Draft Nutrients Workgroup Report

Great Lakes Advisory Board

Theme 1: Seek Advice and Recommendations on Innovative Strategies to Address Legacy Phosphorus

Charge Question to GLAB:

> ***Please identify any strategies, using traditional or innovative technologies or methods, to reduce legacy phosphorus within the Lake Erie watershed (and other Great Lakes and tributaries thereto).***

Executive Summary

The workgroup first defined what is meant by legacy P and then approached the charge question by dividing this challenge into watershed-based strategies and lake-based strategies. Within the watershed, the recognition and identification of critical source areas is critical for tackling legacy P. Management strategies were further subdivided into avoidance practices, controlling practices, and trapping practices, with examples provided for each category. We recommend coordination of GLRI funding and technical expertise to develop regional tools to implement the most effective combination of these practices at all governmental levels to maximize legacy P nutrient and sediment reduction. Furthermore, we recommend GLRI fund and implement long-term comprehensive watershed monitoring programs to 1) evaluate the performance and costs of individual and/or combinations of ACT conservation practices and 2) guide GLRI project funding decisions to maximize legacy P nutrient and sediment reduction.

Within lakes and other water bodies (e.g., drainage ditches and natural rivers), we review physical, chemical, and biological strategies to reduce legacy P stored in sediment. We recommend that GLRI support physical removal of legacy P–laden sediments and encourage GLRI coordination with the U.S. Army Corps of Engineers and local communities to develop innovative ways to sequester and/or beneficially reuse dredge sediment.

Finally, we emphasize the critical need for funding to address long-term monitoring and maintenance. We recommend that GLRI develop and implement a comprehensive long-term monitoring program to assess GLRI-funded project performance and provide the information necessary to guide future GLRI investments in water quality and more effectively manage nutrient pollution in the Great Lakes. To that end, we provide multiple possible options to create this funding mechanism.

T1 - I. Introduction:

For this response, legacy phosphorus (P) is defined as surplus P that is stored and gradually released from the watershed as particulate P or in lakebed sediments that may be gradually released as dissolved reactive P (DRP). Legacy P is derived from historical natural and anthropogenic P sources and is stored in soils and sediments (potential load) and when mobilized, contributes to the baseline P load (i.e., does not include contemporary excess P loads). As legacy P is released from the watershed from point and non-point sources, it is mobilized and remobilized along the land-freshwater transport continuum acting as a continuing P source to downstream water bodies for years, decades, or even centuries (Carpenter 2005; Sharpley et al. 2013). This characteristic makes controlling and reducing legacy P sources especially challenging.

The movement of P across landscapes is a process that requires both a source and a mechanism for transport (Sharpley et al. 2003). Legacy P serves as the source with surface runoff, leaching, and erosion processes acting to remobilize and transport legacy P across the landscape from land to water. Addressing the source and transport processes for legacy P is important for developing a sound nutrient management strategy. Below, we have focused on actions that can be taken on the landscape to address legacy P sources and associated transport processes that transport legacy P to receiving water bodies and lake-based actions that can be taken to address internal P loading from riverine and lake sediments.

T1 - II. Watershed-Based Strategies

<u>Identification of Critical Source Areas</u>

Effective application of agricultural, urban, and other nonpoint source management practices requires that they are properly planned, sited, and sized. An important aspect of the planning process is the identification of critical source areas (CSAs). CSAs are those areas in the watershed that contribute a disproportionately large amount of legacy P nutrient load. These are the locations where a legacy P source in the landscape coincides with active hydrologic transport mechanisms. Because a relatively small area of a watershed can generate a disproportionate amount of legacy P, identifying CSAs can help prioritize conservation practices to better protect water quality and reduce costs (US EPA 2018). Moreover, CSAs have a temporal component, as P loads will be greatest after storm events due to both higher flow and erosive forces moving particulate P across the landscape. In the western basin of Lake Erie, the critical loading period that drives harmful algal blooms has been shown to be from March 1 through July 31 (Annex 4 Task Team 2015, GLWQA Nutrients Annex Subcommittee 2015). In addition, studies have shown that tile drain P loads are highest in the winter months, especially from fields without winter cover crops (Lam et al. 2016; Clement and Steinman 2017).

- **Recommendation: GLRI to support regional project(s) to identify Critical Source Areas in the watershed that contribute a disproportionately large amount of legacy P to nutrient load.**

GLRI to use Critical Source Area information to prioritize and more effectively target legacy P management strategies to maximize removal of legacy P from the system.

Management Strategies

The management of legacy P as it is released from the watershed can be implemented in many ways. One practice-based framework is the USDA-NRCS Avoid, Control, and Trap (ACT) conservation system. The ACT conservation system identifies conservation practices for Avoiding, Controlling and Trapping legacy P-laden sediment and nutrients. To effectively implement these practices, a regulatory approach may be required including, but not limited to, fertilizer applicator certification; seasonal and weather-related restrictions on nutrient application; mandatory nutrient management plans; and inspection and management of home sewage treatment systems. A general description and examples for these management practices are provided below.

Avoiding Practices

Avoiding practices are conservation practices that manage nutrient handling, improve soil health, optimize nutrient use for crop production, and are the first line of defense in preventing nutrient runoff and/or augmentation of Legacy P. These practices are implemented to avoid scenarios that pose an increased risk for nutrient and sediment movement. Examples are provided in table 1 below.

Table 1. Examples of USDA-NRCS ACT Conservation Practices*	
NRCS Practice Code	NRCS Practice Name
Avoiding Practices	
590	Nutrient Management
340	Cover Crops
328	Conservation Cropping Systems (Crop Rotations)
333	Amending Soil with Gypsum Products
* see USDA- NRCS Field Office Technical Guide for additional details	

As an example, an innovative (and effective) approach to nutrient management is the 4 R Nutrient Stewardship Program. The 4 R Nutrient Stewardship Program considers the economic, social, and environmental dimensions of nutrient management. The concept is simple - apply the Right source of nutrients, at the Right rate, at the Right time, and in the Right place (https://www.tfi.org/content/4r-nutrient-stewardship). By targeting specific areas with the right amount of nutrients, excess nutrients will not be incorporated into the soil and/or sediment to become future sources of Legacy P.

Controlling Practices

In situations where avoiding conservation practices are not well established, or where unforeseen, excessive, or even normal weather-related precipitation causes nutrient laden transport of runoff and drainage water to occur, controlling practices can be implemented to reduce effects (erosion, runoff rate and volume) in which transport pathways have a role. Examples are provided in Table 2 below.

TABLE 2. EXAMPLES OF USDA-NRCS ACT CONSERVATION PRACTICES*	
NRCS PRACTICE CODE	NRCS PRACTICE NAME
Controlling Practices	
329 & 345	Residue and Tillage Management
410	Grade Stabilization Structures
554	Drainage Water Management
412	Grassed Waterway
342	Critical Area Planting
* see USDA- NRCS Field Office Technical Guide for additional details	

The development and implementation of strategies to control watershed legacy P can be further divided into upland-based and water-based strategies. The majority of implemented traditional conservation practices are in the upland areas of the watershed, starting within the crop fields and terminating at the edge of the field. In addition, numerous opportunities exist to implement additional transport pathway control strategies (i.e., slow the flow) as we move downstream through the watershed.

Examples of transport pathway control practices include enhanced implement of Two-Stage Ditches (Davis et al. 2015); Cascading Waterways (Chesapeake Bay & Great Lakes: TNC case study for more information); Treatment Trains (Grand Lake St. Marys, Ohio); Off-stream chemical stormwater treatment or nutrient reduction facilities (NuRF) such as the Dixie Drain Phosphorus Removal Facility (Idaho: Sharp 2018); Stormwater Treatment Areas (Florida: Newman and Pietro 2001), and Constructed Treatment/Nutrient Reduction Wetlands (Maumee River Watershed, Ohio: Berkowitz et al. 2020; State of Ohio H2Ohio Initiative 2021).

