively (OMOECC, 2012). Both are to be accomplished through greater understanding of existing agricultural stewardship programs, with the intention of expanding BMP adoption, particularly in priority agricultural systems, while the latter will be accomplished with updated regulations for maximum contaminant concentrations and improving environmental monitoring and data sharing (OMOECC, 2012). The final goal, ensuring environmentally sustainable economic opportunities and innovation, highlights the large body of research which indicates the economic value of protecting the Great Lakes now and into the future, by strengthening cooperative relationships within Ontario and around the world to ensure that Canadian water quality management is adaptive to new innovations to reduce the costs and improve the efficiency of measures to protect the Great Lakes (OMOECC, 2012).

Ontario Water Quality and Nutrient Policy Framework

Though water quality management has been long regarded as primarily being within the jurisdiction of the provincial governments, Ontario has been slow to address minimum surface and groundwater quality standards with provincial legislation, particularly related to non-point source pollution, generally lagging the federal government and other jurisdictions such as the United States (Johns, 2002). Starting in the 1970s, Ontario used the Ontario Water Resources Act and Environmental Protection Act to regulate point sources, invest in point-source reduction technologies and monitoring strategies through the Ministry of Environment and the Municipal-Industrial Strategy for Abatement (MISA) program, which regulated pollution from point sources through a permitting system similarly to the NPDES program in the U.S. (Johns, 2002).

There are several pieces of legislation related to water quality management in Ontario. Following the Walkerton Inquiry, the *Nutrient Management Act* (2002) outlines a preventative approach to ensuring the sustainable use of nutrients, providing the Ministry of Environment's Agricultural Environmental Officers (AEOs) special privileges in encouraging compliance and administering corrective actions for growers who are non-compliant with the *Nutrient Management Act* (OMAFRA, 2021c). Depending on the severity and duration of a grower's status as non-compliant, AEOs may make informal requests for information, issue Provincial Officer's Orders for extended non-compliance which could lead to environmental degradation, or in the event of serious non-compliance and harmful activities, issue tickets (typically including set fines) (OMAFRA, 2021c). In the worst-case scenario, AEOs may make a referral to the

Investigations and Enforcement Branch, initiating an investigation of serious negligence and failure to respond to previous attempts to address issues relating to nutrient management (OMAFRA, 2021c).

Water Quality and Nutrient Offsetting in Ontario

The Ontario Ministry of Environment, Conservation and Parks (MECP) is responsible for managing water quality in the Province of Ontario. Place-based, or area-based management describes management practices which have impact on a specific location or area and has been a focus of environmental management strategies since the 1980s-1990s (Olsen et al., 2010; Government of Ontario, 2021). The province and its Conservation Authorities have tried a variety of instruments, such as permitting and licenses relating to agricultural land use practices (i.e., “sticks”), subsidies or tax incentives (i.e., “carrots”) and informational/educational outreach (i.e., “sermons”) to address non-point source water pollution (Johns, 2002; 2008).

The *Ontario Water Resources Act* (1990) outlines the powers of the province in setting regulations which establish and govern water quality regulations and programs. Under this legislation the province also has authority to oversee and retire water quality trading programs (subsection 75 (1.7)) (RSO 1990, c. O.40). In particular, these powers relate to the Province’s power to designate a person or body to administer trading programs, determine the areas where water quality trading can be applied, what parameters the trading applies to, who/what people or organizations trading applies to, what water quality trading instruments (i.e., offsets, credits or allowances) can be employed, and what requirements must be met by those who the regulations applies to (i.e., maximum discharge limits, monitoring and reporting of water quality parameters for compliance evaluation) (RSO 1990, c. O.40). The Ontario Water Resources Act additionally grants the province the ability to govern any other additional matters relating to the administration of water quality trading programs not included in the initial scope of subsection 71 (1.7) (RSO 1990, c. O.40). There are no existing WQT programs in Ontario.

The province also has a history of supporting Best Management Practices (BMPs) to address non-point source water pollution (Johns, 2002), and since the Walkerton Inquiry has tried to strengthen policies and regulations related to water pollution (Johns, 2008). The Province of Ontario also requires some farms to produce nutrient management plans/strategies (NMPs or NMSs) in compliance with the *Nutrient Management Act* (2002). This requires that nutrient management plans be updated annually describing farm conditions (i.e., the number of animals, acres of crops, types of nutrients used and their quantity), as well as progress towards meeting nutrient reduction goals or implementing BMPs (S.O. 2002, c. 4).

In addition to province-wide legislation and regulations, the province also has basin specific policies and legislation. The *Lake Simcoe Protection Act* (2008) and Lake Simcoe Protection Plan requires that future population growth be accommodated without increasing phosphorus loadings. This included a feasibility study by the Ontario MOE relating to potential water quality trading in the Lake Simcoe basin (Policy 4.25 of the Lake Simcoe Protection Plan) (Ontario Ministry of the Environment, 2009), The Lake Simcoe Protection Plan has set a maximum loading of 44 tonnes/year for the future, the level necessary to support a self-sustaining cold-water fishery in the lake. Reaching this target will require a concerted effort on the part of all dischargers, especially as population grows in the Lake Simcoe watershed and places increasing pressure on sewage treatment plants and stormwater facilities. The Lake Simcoe Protection Plan recognizes that 44 tonnes/year is an ambitious goal and encourages watershed partners to explore innovative ways of reducing pollution to the lake. Water quality trading and offsetting are examples of innovative solutions being considered during the recent LSPP 10-year review.

As outlined above, the province also has intergovernmental agreements and policies related to water quality. To achieve the policy objectives set for the MECP in the GLWQA and Canada-Ontario Agreement on Great Lakes Water Quality, some responsibilities are delegated to both Conservation Authorities (CAs) and municipalities. CAs are empowered by the *Conservation Authorities Act* (RSO 1990, c. C.27) to develop programs which facilitate the protection and restoration of the environment, and the management of natural resources within a watershed. As part of their authority, CAs have the ability to prohibit or permit developments within the watershed which would interfere with ecosystem functions, with particular control over activities relating to flooding, erosion and pollution control (RSO 1990, c. C.27). CAs are responsible for entering into offsetting agreements when provincial environmental Minister's Zoning Orders (MZOs) are issued and can set the requirements for landowners to mitigate the impacts of specific developments (RSO 1990, c. C.27).

