Toward Implementation of a Manure Management Framework

Final Report: April 2023

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Final Report

Prepared for:

The International Joint Commission

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The content of this report represents work undertaken by a consultant team of Potomac-Hudson Engineering, Inc. and LimnoTech, Inc., under contract to the International Joint Commission (IJC). The report was developed to inform work of the Manure Nutrient Management Collaborative (Collaborative), a group formed by the IJC's Great Lakes Water Quality Board (WQB). The views and recommendations contained in the report are those of the consultant and do not necessarily reflect those of the International Joint Commission, Water Quality Board, Collaborative, nor individual members of the Collaborative or their respective organizations.

Executive Summary

Lake Erie has been impacted by excess nutrient loading from point sources and nonpoint sources for decades. Significant loading reductions from point sources have been achieved since the 1970s, but reducing nonpoint sources has not been as effective. This study, conducted by a contractor team with input and oversight from International Joint Commission (IJC) staff and the binational Manure Nutrient Management Collaborative, evaluated aspects of manure management in parts of the Lake Erie watershed in Canada and the United States. The project objectives were to assess the state of knowledge on manure management in the study areas and to suggest measures to improve manure management and reduce nutrient loading to the lake, which causes harmful algal blooms (HABs), among other negative impacts. The presence of large and toxic HABs each summer is of special concern because the lake provides drinking water to millions of people. The study examined manure-related information for two sub-watersheds in the western basin of Lake Erie - Medway Creek, part of the Thames River watershed in Ontario, and the Auglaize River, part of the Maumee River watershed in Ohio and Indiana. The outcomes of the data collection and assessment will be used by the Collaborative to develop recommendations on a binational/Great Lakes manure management framework.

Livestock production is an important component of the agricultural economy in the United States (U.S.) and Canadian drainage areas to the western Lake Erie basin. Beef cattle, dairy cattle, swine, and poultry farming operations are dominant in the region and provide products to local and international markets. Manure can be a valuable organic fertilizer for cash crop agriculture operations that typically surround livestock operations by providing both nutrients to offset crop removal rates, and organic matter to improve soil health. When improperly handled, however, manure can cause environmental problems and become a liability rather than an asset.

The IJC has conducted prior studies of fertilizer and manure management in the Western Lake Erie basin. These previous studies included a detailed comparative analysis of fertilizer and manure management in the Lake Erie basin (see LimnoTech 2017, IJC 2018, and LimnoTech 2019). A separate 2019 report was specific to manure management and included subsequent engagement sessions (Great Lakes WQB, 2019; Great Lakes WQB, 2020). These studies yielded several recommendations, parts of which have been addressed by subsequent work.

Livestock operations in the Lake Erie watershed and elsewhere have changed over the last 30 years from many distributed farms raising smaller numbers of livestock to fewer and larger confined livestock operations that produce large volumes of manure at discrete sites. An important aspect of cattle and hog operations is that the manure generated is in a semi-solid or liquid form, which may make it more mobile when applied to farm fields than solid poultry manure. Manure needs to be managed in a way that minimizes nutrient losses to waterways and downstream loading to Lake Erie. Approaches to manure management have evolved over time and resources invested to address concerns have increased, but there is some disagreement on how best to continue to adjust technologies and policies to maximize benefits and minimize impacts. Continued research investments, pilot demonstration projects and sites (e.g., demonstration farms), and more incentives for innovation are needed, but with close linkages to policy refinement, improvement of management approaches, and technology transfer. Corporate sustainability programs, including attention to supply chains, are beginning to have substantial impacts on agricultural practices outside of regulatory frameworks.

The case studies presented here compare two watersheds in the western Lake Erie basin, the Auglaize River in the U.S. (mostly in the state of Ohio), and the Medway Creek in the province of Ontario, Canada. The comparative study consisted of the following elements:

- Collection and synthesis of data and information related to manure/nutrient inputs, storage, treatment, and application;
- Collection and synthesis of data and information related to manure management rules, regulations, and practices;
- Generation of maps illustrating the data and information collected;
- Evaluation of the data and information collected; and
- Recommendations and insights on manure management.

Data-Based Findings

- Nutrient delivery to U.S. and Canadian watersheds studied and to western Lake Erie is dominated by nonpoint loads. These are primarily the result of dissolved and particulate nutrient transport in runoff and tile drainage from agricultural fields.
- Available water quality monitoring data suggest that while flow-weighted mean concentrations of dissolved reactive phosphorus (DRP) have remained relatively constant in recent years, total DRP loads in the Auglaize River (U.S.) have exhibited an upward trend. Total P concentrations have exhibited a downward trend in Medway Creek (Canada).
- Recent trends show increases in total livestock in the Auglaize River watershed (U.S.), particularly of swine and associated liquid manure, and in and around the Medway Creek watershed (Canada) (see Figures ES-1 and ES-2).
- Estimated overall application and generation values for fertilizer and manure, converted to elemental phosphorus, for the Auglaize and Medway Creek watersheds are shown in Table ES-1 below for 2017. Note that application rates are not directly reflective of nutrient loss rates from fields to waterways.
- Available data suggest that on average, soil phosphorus levels have been gradually declining across northwest Ohio and northeast Indiana (U.S.) and across the Medway Creek watershed. However, this does not include information on legacy manure application hotspots that may still exist across both watersheds.

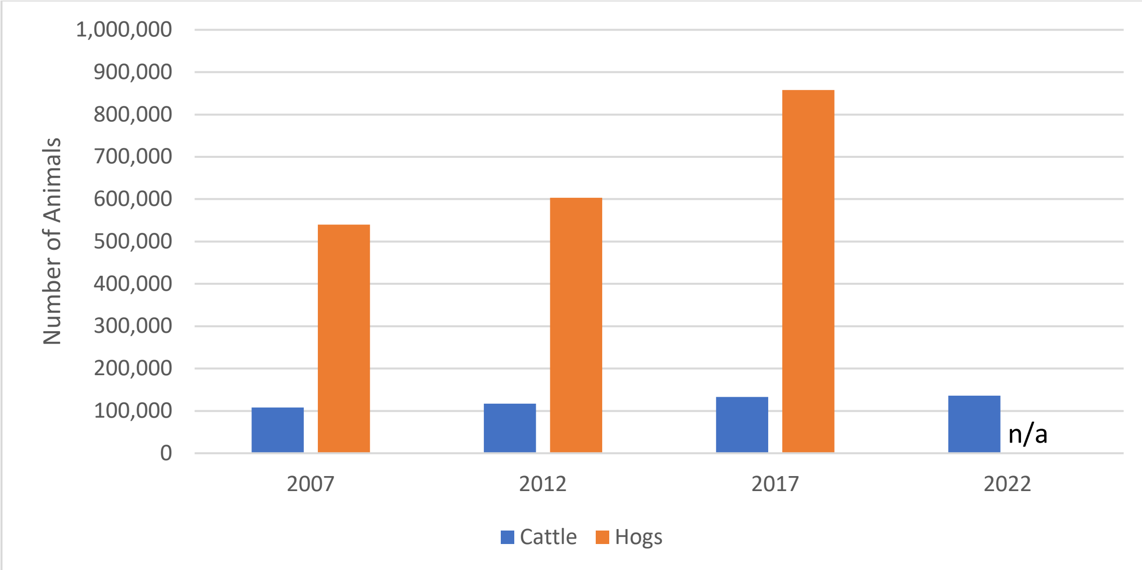

Figure ES-1 Cattle and Hog Population in Counties in and around the Auglaize Watershed

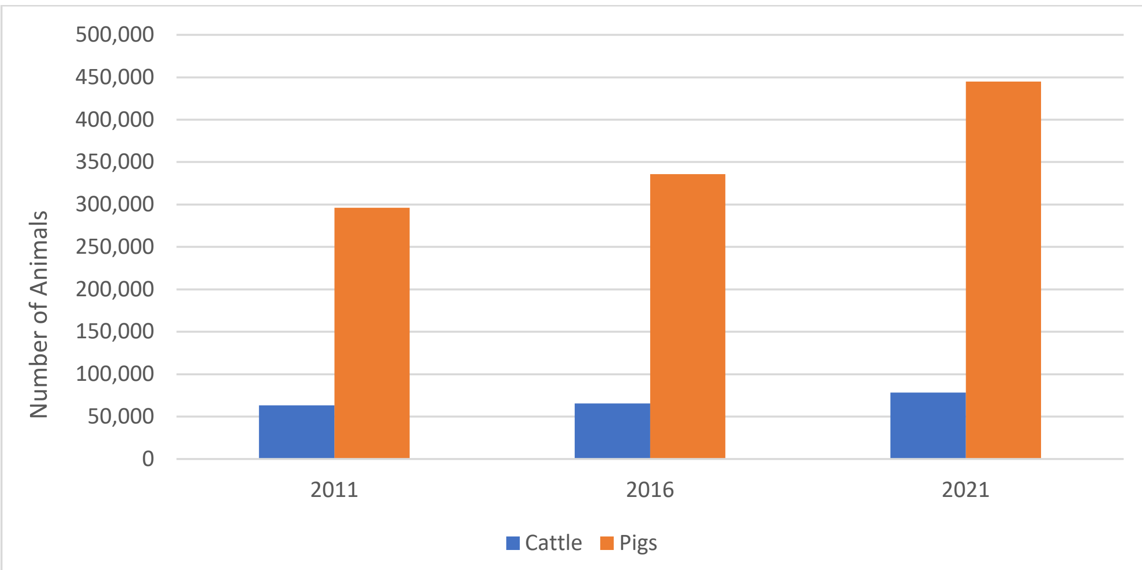

Figure ES-2 Animal Population in Middlesex Census Division, ON, 2011 – 2021

Table ES-1 Summary of Manure and Fertilizer P Inputs

Watershed	Total P from Manure and Commercial Fertilizer (kg)	Total Generated Manure P (kg)	Total Commercial Fertilizer P (kg)	Manure P as Fraction of Total Manure and Fertilizer P	Fertilizer P as Fraction of Total Manure and Fertilizer P
Auglaize[1]	18,287,493	6,797,164	11,490,329	37.2%	62.8%
Medway[2]	6,261,085	2,979,309	3,281,776	47.6%	52.4%

1 Data reflects county-level P-inputs for seven Ohio counties (Allen, Auglaize, Defiance, Hardin, Paulding, Putnam, and Van Wert) and two Indiana counties (Adams and Allen).

2 Data reflects P inputs for Middlesex Center census sub-division, which is a larger area that includes the Medway Creek watershed.

Data and Knowledge Gaps

Important monitoring and knowledge gaps include:

- Locations of animal feeding operations (AFOs) in Ontario, and location of non-permitted AFOs in the U.S.
- Location-specific and publicly available soil P test data across both watersheds.
- Data on manure generated and applied to land in Ontario, and for non-permitted facilities in the U.S., including data on locations where applied, and application rate.
- Data on manure application methods and timing.

Regulatory, Policy, and Program Findings

- The U.S. and Canadian approaches to manure management have similar environmental protection objectives and apply similar concepts of normalizing manure generation across animal types, but the thresholds for different levels of management and the corresponding requirements at the thresholds differ by jurisdiction.
- Canada and the U.S. have developed a collaborative approach to nutrient management, including some components of manure management, under Annex 4 of the Great Lakes Water Quality Agreement. Ontario, Michigan, Indiana, and Ohio all developed Domestic Action Plans in 2018 to reduce nutrient loads to Lake Erie.
- The U.S. approach manages discharge aspects of large livestock operations under federal legislation. States, including Ohio and Indiana, manage many aspects of livestock operations and manure handling and application under their own laws, agencies, and programs. The primary jurisdiction for regulation of manure in Canada is at the provincial level--Ontario in this case.
- State programs and guidelines in Ohio and Ontario have been modified in the last decade to promote more intensive manure management to control nutrient loss to waterways, but additional work remains to be done, especially where livestock operations are expanding. The 4R Nutrient Stewardship Certification Program and the H2Ohio Partnership Program have improved nutrient management in the Maumee River watershed, and the Total Maximum Daily Load Project has set source-specific load reduction targets for the Maumee. In 2016, Ohio statutes restricting the application of manure in the western Lake Erie basin came into effect (ORC 905.326 and 939.08). The Ontario Nutrient Management Act was enacted in 2002 and has been updated periodically since then.

Recommendations

These recommendations are presented with an understanding of IJC's advisory and non-regulatory role, as well as recognition that IJC does not manage substantial resources that could be applied to addressing the issues examined or underwriting ongoing activities of the Collaborative. The outcomes of the data collection and assessment will be used by the Collaborative to develop recommendations on a binational/Great Lakes manure management framework. The Collaborative, associated IJC boards, and resource management agencies should consider the following non-prioritized approaches in the near term (next three years) to address data and policy gaps, improve manure management, and reduce the loss of manure-derived nutrients to waterways:

1. Identify resources to continue convening the Manure Nutrient Management Collaborative to consolidate knowledge and promote consensus building around the most efficient and effective ways to reduce nutrient loss to waterways from livestock operations and associated manure application in the Lake Erie watershed.
2. Continue to focus attention on the Maumee and Thames as watersheds with the greatest nutrient loading impacts to Lake Erie and as locations for improving the reporting of manure data by increasing resolution to sub-watershed or finer scales. This will help to better link water quality improvements and phosphorus load reductions to program investments.
3. Develop draft policy guidance that incorporates and harmonizes the best manure management approaches in the two countries to the extent possible. Consider especially the Ontario Nutrient Management Act framework, Ohio Domestic Action Plan, H2Ohio Program, 4R Certification, and Maumee Watershed Nutrient Total Maximum Daily Load (TMDL) Project. Also consider the properties of specific manure types and corresponding differences in approaches to effectively managing these, as well as the potential role of subsidized centralized manure exchanges in promoting manure application at agronomic rates and allowing for other management options such as biodigestion and energy generation, with appropriate policy safeguards.
4. Coordinate with U.S. state and other agencies to evaluate the potential for requiring currently unregulated AFOs to develop and implement nutrient management plans. Evidence suggests these AFOs generate the majority of manure within the Auglaize Watershed and likely in the U.S. portion of the larger WLEB.
5. Consider whether temporary changes to nutrient management approaches such as sub-watershed-specific or livestock-specific moratoria or other time-limited actions could allow policies and procedures to catch up with the rapid expansion of certain types of livestock operations in some locations, recognizing the corresponding potential for negative impacts and the urgency in mitigating such impacts before they occur and become established.
6. Suggest refinements to data collection and transparency policies and procedures in both countries that better harmonize regulations, balance community needs regarding environmental impacts and exposures with producer privacy, and define the technology, staffing, and financial resources needed to support such expanded data programs. This could include, for example, requiring U.S. drain tile installers or agricultural laboratories to report certain data to agencies.
7. Coordinate with state and provincial agencies and other institutions to promote research and collect data that helps delineate sources of DRP (i.e., manure, commercial fertilizer, legacy sites).
8. Identify existing programs and suggest new or expanded programs to improve linkages, interactions, and formal and informal exchanges between water quality and agricultural experts, agencies, stakeholders with the ultimate goal of reducing manure impacts on waterways while factoring in livestock economics. Define the staffing and financial resources needed to support existing and new programs on an ongoing basis.

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Acronyms

AFO – Animal Feeding Operation

BMP – Best Management Practice

CAD – Canadian Dollars

CAFF – Concentrated Animal Feeding Facility

CAFO – Concentrated Animal Feeding Operation

CFO – Confined Feeding Operations

CLM – Certified Livestock Manager

Collaborative – Manure Nutrient Management Collaborative

CWA – Clean Water Act

DAP – Domestic Action Plan

DO – Dissolved Oxygen

DRP – Dissolved Reactive Phosphorus

ECCC – Environment and Climate Change Canada

EPA – Environmental Protection Agency

EQIP – Environmental Quality Incentives Program

EWG – Environmental Working Group

FSA – Farm Service Agency

FSIS – USDA Food Safety and Inspection Service

FSMP – Free Standing Meat Processing

FWMC – Flow-Weighted Mean Concentration

GIS – Geographic Information System

GLASI – Great Lakes Agricultural Stewardship Initiative

GLWQA – Great Lakes Water Quality Agreement

HAB – harmful algal blooms

HDPE – High-Density Polyethylene

HUC – Hydrologic Unit Code

IDEM – Indiana Department of Environmental Management

IJC – International Joint Commission

K – Potassium

Kg – Kilogram

Kg/ha – kilogram per hectare

lbs – Pounds (U.S)

m – Meter

MECP – Ministry of Environmental Conservation and Parks

mg/l – Milligrams per Liter

N – Nitrogen

N/A – Not Available

NAICS – North American Industry Classification System

NASS – National Agricultural Statistics Service (USDA)

NASTRAT – Nutrient and Sediment Transport Risk Assessment Tool (Indiana)

NCWQR – National Center for Water Quality Research

NGO – Non-Governmental Organization

NMA – Nutrient Management Act of 2002

NMP – Nutrient Management Plan

NMS – Nutrient Management Strategy

NPDES – National Pollutant Discharge Elimination System (USEPA)

NRCS – Natural Resources Conservation Service (U.S.)

NU – Nutrient Unit

ODA – Ohio Department of Agriculture

Ohio EPA – Ohio Environmental Protection Agency

OMAFRA – Ontario Ministry of Agriculture, Food, and Rural Affairs

OSCIA – Ontario Soil and Crops Improvement Association

P - Phosphorus

PDF - Portable Document Format

ppm – Parts Per Million

PTI – Permit to Install

PTO – Permit to Operate

SAB – Science Advisory Board

SEW – Segregated Early Weaning

SPARROW – SPAtially Referenced Regression On Watershed attributes

Sq. Ft – Square feet

SSURGO – Soil Survey Geographic Database

STP – Soil Test Phosphorus

SWAT – Soil and Water Assessment Model

TMDL – Total Maximum Daily Load

TP – Total Phosphorus

U.S. – United States

USD – United States Dollars

USDA – United States Department of Agriculture

USEPA – United States Environmental Protection Agency

USGS – United States Geological Survey

UTRCA – Upper Thames River Conservation Authority

WLEB – Western Lake Erie Basin

WQB – Great Lakes Water Quality Board (IJC)

1. Background and Scope

Potomac-Hudson Engineering, Inc. and LimnoTech, Inc., under contract to the International Joint Commission (IJC) through the United States (U.S.) Department of State, have synthesized available and existing data and information on manure generation and land application, manure management rules and practices, and water quality impacts in two select watersheds - the Auglaize River watershed in the Maumee River watershed (Ohio and Indiana; see Figure 1-1) and the Medway Creek watershed in the Upper Thames River watershed (Ontario; see Figure 1-2); mapped the information and data collected; evaluated the data and information collected; and developed recommendations and insights on manure management.

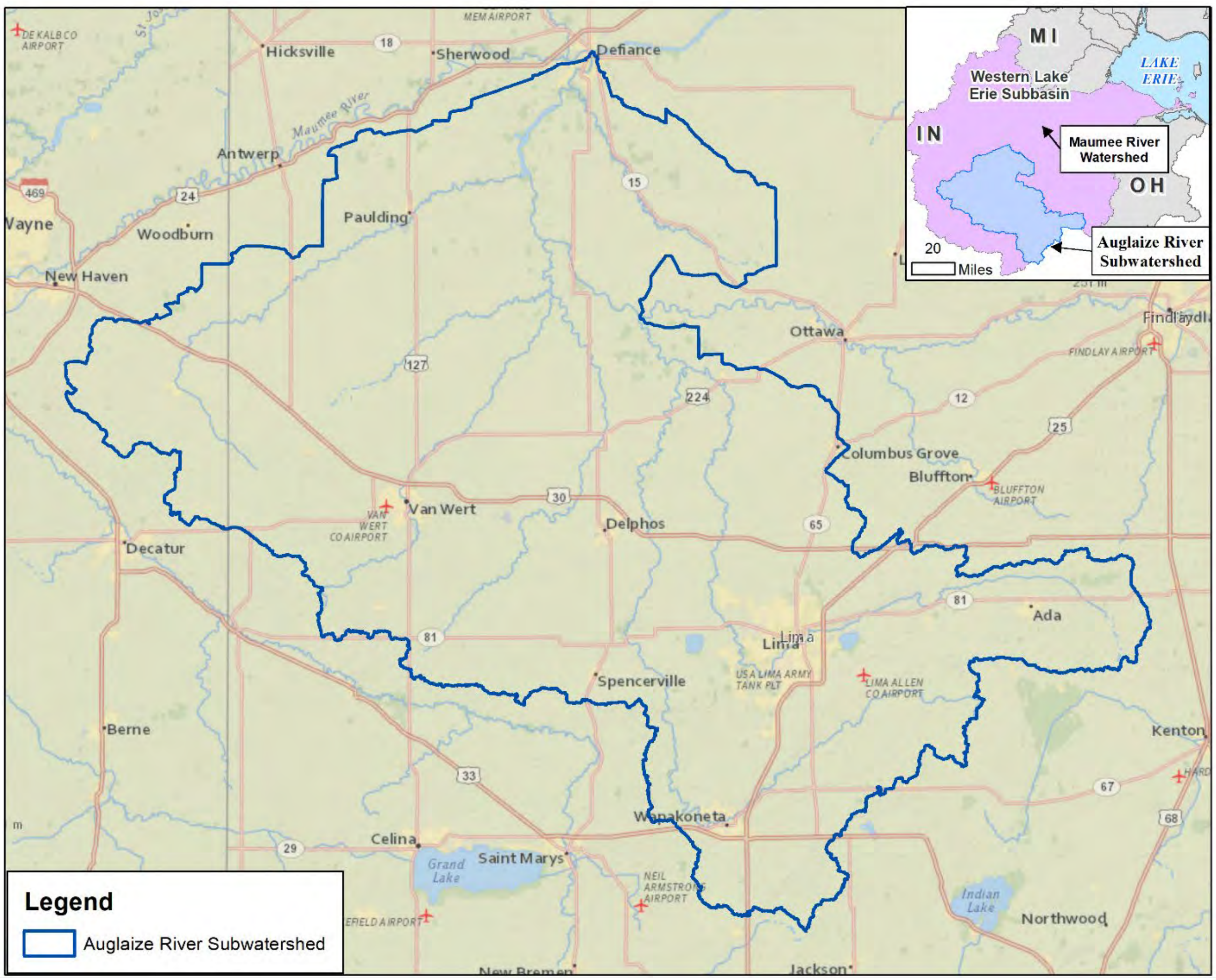


Figure 1-1 Auglaize River Watershed

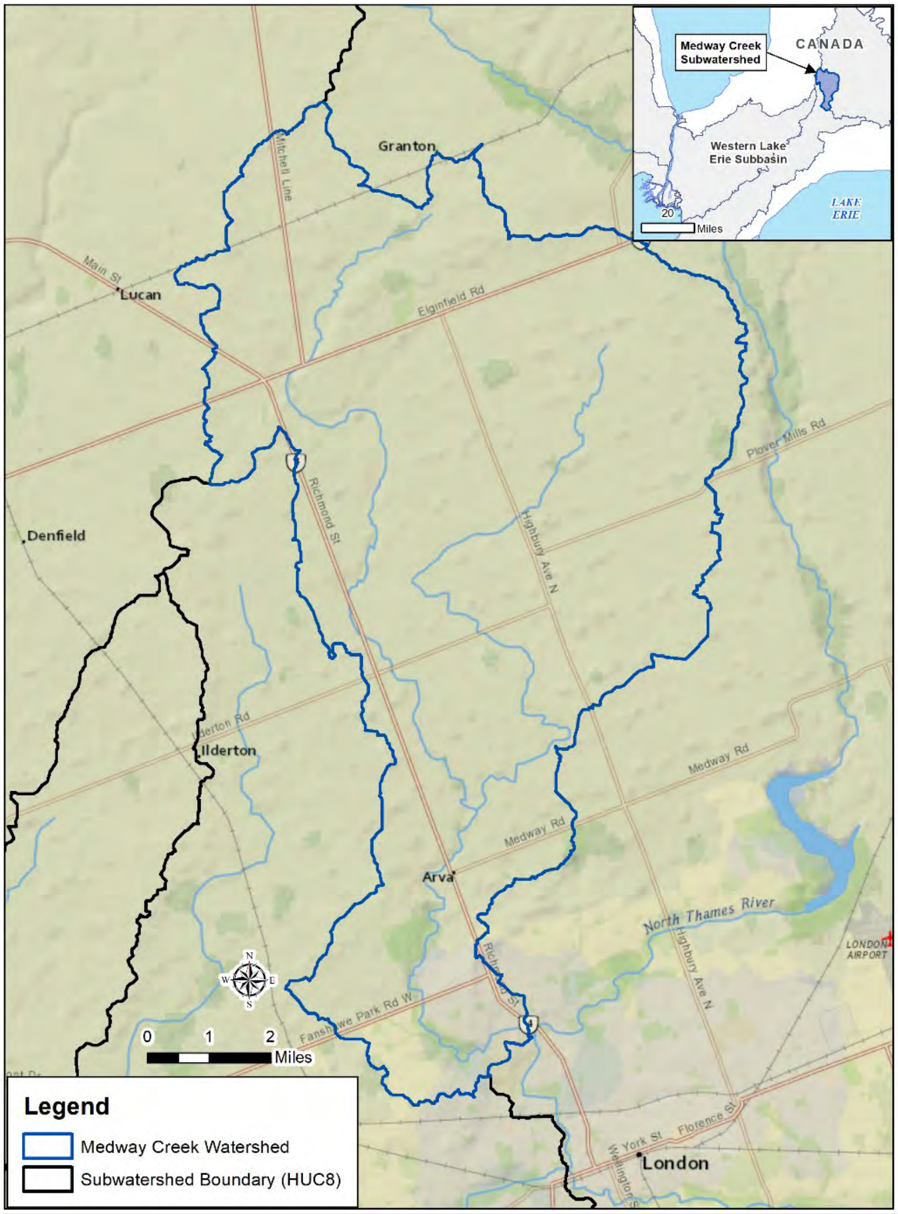


Figure 1-2 Medway Creek Watershed

This project follows the release of a study by the Great Lakes Water Quality Board (WQB), submitted to the IJC in 2019, that resulted in the recognition that manure management in the Great Lakes region needs improvement. The WQB also identified a critical barrier to the implementation of the recommendations from their 2019 report in that there was no entity that existed to gather information and assess manure management programs from interested parties, such as famers and federal/state agencies. In order to create a framework for Great Lakes manure management, the WQB worked to bring together a group of stakeholders into a Manure Nutrient Management Collaborative (the Collaborative).

This project supports the Collaborative as they review manure and nutrient inputs as well as manure policies and practices from a binational perspective. Per the contract Statement of Work, primary project goals were to:

(1) *Collect, review and evaluate available data and information on manure/nutrient generation, storage and application; manure management and/or permitting rules, policies and practices; and land use (including landscape and farm/rural characteristics) in two selected Great Lakes western Lake Erie sub-watersheds, and*

(2) *Develop products that can potentially be used by the Collaborative to develop consensus for manure management and policy recommendations, public outreach, and communications activities*.

A detailed description of project tasks and deliverables is included in Table 1-1.

Table 1-1 Project Tasks and Deliverables

Task	Description/Deliverable

1a	Compile data on a binational basis by county and watershed on the following items:
	• Watershed features including, but not limited to, land use, land cover, geology, soil types, hydrology and climate in the two sub-watersheds.
	• Number of permitted animal feeding operation facilities and estimated number of non-permitted animal feeding operation facilities and nearby livestock processing facilities/abattoirs
	  - For the purposes of this work, permitted and non-permitted facilities are characterized as:
	    ▪ U. S. permitted facilities are those that meet the USEPA size threshold definition (number of animals) for a large, concentrated animal feeding operation (CAFO) or larger
	    ▪ U.S. non-permitted facilities are those that meet the USEPA size threshold definition (number of animals) for a medium or smaller CAFO
	    ▪ Ontario permitted facilities are those that fall under the requirements of the Ontario Nutrient Management Act, 2002 (i.e., >300 Nutrient Units or new and expanding facilities >5 Nutrient Units)
	    ▪ Ontario non-permitted facilities are those that do not fall under the requirements of the Ontario Nutrient Management Act, 2002
	• Locations of permitted and non-permitted facilities, for the purposes of mapping (per Task 2)
	• Animal counts and types for permitted and non-permitted animal feeding operation facilities.
	• Confirm the use of a nutrient management unit in Ohio; identify the Ontario method for calculating a nutrient management unit; and if/how the Ontario method can be applied in Ohio by calculating nutrient production by animal, using scientific standards (i.e., attempt to construct a “nutrient management unit” for U.S. applications).
	• Soil phosphorus levels across the sub-watersheds
	• The type and quantities of manure generated, quantities applied to land, the number of acres of land to which it is applied, the approximate distance from generation to application, and approximate distance from application area to nearby permanent streams
	• Manure application methods and timing
	• Estimated manure phosphorus (P), potassium (K), and nitrogen (N) land application rates for predominant crop types.
	• Number of agricultural acres in each watershed that receive applications of commercial fertilizer, manure and/or biosolids
	• To the extent possible, the potential contribution of phosphorus, dissolved and total, to streams in the two sub-watersheds from commercial vs. manure fertilizers
	• Estimated total and dissolved phosphorus loading to the Medway Creek and Auglaize River
	• Locations where continuous/sustained nutrient monitoring of water is undertaken and the source of the monitoring data

Task	Description/Deliverable
	• Describe the impairment status of the two Lake Erie sub-watershed waterways (under U.S. and Canadian water quality laws), including any existing watershed assessments relevant to nutrients and phosphorus loading/inputs • Information on new manure nutrient management technologies: - Manure storage and treatment technologies, including nutrient removal efficiency, cost of installation, operation, and maintenance - Manure application technologies, efficiency in using manure nutrients, and costs - Funding/incentive opportunities for the implementation of innovative practices
1b	Compile data on manure management rules, regulations, and practices. For the two sub-watersheds specified: • Collect information on existing manure management permitting rules and regulations, such as, but not limited to, criteria to be subjected to permitting requirements; nutrient soil testing and frequency requirements; manure nutrient testing and frequency requirements; rules for the construction manure storage structures; application restrictions/bans; acreage requirements for land application of manure; requirements for the preparation of a nutrient management plan; and enforcement protocols. • Collect information on programs and funding for best management practices related to field management practices (such as tillage practices, cropping systems, water/erosion management, drainage practices) and manure land application practices.
2	Using standard geographic information system (GIS) approaches and the data and information collected from Task 1, map the following, for both sub-watersheds, using existing, publicly available data: • Locations of permitted animal feeding operation facilities and non-permitted facilities and nearby animal processing facilities/abattoirs, where information is available. • For each of the mapped permitted animal feeding operation facilities, include livestock/animal type and number of animals • Proximity of manure application areas and manure storage areas to permanent streams • Sub-surface agricultural tile drainage • Density of manure application areas • General soil phosphorus levels across the two sub-watersheds.
3a	Compile data and information related to manure/nutrient inputs, treatment, and application. Based on the data and information collected in Task 1(a) provide: • Discussion of the gaps in data, including challenges in gathering data; inaccessibility of data (e.g., privately held); lack of data availability (e.g., not reported/collected) • Discussion of differences in data reporting, collection and accessibility between the Ohio and Ontario jurisdictions. • Discussion of what data is needed to determine the impact of manure application in the watershed on water quality. • Discussion on the differences in watershed features (e.g., geology, soils, hydrology, climate, etc.) in the two sub-watersheds and how this can influence: o How manure is stored and applied. o Where manure is applied o When manure is applied o Nutrient loadings to waterbodies • Summary and comparison of new manure management/treatment and application technologies and discussion on their applicability; nutrient removal effectiveness (for treatment technologies); advantages and disadvantages; identify significant differences in costs between technologies; and differences in technologies that may exist between the US vs. Canada
3b	Compile data on manure management rules, regulations, and practices. Based on the information collected in Task 1(b) provide:

Task	Description/Deliverable
	• Discussion on the similarities and differences between the management of manure between the U.S. watershed and Ontario watershed based on - (1) existing manure management permitting rules/regulations and enforcement protocols and - (2) known best management practices. • General observations on the differences in rural economies, infrastructure, advisory/support capacity, and scale of operations in the two sub-watersheds and how this can influence manure management, regulations and opportunities for alternative manure management approaches or technologies • Highlight best management practices being used and estimated phosphorus reductions, and where new technologies could be applied • Evaluate the existing manure management regulatory framework in the two sub-watersheds including strengths and weaknesses in the permitting requirements as it relates to nutrient runoff and water quality.
4	Provide recommendations and insights on manure management. Based on the data and information collected and evaluated (Tasks 1-3), provide recommendations and insights on: • The magnitude and overall implications for nutrient loadings to, and impacts on, the Maumee River watershed, the Thames River watershed and Western Lake Erie. • Identify potential approaches to address the identified data/information/policy gaps to help improve manure management in the Maumee and Thames sub-watersheds • Identify potential approaches to evaluating the effectiveness of a manure management framework.
5	Write a draft report. Using the data and information collected from Tasks 1 to 4 above, develop a draft report, approximately 50-75 pages in length (exclusive of appendices), including: • Description of how each of the tasks have been carried out • Using a combination of tables, graphics, maps, figures and charts (as appropriate) along with narrative text: • Provide a synthesis of the data and information collected (Task 1) and the resulting outcomes of the evaluation of that data, as outlined in Task 3 • Provide a synthesis of the advice and insights generated from the data and information collected and evaluated in Tasks 1-3 (Task 4), • Static maps (per Task 2) are to be a supplementary/appendix document to the report. • The report is to include a reference list as a supplementary/appendix document to the report. The list will include links, where available, of all documents, reports, journal papers, and data used in the generation of the report
6	Develop a final report. Receive feedback, edits, and comments from the Collaborative group on the draft contractor report. Incorporate suggested edits and revisions in a final version of the contractor report. These shall be provided within three weeks of completion of the draft report
7	Develop a PowerPoint slide deck highlighting the outcomes, findings and insights generated through this work project, that could potentially be used by the Collaborative in consensus building, engagement, and outreach efforts.

Lake Erie has been impacted by excess nutrient loading from point sources and nonpoint sources for decades. Significant loading reductions from point sources have been achieved since the 1970s, but reducing nonpoint sources has not been as effective. Livestock production is an important component of the agricultural economy in the United States (U.S.) and Canadian drainage areas to the western Lake Erie basin. Beef cattle, dairy cattle, swine, and poultry farming operations are dominant in the region and provide products to local and international markets. Manure can be a valuable organic fertilizer for cash crop agriculture operations that typically surround livestock operations by providing both nutrients to offset crop removal rates, and organic matter to improve soil health. When improperly handled, however, manure can cause environmental problems and become a liability rather than an asset.

The IJC has conducted prior studies of fertilizer and manure management in the Western Lake Erie basin including a detailed comparative analysis (see 2017 contractor report, 2018 work group report [2018]; see also the 2019 supplement). A separate 2019 report was specific to manure management and included subsequent engagement sessions (see links to reports and summary information at: https://www.ijc.org/en/wqb/oversight-animal-feeding-operations-manure-management-great-lakes-basin). This study yielded the following recommendations (condensed and without all sub-recommendations):

> *Recommendation 1*: Each Great Lakes state and Ontario should conduct an in-depth assessment of permitting rules, requirements, and implementation of manure management to identify successes and challenges in achieving reduced nutrient runoff goals and to support establishment of consistent guidelines and regulations.
>
> *Recommendation 2*: The U.S. Great Lakes states and Ontario should create rules and policies for manure application that include a systematic approach to application rates, tracking of animals and manure application, water quality monitoring, and public notification,
>
> *Recommendation 3*: The federal Canadian and U.S. governments, along with Great Lakes states and the province of Ontario, should provide funding dedicated to assisting agriculture for manure management including reuse and treatment technologies, and best management practice implementation.
>
> *Recommendation 4*: A Canadian and U.S. panel of experts should report on the international management policies, tools, technologies, reporting, and recordkeeping practices of the Netherlands and Denmark, and should assess manure management impacts on Indigenous communities.

Subsequent work has addressed some parts of these recommendations.

Livestock operations in the Lake Erie watershed and elsewhere have changed over the last 30 years from many distributed farms raising smaller numbers of livestock to fewer and larger confined livestock operations that produce large volumes of manure at discrete sites. An important aspect of cattle and hog operations is that the manure generated is in a semi-solid or liquid form, which makes it more mobile when applied to farm fields as fertilizer than solid poultry manure. Manure-derived nutrients need to be managed in a manner that minimizes losses to waterways and downstream loading to Lake Erie. Approaches to manure management have evolved over time and resources invested to address concerns have increased, but there is some disagreement on how best to continue to adjust technologies and policies to maximize benefits and minimize impacts. Continued research investments, pilot demonstration projects and sites (e.g., demonstration farms), and more incentives for innovation are needed, but with close linkages to policy refinement, improvement of management approaches, and technology transfer. Corporate sustainability programs, including attention to supply chains, are beginning to have substantial impacts on agricultural practices outside of regulatory frameworks.

1.1 Project Communication

PHE and LimnoTech discussed project status and coordinated activities with the Collaborative (see Appendix A), its leadership, or other collaborators on the following:

- Kickoff meeting hosted on June 24th, 2022
- Conference call with the Collaborative on July 22nd, 2022
- Conference call with the Collaborative on August 24th, 2022
- Conference call with the Collaborative on September 21st, 2022
- Conference call with the Collaborative on October 26th, 2022
- Conference call with Ohio Department of Agriculture on October 28th, 2022
- Conference call with the Collaborative on November 16th, 2022
- Conference call with the Collaborative on January 23rd, 2023

Additionally, PHE and LimnoTech reached out by email to various government agencies and experts to request data and information relevant to the project goals. The agencies and individuals that were contacted for this project are listed in Appendix B.

1.2 Project Deliverables

The following deliverables were completed on the dates noted:

- Initial draft summary spreadsheet of data and information collected (July 18th, 2022)
- Draft of maps to be utilized in final reporting (October 25th, 2022)
- An update regarding the evaluation of data and information collected (October 25th, 2022)
- A proposed outline for the draft report (November 15th, 2022)
- Draft report including draft narrative text, figures, tables, and maps (December 14th, 2022)
- Draft final report including draft narrative text, figures, tables, and maps (February 20th, 2023)
- Final report including modifications requested by the Collaborative after review of the draft final report, with complete narrative text, figures, tables, maps, and electronic files (April 3rd, 2023).

2. Methodology

This assessment of manure application and impacts was conducted in cooperation with members of the Collaborative. The study had a geographic scope of two sub-watersheds in the western basin of Lake Erie: the Auglaize Rivera sub-watershed in the Maumee River watershed (Ohio and Indiana), and the Medway Creek sub-watershed, in the Thames River watershed (Ontario) (Figures 3-1 and 3-2).

2.1 Data Gathering

Data were gathered systematically and collaboratively, first through focused searches on publicly available sources and secondly through targeted outreach to contacts suggested by the Collaborative. Major public data sources for the Auglaize River in Ohio included the Ohio Environmental Protection Agency (EPA), the Indiana Department of Environmental Management, the 2017 U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS), and the U.S. Geological Survey (USGS). Primary public sources for the Medway Creek watershed in Ontario included the Census of Agriculture from Statistics Canada and the Ontario Data Catalogue. For both watersheds, previous IJC reports served as additional initial sources of information. These previous studies included a detailed comparative analysis of fertilizer and manure management in the Lake Erie basin (see LimnoTech 2017, IJC 2018, and LimnoTech 2019). A separate 2019 report was specific to manure management and included subsequent engagement sessions (Great Lakes WQB, 2019; Great Lakes WQB, 2020).

Following this first step of data gathering, the contractor team identified important gaps in the information found. With these gaps in mind, the Collaborative suggested a variety of additional contacts. Identified groups and individuals included federal and state government agencies and non-governmental organizations (NGOs) as well as commodity groups. See Appendix B for a full list of individuals/organizations contacted. The individuals contacted in this group represented the final step of data gathering.

2.2 Mapping

In order to contextualize the findings from the project's data sources, a selection of maps was developed. This section will convey the list of maps developed and describe the underlying data and sources. Maps are included as figures throughout the report, as needed, and are also included as a group in Appendix C.

2.2.1 Maps created for the Auglaize River Watershed, Ohio, and Indiana

Auglaize River Watershed and Land Cover: The 2019 National Land Cover Database product was utilized to map land use within the Auglaize River watershed.

Auglaize River Watershed Tile Drainage: A 30-meter (m) resolution "most likely" tile-drained map was utilized (Valayamkunnath et al., 2020). This layer was developed from county-level tile drainage area (in hectares per county) from the 2017 USDA Census of Agriculture, the National Land Cover Database 2016 cropland mask (at 30-m resolution), the Shuttle Radar Topography Mission Digital Elevation Model derived slopes at 30-m resolution, and the spatial pattern of soil drainage characteristics from the Soil Survey Geographic Database (SSURGO) soils database at 30-m resolution. Actual tile drain locations are not known in the U.S. watersheds, so proxies such as these are the best alternatives.

Auglaize River Monitoring Stations: Data available from USGS online were utilized to map water quality monitoring stations present within the Auglaize River watershed.

Permitted confined animal feeding operation (CAFO) locations within the Auglaize River Watershed: A map of permitted CAFO locations was created for the Auglaize River watershed using facility address information from facility permit data. Address information for facilities in Ohio was extracted from factsheets provided by Ohio Department of Agriculture (ODA) for 34 permitted facilities within the watershed. As described earlier, the factsheets summarized data elements for each facility including the type of animal and count of permitted animals. Data for facilities in Indiana was obtained from a dataset of regulated CAFOs hosted by Indiana University Bloomington. Separate maps were developed showing permitted facility locations by animal type and by permitted animal counts (facility size).

Animal processing facilities/abattoirs: A list of USDA-inspected animal processing facilities was downloaded from the USDA Food Safety and Inspection Service (FSIS) website. Geographic Information System (GIS) information was available for these facilities, and they have been mapped. Additional lists of state-inspected facilities were obtained from Ohio and Indiana websites, but location data for these facilities were not available.

2.2.2 Maps created for the Medway Creek watershed, Ontario

Medway Creek Watershed and Land Cover: A map of land cover within the Medway Creek watershed was developed based on the 2015 Land Cover of Canada dataset. This dataset is generated by the Canada Centre for Remote Sensing and is available for download at the open.canada.ca website.

Medway Creek Watershed Tile Drainage: Data regarding the locations of drainage tiles installed by licensed agricultural drainage contractors are made available by the government of Ontario via the open.canada.ca website.

Risk of Water Contamination by Phosphorus, Annual, Agri-Environmental Indicator within Medway Creek Watershed: The Agri-Environmental Indicator Risk of Water Contamination by Phosphorus annual dataset estimates the relative risk of phosphorus from Soil Landscapes of Canada agricultural areas contaminating surface water for each year since 1981 to 2016. The dataset provides the relative risk of water contamination by phosphorous from Canadian agricultural land to surface water. It was used, for example, to evaluate and quantify the changes in risk of phosphorus loss over time, and the effectiveness of agricultural management practices that were put in place to reduce the risk of phosphorus contamination (Agriculture and Agri-Food Canada, 2022).

Risk of Phosphorus Movement to Edge of Field, Annual, Agri-Environmental Indicator within Medway Creek Watershed: The risk of phosphorus movement to edge of field provides the estimated risk of phosphorus loss within the landscape for Soil Landscapes of Canada agricultural areas, whether or not that phosphorus has a high probability of movement to surface water, reported for census years since 1981. The dataset provides the risk of phosphorus movement from agricultural land from all nonpoint sources, without considering the connectivity of those phosphorus losses to surface water. This is useful for assessing the potential future risk of down-slope movement of legacy phosphorus, which could guide the implementation of appropriate mitigation practices (Agriculture and Agri-Food Canada, 2022).

Annual P-Balance in Soil, Agri-Environmental Indicator within Medway Creek Watershed: The Agri-Environmental Indicator Annual P-Balance dataset provides an estimate of the annual change in soil P stores, calculated as phosphorus from fertilizer and manure application net of crop removal in Soil Landscapes of Canada polygons for census years since 1981. The dataset provides the relative amount of calculated change in soil P stores on Canadian agricultural land from anthropogenic activities (Agriculture and Agri-Food Canada, 2022).

Soil P-Source (Relative Risk of Phosphorus Release from Soil), Agri-Environmental Indicator within Medway Creek Watershed: The Soil P-Source dataset estimates the relative risk of phosphorus release from soils in Soil Landscapes of Canada for census years since 1981. The dataset provides the relative risk of phosphorus release from agricultural soils, which is useful for estimating the long-term impacts of phosphorus build-up in soils on future phosphorus release (Agriculture and Agri-Food Canada, 2022).

Active Barns within the Medway Creek Watershed: The contractor team reached out to Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA) to obtain information on the number and locations of animal feeding operations. In response, the Environmental Management Branch of OMAFRA provided a "Barn Identification Dataset." Per the data provider, the data includes the following, for all facilities identified using publicly available information (i.e., Google Maps):

- polygon areas of barns and structures;
- livestock type (simplified to Dairy, Beef, Hog, Broiler, Other);
- Active or Inactive status (i.e., does the barn appear to be currently in us);
- manure storage; and
- a unique identifier for each farm ("Farm ID").