Historically, flood control detention basins have been used for short-term storage of flood waters which are then gradually released to minimize downstream flood and erosion impacts (i.e. slow the flow). These basins could be retrofitted with wetlands and/or engineered sediment and nutrient reduction systems to enhance water quality while reducing impacts from high flow events.

Trapping Practices

Trapping conservation practices represent "the last line of defense" in agricultural water quality conservation practice selection. The majority of annual agricultural nutrient and sediment loading usually occurs during only a handful of runoff and drainage events making it important that well considered and designed trapping practices are installed to trap, infiltrate, and retain as much of the runoff and nutrients during these events as possible. Slowing down and retaining runoff waters also reduces stressors on stream channels (e.g., bank erosion) and can provide more sustained base flow to the tributary system. This allows for more opportunity for natural assimilation and processing of nutrients in the aquatic system throughout the year. Examples are provided in Table 3 below.

Table 3. Examples of USDA-NRCS ACT Conservation Practices*	
NRCS Practice Code	NRCS Practice Name
Trapping Practices	
393	Filter Strips/Filter Areas
656	Constructed Wetlands
620	Underground Outlets (Blind Inlets)
782	Phosphorus Removal System
605	Denitrifying Bioreactor
638	Water and Sediment Control Basin
391	Riparian Forest Buffer
436	Irrigation Reservoir
604	Saturated Buffer
* see USDA- NRCS Field Office Technical Guide for additional details	

Trapping conservation practices that promote the retention of sediment and nutrients (filter strips, buffer zones, and wetlands) are effective in reducing off-site movement and protecting downstream water quality. Examples of trapping practices include harvesting/removal of terrestrial and aquatic plant biomass to reduce nutrient levels (Bartodziej et al. 2017); installation of iron slag filters and other types of engineered nutrient removal systems (Hua et al. 2016), construction of new coastal/riparian wetlands and reconnection of existing managed wetlands to capture sediments and process nutrients (Maumee River Watershed, Ohio: Berkowitz et al. 2020; State of Ohio H2Ohio Initiative 2021).

Summary

A recent analysis of the data collected at Ohio USDA-ARS edge-of-field monitoring locations indicate that soil legacy P contributes 80% of the P loss and newly applied (excess P) from fertilizer/manure contributes the remaining 20%. If correct, this would suggest that an emphasis on implementing Controlling (Table 2) and Trapping (Table 3) approaches rather than Avoiding approaches (Table 1) may be more effective because they focus disrupt both legacy and excess P transport processes and alter pathways to the receiving waterbody. This does not imply that efforts to manage excess fertilizer or manure applications on the landscape (i.e., Avoiding practices) be reduced as these nutrients also serve as the source for new legacy P.

Because there are numerous factors that influence the release of legacy P, there is no single practice or solution that will fully address the release of legacy P-laden sediments or nutrients from the watershed. Site-specific characteristics and local agronomic decisions will determine the most effective nutrient management measures. In addition, an economic analysis of P removal and the impact of climate change should be incorporated into project criteria for selection and prioritization. Full cost accounting allows for the evaluation of proposed projects; this involves the inclusion of externalities, improved discount rates, etc. as both a funding decision criterion and a metric to track performance of projects.

Climate change has a vast potential impact on legacy P and it needs to be incorporated into the design of legacy P mitigation projects and recommendations (e.g. sizing projects to accommodate future flow rates and loading through the design life of the practice). Climate predictions indicate more extreme events, resulting in increased nutrient loads into receiving water bodies. In addition, earlier onset and later breakdown of stratification will increase duration and severity of anoxia, exacerbating internal loading and biotic stress. Changes in flow, duration, and frequency should be incorporated into the designs of future projects so they remain functional across a range of different water level or flow regimes.

- **Recommendation: Coordinate GLRI funding and technical expertise to develop regional tools to implement the most effective combination of Avoiding, Controlling, and Trapping practices at federal, state, and local level as identified in the USDA-NRCS ACT program to maximize legacy P nutrient and sediment reduction at HUC-12 watershed scales.**

- **Recommendation: GLRI to fund and implement long-term comprehensive watershed monitoring programs to 1) evaluate the performance and costs of individual and/or combinations of ACT conservation practices and 2) guide GLRI project funding decisions to maximize legacy P nutrient and sediment reduction.**

III. Lake-Based Strategies

Similar to watersheds, legacy P can accumulate in lake and river sediments. When this P is released into the water column, this process is referred to as internal phosphorus loading (IPL). It can be defined as "all physical, chemical, and biological processes by which P is mobilized and translocated from the benthic environment" (Steinman and Spears 2020). IPL is known to occur in Lake Erie (Matisoff et al. 2016; Anderson et al. 2021; Wang et al. 2021), although its relative importance as a legacy P source is debated.

Management strategies to control IPL depend on the mechanism by which the P is leaving the sediment and entering the water column. For more detailed discussions on this topic, see Cooke et al. (2016) and Steinman and Spears (2020). The key physical, chemical, and biological management treatments are discussed briefly below. Clearly, some of these treatments are not feasible in the open water of Lake Erie, due to either logistical or financial constraints. However, they may be operational in certain embayments or tributaries, as well as in other parts of the Great Lakes, as has been shown for drowned river mouth lakes (cf. Steinman and Ogdahl 2012).

Physical Treatments - Sediment Removal and Aeration

Sediment removal and aeration are two common methods to physically control Internal Phosphorus Loading. Sediment removal can involve either excavation (whereby overlying water is first removed) or dredging (removal of sediment without water drawdown). In cases where legacy P- laden sediments have accumulated in shallow riparian or managed coastal wetlands or shallow lakes/detention basins, it may be possible to excavate and remove the P – laden sediment to prevent the release of DRP from sediments saturated with legacy P. The removed sediment could be used for agricultural field placement (with appropriate water management and nutrient reduction controls) and/or for other environmentally beneficial uses.

In larger riverine and lake systems, in-water dredging with upland disposal is a viable mechanism to permanently remove legacy P from the environment. For example, the U.S. Army Corps of Engineers typically will dredge up to 1.5 million cubic yards of sediment from eight federal harbors along the Ohio Lake Erie coastline every year. In Toledo, the U.S. Army Corps of Engineers will dredge 600,000 to 1,000,000 cubic yards of P – laden sediment from the Toledo federal navigation channel every year. In the fall of 2020, more than 635,000 cubic yards of P – laden dredge material were placed into the Port of Toledo's Facility 3 CDF instead of the open-waters of Lake Erie. While sediment removal eliminates legacy P from the water body, it should be noted that there are drawbacks to in-water dredging that include short-term degradation of local water quality during dredging; removal of the benthic community; location and availability of a disposal site; overall costs to dredge, transport, and place the material; and regulatory/permitting issues (Lürling et al. 2020).

Aeration (also including oxygenation) prevents hypoxia (< 2 mg/L dissolved oxygen) or anoxia (<0.1 mg/L DO) from forming at lake bottoms. By keeping DO concentrations elevated promotes the binding of P to Fe^{3+}, preventing the P from diffusing into the water column. While commonly implemented, the results are mixed (see Lürling et al. 2020). Moreover, the application of aeration in large systems is not practical or cost effective. However, aeration could be applied in more localized settings to prevent the release of DRP from retained sediments (such as in smaller nutrient reduction wetlands or detention basins).

Chemical Treatments

There are two main classes of materials used to chemically manage Internal Phosphorus Loading 1) those that oxidize the upper sediment layer, and 2) those that inactivate P directly in-situ (within the water column or sediment) (Lürling et al. 2020). Adding chemicals to oxidize the sediment assumes the sediments are already anoxic and may be releasing P. By providing electron acceptors such as nitrate or manganese (e.g., as calcium nitrate and other formulations) the sediments remain oxic and P remains bound to the oxidized form of iron (Fe^{3+}). Recent work in Lake Erie has shown how the transition among oxic conditions can strongly influence P release (Anderson et al. In Press).