CAs can accept cash-in-lieu of offsetting practices, however it then falls to the CA to ensure that the funds are appropriately spent on offsetting activities, including land acquisitions for the purpose of future environmental restoration projects or of ecologically significant lands which are home to important ecological or hydrologic features (e.g., wetlands) (RSO 1990, c. C.27; Nottawasaga Valley Conservation Authority, 2021). Though each of the CAs managing the watersheds with nutrient management programs do collect water quality samples, only some of this data is available through via open data portals, such as the Ontario Provincial Water Quality Monitoring Network, and many of these datasets are limited to dry-weather conditions between May – October (G. Kaltenecker & J. Dougherty, personal communication).

Municipalities are typically the operators of wastewater treatment facilities and thus are potential buyers in a nutrient offsetting/trading program (Kieser & Associates, XCG Consultants Ltd., D.W. Draper Associates & Commexus Inc., 2010). Additionally, given that it is municipalities which are responsible for outlining plans for future development, they are best equipped to describe the future nutrient offsetting needs resulting from the expansion of large point sources of pollution.

Ontario's Nutrient and Phosphorous Offsetting Program

As outlined in the two previous sections, key considerations of the MECP's water policies grounded in the Ontario Water Resources Act, the Lake Simcoe Protection Act and the Lake Simcoe Protection Plan (LSPP) and the MECP is responsible for managing water quality in the Province of Ontario and sets water quality guidelines for a number of parameters including total phosphorus (0.03 mg/L TP in streams, <0.01-0.02 mg/L in lakes during ice-free periods) (OMECP, 2021b).

Legislation and policies do not prevent the use of offsetting programs that are part of an environmental approval. However, the applicant must demonstrate that all reasonable efforts to protect the receiving waters have been undertaken but where suitable pollution prevention technologies/approaches are not available, or the cost of implementing these technologies/approaches is prohibitive.

In addition to the province's ability to facilitate offsetting, Conservation Authorities can participate in the success of these programs as a result of their mandate to mitigate and adapt to climate change, which includes supporting and implementing mitigation programs within the scope of their mandate such as reforestation, carbon sequestration and LIDs within their jurisdictions (Conservation Ontario, 2015). Adaptive programs relating to climate change monitoring and modelling, green/stormwater management infrastructure, and climate-change related offsetting can similarly be used to support both climate change-specific initiatives, as well as water quality improvements (Conservation Ontario, 2015), due to the interdependencies between water quality and climate change.

Many voluntary programs and policy efforts have tried to target well-known, harmful pollutants such as phosphorus and nitrogen. However, due to uncertainty in transportation and consumption within the watershed, it is not suitable to simply offset P inputs at a 1:1 ratio (O'Grady, 2008). The two primary factors considered in determining the number of kg of P to be purchased are the amount of P to be discharged, and the offset ratio (O'Grady, 2008). In Ontario, the P offset ratio is 4:1, due to the uncertainties in the mass and timing of P transport through watersheds, as well as the proportions of soluble and particulate P; while other jurisdictions have lower offset ratios, a more conservative ratio provides greater confidence to the community that mitigation practices are effective (O'Grady, 2008). This is common for agricultural offsets. In practice, in Ontario, the ratio can be lower based on certainty of the offset. Higher offset ratios reflect the challenge of attributing a reduction in the environment to implementation of a BMP.

A crucial component of an offset associated with an environmental approval is the establishment of an appropriate **offset ratio** (minimum amount of reduction required for the exceedance of a discharge target or limit) which reflects the level of risk to achieve desired reduction (i.e., reliability and longevity of offset projects) and considers cost-effectiveness. Rather than being established through legislation or other policies, these ratios are developed on an individual case-by-case basis and take into consideration the concerns of the community they serve. As a result, this can lead to higher offsetting ratios to improve public confidence in the offsetting program (e.g. South Nation Conservation in O'Grady, 2008). WWTP approvals with offsetting conditions typically list SWM offset projects with a ratio of 2:1 or agriculture offset projects that use best management practices with ratios of >2:1 (e.g., Lake Simcoe), however this is dependent on negotiations with the Ontario Ministry of Environment and the results of any relevant Environmental Assessments (T. Krsul, personal communication).

Ontario has primarily employed offsetting programs in the context of WWTPs, often as a stipulation in environmental approvals (environmental assessments or environmental compliance approvals) for new and expanded sewage works which are limited in the amount of P they can discharge into a receiving water body (T. Krsul, personal communication). Examples of P offsetting programs in Ontario include those in the South Nation, and Acton, Tottenham and Nobleton WWTPs, which offset WWTP discharge with a range of abatement methods, such as building or upgrading SWM works, retiring septic beds, or improved agricultural BMPs. After all other reasonable efforts to protect water quality have been undertaken, offsetting can be considered when pollution prevention/reduction technologies or approaches are not available or are prohibitively expensive (T. Krsul, personal communication). These offsetting programs require offset ratios which compensate for the risk associated with the possibility of nutrient offsetting practices failing to achieve target reductions (T. Krsul, personal communication).

Phosphorus offset in the context of a WWTP is a procedure whereby environment approvals (EA or ECA) for a new or expanded Sewage works (most commonly a WWTP) would be granted a limited increase in the amount of acceptable phosphorus it can directly discharge into a receiver. The increase is ‘offset’ by reductions elsewhere in the same watershed/ receiving water body. Past examples include South Nation, Acton (Halton Hills), Tottenham (Nottawasaga), and Nobleton (Uxbridge) WWTPs. Increased phosphorus from the WWTPs has been offset by retrofitting or building new stormwater management (SWM) works for areas that currently do not have adequate SWM; retiring septic beds; providing agricultural best management practices such as buffer lands and livestock fencing; and erosion control works.

In addition, the province continues to seek opportunities to achieve nutrient reductions in the tributaries of the Great Lakes, including by working with regional and municipal governments. For example, the province has worked with the Regional Municipality of Waterloo and the Grand River Conservation Authority (GRCA) to implement a nutrient offsetting program in the Grand River watershed (Hutchinson Environmental Services Ltd., 2017).