Animal processing facilities/abattoirs: A list of provincially licensed animal processing facilities was downloaded from the Data Ontario website. However, GIS information was only available for a subset of these facilities; facilities in and around Medway Creek have been mapped.

Manure Application Sites: The contractor team was provided a dataset showing the location of 32 farm fields in the northern portion of the Medway Creek watershed where manure had been applied. The data provided included the application date and method, the type of manure, whether the manure was incorporated into soil, and the crops being grown.

2.2.3 Data Availability

In addition to the maps described above and presented throughout this report, certain maps could not be developed due to a lack of data availability. In some cases, the contractor team could not identify a source for the data; in other cases, potential data sources were identified but the data could not be obtained, as described below.

- Non-permitted animal feeding operations (Auglaize): No publicly available dataset could be identified. The Environmental Working Group (EWG), a non-profit organization, has carried out analyses of aerial imagery to identify non-permitted animal feeding operations (AFOs) in the Maumee River watershed. A data request was submitted to EWG, but a response could not be obtained in time.

- Soil phosphorus maps for the Auglaize: No publicly available dataset could be identified. Many agricultural laboratories carry out soil phosphorus tests, but the data are typically confidential and could not be obtained for use in this project. Publicly available soil P test data is presented in Chapter 3; however, it is generalized by geography and not available by field location.

- Location of manure application sites: Limited data is available to allow the mapping of manure application fields. The Upper Thames River Conservation Authority (UTRCA) provided a dataset of fields where manure was applied in a small area within the headwaters of Medway Creek; however, no data was available for the remaining portion of Medway Creek.

2.3 Data Evaluation and Recommendations

Several steps were taken to evaluate the data and develop recommendations. First, prior to the first step of information gathering, a comprehensive data matrix was developed that included each portion of data mentioned within the Statement of Work. This allowed for gaps in publicly available data to be readily identified following the first data sweep. This matrix was further filled in following the second information step of contacting agencies and individuals (as listed in Appendix B). This product is available in its entirety in Appendix D.

Following the completion of these steps, the matrix was then reviewed for remaining gaps. The contractor team evaluated whether the data available filled each row within the table to a “high”, “medium”, or “low” degree. The result of this evaluation is included within this report as Table 4-1. Final recommendations were created with these ratings in mind. Areas where data availability was remarked to be “low” were identified as gaps, and the final recommendations include suggestions tailored to these identified data gaps.

3. Data and Information Identified

This section summarizes the information collected under Task 1 and presents key maps developed under Task 2.

3.1 Watershed Features

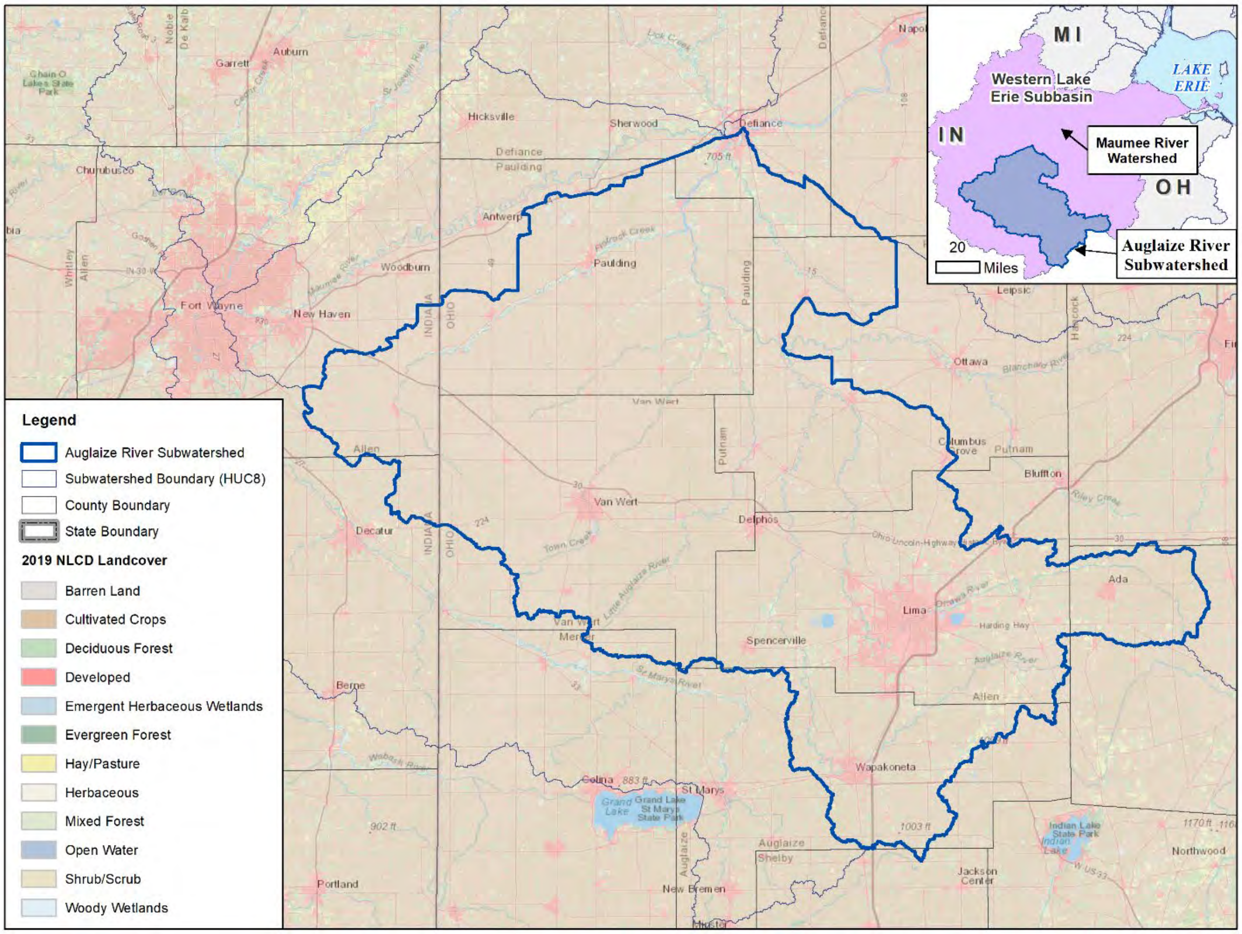
Section 3.1 provides a description of the physical features and land use in each watershed.

Auglaize River

The Auglaize River watershed is located mainly in northwestern Ohio with a small area extending into Indiana. It is part of the larger Maumee River watershed draining into the Western Basin of Lake Erie (Figure 3-1). It is one Hydrological Unit Code (HUC)-08 (04100007) of the seven that comprise the entire Maumee River Watershed. With its headwaters in southeastern Allen County, Ohio, it travels approximately 102 miles before joining with the Maumee River at its confluence in Defiance, Ohio (Civil & Environmental Consultants, Inc., 2020). Major tributaries include the Blanchard River (another of the seven HUC-08 watersheds belonging to the Maumee River watershed) and the Ottawa River. The watershed area includes portions of Defiance, Paulding, Putnam, Van Wert, Allen, Auglaize, and Hardin Counties in Ohio, and Allen and Adams Counties in Indiana. The watershed covers an area of over 1,660 square miles.

The Auglaize River watershed is relatively flat with the majority of the watershed having less than a 2 percent slope and is largely agricultural with only 14 percent of the area dedicated to non-agricultural uses (Western Lake Erie Basin Partnership, n.d.). Within the Upper Auglaize watershed, approximately 89 percent of the land is used for cropland and pasture (Ohio EPA, 2004), while the Lower Auglaize is approximately 84 percent agricultural (Ohio EPA, 2014) (see Figure 3-1). The major Level-III ecoregions are the Huron-Erie Lake Plains ecoregion, which is typified as being broad, flat, and fertile, and the Eastern Corn Belt Plain. Soil drainage within the Huron-Erie Lake Plains ecoregion is generally poorer in comparison to the neighboring Eastern Corn Belt Plain ecoregion (USGS, 2015). Fertile and often fine-grained soils such as the Blount, Roselms, Paulding, Latty, Hoytville, Fulton, Pewamo, Glynwood, and other similar groups are found here (Ohio EPA, 2004 & Ohio EPA, 2014).

Total annual precipitation in northwest Ohio is approximately 33 inches (Tetra Tech, Inc., 2012). Over time, rainfall has been increasing across the watershed in annual amount and in intensity. From 1975 to 2017, researchers found that average annual total rainfall increased by approximately 4 inches within the Maumee River Watershed, which includes the Auglaize Watershed (Williams & King, 2020). The researchers also noted an increase in the discharge to rainfall ratio for most watersheds studied, especially since 2002, which may be related to the expanding use of drain tiles. Further, the study noted a correlation between trends in discharge volumes and dissolved reactive phosphorus (DRP) loading and concentrations.



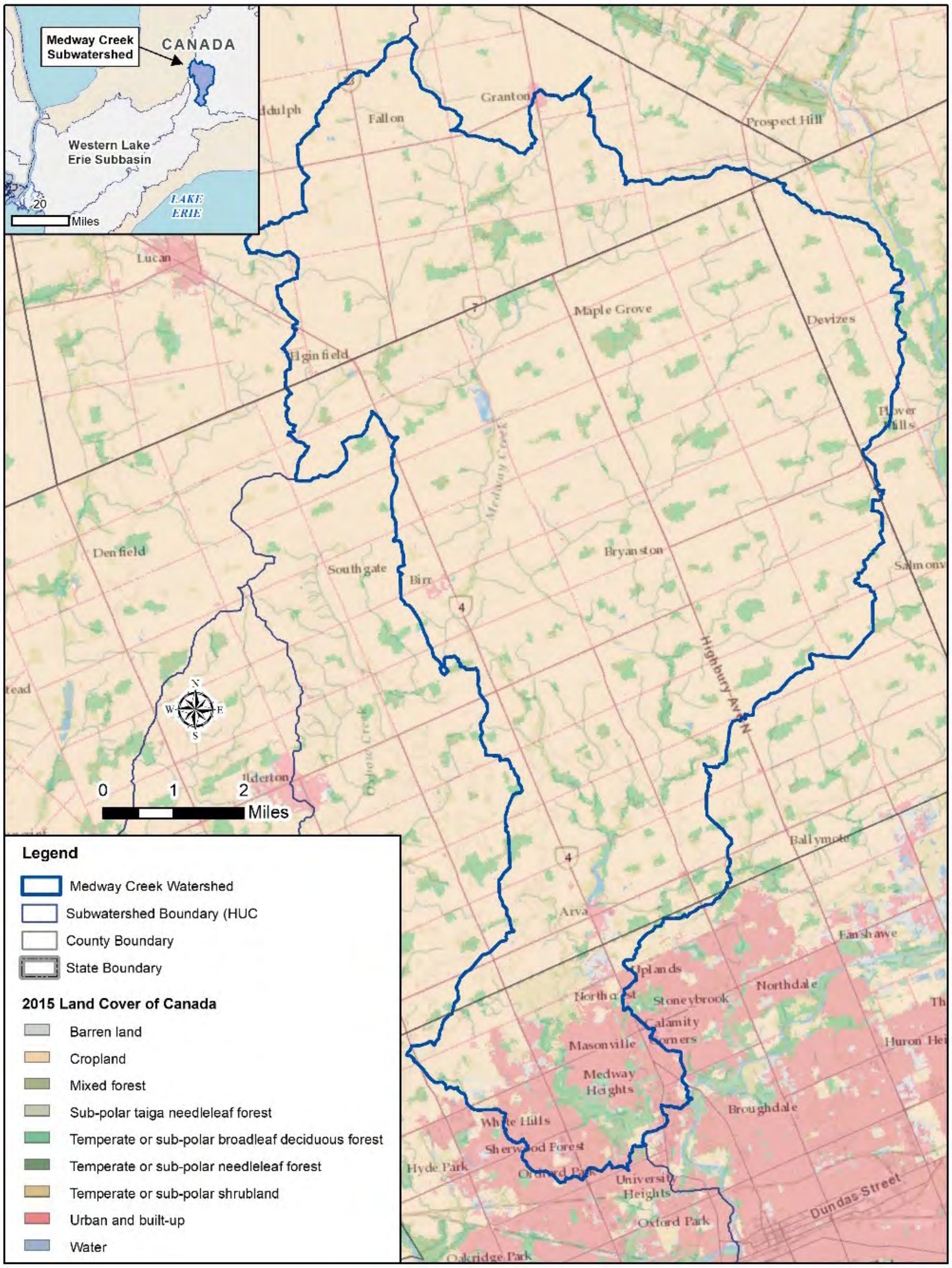
Source: USGS 2019 National Land Cover Database, https://www.mrlc.gov/

Figure 3-2 Land Cover within the Auglaize River Watershed

Medway Creek

Medway Creek watershed is a sub-watershed of the Thames River in Ontario, Canada (Figure 3-2). The headwaters are located around Granton in the Township of Lucan Biddulph, and the creek flows approximately 133 miles before meeting with the North Thames River in London, Ontario. The Thames River drains through the province of Ontario before emptying into Lake St. Clair. Medway Creek watershed municipalities include Middlesex Centre, Lucan Biddulph, City of London, and Thames Centre. This watershed is significantly smaller than the Auglaize at approximately 79 square miles in size (less than 5 percent of the Auglaize area; Upper Thames River Conservation Authority, 2017).

Like the Auglaize, the Medway Creek watershed is highly agricultural with an estimated 82 percent of the landscape utilized for agricultural purposes and with less than 10 percent of the land use classified as urban (Figure 3-2). In general, the Medway Creek watershed can be described as relatively flat to gently rolling. Over 60 percent of the watershed is represented by clay loam and silty loam soils. Portions of the watercourse are intermittent, with slightly less than 60 percent having permanent flow (Upper Thames River Conservation Authority, 2017).



Source: 2015 Land Cover of Canada, https://open.canada.ca/data/en/dataset/4e615eae-b90c-420b-adee-2ca35896caf6

Figure 3-2 Land Cover within the Medway Creek Watershed

3.2 Subsurface Artificial Drainage and Trends

Subsurface artificial drains, also known as tile drains, are a crucial component of agricultural production in poorly drained soils, which are commonly present in the Midwestern U.S. and southern Ontario. Tile drains are utilized to lower the water table and drain excess field water following periods of heavy precipitation. This action allows producers to maintain field access and improves plant survival through increased root aeration. Generally, agricultural fields gain subsurface drainage through the installation of field tile, a perforated type of tubing made primarily of high-density polyethylene (HDPE) which generally range in diameter from 3 to 6 inches (76 to 152 millimeters). Historically, before the advent of HDPE drainage tubing, tile drains consisted of fired clay pipes or arched segments. Tile drain lines are laid in either a systematic pattern over the whole field or applied just to certain wet spots within the field. Tile drain lines may drain to either another larger tile called a 'main' or to a surface drainage ditch at the field edge.

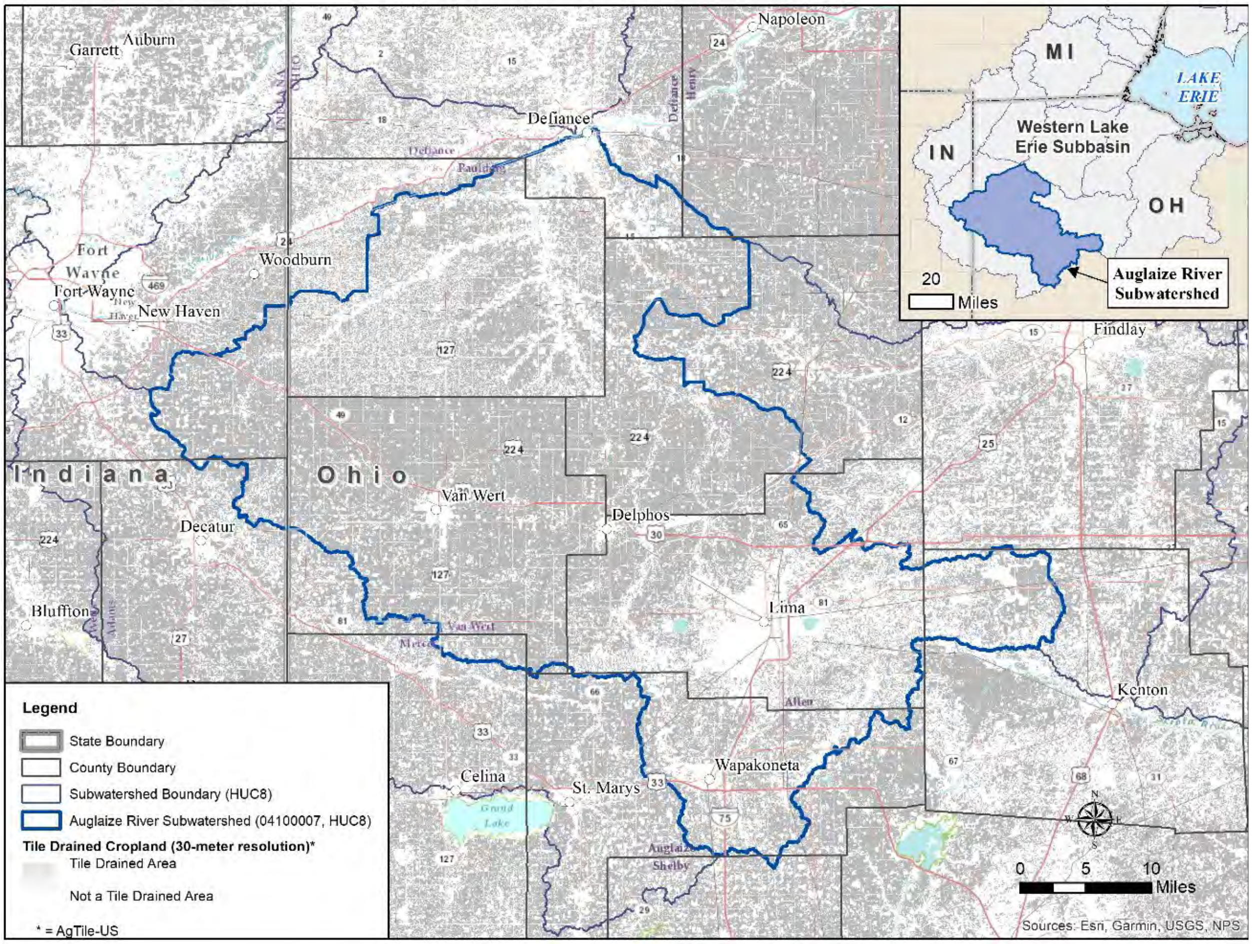
Tile drains can carry a substantial amount of flow from flat or nearly flat fields, such as those that are common in much of the Western Lake Erie Basin. During a review of tile drainage literature in support of an Indiana Soil and Water Assessment Tool (SWAT) modeling study, Boles et al. (2015) found that average tile flow amounted to 23.2 percent of annual precipitation on tile-drained fields. Jarvie et al. (2017) studied the effect of tile drainage on P loading in the Western Lake Erie basin and found that increased subsurface drainage likely contributed to increased DRP loads in the Western Lake Erie Basin, along with increased use of no-till, conservation growing practices. Miller and Lyon (2021) found that the presence of tile drainage contributed to a slight increase in P loadings in wet years. Similarly, Tan and Zhang (2011) found that subsurface tile drainage played a predominant role in soil P loss in southern Ontario.

Note that other subsurface features such as abandoned tile drains, pipelines, wells, utility trench backfill, leach fields, and buried paleochannels can also serve as preferential flow pathways, linking nutrients from surface-applied manure to waterways.

Auglaize River

In the U.S., drainage tiles are typically installed at depths of 3 to 4 feet in the soil profile for soils with moderately low to very low subsoil permeability and are spaced 35 to 130 feet apart (Wright and Sands, 2001). In the cool, shallower soils of Canada, tiles are commonly placed at depths of 2 to 3 feet and spaced 25 to 60 feet apart (OMAFRA, 2007). Newer tile drains are often placed systematically under entire fields, while older tile drains often were placed in patterns that were more random and coincided with areas that were especially poorly drained.

Few data exist that quantify actual trends in tile drainage in the midwestern U.S. Anecdotal evidence suggests that tiling has increased in the recent decade, both in acres tiled and in the relative efficiency of the installed systems. A 30-m resolution "most likely" tile-drained map indicates that the vast majority of the agricultural landscape in the Auglaize River watershed is likely to contain subsurface tile drainage (Valayamkunnath et al., 2020) (Figure 3-3).

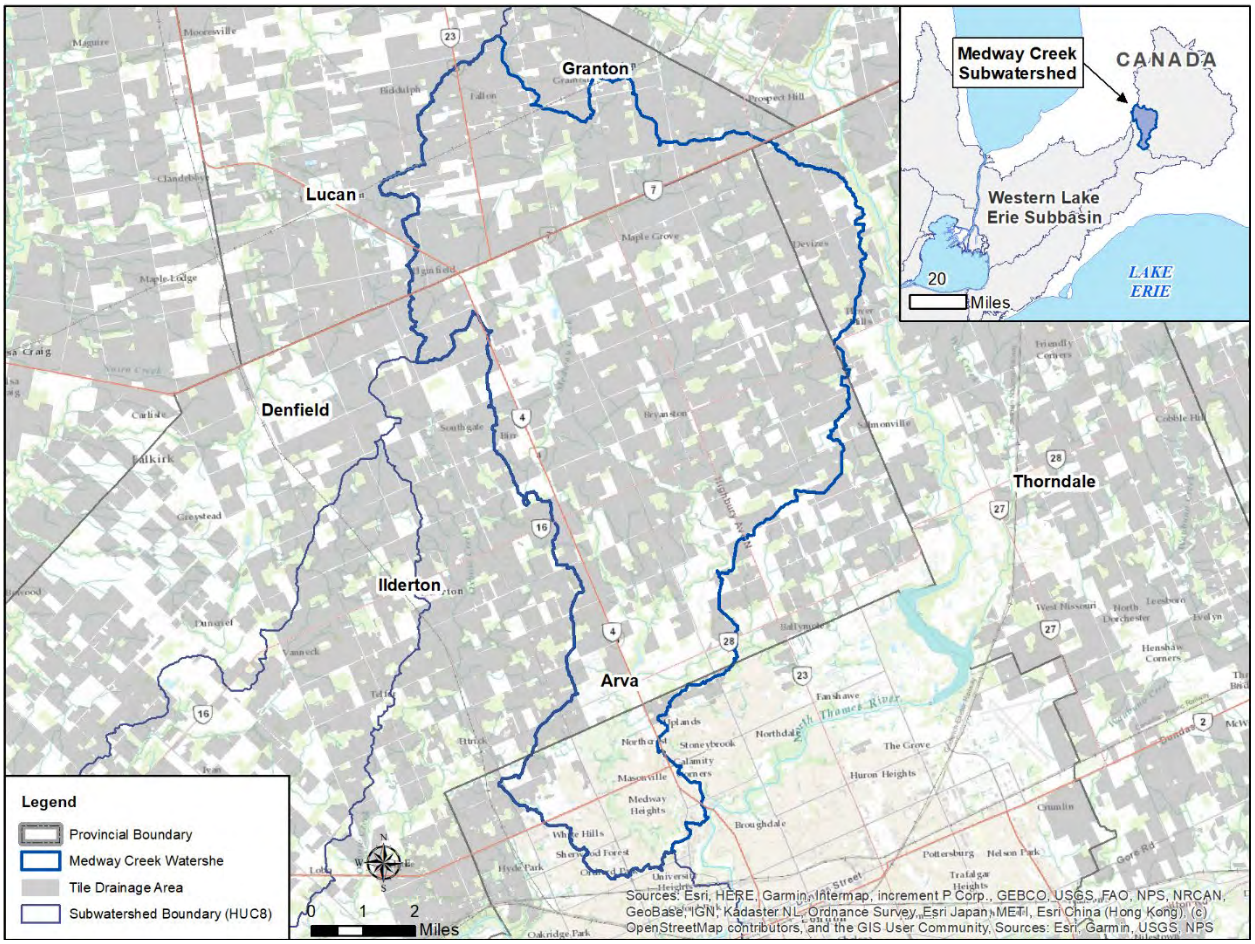


Source: Valayamkunnath et al., 2020

Figure 3-3 Auglaize River Watershed Areas Most-Likely Tile Drained

Medway Creek

Land Information Ontario collects field level data about tile drains for the purpose of determining whether the field is drained in a random or systematic pattern. Figure 3-4 shows tile-drained fields in the Medway Creek watershed. As with the Auglaize River watershed, a significant portion of the Medway Creek watershed is shown to have tile drains.



Source: Land Information Ontario, https://geohub.lio.gov.on.ca/datasets/31e41d9e9dbd4f59a995a89e1fd1e5b5/about

Figure 3-4 Medway Creek Watershed Tile Drainage

3.3 Water Quality Attainment Status

This section briefly summarizes the mechanism for managing water quality in the Auglaize River and Medway Creek watersheds. Section 3.4 summarizes available water quality data for the two watersheds, with respect to nutrient concentrations and loads.

Auglaize River Watershed:

Section 303(d) of the 1972 Clean Water Act (CWA) requires states to list and prioritize waters that are failing to meet water quality standards (i.e., are “impaired”). While much of the Auglaize River watershed is currently in attainment with water quality standards, certain sections do not meet these criteria and are considered impaired. Ohio EPA lists mainstem and tributary segments of the Upper Auglaize and Lower Auglaize watersheds are currently included on Ohio’s 303(d) list of impaired waters. Additionally, several tributary segments of the Auglaize River basin within Indiana are included on Indiana Department of Environmental Management (IDEM) 303(d) list of impaired waters.

In 2004, as part of a total maximum daily load (TMDL) determination, removal or reduction of significant sources of nutrient enrichment and/or bacteria was determined to be necessary to restore designated uses in some stream segments into full attainment of the designated uses. The parameters selected for TMDL development were habitat (flow and sedimentation), dissolved oxygen (DO), total phosphorus (TP), ammonia, and bacteria. In addition to the Upper Auglaize aquatic life impairment, the Lower Auglaize River TMDL project is addressing recreational impairment due to bacteria and nitrate public water supply impairment for the city of Delphos (no TMDL established yet, but 2014 assessment complete).

The University of Maryland Center for Environmental Science prepared a scorecard for the entire Western Lake Erie Basin, with grades assigned to HUC-8 watersheds based on performance across a range of indicators (UMD CES 2020). The indicators were grouped into three categories, including water quality, biology, and toxics. The water quality group included indicators for total and dissolved phosphorus, which received poor and very poor scores respectively. The Maumee region of the Basin received very poor scores for both. Indicators for total and dissolved P were based on the number of samples exceeding the U.S. Environmental Protection Agency (USEPA) ecoregion threshold of 0.076 milligrams per liter (mg/L) (for total P) and a threshold of 0.02 mg/L for dissolved P.

The Maumee Watershed Nutrient TMDL project is addressing harmful algal blooms linked to Maumee River nutrient loading in the Western Basin of Lake Erie, which impact recreation and source water for drinking water use. The Ohio EPA released the draft Maumee River Watershed Nutrient Water Quality Improvement Plan in December 2022 (Ohio EPA, 2022a). The draft management plan includes an extensive review of nutrient sources and trends.

Annex 4 of the Great Lakes Water Quality Agreement (GLWQA) establishes a set of commitments, as part of which the U.S. and Canada agreed to develop objectives and develop and implement strategies to reduce phosphorus loading in Lake Erie. As part of this Annex, both countries agreed to take steps to achieve a 40 percent reduction in total phosphorus load entering the Western and Central Basins of Lake Erie; further, the U.S. has a goal of reducing spring total and reactive phosphorus loads from the Maumee River by 40 percent.

As part of U.S. actions to reduce nutrient loading in Lake Erie, Ohio and Indiana have prepared Domestic Action Plans (DAP). Ohio's DAP was prepared in 2018 and updated in 2020. The Ohio DAP outlines strategies and actions to reduce in P load. These include agricultural strategies related to improving nutrient management, erosion management, and water management. The Ohio DAP also includes an assessment of the contributions of each HUC-12 sub-watershed to springtime total P loads in the Maumee River (see Figure 3-5). According to this analysis, several Auglaize River sub-watersheds are among the higher contributors to total P loads within the Maumee River basin.

Similar to Ohio, the Indiana DAP, published in 2018, outlines that state's strategies to reduce P runoff. Appendix 2 of the DAP includes data on water quality and monitoring locations. The DAP identifies a number of priority sub-watersheds, with the majority lying within the St. Mary's River watershed, followed by the St. Joseph and Upper Maumee Watersheds. The Indiana portion of the Auglaize River watershed is not identified as a priority region for nutrient load reduction.

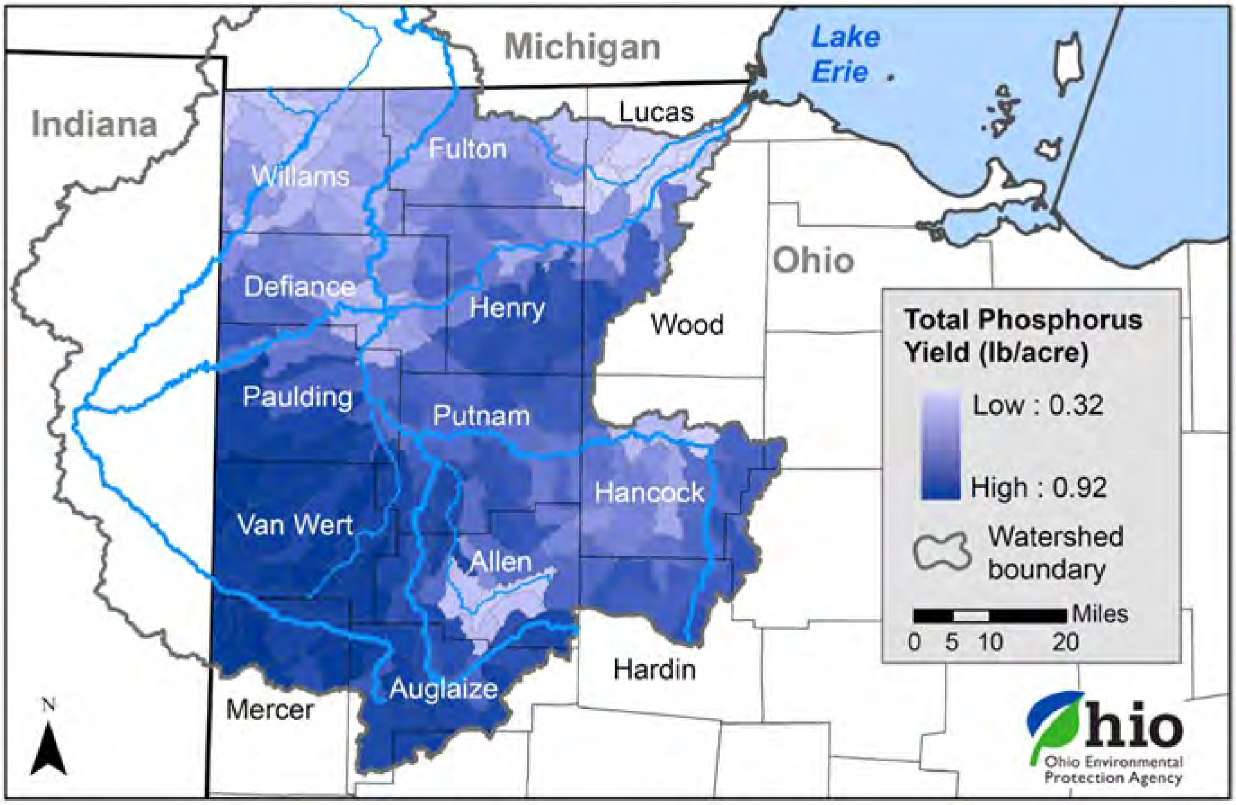


Figure 3-5. Estimated Total P yields by HUC-12 Sub-watershed (Source: Ohio DAP 2020)

Medway Creek Watershed

Canada and the province of Ontario have been working jointly for many years to address Great Lakes water quality in general, and Lake Erie algal blooms in particular. Under Annex 1 (Nutrients) of the 2021 Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health the jurisdictions committed to the following under Result 1(g): "Support the development by 2022 and implementation of phosphorus management plans for Lake Erie priority watersheds, including the Thames River…" In addition, under Result 2(b): "Establish additional tributary loading targets for Lake Erie, if required." Ontario manages watersheds under the Conservation Authorities Act of 1990, which was most recently amended in 2021.

In 2018, Environment and Climate Change Canada (ECCC) and Ontario's Ministry of Environment, Conservation and Parks (MECP; formerly the Ministry of Environment and Climate Change) released the Canada-Ontario Lake Erie Action Plan (ECCC & Ontario Ministry of the Environment, 2018). The plan outlines strategies to reduce P load to Lake Erie from a variety of sources and sectors, including agriculture. Recommended strategies for agriculture include 4R practices and drainage management.

As discussed above, the University of Maryland Center for Environmental Science prepared a scorecard for the entire Western Lake Erie Basin (UMD CES, 2020). The Northwest region of the basin, which includes the portion of the lake receiving inflow from Lake St. Clair, received a poor score on total P and a moderate score on dissolved P.

Medway Creek falls under the responsibility of the UTRCA. The UTRCA issues report cards every 5 years on its 28 sub-watersheds, including Medway Creek's most recent one (UTRCA, 2022). The 2022 letter grade for surface water quality in the watershed was "C", with phosphorus, bacteria, and benthic organism values exceeding provincial guidelines. Phosphorus concentrations have improved since monitoring began in 1996. The UTRCA has set a goal of achieving a B letter grade for water quality in the Medway Creek sub-watershed by 2037. As part of the Thames River watershed, a priority Canadian watershed, Medway Creek improvements would contribute to the overall federal target goal of reducing phosphorus loading to Lake Erie by 40 percent by 2025 under the Canada-Ontario Lake Erie Action Plan (ECCC & Ontario Ministry of the Environment, 2018) and the Lake Erie Binational Phosphorus Reduction Strategy (MECP, 2019).

Since 1997, benthic samples have been collected by the UTRCA within the Medway Creek Watershed (Medway Creek Community-based Enhancement Strategy). Within the watershed, the results of this sampling have been found to range from very poor to good habitat conditions and water quality. Within watersheds that contain both intense agricultural land uses and urban/industrial areas, these results are fairly typical.

3.4 Water Quality Monitoring and Nutrient Loads

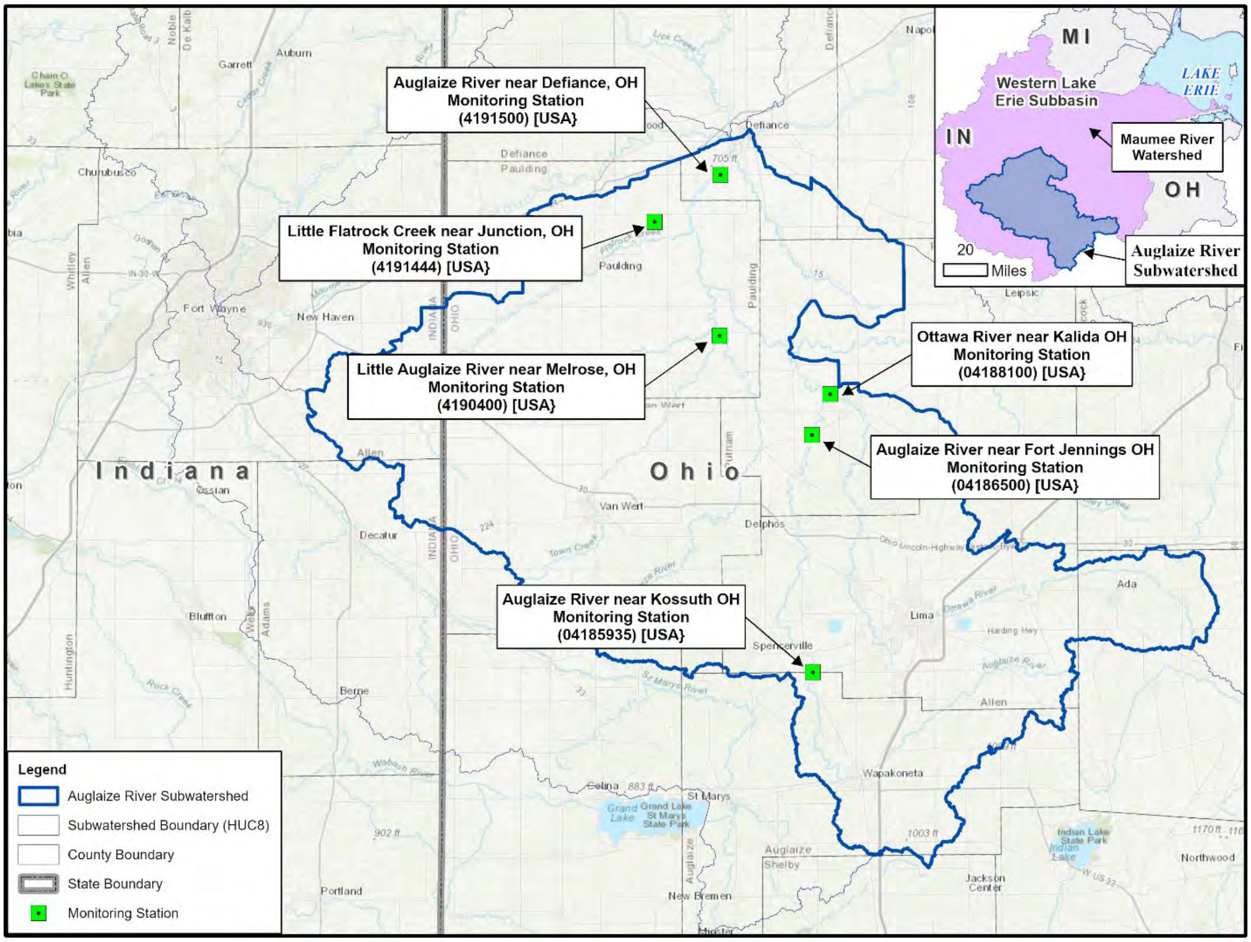
Auglaize River Watershed

There are two organizations primarily involved with tributary nutrient load monitoring in the state of Ohio: the National Center for Water Quality Research at Heidelberg University (NCWQR) and the USGS's Ohio-Kentucky-Indiana Water Science Center. The USGS, over time, established a stream gage network with the intention of supporting research and other hydrologic information goals. Heidelberg University established (and continues to maintain) a tributary monitoring program at mainstem and small tributary sites to supplement the USGS's network.

In the Ohio portion of HUC-04100007, the Auglaize River, there are six tributary load monitoring stations as of November 2020, all maintained by USGS, which report daily stream flow and nutrient concentration data (OH-LEC, 2020) (Figure 3-6):

- 04185935 - (Upper) Auglaize River near Kossuth, OH
- 04186500 - Auglaize River near Fort Jennings, OH
- 04188100 - Ottawa River near Kalida, OH
- 04191058 - Little Auglaize River at Melrose, OH
- 04191444 - Little Flatrock Creek near Junction, OH
- 04191500 - Auglaize River near Defiance, OH

In addition, there is one monitoring location within the Indiana portion of the Auglaize River watershed, located along Flatrock Creek in Allen County near the Indiana-Ohio state line (Allen SWCD site 401). Data for this site can be accessed via the Water Quality Information System maintained by the City of Ft. Wayne, Indiana.



Source: USGS National Water Dashboard, https://dashboard.waterdata.usgs.gov/app/nwd/en/?region=lower48&aoi=default

Figure 3-6 Auglaize River Monitoring Stations

Flow-weighted mean concentration (FWMC) goals have been established to help track progress on nutrient reduction efforts (OH-LEC, 2020). Compared to nutrient loads, which are influenced by streamflow, FWMCs provide a measure of nutrient contribution that is more independent of basin size and flow conditions. Using FWMCs helps with making comparisons between periods with differing flow conditions. The GLWQA Annex 4 goals for FWMC are 0.23 mg/L for total P and 0.05 mg/L for DRP. Note that these goals were established for the Maumee River at Waterville, OH. While not directly applicable to upstream portions of the Maumee watershed, they still provide a useful benchmark to understand the contribution of individual sub-watersheds to overall P loads.

Spring loads and flow-weighted mean concentrations were tabulated for two Auglaize River sites for 2019 in the Ohio Lake Erie Commission 2020 report (OH-LEC, 2020). Results from these sites are included here as an example of spring loading conditions observed along the Auglaize River (Figure 3-7; Tables 3-1 and 3-2).

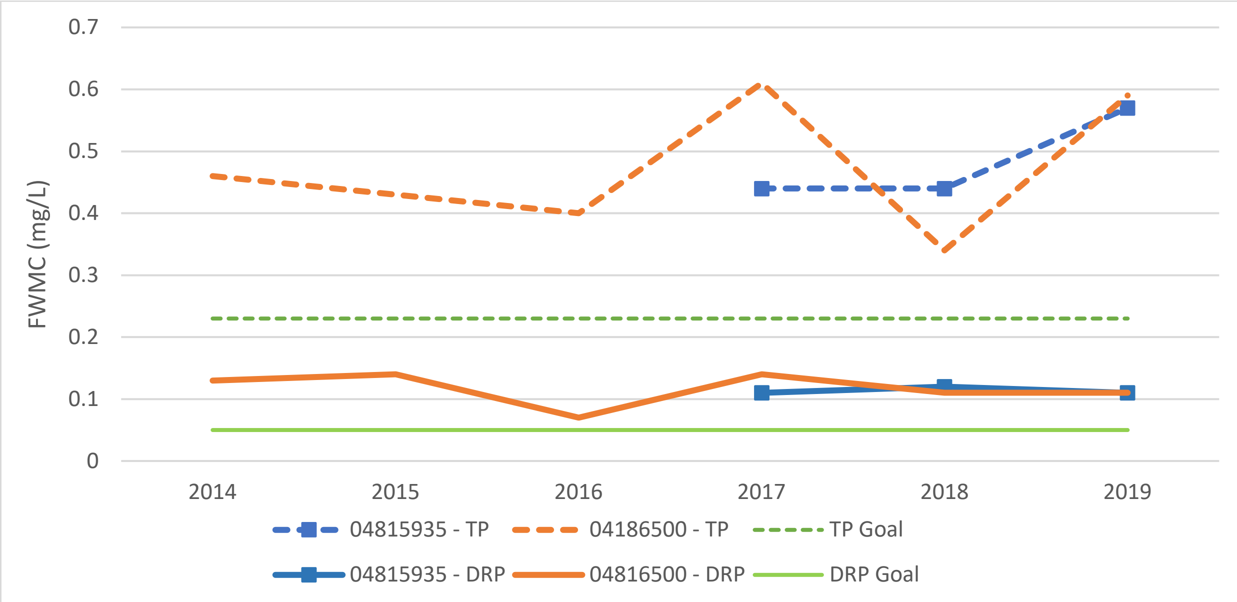


Figure 3-7 Spring Total P and DRP FWMC Values for Two Sites in the Auglaize River Watershed, Ohio (04815935 – Auglaize R. near Kossuth, 04816500 – Auglaize R. near Ft. Jennings)

Table 3-1 Spring FWMC (mg/L) for USGS Monitoring Sites in the Auglaize River Watershed

Site	Pollutant	2014	2015	2016	2017	2018	2019
04185935 - (Upper) Auglaize River near Kossuth, OH	Total Phosphorus	--	--	--	0.44	0.44	0.57
	Dissolved Reactive Phosphorus	--	--	--	0.11	0.12	0.11
	Nitrate + Nitrite	--	--	--	6.96	5.24	2.73
04186500 - Auglaize River near Fort Jennings, OH	Total Phosphorus	0.46	0.43	0.40	0.61	0.34	0.59
	Dissolved Reactive Phosphorus	0.13	0.14	0.07	0.14	0.11	0.11
	Nitrate + Nitrite	7.05	4.76	5.96	6.27	7.09	3.17

Table 3-2 Nutrient Loads (metric tons) for USGS Monitoring Sites in the Auglaize River Watershed

Site	Pollutant	2014	2015	2016	2017	2018	2019
04185935 - (Upper) Auglaize River near Kossuth, OH	Total Phosphorus	--	--	--	64.6	42.9	109
	Dissolved Reactive Phosphorus	--	--	--	16.3	12.1	20.4
	Nitrate + Nitrite	--	--	--	1,030	508	518
04186500 - Auglaize River near Fort Jennings, OH	Total Phosphorus	73.8	173	47.6	156	51.6	192
	Dissolved Reactive Phosphorus	20.5	55.3	8.69	35.1	16.3	36.7
	Nitrate + Nitrite	1,130	1,900	703	1,610	1,070	1,020

In addition, weekly monitoring data from a site in Allen County, Indiana (Allen SWCD Site 401, Flatrock Creek/Auglaize River) are available from the City of Ft. Wayne's Water Quality Information System (Figure 3-8). Note that these data were provided as individual sample results rather than FWMC values and cannot be used to estimate P loads or compared directly to GLWQA Annex 4 goals. The data also exhibit significant variability, especially for DRP, which exceeded 1 mg/L on several occasions in 2019 and 2020, and even exceeded Total P during this time frame. Total P trends were more consistent, with peaks occurring during the late spring and summer in most years. Note that Figure 3-8 does not show DRP, given the inconsistency in those data.