P inactivants can be added to water bodies in liquid or solid form. Aluminum- and iron-based salts are the most common liquid formations, applied either to the water column where they can strip P as they settle to the sediment, or injected directly into the sediment to avoid resuspension. The efficacy of these inactivants varies widely based on sediment and lake characteristics and range from <1 to > 20 yr (Cooke et al. 2016). Many different solid phase P adsorbents have been developed recently; perhaps the most well studied is lanthanum-modified bentonite (Phoslock®) (Spears et al. 2013). With all these chemical treatments, application concentration must be carefully determined to ensure sufficient material to bind P but not so much as to cause ecotoxicity.

Biological Treatments

Biomanipulation, usually involving the removal of benthivorous fish (e.g., gizzard shad) to avoid sediment disturbance and subsequent release of P into the water column, has had success in small inland lakes (Godwin et al. 2011) but its feasibility in large, open waters is much more doubtful. In addition, other organisms can be major bioturbators, such as chironomids, and biomanipulation may stimulate their activity which may promote the release of legacy P.

- **Recommendation: GLRI to support physical removal of legacy P–laden sediments as an effective method to remove legacy P from the environment. Encourage GLRI coordination with the U.S. Army Corps of Engineers and local communities to develop innovative ways to sequester and/or beneficially reuse dredge sediment for agricultural field placement, habitat restoration, or other environmentally suitable uses.**

T1 - IV. Long-Term Monitoring and Maintenance

The controlling and trapping conservation practices described above may concentrate P at specific locations on the watershed, including within wetlands and detention basins. These practices will effectively reducing short-term excess P loads while simultaneously creating a potential future source of legacy P. As a result, the anticipated rate of downstream water quality improvement may be reduced over the long term by offsetting releases of legacy P from saturated sediments (IPL). This delay, referred to as lag-time, can be in the range of years, decades, or even centuries. Given this variable time frame, traditional post-management monitoring periods of 5 to 10 years may be insufficient to capture the true and total impacts (or benefits) of implementing these conservation practices (Sharpley et al. 2013).

Long-Term Monitoring

Moreover, there is a need to re-assess current monitoring approaches. GLRI-funded water quality projects are typically monitored when the GLRI grant award is active (generally three to five years), but in many cases may not be physically monitored at all. The nutrient reduction metrics used are based on regional assumptions of the P-reduction performance of a specific type or class of project to calculate pounds of P removed to meet long-term goals and targets. The current monitoring program (even though it is beginning to improve) is inadequate and does not provide the information or data necessary to understand how well these GLRI-funded projects perform over the long term.

- **Recommendation: GLRI to develop and implement a comprehensive long-term monitoring program to assess GLRI-funded project performance and provide the information necessary to guide future GLRI investments in water quality and more effectively manage nutrient pollution in the Great Lakes.**

<u>**Critical Need for Long-Term Funding**</u>

Long-term monitoring and maintenance of legacy P nutrient reduction projects will require a commitment to dedicated long-term funding. Funding mechanisms to support long term monitoring are particularly challenging because federal and state agencies cannot make long term financial commitments due to annual and/or biennial budget cycles.

One solution that has been successfully applied is the creation of an Endowment Funds to provide the resources to support long-term environmental protection and restoration efforts in Muskegon Bay (cf. Steinman and Ogdahl 2004). Suggestions were made on different ways to capitalize such an endowment fund, including fines from environmental violations and bond initiatives. Experience has showed that several revenue streams would likely be necessary for capitalization of the Fund. GLRI could manage such an endowment fund and the $375 million dollars appropriated annually to GLRI is an important potential source of funding for long-term monitoring, with the caveat that the endowment fund disbursements would carry a match requirement from a non-federal entity. Below, we identify a number of alternative mechanisms to fund long-term monitoring and maintenance.

1. <u>GLRI funding</u>: redirect 2% of the annual GLRI appropriation (FY 2021-2022: $7.5 million) to a long-term monitoring and maintenance endowment fund (see below), which would be available as part of a competitive proposal process.
2. <u>Pay-for-Performance Conservation</u>: providing flexible conservation options to farmers while delivering quantifiable water quality benefits in agricultural watersheds (see http://glpf.org/funded-projects/reducing-phosphorus-loads-from-agriculture-creating-a-pay-for-performance-program-using-field-specific-information/).
3. <u>Public-private partnerships</u>: encourage these partnerships, which allow leveraging of resources through private donations and promote broad community engagement (Meissner 2019); see (https://outdoordiscovery.org/project-clarity/).
4. <u>Match requirements</u>: for certain projects, require a cash match that would go into the monitoring and maintenance endowment fund.

The monitoring described above is designed to evaluate the success and ongoing performance of specific projects. In addition, a more collective assessment of GLRI progress in specific bays or whole lakes can be assessed by evaluating existing regional monitoring programs for improvements in: 1) SOLEC indicators over time; 2) trends in long term monitoring data collected through GLNPO annual monitoring on the Lake Guardian; and 3) results of the 5-year CSMI intensive lake monitoring surveys. All three of these initiatives are led or conducted by the GLNPO monitoring and indicators branch. It is important that these monitoring programs continue to be supported over the long-term to assess the overall condition of the lakes, emerging issues, and progress that is being made through GLRI investments.

- **Recommendation: GLRI to create an Endowment Fund (or Funds) to provide a stable long-term funding source to support continued monitoring and assessment work of GLRI-funded nutrient reduction projects.**

- **Recommendation: GLRI continue to fund existing broader regional long-term monitoring efforts to assess the regional benefits (or impacts) of the GLRI-funded portfolio of nutrient reduction projects within the Great Lakes.**

--

Theme 1: Seek Advice and Recommendations on Innovative Strategies to Address Legacy Phosphorus

Recommendations

- **GLRI to support regional project(s) to identify Critical Source Areas in the watershed that contribute a disproportionately large amount of legacy P to nutrient load. GLRI to use Critical Source Area information to prioritize and more effectively target legacy P management strategies to maximize removal of legacy P from the system.**

- **Coordinate GLRI funding and technical expertise to develop regional tools to implement the most effective combination of Avoiding, Controlling, and Trapping practices at federal, state, and local level as identified in the USDA-NRCS ACT program to maximize legacy P nutrient and sediment reduction at HUC-12 watershed scales.**

- **GLRI to fund and implement a long-term comprehensive monitoring program to evaluate the performance and costs of individual and/or combinations of ACT conservation practices to guide GLRI funding decisions to maximize legacy P nutrient and sediment reduction.**

- **GLRI to support physical removal of legacy P–laden sediments as an effective method to remove legacy P from the environment. Encourage GLRI coordination with the U.S. Army Corps of Engineers and local communities to develop innovative ways to sequester and/or beneficially reuse dredge sediment for agricultural field placement, habitat restoration, or other environmentally suitable uses.**

- **GLRI to develop and implement a comprehensive long-term monitoring program to assess GLRI-funded project performance and provide the information necessary to guide future GLRI investments in water quality and more effectively manage nutrient pollution in the Great Lakes.**

- **GLRI to create an Endowment Fund (or funds) to provide a stable long-term funding source to support continued monitoring and assessment work of GLRI-funded nutrient reduction projects.**

- **GLRI continue to fund existing broader regional long-term monitoring efforts to assess the regional benefits (or impacts) of the GLRI-funded portfolio of nutrient reduction projects within the Great Lakes.**

Theme 2: Seek advice and Recommendations on Managing Excess Nutrients.

Charge Question to GLAB:

Balancing the need for the continued production of agricultural commodities in the Great Lakes region, the contribution to excess nutrient loading in Lake Erie associated with agricultural production activities, and the need to significantly reduce the extent and duration of HABs on Lake Erie, what innovative actions could reasonably be taken to accelerate the reduction of excess nutrients and HABs or duration of HAB events in Lake Erie?