To achieve nutrient load reductions in the sub-watersheds of the Great Lakes Basin, the MECP has identified several key criteria to be evaluated for in existing nutrient management/offsetting pilot projects (Table 11), which will serve as the basis for future, province-wide efforts to reduce nutrient loading to the Great Lakes, and specifically, Lake Erie.

Table 11: Evaluation Criteria from Ontario MECP Phosphorus Offsetting Project Description: Assessment of nutrient management program design characteristics.

Criteria	Assessed based on:
Level of Support for adoption	- Stakeholder engagement and participation within the watershed - Presence of innovative practices and/or technologies
Reliance on conventional infrastructure funding?	- Source of funding (Province, CA, municipal, shared) - Limitations to specific types of projects (BMPs, WWTP upgrades; what type)
Changes in stormwater runoff volumes and pollutant loadings over time	- Availability of TP concentration and stream discharge data (daily/monthly/annual loads; event sampling; dataset size)
Ecological benefits	- Monitoring of chemical/biological parameters (species abundance, dissolved oxygen, pH, etc.) - Location of observed nutrient reductions (streams vs lakes)
Co-benefits, other economic/social benefits	- Type of offsets applied - Location of offsets - Cost of nutrient abatement practices relative to alternative point source abatement

Tactics/design associated with managing risk and uncertainty associated with offset ratios and payments in lieu of mitigation	- Models are used to determine offsetting ratio (how uncertain are estimates, what offsetting practices are being used) - Data sources for nutrient loads (location specific or broad coverage of North American farms)

Source: MECP, 2022.

Bibliography:

Arrow, K. J. 1974. *The Limits of Organization.* Norton, New York.

Atkinson, S. E., & Lewis, D. H. (1974). A cost-effectiveness analysis of Alternative Air Quality Control Strategies. *Journal of Environmental Economics and Management*, *1*(3), 237–250. https://doi.org/10.1016/0095-0696(74)90005-9

Ator, S. W., Blomquist, J. D., Webber, J. S., & Chanat, J. G. (2020). Factors driving nutrient trends in streams of the Chesapeake Bay Watershed. *Journal of Environmental Quality*, *49*(4), 812–834. https://doi.org/10.1002/jeq2.20101

Ator, S. W., García, A. M., Schwarz, G. E., Blomquist, J. D., & Sekellick, A. J. (2019). Toward explaining nitrogen and phosphorus trends in Chesapeake Bay Tributaries, 1992–2012. *JAWRA Journal of the American Water Resources Association*, *55*(5), 1149–1168. https://doi.org/10.1111/1752-1688.12756

Attridge, I.C. (1997). Conservation Easement Valuation and Taxation in Canada, Report No. 97-01, prepared for the North American Wetlands Conservation Council and Environment Canada, Canadian Wildlife Service, Habitat Conservation Division. Ottawa: Environment Canada.

Bemelmans-Videc, M.-L., Rist, R. C., Vedung, E., & Vedung, E. (1998). Policy instruments: Typologies and theories. In *Carrots, sticks and sermons: Policy Instruments and their evaluation* (Vol. 1). essay, Transaction Publishers.

Canada Water Act. (1985). R.S.C. 1985, c. C-11. Retrieved from: https://laws-lois.justice.gc.ca/eng/acts/c-11/index.html

Canadian Environmental Assessment Act. (2012). S.C. 2012, c. 19, s. 52. Retrieved from: https://laws-lois.justice.gc.ca/eng/acts/C-15.21/index.html

Canadian Environmental Protection Act. (1999). S.C. 1999, c. 33. Retrieved from: https://laws-lois.justice.gc.ca/eng/acts/c-15.31/

Cappiella, K., Hirschman, D., Stack, B. (2013). Using Nutrient Credits and Offsets to Achieve Stormwater Compliance with the Chesapeake Bay TMDL. Watershed Science Bulletin. Retrieved from: https://owl.cwp.org/mdocs-posts/using-nutrient-credits-and-offsets-to-achieve-stormwater-compliance-with-the-chesapeake-bay-tmdl/

Chung, K. S., & Pruitt , S. W. (1994). A simple approximation of Tobin's Q. Financial Management 5(Autumn) 70–74. *Financial Management* , *5*, 70–74.

Clean Water Act, 33 U.S.C. § 1251 *et seq*. (1972).

Cole, D. H., & Grossman, P. Z. (1999). When is command-and-control efficient? institutions, technology, and the comparative efficiency of alternative regulatory regimes for environmental protection. *The Theory and Practice of Command and Control in Environmental Policy*, 115–166. https://doi.org/10.4324/9781315197296-7

Conservation Authorities Act. (1990). R.S.O 1990, c. C.27. Retrieved from: https://www.ontario.ca/laws/statute/90c27

Conservation Ontario. (2015). Protecting Our Future: Ontario Provincial Plans and Conservation Authorities. Retrieved from: https://conservationontario.ca/fileadmin/pdf/conservation_authorities_section_planning___regulations/Protecting_Our_Future_-_Ontario_Provincial_Plans_and_Conservation_Authorities.pdf

Dahlman, C. J. (1979). The problem of externality. *The Journal of Law and Economics*, *22*(1), 141–162. https://doi.org/10.1086/466936

Davey, W.B. (1977). Conservation Districts and 208 Water Quality Management, US Environmental Protection Agency. National Association of Conservation Districts under Environmental Protection Agency Grant No. T90057401-0.