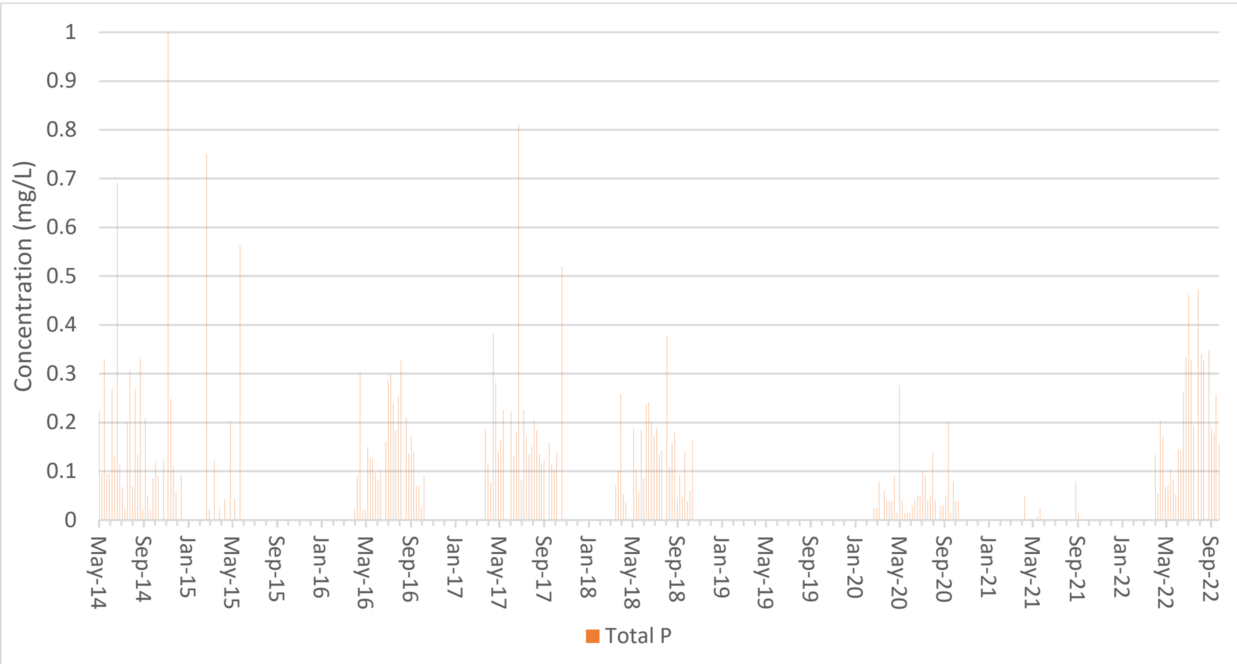
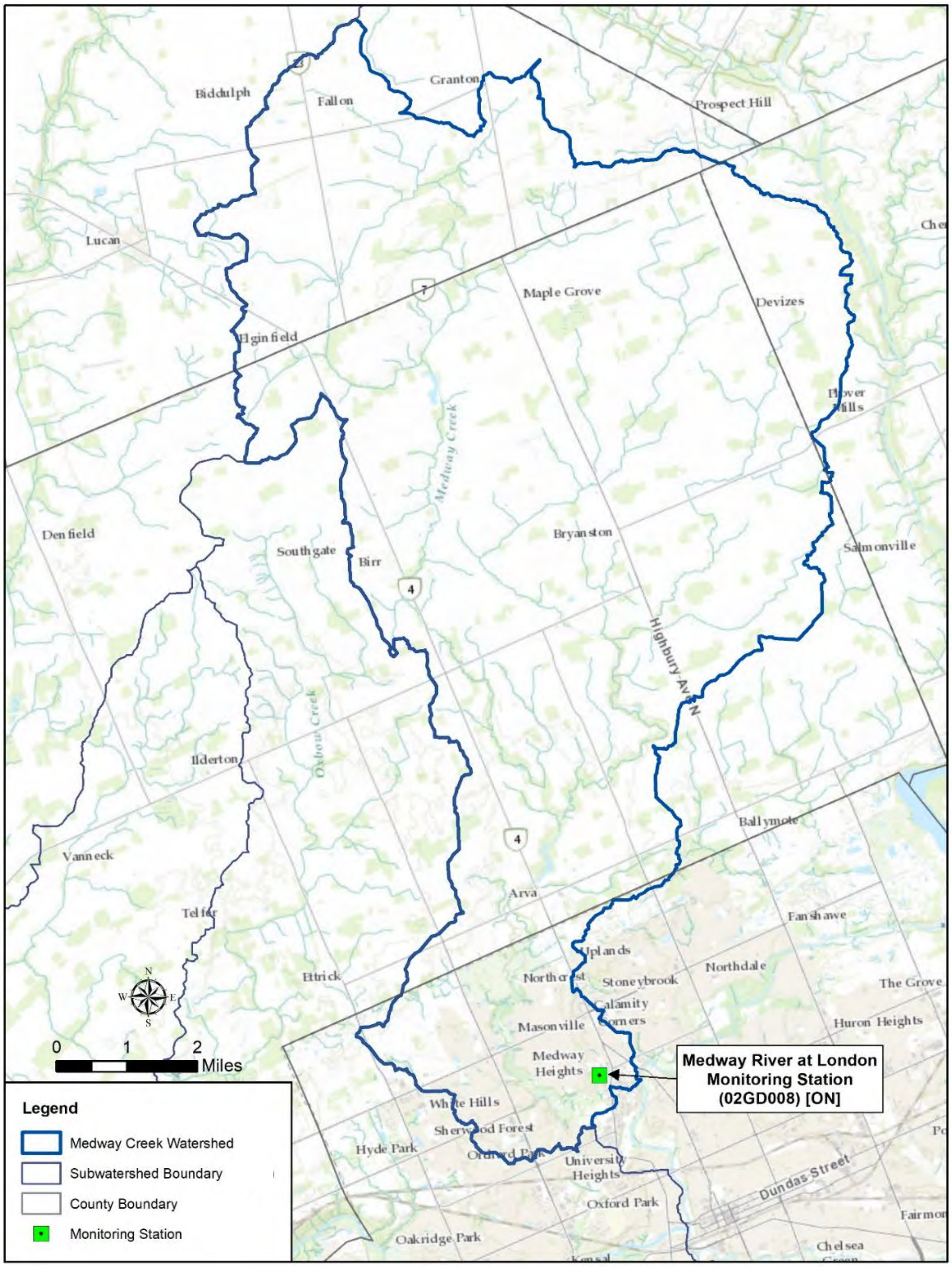


Figure 3-8 Total P Concentration, Flatrock Creek Monitoring Station, Indiana

Medway Creek

Real-time hydrometric data is available from the Water Office of the Government of Canada for a station located on Medway Creek at London (*station: MEDWAY RIVER AT LONDON (02GD008) [ON]*) (Figure 3-9). The province of Ontario also maintains a network of stream monitoring stations. There is a station on Medway Creek at the City of London (04001311202, Glenmore Dr at Windermere), but it is currently inactive; the last reported data for this station are from 2012.

To obtain information about surface water quality, the City of London has been sampling the creek at the Western Road bridge upstream of the confluence with the North Thames River once per month since 1978 (Medway Creek Community-based Enhancement Strategy). The samples are analyzed for 12 water chemistry parameters by the city's Greenway Pollution Control Centre Laboratory: temperature, DO (in mg/L and percent saturation), pH, total coliforms, E. coli, total phosphorus, total ammonia, nitrate, nitrite, conductivity, suspended solids, and chloride. However, these monitoring data were not available for inclusion in this report.



Source: Government of Canada, https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=02GD008

Figure 3-9 Medway River at London Monitoring Station

Every five years, UTRCA publishes a scorecard evaluating water quality and watershed health for each sub-watershed within the Upper Thames River watershed. The last scorecard for Medway Creek was completed in 2022, including an assessment of P loads (UTRCA 2022). The assessment shows a significant decrease in total P concentrations, based on City of London monitoring data, but total P concentrations were still higher than the provincial guidelines for aquatic life, as of the last assessment period (2016-2020) (Figure 3-10).

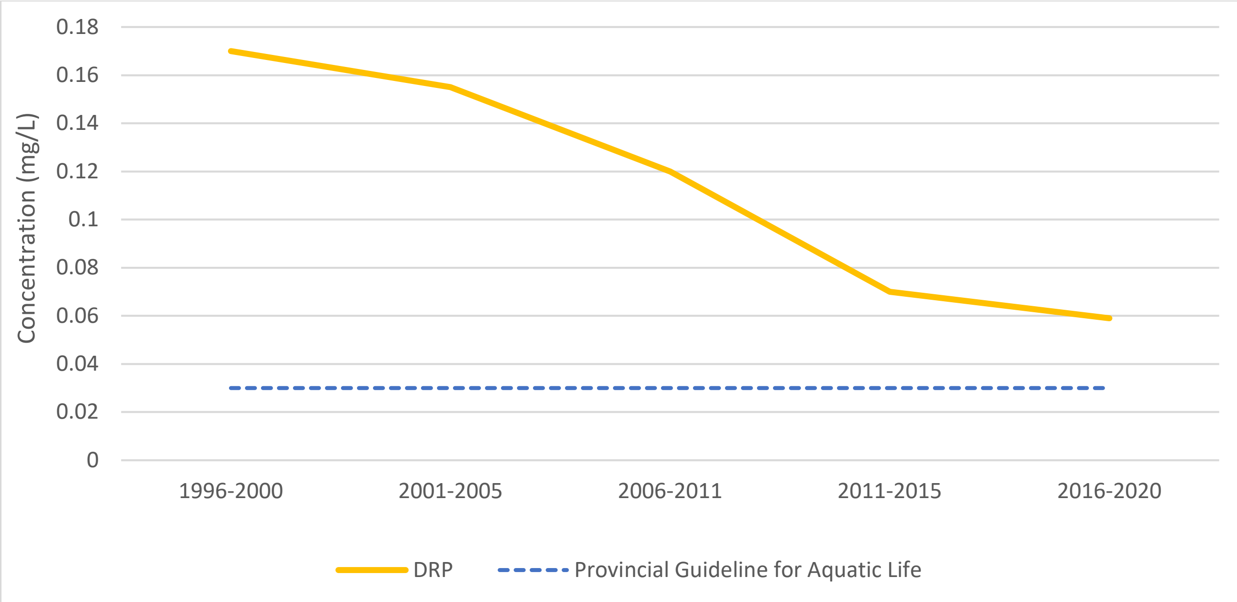


Figure 3-10 Total P Concentration, Medway Creek at London Monitoring Station

Another assessment of water quality and nutrient and sediment loading in the Thames River was completed for the UTRCA in 2015 (Freshwater Research, 2015). The assessment also reviewed monitoring data from City of London, as well as other monitoring locations along the Thames River. The study analyzed data from 1986 to 2012, and found that FWMC total P was significantly higher in Medway Creek compared to the next upstream station on the Thames River main stem (Clarke). The study estimated that the Medway Creek adds approximately 17 percent to the TP load estimated for the Clarke station.

The study did not present trends in P loading for Medway Creek but did provide total P and DRP FWMC data for stations upstream and downstream of the confluence of North Thames River and Medway Creek (Figures 3-11 and 3-12). Note that these monitoring stations are located outside the Medway Creek watershed. FWMC data for total P for upstream stations (223.1 – North Thames River and 313.3 – South Thames River) are lower than the first downstream station (202.2 – Byron), which also suggests that Medway Creek contributed significantly to the TP load in this segment of Thames River over the period studied.

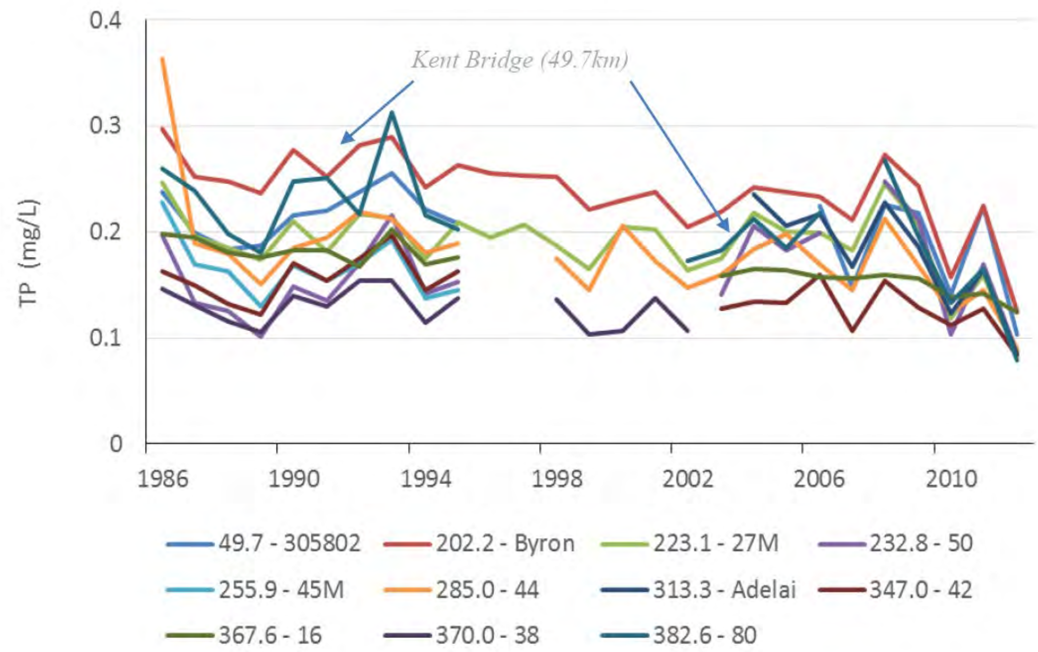


Figure 3-11 FWMC data for Total P, at monitoring stations along the Thames River *(reproduced from Freshwater Associates 2015)*

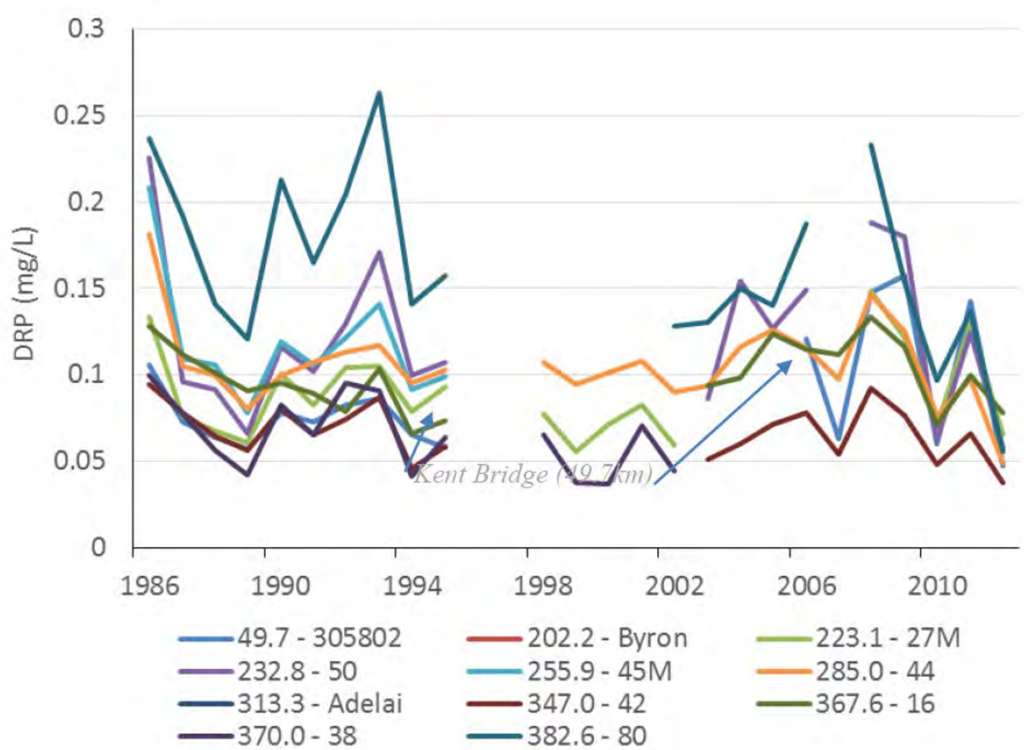


Figure 3-12 FWMC data for DRP, at monitoring stations along the Thames River *(reproduced from Freshwater Associates 2015)*

3.5 Manure/Nutrient Inputs

This section presents a summary of information related to manure generation, application, and likely phosphorus loading to waterbodies from manure application.

3.5.1 Permitted AFO Locations

Auglaize River

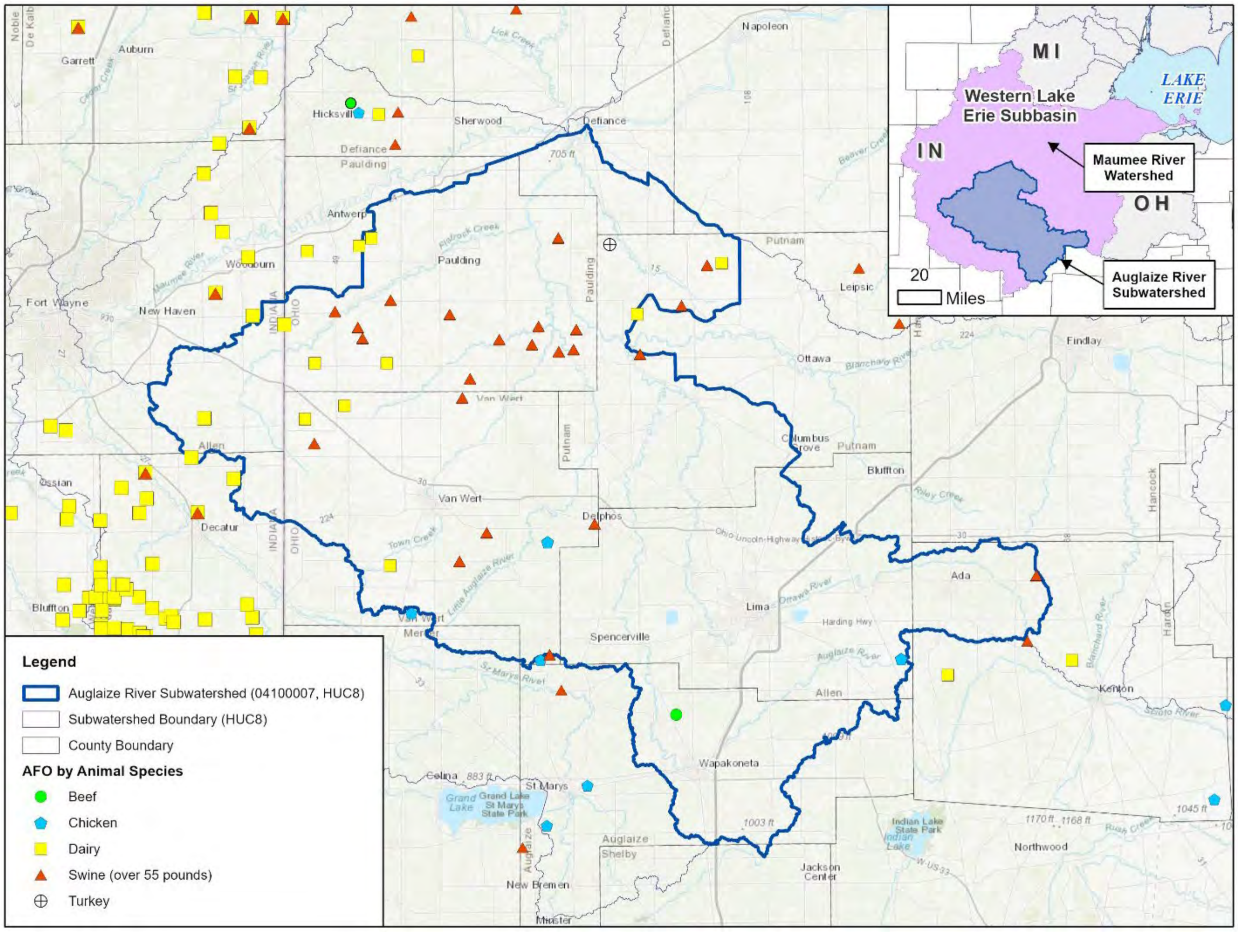
For the Auglaize River watershed, a request was submitted to the ODA for all operating Concentrated Animal Feeding Facility (CAFFs) within the Ohio counties of Defiance, Paulding, Putnam, Van Wert, Allen, Auglaize, and Hardin. Information sheets were returned for 59 facilities within these counties. Of these, 34 were located within the boundaries of the Auglaize River watershed (Figure 3-10). These facilities were comprised of the following:

- 8 facilities noted as “dairy”
- 1 facility noted as “beef”
- 0 facilities noted as “chicken-pullets”
- 3 facilities noted as “chickens-layers”
- 21 facilities noted as “swine-over 55 pounds (lbs)”
- 1 facility noted as “turkey”

In Indiana, the locations of both “confined feeding operations” and CAFOs are publicly available[1]. Data are current as of April of 2020. These data are provided as an ESRI shape file and display swine, chicken, turkey, beef, or dairy agribusinesses that exceed state permitting thresholds.

Figure 3-13 shows permitted CAFFs within the Auglaize River watershed by size classification based on animal counts.

[1] https://maps.indiana.edu/previewMaps/Environment/Agribusiness_Confined_Feeding_Operations.html



Source: Ohio Department of Agriculture. Indiana University, https://maps.indiana.edu/layerGallery.html?category=Agribusiness.

Figure 3-13 Permitted CAFFs and CAFOs within the Auglaize River Watershed

Medway Creek

For the Medway Creek watershed, all AFOs are discussed in Section 3.5.3, "Non-permitted Animal Feeding Operations." This is because Ontario does not issue permits to AFOs, although all but the smallest AFOs are subject to some level of regulation.

3.5.2 Animal Counts in Permitted AFOs

Auglaize River

For Ohio, animal counts for permitted facilities were taken directly from the facility fact sheets provided by ODA. The facility data received by the contractor team included a summary fact sheet for each facility; therefore, the request did not provide sufficient information to evaluate a change in animal counts by year.

For Indiana, permitted animal counts were taken from 2020 facility data downloaded from Indiana University's website.

Permitted animal counts for Ohio and Indiana are shown in Table 3-3.

Table 3-3 Total animal counts within permitted facilities

Animal Species	Animal Counts - Ohio	Animal Counts – Indiana
Beef	2,058	110
Chickens-Layers	2,851,904	--
Dairy	19,784	380
Swine - over 55 lbs.	154,329	2,800
Turkey	74,000	--

Subsequently, a second request was made to ODA for the Permit to Install (PTI), Permit to Operate (PTO), and most recent inspection report for three example facilities in the Auglaize River watershed. One facility housed swine, one was a dairy operation, and one was a turkey facility. Two Portable Document Format (PDFs) for each facility were provided, one contained the inspection report, and the other was the PTI-PTO. Inspection reports were generally large, ranging from 37 to 146 pages in length. The permitting documentation provided was extensive with each of the three documents exceeding 250 pages in length.

The requested swine facility reported a total of 4,271 animals in their inspection report dated June of 2017, with a permitted capacity of 4,800 animals. Inspection of the provided documents, including the fact sheet dated June 2021, revealed that "*the draft Permit to Install (PTI) proposes to authorize producer to combine the existing 2-barn facility (4,800 swine) located at Site #1 with an existing barn (2,400 swine) located at Site #2. In addition, the draft Permit to Install (PTI) proposes to authorize producer to construct a new 2,400 head swine finishing barn at Site #2*." Therefore, from 2017 to 2021, this individual producer expanded from having facilities for 7,200 swine to 9,600 swine.

The requested dairy facility reported a total of 2,230 animals in their inspection report dated July of 2017. The facilities' maximum number of animals was reported to be 2,250. Their fact sheet was dated 2022 and stated an animal capacity of 2,250 animals.

The requested turkey facility reported a total of 50,608 animals in their inspection report dated January of 2020. At the time of the inspection report, the approved design capacity was 54,500 animals and the maximum permitted design capacity was 74,000 animals. This facilities' fact sheet was from 2019 and reported a capacity of 74,000 animals.

To obtain a precise look at the change in animal counts over time housed in permitted facilities, an extensive data request would need to be submitted to the ODA. Each inspection report and facility annual report would need to be obtained and reviewed for the date of inspection and the current number of animals.

Medway Creek

For the Medway Creek watershed, all animal counts are included in the Section 3.2.2, "Non-permitted Animal Feeding Operations."

3.5.3 Non-permitted AFO Locations

Auglaize River

Non-permitted AFOs were more challenging to locate, with very limited data available. Note that there is a decades-long trend in animal production away from smaller pastured operations to larger confined feeding operations. This shift has also prompted major changes in how manure is produced and handled.

An analysis completed by the EWG (EWG, 2019; EWG, 2022) of AFOs in the entire Maumee River Watershed found that, between 2005 and 2018, the total number of livestock operations increased from 545 to 775, including permitted and non-permitted facilities. EWG updated the study, receiving location data of permitted facilities for the Maumee River watershed plus a 5-mile buffer from the ODA, IDEM, and the MIWATERs websites between May and November of 2020. Following the receipt of location data for permitted facilities, EWG scanned aerial imagery to find additional AFOs. In Indiana and Ohio, with the exception of Indiana swine facilities, the vast majority of identified operations were non-permitted. Findings from this study are reproduced below, in Table 3-4.

Table 3-4 Permitted and Non-permitted AFOs in the Maumee River Watershed, 2020[2]

Animal Species	Permitted AFOs	Non-permitted AFOs	Total	% Non-permitted
Indiana				
Swine	77	60	137	44%
Poultry	15	74	89	83%
Cattle (dairy + beef)	24	277	301	92%
Total	**116**	**411**	**527**	**78%**
Ohio				
Swine	53	546	599	91%
Poultry	20	164	184	89%
Cattle (dairy + beef)	26	989	1015	97%
Total	**99**	**1699**	**1798**	**94%**

Medway Creek

Within the Medway Creek watershed, one source of information was the “Farms classified by farm type, Ontario, Census of Ag 2021 historical data” available from Statistics Canada. This dataset includes the number of farms by Census division and sub-division but does not specify farm locations. The watershed spans four Census Consolidated Subdivisions: Middlesex Centre (33), London (36), Thames-Centre (27), and Lucan Biddulph (60), with the majority of the watershed residing in the Middlesex Centre subdivision (Statistics Canada, 2021a). This places the watershed entirely within the Southern Ontario Region (1) and the Middlesex Census Division (39) (see Figure 3-14). Results for the number of farms from the 2011, 2016 and 2021 census are shown below in Table 3-5.

[2] Table reproduced from: EWG. (2022). *Methodology: New analysis identifies animal feeding operation ‘hot spots’ in Western Lake Erie Basin | Environmental Working Group*. https://www.ewg.org/wlealgaemethods

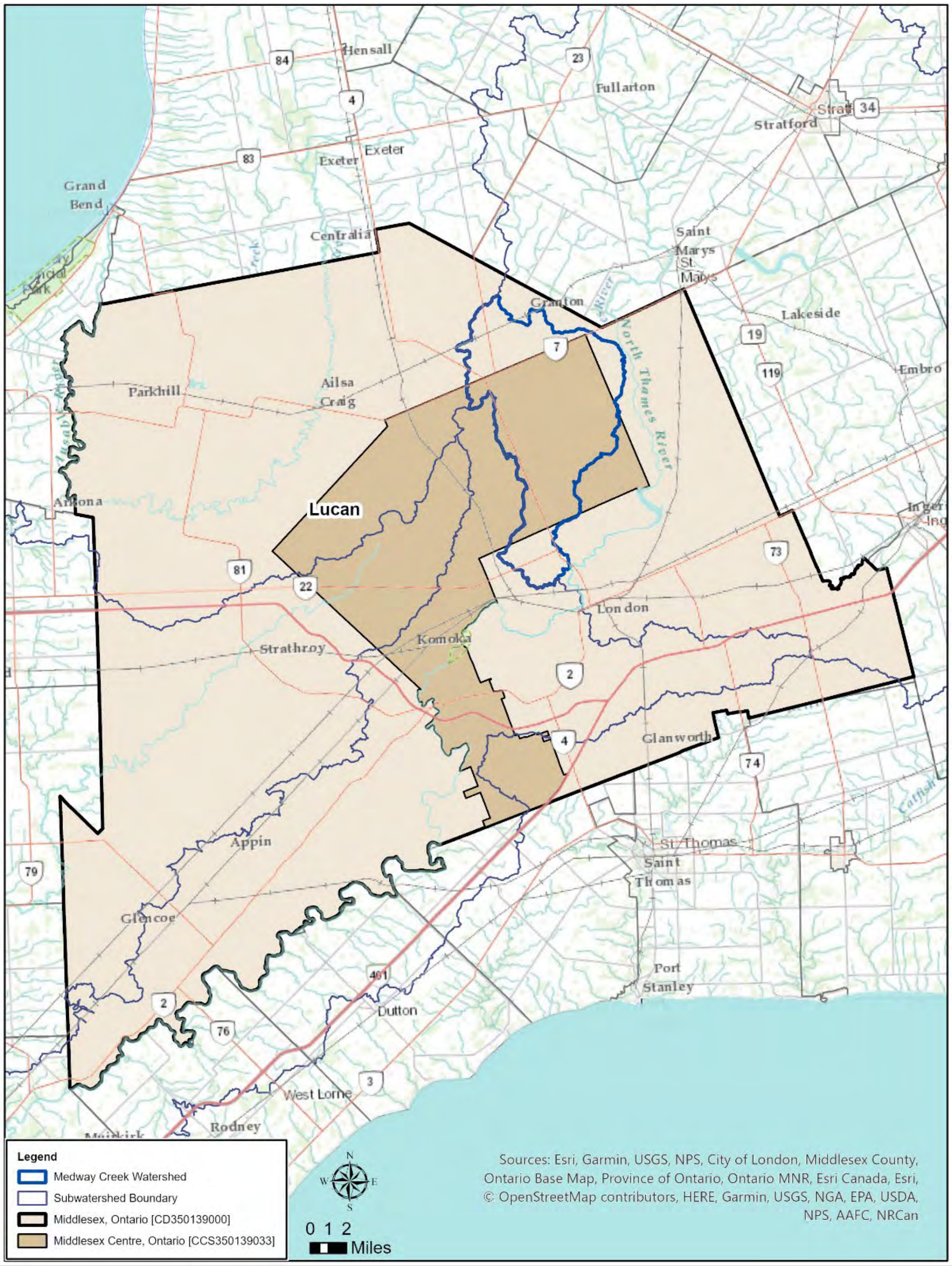


Figure 3-14 Middlesex Census Division and Middlesex Center Census Subdivision

Table 3-5 Total Number of AFOs, Middlesex Census Division and Middlesex Centre Census Subdivision[3]

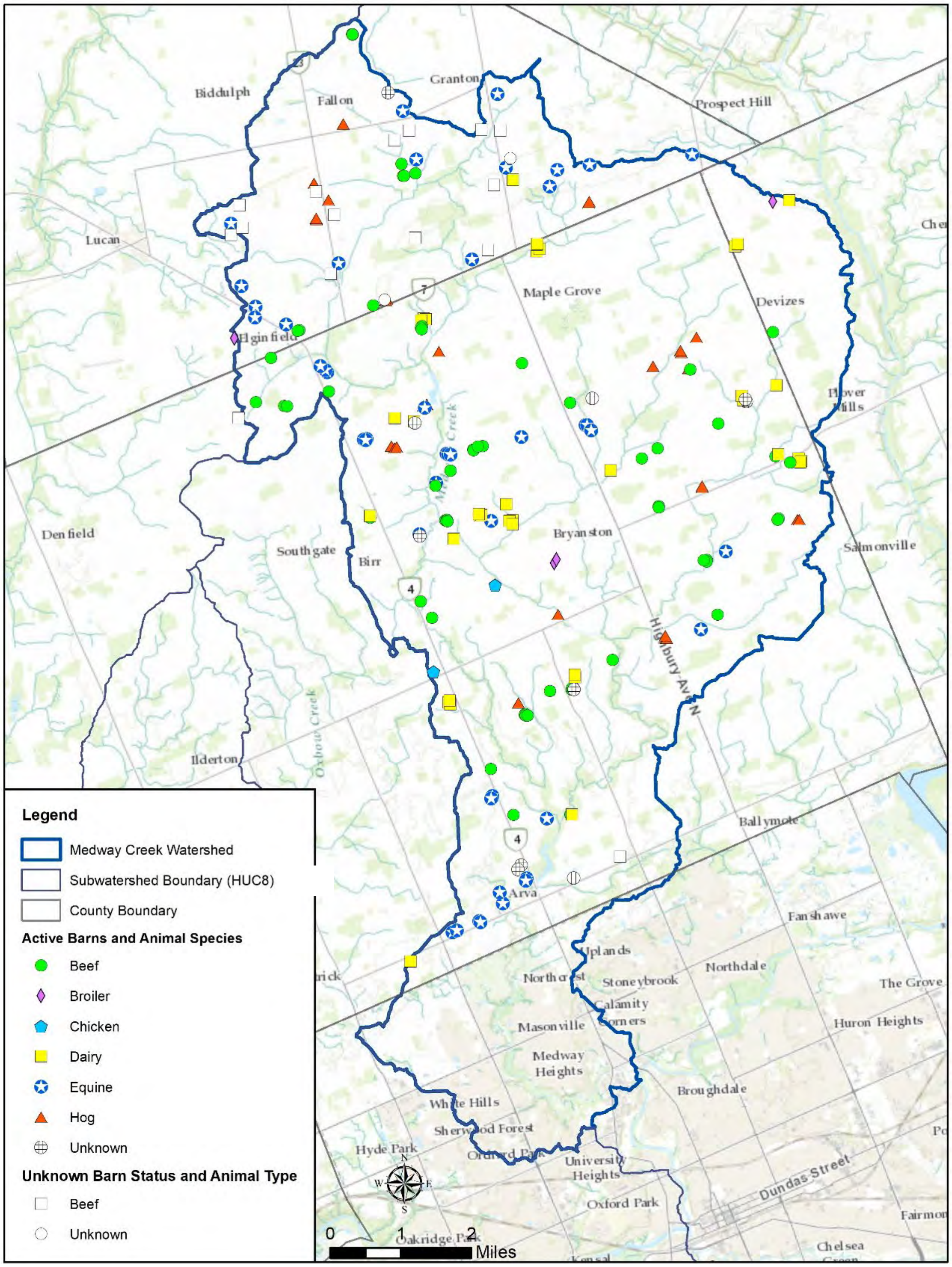
North American Industry Classification System (NAICS)	Middlesex, Ontario [CD350139000]			Middlesex Centre, Ontario [CCS350139033]		
	2011	2016	2021	2011	2016	2021
Cattle ranching and farming [1121]	269	277	351	59	50	59
Hog and pig farming [1122]	103	100	112	13	14	14
Poultry and egg production [1123]	93	91	126	17	12	19
Sheep and goat farming [1124]	47	33	46	5	9	7
Other animal production [1129]	258	224	189	73	63	54

Additionally, the contractor team reached out to the OMAFRA to obtain information on the number and locations of animal feeding operations. In response, the Environmental Management Branch of OMAFRA provided a "Barn Identification Dataset" (Figure 3-15). Per the data provider, the data includes the following:

- polygon areas of barns and structures;
- livestock type (simplified to Dairy, Beef, Hog, Broiler, Other);
- Active or Inactive status (i.e., does the barn appear to be currently in use);
- manure storage; and
- a unique identifier for each farm ("Farm ID").

Beyond the barn ID dataset, additional data on the location of livestock facilities were not available including the number of animals or nutrient units (NU), or whether the facility was subject to a permit to construct.

[3] Statistics Canada. Table 32-10-0231-01 Farms classified by farm type, Census of Agriculture, 2021



Source: OMAFRA.

Figure 3-15 Active Barns within the Medway Creek Watershed

3.5.4 Animal Counts in Non-permitted AFOs

Auglaize River

Limited data were available on animal counts in non-permitted facilities within the Auglaize River watershed. The analysis of the larger Maumee River Watershed by the EWG estimated that, between 2005 and 2018, the total number of animals in the watershed increased significantly. Note that total animal counts include several different animal species, from cattle to chickens, and do not accurately reflect trends in manure generation and impacts on water quality. EWG used updated facility estimates along with the 2017 USDA Census of Agriculture to create census-derived rates for non-permitted cattle, poultry, and swine animal counts.

Given the lack of watershed-level data, county-level data from USDA NASS Census of Agriculture were used as a proxy to estimate watershed-level animal populations and trends. Although the county-level data do not align perfectly with the watershed boundaries, they can help illustrate trends in the region and also identify parts of the watershed where growth in AFOs and animal counts may be particularly high. For this analysis, data from Allen, Auglaize, Defiance, Hardin, Paulding, Putnam, and Van Wert Counties in Ohio and Adams and Allen Counties in Indiana were used, for the last three census years available (2007, 2012, and 2017). Data for 2022 were only available for cattle, which are published on an annual basis unlike other species for which data is available every 5 years.

In general, there is an upward trend in the populations of most animal species in the region (see Figures 3-16 through 3-18 and Tables 3-6 and 3-7). Livestock in the region consists primary of hogs and cattle, with much smaller numbers of sheep and other animal species. Poultry operations are also present, but poultry data are not consistently presented in the USDA census due to confidentiality issues, and therefore have not been charted or mapped.

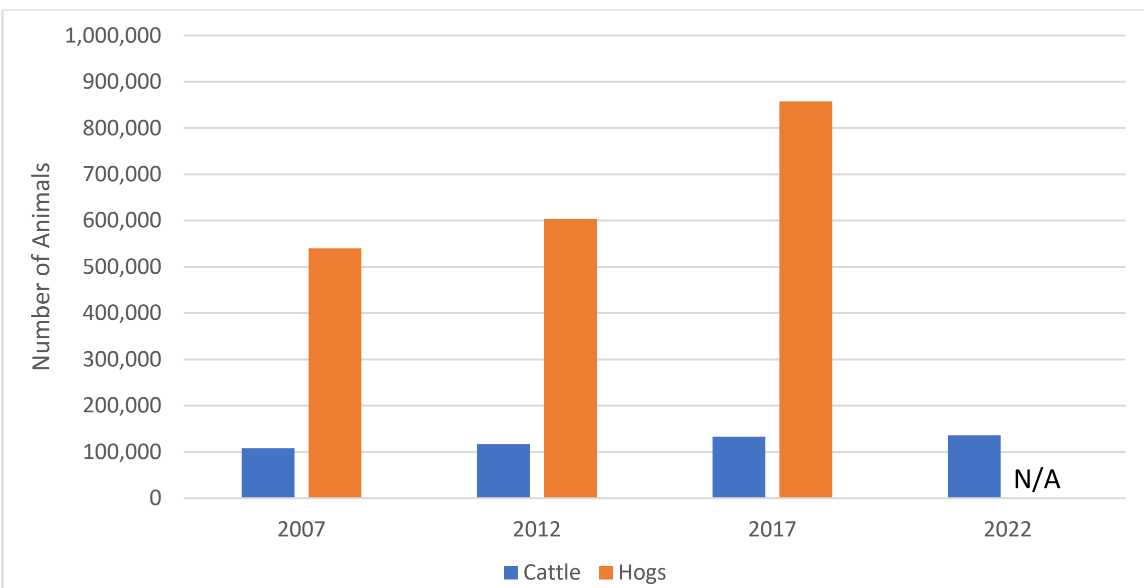
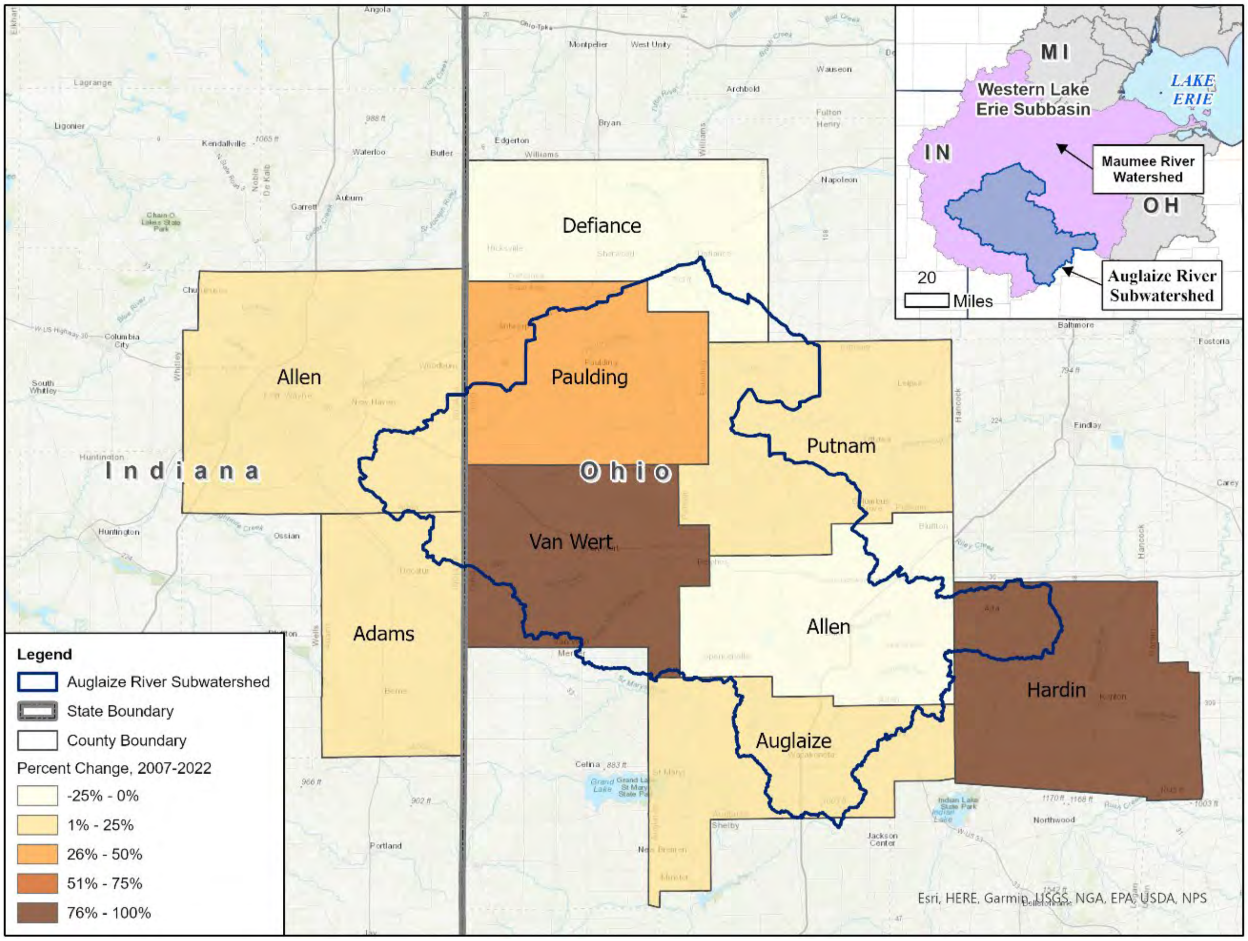
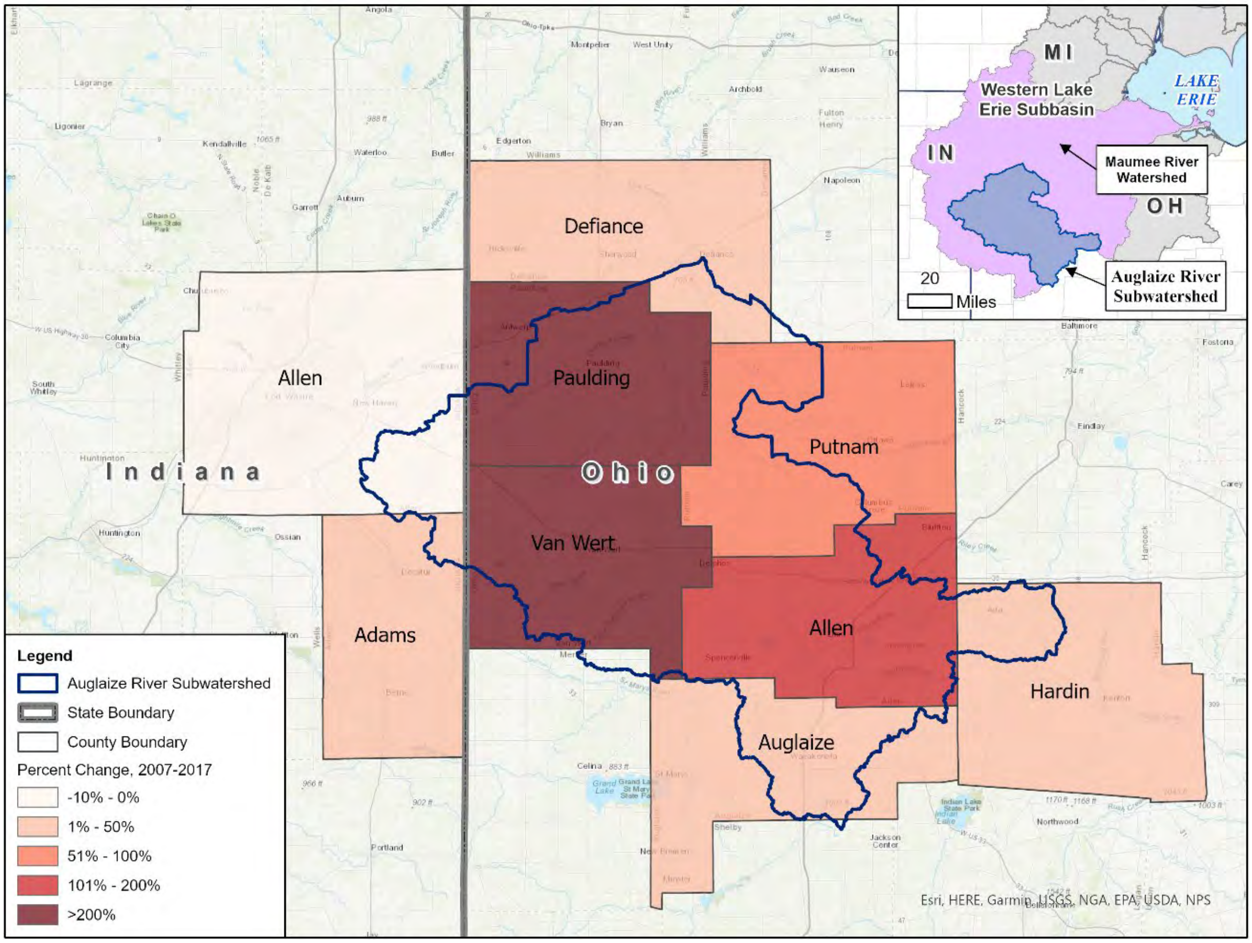


Figure 3-16 Cattle and Hog Population in Counties in and around the Auglaize Watershed
Includes Allen, Auglaize, Defiance, Hardin, Paulding, Putnam, and Van Wert Counties, OH, and Adams and Allen Counties in IN



Source: USDA NASS QuickStats, https://www.nass.usda.gov/Quick_Stats/

Figure 3-17 Percent Change in Cattle Population, by County, 2007 - 2022



Source: USDA NASS QuickStats, https://www.nass.usda.gov/Quick_Stats/

Figure 3-18 Percent Change in Hog Population, by County, 2007 - 2017

Table 3-6 Cattle Population by County, 2007 – 2022

County	2007	2012	2017	2022
Adams, IN	24,057	23,500	31,000	28,500
Allen, IN	11,269	11,100	15,400	13,600
Allen, OH	6,915	6,900	6,400	6,000
Auglaize, OH	20,055	20,000	22,000	24,500
Defiance, OH	10,678	10,700	11,100	10,500
Hardin, OH	7,321	15,300	14,000	14,000
Paulding, OH	7,538	8,700	10,980	10,800
Putnam, OH	13,949	14,000	14,000	16,000
Van Wert, OH	6,569	6,600	8,000	12,000
Total	**108,351**	**116,800**	**132,880**	**135,900**

Table 3-7 Hogs, Sheep, and Poultry Population by County, 2007 – 2017

County	Hogs			Sheep			Chickens		
	2007	2012	2017	2007	2012	2017	2007	2012	2017
Adams, IN	152,980	109,912	185,713	1,093	1,332	1,753	226	893,885	D
Allen, IN	46,094	34,093	43,283	560	855	1,307	97	46,508	119,720
Allen, OH	62,910	80,372	178,781	820	704	962	452	D	1,528
Auglaize, OH	91,925	104,701	110,134	775	1,335	803	670,918	D	D
Defiance, OH	10,891	5,675	13,938	604	597	468	484	1,745	947
Hardin, OH	55,545	78,855	68,974	1,148	1,161	643	D	D	D
Paulding, OH	17,440	28,937	61,268	222	63	198	639	321	921
Putnam, OH	77,003	81,249	119,011	1,014	782	1,269	194,332	D	D
Van Wert, OH	25,344	79,807	76,417	997	428	622	D	276,540	D
Total	**540,132**	**603,601**	**857,519**	**7,233**	**7,257**	**8,025**	**867,148**	**1,218,999**	**123,116**

D = data withheld for privacy reasons

Given that facility regulation occurs above specified animal limits, AFOs may choose to balance scale with regulatory burden and keep total animal numbers below that requiring regulation. A 2019 report from the Great Lakes Water Quality Board highlighted this issue, stating[4]:

> *A 2017 report to a committee of the Ohio Department of Agriculture showed that 77 percent of the over two million swine in Ohio were in non-permitted facilities.*

Medway Creek

Like the total number of farms, animal counts are tabulated in Canada by census divisions and subdivisions. Each species is broken down into sub-sections based on growth stage, sex, and/or purpose. The 2021 census indicates there are a total of 13,697 cattle, 74,525 pigs, and 925,556 hens and chickens within the Middlesex Centre census subdivision (Table 3-8). While populations of sheep and other livestock declined across both regions, cattle and pig populations increased (Figure 3-19). Poultry numbers rose within the larger Middlesex census division but declined in the Middlesex Center census subdivision.