Consider if there are new or different applications of traditional federal funding sources, opportunities to partner with the private sector (including tourism, drinking water systems, and others affected by HABs), or community-driven or market-based approaches to financing water quality improvements.

Executive Summary

The workgroup defined what is meant by excess nutrients (or excess P) and then approached the charge question by exploring potential structural (physical) and non-structural (policy, regulatory, and market-based) watershed nutrient reduction strategies. As recommended in Theme 1, the recognition and identification of critical watershed source areas is critical to address excess nutrient loads. We recommend that GLRI develop mechanisms to foster cross-jurisdictional coordination and fund regional coordination efforts to identify Critical Source Areas and implement regionally coordinated watershed-scale structural ACT nutrient reduction practices (by applying landscape conservation design principles) to maximize nutrient removal efficiencies across the basin.

We recommend that GLRI invest in promising innovative technology/nutrient reduction practices coupled with innovative funding strategies to leverage GLRI resources with public-private and/or pay for performance funds (i.e., long-term funding). This would support the implementation of innovative nutrient reduction practices along with long-term comprehensive watershed monitoring programs in the basin. Moreover, market-based incentives provide the opportunity to leverage local, state, and federal funds with corporate and private funds.

Finally, we encourage GLRI to support and fund TMDL implementation using a distributed mass balance approach applied at the HUC-12 subwatershed scale in combination with implementation of 9-element Nonpoint Source Implementation Strategies (NPS-IS plans) as an effective way to link local subwatershed nutrient reduction projects (BMPs) to regional TMDL/distributed load water quality targets. This would include GLRI-supported calibration of SWAT and land-use planning models with HUC-12 water quality monitoring data to identify critical source areas that disproportionately contribute to excess P loads from HUC-12 watersheds.

T2 - 1. Introduction

Addressing the sources and transport processes for excess nutrients is important to develop sound nutrient management strategies. These include nutrients derived from urban/suburban point and nonpoint sources (e.g., wastewater treatment facilities, stormwater outfalls, surface runoff), agricultural nonpoint sources (e.g., fertilizer, manure, AG drain tiles, drainage ditches), and other point and nonpoint sources (e.g., home septic treatment systems - HSTS) (Chen et. al 2015; Cornell 2011). Regardless of source, all nutrients that exceed agronomic and food web requirements and are released and transported downstream are considered to be excess nutrients and collectively contribute to eutrophication, hypoxia, and harmful algal blooms in the Great Lakes (Madenjian, et al., 2002; Scavia et al., 2019).

Surface runoff, leaching, and tile drainage are the primary mechanisms/pathways that mobilize and transport excess nutrients from the landscape into streams and rivers. Excess nutrients transported to streams and rivers ultimately end up in the Great Lakes and originate from all land uses (Allan, 2004; Robertson and Saad, 2011). Moreover, excess nutrients when incorporated into soils and/or bound to sediment, may also be a source of future legacy P.

To address increasing impacts of excessive nutrient loads into the Great Lakes, Great Lakes States have developed and are implementing nutrient reduction plans that focus on a combination of both structural and non-structural strategies applied across all sectors and sources to achieve nutrient reduction goals (e.g., Illinois nutrient loss reduction strategy 2014, State of Ohio Domestic Action Plan 2020, State of Michigan Domestic Action Plan 2012). These nutrient reduction strategies describe multiple approaches to nutrient reduction including structural approaches that either control or trap excess nutrients across the landscape and non-structural practices that attempt to minimize excess nutrients at the source through governance, regulatory, and market-based (economic incentive) means.

Identification of Critical Source Areas

Similar to the recommendations made in Theme 1 (legacy P) earlier in this draft report, an important aspect of the planning process is the identification of critical source areas (CSAs). CSAs are those areas in the watershed that contribute a disproportionately large amount of excess P to the nutrient load. These are the locations where sources of excess nutrients on the landscape coincides with active hydrologic transport mechanisms. Because a relatively small area of a watershed can generate a disproportionate amount of excess nutrients, identifying CSAs can help prioritize conservation practices to better protect water quality and reduce costs (US EPA 2018). This requires the ability to identify those watersheds contributing the highest loads, determining the land use practices and specific locations within those watersheds contributing excess nutrient loads, and then applying appropriate structural (controlling and trapping) practices and/or non-structural (avoiding) practices to minimize excess nutrient loads derived from the landscape.

Examples include quantities (amount) of commercial fertilizer/manure applied to the landscape as a function season and crop rotation, identification of persistent high-source areas within the watershed that consistently contribute excess nutrients over longer periods of time and understanding the mobilization and transport pathways from CSAs through the watershed (e.g., surface runoff vs. leaching vs. tile drainage vs. other).

Moreover, to maximize nutrient reduction benefits, structural nutrient removal systems should be located near the pour points of Critical Source Areas to maximize effectiveness. In instances where multiple input sources and multiple HUC-12 watersheds are cumulatively contributing excess nutrients to a receiving waterbody, it may be most efficient to implement large-scale structural nutrient removal projects closer to the impacted receiving water body. There are efficiencies to be gained as larger-scale projects may be easier to maintain and monitor over the long-term and of sited properly, these projects have the potential to remove excess nutrients that have not been addressed by BMPs and watershed practices further upstream.

- **Recommendation: GLRI to support and fund regional projects to identify watersheds where GLWQA target nutrient loads are consistently exceeded (excess P) during March 1 through July 31 timeframe to identify potential target watersheds for potential follow-on funding of Critical Source Area identification projects** (see following recommendation).

- **Recommendation: GLRI to support and fund projects that identify <u>Critical Source Areas</u> within the watersheds that contribute a disproportionately large amount of excess P to nutrient load. GLRI to use Critical Source Area information to prioritize and more effectively target excess P management strategies to maximize removal of excess P from the system.**

- **Recommendation: GLRI to encourage, support, and fund larger-scale nutrient reduction projects within lower watershed tributaries near, or adjacent to, receiving water bodies to maximize potential nutrient reduction benefits.**

T2 - II. Structural Nutrient Removal Systems

Structural nutrient removal systems are focused primarily on controlling and trapping excess nutrients as they are mobilized and transported by surface runoff, leaching, and tile drainage from the landscape into water. A detailed summary of specific conservation practices based on the USDA-NRCS Avoid, Control, and Trap (ACT) conservation system has already been provided in the **Charge Theme 1 - Section II - Watershed-Based Strategies** of this draft report. Many of the controlling and trapping practices listed in Tables 2 and 3 in the Theme 1 section are structural (physical) nutrient removal systems. These conservation practices are effective at removing excess nutrients and the reader is referred to the recommendations made in that Section.

<u>Innovative Technologies/Nutrient Removal Systems</u>

TBD – P Removal Traps.

TBD – Tile/Drain Controls.

TBD - Chemical inactivant injected into waters to remove excess P from the water column.

TBD - Algal harvesting/processing/filtration technologies that remove and sequester algae.

TBD – Peak flow nutrient removal systems integrated with flow management, retention (flood control), and innovative treatment systems.

Table 4. Potential Innovative Technology/Nutrient Removal Systems

Structural Practice	Ongoing	Pilot	Location considerations	Managing entity
P removal traps (e.g. slag filters)	*X*	*X*	*site specific*	*Federal, State, Local*
End of tile treatments	*X*		*field runoff, field tiles, or ag. drains*	*USDA, NRCS, SWCDs*
End of legal drain treatments	*X*		*field tiles, ag. drains*	*County Drainage Boards*
Dredging removal/sequestration of high particulate P (and legacy P)	*X*	*X*	*Federal/State commercial and recreational harbors*	*USACE Federal, State, private*
Chemical inactivant injection system		*X*	*?*	*?*
Algal harvesting/filtration technologies		*X*	*smaller lakes & tributaries*	*Federal, State, Local*
Hybrid technology/natural infrastructure projects		*X*	*coastal and riparian wetlands*	*Federal, State, Local*
Peak flow management nutrient removal system		*X*	*riparian overflow wetlands*	*Federal, State, Local*
Sequential nutrient removal and processing system	*X*	*X*	*landscape/system scale*	*Federal, State, Local*
Flow management, retention, treatment	*X*	*X*	*field runoff, field tiles, or ag. drains*	*USDA, NRCS, SWCDs, FEMA*

Table 4. Provides a list and general status of innovative structural nutrient removal practices that are being considered or are in the process of being implemented within the basin. These practices may require additional research and/or funding to support initial on-the-ground pilot projects and long-term monitoring/assessment.