Díaz‐Zorita, M., Grove, J. H., Murdock, L., Herbeck, J., & Perfect, E. (2004). Soil structural disturbance effects on crop yields and soil properties in a No‐till production system. *Agronomy Journal*, *96*(6), 1651–1659. https://doi.org/10.2134/agronj2004.1651

Diebel, M. W., Maxted, J. T., Nowak, P. J., & Vander Zanden, M. J. (2008). Landscape Planning for Agricultural Nonpoint Source Pollution Reduction I: A geographical allocation framework. *Environmental Management*, *42*(5), 789–802. https://doi.org/10.1007/s00267-008-9186-3

Dinnes, D. L. (2004). Assessments of practices to reduce nitrogen and phosphorus nonpoint source pollution of Iowa's surface waters. *USDA-ARS, National Soil Tilth Laboratory.*

Dolan, D. M., & Chapra, S. C. (2012). Great Lakes Total Phosphorus Revisited: 1. Loading Analysis and update (1994–2008). *Journal of Great Lakes Research*, *38*(4), 730–740. https://doi.org/10.1016/j.jglr.2012.10.001

Dowell, G., Hart, S., & Yeung, B. (2000). Do corporate global environmental standards create or destroy market value? *Management Science*, *46*(8), 1059–1074. https://doi.org/10.1287/mnsc.46.8.1059.12030

Drevno, A. (2016). Policy tools for Agricultural Nonpoint Source Water Pollution Control in the U.S. and E.U. *Management of Environmental Quality: An International Journal*, *27*(2), 106–123. https://doi.org/10.1108/meq-12-2014-0177

Environment Canada and the Ontario Ministry of the Environment and Climate Change (EC & OMOECC). (2014). Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health. Retrieved from: https://publications.gc.ca/collections/collection_2014/ec/En164-51-2014-eng.pdf

Environmental Law Institute (ELI). (1998). Almanac of enforceable state laws to control nonpoint source water pollution. Environmental Law Institute Research Report, Washington, DC.

European Commission. (2014). The EU water framework directive – integrated river basin management for Europe. Brussels. Retrieved from: http://ec.europa.eu/environment/water/water-framework/index_en.html

Fink, D. F., & Mitsch, W. J. (2004). Seasonal and storm event nutrient removal by a created wetland in an agricultural watershed. *Ecological Engineering*, *23*(4-5), 313–325. https://doi.org/10.1016/j.ecoleng.2004.11.004

Fisher, J., & Acreman, M. C. (2004). Wetland nutrient removal: A review of the evidence. *Hydrology and Earth System Sciences*, *8*(4), 673–685. https://doi.org/10.5194/hess-8-673-2004

Fisheries Act. (1985). R.S.C. 1985, c. F-14. Retrieved from: https://laws-lois.justice.gc.ca/eng/acts/f-14/

Fleming, P. M., Stephenson, K., Collick, A. S., & Easton, Z. M. (2022). Targeting for nonpoint source pollution reduction: A synthesis of lessons learned, remaining challenges, and emerging opportunities. *Journal of Environmental Management*, *308*, 114649. https://doi.org/10.1016/j.jenvman.2022.114649

Fox, R. J., Fisher, T. R., Gustafson, A. B., Koontz, E. L., Lepori-Bui, M., Kvalnes, K. L., Bunnell-Young, D. E., Gardner, J. R., Lewis, J., Winsten, J. R., Fisher, K. A., & Silaphone, K. (2021). An evaluation of the Chesapeake Bay Management Strategy to improve water quality in small agricultural watersheds. *Journal of Environmental Management*, *299*, 113478. https://doi.org/10.1016/j.jenvman.2021.113478

Gitau, M.W., Gburek, W.J., & Jarrett, A.R. (2005). A tool for estimating best management practice effectiveness for phosphorus pollution control. *Journal of Soil and Water Conservation*, *60*(1), 1–10.

The Gordon Foundation. (2022). Great Lakes DataStream. Retrieved from: https://greatlakesdatastream.ca/

Government of Ontario. (2021). Guidance to support area-based water quality management. Retrieved from: https://www.ontario.ca/page/guidance-support-area-based-water-quantity-management

Great Lakes Executive Committee (GLEC). (2022). 2022 Progress Report of the Parties – Pursuant to the 2012 Canada-United States Great Lakes Water Quality Agreement (DRAFT 12/9/2021).

Great Lakes Water Quality Agreement (GLWQA) Nutrients Annex Subcommittee. (2019). Lake Erie Binational Phosphorus Reduction Strategy. Retrieved from: https://binational.net/wp-content/uploads/2019/06/19-148_Lake_Erie_Strategy_E_accessible.pdf

Gunningham, N., Grabosky, P. N., & Sinclair, D. (1998). *Smart regulation: Designing environmental policy*. Oxford University Press.

Hart, S. L. (1995). A natural-resource-based view of the firm. *The Academy of Management Review*, *20*(4), 986. https://doi.org/10.2307/258963

Hasan, S., Hansen, L. B., Smart, J. C., Hasler, B., & Termansen, M. (2022). Tradeable nitrogen abatement practices for diffuse agricultural emissions: A 'smart market' approach. *Environmental and Resource Economics*, *82*(1), 29–63. https://doi.org/10.1007/s10640-022-00657-2

Hayman, D. (1989). Subsurface drainage contamination with milkhouse wastewater: An environmental concern. Pan-American Regional Conference. pp. 209-218.

Hecky, R. E., Smith, R. E. H., Barton, D. R., Guildford, S. J., Taylor, W. D., Charlton, M. N., & Howell, T. (2004). The nearshore phosphorus shunt: A consequence of Ecosystem Engineering by Dreissenids in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, *61*(7), 1285–1293. https://doi.org/10.1139/f04-065

Hutchinson Environmental Sciences Limited. (2022). Peer Review of the Halton Hills Total Phosphorus Offset Program.

Hutchinson Environmental Sciences Limited. (2017). Region pf Waterloo Wastewater Treatment Master Plan Update Appendix J: TM9A – Phosphorus Offsetting: Review of Existing Ontario Programs and Opportunities. Retrieved from: https://www.regionofwaterloo.ca/en/living-here/resources/Documents/water/projects/wastewater/plan/WS2018V5-Tech_Memo_9A_WWTMP-Phosphorus_Offsetting_2017.PDF

Imbrium Systems. (n.d). Stormwater Treatment Solutions - Jellyfish Filter. Retrieved from: https://www.imbriumsystems.com/stormwater-treatment-solutions/jellyfish-filter

International Institute for Sustainable Development (IISD). (2019). Case Study Research on Offsets for Water Quality Management. Retrieve from: https://www.iisd.org/system/files/publications/offsets-water-quality-management.pdf

Jain, C. K., & Singh, S. (2019). Best management practices for agricultural nonpoint source pollution: Policy interventions and way forward. *World Water Policy*, *5*(2), 207–228. https://doi.org/10.1002/wwp2.12015

James, E. E. (2005). Factors influencing the adoption and non-adoption of the conservation reserve enhancement program in the Cannonsville Watershed, New York. M.Sc. Diss. thesis. Department of Agricultural Economics and rural Sociology, The Pennsylvania State University, University Park.