[4] Great Lakes Water Quality Board. (2019). *Oversight of Animal Feeding Operations for Manure Management in the Great Lakes Basin*. https://ijc.org/sites/default/files/2020-01/WQB_ManureManagementReport_2019.pdf

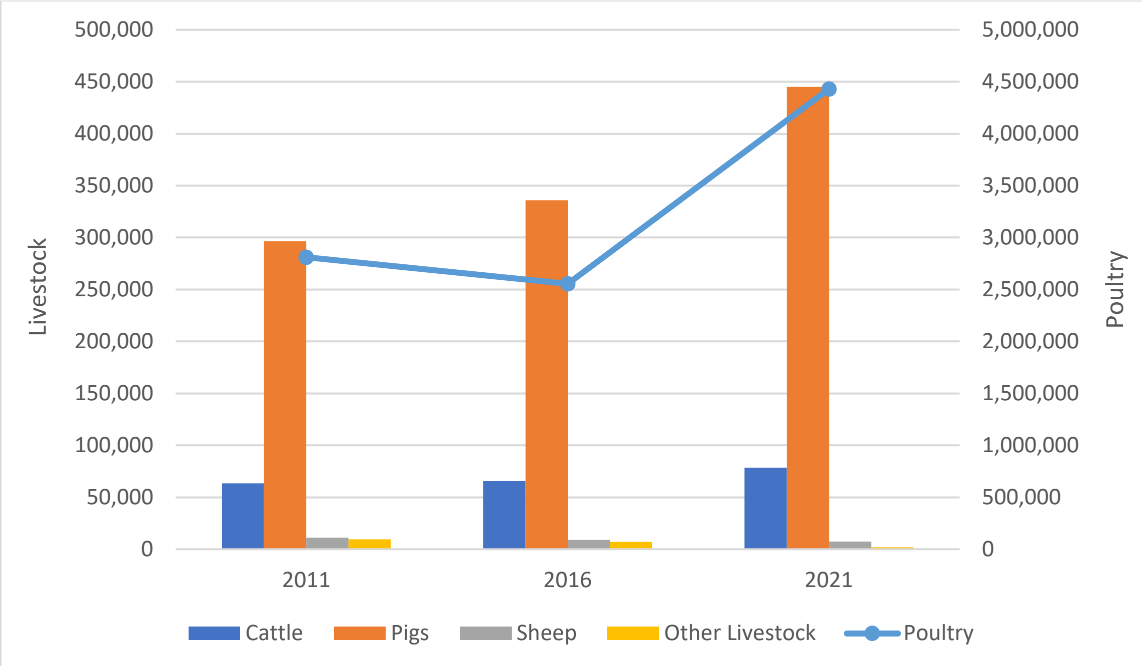


Figure 3-19 Animal Population in Middlesex Census Division, ON, 2011 – 2021

Table 3-8 Inventory of Animals by Species for the Middlesex Census Division and the Middlesex-Centre Census Subdivision[5]

	Number of Animals					
Species	Middlesex, Ontario [CD350139000]			Middlesex Centre, Ontario [CCS350139033]		
	2011	2016	2021	2011	2016	2021
Cattle	63,287	65,584	78,508	11,845	13,446	13,697
Pigs	296,334	335,852	445,061	33,813	48,623	74,525
Sheep	11,205	8,953	7,524	2,331	2,115	1,980
Other Livestock	9,465	7,091	1,852	1,920	1,638	756
Poultry	2,811,828	2,554,895	4,430,756	1,136,826	695,439	925,556

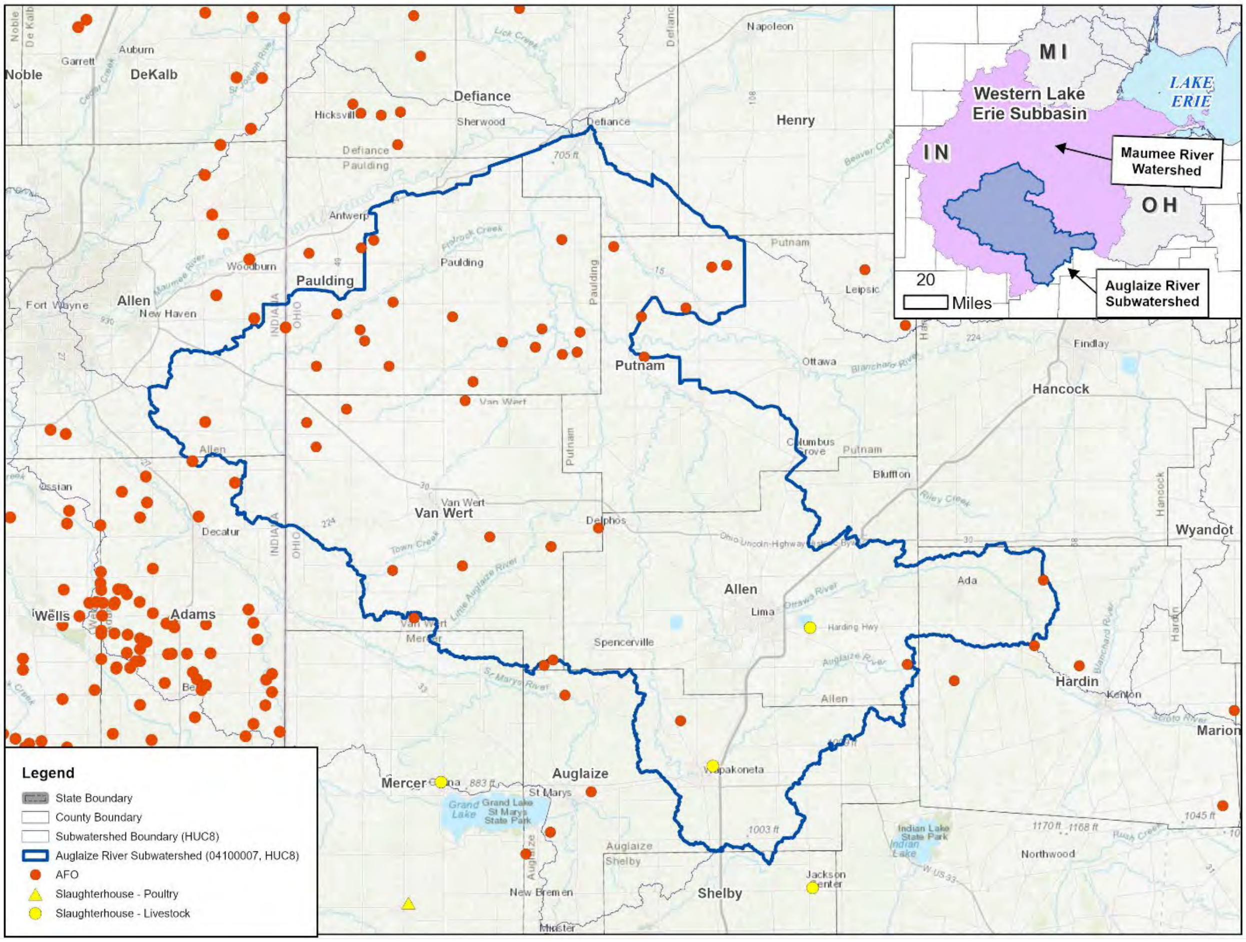
3.5.5 Locations of Nearby Animal Processing Facilities

Auglaize River

Data on slaughterhouses and animal processing facilities in and near the Auglaize River watershed was obtained from the USDA Food Safety Inspection Service (FSIS)[6], the ODA Division of Meat Inspection[7], and the Indiana State Board of Animal Health[8]. USDA FSIS-inspected facilities in the Auglaize River watershed include Keystone Meats Inc., Lima, OH (beef), and KAH and Company, Inc., Wapakoneta, OH (beef).

[5] Statistics Canada. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210015501, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210037301.
[6] https://www.fsis.usda.gov/inspection/establishments/meat-poultry-and-egg-product-inspection-directory
[7] https://agri.ohio.gov/divisions/meat-inspection
[8] https://www.in.gov/boah/meat-and-poultry-inspection/

Location data were available only for USDA FSIS-inspected facilities, which are shown in Figure 3-20. Additionally, there are 19 smaller state-inspected slaughterhouses located in the watershed (see Table 3-9); however, location data were not available for these facilities.



Source: USDA Food Safety Inspection Service, https://www.fsis.usda.gov/inspection/fsis-inspected-establishments

Figure 3-20 USDA FSIS-Inspected Animal Processing Facilities in Ohio and Indiana

Table 3-9 State-Inspected Animal Processing Facilities

Establishment Name	Business City/State/Zip	County	State	Type Business
Sinns Meat Market	Grover Hill, OH 45849	Paulding	OH	Livestock
Jacob's Meats, Inc.	Defiance, OH 43450	Defiance	OH	Livestock
Walter & Sons Inc	Wapakoneta, OH 45895	Auglaize	OH	Livestock
Hengleson Sausage Co.	Lima, OH 45805	Allen	OH	Livestock
Leap Meats	Ottawa, OH 45875	Putnam	OH	Livestock
The Buck Shop	Ft. Jennings, OH 45844	Putnam	OH	Livestock
Ted A Sigler, LLC	Pandora, OH 45877	Putnam	OH	Livestock
Trailside Custom Meats, LLC	Kenton, OH 43326	Hardin	OH	Livestock
Rodabaugh Bros. Meats, LLC	Pandora, OH 43326	Hardin	OH	Livestock
Fort Defiance Meats, Inc.	Defiance, OH 43512	Defiance	OH	Livestock

Establishment Name	Business City/State/Zip	County	State	Type Business
Sanderson's Meats	Grover Hill, OH 45849	Paulding	OH	Livestock
Hermiller's Butcher Shop LLC	Ottawa, OH 45875	Putnam	OH	Livestock
Ebel's Chicken Coop	Grover Hill, OH 45849	Paulding	OH	Poultry
Custom Quality Meats	New Haven, IN 46774	Allen	IN	Livestock
E & L Farms & Processing	Grabill, IN 46741	Allen	IN	Livestock
Feders Meats	Fort Wayne, IN 46815	Allen	IN	Livestock
Gustin Custom Meats, LLC	Harlan,IN 46743	Allen	IN	Livestock
Manley Meats, Inc.	Decatur, IN 46733	Adams	IN	Livestock
Tim Didier Meats	Fort Wayne, IN 46808	Allen	IN	Livestock

Medway Creek

Data on animal processing facilities in and around Medway Creek was obtained from Ontario's Data Catalogue[9]. Location data were available for only a subset of facilities, as shown in Figure 3-21. The full list of facilities is shown in Table 3-10.

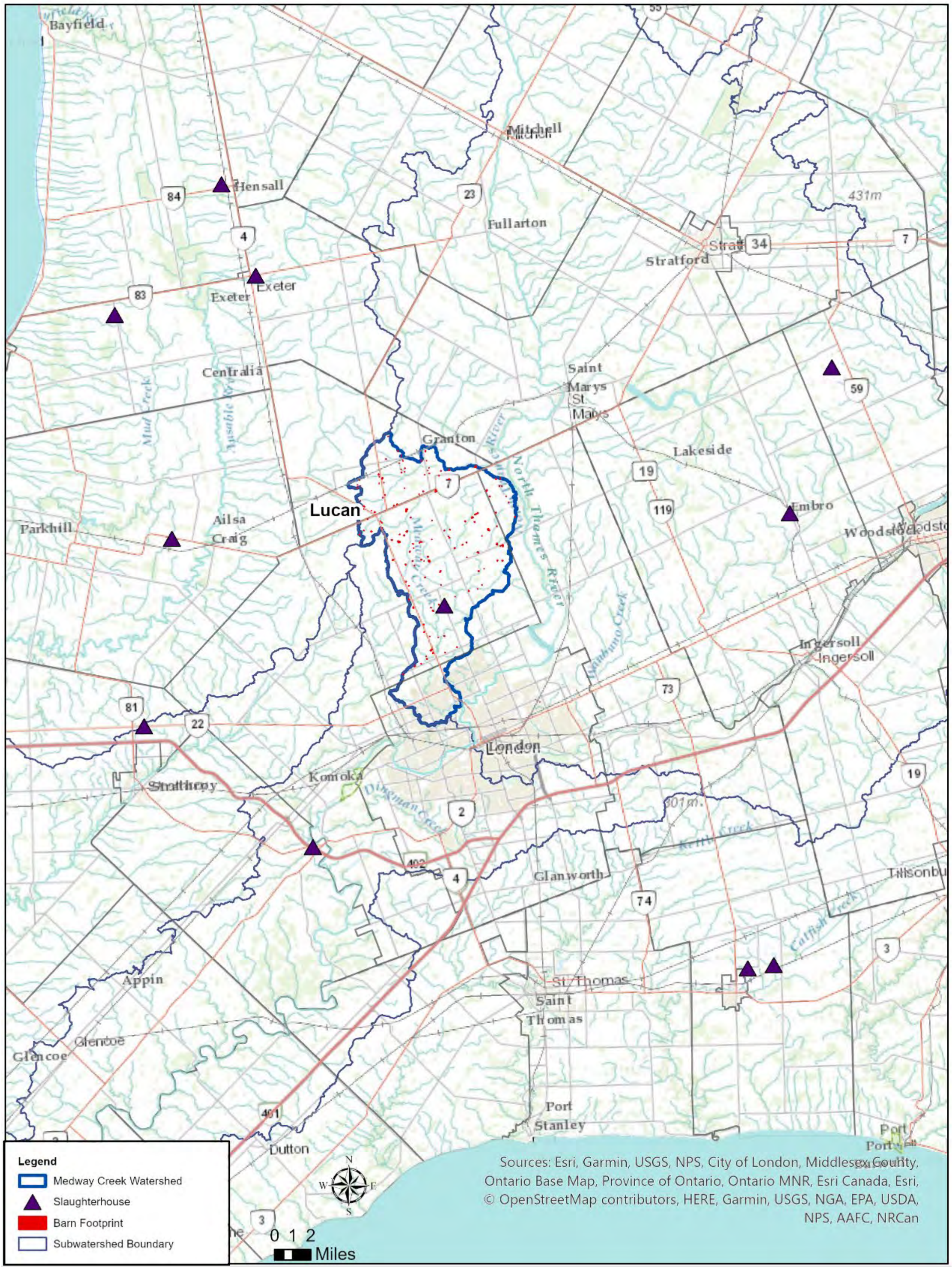
Table 3-10 Animal Processing Facilities in and Around Medway Creek

Establishment Name	Business City/Province/Zip	Type Business	Inspection
Square Deal Market	1231 Drouillard Road, Windsor, ON	Livestock	FSMP
Brenner Packers Limited	497 Cataraqui, Windsor, ON	Livestock	FSMP
Naples Pizza Limited	1493 Rooney Street, Windsor, ON	Livestock	FSMP
Weston Abattoir Limited	5409 North Talbot Road, Maidstone, ON	Livestock	Further Processing
Wigle's Gourmet Meat & Deli	30 Renaud Street, Amherstburg, ON	Livestock	FSMP, Provincially Licensed
Windsor Quality Poultry Inc.	7095 Manning Road, Maidstone, ON	Poultry	FSMP, Provicncially Licensed
4D Sausage Kitchen	429 South Talbot Road, Rr 1, Essex, ON	Livestock	FSMP, Provincially Licensed
Edewell Farms	1282 Oriole Park Drive, Woodslee, ON	Livestock	Provinicially Licensed
Deda's Meats & Deli Inc.	5211 Tecumseh Road East, Windsor, ON	Livestock	FSMP, Provincially Licensed
Gord's Abattoir Inc.	643 Hwy 77, Leamington, ON	Livestock	Provincially Licensed (Further Processing)
Uranu's Sausage	113 Mersea Road 3, Leamington, ON	Livestock	FSMP, Provincially Licensed
Country Fresh Packers Limited	4049 Bonneau Line, Tilbury, ON	Livestock	Provincially Licensed (Further Processing)
Giesbrecht Sausages	5417 Queen'S Line, Rr 1, Tilbury, ON	Livestock	FSMP, Provincially Licensed
Roesch Meats	10910 Northwood Line, Rr 2, Kent Bridge, ON	Livestock	FSMP, Provincially Licensed
Highgate Tender Meats Limited	14680 Hastings Line, Highgate, ON	Livestock	FSMP, Provincially Licensed
Dresden Meat Packers Limited	R.R. #2, 78 Hwy, 10210 Mccreary Line, Dresden, ON	Livestock	Provincially Licensed (Further Processing)
Brennan Poultry	7109 Mosside Line, Alvinston, ON	Poultry	Provincially Licensed (Further Processing)

[9] https://data.ontario.ca/dataset/provincially-licensed-meat-plants

Establishment Name	Business City/Province/Zip	Type Business	Inspection
Lambton Meat Products	3099 Broadway Street, PO Box 263, Alvington, ON	Livestock	FSMP, Provincially Licensed
Weiland Meats Limited	340 Centre Street, Petrolia, ON	Livestock	Provincially Licensed (Further Processing)
Istanbul Halal Meat Packers	5814 Minielly Road, Wyoming, ON	Livestock	Provincially Licensed (Further Processing)
Evelyn's Sausage Kitchen	35809 Talbot Line, Shedden, ON	Livestock	FSMP, Provincially Licensed
Mount Brydges Abattoir Limited	21618 Adelaide Road Mount Brydges, ON	Livesock	Provincially Licensed (Further Processing)
Ralph Bos Meats Limited	3742 Egremont Drive, Strathroy, ON	Livestock	Provincially Licensed (Further Processing)
Scotian Isle Baked Goods Inc.	13-972 Hamilton Road, London, ON	Livestock	FSMP, Provincially Licensed
Arvaspring Farms Limited	22370 Adelaide Street North, Rr 3, Ilderton, ON	Livestock	Provincially Licensed (Further Processing)
Parkhill Meats Limited	3900 Elginfield Road, Parkhill, ON	Livestock	Provincially Licensed (Further Processing)
Springwaters Meats	9040 Springwater Road, Alymer, ON	Livestock	FSMP, Provincially Licensed
Johnson Meats	49801 Glen Colin, Rr 4, Aylmer, ON	Livestock	Provincially Licensed (Further Processing)
Chicken Little	50639 Glencolin Line, Aylmer,ON	Poultry	Provincially Licensed (Further Processing)

FSMP – Free Standing Meat Processing



Source: Government of Ontario, https://data.ontario.ca/dataset/provincially-licensed-meat-plants

Figure 3-21 Provincially Licensed Animal Processing Facilities in Ontario

3.5.6 Soil Phosphorus

Phosphorus is a key nutrient for crop growth and production, but its overapplication can lead to increased concentrations in runoff and adverse effects on surface water quality. Manure and commercial fertilizers are both sources of phosphorus (and other nutrients) and are often used in combination. Manure may be liquid or solid, and it may be surface applied by spraying or incorporated or injected into the soil. Surface application without incorporation leads to higher P concentrations in the topmost soil layer, which are in turn more susceptible to runoff. Soil testing is commonly used to determine existing soil P levels and the amount of phosphorus that must be applied to ensure an optimal range for crop growth.

Auglaize River

There are three major soil testing laboratories that service farmers in Ohio: A&L Great Lakes Laboratories, Brookside Laboratories, and Spectrum Analytic. A&L hosts annual soil test summaries on their website with data spanning years 2005 to 2021[10] as of this report date. These data are aggregated by region and are not available on a county or watershed basis. Laboratories maintain field-level data, but these are typically confidential and are not widely available for public use.

For this effort, regional soil P test data for Northwest Ohio and Northeast Indiana were downloaded from A&L Laboratories' website. The data for Northwest Ohio show a slight decline in average Bray-P1 soil test results (see Figure 3-22). At the same time, the percentage of test results at 30 parts per million (ppm) or below has increased slightly while the percentage of test results above 30 ppm has decreased. Trends were similar in Northeast Indiana, with the main difference that the average Bray-P1 test values were slightly higher in Northeast Indiana compared to Northwest Ohio.

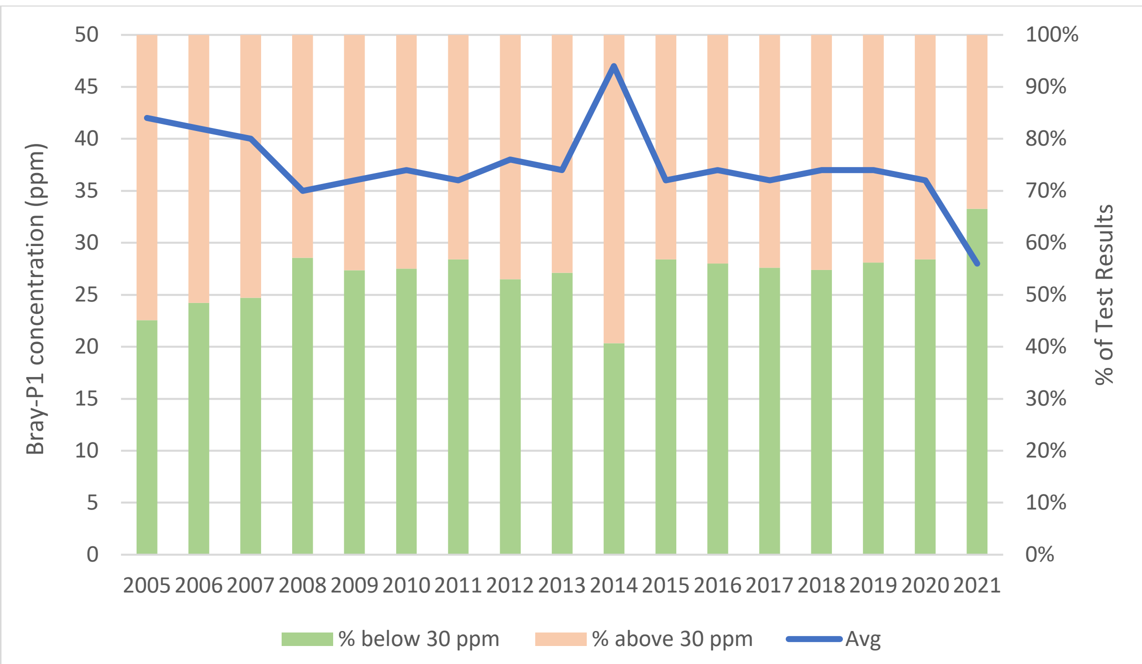


Figure 3-22 Trends in Bray-P1 Soil Test Data from A&L Labs, Northwest Ohio, 2005 – 2021

10 https://algreatlakes.com/pages/soil-test-summaries

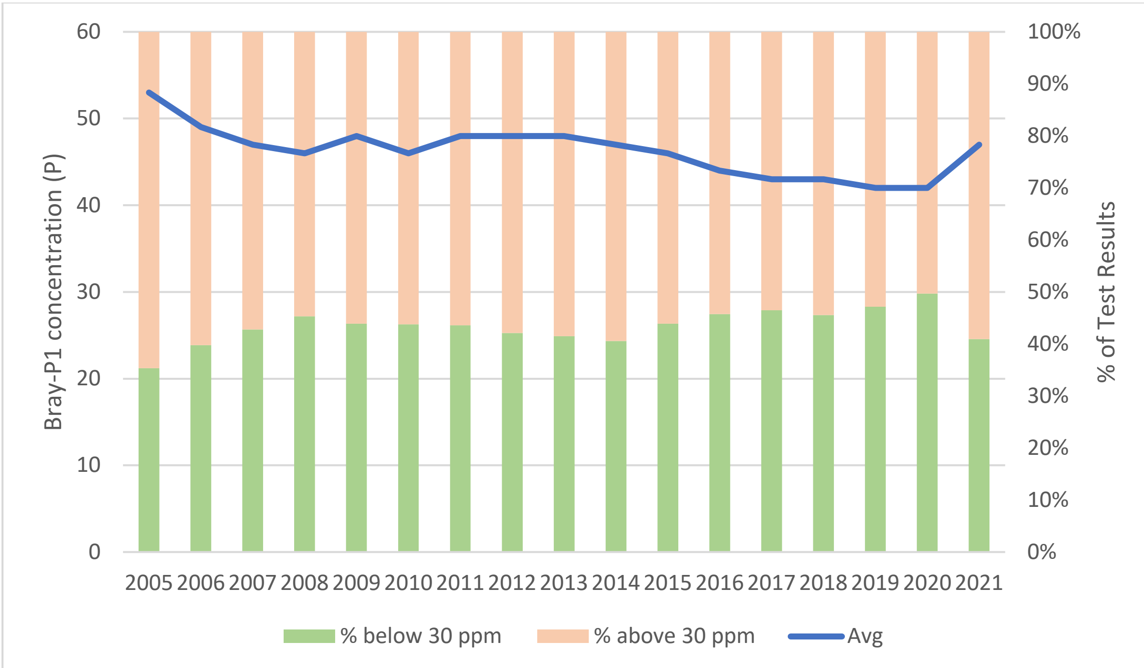


Figure 3-23 Trends in Bray-P1 Soil Test Data from A&L Labs, Northeast Indiana, 2005 – 2021

Table 3-11 Phosphorus (Bray-P1), ppm Soil Test Results from A&L Great Lakes Laboratories from 2011 - 2021

Location	Year	Average	Std. Dev.	Percent of Samples by Soil Test Rating				
				Very Low (<10 ppm)	Low (10-20 ppm)	Medium (20-30 ppm)	High (30-40 ppm)	Very High (>50 ppm)
NE IN	2011	48	58	6.3	18.9	18.4	25.5	30.9
	2013	48	53	5.6	17.2	18.7	27.4	31.1
	2015	46	56	6.4	18.4	19.1	27	29.1
	2017	43	47	6.9	19.9	19.7	26.3	27.2
	2019	42	42	6.9	20.1	20.2	26.9	26
	2021	47	49	4.2	16.9	19.8	28.4	30.6
NW OH	2011	36	37	6.7	25.3	24.9	24.8	18.4
	2013	37	39	6.7	23.6	23.9	26.1	19.6
	2015	36	40	7.9	25.1	23.9	24.4	18.8
	2017	36	36	6.5	24	24.7	25.9	18.9
	2019	37	42	7.4	25.6	23.2	24.3	19.5
	2021	28	26	12.7	32.3	21.5	20.3	13.1

Through 2011, A&L Laboratories' P1 test data summaries also included minimum and maximum values, with the maximum values typically well over 1,000 ppm in most years. However, this data is no longer included in the summaries for 2012 and later years.

Dayton et al. (2020) also analyzed county-level trends in soil P across Ohio and found a mixture of results for counties in northwest Ohio, with median Mehlich-3 Soil Test Phosphorus (STP) levels decreasing in 44 – 63 percent of counties but increasing in 11 – 21 percent, with the remainder not showing any significant trend. Table 3-12 summarizes their results for the seven Ohio counties that overlap the Auglaize River watershed. Five counties showed a decline in median STP test values, while two had increasing median STP values.

Table 3-12 County-level Median STP (Mehlich-3) Values and Trends

County	Median STP Value (ppm)	Trend
Allen, OH	40	Increasing
Auglaize, OH	33	Decreasing
Defiance, OH	28	Decreasing
Hardin, OH	32	Decreasing
Paulding, OH	27	Decreasing
Putnam, OH	35	Decreasing
Van Wert, OH	36	Increasing

Brooker et al. (2021) conducted a more localized assessment of soil P levels, working through a partnership with agricultural soil testing retailers and farmers. They found that many of the sites with elevated soil P test levels above 100 ppm had a history of livestock operations or manure or biosolids applications. They also found that approximately 4 percent of soil samples in their data had soil P concentrations above 100 ppm, but these elevated concentrations were often confined to zones within fields. The researchers also noted a strong negative correlation between interest in participating in the project and the presence of high soil-P levels, suggesting potential challenges in recruiting these farms to participate in best management practices to limit offsite migration of nutrients. One possible cause suggested by the researchers was the farmers' concern about privacy and data confidentiality.

Medway Creek

Similar data for the Medway Creek watershed did not exist in a public format. Reid and Schneider (2019) evaluated the net changes in cumulative phosphorus balance (kilogram [kg] per hectare [ha]) for agricultural regions of Canada and noted the following:

> *In southern Ontario, the areas of highest P accumulation are along the north shore of Lake Erie (i.e., coinciding with regions dominated by poultry production in Niagara, tobacco and field horticulture on the Norfolk sand plain, and mixed field horticulture further west), and then north into mid-western Ontario where there is a high density of swine and dairy farms.*

The Government of Canada does provide an Agri-Environmental Indicator – Risk of Water Contamination by Phosphorus Data Series. Per the Open Government website, this dataset "estimates the relative risk of phosphorus loss from Soil Landscapes of Canada agricultural areas to surface water". In total, four of these datasets are available: the annual phosphorus balance in the soil (for census years since 1981), soil phosphorus source that estimates the relative risk of phosphorus release from soils (for census years since 1981), the risk of water contamination by phosphorus, and the risk of phosphorus movement to edge of field. Based on these datasets, the risk of water contamination by phosphorus appears to have decreased across the Medway Creek watershed from 1981 to 2016. Maps of these data products are provided in Appendix C.

3.5.7 Manure Application: methods, timing, land application rates, area applied, contribution of manure to P

Auglaize River

Permitted livestock facilities in Ohio are inspected at least once, and often times twice, per year by the Ohio Department of Agriculture. These inspection reports, along with the facility's PTO are available upon request from the ODA. Together, these reports provide a selection of data that help to clarify how any given facility is handling the manure their animals generate. These documents are available to the public upon request from the ODA.

As part of this effort, permit documents were requested from three facilities (as discussed in Section 3.5.2) and reviewed. Due to the volume of documents received from the three facilities, this report does not provide a comprehensive evaluation of manure management practices but outlines the types of information available in permit documents. Future efforts could request and review permits and associated documents for a larger population of AFOs, in order to draw representative conclusions about manure management activities at these facilities.

In the PTO, sections are available covering:

- Building type
- Permitted animal capacity
- Equipment type, including information about:
  - Capacity/size
  - Number available
  - Maintenance frequency
  - Calibration frequency
- Manure storage and treatment facilities, including information about:
  - Annual volume of manure removed
  - Inspection frequency
  - Maximum operating level and freeboard
  - Total manure storage volume
  - Storage period provided
- Animal manure volumes, by animal species, resulting in "as is tons or gallons" generated
- Manure nutrient characteristics
- Total nutrient budget
  - Budget includes sections for manure applied to land under the control of the facility and manure to be distributed to others
- Annual nutrient removal by crops
- Predicted soil test phosphorus
- Narrative of manure application procedures

In the inspection report, sections are available covering:

- Current number of animals

- Presence of well at facility and groundwater sampling results (if well present)
- Manure sampling results
- Manure storage records
- Indications of whether commercial fertilizer was used
- Manure management, including information about the dates of manure application, tons/gallons applied to the field, the acres applied to, pounds of P_2O_5 applied, and the soil test phosphorus concentration of the crop field as reported at the time of application in ppm
- Cropping schedules
- Notation of any land application sites with over 150 ppm soil phosphorus concentration
- Soil test ppm in Bray P1 or Mehlich-3 for selected field IDs
- Crop yield records

Inspectors note whether application setbacks are being followed, whether application occurred on frozen ground, and whether rainfall before/during/after application are noted in the records.

Kast et al. (2019) carried out a study of manure management practices at permitted CAFFs in the Maumee Watershed in Ohio. The authors reviewed manure management plans and inspection reports obtained from ODA to assess manure management practices in 2014 and 2015. They found that:

- Liquid manure was mainly applied between April and October, which aligned with facility manure management plans.
- The average distance from CAFFs' swine holding barns to the fields where manure was applied was 1.43 miles, while this distance for cattle CAFFs was 1.91 miles.
- Approximately 78 percent of the total manure P generated at the CAFFs was planned to be transferred through third-party brokers and applicators. Virtually all poultry manure was transferred in this manner.
- Approximately 79 percent of the land area that received manure applications under control of the CAFFs had Bray-P1 test values below 50 ppm, while 3 percent of the land had Bray-P1 in excess of 100 ppm. A subset of CAFFs provided STP results for fields where manure was applied by third-party applicators. 57 percent had Bray-P1 values below 50ppm, while 5% had Bray-P1 results in excess of 100 ppm.

The authors noted that while permitted CAFFs appeared to be adhering to their permits, a significant gap exists in that there is little information on manure management from non-permitted AFOs.

Medway Creek

In Ontario, AFOs are not subject to permitting but, depending on size, are required to prepare nutrient management plans, describing their approach to manure management to ensure that impacts to water quality are avoided or minimized. These documents are confidential and are generally not available to the public.

As part of this effort, a data request was submitted to the Ontario Soil and Crops Improvement Association (OSCIA) requesting data on manure generation and management, including application methods, timing, and estimated application rates for various types of crops. In response, OSCIA provided (through UTRCA) a dataset that was collected as part of a study on manure management and water quality impacts in a limited area of the Medway Creek headwaters. The data provided included details on manure application on 32 farm fields, as shown in Table 3-12 (note that the numbers are the applicable number of farm fields). The study included manure application from 2016 to 2021. Approximately 14% of the total land area included in the study had manure applied at least once over this period.

Table 3-12 Summary of Manure Application Data for Medway Creek Headwaters

Crops Grown	
Corn	1,297 acres (77%)
Soybeans	274 acres (16%)
Wheat	84 acres (5%)
Hay	19 acres (1%)
Manure Source	
Hog	1,202 acres (72%)
Dairy	388 acres (23%)
Beef	84 acres (5%)
Manure Type	
Liquid	1,590 acres (95%)
Solid	84 acres (5%)

Application Method	
Broadcast with incorporation	694 acres (41%)
Broadcast w/o incorporation	859 acres (51%)
Not specified	121 acres (7%)
Incorporation Days	
0 days	201 acres (29%)
2 days	147 acres (21%)
3 days	100 acres (14%)
4 days	100 acres (14%)
15 days	95 acres (14%)
Not specified	52 acres (8%)

Additionally, three years of P stream loading data (expressed as kg/ha of total P and DRP) were provided from a sampling location at the study area drainage boundary along Medway Creek. However, it is difficult to draw a connection between manure application and water quality in this instance because of the lack of information about commercial fertilizer applications in the area, and because more than 50 percent of the manure applications included in the dataset occurred before Oct 2019, which is the start of the sampling period. Table 3-13 presents the P loading data.

Table 3-13 Stream Loading Data for Medway Creek Headwaters

Year/Time Period	TP (kg/ha)	DRP (kg/ha)	TP (metric tons)	DRP (metric tons)
2019-2020 NGS (Oct 1 - Apr 30)	1.15	0.2190	2.30	0.44
2019-2020 GS (May 1 - Sept 30)	0.09	0.0051	0.18	0.01
2020-2021 NGS (Oct 1 - Apr 30)	0.39	0.1034	0.77	0.21
2020-2021 GS (May 1 - Sept 30)	0.49	0.1660	0.99	0.33
2021-2022 NGS (Oct 1 - Apr 30)	0.68	0.1787	1.36	0.36
2021-2022 GS (May 1 - Sept 30)	0.07	0.0208	0.14	0.04

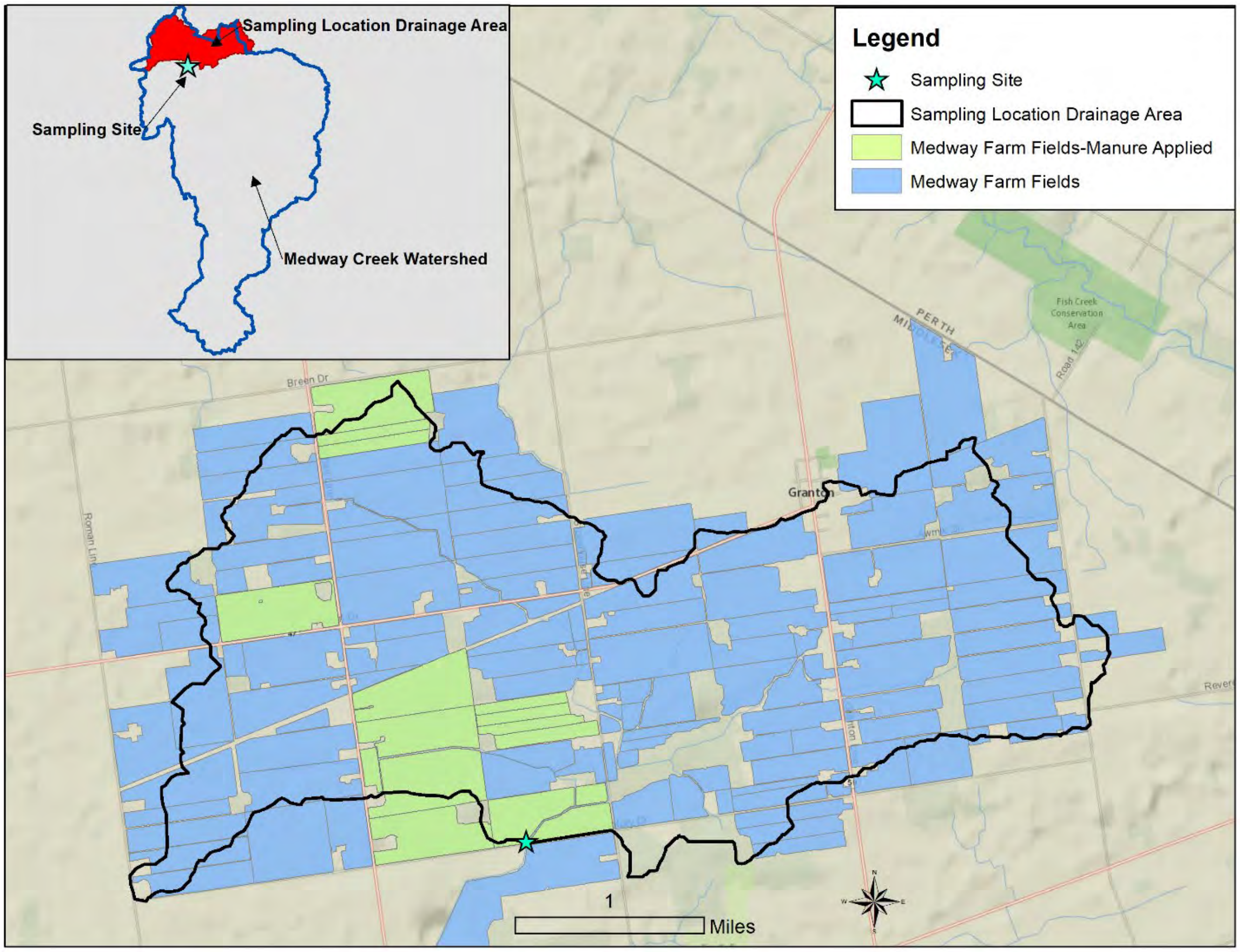
GS – growing season; NGS – non-growing season

The following trends were noted for the fields and time-frame included in the sample:

- The vast majority (95 percent) of the fields with manure application had liquid manure applied.
- Hog manure was the most commonly applied, accounting for 72 percent of fields by land area.
- Of the fields for which data was provided, just under half (41 percent) applied liquid manure by broadcasting with incorporation, which 51 percent used broadcast without incorporation. No data was provided for 7% of the fields.

- In 2019-2020 and 2021-2022, TP and DRP loading rose during the non-growing season and fell sharply during the growing season. However, in 2020-2021 the trend was reversed, with higher TP and DRP load seen during the growing season.

Figure 3-24 shows the location of the fields included in the study, along with the water sampling location.