- **Recommendation: GLRI to support and fund innovative technology/nutrient removal systems along with innovative funding strategies to support long-term monitoring and assessment of these technologies to evaluate their effectiveness.**

The following recommendations are made to facilitate the selection, siting, and funding of watershed-scale structural practices:

- **Recommendation: Coordinate GLRI funding and technical expertise to develop regional tools to implement the most effective combination of Avoiding, Controlling, and Trapping practices at federal, state, and local level as identified in the USDA-NRCS ACT program to maximize excess P nutrient and sediment reduction at HUC-12 watershed scales.**

  Currently state and federal agencies, academic institutions, and consulting firms are collecting data and conducting modeling efforts to understand the sources and amount of nutrients contributing to algal blooms and hypoxia events in the western basin of Lake Erie. Unfortunately, these efforts are not well-coordinated at a regional or cross-jurisdictional level. There may be an opportunity for GLRI to fund efforts to develop mechanisms to foster cross-jurisdictional coordination at a regional landscape and/or basin-wide scale. This would create an opportunity to apply landscape conservation design principles to systematically link structural nutrient reduction practices to maximize nutrient removal efficiencies.

- **Recommendation: GLRI to develop mechanisms to foster cross-jurisdictional coordination and fund regional coordination efforts to identify Critical Source Areas and implement regionally coordinated watershed scale structural nutrient reduction practices (by applying landscape conservation design principles) to maximize nutrient removal efficiencies.**

T2 – III. Nonstructural Practices, Planning, and Market-Based Incentives

Nonstructural nutrient removal systems are focused primarily on avoiding and controlling nutrient reduction practices as they are applied to the landscape. Nonstructural approaches also include policy, planning, or market-based (i.e., economic) activities that result in changes in behavior, investments, and/or change in land use that result in nutrient load reductions within a watershed. An example would be land use planning efforts that change the % of developed land vs. % of agricultural land within a watershed that result in a reduction of nutrient loads.

A detailed summary of specific conservation practices based on the USDA-NRCS Avoid, Control, and Trap (ACT) conservation system has already been provided in the **Charge Theme 1 - Section II - Watershed-Based Strategies** of this draft report. Many of the avoiding and controlling practices listed in Tables 1 and 2 in the Theme 1 section are non-structural nutrient removal programs designed to manage the application/distribution of nutrients on the landscape in order to reduce excess nutrient loads. When properly implemented, these conservation practices are effective at reducing excess nutrient loads and the reader is referred to the recommendations made in that Section and described below.

Land Use Planning

The most effective way to control nutrients entering the Great Lakes over time is to prevent watersheds from developing land uses that increase nutrient runoff and loading to streams. Research has shown that the percentages of urban, suburban, and agricultural land use in a watershed are indicative of stream health (Wiley et al. 2010; Pijanowski et al., *in revision*). Watershed land use (% developed land area, % drained agricultural land area) and variable weather/storm runoff events (e.g., precipitation) collectively account for up to 94% of the annual variation in riverine total Phosphorus fluxes (Tang et al., 2005; Wiley et al. 2010; LaBeau et al, 2014; Chen et. al 2015).

Land use planning can be used to guide local entities (e.g., local and regional planning commissions, soil and water conservation districts, etc.) to promote land use change and encourage conservation practices that reduce nutrient loading to streams. However, there are limited funding opportunities available to support the development and implementation of watershed plans in watersheds that are not already degraded. EPA 319 funds and GLRI funding is usually targeted at areas where nutrient loading is high, current land uses are problematic, and remediation is required. That funding needs to be maintained. However, GLRI also needs to develop competitive funding opportunities to develop and implement land use plans that continue to protect and preserve existing high-quality watersheds that have low-moderate nutrient loads.

In addition, current land-use planning models may not consider potential water quality/nutrient reduction benefits due to changes in land use that result in reduced runoff and trap and process nutrients on the landscape. It may be possible to Incorporate modeling results that estimate nutrient load reductions resulting from implementation of new land use and watershed plans (Tang et al., 2005). New performance metrics are required to document future potential reductions in nutrient loading that may result by implementing changes in land use.

- **Recommendation: GLRI to support and fund watershed land-use plans and conservation practices that protect and maintain existing high-quality watersheds that that do not contribute significant (excess) nutrient loads to the basin (i.e., protect and preserve what is already working).**

- **Recommendation: GLRI to support the development of new performance metrics to recognize and document future potential reductions in nutrient loading that may result by implementing changes in land use. Those metrics need to be incorporated into land use models to identify potential land use changes that maximize nutrient reduction benefits within a watershed.**

Market-Based Approaches

Healthy ecosystems provide numerous benefits such as clean water and air, flood prevention, healthy soils, and wildlife habitat. Collectively, these environmental benefits are referred to as ecosystem services. When ecosystem services can be measured and quantified, they can be sold and purchased through emerging ecosystem or environmental credit markets.

Companies and corporations of various sizes across many industries are announcing new corporate sustainability commitments. They are focusing on the public goodwill they will earn as consumers see them as playing a part in improving our climate; water, air, and soil resources; conservation; biodiversity; as well as creating pollinator/wildlife habitats. They are establishing corporate sustainability programs and investing in environmentally sustainable development projects and ecosystem credit markets.

The ecosystem credit markets are constantly evolving, and many are under development or being refined in pilot stages. Regardless of the stage of development, several common themes exist throughout all ecosystem credit markets. Chief among them is a voluntary, incentive-based structure that connects buyers and sellers of ecosystem services credits. Typically, farmers will be the generator and the seller of the credits. They will receive payment for using conservation stewardship practices proven to meet established ecosystem benefit criteria.

- **Recommendation: GLRI to support the development of an incentive-based ecosystem credit marketplace that connects buyers and sellers of ecosystem credits. There may be an opportunity to link these markets to the Blue Accounting Coastal Wetland project with an emphasis on excess nutrient reduction and water quality improvement.**

Another market-based approach is the tradable permit model. A tradable permit model requires that an authorized agency, i.e., federal (EPA) or state agency (e.g., DNR) set limits on the amount and type of pollutants that can be discharged into the system. Permits are then allocated to permitted operators distributing a portion of the permitted limit to each operator. Operators can then either exercise their permit or sell their allocation to another licensed operator. This structure ensures that annual limits are not exceeded and incentivizes efficiency. Those discharging facilities that have upgraded their systems and discharge less than their permitted amount can sell the excess to a less efficient operator. Those less efficient operators now have to pay more to discharge their pollutants and in time can be more efficient by upgrading their systems. The efficient operators get some financial return for their investment in cleaner technologies.

The tradable permit model is well suited to an impaired watershed where a Total Maximum Daily Load (TMDL) has been established for the watershed and EPA has set maximum P discharge limits. All point sources already have NPDES permits from EPA and are required to do regular testing to document their discharge amounts. To implement a tradable permit system for nutrients, EPA (or other authorized agency) would need to calculate the amount of P that could be discharged by each NDPES holder each year to meet TMDL limits. Second, other large sources of P not currently required to have NPDES permits (i.e. nonpoint sources) would have to be brought into the system.

The most efficient way to accomplish this would be to require large nonpoint source P contributors (i.e., County agricultural drains, discharging septic systems, confined animal feeding operations) to meet NPDES requirements within the TMDL area. Within this category, permit holders would be allocated their share of the load they could discharge annually. It would incentivize the use of targeted BMPs, and increase the number of non-discharging septic systems, and ensure that overall TMDL limits for the watershed are not exceeded.