Jensen, R. (1982). Adoption and diffusion of an innovation of uncertain profitability. *Journal of Economic Theory*, *27*(1), 182–193. https://doi.org/10.1016/0022-0531(82)90021-7

Johns, C.M. (2000). Non-point source water pollution management in Canada and the United States: A comparative analysis of institutional arrangements and policy instruments. Ph.D. Diss. Department of Political Science, McMaster University. Hamilton, Ontario, Canada.

Johns, C. M. (2002). Policy Instruments to Manage Non-point Source Water Pollution: Comparing the United States and Ontario. *Queen's Printer of Ontario*.

Johns, C. M. & Rasmussen, K. (2008). Institutions for Water Resource Management in Canada. In M. Sproule-Jones, C. M. Johns, & T. Heinmiller (Eds.) Canadian Water Politics: Conflicts and Institutions. McGill-Queen's University Press.

Kay, P., Edwards, A. C., & Foulger, M. (2009). A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK Water Industry. *Agricultural Systems*, *99*(2-3), 67–75. https://doi.org/10.1016/j.agsy.2008.10.006

Kieser & Associates, XCG Consultants Ltd., D.W. Draper Associates & Commexus Inc. (2010). Water Quality Trading in the Lake Simcoe Watershed – Feasibility Study. Retrieved from: http://kieser-associates.com/uploaded/simcoe_water_quality_trading_feasibility_study.pdf

King, A., & Lenox, M. (2002). Exploring the locus of profitable pollution reduction. *Management Science*, *48*(2), 289–299. https://doi.org/10.1287/mnsc.48.2.289.258

Klassen, R. D., & Whybark, D. C. (1999). The impact of environmental technologies on manufacturing performance. *Academy of Management Journal*, *42*(6), 599–615. https://doi.org/10.5465/256982

Kroll, S. A., Oakland, H. C., & Minerovic Frohn, A. (2021). Macroinvertebrate and diatom indicators of baseline conditions for setting targets in agricultural BMP Restoration. *Ecosphere*, *12*(11). https://doi.org/10.1002/ecs2.3798

Lake Erie Nutrient Science Task Group. (2015). Status of Nutrients in the Lake Erie Basin. Retrieved from: https://www.epa.gov/sites/default/files/2015-10/documents/status-nutrients-lake-erie-basin-2010-42pp.pdf

Lake Simcoe Protection Act. (2008). S.O. c. 23. Retrieved from: https://www.ontario.ca/laws/statute/08l23

Lake Simcoe Region Conservation Authority (LSRCA). (n.d. a) https://www.lsrca.on.ca/our-watershed

Lake Simcoe Region Conservation Authority (LSRCA). (n.d. b). Watershed Health – Phosphorus. Retrieved from: https://www.lsrca.on.ca/watershed-health/phosphorus

Lake Simcoe Region Conservation Authority (LSRCA). (2017). Watershed Map. Retrieved from: https://www.lsrca.on.ca/Shared%20Documents/Lake-Simcoe-Watershed-Map.pdf

Lake Simcoe Region Conservation Authority (LSRCA). (n.d. c). Phosphorus Loads Update: 2015-2017. Retrieved from: https://www.lsrca.on.ca/Pages/Phosphorus-Loads-Update.aspx

Lake Simcoe Region Conservation Authority (LSRCA). (2021a). Phosphorus Offsetting Policy. Retrieved from: https://www.lsrca.on.ca/Shared%20Documents/Phosphorus_Offsetting_Policy.pdf

Lake Simcoe Region Conservation Authority (LSRCA). (2021b). Water Balance Recharge Policy for the Lake Simcoe Protection Plan. Retrieved from: https://www.lsrca.on.ca/Shared%20Documents/lspp-water-budget-policy.pdf

Lintern, A., McPhillips, L., Winfrey, B., Duncan, J., & Grady, C. (2020). Best management practices for diffuse nutrient pollution: Wicked problems across urban and agricultural watersheds. *Environmental Science & Technology*, *54*(15), 9159–9174. https://doi.org/10.1021/acs.est.9b07511

Macgregor, A. N., Bowler, D. G., Tan, T. O., & Syers, J. K. (1982). Removal of nitrogen and phosphorus from untreated milking-shed wastes after application to permanent pasture. *Agricultural Water Management*, *5*(2), 181–191. https://doi.org/10.1016/0378-3774(82)90006-3

Melland, A. R., Fenton, O., & Jordan, P. (2018). Effects of agricultural land management changes on surface water quality: A review of Meso-scale catchment research. *Environmental Science & Policy*, *84*, 19–25. https://doi.org/10.1016/j.envsci.2018.02.011

Moatar, F., & Meybeck, M. (2005). Compared performances of different algorithms for estimating annual nutrient loads discharged by the Eutrophic River Loire. *Hydrological Processes*, *19*(2), 429–444. https://doi.org/10.1002/hyp.5541

Mohamed, M. N., Wellen, C., Parsons, C. T., Taylor, W. D., Arhonditsis, G., Chomicki, K. M., Boyd, D., Weidman, P., Mundle, S. O., Cappellen, P. V., Sharpley, A. N., & Haffner, D. G. (2019). Understanding and managing the re-eutrophication of Lake Erie: Knowledge gaps and research priorities. *Freshwater Science*, *38*(4), 675–691. https://doi.org/10.1086/705915

Moran, M. (2003). *The British Regulatory State High Modernism and hyper-innovation*. Oxford University Press.

Moss, T. (2004). The governance of land use in river basins: prospects for overcoming problems of institutional interplay with the EU water framework directive. Land Use Policy, Vol. 21 No. 1, pp. 85-94.

Mulroy, K. (2010). Assessing the Performance of Two Stormwater Management Ponds in Waterloo, Ontario. M.Sc. Diss. thesis. Department of Geography, University of Waterloo, Waterloo, Ontario, Canada.