Source: UTRCA

Figure 3-24 Medway Creek Farm Fields with Manure Application and Stream Monitoring Site

Statistics Canada maintains data from the Farm Management Survey, which includes data from 2017 and 2021 on manure application methods[11]. Table 3-14 summarizes results for Ontario; the numbers represent the percentage of farms that using the respective methods. Note that respondents to the survey could select more than one option; therefore, the percentages add up to more than 100. The responses indicate that broadcast followed by incorporation is more common than broadcast without incorporation. However, between 2017 and 2021 there was a slight decrease in the percentage of production where manure was incorporated following application, and a corresponding (although unequal) increase in the application of manure without incorporation.

[11] Statistics Canada. Table 32-10-0388-01 Method of manure application, by farm production type

Table 3-14 Method of Manure Application, Ontario

Method	Percent of Farm Production	
	2017	2021
Direct injection into the soil*	--	--
Narrow band on soil surface, below crop canopy*	--	--
Broadcast on surface and not worked into the soil	26	32
Broadcast on surface and worked into the soil	90	86

* Data considered too unreliable to be published
Survey responses allowed selection of multiple options; hence, columns may not add up to 100%.

3.5.8 Manure and Commercial Fertilizer Contributions to P, K and N Land Application

Auglaize River

Falcone (2021) published estimates of county-level nitrogen (N) and phosphorus from both fertilizer and manure from 1950 through 2017 for the entire conterminous United States. Per the author: "*Nutrients from fertilizer for 1950–2012 are exactly those previously described in U.S. Geological Survey (USGS) reports and datasets; however, estimates of nutrient masses from fertilizer applied in 2017 are described here as a new product modeled from 11 predictor variables for 2017 including county-level fertilizer expenditures, land use, and acres of fertilized land*." Data are available as tabular datasets, linked in a USGS data release. P input data are summarized in Figures 3-25 through 3-28, and Tables 3-15 through 3-17. Note that these are county-level data and do not align precisely with watershed boundaries; however, they are useful in that they provide an estimate of fertilizer and manure P inputs in the region.

In general, commercial fertilizer P inputs remained within a relatively constant range over the last 3 decades, but P inputs from manure showed an increasing trend, especially since the early 2000s. The increase in animal manure P input is primarily associated with the increase in the number of hogs in the region, followed by a slight increase in the number of cattle.

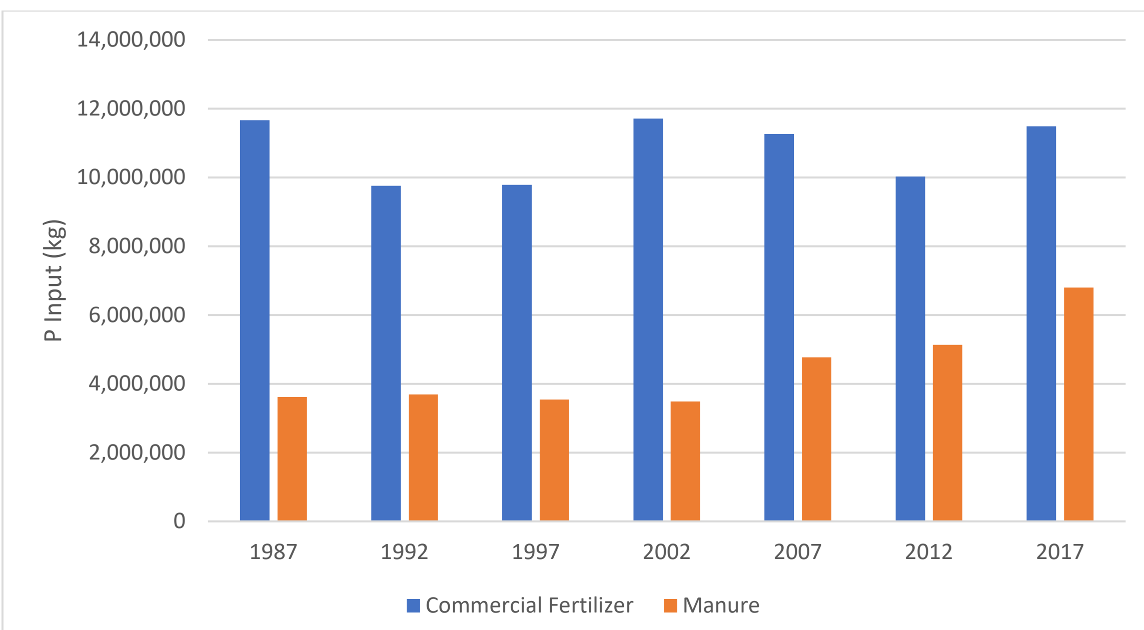


Figure 3-25. County-level P Input: Commercial Fertilizer and Manure, 1987 – 2017

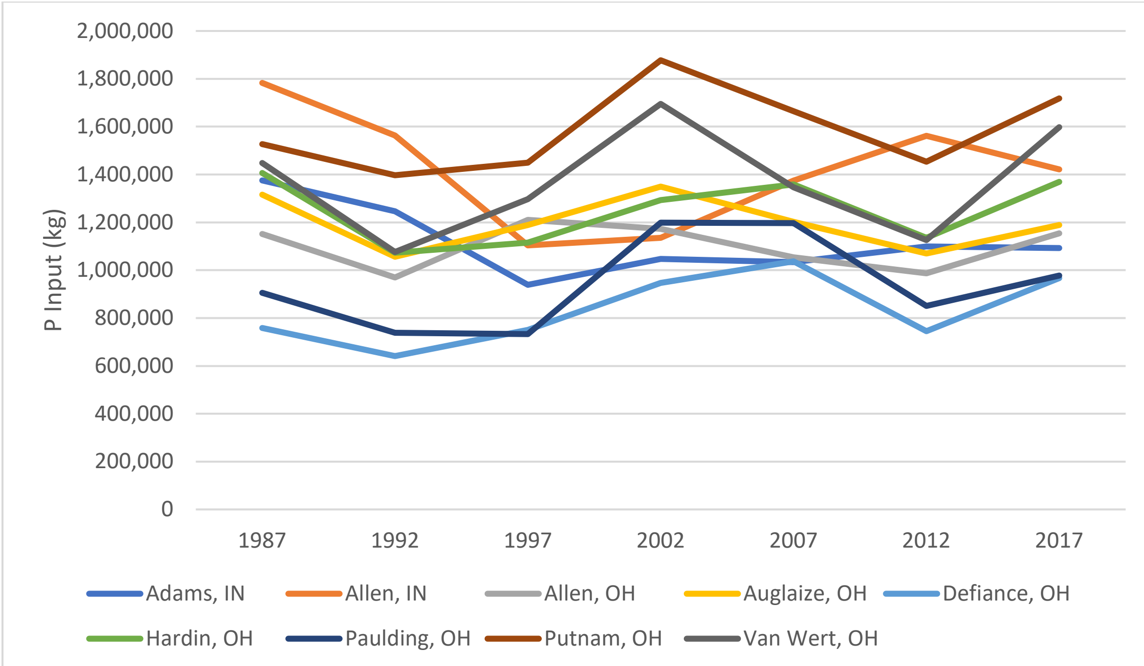


Figure 3-26. P Input: Commercial Fertilizer by County, 1987 - 2017

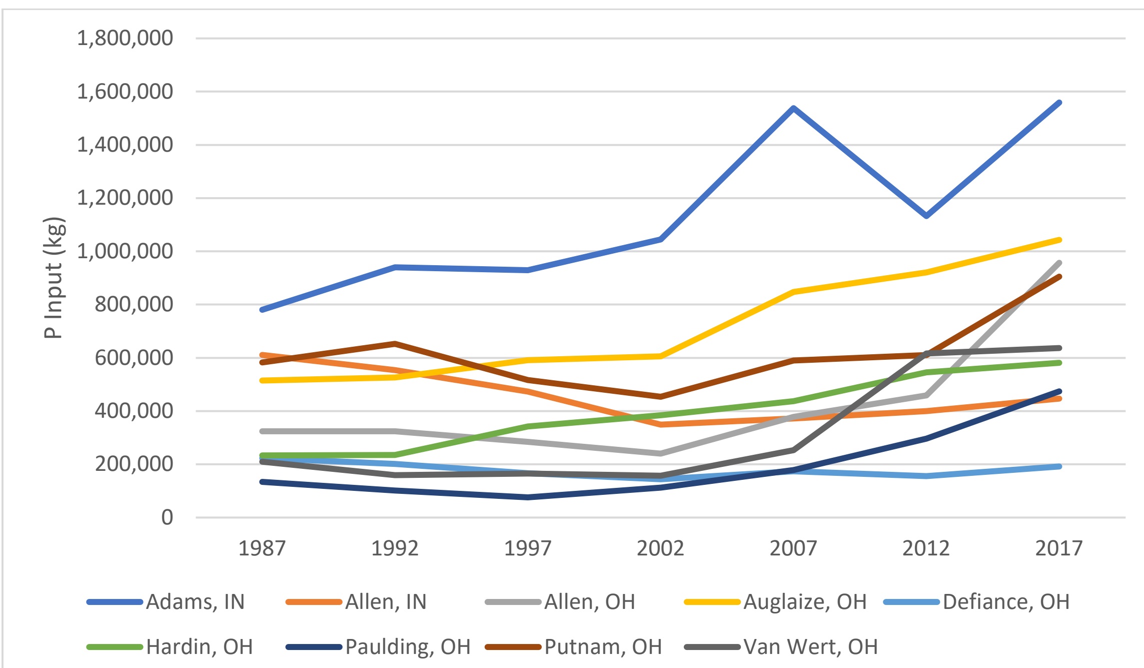


Figure 3-27. P Input: Manure by County, 1987 - 2017

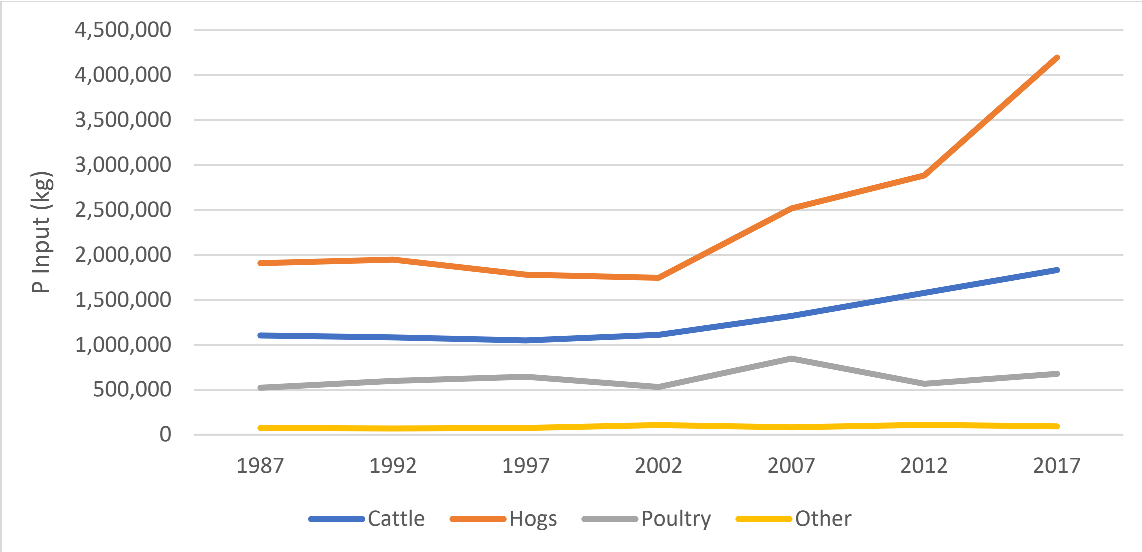


Figure 3-28. P Input: Manure by Animal Species, 1987 - 2017

Table 3-15 Phosphorus (as P) from Commercial Farm Fertilizer, in kilograms, 1987-2017

County Name	State	1987	1992	1997	2002	2007	2012	2017
Adams	IN	1,375,328	1,245,688	938,905	1,047,806	1,034,296	1,099,679	1,093,026
Allen	IN	1,782,907	1,562,474	1,103,819	1,134,894	1,374,789	1,562,328	1,421,678
Allen	OH	1,151,058	969,662	1,210,457	1,172,354	1,053,928	986,443	1,154,719
Auglaize	OH	1,316,351	1,056,194	1,188,682	1,349,517	1,202,073	1,069,522	1,188,645
Defiance	OH	757,801	640,981	749,973	947,259	1,037,018	744,532	966,703
Hardin	OH	1,406,488	1,073,109	1,114,748	1,292,926	1,358,110	1,134,879	1,369,846
Paulding	OH	905,616	738,196	732,925	1,198,749	1,196,624	850,506	977,129
Putnam	OH	1,526,838	1,396,982	1,450,151	1,877,625	1,665,298	1,454,081	1,718,554
Van Wert	OH	1,448,685	1,076,136	1,297,388	1,695,184	1,346,649	1,126,530	1,598,012
Total	--	**11,673,059**	**9,761,414**	**9,789,045**	**11,718,316**	**11,270,792**	**10,030,512**	**11,490,329**

Table 3-16 Phosphorus (as P) from Manure, in kilograms, 1987-2017 by County

County Name	State	1987	1992	1997	2002	2007	2012	2017
Adams	IN	780,482	940,363	928,782	1,044,469	1,537,431	1,131,915	1,559,149
Allen	IN	610,844	554,426	473,476	349,069	372,095	399,815	447,135
Allen	OH	324,275	324,183	284,348	240,211	378,392	458,299	957,046
Auglaize	OH	514,683	526,144	591,384	605,340	847,969	920,801	1,043,050
Defiance	OH	223,091	200,871	166,304	143,867	174,262	155,231	191,824
Hardin	OH	233,417	235,481	341,824	384,728	436,658	545,814	581,209
Paulding	OH	133,894	101,710	75,897	111,845	178,227	296,311	474,016
Putnam	OH	582,336	652,263	516,557	453,734	590,106	610,586	904,983
Van Wert	OH	209,509	158,836	165,439	157,176	253,699	616,624	636,735
Total	--	**3,614,518**	**3,696,269**	**3,546,008**	**3,492,441**	**4,770,846**	**5,137,408**	**6,797,164**

Table 3-17 Phosphorus (as P) from Manure, in kilograms, 1987-2017 by Species

Animal Species	1987	1992	1997	2002	2007	2012	2017
Cattle	1,104,426	1,080,423	1,048,362	1,110,807	1,322,024	1,575,803	1,831,071
Hogs	1,909,404	1,947,449	1,778,669	1,744,852	2,516,344	2,883,709	4,195,115
Poultry	522,271	597,566	643,360	528,820	846,684	566,443	676,878
Other	76,430	68,837	73,619	105,960	83,785	109,440	92,084

Fertilizer phosphorus contributions have generally remained steady (and consistently much higher than manure contributions) for more than the past decade, but P inputs from manure have increased significantly in recent years. Note, however, that application rates of commercial fertilizer and manure do not directly correlate with loss rates to waterways. Differences in forms of fertilizer and manure, application methods, field conditions, weather conditions, and timing of application can result in different rates of nutrient loss to waterways. For example, manure or commercial fertilizer that is broadcast on the soil surface and not incorporated is more likely to be mobilized in runoff during rain events; liquid manure may be more readily mobilized compared to solid manure if precipitation occurs soon after application. In addition, if liquid manure enters drain tiles it may be rapidly transported to surface waters. Processes and pathways that affect net nutrient loss from fields and the ultimate delivery of nutrients to Lake Erie are areas of active research.

Other studies have also estimated P inputs in the Great Lakes basin. Hamlin et al. (2020) estimated P inputs from a variety of sources across the entire U.S. portion of the Great Lakes Basin, and for HUC-8 and HUC-12 watersheds. Agricultural sources account for approximately 90 percent of total P inputs within the Lake Erie basin, with manure accounting for approximately 30 percent of total P and commercial fertilizers accounting for approximately 60 percent. The authors estimate agricultural fertilizer P input within the Auglaize River watershed at 4,475 metric tons per year, and manure P input at 2,047 metric tons per year.

Additionally, along with nutrient inputs, it is important to consider nutrient removal through crops. Dayton et al. (2020) estimated the soil P balance, by county, for Ohio; all seven Auglaize River watershed counties had a negative P balance, indicating more P removed by crops than added through fertilizer and manure application. However, the negative P balance was statistically significant in only three counties (Allen, Auglaize, and Paulding).

Medway Creek

P input data for the Medway Creek watershed were not available; however, a dataset estimating P inputs at the county (census division) level was identified for Ontario (Van Staden et al., 2021). Fertilizer and manure P inputs were estimated for the Middlesex census division, from 1986 through 2016. Fertilizer inputs are estimated based on total fertilizer sales in Ontario, and the total land area fertilized in Ontario and in Middlesex County. Manure P inputs are estimated based on the number of farm animals present in any given year. Using this dataset, manure P inputs appear to be a relatively higher proportion of total P inputs (nearly 50 percent) for the Middlesex census division as compared to the Auglaize River region.

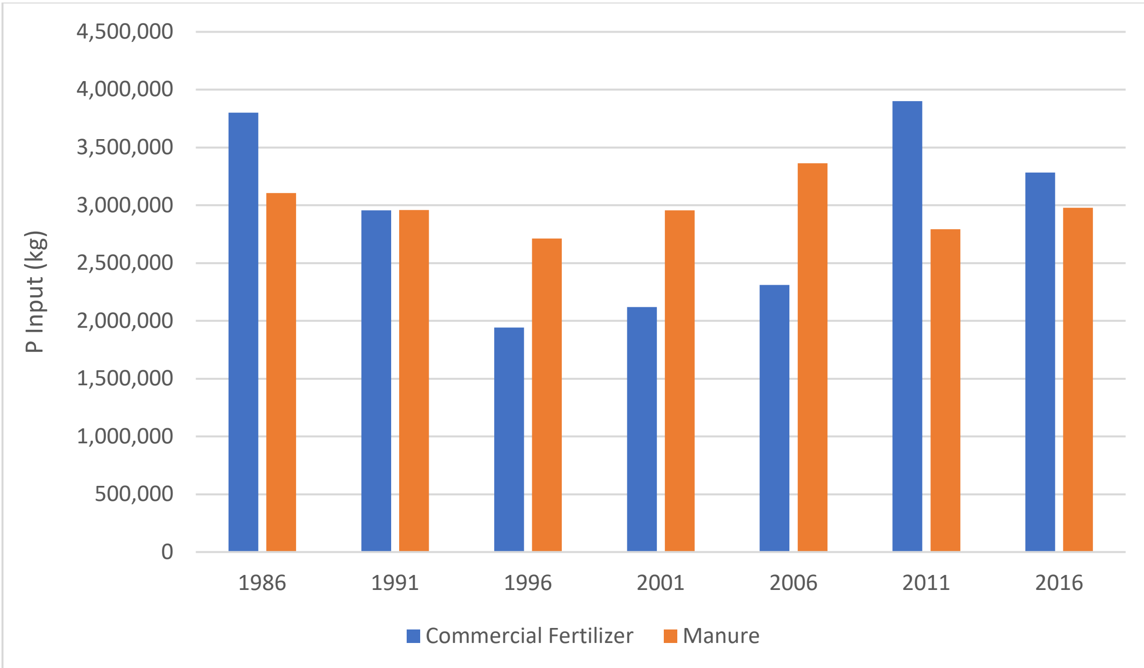


Figure 3-29. P Input: Commercial Fertilizer and Manure, Middlesex Census Division, 1986 – 2016

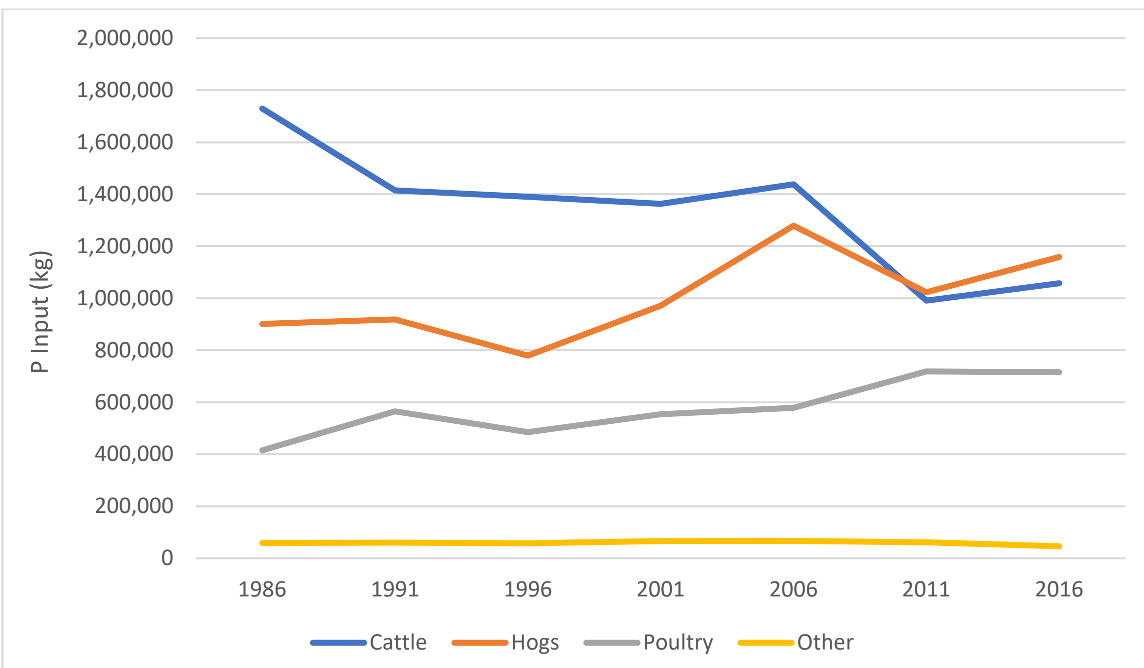


Figure 3-30. P Input: Manure by Animal Species, Middlesex Census Division, 1986 - 2016

Table 3-18 Phosphorus Inputs in Middlesex Census Division, in kilograms, 1986-2016

Source	1987	1992	1997	2002	2007	2012	2017
Commercial Fertilizer							
Fertilizer, Total	3,800,540	2,955,973	1,942,581	2,119,095	2,311,755	3,900,675	3,281,776
Manure							
Cattle	1,729,384	1,415,345	1,389,662	1,363,085	1,438,279	990,944	1,057,881
Pigs	901,587	919,081	779,476	972,126	1,279,101	1,022,710	1,159,095
Poultry	415,372	565,458	484,823	554,045	578,815	718,729	715,843
Other	58,664	60,290	57,775	66,943	67,303	61,106	46,490
Manure, Total	3,105,007	2,960,174	2,711,737	2,956,199	3,363,497	2,793,489	2,979,309

3.5.9 Manure and Commercial Fertilizer Contributions to P Loads

P loads typically refer to the amount of P entering streams and other waterbodies whereas P inputs reflect the quantity of P applied to land in the form of fertilizer, manure, and other sources. Estimating source contributions to P loads is challenging, as it depends on a variety of factors including application timing and methods, application rates, uptake by crops, amount of precipitation, and controls on field discharge including drainage water management and edge-of-field practices. Data on manure and fertilizer contributions to P loads within the Auglaize and Medway Creek watersheds were not generally available; however, two recent studies are discussed below.

Meyer at al. (2022) analyzed satellite imagery and permit data to identify AFO locations in the Maumee Watershed and estimate animal counts where data were unavailable. They used hydrological GIS data to identify stream reaches that were closest to AFO locations and therefore most likely to be impacted by any runoff from manure application. Finally, they used available stream monitoring data to estimate the impact of AFOs on downstream water quality. Their results indicate an increase of 10.2% in DRP levels following the addition of 1,000 animal units within 20 km upstream of the monitoring location. They also found that commercial fertilizer use likely plays a larger role in DRP concentrations than AFOs.

Robertson et al. (2019) developed a SPARROW model to estimate phosphorus and nitrogen transport in the entire Great Lakes basin and estimate source contributions to lake P loads. The modeling effort was based on nutrient inputs similar to 2002. The SPARROW model developed by Robertson et al. included nutrient contributions from both the U.S. and Canadian portions of the Great Lakes basin. This section discusses overall model results for the Great Lakes basin, including Lake Erie; data are not available for the Auglaize River and Medway Creek watersheds.

Robertson et al. (2019) estimated total phosphorus load to Lake Erie at 9,860 metric tons per year. Farm fertilizers were estimated to account for approximately 24.4 percent of this load, and manure loading was an additional 9.9 percent. Together, farm fertilizers and manure accounted for approximately 34.3 percent of P load to Lake Erie. Figure 3-31 shows overall source contributions to each of the Great Lakes. Note that this analysis did not differentiate DRP from total P loads.

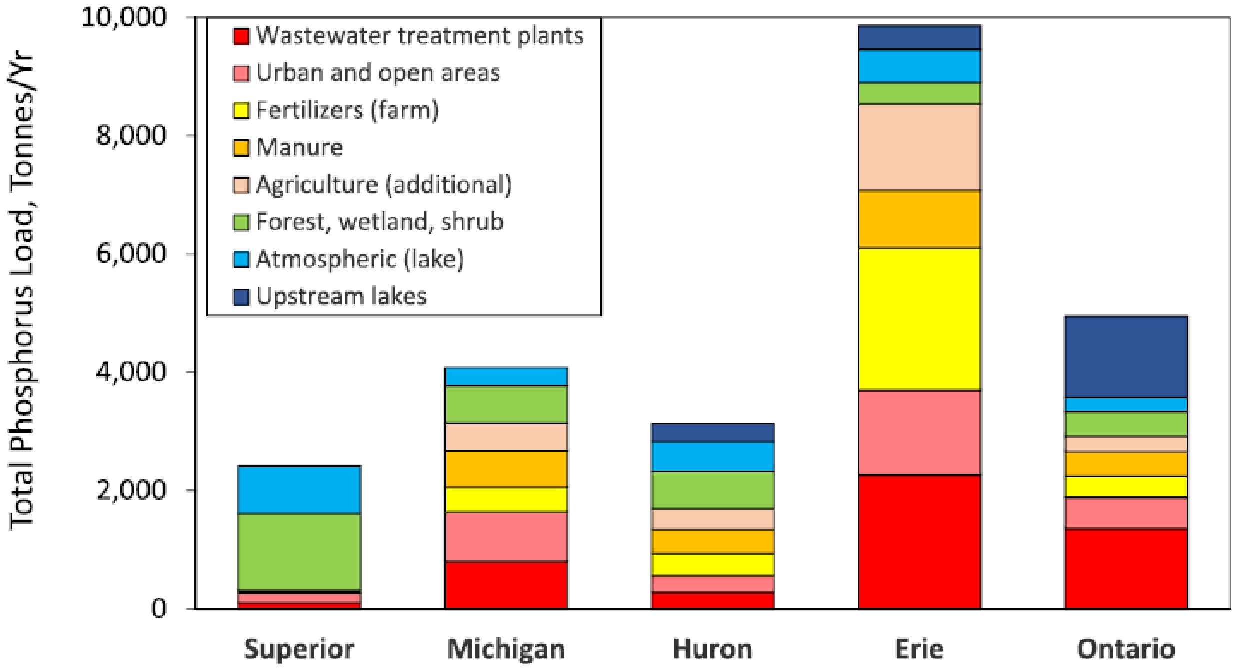


Figure 3-31. SPARROW-model Estimated Total P Loads by Source *(Reproduced from Robertson et al. 2019)*

3.6 Regulation and Management of AFOs and Manure Application

Both the U.S. and Canada require nutrient management planning for large livestock operations, but their approaches to determining the size of the operations have important differences. In addition, within the U.S., there are significant differences in manure management regulations between states, as discussed below.

In general, distinctions between AFOs that require permitting and those that do not are based on animal counts, with different numerical thresholds typically used for different animal types (e.g., cows, hogs, or chickens). This is based on the recognition that manure generation per animal and the form of the manure (solid versus liquid) vary by type of animal. Effectively, this means that more smaller animals than larger animals are allowed per farm before a permitting requirement is triggered.

3.6.1 U.S.

In the U.S., some AFOs are subject to wastewater discharge permitting under federal regulations, primarily under the CWA. In addition, many states require permits for other AFOs under state agricultural management regulations, and otherwise regulate the operation of these facilities.

Clean Water Act (CWA) Rules

Under the CWA, certain AFOs are subject to federal wastewater discharge permitting requirements. The USEPA defines AFOs as agricultural operations where animals are kept and raised in confined situations[12].

[12] https://www.epa.gov/npdes/animal-feeding-operations-afos

According to the USEPA, an AFO is a lot or facility (other than an aquatic animal production facility) where the following conditions are met:

- animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and
- crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.

Not all AFOs are subject to permitting requirements under the CWA rules. CWA implementing regulations define size thresholds for small, medium, and large CAFO, which may be subject to National Pollutant Discharge Elimination System (NPDES) permitting requirements (see Table 3-19). CAFOs are required to obtain NPDES permits if they "discharge or propose to discharge," i.e., if the facility is designed, constructed, operated, or maintained such that a discharge will occur.

Table 3-19 USEPA Regulatory Definitions of Large, Medium, and Small CAFOs[13]

Animal Category	Number of Animals for Threshold		
	Small CAFO	Medium CAFO	Large CAFO
Cattle	<300	300-999	≥ 1,000
Dairy Cattle	<200	200-699	≥ 700
Swine (over 55 pounds)	<750	750-2,499	≥ 2,500
Swine (under 55 pounds)	<3,000	3,000-9,999	≥ 10,000
Turkeys	<16,500	16,500-54,999	≥ 55,000
Laying Hens: non-liquid manure handling	<25,000	25,000-81,999	≥ 82,000
Laying Hens: liquid manure	<9,000	9,000-29,000	≥ 30,000
Hens: non-laying	<37,500	37,500-124,999	≥ 125,000

NPDES permit requirements under the federal rule include:

- Prohibition of discharge from the operation's production area, except in the event of a 25-year, 24-hour storm event (or a 100-year, 24-hour storm event for new veal, poultry, and swine facilities) if the required records are maintained.
- Development and implementation of a manure management plan that includes best management practices to protect water quality (see additional information under USDA programs, below).
- Application of manure based on nitrogen and phosphorus restrictions.
- Record-keeping.
- Annual reporting.

[13] Table reproduced from: Great Lakes Water Quality Board. (2019). *Oversight of Animal Feeding Operations for Manure Management in the Great Lakes Basin*. https://ijc.org/sites/default/files/2020-01/WQB_ManureManagementReport_2019.pdf

Ohio and Indiana have the authority to regulate CAFOs under their state NPDES permitting programs, as discussed below. Ohio EPA and the IDEM are responsible for implementing the NPDES permitting programs in their respective states. In Ohio, NPDES permits are required for facilities that meet the large CAFO definition, and that have either a designed wastewater discharge or are in violation of CWA requirements. A list of CAFOs permitted under Ohio's NPDES regulations is available on the Ohio EPA's CAFO website (Ohio EPA, 2022b). In Indiana, NPDES permits are required for facilities meeting the USEPA's large CAFO definitions. Note that currently, there are no CAFOs in Indiana subject to NPDES permitting requirements[14].

Both Ohio and Indiana have additional state permitting requirements for certain AFOs, as discussed below.

U.S. Department of Agriculture (USDA)

The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) provides technical and financial assistance to support farmers in adopting practices that protect the country's natural resources. NRCS offers the Environmental Quality Incentive Program (EQIP) financial assistance program for the storage, treatment, and implementation of conservation practices to AFOs[15]. The USDA NRCS also promulgates standards for nutrient management, including the Conservation Practice Standard for Nutrient Management, Code 590[16]. NRCS 590 discusses a range of nutrient types including animal manure. The NRCS 590 standard includes tools to help determine the risk of nutrient loss from farm fields.

Ohio and Indiana have adopted state-specific versions of the NRCS 590 standard. The Ohio 590 standard includes guidance on "Assessing Nutrient Loss Risk in Ohio" while the Indiana 590 standard includes the "Indiana Nutrient and Sediment Transport Risk Assessment Tool" (NASTRAT). While the two risk assessment tools differ in their specifics, they include an assessment of existing soil P levels using the Mehlich-3 (Ohio) or Mehlich-3/Bray-P1 test (Indiana). Ohio defines P loss risk as high for soils if the Mehlich-3 test result is greater than 120 ppm, while Indiana defines P loss risk as high if the Bray-P1 or Mehlich-3 test returns a value over 50 ppm. Note that a Mehlich-3 test of 120 ppm is equivalent to a Bray-P1 value of approximately 90 ppm[17]. The Indiana 590 standard also considers other factors in the P loss risk assessment including soil and water erosion risk, leach index, subsurface drainage potential, flooding frequency, and distance to waterbody. Both state standards require mitigation, including limits on nutrient application rates, if risk is determined to be "High" or "Very High."

Ohio Department of Agriculture

The ODA, Division of Livestock Environmental Permitting regulates concentrated AFOs, termed in the state as Concentrated Animal Feeding Facilities (CAFF). ODA has the authority to issue two types of permits: Permits to Operate (PTO) and Permits to Install (PTI). Note that NPDES permits are only required for

[14] https://www.in.gov/idem/cfo/resources/pending-and-issued-cfo-permits/
[15] https://www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives
[16] https://www.nrcs.usda.gov/wps/cmis_proxy/https/ecm.nrcs.usda.gov%3A443/fncmis/resources/WEBP/ContentStream/idd_90999673-0000-C813-A5C2-1EFCEA3826AF/0/FY20_TECH_RESOURCE_590_Nutrient_Management-Revision_Process_Ohio_FACTSHEET_07_20.pdf
[17] https://ohioline.osu.edu/factsheet/anr-75

facilities that "discharge or propose to discharge" and these permits are administered by the Ohio EPA. ODA permitting requirements apply to all facilities that meet the USEPA size threshold for large CAFOs (> 1,000 animal units), regardless of discharge status. CAFFs are required to prepare manure management plans, maintain application records, and meet manure storage requirements including a minimum of 180 days for fabricated structures or lagoons storing liquid manure, and 120 days for fabricated structures storing solid manure, plus sufficient freeboard. Additionally, all Permits to Operate are required to be renewed every five years, which includes updating the manure management plan.

Ohio Revised Code Chapter 939, Section 09 includes additional restrictions on manure application in the WLEB, including:

- Prohibiting the surface application of manure in the western basin of Lake Erie (including the Auglaize River watershed) on frozen or snow-covered soil or when the top two inches of soil is saturated from precipitation.
- Prohibiting the surface application of manure when the local weather forecast contains greater than a 50 percent chance of precipitation exceeding one-half inch in a 24-hour period, but allows for manure to be injected into the ground, incorporated within 24 hours of surface application, or applied onto a growing crop.

In addition to managing AFOs, ODA requires a Certified Livestock Manager (CLM) certification for the following:

- Livestock manure brokers that buy, sell, or land apply more than 4,500 dry tons of solid manure per year or 25 million gallons of liquid manure, or its equivalent.
- Livestock manure applicators who land apply and transport more than 4,500 dry tons of solid manure per year, or 25 million gallons of liquid manure, or its equivalent.

The certification must be renewed every three years. CLMs are required to maintain records of manure application in accordance with Ohio Administrative Code Rule 901:10-2-16, including the area of land where manure was applied, soil test records, inspections of discharge from subsurface drains, inspection of setbacks and edge-of-field practices, and the date, rate, quantity, and method of application. According to ODA personnel, more than 90 percent of manure generated by permitted CAFFs is managed under ODA oversight, either by the facilities themselves or by CLMs (Mullins, S., personal communication, October 28, 2022).

The ODA uses “animal units” to assess whether individual AFOs are subject to regulation (see Figure 3-32). Animal units convert different species into a common number using conversion factors, to normalize the different impact of each species on manure generation.

Animal Category	Large CAFO/CAFF Permit Threshold	Animal Unit
Beef Cattle/Heifers/Calves	1,000	1 AU = 1 beef cow/heifer/calf
Mature Dairy Cattle	700	1 AU = 0.7 mature dairy cow
Swine (≥ 55 lbs.)	2,500	1 AU = 2.5 swine (≥ 55 lbs.)
Swine (< 55 lbs.)	10,000	1 AU = 100 swine (< 55 lbs.)
Turkeys	55,000	1 AU = 55 Turkeys
Laying Hens (solid manure system)	82,000	1 AU = 82 hens (solid manure system)
Laying Hens (liquid manure system)	30,000	1 AU = 30 hens (liquid manure system)
Hens: non-laying (solid manure system)	125,000	1 AU = 125 hens, non-laying (solid manure system)

Figure 3-32. ODA Conversion Factors Used to Estimate Animal Units

Indiana Department of Environmental Management

In Indiana, AFOs are regulated by the IDEM, as described in IC 13-18-10 of the Indiana Code. Per Indiana law, all regulated feeding operations within the state are considered to be Confined Feeding Operations (CFOs) once they exceed the following counts:

- 300 or more cattle
- 600 or more swine or sheep
- 30,000 or more poultry (chicken, turkey, or duck)
- 500 horses in confinement

The next threshold the state recognizes are CAFOs; farms that exceed these animal counts are still permitted under the CFO rule but have additional regulatory requirements. The USEPA's definition of a large CAFO is used to determine when a CFO becomes a CAFO in Indiana (Table 3-13). The IDEM maintains a publicly accessible list of NPDES permitted CAFOs[18].

Indiana rules under the Confined Feeding Operation Rule, 327 Indiana Administrative Code 19 contain restrictions on manure application in the WLEB[19]. CFOs are also required to provide at least 180 days of manure storage capacity.

3.6.2 Canada

In Canada, AFOs are regulated at the provincial level. The OMAFRA oversees animal feeding operations in Ontario, including within the Medway Creek watershed. The 2003 Nutrient Management Protocol for

[18] https://www.in.gov/idem/cfo/resources/pending-and-issued-cfo-permits/
[19] http://iac.iga.in.gov/iac/T03270/A00190.PDF

Ontario Regulation 267/03, established under the Nutrient Management Act of 2002 (NMA), regulates livestock operations in the province, implemented by the OMAFRA. The NMA was partially developed to address concerns resulting from the Walkerton drinking water incident in 2000, where hundreds of illnesses and six deaths were caused by contamination of a public water supply by manure following heavy rains and flooding, which allowed manure-contaminated water from a livestock farm to enter a downslope drinking water well.

The NMA requires the use of "Nutrient Units" (NUs) to manage AFOs[20]. The NMA approach is to convert each type of animal (34 different types are specified) as the fractional equivalent or multiple of a beef cow (= 1.0 NU). For example, 1.0 NU is the equivalent of 6.0 dairy calves, 150 laying hens, or 0.7 large-frame dairy cows[21]. The total NU count must be calculated for each farm to determine whether a nutrient management strategy or plan will need to be prepared for the operation and what level of review and approval is required. A selection of examples of farm animal operations by size is shown below in Table 3-20, reproduced from the OMAFRA.gov website.

Table 2-20 Examples of Farm Animal Operations by Size

Animal Sector Examples	Farm Units >5 NUs	Farm Units >5 NUs, but <150 NUs	Farm Units ≥150 NUs, but <300 NUs	Farm Units ≥300 NUs
Milking-aged Holstein dairy cows (includes calves & heifers, so use 0.55 dairy cows/NU)	>3	>3, but <82	≥ 82, but <165	≥ 165
Milking-aged Jersey dairy cows (includes calves & heifers, so use 0.77 dairy cows/NU)	>4	>4, but <115	≥ 115, but <231	≥ 231
Beef cows (including unweaned calf & replacements)	>5	>5, but <150	≥ 150, but <300	≥ 300
Beef feeders (575-1250 lbs) (# of feeding spaces)	>15	>15, but <450	≥ 450, but <900	≥ 900
SEW Weaners (15-60 lbs) (# of weaner spaces)	>100	>100, but <3,000	≥ 3,000, but <6,000	≥ 6,000
Finishing pigs (60-230 lbs) (# of spaces in barn)	>30	>30, but <900	≥ 900, but <1,800	≥ 1,800
Laying hens (# of layer spaces in barn)	>750	>750, but <22,500	≥ 22,500, but <45,000	≥ 45,000
Chicken broilers (total sq.ft of floor growing area)	>1335 sq.ft	>1,335 but <40,000 sq.ft	≥ 40,000, but <80,000 sq.ft	≥ 80,000 sq.ft
Turkey broilers/hens/toms (total sq.ft of floor growing area)	>1350 sq.ft	>1,350, but <40,000 sq.ft	≥ 40,000, but <80,000 sq.ft	≥ 80,000 sq.ft

SEW – Segregated early weaning

For farms with less than 5 NUs, no action is required. Farms with more than 5 NUs are regulated and require an approved Nutrient Management Strategy (NMS; covers manure handling and storage) or a Nutrient Management Plan (NMP; covers field application of manure). Operations with more than 5 but less than 150 NUs may be eligible to use a short form of the NMS or NMP. For operations with more than 150 but less than 300 NUs, new operations are subject to the regulation with application for building permit and their NMS or NMP must be approved by province per Part 4 of the Regulation. At greater than or equal to 300 NUs, both new and expanding operations are subject to the regulation with application

[20] http://omafra.gov.on.ca/english/nm/regs/nmpro/nmpro03-jun03.htm
[21] https://www.ontario.ca/page/calculating-nutrient-units-livestock-and-poultry

for building permit. Their NMS or NMP must be approved by province per Part 4 of the Regulation[22]. Per the NMA, all facilities that require an NMS must provide a minimum of 240 days of manure storage.

Ontario discourages but does not prohibit the spreading of manure in winter, or when soil is saturated or rainfall is forecast. Environmental laws in Canada do make it an offense for manure to enter surface water at any time of year. These laws include the Canadian Environmental Protection Act, the Ontario Water Resources Act, and the federal Fisheries Act.

3.6.3 Comparison of U.S. and Canadian Manure Management Regulations and Policies

Both the U.S. and Canada require planning, management, and oversight of large livestock operations by state or provincial agencies. However, there are key difference between the two countries, as well as between Ohio and Indiana. Some of the key differences include:

- The regulatory threshold is significantly lower in Ontario versus the U.S. For example, the lowest level of regulation kicks in for an operation with 5 beef cattle in Ontario, but the initial trigger would be 300 cattle in Indiana or 1,000 beef cattle in Ohio (see Table 3-21). Note that depending on the animal species, different regions' regulatory thresholds may be reached sooner or later.
- The regulations are implemented by the provincial agriculture agency, OMAFRA, in Ontario, and ODA in Ohio. However, in Ohio some facilities with discharge permits are also regulated by the state environmental agency, Ohio EPA, which also regulates drinking water, urban stormwater, industrial and municipal wastewater, and other waste disposal and waste management programs. In Indiana, the state environmental regulatory agency, IDEM, is responsible for all CFO and CAFO permitting and oversight.
- There are also some key differences in manure management requirements.
    - Regulated AFOs in Ontario are typically required to provide more on-site manure storage (240 days) compared to AFOs in Indiana (180 days) or Ohio (180 or 120 days, depending on the type of manure).
    - Manure application on frozen or snow-covered ground is prohibited in Ohio and Indiana, but not in Ontario; however, it is discouraged by OMAFRA.

Table 3-21 Examples of Farm Animal Operations by Size

Permitting Threshold	Ohio	Indiana	Ontario
5 cattle	--	--	Nutrient Management Strategy (NMS) and/or Nutrient Management Plan (NMP) required (short form)
150 cattle	--	--	Full NMP and/or NMS required, permit for new facilities
300 cattle	--	CFO permit required	Permit required for new or expanding facilities

[22] http://omafra.gov.on.ca/english/nm/regs/nmpro/nmpro03-jun03.htm

1000 cattle	CAFF Permit required/CAFO permit required if discharge also occurs	CAFO permit required, if discharge also occurs	--

3.6.4 Best Management Practices for Manure Management

4R Nutrient Stewardship Program

The 4R program was launched in March 2014 to encourage agricultural retailers, nutrient service providers, and other certified professionals to adopt best practices through the 4Rs, the Right source of nutrients at the Right rate and Right time in the Right place. Since its start in the Western Lake Erie Basin, the program expanded to include all of Ohio in 2017 and became international in 2019. The program outlines a set of cumulative criteria to be implemented over a 3-year period. Annual inspections from independent auditors certify that the nutrient service provider meets the criteria. As of December 2022, there were 55 certified branch facilities and 2.5 million acres in the program, of which 45 facilities and 1.53 million acres were located in the Western Lake Erie Basin[23].

The four primary goals of the program are:

1) Maximize crop nutrient uptake and minimize crop loss
2) Positively impact local water bodies
3) Provide up-to-date information on nutrient stewardship
4) Help the agricultural sector adapt to new research and technology

In Canada, the 4R program certifies nutrient service providers across Ontario. It is funded and guided by a 4R Ontario Steering Committee and is administered by Fertilizer Canada. To date, more than 113,000 acres of farmland in Ontario have been brought under 4R Nutrient Stewardship, with roughly 67 per cent of farms implementing some form of this nutrient planning and management method.

H2Ohio

The H2Ohio program was launched in 2019 to address a range of water-related issues in Ohio, including harmful algal blooms in Lake Erie caused by phosphorus runoff from farm fertilizer. First funded in 2020-2021, H2Ohio aims to reduce phosphorus runoff from farms through seven nutrient management best practices and the creation of phosphorus-filtering wetlands. H2Ohio provides economic incentives to famers who implement best management practices, starting with a voluntary nutrient management plan[24].