Table 5. Market-Based Approaches for Nutrient Reduction

Practice/Programs	Ongoing	Pilot Test	Managing entity
Great Lakes Impact Investment Platform	**X**		**Conference of Great Lakes St. Lawrence Governors & Premiers**
Water Quality Trading (permits)	**X**	**X**	**State EPAs, Ag Depts, SWCDs, Communities**
Public-Private Partnerships	**X**	**X**	**State EPAs, Ag Depts, SWCDs, Communities, Businesses, Investors**
Pay for Performance Conservation	**X**	**X**	**NPDES Permit Holders, Public Water Supplies, State EPAs, Ag Depts, SWCDs, Communities**

- **Recommendation: GLRI to consider opportunities to support and develop mechanisms to leverage GLRI resources with public-private and/or pay for performance funds (i.e., long term funding) to implement in nutrient reduction practices in the basin. Market-based incentives provide the opportunity to leverage local, state, and federal funds with corporate and private funds. The development of corporate sustainability programs provides opportunities to invest in environmentally sustainable development projects and ecosystem credit markets.**

T2 – III. Governance and Regulatory Considerations

Regulatory considerations presented here are intended to provide options within EPA's jurisdictions when voluntary and practice-based approaches are deemed insufficient to achieve necessary nutrient reductions to meet GLWQA targets.

<u>Total Maximum Daily Load (TMDL)</u>

Total Maximum Daily Load (TMDL) is based on the loading capacity of a waterbody and used to allocate pollutant (in this case nutrient and sediment) loads among different sources to achieve desired water quality standards. Point and nonpoint sources of nutrient loading within the watershed and their relative contributions are identified, and a portion of the allowable load is allocated to sources (by usually reducing source loads) to achieve target loads that meet water quality goals. TMDLs have been used with some success in the Chesapeake Bay region where U.S. EPA has mandated specific implementation strategies based on the ability to meet TMDLs developed by the States to achieve broader-scale water quality objectives in Chesapeake Bay.

The Chesapeake Bay TMDL is unique because of the extensive measures EPA and the jurisdictions have adopted to ensure accountability for reducing pollution and meeting deadlines for progress. The accountability framework includes successful implementation of Watershed Improvement Plans, two-year progress milestones, tracking and assessment of restoration progress, and the implementation of specific federal actions if the jurisdictions do not meet their commitments.

Salient elements from the Chesapeake TMDL include:

- Establish clear goals and targets for TMDL implementation
- Identify implementation scales; Establish a clear timeline for progress with benchmarks
- Identify clear implementation strategies; Set implementation milestones; Monitor and assess progress; Incorporate adaptive management strategies
- Regulatory consequences if TMDL commitments are not met

<u>TMDLs and Distributed Load Model for the Maumee River Watershed</u>

A Nutrient TMDL is currently under development for the Maumee River watershed of Lake Erie. TMDL's are intended to establish an average daily nutrient load limit and then develop practices and policies that will keep loading below this limit. Most actions considered in TMDL implementations are practice based. The following are recommendations for the Maumee River nutrient TMDL based on lessons learned from other TMDL's in large agricultural and urbanizing landscapes (e.g., Chesapeake Bay). We have included regulatory options in the succeeding 2 subheadings that could also be considered if TMDL limits cannot be achieved through practice-based changes alone.

For Western Lake Erie, TMDL implementation should clearly identify the links between water quality degradation in the (excess productivity/HABs); the sources of nutrient loads causing the excess productivity (point and non-point sources); and establish nutrient load reductions needed to meet applicable nutrient load targets.

Even though multiple modeling studies using regional-scale SWAT models have been applied to many Great Lakes watersheds. However, when scaled down to smaller subwatershed scales (HUC 12) in the Maumee River watershed, the predicted SWAT modeling results do not match field-based water quality sampling data due to model calibration errors. This has been clearly demonstrated in the Maumee River watershed of Ohio.

As part of a comprehensive mass balance study implemented by the Ohio EPA, an extensive water quality monitoring network has been established by Ohio EPA and the National Water Quality Center at Heidelberg University where the pour points of HUC-12 watersheds are monitored three times daily for water quality (State of Ohio Domestic Action Plan 2020). These high-resolution data sets are combined with a nutrient mass balance approach that integrates nutrient load data from three primary sources: nonpoint landscape sources (agricultural, developed, and natural lands), point sources (NPDES permits), and household sewage treatment systems (HSTS) to establish nutrient load targets (TMDLs) at individual HUC-12 pour points at a subwatershed scale.

The distributed load approach provides the flexibility to evaluate different combinations of nutrient reduction measures (BMPs) to optimize nutrient reduction benefits from agricultural, developed, and natural lands at local subwatershed scales. These loads can be used to guide the development of 9-element Nonpoint Source Implementation Strategies (NPS-IS plans) within HUC-12 subwatersheds (State of Ohio Domestic Action Plan 2020). As nutrient management actions are implemented by farmers, property owners, and communities at a local level, these NPS-IS plans provide a critical linkage between nutrient reduction projects (BMPs) implemented by local stakeholders and the HUC-12 (TMDL) loading targets. Moreover, using a mass balance approach, nutrient loads can be integrated across all HUC-12 watersheds and individual HUC-12 loading targets (and associated nutrient reduction projects to achieve those targets) can be modified to meet regional TMDL loading targets for the entire watershed.

TMDLs and Septic System (HSTS) Discharges

Controlling septic system and wastewater discharges not only reduces the amount of P loading to streams and the Great Lakes annually, but also can impact the amount of legacy P that is reactivated (carbon source) causing algal blooms in Great Lakes water bodies. Current research has determined that HSTS discharges can account for up to 20% of the P loading to the Great Lakes (Wan et al. *in prep*).

Currently many soil types in the Great Lakes basin and specifically in the western basin of Lake Erie, are not suitable for standard leach field systems. Septic system regulations can vary by state and usually are controlled by the county/state board of health, State EPA office, or local government agency. Some jurisdictions with increasing development pressure are exploring and implementing new requirements to protect human health, protect water quality, and reduce P loading into streams and rivers.

All septic leach field systems have useful life limitations (most under 25 years), yet few communities have useful life monitoring or inspection requirements. Some communities are addressing septic system issues by requiring subdivisions to develop and maintain either cluster systems (multiple houses on one system) with maintenance paid for by homeowner association dues or requiring new subdivisions to be connected to the local municipal sewage treatment system. Should additional measures be required to meet TMDL limits in the western Lake Erie watershed, three HSTS recommendations could be considered: 1) Require new septic systems to be compatible with soil characteristics; 2) Require maintenance or useful life requirements for existing systems; and 3) Require new subdivision development to have cluster systems or to be connected to the municipal sewage treatment system.

- **Recommendation: GLRI to support and fund TMDL implementation using a distributed mass balance approach applied at the HUC-12 subwatershed scale in combination with the funding, development, and implementation of 9-element Nonpoint Source Implementation Strategies (NPS-IS plans) as an effective way to link local subwatershed nutrient reduction projects (BMPs) to regional TMDL/distributed load water quality targets.**

- **Recommendation: GLRI to support and fund the calibration of SWAT and land-use planning models with HUC-12 water quality monitoring data to identify critical source areas that disproportionately contribute to excess P loads from the watershed. These models would be used to evaluate the appropriate suite of practices and land-use changes that maximize nutrient reduction benefits within HUC-12 watersheds.**

Theme 2: Seek advice and Recommendations on Managing Excess Nutrients.

Recommendations

- **GLRI to support and fund regional projects to identify watersheds where GLWQA target nutrient loads are consistently exceeded (excess P) during the March 1 through July 31 timeframe to identify potential target watersheds for potential follow-on funding of Critical Source Area identification projects**.