Nelligan, C., Sorichetti, R. J., Yousif, M., Thomas, J. L., Wellen, C. C., Parsons, C. T., & Mohamed, M. N. (2021). Then and now: Revisiting nutrient export in agricultural watersheds within Southern Ontario's Lower Great Lakes Basin. *Journal of Great Lakes Research*, *47*(6), 1689–1701. https://doi.org/10.1016/j.jglr.2021.08.010

Newman, J. M., Clausen, J. C., & Neafsey, J. A. (2000). Seasonal performance of a wetland constructed to process dairy milkhouse wastewater in Connecticut. *Ecological Engineering*, *14*(1-2), 181–198. https://doi.org/10.1016/s0925-8574(99)00028-2

Nottawasaga Valley Conservation Authority (NVCA). (2018a). Lower Nottawasaga River Subwatershed Health Check - 2018. Retrieved from: https://www.nvca.on.ca/Shared%20Documents/2018%20Watershed%20Health%20Check/2018%20Watershed%20Health%20Check_Lower%20Nottawasaga%20Subwatershed.pdf

Nottawasaga Valley Conservation Authority (NVCA). (2018b). Middle Nottawasaga River Subwatershed Health Check - 2018. Retrieved from: https://www.nvca.on.ca/Shared%20Documents/2018%20Watershed%20Health%20Check/2018%20Watershed%20Health%20Check_Middle%20Nottawasaga%20River%20Subwatershed.pdf

Nottawasaga Valley Conservation Authority (NVCA). (2018c). Upper Nottawasaga River Subwatershed Health Check - 2018. Retrieved from: https://www.nvca.on.ca/Shared%20Documents/2018%20Watershed%20Health%20Check/2018%20Watershed%20Health%20Check_Upper%20Nottawasaga%20River%20Subwatershed.pdf

Nottawasaga Valley Conservation Authority (NVCA). (2021). Achieving Net Gains through Ecological Offsetting. Retrieved from: https://www.nvca.on.ca/Shared%20Documents/NVCA_Policy_Guidelines_for_Achieving_Ecological_Net_Gains_FINAL%20costing%20examples%2012-MAY-2021.pdf

Nutrient Management Act. (2002). S.O. 2002, c. 4. Retrieved from: https://www.ontario.ca/laws/statute/02n04

Pennsylvania Nutrient Management Act. (2005). 3. PA.C.S. Retrieved from: https://extension.psu.edu/programs/nutrient-management/act-38-law-and-regulations/act-38-of-2005

O'Connor, D. R. (2002). *Report of the Walkerton Inquiry*. Ontario Ministry of the Attorney General.

Ogilvie, Ogilvie & Company. (2013). Citizen's Guide to Water Quality Trading. Prepared for Lake Simcoe Conservation Authority.

Olsen, E., Kleiven, A. R., Skjoldal, H. R., & von Quillfeldt, C. H. (2010). Place-based management at different spatial scales. *Journal of Coastal Conservation*, *15*(2), 257–269. https://doi.org/10.1007/s11852-010-0108-1

Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). (2021a). Best Management Practices Series. Retrieved from: http://www.omafra.gov.on.ca/english/environment/bmp/series.htm

Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). (2021b). Canada-Ontario Environmental Farm Plan. Retrieved from: http://www.omafra.gov.on.ca/english/environment/efp/efp.htm

Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). (2021c). Compliance Tools for Nutrient Management. Retrieved from: http://www.omafra.gov.on.ca/english/nm/approvals/tools.htm

Ontario Ministry of the Environment and Climate Change (OMOECC). (2012). Ontario Great Lakes Strategy. Retrieved from: https://dr6j45jk9xcmk.cloudfront.net/documents/896/5-1-5-great-lakes-strategy-en.pdf

Ontario Ministry of Environment, Conservation and Parks (OMECP). (2021a). Provincial (Stream) Water Quality Monitoring Network. Retrieved from: https://files.ontario.ca/moe_mapping/downloads/2Water/PWQMN_by_year/pwqmn_rawdata_2020.xlsx

Ontario Ministry of Environment, Conservation and Parks (OMECP). (2021b). Water management: policies, guidelines, provincial water quality objectives. Retrieved from: https://www.ontario.ca/page/water-management-policies-guidelines-provincial-water-quality-objectives

Ontario Ministry of Environment (OMOE). (2002). Memorandum on Uxbridge Water Pollution Control Plant (WPCP) Request for Deviation from Policy 2.

Ontario Ministry of Environment and Energy (OMOEE). (1994). Water management: policies, guidelines, provincial water quality objectives. Retrieved from: https://www.ontario.ca/page/water-management-policies-guidelines-provincial-water-quality-objectives

Ontario Ministry of Environment and Energy (OMOEE). (1993). Uxbridge Water Pollution Control Plant (WPCP) Request for Deviation from Policy 2.

Ontario Water Resources Act. (1990). R.S.O. 1990, c. O.40. Retrieved from: https://www.ontario.ca/laws/statute/90o40

O'Grady, D. (2008). Point to non-point phosphorus trading in the South Nation River Watershed. *WIT Transactions on Ecology and the Environment*. https://doi.org/10.2495/eeia080191

Palmer, G.K., Templeton, M., Weinstock, R., Abrams, J.P., Harkness, A., & Current, S.T. (2021). Conveners' Report on the Illinois Nutrient Trading Initiative Stakeholder Process. Retrieved from: https://static1.squarespace.com/static/603d84c3b72bf900248e20c9/t/61af5d191883f629bb05e340/1638882586485/INTI+Conveners%27+White+Paper+12.03.21+%28Final%29.pdf

Palm-Forster, L. H., Swinton, S. M., Redder, T. M., DePinto, J. V., & Boles, C. M. W. (2016). Using conservation auctions informed by environmental performance models to reduce agricultural nutrient flows into Lake Erie. *Journal of Great Lakes Research*, *42*(6), 1357–1371. https://doi.org/10.1016/j.jglr.2016.08.003

Pendell, D. L., Williams, J. R., Rice, C. W., Nelson, R. G., & Boyles, S. B. (2006). Economic feasibility of no‐tillage and manure for soil carbon sequestration in corn production in northeastern Kansas. *Journal of Environmental Quality*, *35*(4), 1364–1373. https://doi.org/10.2134/jeq2005.0149

Reinhardt, M., Gächter, R., Wehrli, B., & Müller, B. (2005). Phosphorus retention in small constructed wetlands treating agricultural drainage water. *Journal of Environmental Quality*, *34*(4), 1251–1259. https://doi.org/10.2134/jeq2004.0325