As part of the H2Ohio plan, counties in the Maumee River Watershed each have a localized phosphorus target to help ensure accountability. Individualized nutrient management plans are developed for participating farms to identify which H2Ohio best management practices (BMPs) will reduce the most phosphorus runoff at each location. Soil and Water Conservation District Offices in each county lead local efforts to help farmers enroll in the H2Ohio program and to help them implement best practices. Another

[23] https://4rcertified.org/
[24] https://h2.ohio.gov/

strategy to reduce phosphorus runoff under the program is to create wetlands. H2Ohio is led by the Ohio Department of Agriculture, Ohio Department of Natural Resources, Ohio Environmental Protection Agency, and the Lake Erie Commission.

Manure-related BMPs recognized under H2Ohio include developing and implementing nutrient management plans, planting overwintering cover crops, manure incorporation, conservation crop rotation, and drainage water management. As of 2022, H2Ohio had enrolled over 9,200 projects with an estimated P reduction of over 250,000 lbs.

Other Technologies for Nutrient Management

Many management technologies exist to optimize the value of manure as a crop fertilizer and to minimize its mobility and potential negative impacts on water quality. The basic components of these systems have existed for many years and have included approaches to reducing the water content of manure, thereby making the handling of the manure easier and reducing the chances that associated nutrients will migrate away from the site of application to a ditch, creek, or river. Additional treatment and management technologies are intended to extract value from the manure in the form of energy or recycled material that is not intended for use as fertilizer and to reduce or eliminate pathogens.

Table 3-18 describes a suite of manure technologies or technology categories. Although not all are new, many have become increasingly sophisticated in recent years due to the advent of electronic monitoring, management, and control systems and enhanced biotechnology and chemical engineering. Other innovations include combining two or more technologies that were previously used independently and generally integrating process management from feed selection on the generation end to microbial soil health management on the field crop end. One key component of many of the technologies is that they only become cost-effective at large scales and may require manure inputs from multiple facilities and dedicated full-time operators.

Table 3-22 lists some management options for animal manure. Some are more suitable for certain types (e.g., solid vs liquid manure), and certain treatments may need to be used in sequence (e.g., solids separation followed by composting).

Table 3-22 Manure Management Technologies

Technology	Description	Cost	Applicability	Nutrient Removal	Challenges
Anaerobic Digesters	Large tanks or covered lagoons allow for microbial breakdown of manure to methane	High	Most efficient at large, multi-farm facilities; high capital costs; can be combined with biorefining to create more marketable products (biofuels)	Does not remove P—only reduces organic content, some N	Technically challenging to operate; digestate disposal challenges remain
Aerobic Treatment	Treatment of manure slurries by oxygen-consuming bacteria to reduce biomass and odor	High	Most efficient at large, multi-farm facilities; high capital costs	Can remove nitrogen but not P	Operating motors, compressors or fans to supply oxygen to bacteria is expensive and challenging
Solids Separation	Reduction of water content of manure by settling, air drying, pressing, centrifugation or other means to improve the ability to manage it	Low to high	Not necessary for dry manures (poultry); more challenging as water content increases (e.g., hog manure)	Reduces P mobility and facilitates transportation (less weight), some incidental N loss possible by degassing	Capital and maintenance costs for more complex mechanical equipment can be high; liquid effluent may require treatment
Storage Covers	Roofs, tarps, or other barriers that minimize increases of manure volume and mobilization during storage by precipitation	Moderate	Applicable to manure piles and smaller lagoons	None—mostly protects from mobilizing by runoff during storage	Securing non-rigid covers from wind may be difficult; large lagoons are impractical to cover
Composting and vermi-composting	Use of managed microbial decomposing of manure to reduce volume, kill pathogens, kill parasites, reduce weed seeds, and improve soil health; vermicomposting uses worms in the process	Moderate	Suitable for high-solids manure or mixtures with organic residues; long history of use for many types of manures and crops; additional composting area and facilities or equipment may be required	Little impact on P, some incidental N loss possible by degassing; methane and water loss	Can be challenging to maintain sufficient temperature in compost piles in winter; requires ongoing monitoring and turning; process takes several months

Technology	Description	Cost	Applicability	Nutrient Removal	Challenges
Subsurface Injection (Field)	Technologies to allow for direct subsurface placement of manure in fields with minimal soil disturbance and possibility for runoff	High	Typically spring or fall application of high-liquid manure to fields without crops; some ability to apply through thin snow/frost	Not applicable--intended to reduce manure loss in runoff	Associated toolbars may require upgrades to tractors and other equipment to handle needed power and tanks

As with other areas of technology development, manure technology innovators compete in challenges, prize or award competitions, and investor pitch sessions to attract capital and customers. One example is the Manure Challenge[25]. Financial incentives related to manure management stand to accelerate innovation and investment related to manure including nutrient trading programs, carbon credit programs, and government grant programs to offset geopolitical factors that are driving up the price of fertilizer. As an example of the latter, the USDA announced in 2022 that it was making available 500 million U.S. dollars (USD) in grants to increase innovative U.S.-made fertilizer production[26].

3.6.5 Financial Support and Funding Opportunities

One of the primary USDA NRCS programs for conservation funding under the U.S. Farm Bill, including for improving manure management, is the EQIP[27]. The maximum cap for a single farm for EQIP funds (all programs, not just manure-related) over 5 years is 450,000 USD. The USDA, through the Farm Service Agency (FSA), also provides loans to livestock producers. The Ohio clean water initiative, H2Ohio, approved the use of funds for enhancing subsurface nutrient placement and manure incorporation into soil in 2022[28]. As an example, the DataOhio interactive dashboard tool shows that for Auglaize County, 23.4 percent of the cropland was covered by at least one H2Ohio agricultural BMP, including almost 42,000 acres and 109 producers, with funding of 1.24 million USD. State and federal agricultural extension agents aid producers with preparing applications for grant programs and provide technical advice free of charge to livestock operators.

In Canada, a variety of funding programs provide grants, cost share, or other incentives and subsidies for improved manure management in the Upper Thames River Watershed. These include the federal-provincial Canadian Agricultural Partnership, which provides a 25 percent cost-share up to 20,000 Canadian dollars (CAD) for manure storage improvements[29]. In 2022, Ontario's On-Farm Climate Action

[25] https://www.manurechallenge.com/; https://www.agproud.com/articles/36586-8-innovative-technologies-offer-solutions-for-manure-management
[26] https://www.usda.gov/media/press-releases/2022/09/27/biden-harris-administration-makes-500-million-available-increase
[27] https://www.nrcs.usda.gov/sites/default/files/2022-10/EQIP%20Livestock.pdf
[28] https://h2.ohio.gov/h2ohio-producers-eligible-for-next-phase-of-program-incentives/
[29] https://ontarioprogramguides.net/pc-en-esim-pd-e/

Fund has provided incentives for new practices regarding the use of manure, compost, and digestate as commercial fertilizer substitutes up to a cost-share of 65 percent and 30,000 USD[30]. A program that ran from 2015-2018, known as the Great Lakes Agricultural Stewardship Initiative (GLASI), provided cost-share for agricultural BMPs in Ontario's Lake Erie Basin, including manure-related practices, of up to 75 percent, to a maximum of 25,000 CAD[31].

Limited additional financial or technical assistance for improving manure management practices, increasing adoption of practices, and advancing related research in Canada and the U.S. is provided by non-profit environmental conservation organizations (e.g., The Nature Conservancy, National Wildlife Federation), private foundations (e.g., Rotary Foundation, The County Foundation, Foundation for Food and Agricultural Research), and for-profit corporations (e.g., Royal Bank of Canada's Blue Water Project, Cargill).

[30] https://www.biocycle.net/ontarios-on-farm-climate-action-fund/
[31] https://news.ontario.ca/en/release/31692/great-lakes-agricultural-stewardship

4. Overall Data Assessment

To begin the data assessment, gaps in the available data were identified, including any challenges in identifying, accessing, or using the data, or simple lack of data availability.

Auglaize River

In the Auglaize River watershed, several key data gaps were identified:

Locations of permitted facilities in Ohio: For Indiana, geospatial data on the locations of permitted CFO and CAFO facilities was available from maps.indiana.edu. To get a list of locations for permitted facilities in Ohio, a data request must be submitted to the ODA. Previously, a map of facilities in Ohio was available for viewing; however, it is no longer hosted by either the ODA or the Ohio EPA.

Non-permitted facilities (location and number): There are no official sources of data providing the locations of non-permitted AFOs in either Ohio or Indiana. A map that estimates the locations of non-permitted facilities in the Maumee River watershed via aerial imagery review is available from the EWG; however, it is only accessible through an online map viewer. The underlying GIS data are not available for download. Additionally, the EWG study may fill a gap here for locations, but it is not available everywhere in the U.S. or even everywhere in Ohio. The total number of AFOs may be obtained from USDA NASS.

Animal counts: Up-to-date total animal counts were not readily available as the most recent USDA census was from 2017. Counts for permitted facilities can be obtained through two methods, review of annual inspection reports or review of facility fact sheets. This requires a data request to ODA.

Manure application practices: Manure application is farm-level data due to the variability in application rates, application timing, application frequency, and application method. There is no single, accessible source that catalogs detailed information about how much land manure is applied to, when, at what rates, and at what distance to streams, in a uniform manner for either Ohio or Indiana. The best information available comes from a review of the facility inspection reports; however, this requires a data request from ODA and an extensive review of multiple reports to cover all permitted facilities in a given watershed for a selection of years. In addition, non-permitted facilities are not required to have inspection reports.

Medway Creek

Similar key data gaps were identified In the Medway Creek watershed:

Non-permitted/Permitted facility location: Data on individual intensive livestock operations in Ontario is not readily accessible online, similar to the findings documented in LimnoTech (2017). Studies such as the one completed for the Maumee River watershed by EWG have not been completed for the Thames River or the Medway Creek watersheds.

Animal counts: Inventories of animals were available at the level of a consolidated subdivision for all the census blocks included within the boundary of the Medway Creek watershed. However, there wasn't data about the location of animal feeding facilities at this scale that would allow for the contractor team to determine the number of animals within the watershed boundary versus outside of it. For a larger watershed, it may have been useful to have the data at a scale that is comparatively finer than the county-level for U.S. census surveys, but given the size of the Medway Creek watershed, a census subdivision was still too coarse.

Manure application practices: Like the Auglaize River watershed, detailed information about manure application practices (how much land is it applied to and at what distance, what distance to streams, etc.) were not readily available. This is a larger gap in the Medway Creek watershed than in the Auglaize River watershed as the former lacks the equivalent of the inspection reports available for Ohio facilities.

General gaps, observed for both watersheds, include:

- Smaller AFOs do not appear in many datasets; data compilation for this type of analysis should be by watershed—not by county or municipal designation
- Additional data would be needed to assess impacts, i.e., link BMPs to changes in water quality data
- General availability of discussion on best management technologies: focus on top BMPs (subsurface placement, low till, buffer strips; complexity of wetland restoration; high cost of phosphorus traps (filter media, engineering, maintenance) and biodigesters.

Key Differences in Data Availability between the Auglaize River and Medway Creek

The next portion of the data evaluation was to evaluate differences in data reporting, collection and accessibility between the Ohio/Indiana and Ontario jurisdictions. The first, and most obvious, difference identified was the existence of permitted facilities in Ohio and Indiana versus Ontario. This impacts data accessibility and reporting in a number of ways simply because additional regulation typically results in additional records. The next difference identified was the timescale of available survey data. While in Canada, 2021 data are available, the most recent national U.S. survey available is the 2017 USDA NASS data. For other Canadian items, the 2016 is the most recent.

In addition to the general items identified above, there were also differences in the nutrient-/manure-specific data available. For example, county levels of nutrient inputs via manure are available for the U.S. via USGS, but no equivalent body of data was identified for Canada. Work by the USGS and Heidelberg University has also led to robust water quality data for the Auglaize River; similar data were not available for the Medway Creek watershed. Finally, as noted earlier, the aerial imagery work completed by the EWG meant estimates on animal counts and locations were available for the study-relevant portions of Ohio and Indiana, but not Canada.

Canada's manure data management is more sophisticated in some ways than U.S. data management. The availability of data at the census subdivision level is, in Ontario, more specific than at the county-level scale utilized in the U.S. More recent data were available for Canada than for the U.S. Additionally, the online interface for the Canadian data was noted as being excellent for querying data on any one of the available geographic scales simply by searching the name of the division.

Data Needs for Manure Impact Assessment

For the third portion of the data evaluation, the contractor team considered what additional data would be needed to determine the impact of manure application on water quality in a given watershed, and the geographic and temporal scale at which this data would be needed. Based on experience with the development of water quality models a list was developed that specified typical items either (1) seen in manure analysis studies or (2) estimated in some manner during model development and application. This list included:

- The number of animals in any given watershed. Available data (e.g., USDA NASS) are typically organized by county rather than watershed.
  - This total value should include not just permitted animals, but non-permitted as well
  - Total values should be by type of animal
- An estimate of the nutrient loss in storage, transport, or other handling necessary to get the manure to the field.
- An estimate of any transport of generated manure out of the basin of the interest
- A comprehensive analysis of the application methods commonly used and an estimate of how frequently each identified application method is used.
- Common application rates, by manure type and application method
  - Analyses showing the acres applied and tons generated will allow for an average (this data is available for large, permitted facilities), but it would be beneficial to know what the 'worst case scenario' and/or maximum application rates look like
- The timing of applications, by manure type and application method
- The frequency of application, by manure type and application method

Differences in watershed features (e.g., geology, soils, hydrology, climate, etc.) between the two watersheds can also influence various manure-related factors. These two watersheds have a difference in annual average temperature, as Medway Creek is colder than the Auglaize River. This can have an impact on factors such as frozen soil application times and/or application methods by manure state (solid/liquid/slurry). Both of the watersheds are relatively flat, so large differences in runoff/erosion potential were not considered during the analysis. It was also noted that livestock operations are shrinking in the Medway Creek watershed while they seem to be growing in the U.S.

Finally, the contractor team evaluated the collected information with respect to manure management rules, regulations, and practices. Although the need for some data anonymization and consolidation for producers is recognized, more transparency and linkages to enforcement and water quality data, and more spatially explicit tracking of manure and soil testing would be helpful in assessing the state of practices and quantifying long-term environmental impacts. One item that would have driven this evaluation further forward would have been a more in-depth assessment of the technical maturity and economic viability of manure-related technology or promising new approaches to management. There are also linkages to be made from observations on economies, infrastructure, capacity, and scale narratives, such as the link to markets (both national and international), out-of-basin demand driving in-basin loading, and the lack of multi-farm infrastructure (treatment, manure markets, trading programs).

A full analysis, reviewing the gaps by data type, is available in Table 4-1.

Table 4-1 Data Gap Matrix

		Auglaize (US)		Medway		Notes
Scope of Work Task	Data Element	Quality	Accessibility	Quality	Accessibility	
Data and information related to manure/nutrient inputs, storage, treatment, and application	Watershed features including, but not limited to, land use, land cover, geology, soil types, hydrology, and climate in the two sub-watersheds	High	High	High	High	
	Number of permitted animal feeding operation facilities	High	High	NA	NA	
	Estimated number of non-permitted animal feeding operation facilities	Medium	Medium	Low	Low	Generally low; EWG study in Maumee. USDA NASS and Canadian Census of Ag. data available by county.
	Estimated number of nearby livestock processing facilities/abattoirs	Medium	High	Medium	High	
	Locations of permitted facilities, for the purposes of mapping (per Task 2)	High	Medium	Low	Low	
	Locations of non-permitted facilities, for the purposes of mapping (per Task 2)	Medium	Medium	Low	Low	
	Animal counts and types for permitted animal feeding operation facilities	High	High	N/A	N/A	
	Animal counts and types for non-permitted animal feeding operation facilities	Low	Low	Low	Low	USDA NASS, Canadian Census of Ag. data by county
	Soil phosphorus levels across the sub-watersheds	Low	Low	Medium	Medium	
	The type and quantities of manure generated – permitted	High	Medium	N/A	N/A	
	The type and quantities of manure generated – non-permitted	Medium	Low	Low	Low	
	Quantities of manure applied to land - permitted	High	Medium	N/A	N/A	
	Quantities of manure applied to land - non-permitted	Medium	Low	Low	Low	
	The number of acres of land to which manure is applied - permitted	High	Medium	N/A	N/A	
	The number of acres of land to which manure is applied – non-permitted	Low	Low	Low	Low	
	The approximate distance from manure generation to application	Low	Low	Low	Low	
	The approximate distance from manure application area to nearby permanent streams	Low	Low	Low	Low	

		Auglaize (US)		Medway		Notes
Scope of Work Task	Data Element	Quality	Accessibility	Quality	Accessibility	
	Number of agricultural acres in each watershed that receive applications of commercial fertilizer, manure and/or biosolids	Medium	Medium	Medium	Medium	
	To the extent possible, the potential contribution of phosphorus, dissolved and total, to streams in the two sub-watersheds from commercial vs. manure fertilizers	Low	Low	Low	Low	
	Estimated total and dissolved phosphorus loading to the Medway Creek and Auglaize River	High	High	Medium	Medium	
	Locations where continuous/sustained nutrient monitoring of water is undertaken and the source of the monitoring data	High	High	Medium	Medium	
	Manure application methods and timing	Medium	Low	Low	Low	
	Estimated manure phosphorus (P), potassium (K), and nitrogen (N) land application rates for predominant crop types.	Medium	Medium	Medium	Medium	
	Describe the impairment status of the two Lake Erie sub-watershed waterways (under U.S. and Canadian water quality laws), including any existing watershed assessments relevant to nutrients and phosphorus loading/inputs	High	High	Medium	Medium	
	Information on new manure nutrient management technologies	Medium	Medium	Medium	Medium	
Manure management rules, regulations, and practices	Collect information on existing manure management permitting rules and regulations	High	High	High	High	
	Collect information on programs and funding for best management practices related to field management practices and manure land application practices	Medium	Medium	Medium	Medium	

Quality – high (good spatial and temporal coverage, user-friendly format); medium (inconsistent spatial or temporal coverage, less user-friendly); low (poor coverage, low confidence, not user-friendly)

Accessibility – high (readily available, timely); medium (needs to be requested, medium latency); low (proprietary/restricted or non-existent, high latency)

5. Summary and Recommendations

Nutrient loading to U.S. and Canadian watersheds and Western Lake Erie is dominated by non point loads. These are primarily the result of runoff and tile drainage from agricultural fields carrying dissolved and particulate phosphorus originating as commercial fertilizer and manure. Study findings and recommendations are summarized below.

Data-Based Findings

- Nutrient delivery to U.S. and Canadian watersheds studied and to western Lake Erie is dominated by nonpoint loads. These are primarily the result of dissolved and particulate nutrient transport in runoff and tile drainage from agricultural fields.
- Available water quality monitoring data suggest that while flow-weighted mean concentrations of dissolved reactive phosphorus (DRP) have remained relatively constant in recent years, total DRP loads in the Auglaize River (U.S.) have exhibited an upward trend. Total P concentrations have exhibited a downward trend in Medway Creek (Canada).
- Recent trends show increases in total livestock in the Auglaize River watershed (U.S.), particularly of swine and associated liquid manure, and in and around the Medway Creek watershed (Canada) (see Figures ES-1 and ES-2).
- Estimated overall application and generation values for fertilizer and manure, converted to elemental phosphorus, for the Auglaize and Medway Creek watersheds are shown in Table ES-1 below for 2017. Note that application rates are not directly reflective of nutrient loss rates from fields to waterways.
- Available data suggest that on average, soil phosphorus levels have been gradually declining across northwest Ohio and northeast Indiana (U.S.) and across the Medway Creek watershed. However, this does not include information on legacy manure application hotspots that may still exist across both watersheds.

Table 5-1 Summary of Manure and Fertilizer P Inputs

Watershed	Total P from Manure and Commercial Fertilizer (kg)	Total Generated Manure P (kg)	Total Commercial Fertilizer P (kg)	Manure P as Fraction of Total Manure and Fertilizer P	Fertilizer P as Fraction of Total Manure and Fertilizer P
Auglaize[1]	18,287,493	6,797,164	11,490,329	37.2%	62.8%
Medway[2]	6,261,085	2,979,309	3,281,776	47.6%	52.4%

1 Data reflects county-level P-inputs for seven Ohio counties (Allen, Auglaize, Defiance, Hardin, Paulding, Putnam, and Van Wert) and two Indiana counties (Adams and Allen).
2 Data reflects P inputs for Middlesex Center census sub-division, which is a larger area that includes the Medway Creek watershed.

Data and Knowledge Gaps

Important monitoring and knowledge gaps include:

- Locations of AFOs in Ontario, and location of non-permitted AFOs in the U.S.

- Soil P test data across both watersheds.
- Data on manure generated and applied to land in Ontario, and for non-permitted facilities in the U.S., including data on locations where applied, and application rate.
- Data on manure application methods and timing.

Regulatory, Policy, and Program Findings

- The U.S. and Canadian approaches to manure management have similar environmental protection objectives and apply similar concepts of normalizing manure generation across animal types, but the thresholds for different levels of management and the corresponding requirements at the thresholds differ by jurisdiction.
- Canada and the U.S. have developed a collaborative approach to nutrient management, including some components of manure management, under Annex 4 of the GLWQA. Ontario, Michigan, Indiana, and Ohio all developed Domestic Action Plans to reduce nutrient loads to Lake Erie in 2018.
- The U.S. approach manages discharge aspects of large livestock operations under federal legislation. States, including Ohio, manage many aspects of livestock operations and manure handling and application under their own laws, agencies, and programs. The primary Canadian regulation is at the provincial level--Ontario in this case.
- State programs and guidelines in Ohio and Ontario have been modified in the last decade to promote more intensive manure management to control nutrient loss to waterways, but additional work remains to be done, especially where livestock operations are expanding. The 4R Nutrient Stewardship Certification Program and the H2Ohio Partnership Program have improved nutrient management in the Maumee River watershed, and the Total Maximum Daily Load Project has set source-specific load reduction targets for the Maumee. In 2016, Ohio statutes restricting the application of manure in the western Lake Erie basin came into effect (ORC 905.326 and 939.08). The Ontario Nutrient Management Act was enacted in 2002 and has been updated periodically since then.

Recommendations

These recommendations are presented with an understanding of IJC's advisory and non-regulatory role, as well as recognition that IJC does not manage substantial resources that could be applied to addressing the issues examined or underwriting ongoing activities of the Collaborative. The Collaborative, associated IJC boards, and resource management agencies should consider the following non-prioritized approaches in the near term (next three years) to address data and policy gaps, improve manure management, and reduce the loss of manure-derived nutrients to waterways:

1. Identify resources to continue convening the Manure Nutrient Management Collaborative to consolidate knowledge and promote consensus building around the most efficient and effective ways to reduce nutrient loss to waterways from livestock operations and associated manure application in the Lake Erie watershed.
2. Continue to focus attention on the Maumee and Thames as watersheds with the greatest nutrient loading impacts to Lake Erie and as locations for improving the reporting of manure

data by increasing resolution to sub-watershed or finer scales. This will help to better link water quality improvements and phosphorus load reductions to program investments.

3. Develop draft policy guidance that incorporates and harmonizes the best manure management approaches in the two countries to the extent possible. Consider especially the Ontario Nutrient Management Act framework, Ohio Domestic Action Plan, H2Ohio Program, 4R Certification, and Maumee Watershed Nutrient Total Maximum Daily Load (TMDL) Project. Also consider the properties of specific manure types and corresponding differences in approaches to effectively managing these, as well as the potential role of subsidized centralized manure exchanges in promoting manure application at agronomic rates and allowing for other management options such as biodigestion and energy generation, with appropriate policy safeguards.
4. Coordinate with U.S. state and other agencies to evaluate the potential for requiring currently unregulated AFOs to develop and implement nutrient management plans. Evidence suggests these AFOs generate the majority of manure within the Auglaize Watershed and likely in the U.S. portion of the larger WLEB.
5. Consider whether temporary changes to nutrient management approaches such as sub-watershed-specific or livestock-specific moratoria or other time-limited actions could allow policies and procedures to catch up with the rapid expansion of certain types of livestock operations in some locations, recognizing the corresponding potential for negative impacts and the urgency in mitigating such impacts before they occur and become established.
6. Suggest refinements to data collection and transparency policies and procedures in both countries that better harmonize regulations, balance community needs regarding environmental impacts and exposures with producer privacy, and define the technology, staffing, and financial resources needed to support such expanded data programs. This could include, for example, requiring U.S. drain tile installers or agricultural laboratories to report certain data to agencies.
7. Coordinate with state and provincial agencies and other institutions to promote research and collect data that helps delineate sources of DRP (i.e., manure, commercial fertilizer, legacy sites) and identifies management strategies best suited to mitigate the largest sources.
8. Identify existing programs and suggest new or expanded programs to improve linkages, interactions, and formal and informal exchanges between water quality and agricultural experts, agencies, stakeholders with the ultimate goal of reducing manure impacts on waterways while factoring in livestock economics. Define the staffing and financial resources needed to support existing and new programs on an ongoing basis.

6. References

Agricultural Information Atlas Help. (n.d.). Retrieved July 8, 2022, from http://omafra.gov.on.ca/english/landuse/gis/agatlas-help.htm

Agriculture and Agri-Food Canada. 2022. ISO 19131 Agri-Environmental Indicator – Risk of Water Contamination by Phosphorus – Data Series Product Specifications. Retrieved December 14, 2022 from https://open.canada.ca/data/en/dataset/8b13d884-c0bf-4ee4-9f44-eb2efbb760a6.

A&L Great Lakes. (n.d.). *Soil Test Summaries*. A&L Great Lakes. Retrieved December 12, 2022, from https://algreatlakes.com/pages/soil-test-summaries

Best Management Practices: Managing Crop Nutrients. (n.d.). Retrieved July 15, 2022, from http://omafra.gov.on.ca/english/environment/bmp/crop_nut.htm

Best Management Practices: Manure Management. (n.d.). Retrieved July 15, 2022, from http://omafra.gov.on.ca/english/environment/bmp/manure.htm

Boles, C.M.W., Frankenberger, J.R. , and Moriasi, D.N. (2015). *Tile Drainage Simulation in SWAT2012: Parameterization and Evaluation in an Indiana Watershed.* Transactions of the ASABE. 58(5): 1201-1213.

Brooker, M.R., D'Ambrosio, J., Jones, M.M.L., Kalcic, M., King, K.W., LaBarge, G., Panchalingam, T., Roe, B.E., Schwab, E.R., Soldo, C., Stoltzfus, N.D., Wilson, R.S., Winston, R.J. and Martin, J.F. (2021). A Public-Private Partnership to Locate Fields for Implementation and Monitoring of Best Management Practices to Treat Legacy Phosphorus. Front. Sustain. Food Syst. 5:742817. doi: 10.3389/fsufs.2021.742817

Civil & Environmental Consultants, Inc. (2020). *Nine-Element Nonpoint Source Implementation Strategy (NPS-IS) for Sims Run-Auglaize River HUC-12*. https://epa.ohio.gov/static/Portals/35/nps/Approved%209-Element%20Plans/Sims%20Run-Auglaize%20River_Ver1.0_4-29-2020.pdf

Dayton, E., Shrestha, R., Fulford, A., Love, K., Culman, S., & Lindsey, L. (2020). Soil test phosphorus and phosphorus balance trends: A county-level analysis in Ohio. *Agronomy Journal*, *112*. https://doi.org/10.1002/agj2.20146

Environment and Climate Change Canada (ECCC) & Ontario Ministry of the Environment. (2018). *Canada-Ontario Lake Erie Action Plan Partnering on Achieving Phosphorus Loading Reductions to Lake Erie from Canadian Sources*. https://www.canada.ca/content/dam/eccc/documents/pdf/great-lakes-protection/dap/action_plan.pdf

Eum, H.-I., & Simonovic, S. P. (2009). *City of London: Vulnerability of Infrastructure to Climate Change* (No. 068). University of Western Ontario: Dept. of Civil and Environmental Eng. https://www.eng.uwo.ca/research/iclr/fids/publications/products/68.pdf

EWG. (2019). *Explosion of Unregulated Factory Farms in Maumee Watershed Fuels Lake Erie's Toxic Blooms*. http://www.ewg.org/interactive-maps/2019_maumee/

EWG. (2022). *Methodology: New analysis identifies animal feeding operation 'hot spots' in Western Lake Erie Basin | Environmental Working Group*. https://www.ewg.org/wlealgaemethods

Falcone, J. A. (2021). Estimates of county-level nitrogen and phosphorus from fertilizer and manure from 1950 through 2017 in the conterminous United States. In *Open-File Report* (No. 2020–1153). U.S. Geological Survey. https://doi.org/10.3133/ofr20201153

Friends of Medway Creek. (n.d.-a). *Medway Creek Community-based Enhancement Strategy*. Retrieved July 15, 2022, from https://thamesriver.on.ca/wp-content/uploads//MedwayCreek/MedwayCBES-report.pdf

Friends of Medway Creek. (n.d.-b). *Medway Creek Community-based Enhancement Strategy: Appendices*. Retrieved July 15, 2022, from https://thamesriver.on.ca/wp-content/uploads//MedwayCreek/MedwayCBES-appendices.pdf

Freshwater Research. (2015). Water Quality Assessment in the Thames River Watershed - Nutrient and Sediment Sources. https://thamesriver.on.ca/wp-content/uploads/SurfaceWater/TRWaterQualityAssessment-NutrientSedimentSources-Report.pdf

Government of Canada, S. C. (2022a, May 11). *Farms classified by farm type, Census of Agriculture, 2021*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210023101

Government of Canada, S. C. (2022b, June 15). *Ontario is an agricultural powerhouse that leads in many farming categories*. https://www150.statcan.gc.ca/n1/pub/96-325-x/2021001/article/00006-eng.htm

Government of Ontario. (2014, July 24). *Consolidated laws—English View*. Ontario.Ca. https://www.ontario.ca/laws/view

Great Lakes Water Quality Board (WQB). (2019). *Oversight of Animal Feeding Operations for Manure Management in the Great Lakes Basin*. https://ijc.org/sites/default/files/2020-01/WQB_ManureManagementReport_2019.pdf

Great Lakes Water Quality Board (WQB). (2020). *Oversight of Animal Feeding Operations for Manure Management in the Great Lakes Basin – Summary of Insights Learned Through Webinar Input.* https://www.ijc.org/sites/default/files/2020-11/WQB_ManureManagementReport_2020_PublicInputandNextSteps.pdf

Gronberg, J. M., & Arnold, T. (2017). County-level estimates of nitrogen and phosphorus from animal manure for the conterminous United States, 2007 and 2012. In *Open-File Report* (No. 2017–1021). U.S. Geological Survey. https://doi.org/10.3133/ofr20171021

Guidance Manual to the Western Lake Erie Basin Nutrient Source Inventory. (n.d.). Retrieved December 12, 2022, from https://lceo.maps.arcgis.com/apps/MapJournal/index.html?appid=5c8129780ea844d291be8d47206e2561

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, e2019JG005134. https://10.4211/10.1029/2019JG005134

Heagy, E. (n.d.). Friends of Medway Creek. *Upper Thames River Conservation Authority*. Retrieved July 15, 2022, from https://thamesriver.on.ca/education-community/watershed-friends-of-projects/medway/friends-of-medway-creek/

Howe, E., Moore, J., & Environmental, S. (2016). *54 West Shore Road Grand Isle, VT 05458*.

Huffman, T., Yang, J. Y., Drury, C. F., De Jong, R., Yang, X. M., & Liu, Y. C. (2008). Estimation of Canadian manure and fertilizer nitrogen application rates at the crop and soil-landscape polygon level. *Canadian Journal of Soil Science*, *88*(5), 619–627. https://doi.org/10.4141/CJSS07020

IDEM. (2021, February 16). *About Confined Feeding Operations and Concentrated Animal Feeding Operations*. Indiana Dept. of Environmental Mgmt. https://www.in.gov/idem/cfo/about-confined-feeding-operations-and-concentrated-animal-feeding-operations/

International Joint Commission (IJC). (2018). *Fertilizer Application Patterns and Trends and Their Implications for Water Quality in the Western Lake Erie Basin* (p. 89).

Jamesson, G. (2017, March 9). *Ohio EPA's Nutrient Mass Balance Study for Ohio's Major Rivers*. One Water – Government & Regulatory Affairs Workshop. https://www.onewaterohio.org/docs/Ohio_EPA_Nutrient_MB.pdf

Jarvie, P. H., et al. 2017. Increased Soluble Phosphorus Loads to Lake Erie: Unintended Consequences of Conservation Practices? Journal of Environmental Quality 46:123–132 (2017). doi:10.2134/jeq2016.07.0248

Kast, J. B. et al. 2021. Source contribution to phosphorus loads from the Maumee River watershed to Lake Erie. Journal of Environmental Management 279 (2021) 111803.

Kast, J.B. et al. 2019. Manure Management at Ohio Confined Animal Feeding Facilities in the Maumee River Watershed. Journal of Great Lakes Research 45 (2019) 1162 – 1170.

LimnoTech. (2017). *Assessment of Fertilizer and Manure Application in the Western Lake Erie Basin*. https://legacyfiles.ijc.org/publications/LimnoTech_IJC_Fertilizer.pdf

LimnoTech. (2019). *Assessment of Fertilizer and Manure Application in the Western Lake Erie Basin—Supplement* [Supplemental report for: International Joint Commission Science Advisory Board]. https://www.ijc.org/sites/default/files/2019-09/SAB-SPC_FertilizerManureLakeErie_Supplement_2019%5B1%5D.pdf

Meyer, A., et al. (2022). *Remotely Sensed Imagery Reveals Animal Feeding Operations Increase Surface Waterbody Concentrations of Dissolved Reactive Phosphorus*. Unpublished manuscript. https://andrewgmeyer.com/wp-content/uploads/2022/05/afos_imagery.pdf.

Michaud, A. R., Poirier, S.-C., & Whalen, J. K. (2019). Tile Drainage as a Hydrologic Pathway for Phosphorus Export from an Agricultural Subwatershed. *Journal of Environmental Quality*, *48*(1), 64–72. https://doi.org/10.2134/jeq2018.03.0104

Miller, S. A., & Lyon, S. W. (2021). Tile Drainage Increases Total Runoff and Phosphorus Export During Wet Years in the Western Lake Erie Basin. *Frontiers in Water*, *3*. https://www.frontiersin.org/articles/10.3389/frwa.2021.757106

ODA. (n.d.). *Welcome to the Division of Livestock Environmental Permitting | Ohio Department of Agriculture*. Retrieved December 13, 2022, from https://agri.ohio.gov/divisions/livestock-environmental-permitting

Ohio EPA: Division of Surface Water. (2019). *Upper Auglaize River Watershed – Biological and Water Quality Survey Planning, 2019*. https://epa.ohio.gov/static/Portals/35/tmdl/Study%20Plan/UpperAuglaize_QAPP%20Fact%20Sheet.pdf

Ohio EPA. (2004). *Total Maximum Daily Loads for the Upper Auglaize River Watershed*. https://epa.ohio.gov/static/Portals/35/tmdl/UpperAuglaizeFinalTMDL.pdf

Ohio EPA. (2014). *2014 Study Plan for the Lower Auglaize River Tributaries: Defiance, Mercer, Paulding, Putnam, and Van Wert Counties, Ohio*. https://epa.ohio.gov/static/Portals/35/tmdl/LowerAuglaize_StudyPlan_041114.pdf

Ohio EPA. (2015, March). *CAFO NPDES Permit – General Overview of Federal Regulations*. https://epa.ohio.gov/static/Portals/35/cafo/NPDESPartI.pdf

Ohio EPA. (2022a). *Ohio EPA Issues Draft Maumee River Watershed Nutrient Water Quality Improvement Plan.* https://epa.ohio.gov/about/media-center/news/ohio-epa-issues-draft-maumee-river-watershed-nutrient-water-quality-improvement-plan

Ohio EPA. (2022b). *Concentrated Animal Feeding Operations | Ohio Environmental Protection Agency*. https://epa.ohio.gov/divisions-and-offices/surface-water/permitting/concentrated-animal-feeding-operations

Ohio EPA. (2022c). *Loading Analysis Plan and Supporting Data Acquisition Needed for the Lower Auglaize River Tributaries Basin Total Maximum Daily Load Development*. https://epa.ohio.gov/static/Portals/35/tmdl/LAPs/2014_LowerAuglaize_LAP.pdf

Ohio EPA Division of Surface Water. (2016). *Biological and Water Quality Study of Lower Auglaize River Tributaries* (DSW/EAS 2016-11-06). https://epa.ohio.gov/static/Portals/35/documents/2014%20Lower%20Auglaize%20River%20Tributaries%20TSD.pdf

Ohio Lake Erie Commission (OH-LEC). (2020). *Expanded Lake Erie Tributary Nutrient Load Monitoring*. https://lakeerie.ohio.gov/static/Water_Monitoring_Summary/Expanded_load_monitoring_report_2020_FINAL.pdf

Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA). 2007. Drainage Guide for Ontario. Publication 29. https://www.ontario.ca/page/drainage-guide-ontario.

Ontario Ministry of Agriculture, Food and Rural Affairs. (n.d.). *Agricultural Information Atlas Help*. Retrieved December 12, 2022, from http://omafra.gov.on.ca/english/landuse/gis/agatlas-help.htm

Part 10 – Outdoor Livestock Feeding Operations. (n.d.). Retrieved July 18, 2022, from http://omafra.gov.on.ca/english/nm/regs/nmpro/nmpro10-jun03.htm#1

Part 122—EPA Administered Permit Programs: The National Pollutant Discharge Elimination System, The Clean Water Act, 33 U.S.C. 1251. Retrieved December 12, 2022, from https://www.epa.gov/sites/default/files/2015-08/documents/cafo_final_rule2008_comp.pdf

Reid, K., & Schneider, K. D. (2019). Phosphorus accumulation in Canadian agricultural soils over 30 yr. *Canadian Journal of Soil Science*, *99*(4), 520–532. https://doi.org/10.1139/cjss-2019-0023

Robertson, D.M., Saad, D. A., Benoy, G. A., Vouk, I., Schwarz, G. E., and Laitta, M. T. (2019). "Phosphorus and Nitrogen Transport in the Binational Great Lakes Basin Estimated Using SPARROW Watershed Models." Journal of the American Water Resources Association 54 (4): 1401–1424. https://doi.org/10.1111/1752-1688.12792.

Secretariat, T. B. of C., & Secretariat, T. B. of C. (n.d.-a). *Agri-Environmental Indicator – Risk of Water Contamination by Phosphorus Data Series—Open Government Portal*. Retrieved December 12, 2022, from https://open.canada.ca/data/en/dataset/8b13d884-c0bf-4ee4-9f44-eb2efbb760a6

Secretariat, T. B. of C., & Secretariat, T. B. of C. (n.d.-b). *Agri-Environmental Indicator – Risk of Water Contamination by Phosphorus Data Series—Open Government Portal*. Retrieved December 13, 2022, from https://open.canada.ca/data/en/dataset/8b13d884-c0bf-4ee4-9f44-eb2efbb760a6

Secretariat, T. B. of C., & Secretariat, T. B. of C. (n.d.-c). *Tile drainage area—Open Government Portal*. Retrieved December 12, 2022, from https://open.canada.ca/data/en/dataset/e9936477-864d-4567-a388-052e60f96add

Statistics Canada. (2001). *Distribution and Concentration of Canadian Livestock*. https://www150.statcan.gc.ca/n1/en/pub/21-601-m/2001047/4193596-eng.pdf?st=rhS1W_Dx

Statistics Canada. (2021a). *2021 Census Agricultural Regions and Census Divisions* [Map]. https://www150.statcan.gc.ca/n1/en/pub/95-630-x/2022001/pdf/Prov35_CARCD_e.pdf?st=XEq-VSPT

Statistics Canada. (2021b). *2021 Census Divisions and Census Consolidated Subdivisions* [Map]. https://www150.statcan.gc.ca/n1/en/pub/95-630-x/2022001/pdf/Prov35_CDCCS_2a_e.pdf?st=uSyLptuB

Story Map Journal. (n.d.). Retrieved July 8, 2022, from https://lceo.maps.arcgis.com/apps/MapJournal/index.html?appid=5c8129780ea844d291be8d47206e2561

Tan, C. S., & Zhang, T. (2011). Surface Runoff and Sub-surface Drainage Phosphorus Losses under Regular Free Drainage and Controlled Damage with Sub-irrigation Systems in Southern Ontario. *Canadian Journal of Soil Science, 91*, 349-359. https://doi.org/10.4141/CJSS09086

Tetra Tech, Inc. (2012). *Total Maximum Daily Loads for the Maumee River (lower) Tributaries and Lake Erie Tributaries Watershed*. https://epa.ohio.gov/static/Portals/35/tmdl/MLLEtribs_Final_Report.pdf

University of Maryland Center for Environmental Science (UMD CES). (2020). *Western Lake Erie Report Card – Scores and Scoring Methodology.* https://ecoreportcard.org/site/assets/files/2270/the_development_process_and_methods_for_the_western_lake_erie_report_card.pdf

University of Michigan Water Center. (2019). *Watershed Assessment of Detroit River Phosphorus Loads to Lake Erie*. https://graham.umich.edu/media/pubs/Watershed-Assessment-of-Detroit-River-05032019.pdf

Upper Thames River Conservation Authority (UTRCA). (2022). *2022 Watershed Report Card Medway Creek.* https://thamesriver.on.ca/wp-content/uploads/RC_Medway.pdf

Upper Thames River Conservation Authority (UTRCA). (2017). *2017 Watershed Report Card Medway Creek*. https://thamesriver.on.ca/wp-content/uploads//WatershedReportCards/RC_Medway.pdf

Upper Thames River Conservation Authority (UTRCA). (2013). *Upper Thames River Watershed Report Card*. https://watershedcheckup.ca/report_cards/UpperThamesRiverCA_print.pdf

USDA National Agricultural Statistics Service (USDA NASS). (2017). NASS - Quick Stats. USDA National Agricultural Statistics Service. https://data.nal.usda.gov/dataset/nass-quick-stats.

US EPA, O. (2015, November 25). *Level III and IV Ecoregions of the Continental United States* [Data and Tools]. https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states

USGS. (n.d.). *Huron/Erie Lake Plains—ScienceBase-Catalog*. Retrieved December 12, 2022, from https://www.sciencebase.gov/catalog/item/55c77fc6e4b08400b1fd836a

Valayamkunnath, P., Barlage, M., Chen, F., Gochis, D. J., & Franz, K. J. (2020). Mapping of 30-meter resolution tile-drained croplands using a geospatial modeling approach. *Scientific Data*, *7*(1), 1. https://doi.org/10.1038/s41597-020-00596-x

Van Staden, T., et al. 2021. Anthropogenic Phosphorus Mass Balance in Ontario Counties and Watersheds. https://doi.org/10.20383/101.0208

Western Lake Erie Basin Partnership. (n.d.). *Watersheds: Auglaize*. Retrieved December 12, 2022, from http://wleb.org/watersheds/auglaize.html

Williams, M. R., & King, K. W. (2020). Changing rainfall patterns over the Western Lake Erie Basin (1975–2017): Effects on tributary discharge and phosphorus load. Water Resources Research (56). https://doi.org/10.1029/2019WR025985

Wright, J. & Sands, G. (2001). *Planning an Agricultural Subsurface Drainage System.* Agricultural Drainage Publication Series, University of Minnesota Extension Service, St. Paul, Minnesota.