- **GLRI to support and fund projects that identify <u>Critical Source Areas</u> within the watersheds that contribute a disproportionately large amount of excess P to nutrient load. GLRI to use Critical Source Area information to prioritize and more effectively target excess P management strategies to maximize removal of excess P from the system.**

- **GLRI to encourage, support, and fund larger-scale nutrient reduction projects within lower watershed tributaries near, or adjacent to, receiving water bodies to maximize potential nutrient reduction benefits.**

- **GLRI to support and fund innovative technology/nutrient removal systems along with innovative funding strategies to support long-term monitoring and assessment of these technologies to evaluate their effectiveness.**

- **Coordinate GLRI funding and technical expertise to develop regional tools to implement the most effective combination of Avoiding, Controlling, and Trapping practices at federal, state, and local level as identified in the USDA-NRCS ACT program to maximize excess P nutrient and sediment reduction at HUC-12 watershed scales.**

- **GLRI to develop mechanisms to foster cross-jurisdictional coordination and fund regional coordination efforts to identify Critical Source Areas and implement regionally coordinated watershed scale structural nutrient reduction practices (by applying landscape conservation design principles) to maximize nutrient removal efficiencies.**

- **GLRI to support and fund watershed land-use plans and conservation practices that protect and maintain existing high-quality watersheds that that do not contribute significant (excess) nutrient loads to the basin (i.e., protect and preserve what is already working).**

- **GLRI to support the development of new performance metrics to recognize and document future potential reductions in nutrient loading that may result by implementing changes in land use. These metrics need to be incorporated into land use models to identify potential land use changes that maximize nutrient reduction benefits within a watershed.**

- **GLRI to support the development of an incentive-based ecosystem credit marketplace that connects buyers and sellers of ecosystem credits. There may be an opportunity to link these markets to the Blue Accounting Coastal Wetland project with an emphasis on excess nutrient reduction and water quality improvement.**

- **GLRI to consider opportunities to support and develop mechanisms to leverage GLRI resources with public-private and/or pay for performance funds (i.e., long term funding) to implement in nutrient reduction practices in the basin. Market-based incentives provide the opportunity to leverage local, state, and federal funds with corporate and private funds. The development of corporate sustainability programs provides opportunities to invest in environmentally sustainable development projects and ecosystem credit markets.**

- **GLRI to support and fund TMDL implementation using a distributed mass balance approach applied at the HUC-12 subwatershed scale in combination with the funding, development, and implementation of 9-element Nonpoint Source Implementation Strategies (NPS-IS plans) as an effective way to link local subwatershed nutrient reduction projects (BMPs) to regional TMDL/distributed load water quality targets.**

- **GLRI to support and fund the calibration of SWAT and land-use planning models with HUC-12 water quality monitoring data to identify critical source areas that disproportionately contribute to excess P loads from the watershed. These models would be used to evaluate the appropriate suite of practices and land-use changes that maximize nutrient reduction benefits within HUC-12 watersheds.**

Theme 1: Seek Advice and Recommendations on Innovative Strategies to Address Legacy Phosphorus

References Cited

Anderson HS, Johengen TH, Godwin CM, Purcell H, Alsip PJ, Ruberg SA, Mason LA. 2021. Continuous in situ nutrient analyzers pinpoint the onset and rate of internal phosphorus loading under anoxia in Lake Erie's central basin. ACS EST Water 1, 4: 774–781.

Anderson, Godwin, Johengen. In Press. Accelerated release of phosphorus from sediments in Lake Erie's central basin is a symptom of anoxia, not hypoxia. Limnol. Oceanogr.

Bartodziej WM, Blood SL, Pilgrim K. 2017. Aquatic plant harvesting: An economical phosphorus removal tool in an urban shallow lake. J Aquat Plant Manage 55: 26-34.

Berkowitz JF, Schlea DA, VanZomeren CM, Boles CMW. 2020. Coupling watershed modeling, public engagement, and soil analysis improves decision making for targeting P retention wetland locations. J Great Lakes Res 45: 1331-1339.

Carpenter SR. 2005. Eutrophication of aquatic ecosystems: bistability and soil phosphorus. Proc Natl Acad Sci USA 102:10002–5.

Cooke GD, Welch EB, Peterson S, Nichols SA. 2016. Restoration and management of lakes and reservoirs. CRC Press.

Davis RT, Tank JL, Mahl UH, Winikoff SG, Roley SS. 2015. The influence of two-stage ditches with constructed floodplains on water column nutrients and sediments in agricultural streams. J the Am Water Res Assoc 51:941-955.

Godwin W, Coveney M, Lowe E, Battoe L. 2011. Improvements in water quality following biomanipulation of gizzard shad (*Dorosoma cepedianum*) in Lake Denham, Florida. Lake Reserv Managem 27:287-297.

Hua, G., M.W. Salo, C.G. Schmit, and C.H. Hay. 2016. Nitrate and Phosphate Removal from Agricultural Subsurface Drainage Using Laboratory Woodchip Bioreactors and Recycled Steel Byproduct Filters. Water Research 102: 180–89.

Lieberman D. 2014. The story of the human body: evolution, health, and disease. Vintage Press.

Lürling M, Smolders AJP, Douglas GD. 2020. Methods for the management of internal phosphorus loading in lakes. In: (Steinman AD, Spears BM: editors) Internal Phosphorus Loading of Lakes: Causes, Case Studies, and Management. J. Ross Publishing.

Matisoff G, Kaltenberg EM, Steely RL, Hummel SK, Seo J, Gibbons KJ, Bridgeman TB, Seo Y, Behbahani M, James WF, Johnson LT. 2016. Internal loading of phosphorus in western Lake Erie. J Great Lakes Res 42: 775-88.

Meissner D. 2019. Public-private partnership models for science, technology, and innovation cooperation. J Knowledge Econ 10:1341-61.

Merriam-Webster. 2021. *Merriam-Webster.com Dictionary*, https://www.merriam-webster.com/dictionary/anthropogenic. Accessed 15 June 2021.

Newman S, Pietro K. 2001. Phosphorus storage and release in response to flooding: implications for Everglades stormwater treatment areas. Ecol Eng 18:23-38.

Sharp D. 2018. Dixie Drain 2017 Temperature Monitoring and Analysis Report. Accessed at: https://www.researchgate.net/profile/Darcy-Sharp/publication/328390056_Dixie_Drain_2017_Temperature_Report/links/5bca087b299bf17a1c618c57/Dixie-Drain-2017-Temperature-Report.pdf

Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 2003. Agricultural Phosphorus and Eutrophication Second Edition. U.S. Department of Agriculture, Agricultural Research Service, ARS-149, 44pp.

Sharpley A, Jarvie HP, Buda A, May L, Spears B, Kleinman P. 2013. Phosphorus legacy: overcoming the effects of past management practices to mitigate future water quality impairment. J Environ Qual 42:1308–26.

Spears BM, Lürling M, Yasseri S, Castro-Castellon AT, Gibbs M, Meis S, McDonald C, McIntosh J, Sleep D, Van Oosterhout F. 2013. Lake responses following lanthanum-modified bentonite clay (Phoslock®) application: an analysis of water column lanthanum data from 16 case study lakes. Water Res 47:5930-5942.

Steinman AD, Ogdahl M. 2004. An innovative funding mechanism for the Muskegon Lake AOC. J Great Lakes Res 30:341-3.

Steinman AD, Ogdahl ME. 2012. Macroinvertebrate response and internal phosphorus loading in a Michigan Lake after alum treatment. J Environ Qual 41:1540-1548.

Steinman AD, Spears BM. 2020. Internal phosphorus loading in lakes: Causes, case studies, and management. J. Ross Publishing.

The Nature Conservancy, Cascading Grassed Waterway: A Case Study Wrestle Creek Auglaize River Watershed Allen County, Ohio https://www.nature.org/content/dam/tnc/nature/en/documents/allen-cascading-waterway-case-study.pdf

United States Environmental Protection Agency. 2018. Critical Source Area Identification and BMP Selection: Supplement to Watershed Planning Handbook. EPA 841-K-18-001.