Russo, M. V., & Fouts, P. A. (1997). A resource-based perspective on corporate environmental performance and profitability. *Academy of Management Journal*, *40*(3), 534–559. https://doi.org/10.5465/257052

Sharpley, A. N., Kleinman, P. J. A., Jordan, P., Bergström, L., & Allen, A. L. (2009). Evaluating the success of phosphorus management from field to watershed. *Journal of Environmental Quality*, *38*(5), 1981–1988. https://doi.org/10.2134/jeq2008.0056

Shortle, J. S., & Dunn, J. W. (1986). The relative efficiency of agricultural source water pollution control policies. *American Journal of Agricultural Economics*, *68*(3), 668–677. https://doi.org/10.2307/1241551

Smith, S. J., Sharpley, A. N., Berg, W. A., Naney, J. W., & Coleman, G. A. (1992). Water quality characteristics associated with Southern Plains Grasslands. *Journal of Environmental Quality*, *21*(4), 595–601. https://doi.org/10.2134/jeq1992.00472425002100040012x

South Nation Conservation, 2003. Phosphorus Loading Algorithms for the South Nation River. Retrieved from: https://www.nation.on.ca/sites/default/files/Final%20Phosphorous%20Algorithm%20Report%20phase%20II.Jan%202003.pdf

South Nation Conservation, 2018. State of the Nation: Watershed Report Card. Retrieved from: https://www.nation.on.ca/sites/default/files/SNCA5YR_Watershed_Report-ENG.pdf

South Nation Conservation & Jay Kassirer, 2004. South Nation River Watershed Total Phosphorus Management: 5-Year Program Evaluation.

Spofford, W.O. (1984). Efficiency properties of alternative source control policies for meeting ambient air quality standards: an empirical application to the lower Delaware Valley (Resources for the Future Discussion Paper No. D- 118, 1984)

Statistics Canada. (2022). 2021 Census of Population. Statistics Canada Catalogue no. 98-316-X2021001. Ottawa, Released April 27, 2022. Retrieved from: https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E

Stavins, R. N., 1995. Transaction Costs and Tradable Permits. Journal of Environmental Economics and Management 29:133-48.

Stephenson, K., Aultman, S., Metcalfe, T., & Miller, A. (2010). An evaluation of nutrient nonpoint offset trading in Virginia: A role for agricultural nonpoint sources? *Water Resources Research*, *46*(4). https://doi.org/10.1029/2009wr008228

Su, J.-Y., Goel, R., Burian, S., Hinners, S. J., Kochanski, A., Strong, C., & Barber, M. E. (2021). Water quality trading framework with uncertainty for river systems due to climate and population characteristics. *Water*, *13*(13), 1738. https://doi.org/10.3390/w13131738

Sundahl, A.M. (1985). Planning for Non-Polluting Wastewater Treatment in Animal Production. Proceedings of the 5th National Symposium on Agricultural wastes. Am. Soc. Agr. Eng. (ASAE). pp. 393-397.

Tietenberg, T. (2000). Environmental and Natural Resource Economics (Fifth Edition). Addison Wesley Longman, New York, New York.

Township of Uxbridge. (2016). Uxbridge Urban Area Stormwater Management Study, Report to MOE. AECOM Project Number 42-61070.

United States & Canada; International Joint Commission. (1909). Boundary Waters Treaty. Retrieved from: https://www.ijc.org/sites/default/files/2018-07/Boundary%20Water-ENGFR.pdf

United States Environmental Protection Agency (US EPA). (2000). National water Quality Inventory. Retrieved from: https://www.epa.gov/sites/default/files/2015-09/documents/2000_national_water_quality_inventory_report_to_congress.pdf

United States Environmental Protection Agency (US EPA). (1995). Progress Report.

United States Environmental Protection Agency (US EPA) & Environment and Climate Change Canada. n.d. Climate Change Impacts (Annex 9). Retrieved from: https://binational.net/annexes/a9/

United States Environmental Protection Agency (US EPA) Science Advisory Board. (2006). Integrated Env. Decision Making In the 21st Century: Summary Recommendations.

United States Environmental Protection Agency (US EPA) & Environment and Climate Change Canada (ECCC). (2015). Recommended Phosphorus Loading Targets for Lake Erie. Retrieved from: https://www.epa.gov/sites/default/files/2015-06/documents/report-recommended-phosphorus-loading-targets-lake-erie-201505.pdf

United States Environmental Protection Agency (US EPA) & Environment and Climate Change Canada (ECCC). (2012). Great Lakes Water Quality Agreement. Retrieved from: https://www.canada.ca/content/dam/eccc/migration/main/grandslacs-greatlakes/a1c62826-72be-40db-a545-65ad6fceae92/1094_canada-usa-20glwqa-20_e.pdf

Vandenbergh, M. P. (2001). The Social Meaning of Environmental Command and Control. *Virginia Environmental Law Journal.* , *191*.

Virginia Department of Conservation and Recreation (DCR). 2022. Virginia Agricultural Cost Share Manual – Program Year 2023 (July 1, 2022 – June 30, 2023). Retrieved from: http://consapps.dcr.virginia.gov/htdocs/agbmpman/agbmptoc.htm

Virginia Department of Environmental Quality (DEQ). 2022. Virginia Water Quality Assessment 305(b) Report: Chapter 5 - NONPOINT SOURCE ASSESSMENT, PRIORITIZATION, AND ACTIVITIES. Retrieved from: http://consapps.dcr.virginia.gov/htdocs/305b22/npschapt_2022.pdf

Virginia Department of Environmental Quality (DEQ). 2016. Virginia Water Quality Assessment 305(b) Report. Retrieved from: https://www.deq.virginia.gov/home/showpublisheddocument/5568/637504652823970000

Voora, V. A., McCandless, M., Roy, D., Venema, H. D., & Oborne, B. (2012). Water quality trading in the Lake Winnipeg Basin: A Multilevel Architecture. *Journal of Great Lakes Research*, *38*, 183–192. https://doi.org/10.1016/j.jglr.2011.09.009

Waite, T. D. (1984). Water quality standards and management approaches. *Principles of Water Quality*, 234–283. https://doi.org/10.1016/b978-0-12-730860-9.50015-5