Appendix A - Manure Management Collaborative Members

Name	Affiliation
Jon Allan	IJC WQB Member, University of Michigan
Tracy Annett	Upper Thames River Conservation Authority
Nandita Basu	IJC SAB Member, University of Waterloo
Sandy Bihn	IJC WQB Member (Project Co-Lead), Lake Erie Waterkeeper
Ron Campbell	Ontario Agri Business Association
Kari Gerwin	Toledo Metropolitan Area Council of Governments
Amy Holtshouse	The Nature Conservancy in Ohio
Peter Jeffery	Former Ontario Federation of Agriculture
Laura Johnson	Heidelberg University National Center for Water Quality Research
Bill Knapke	Cooper Farms
Greg Lake	Allen County Soil and Water Conservation District
Charles Lalonde	Thames River Phosphorus Coalition
Joe Logan	Ohio Farmers Union
Michael Murray	IJC SAB Member, U of Michigan School for Environmental and Sustainability
Joe Nester	Nester Ag, LLC
Mark Reusser	Ontario Federation of Agriculture
Jeff Reutter	Former Ohio Sea Grant, Stone Lab
Mark Smith	Ohio Natural Resources Conservation Service
Ryan Smith & Chris Adamo	Danone North America
Ron Snyder	Grain farm owner
Joe Tomandl	WQB Member, Dairy Grazing Apprenticeship
Lambert VanderMade	VanderMade Dairy Farm
Mark Wales	IJC WQB Member (Project Co-Lead), former Ontario Federation of Agriculture
Denise Watkins	USDA NRCS East National Technology Support Center
Bill Wolf	Agriculture Consultant
Gayle Wood	IJC WQB Member, Former Conservation Authorities

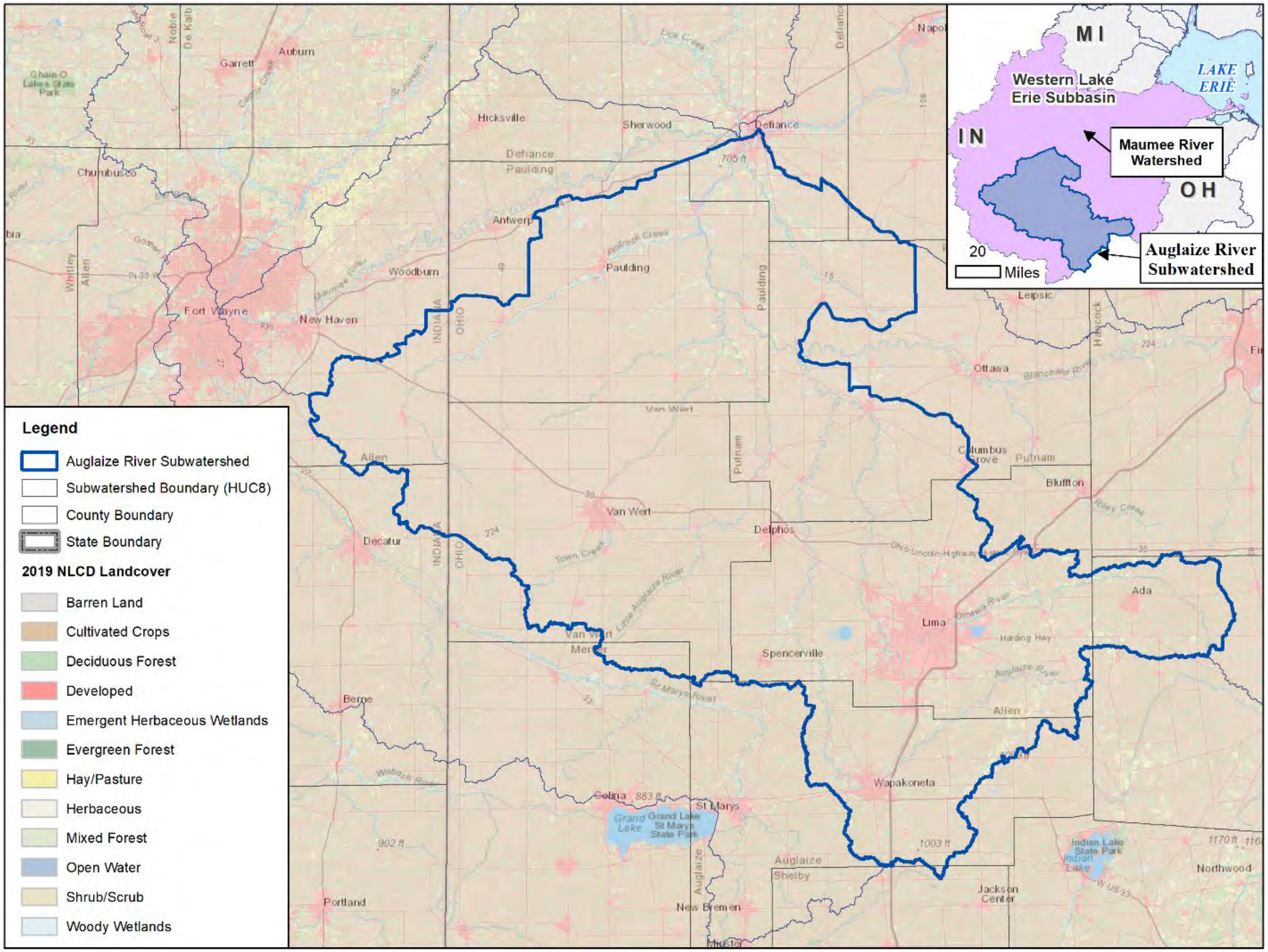
Appendix B – List of Groups and Individuals Contacted

Name	Affiliation/Description
D. Keith Reid	Agriculture and Agri-Food Canada (retired), contacted regarding soil P GIS data for Medway Creek
Jake DeBruyn	OMAFRA, contacted regarding AFO location data for Medway Creek
Luke Baker	President/CEO, Brookside Labs, contacted to request soil P test data
Nandita Basu	University of Waterloo, contacted regarding soil P GIS data for Medway Creek
Samuel Mullins	ODA, contacted to discuss availability of permitted AFO data for Auglaize River
Tatianna Lozier	UTRCA, contacted to discuss local regulations of AFOs in Medway Creek

Appendix C – Maps Developed

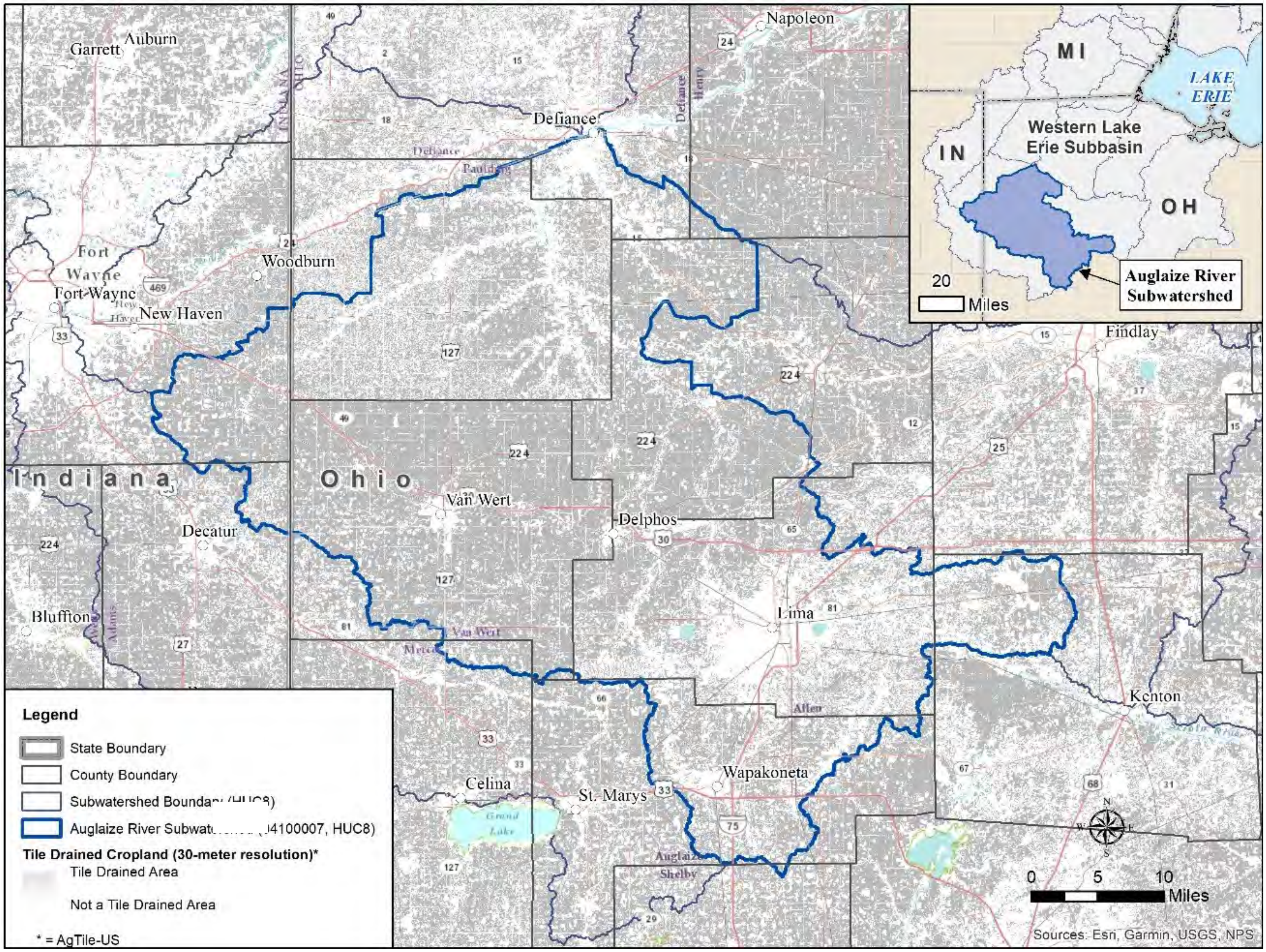
Auglaize River Watershed Maps

Medway Creek Watershed Maps



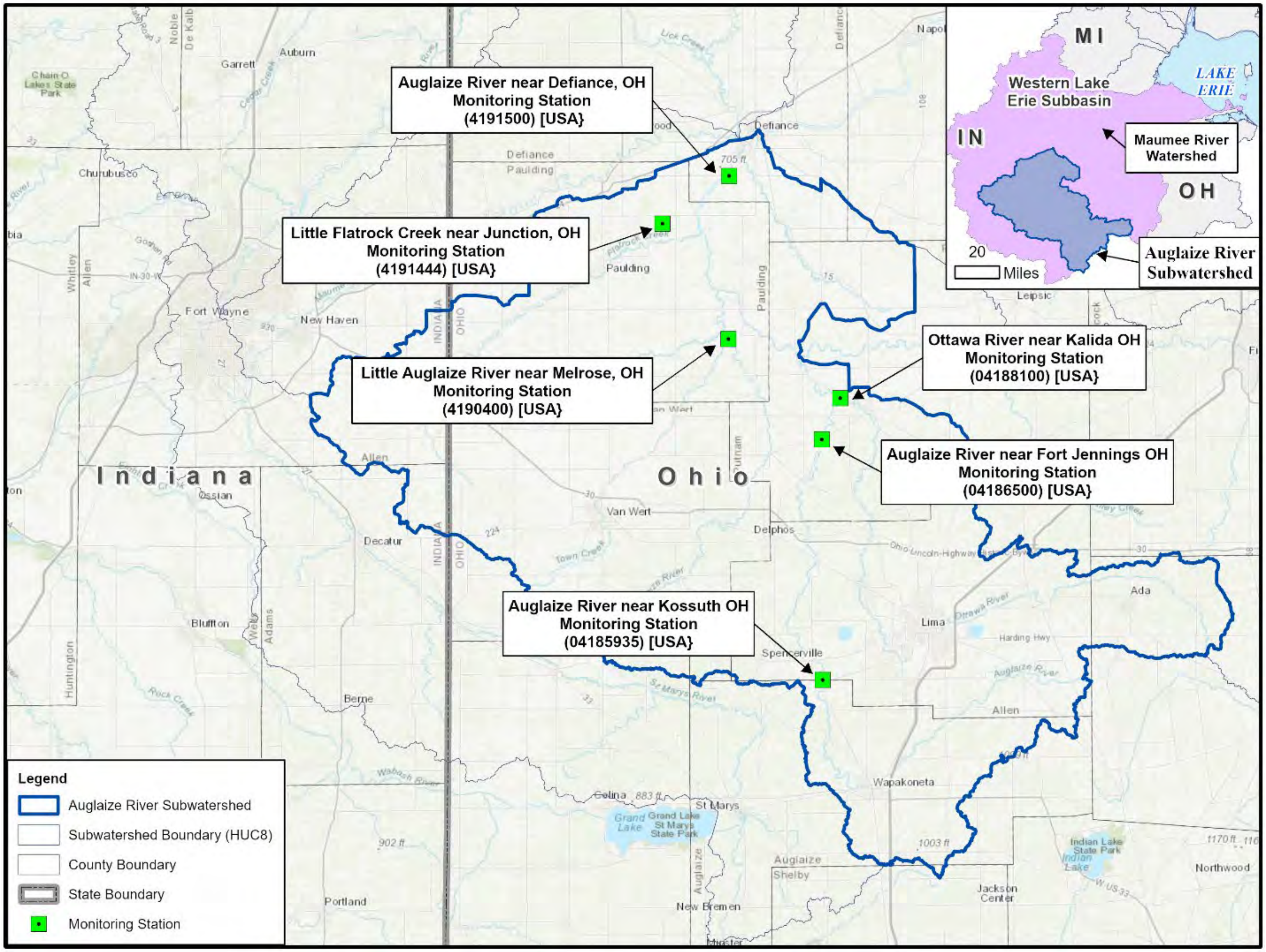
Source: USGS 2019 National Land Cover Database, https://www.mrlc.gov/

Figure C.1 Land Cover within the Auglaize River Watershed



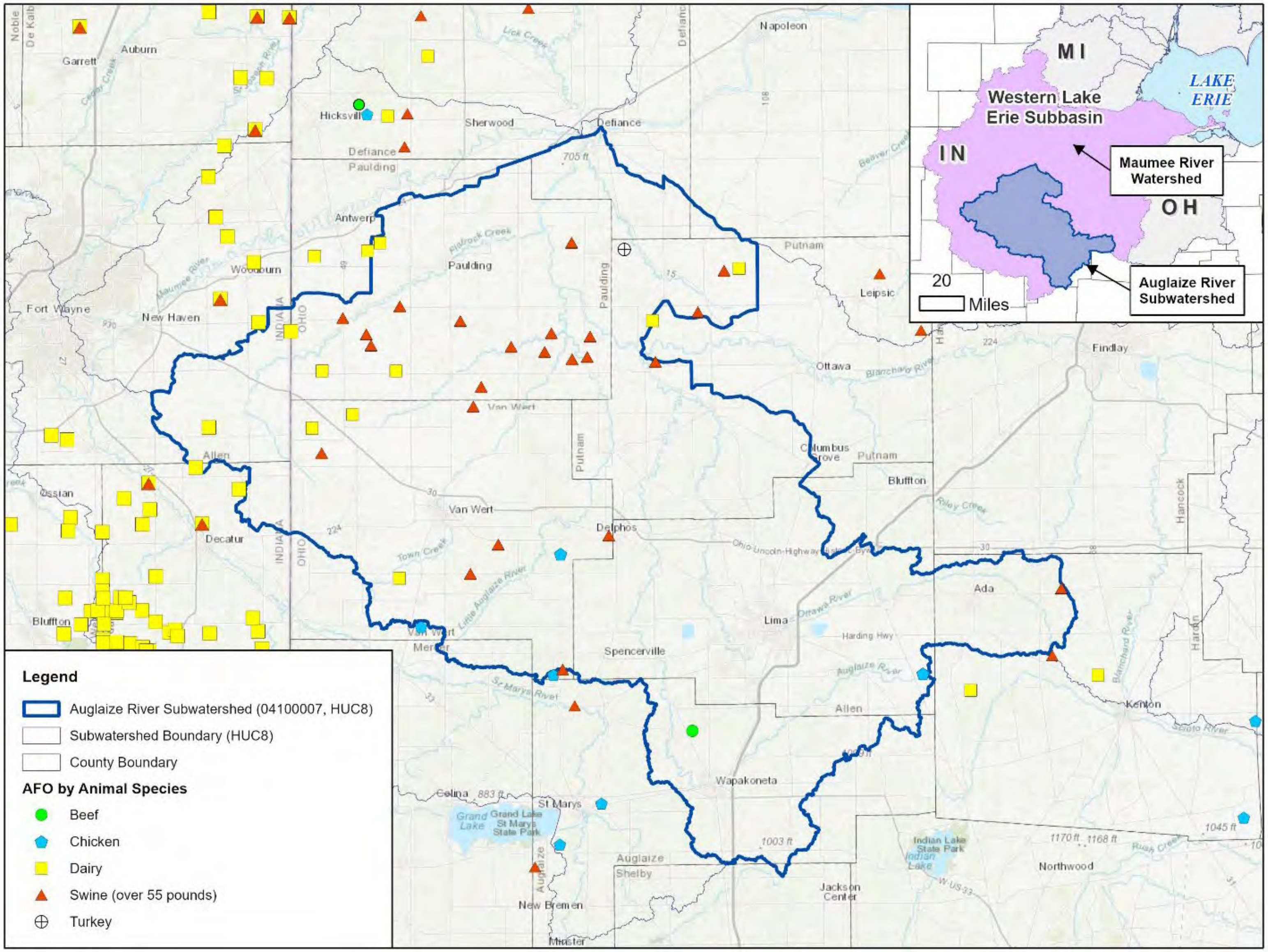
Source: Valayamkunnath et al., 2020

Figure C.2 Auglaize River Watershed Areas Most-Likely Tile Drained



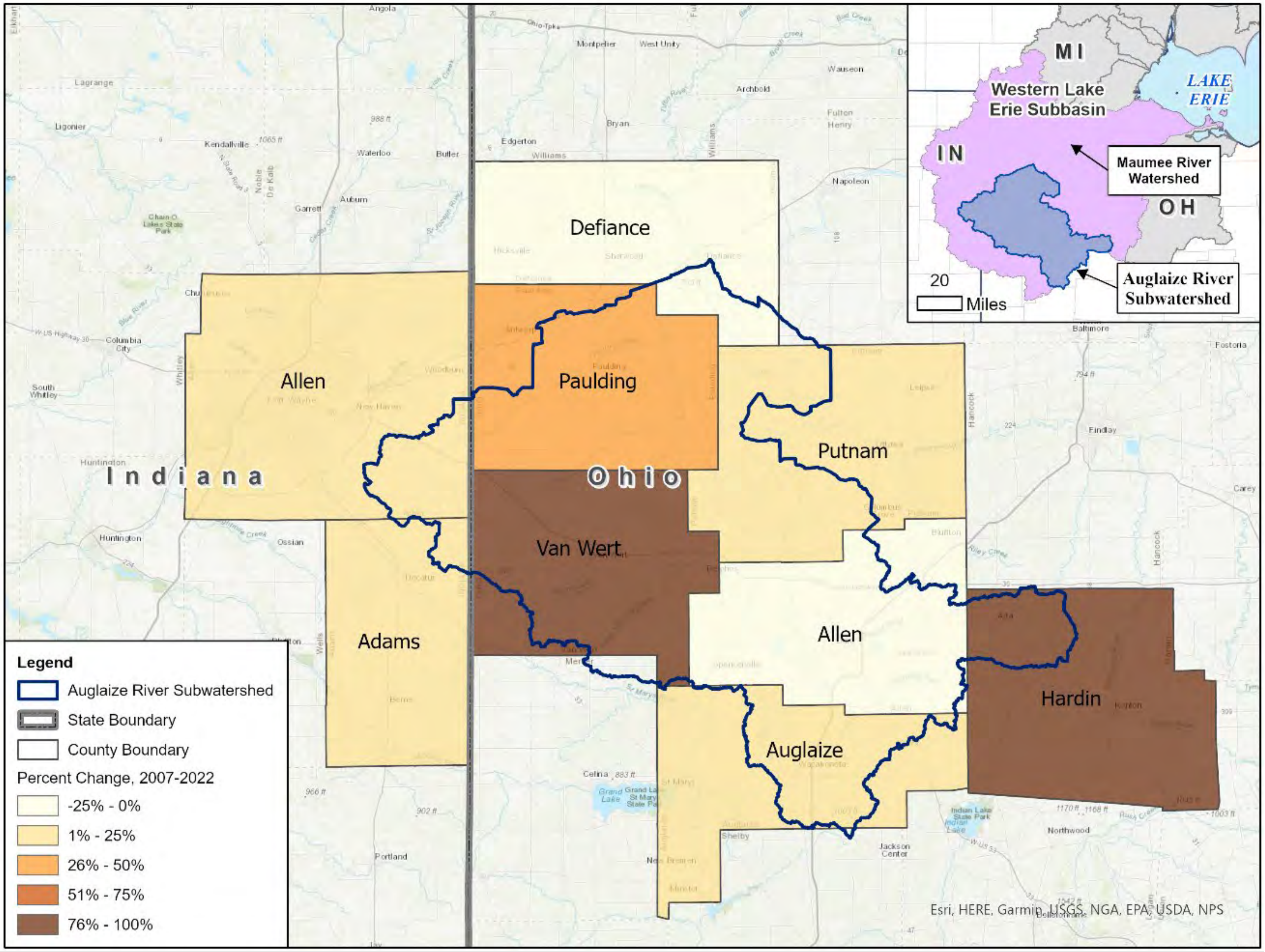
Source: USGS National Water Dashboard, https://dashboard.waterdata.usgs.gov/app/nwd/en/?region=lower48&aoi=default

Figure C.3 Auglaize River Monitoring Stations



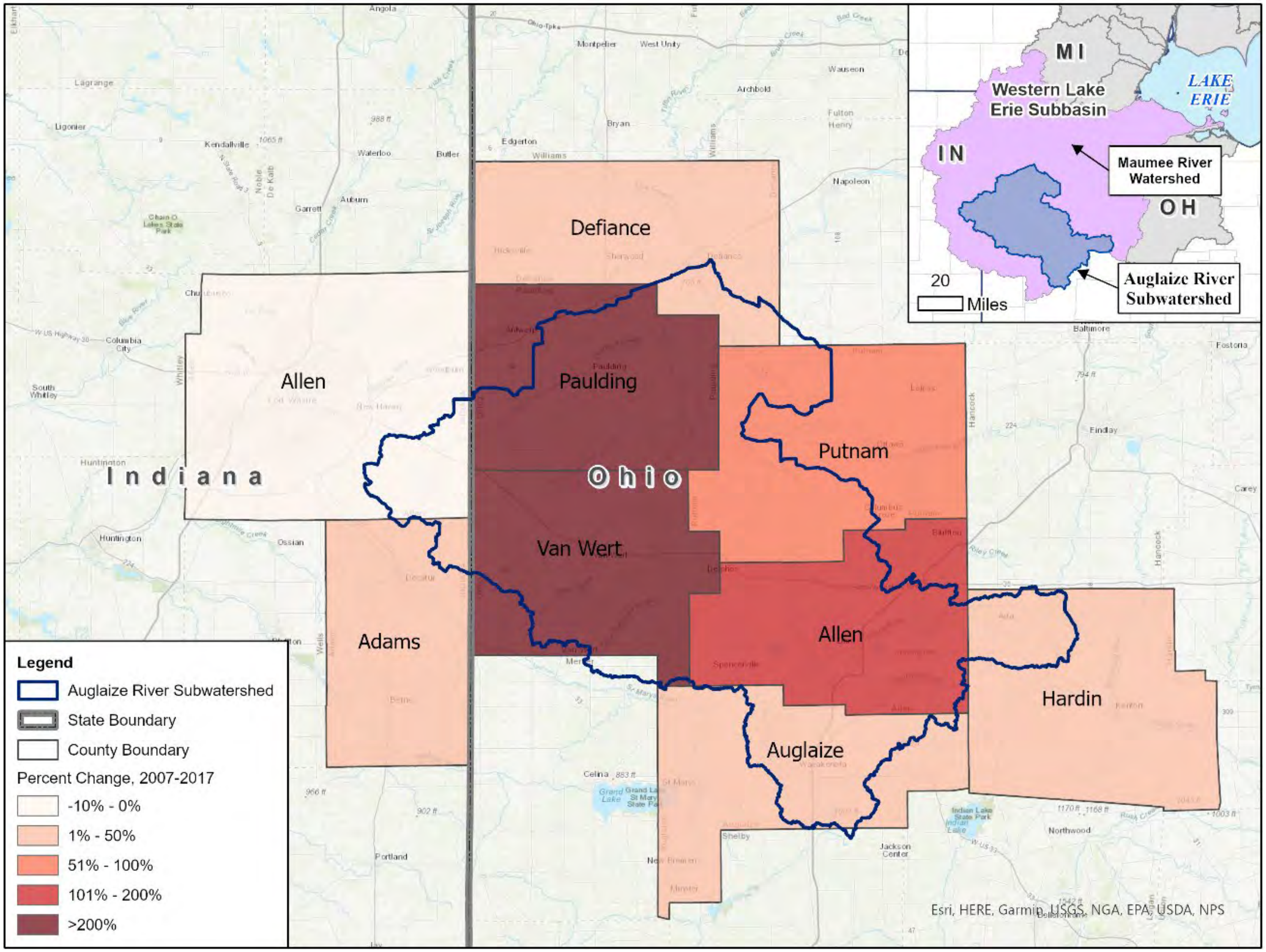
Source: Ohio Department of Agriculture. Indiana University, https://maps.indiana.edu/layerGallery.html?category=Agribusiness.

Figure C.4 Permitted CAFFs and CAFOs within the Auglaize River Watershed



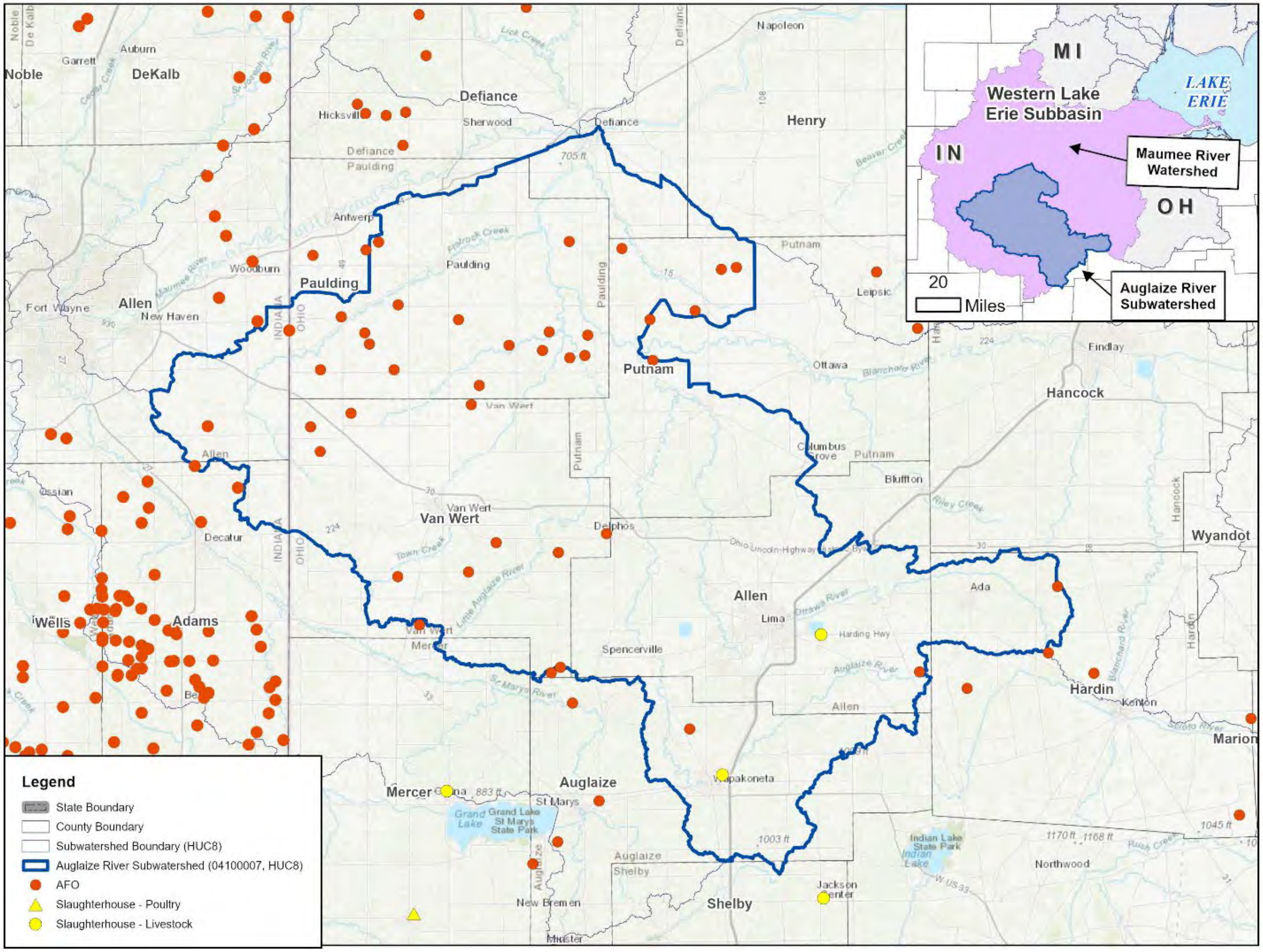
Source: USDA NASS QuickStats, https://www.nass.usda.gov/Quick_Stats/

Figure C.5 Percent Change in Cattle Population, by County, 2007 - 2022



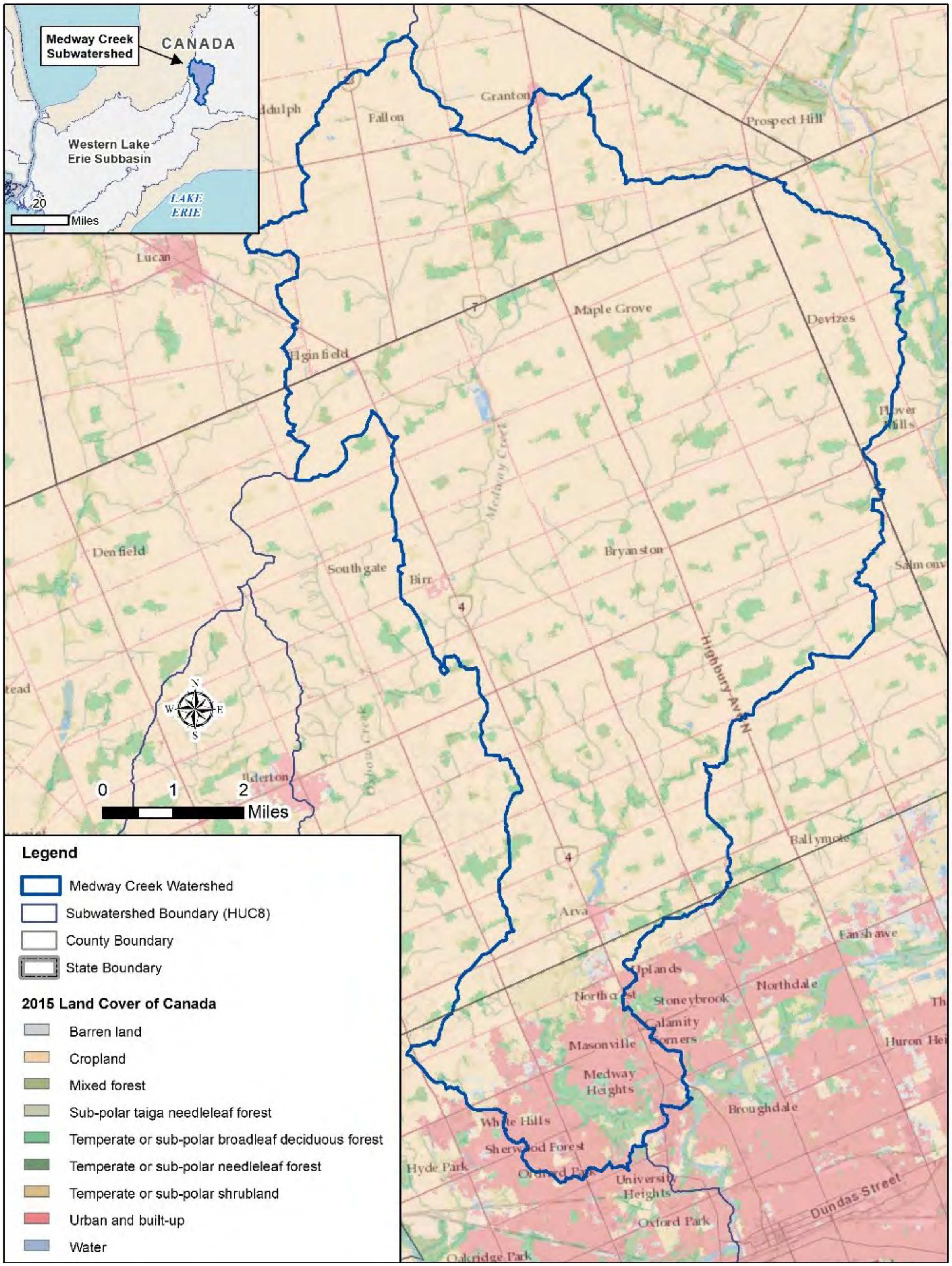
Source: USDA NASS QuickStats, https://www.nass.usda.gov/Quick_Stats/

Figure C.6 Percent Change in Hog Population, by County, 2007 - 2017



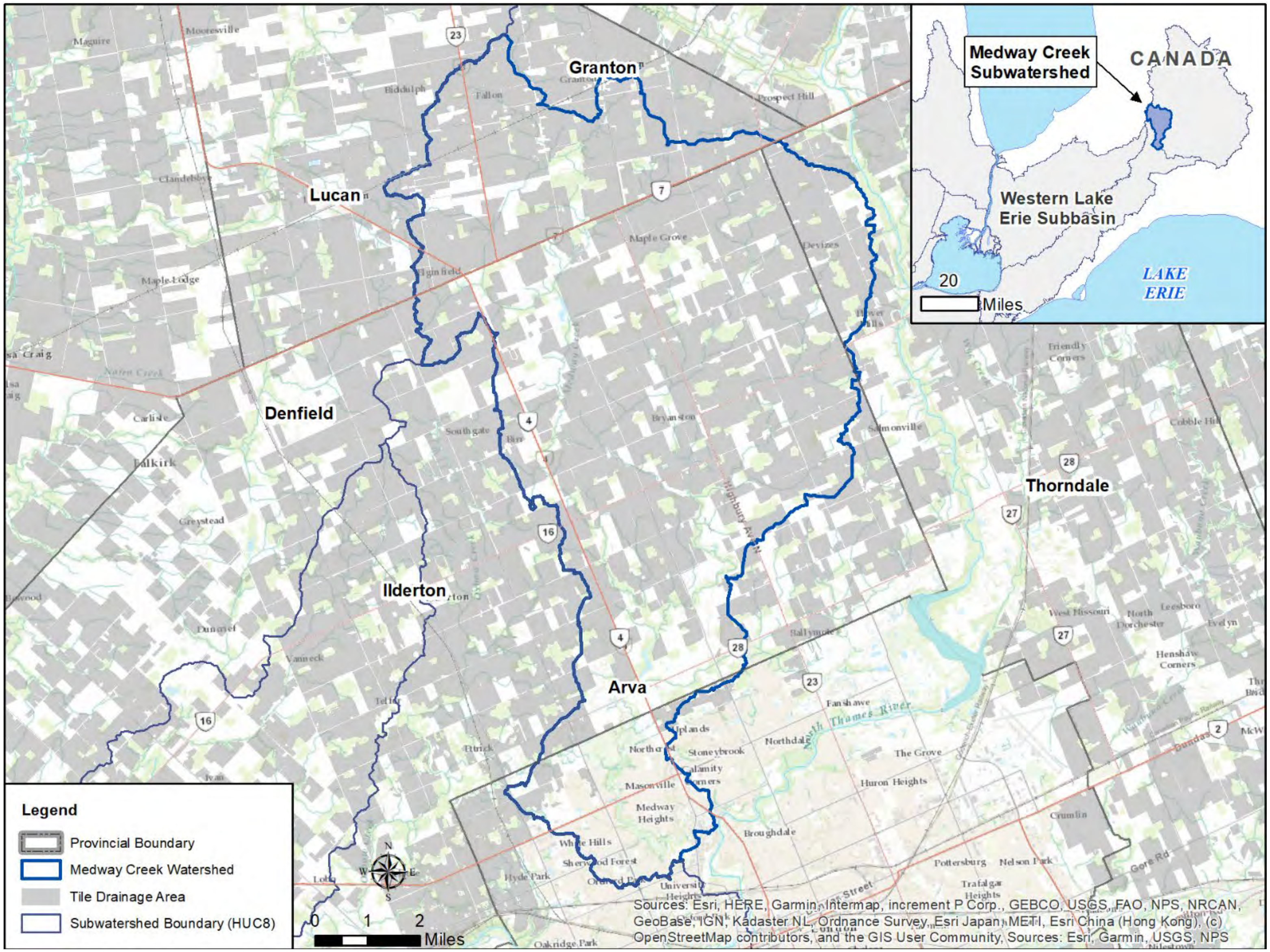
Source: USDA Food Safety Inspection Service, https://www.fsis.usda.gov/inspection/fsis-inspected-establishments

Figure C.7 USDA FSIS-Inspected Animal Processing Facilities in Ohio and Indiana



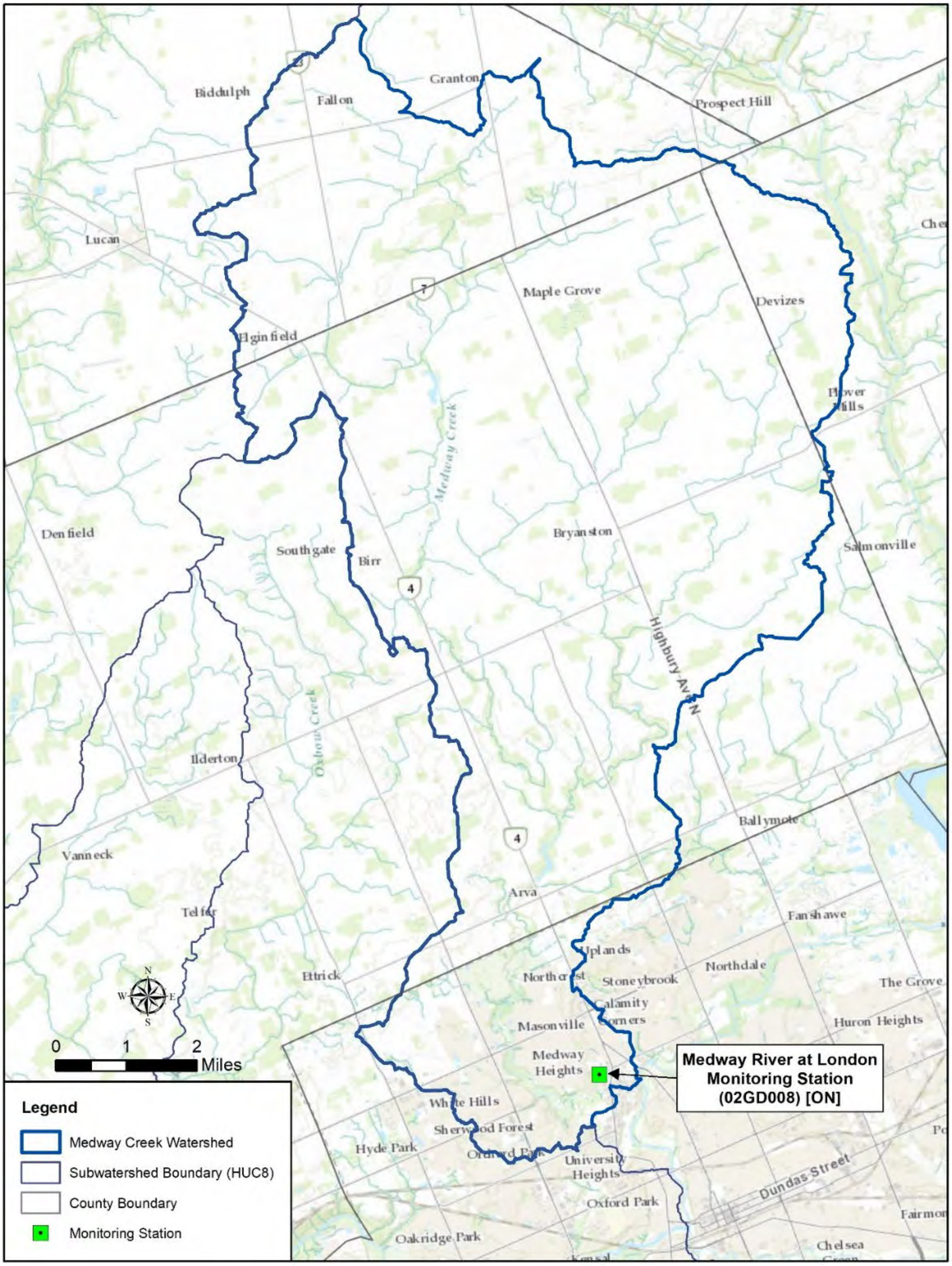
Source: 2015 Land Cover of Canada, https://open.canada.ca/data/en/dataset/4e615eae-b90c-420b-adee-2ca35896caf6

Figure C.8 Land Cover within the Medway Creek Watershed



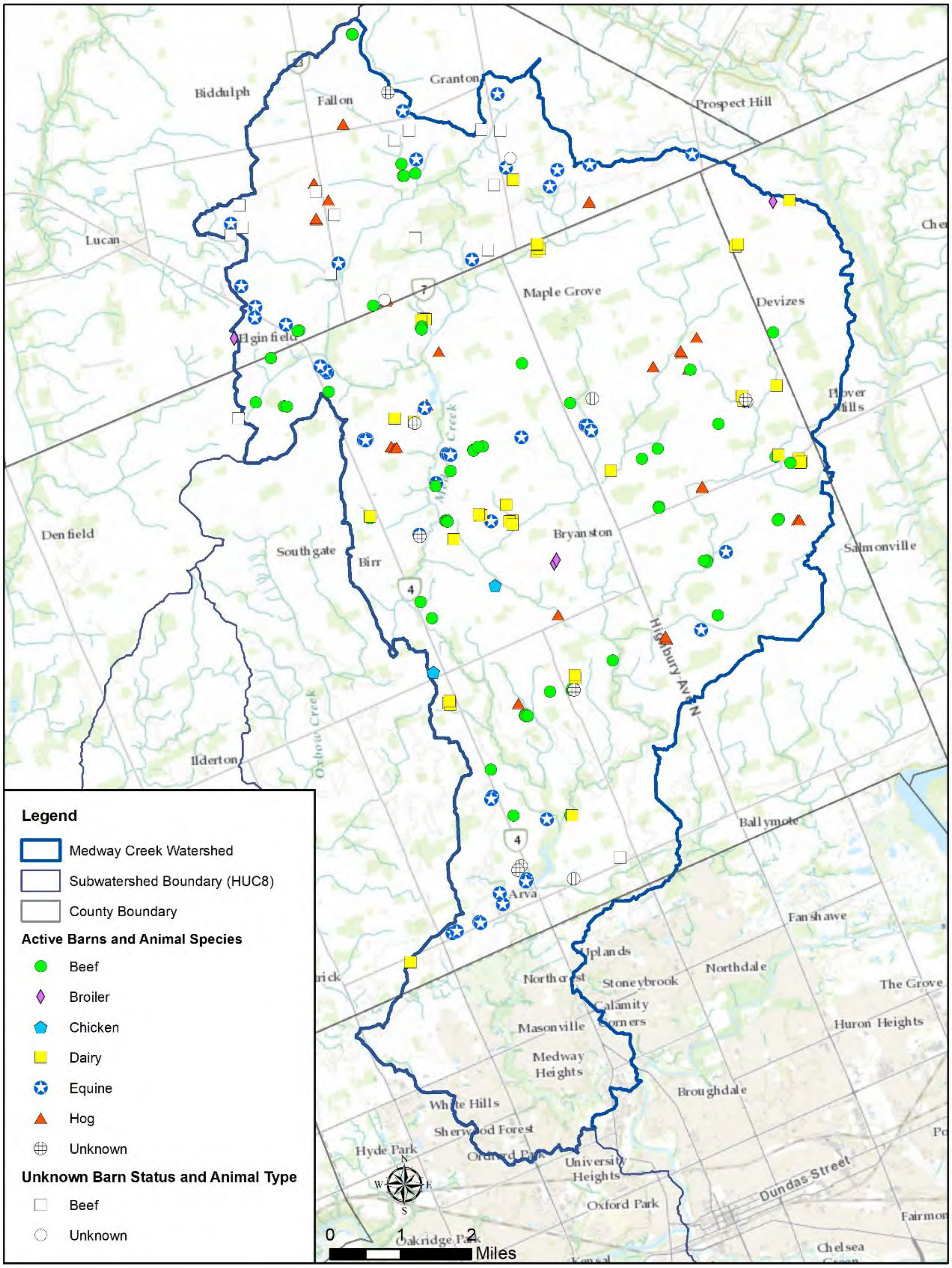
Source: Land Information Ontario, https://geohub.lio.gov.on.ca/datasets/31e41d9e9dbd4f59a995a89e1fd1e5b5/about