United States Department of Agriculture – Natural Resources Conservation Service. 2021. Field Office Technical Guide https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/fotg/

Wang YT, Zhang TQ, Zhao YC, Ciborowski JJ, Zhao YM, O'Halloran IP, Qi ZM, Tan CS. 2021. Characterization of sedimentary phosphorus in Lake Erie and on-site quantification of internal phosphorus loading. Water Res 188: 116525.

Theme 2: Seek advice and Recommendations on Managing excess nutrients.

References Cited

Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annu. Rev. Ecol. Evol. Syst.*, *35*, 257-284.

Annex 4 Task Team. (2015). Recommended Phosphorus Loading Targets for Lake Erie. Final Report to the Nutrients Subcommittee. https://www.epa.gov/sites/default/files/2015-06/documents/report-recommended-phosphorus-loading-targets-lake-erie-201505.pdf

Chen, D., M. HU, Y. Guo, and R. A. Dahlgren. 2015. Influence of legacy phosphorus, land use, and climate change on anthropogenic phosphorus inputs and riverine export dynamics. Biogeochemistry Vol. 123, No. 1/2, pp. 99-116.

Clement, D. R., & Steinman, A. D. (2017). Phosphorus loading and ecological impacts from agricultural tile drains in a west Michigan watershed. *Journal of Great Lakes Research, 43(1)*, 50-58.

Cornell, S. E. (2011). Atmospheric nitrogen deposition: Revisiting the question of the importance of the organic component. *Environmental Pollution*, *159*(10), 2214-2222.

GLWQA Nutrients Annex Subcommittee. (2015). Factsheet: Recommended Binational Phosphorus Targets to Combat Lake Erie Algal Blooms. https://www.epa.gov/sites/default/files/2015-06/documents/recommended-binational-phosphorus-targets-20150625-8pp.pdf

Groffman, P. M., Baron, J. S., Blett, T., Gold, A. J., Goodman, I., Gunderson, L. H., & Wiens, J. (2006). Ecological thresholds: the key to successful environmental management or an important concept with no practical application?. *Ecosystems*, *9*(1), 1-13.

Hamlin, Q. F., Kendall, A. D., Martin, S. L., Whitenack, H. D., Roush, J. A., Hannah, B. A., & Hyndman, D. W. (2020). Quantifying landscape nutrient inputs with spatially explicit nutrient source estimate maps. *Journal of Geophysical Research: Biogeosciences*, *125*(2), 1-24. https://doi.org/10.1029/2019JG005134

Jarvie, H.P., M.D. Jurgens, R.J. Williams, C. Neal, J.J.L.Davies, C. Barrett, and J. White, 2005. Role of riverbed sediments as sources and sinks of phosphorus across two major eutrophic UK river basins. The Hampshire Avon and Herefordshire Wye. J. Hydrol. 304:51-74. doi:10.1016/j.jhydrol.2004.10.002

LaBeau, M. B., Robertson, D. M., Mayer, A. S., Pijanowski, B. C., & Saad, D. A. (2014). Effects of future urban and biofuel crop expansions on the riverine export of phosphorus to the Laurentian Great Lakes. *Ecological modelling*, *277*, 27-37.

Lam, W. V., Macrae, M. L., English, M. C., O'Halloran, I. P., & Wang, Y. T. (2016). Effects of tillage practices on phosphorus transport in tile drain effluent under sandy loam agricultural soils in Ontario, Canada. *Journal of Great Lakes Research, 42(6),* 1260-1270.

Luscz, E. C., Kendall, A. D., & Hyndman, D. W. (2015). High resolution spatially explicit nutrient source models for the Lower Peninsula of Michigan. *Journal of Great Lakes Research*, *41*(2), 618–629. https://doi.org/10.1016/j.jglr.2015.02.004

Luscz, E. C., Kendall, A. D., & Hyndman, D. W. (2017). A spatially explicit statistical model to quantify nutrient sources, pathways , and delivery at the regional scale. *Biogeochemistry*, *133*(1), 37–57. https://doi.org/10.1007/s10533-017-0305-1

Madenjian, C. P., Fahnenstiel, G. L., Johengen, T. H., Nalepa, T. F., Vanderploeg, H. A., Fleischer, G. W., ... & Ebener, M. P. (2002). Dynamics of the Lake Michigan food web, 1970 2000. *Canadian Journal of Fisheries and Aquatic Sciences*, *59*(4), 736-753.

Nah E. Kim; Kristen Bellisario, Kimberly D. Robinson, David Savage, Bryan C Pijanowski. 2020. Tipping Points: What are they? Why are they important? Purdue Extension, FNR-602-W. At https://mdc.itap.purdue.edu/item.asp?Item_Number=FNR-602-W.

Palmer-Felgate, E.J., R.J.G. M Mortimer, M.D. Krom, and H.J. Jarvic. 2010. Impact of point-source pollution on phosphorus and nitrogen cycling in stream-bed sediments. Environ. Sci. Technol. 44:908-914. doi: 10.1021/cs902706r

Riseng C.M. , M. J. Wiley, P. W. Seelbach, and R. J. Stevenson, An ecological assessment of Great Lakes tributaries in the Michigan Peninsulas, Journal of Great Lakes Research, Volume 36, Issue 3, 2010, Pages 505-519, ISSN 0380-1330, https://doi.org/10.1016/j.jglr.2010.04.008.

Riseng, C. M., Wiley, M. J., Black, R. W., & Munn, M. D. (2011). Impacts of agricultural land use on biological integrity: a causal analysis. *Ecological Applications*, *21*(8), 3128-3146.

Robertson, D. M., & Saad, D. A. (2011). Nutrient inputs to the Laurentian Great Lakes by source and watershed estimated using SPARROW watershed models 1. *JAWRA Journal of the American Water Resources Association*, *47*(5), 1011-1033.

Robertson, D. M., & Saad, D. A. (2011). Nutrient inputs to the Laurentian Great Lakes by source and watershed estimated using SPARROW watershed models 1. *JAWRA Journal of the American Water Resources Association*, *47*(5), 1011-1033.

Scavia, D., Allan, J. D., Arend, K. K., Bartell, S., Beletsky, D., Bosch, N. S., ... & Zhou, Y. (2014). Assessing and addressing the re-eutrophication of Lake Erie: Central basin hypoxia. *Journal of Great Lakes Research*, *40*(2), 226-246.

Sharpley, A., H. P. Jarvie, A. Bud, L. May, B. Spears, and P. Kleinman. 2013. Phosphorus Legacy: Overcoming the effects of past management practices to mitigate future water quality impairment. J. Environ. Qual. 42:1308-1326.

State of Ohio Domestic Action Plan. 2020. Promoting Clean and Safe Water in Lake Erie: Ohio's Domestic Action Plan 2020 to Address Nutrients. 107 p. https://lakeerie.ohio.gov/wps/portal/gov/lec/planning-and-priorities/02-domestic-action-plan

Tang, Z., Engel, B. A., Pijanowski, B. C., & Lim, K. J. (2005). Forecasting land use change and its environmental impact at a watershed scale. *Journal of environmental management*, *76*(1), 35-45.

Wan, L., Kendall, A. D., Martin, S. L., Hamlin, Q. F., & Hyndman, D. W. (2021). Identifying the Key Pathways for Landscape Nutrient Transport with SENSEflux. *Manuscript in Preparation.*

Wiley, M. J., Hyndman, D. W., Pijanowski, B. C., Kendall, A. D., Riseng, C., Rutherford, E. S., ... & Rediske, R. R. (2010). A multi-modeling approach to evaluating climate and land use change impacts in a Great Lakes River Basin. In *Global Change and River Ecosystems—Implications for Structure, Function and Ecosystem Services* (pp. 243-262). Springer, Dordrecht. https://doi.org/10.1007/s10750-010-0239-2