Walker, C., Tondera, K., & Lucke, T. (2017). Stormwater treatment evaluation of a constructed floating wetland after two years operation in an urban catchment. *Sustainability*, *9*(10), 1687. https://doi.org/10.3390/su9101687

Wellen, C., Van Cappellen, P., Gospodyn, L., Thomas, J. L., & Mohamed, M. N. (2020). An analysis of the sample size requirements for acceptable statistical power in water quality monitoring for improvement detection. *Ecological Indicators*, *118*, 106684. https://doi.org/10.1016/j.ecolind.2020.106684

Woodward, R. T., Kaiser, R. A., & Wicks, A.-M. B. (2002). The structure and practice of water quality trading markets. *Journal of the American Water Resources Association*, *38*(4), 967–979. https://doi.org/10.1111/j.1752-1688.2002.tb05538.x

Wu, J., & Babcock, B. A. (2001). Spatial heterogeneity and the choice of instruments to control nonpoint pollution. *Environmental and Resource Economics*, *8*, 173–192. https://doi.org/https://doi.org/10.1023/A:1011164102052

XCG. (2014). Lake Simcoe Phosphorus Offset Program draft summary report (XCG File No.: 3-3111-01-01).

Xie, H., Chen, L., & Shen, Z. (2015). Assessment of agricultural best management practices using models: Current issues and future perspectives. *Water*, *7*(12), 1088–1108. https://doi.org/10.3390/w7031088

Appendix I: Comparison of Nutrient Management Evaluation Programs

Table 1: Comparing nutrient management evaluation programs.

Study & Geographic Area	Key Objectives	Key Findings
Diebel et al., 2008 Wisconsin, USA	Simulate and assess efficiency gains from geographic targeting of pollution control efforts within a watershed.	Recommends a 4-step approach; Prioritizing highest pollutant loading watersheds for nutrient reduction efforts, and additionally prioritizing the top 30% contributing fields from each of the top ranked subwatersheds could be an effective method to ensuring the greatest nutrient loading reductions possible.
Stephenson et al. 2010 Virginia, USA (Chesapeake Bay)	Compare/Evaluate agricultural non-point source offsets against other possible options for reducing regional nutrient loading from point sources. Focus on cost, feasibility, certainty in reductions and administrative risks.	Agricultural non-point source offsetting/trading can be comparable (cost) to point source reductions, but in some cases can be more expensive. Future reduction potential is limited (i.e., reduction per acre is small, requiring large areas in compliance). Cost uncertainty remains high at time of study; requires further evaluation to quantify precisely.
Voora et al., 2012 Manitoba, Canada (Lake Winnipeg)	Summarize program design considerations for reductions of phosphorus loading and promoting integrated water resource management in a transboundary watershed.	18 considerations from 4 main groups (emission, environmental, legal and institutional, and economic) of considerations; transboundary watersheds are possible, but challenging, cases for nutrient offsetting/water quality trading programs.
Cappiella et al., 2013 Virginia, USA (Chesapeake Bay)	Consider the possibility of nutrient offsets to maintain compliance with the Chesapeake Bay TMDL, outlining the requirements and challenges to be compliant with stormwater regulations.	Developers must control pollution at the source before generating/purchasing offsets. Verification of offset generation (i.e., maintenance plans, regulatory oversight and financial assurances must be in place). Integration of goals at the watershed scale by all involved parties will further facilitate water quality improvement.
Drevno, 2016 Various subwatersheds, primarily North America	Assess non-point source pollution management strategies, and present policy frameworks for identifying the specific challenges unique to nutrient management.	An integrated management approach, in conjunction with a transition from voluntary practices, is necessary to achieve greater control of non-point sources of nutrients. These require robust water quality monitoring, local participation/engagement, and a political will to properly address and engage users across a range of non-point sources.
IISD, 2019	Highlight policy/program mechanisms that facilitated achievement of nutrient	Highlighted 10 key elements of successful nutrient trading or offsetting programs based on 6 case studies (including the Lake Simcoe and South Nation

Manitoba, Canada (Lake Winnipeg)	reduction goals to inform the design of a possible program for the reduction of nutrient pollution in Lake Winnipeg in Manitoba.	Conservation programs). Most cases relate to using agricultural practices for the offsetting of point source polluters (the latter being regulated to specific targets) through voluntary methods. Despite complexities relating to the successful operation of such programs, offsetting is recommended to be a component of a larger plan for reducing nutrients, alongside planned WWTP upgrades, to meet regulatory requirements as necessary.
Lintern et al., 2020 Various subwatersheds, primarily North America	Identify gaps in understanding that are preventing meaningful nutrient reductions at the watershed scale, to better understand the known and unknown "unknowns".	Reviewed 94 studies around the world, finding a need for improved monitoring of BMPs over their lifetime to understand how maintenance schedules impact nutrient reductions, as well as for consideration of the socio-economic factors alongside biophysical, technological and political considerations in the context of climate change.
Fox et al., 2021 Virginia, USA (Choptank Basin, a tributary of the Chesapeake Bay)	Assess water quality changes in a small agricultural subwatershed to determine whether non-point source nutrient abatement practices are effective in the Chesapeake Bay watershed.	While progress is being made, it is slow and non-uniform across different sites in the subwatershed, with % agricultural land uses and soil compositions strong controls on nutrient reduction effectiveness. Increased outreach is necessary to overcome challenges pertaining to farmer hesitancy to adopt BMPs (including concerns about costs, management interference and lack of local BMP demonstrations).
Fleming et al., 2022 Virginia, USA (Chesapeake Bay)	Establish conceptual framework for identifying the main components of water quality trading/ offsetting program designs, with the purpose of highlighting opportunities and challenges to policy implementation.	Systematic evaluative tools are needed to properly assess existing programs and potential alternatives (including pre-/post-implementation monitoring). Offsetting programs must include flexibility in their plans so as not to force incentive programs where they are not necessary to attain program adoption by point/non-point source polluters.
Hasan et al., 2022 Denmark (Limfjorden)	Simulate a "smart market" for nutrient trading in a coastal catchment for comparison with traditional "command and control" regulatory approaches.	A smart market could result in substantial cost savings as compared to traditional regulatory approaches for achieving an 18-24% reduction in nutrient loads, however low participation (especially among major polluters) could result in insufficient offset production and thus increased costs.