Figure C.9 Medway Creek Watershed Tile Drainage



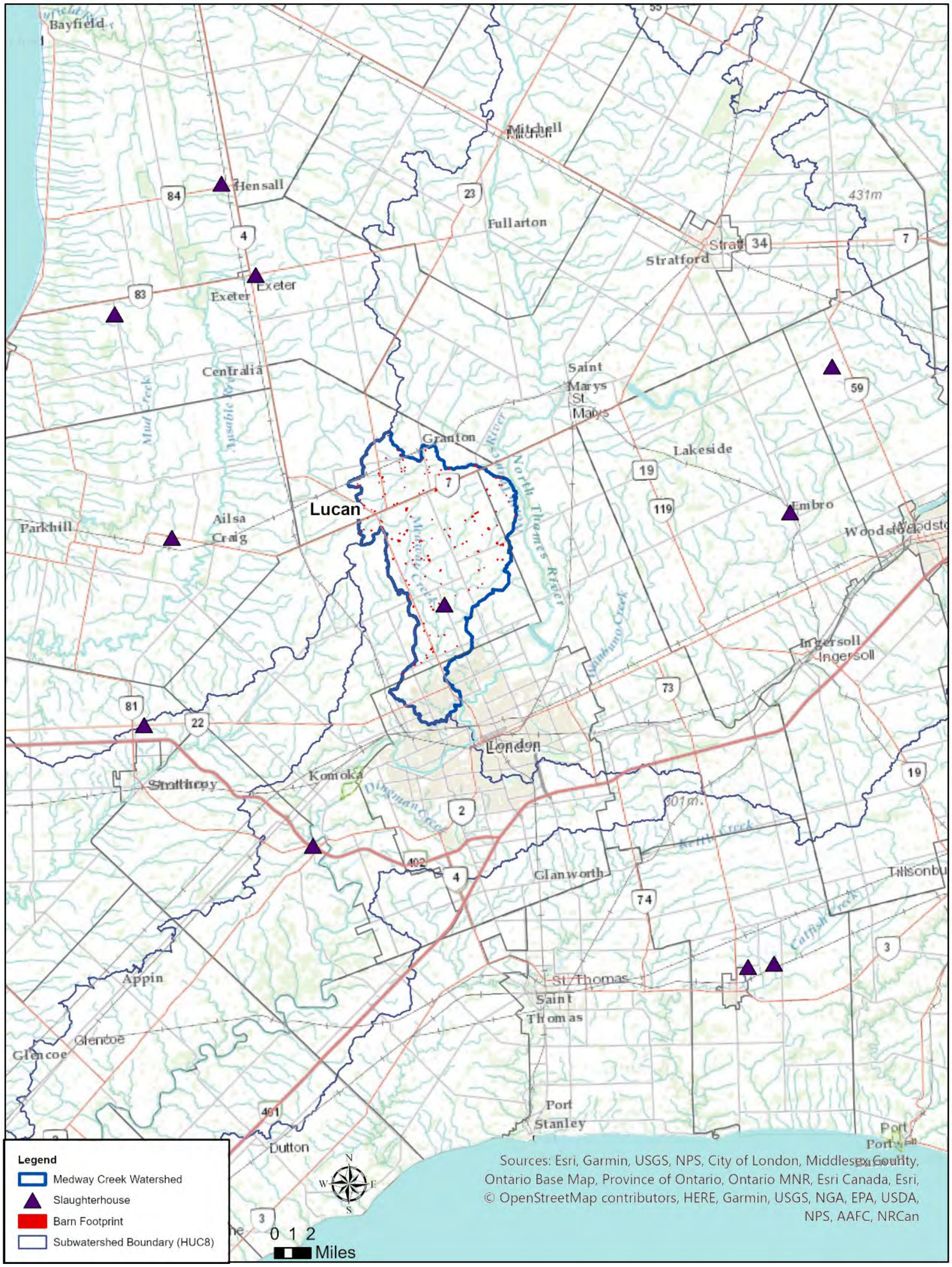
Source: Government of Canada, https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=02GD008

Figure C.10 Medway River at London Monitoring Station



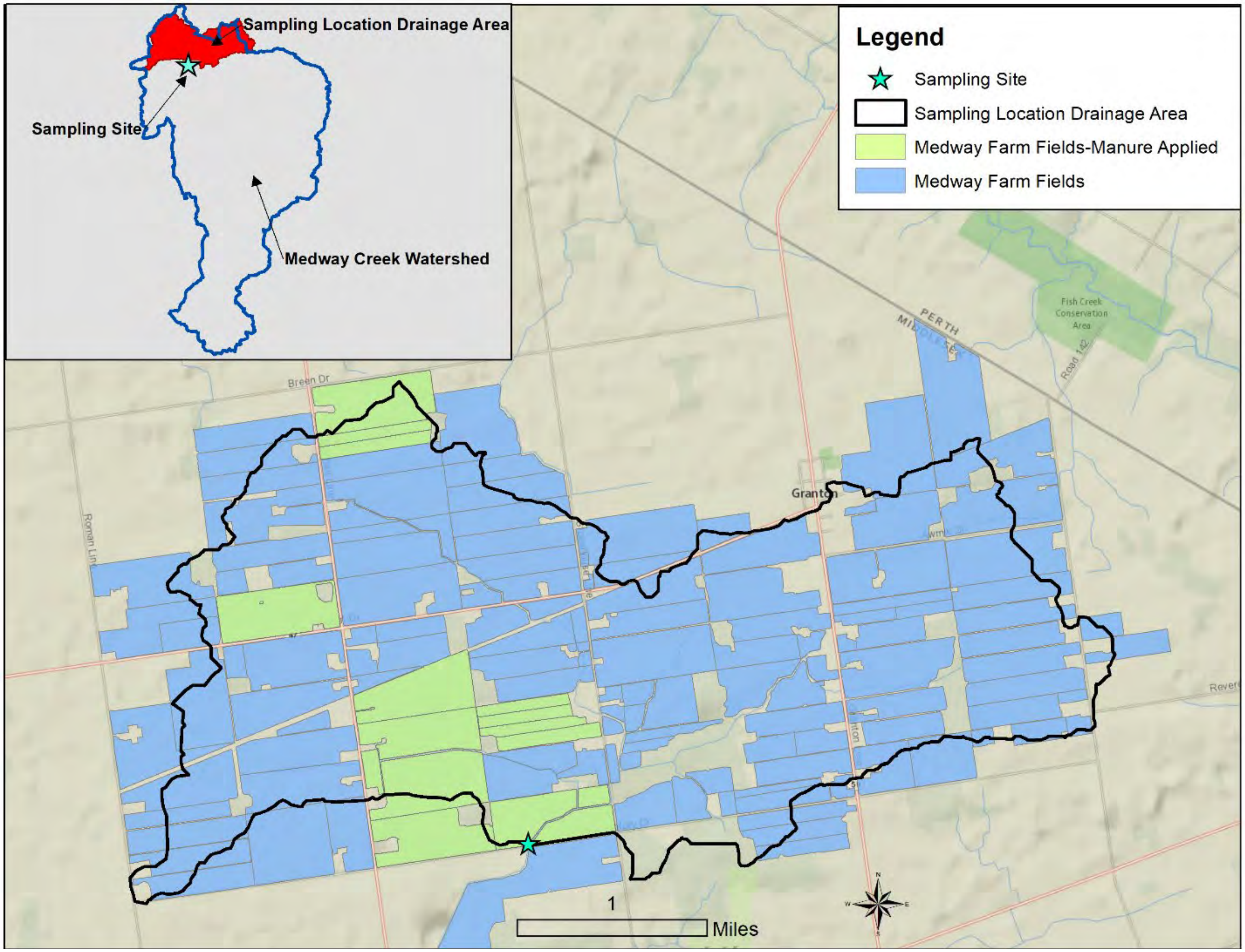
Source: OMAFRA.

Figure C.11 Active Barns within the Medway Creek Watershed



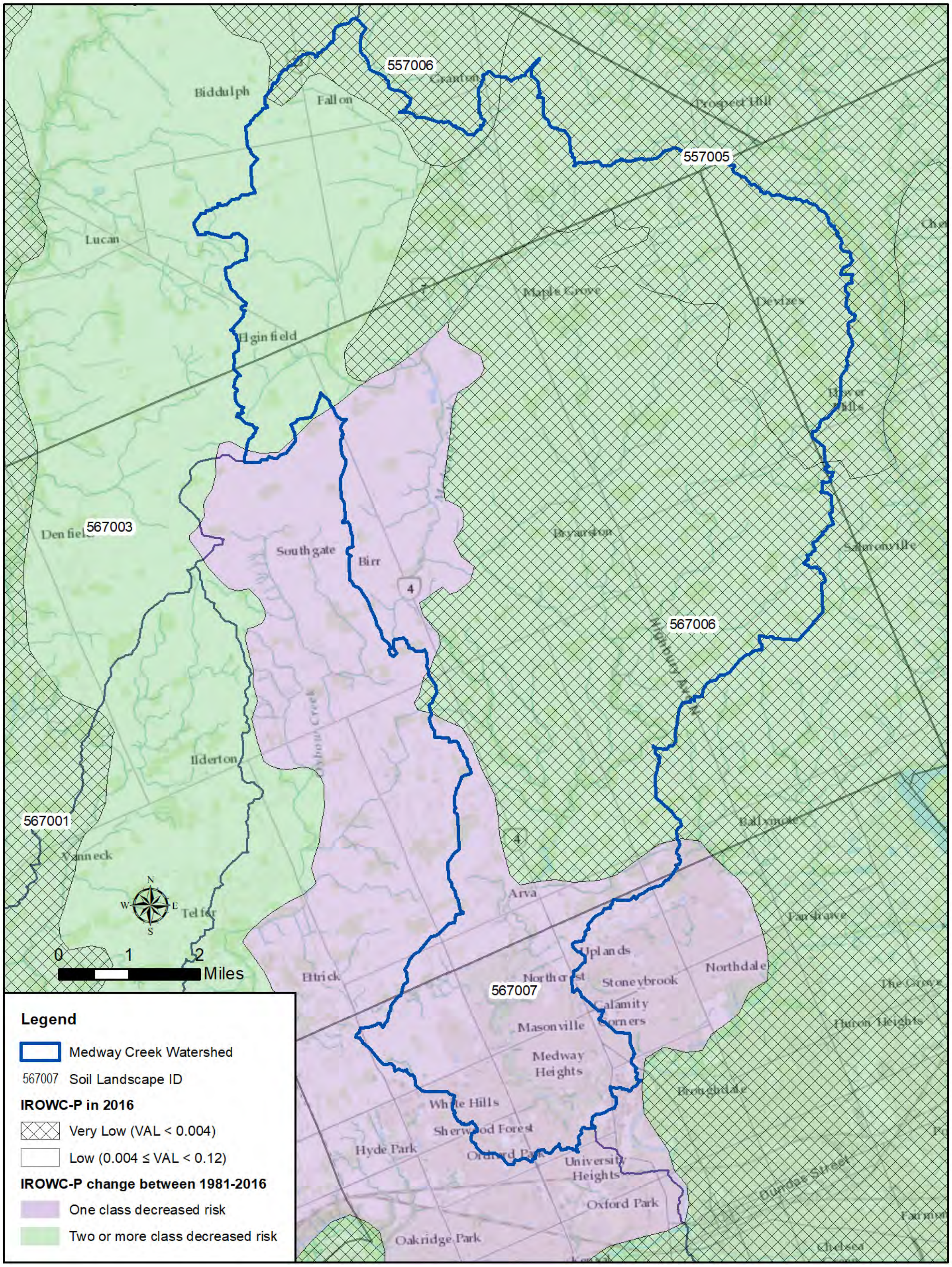
Source: Government of Ontario, https://data.ontario.ca/dataset/provincially-licensed-meat-plants

Figure C.12 Provincially Licensed Animal Processing Facilities in Ontario



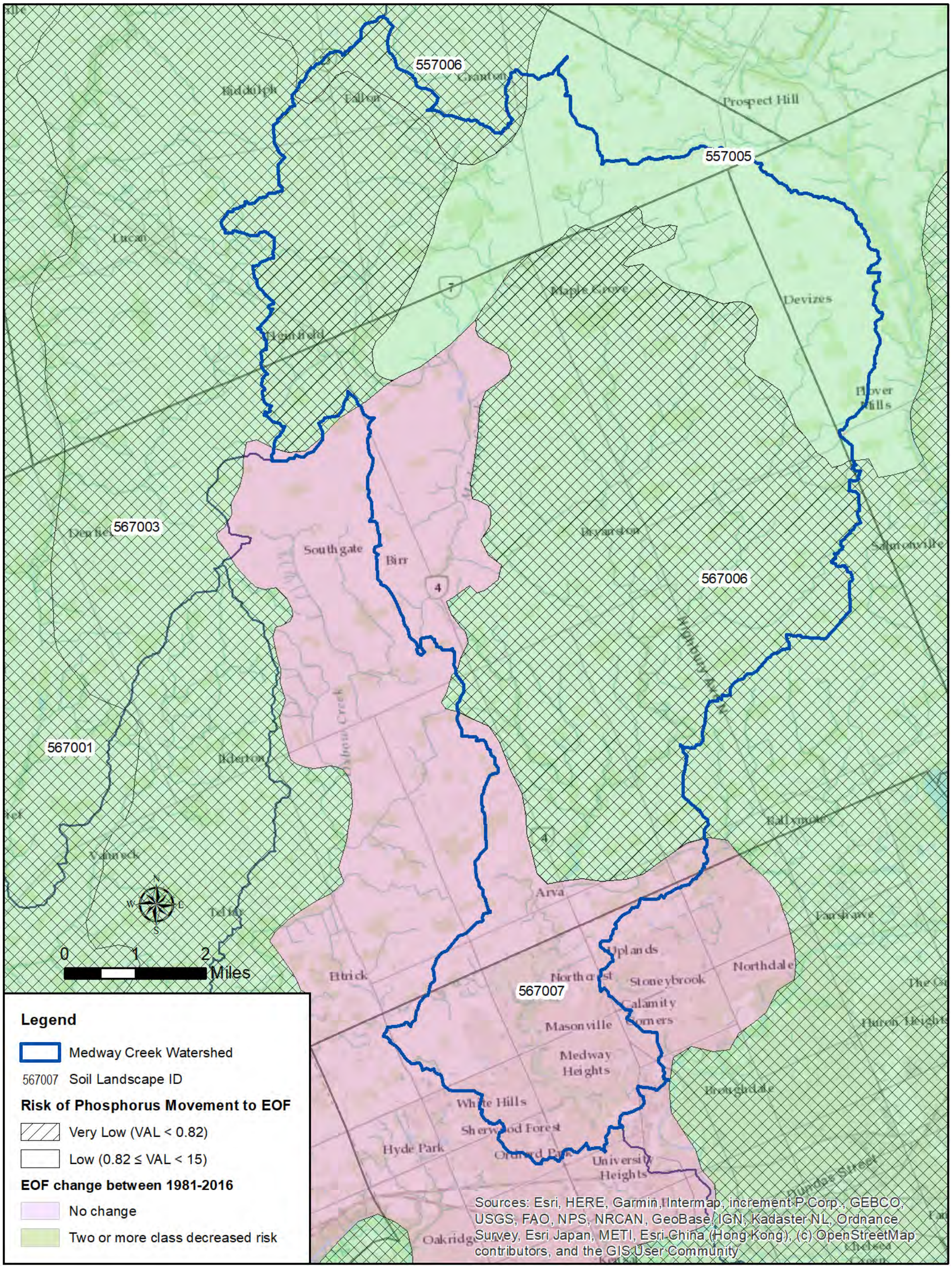
Source: UTRCA

Figure C.13 Medway Creek Farm Fields with Manure Application and Stream Monitoring Site (Source: UTRCA)



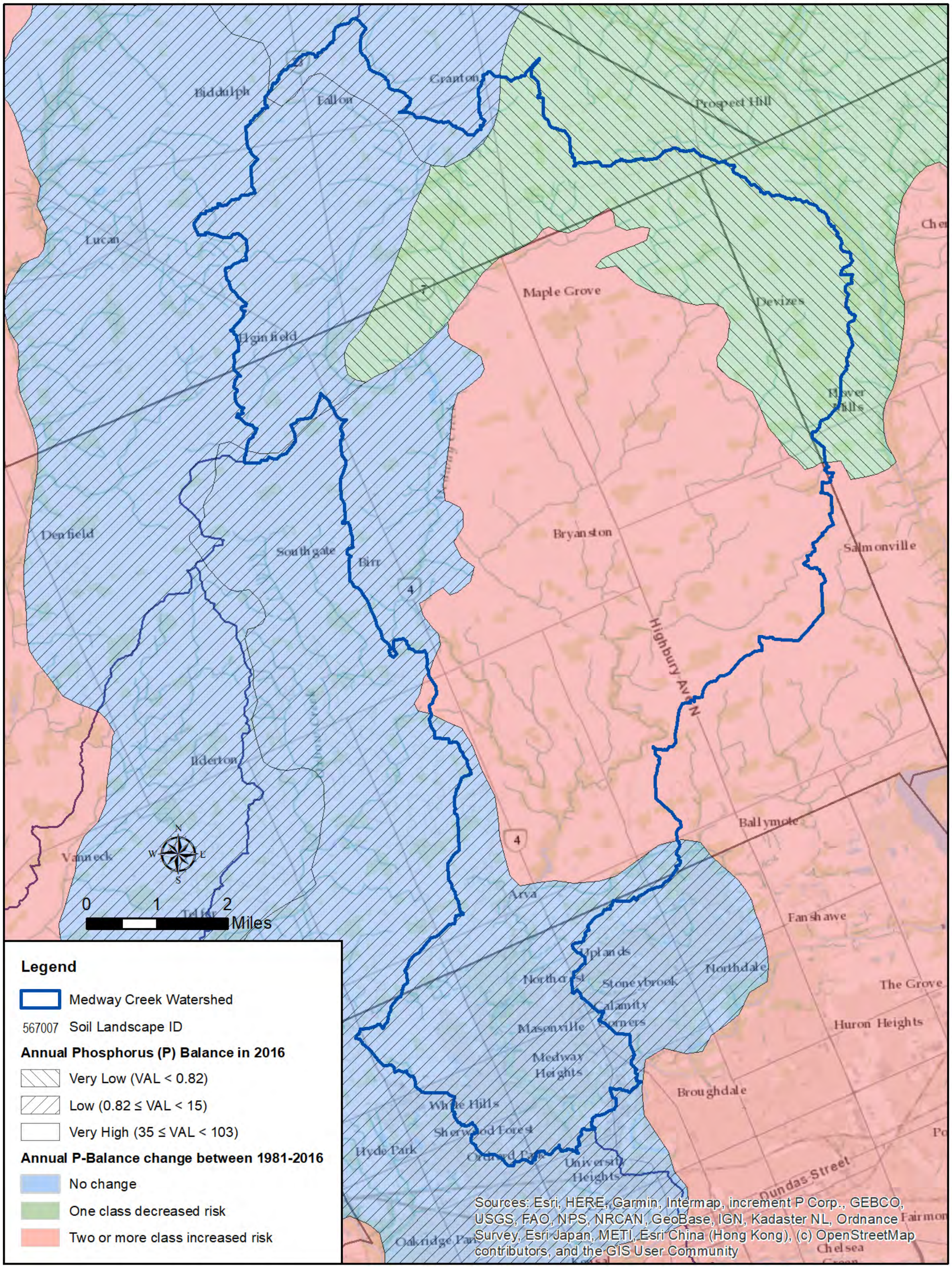
Source: Government of Canada, https://open.canada.ca/data/en/dataset/8b13d884-c0bf-4ee4-9f44-eb2efbb760a6

Figure C.14 Annual Risk of P Water Contamination in the Medway Creek Watershed



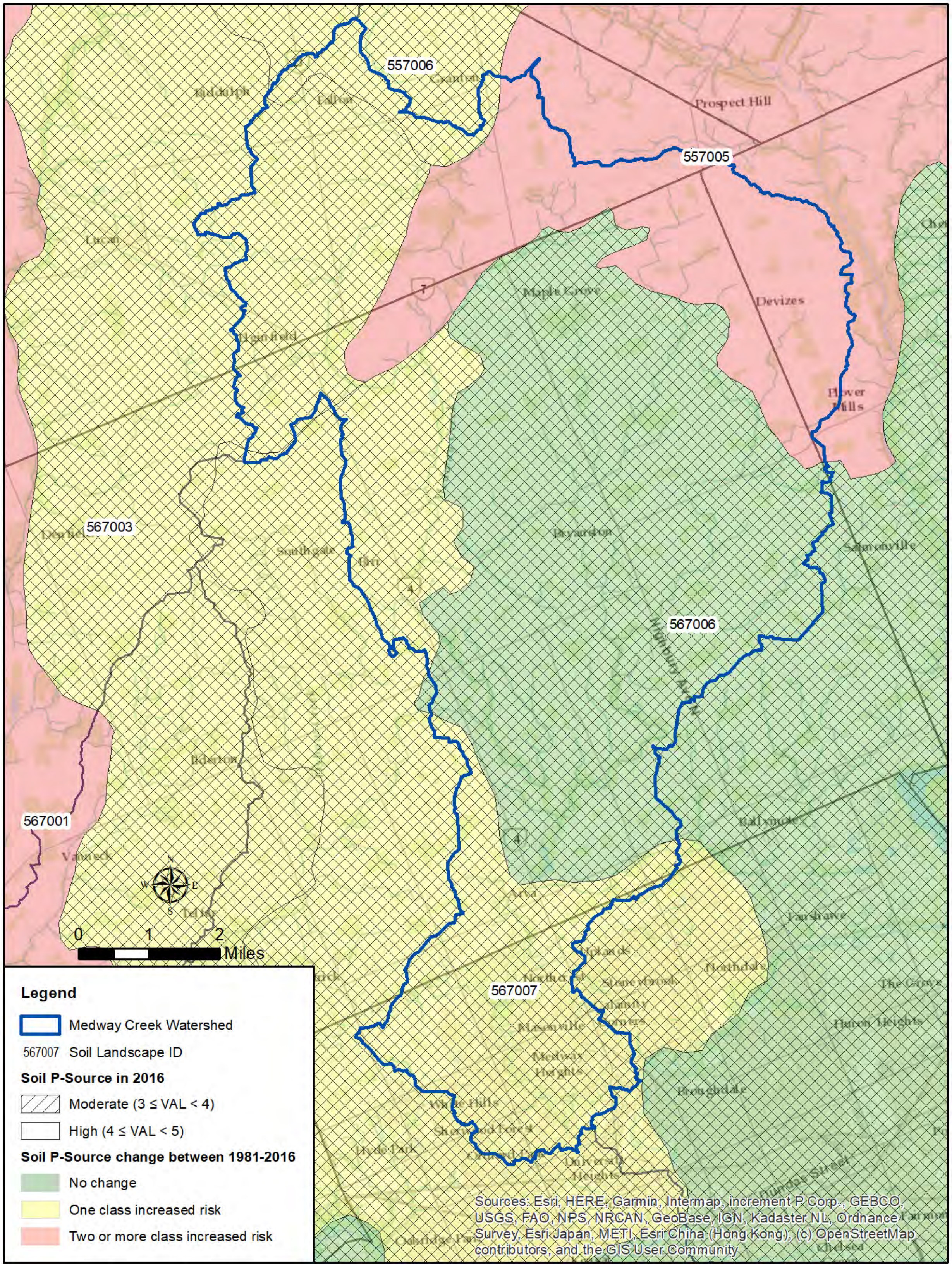
Source: Government of Canada, https://open.canada.ca/data/en/dataset/8b13d884-c0bf-4ee4-9f44-eb2efbb760a6

Figure C.15 Annual Risk of P Movement to Edge of Field in the Medway Creek Watershed



Source: Government of Canada, https://open.canada.ca/data/en/dataset/8b13d884-c0bf-4ee4-9f44-eb2efbb760a6

Figure C.16 Annual P Balance in the Medway Creek Watershed



Source: Government of Canada, https://open.canada.ca/data/en/dataset/8b13d884-c0bf-4ee4-9f44-eb2efbb760a6

Figure C.17 Annual Risk of P Release from Soils in the Medway Creek Watershed

Appendix D – List of Data Collected

Auglaize (US)

Data Element	Resource Title/Description	Link
Watershed features including, but not limited to, land use, land cover, geology, soil types, hydrology and climate in the two subwatersheds	Description of Auglaize River Watershed from the Western Lake Erie Basin Partnership (includes quick facts such as land use)	http://wleb.org/watersheds/auglaize.html
	Biological and Water Quality Study of Lower Auglaize River Tributaries (includes discussion of stream physical habitat)	https://epa.ohio.gov/static/Portals/35/documents/2014%20Lower%20Auglaize%20River%20Tributaries%20TSD.pdf
	Little Auglaize River Basin Underground Water Resources (includes discussion of general geology)	https://ohiodnr.gov/static/documents/geology/A2_LittleAuglaizeRiverBasin_1959.pdf
	Rapid Watershed Assessment - Data Profile Auglaize Watershed (includes sections on soil resources and text on average annual precipitation, land use, crop type, etc.)	https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_028995.pdf
Number of permitted animal feeding operation facilities	Available in spreadsheet for IN portion of watershed;	https://www.in.gov/idem/cfo/resources/pending-and-issued-cfo-permits/; https://www.ewg.org/interactive-maps/2019_maumee/
	2017 census of Ag - OPERATIONS WITH INVENTORY of cattle, hogs, poultry etc by county	https://www.nass.usda.gov/Quick_Stats/CDQT/chapter/2/table/11/state/OH/county/125/year/2017
	EWG and ELPC study	https://elpc.org/wp-content/uploads/2020/05/CAFOFactsheet_ELPC_1.pdf
Estimated number of unpermitted animal feeding operation facilities	EWG and ELPC study	https://elpc.org/wp-content/uploads/2020/05/CAFOFactsheet_ELPC_1.pdf
Estimated number of nearby livestock processing facilities/abattoirs	Ohio Slaughter Houses Custom Slaughter	http://ohioagriculture4u.com/ohio_slaughter_houses.htm
	OH Dept of Ag - Division of Meat Inspection	https://www.nichemeatprocessing.org/wp-

Auglaize (US)

		content/uploads/2019/07/Ohio_Plant_List.pdf
	Division of Meat Inspection Coverage - map and list of establishments	https://agri.ohio.gov/divisions/meat-inspection/meat-district-coverage-map
	IN Locations of State Inspected Plants	https://www.in.gov/boah/files/Meat_and_Poultry_Buyers_Guide_2020.pdf
	USDA Food Safety Inspection Service	https://www.fsis.usda.gov/inspection/fsis-inspected-establishments
Locations of permitted and unpermitted facilities, for the purposes of mapping (per Task 2)	EWG Animal Feeding Operations Interactive Map for the Maumee	https://www.ewg.org/interactive-maps/2019_maumee/map/
	Map of CAFOs last updated in 2014, now removed. For current information and questions about the permitting or location of Concentrated Animal Feeding Facilities, contact the Ohio Department of Agriculture	http://wwwapp.epa.ohio.gov/dsw/gis/cafo/
	List of Individual CAFO Permits	https://epa.ohio.gov/divisions-and-offices/surface-water/permitting/concentrated-animal-feeding-operations
	Map prepared June 2008 - Permitted Livestock Facilities, Ohio, USA	See attached map, received in support of prior work
	Figure 3-30: Locations of permitted CAFOs in the U.S	https://legacyfiles.ijc.org/publications/LimnoTech_IJC_Fertilizer.pdf
	Indiana Department of Environmental Management. Environment>Agribusiness>Confined Feeding Operations Facilities in Indiana.	https://maps.indiana.edu/LayerGallery.html
	Confined Feeding Operation Facilities, 20200402 - Shows swine, chicken, turkey, beef or dairy agribusinesses that have large enough numbers of animals that IDEM regulates for environmental concerns, as defined by IC 13-18-10 of the Indiana Code	https://maps.indiana.edu/previewMaps/Environment/Agribusiness_Confined_Feeding_Operations.html

Auglaize (US)

Animal counts and types for permitted and unpermitted animal feeding operation facilities	EWG and ELPC study	https://elpc.org/wp-content/uploads/2020/05/CAFOFactsheet_ELPC_1.pdf
	Cattle and calves inventory, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf
	Hogs and pigs inventory, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf
	Sheep and lambs inventory, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf
	Horses and ponies inventory, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf
	Goats inventory, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf
	Chickens inventory, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf
	2017 census of ag - inventory of cattle, hogs, poultry etc by county	https://www.nass.usda.gov/Quick_Stats/CDQT/chapter/2/table/11/state/OH/county/125/year/2017
Soil phosphorus levels across the subwatersheds	County level study by Dayton et al.	https://www.researchgate.net/publication/340074348_Soil_test_phosphorus_and_phosphorus_balance_trends_A_county-level_analysis_in_Ohio
	Soil Test Summaries	https://algreatlakes.com/pages/soil-test-summaries
The type and quantities of manure generated	County-level estimates of nutrients applied to the soil in fertilizer and livestock manure	https://nugis.tfi.org/

Auglaize (US)

Quantities of manure applied to land	Estimation methodology	See methods in http://scavia.seas.umich.edu/wp-content/uploads/2018/03/Long-et-al.-2018.pdf
	County-Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States, 1982–2001	https://pubs.usgs.gov/sir/2006/5012/
	County-Level Estimates of Nitrogen and Phosphorus from Animal Manure for the Conterminous United States, 2007 and 2012	https://pubs.usgs.gov/of/2017/1021/ofr20171021.pdf
The number of acres of land to which manure is applied	Acres - manure used, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf
The approximate distance from manure generation to application	Estimation methodology (see methods in linked report)	http://scavia.seas.umich.edu/wp-content/uploads/2018/03/Long-et-al.-2018.pdf
The approximate distance from manure application area to nearby permanent streams	Estimation methodology (see methods in linked report)	http://scavia.seas.umich.edu/wp-content/uploads/2018/03/Long-et-al.-2018.pdf
Number of agricultural acres in each watershed that receive applications of commercial fertilizer, manure and/or biosolids	Biosolids application fields and potentially other useful GIS data / maps:	https://oepa.maps.arcgis.com/apps/MapAndAppGallery/index.html?appid=a61479e80eec4bbbb0c240ece0a39b61
	County-Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States, 1982–2001	https://pubs.usgs.gov/sir/2006/5012/
	Acres - Commercial fertilizer, lime, and soil conditioners used, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf
	Acres - manure used, 2017 and 2012 Western Lake Erie 041000	https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Watersheds/gl04.pdf

Auglaize (US)

	County-Level Estimates of Nitrogen and Phosphorus from Commercial Fertilizer for the Conterminous United States, 1987-2012	https://data.usgs.gov/datacatalog/data/USGS:5851b2d1e4b0f99207c4f238
	Estimates of County-Level Nitrogen and Phosphorus from Fertilizer and Manure from 1950 through 2017 in the Conterminous United States	https://pubs.er.usgs.gov/publication/ofr20201153
	County-Level Estimates of Nitrogen and Phosphorus from Animal Manure for the Conterminous United States, 2007 and 2012	https://pubs.usgs.gov/of/2017/1021/ofr20171021.pdf
To the extent possible, the potential contribution of phosphorus, dissolved and total, to streams in the two subwatersheds from commercial vs. manure fertilizers	County-level estimates of nutrients applied to the soil in fertilizer and livestock manure	https://nugis.tfi.org/
	Source contribution to phosphorus loads from the Maumee River watershed to Lake Erie (Kast et al, 2021)	https://sparrow.wim.usgs.gov/sparrow-midwest-2012/; https://www.sciencedirect.com/science/article/pii/S030147972031728X?via%3Dihub
	Estimates of County-Level Nitrogen and Phosphorus from Fertilizer and Manure from 1950 through 2017 in the Conterminous United States	https://pubs.er.usgs.gov/publication/ofr20201153
Estimated total and dissolved phosphorus loading to the Medway Creek and Auglaize River	Western Lake Erie Tributary, Water Monitoring Summary, March 1, 2020 - July 31, 2020 loads of both TP and DRP for Gage 04191500 - Auglaize River near Defiance d/s dam	https://lakeerie.ohio.gov/static/Water_Monitoring_Summary/Water+Monitoring+Fact+Sheet+2020+FINAL.pdf
	Ohio EPA's Nutrient Mass Balance Study for Ohio's Major Rivers	https://www.onewaterohio.org/docs/Ohio_EPA_Nutrient_MB.pdf
	Lake Erie Tributary Nutrient Load Monitoring, 2019 Spring Load and 2019 Water Year Loading for multiple stations in the Auglaize	https://lakeerie.ohio.gov/static/Water_Monitoring_Summary/Expanded_load_monitoring_report_2020_FINAL.pdf
	Nutrient Mass Balance Study for Ohio's Major Rivers 202	https://epa.ohio.gov/static/Portals/35/documents/Nutrient-Mass-Balance-Study-2020.pdf
	Variability in DRP Concentrations in the Maumee River Watershed - map of DRP conc. by HUC12 for Auglaize	Meyer et al 2022 (sent to us, not posted online)

Auglaize (US)

Locations where continuous/sustained nutrient monitoring of water is undertaken and the source of the monitoring data	6 sustained monitoring locations in Auglaize HUC8.	https://lakeerie.ohio.gov/static/Water_Monitoring_Summary/Expanded_load_monitoring_report_2020_FINAL.pdf
Manure application methods and timing	Section 3.2.1.e Manure Application: Method and Timing (Summary)	https://legacyfiles.ijc.org/publications/LimnoTech_IJC_Fertilizer.pdf
	Ohio Senate Bill 1	https://www.legislature.ohio.gov/legislation/legislation-summary?id=GA131-SB-1
Estimated manure phosphorus (P), potassium (K), and nitrogen (N) land application rates for predominant crop types.	TRI-STATE FERTILIZER RECOMMENDATIONS for Corn, Soybean, Wheat, and Alfalfa	https://www.canr.msu.edu/soilfertility/Files/Main-page/FINAL%20PRINT.pdf
	Rule 901:10-2-14 | Contents of manure management plan: land application methods	https://codes.ohio.gov/ohio-administrative-code/rule-901:10-2-14
Describe the impairment status of the two Lake Erie subwatershed waterways (under U.S. and Canadian water quality laws), including any existing watershed assessments relevant to nutrients and phosphorus loading/inputs	Ohio 2022 Integrated Water Quality Monitoring and Assessment Report	https://epa.ohio.gov/static/Portals/35/tmdl/2022intreport/Full-2022-IR.pdf
	Total Maximum Daily Loads for the Upper Auglaize River Watershed	https://epa.ohio.gov/static/Portals/35/tmdl/UpperAuglaizeFinalTMDL.pdf
	Maumee Watershed Nutrient TMDL Project, Addressing Lake Erie Impairments	https://epa.ohio.gov/static/Portals/35/tmdl/MaumeeNutrient/Maumee-Nutrient-TMDL-062022.pdf
Information on new manure nutrient management technologies: - Manure storage and treatment technologies, including nutrient removal efficiency, cost of installation, operation and maintenance - Manure application technologies,	2019 - Manure Treatment Technologies	https://lpelc.org/manure-treatment-technologies/
	2020 - 8 innovative technologies offer solutions for manure management	https://www.progressivedairy.com/topics/manure/8-innovative-technologies-offer-solutions-for-manure-management
	2018 Virginia Tech Cooperative Extension guidance on selecting manure treatment technologies	https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/442/442-306/BSE-242.pdf

Auglaize (US)

efficiency in using manure nutrients, and costs - Funding/incentive opportunities for the implementation of innovative practices	2020 - Manure Treatment	https://cals.cornell.edu/pro-dairy/our-expertise/environmental-systems/manure-management/manure-treatment
	Undated EPA draft report on manure management technologies, with information on applicability and costs	https://www3.epa.gov/npdes/pubs/cafo_report.pdf
Collect information on existing manure management permitting rules and regulations, such as, but not limited to, criteria to be subjected to permitting requirements; nutrient soil testing and frequency requirements; manure nutrient testing and frequency requirements; rules for the construction manure storage structures; application restrictions/bans; acreage requirements for land application of manure; requirements for the preparation of a nutrient management plan; and enforcement protocols	Ohio Livestock Manure Management Guide (chapters on manure-management systems; land application of manure; rules and regulations. Appendices on sampling livestock waste for analysis; reporting manure analysis results)	https://agcrops.osu.edu/sites/agcrops/files/imce/fertility/bulletin_604.pdf
	Fertilizer & Manure Guide	https://agri.ohio.gov/divisions/plant-health/resources/fertilizer-manure
	USDA NRCS Conservation Practice Standard. Nutrient Management. Code 590 (includes soil sampling, testing, and analysis; nutrient application rates; nutrient application timing and placements; additional considerations and strategies)	https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1192371.pdf
	Ohio Revised Code Title 9, Chapter 939. Section 939.08 (Application of manure in the western basin)	https://codes.ohio.gov/ohio-revised-code/section-939.08
	Plowing into Conservation Tillage: What is it and Why is it so Popular?	https://partnershipfarm.org/wp-content/uploads/2020/04/PARM-Trifold-Pages-0919.pdf
Collect information on programs and funding for best management practices related to field management practices (such as tillage practices, cropping systems, water/erosion management, drainage practices) and manure land application practices	H2Ohio (funded by Ohio General Assembly to begin the long-term process to reduce phosphorus runoff from farms through the use of proven, science-based nutrient management BMPs and the creation of phosphorus-filtering wetlands)	https://h2.ohio.gov/about-h2ohio/
	USDA NRCS Environmental Quality Incentives Program (provides financial and technical assistance to agricultural producers and non-industrial forest managers to address natural resource concerns and deliver environmental benefits.	https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/eqip/?cid=nrcseprd1342638

Medway (Canada)

Data Element	Resource Title/Description	Link
Watershed features including, but not limited to, land use, land cover, geology, soil types, hydrology and climate in the two subwatersheds	2017 Watershed Report Card: Medway Creek (includes summaries of land use, soil type, physiography, tilling & drainage; vegetation covers and types; surface water quality; agricultural BMPs)	http://thamesriver.on.ca/wp-content/uploads//WatershedReportCards/RC_Medway.pdf
	Climate: precipitation UTRCA station at Medway	https://apps.thamesriver.on.ca/ffw/UTRCA_PP.html
	Ontario Census Divisions and consolidated subdivisions	https://www150.statcan.gc.ca/n1/pub/95-630-x/95-630-x2022001-eng.htm
Number of permitted animal feeding operation facilities	*See links below for Animal Counts; data included under "number of farms reporting"*	
	Farms classified by farm type, Ontario, Census of Ag 2021 historical data	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210016601&pickMembers%5B0%5D=1.7&cubeTimeFrame.startYear=2006&cubeTimeFrame.endYear=2021&referencePeriods=20060101%2C20210101
	Number of farms available by county as well	http://www.omafra.gov.on.ca/english/stats/county/southern_ontario/middlesex.xlsx
Estimated number of unpermitted animal feeding operation facilities	*See links below for Animal Counts; data included under "number of farms reporting"*	
Estimated number of nearby livestock processing facilities/abattoirs	Provincially licensed dairy plants	https://data.ontario.ca/dataset/provincially-licensed-dairy-plants
	Provincially licensed meat plants	https://data.ontario.ca/dataset/provincially-licensed-meat-plants
	Provincially licensed meat plants approved to process non-emergency slaughter (NES)	https://data.ontario.ca/dataset/provincially-licensed-meat-plants-approved-to-process-non-emergency-slaughter-nes
	Provincially licensed operators that collect, transport, process and dispose of deadstock (dead farm animals) in Ontario	https://data.ontario.ca/dataset/ontario-deadstock-operators-and-facilities

Medway (Canada)

Locations of permitted and unpermitted facilities, for the purposes of mapping (per Task 2)	Dairy goat farm inspection results, Ontario (would have addresses, currently not available)	https://data.ontario.ca/dataset/dairy-goat-farm-inspection-results
	List of feedlots in Canada Canadian Cattlemen	Canadian Cattleman Feedlot Guide
Animal counts and types for permitted and unpermitted animal feeding operation facilities	Statistics Canada. Table 32-10-0155-01 Selected livestock and poultry, Census of Agriculture historical data (All of Ontario)	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210015501&pickMembers%5B0%5D=1.7&cubeTimeFrame.startYear=2001&cubeTimeFrame.endYear=2021&referencePeriods=20010101%2C20210101
	Cattle inventory on farms, London census block, 2021	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210037001&pickMembers%5B0%5D=1.1108
	Sheep inventory on farms, Census of Agriculture, 2021, london census block	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210037101&pickMembers%5B0%5D=1.1108
	Pig inventory on farms, Census of Agriculture, 2021, london census block	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210037201&pickMembers%5B0%5D=1.1108
	Poultry inventory on farms, Census of Agriculture, 2021, london census block	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210037401&pickMembers%5B0%5D=1.1108
	Poultry production, Census of Agriculture, 2021, London census block	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210037501&pickMembers%5B0%5D=1.1108
	Commercial poultry hatcheries, Census of Agriculture, 2021, London census block	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210037701&pickMembers%5B0%5D=1.1108
	Ontario livestock inventories, by county	https://data.ontario.ca/dataset/ontario-livestock-by-county
Soil phosphorus levels across the subwatersheds	Phosphorus accumulation in Canadian agricultural soils over 30 yr	https://cdnsciencepub.com/doi/10.1139/cjss-2019-0023

Medway (Canada)

	Agri-Environmental Indicator – Risk of Water Contamination by Phosphorus Data Series	https://open.canada.ca/data/en/dataset/8b13d884-c0bf-4ee4-9f44-eb2efbb760a6
The type and quantities of manure generated	Acres receiving liquid manure/Acres receiving composed manure, London census block, 2021	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210036801&pickMembers%5B0%5D=1.1108
	Manure production, geographically (kg/ha) by sub-sub drainage areas in 2006 (Hoffman, 2008)	https://www150.statcan.gc.ca/n1/pub/16-002-x/2008004/article/10751-eng.htm
	Total nitrogen and phosphorus content of manure, by livestock type, 2006	https://www150.statcan.gc.ca/n1/pub/16-002-x/2009001/tbl/prod/tbl001-eng.htm
Quantities of manure applied to land	Estimation of Manure Application	2018 Report Fertilizer Application Patterns and Trends and Their Implications for Water Quality in the Western Lake Erie Basin
The number of acres of land to which manure is applied	Acres, manure applied, London census block for 2021	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210036801&pickMembers%5B0%5D=1.1108
	Acres, manure applied, southern Ontario CAR, 2021	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210036801&pickMembers%5B0%5D=1.1050
The approximate distance from manure generation to application	Estimation methodology (see methods in linked report)	http://scavia.seas.umich.edu/wp-content/uploads/2018/03/Long-et-al.-2018.pdf
The approximate distance from manure application area to nearby permanent streams	Estimation methodology (see methods in linked report)	http://scavia.seas.umich.edu/wp-content/uploads/2018/03/Long-et-al.-2018.pdf
Number of agricultural acres in each watershed that receive	Acres, commercial fertilizer, London census block for 2021	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210036801&pickMembers%5B0%5D=1.1108

Medway (Canada)

applications of commercial fertilizer, manure and/or biosolids	Acres, manure applied, southern Ontario CAR, 2021	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210036801&pickMembers%5B0%5D=1.1050
	Proportion of farms reporting cropland where commercial fertilizers were used by census division (CD), 2015 Canada	https://www150.statcan.gc.ca/n1/pub/95-634-x/2017001/article/54903/catm-ctra-257-eng.htm
	Farm property class tax is available by parcel for 2016 to 2021 and provides potential ag acres, spatially	https://www.lioapplications.lrc.gov.on.ca/AgMaps/Index.html?viewer=AgMaps.AgMaps&locale=en-CA
To the extent possible, the potential contribution of phosphorus, dissolved and total, to streams in the two subwatersheds from commercial vs. manure fertilizers	Commercial fertilizer application rates through time (kg P/hectare of cropland) for subwatersheds	Lake Erie Fertilizer and Manure Study: Supplemental Report Final Revision: July 9, 2019
	Estimation of Manure Application	2018 Report Fertilizer Application Patterns and Trends and Their Implications for Water Quality in the Western Lake Erie Basin
Estimated total and dissolved phosphorus loading to the Medway Creek and Auglaize River	Discharge measured at MEDWAY RIVER AT LONDON (02GD008) [ON]	https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=02GD008
Locations where continuous/sustained nutrient monitoring of water is undertaken and the source of the monitoring data	Long-term freshwater quality data from federal and federal-provincial sampling sites throughout Canada's aquatic ecosystems	https://open.canada.ca/data/en/dataset/67b44816-9764-4609-ace1-68dc1764e9ea
	Provincial Groundwater Monitoring Network - several locations just outside of Medway watershed boundary	https://www.ontario.ca/page/map-provincial-groundwater-monitoring-network
Manure application methods and timing	Three manure application methods are used on farmlands: surface application, surface application and incorporation, and direct injection	Medway Creek Community-based Enhancement Strategy
	Manure: Injected, incorporated, not incorporated, London census block, 2021	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210036801&pickMembers%5B0%5D=1.1108

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	Manure: Injected, incorporated, not incorporated, southern Ontario CAR, 2021	https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210036801&pickMembers%5B0%5D=1.1050
Estimated manure phosphorus (P), potassium (K), and nitrogen (N) land application rates for predominant crop types.	Fertilizer Recommendations	http://www.omafra.gov.on.ca/english/crops/pub611/pub611ch7.pdf
Describe the impairment status of the two Lake Erie subwatershed waterways (under U.S. and Canadian water quality laws), including any existing watershed assessments relevant to nutrients and phosphorus loading/inputs	Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health 2021	https://files.ontario.ca/mecp-coa-great-lakes-en-2021-05-26.pdf
	2017 Watershed Report Card: Medway Creek	http://thamesriver.on.ca/wp-content/uploads//WatershedReportCards/RC_Medway.pdf
	Canada-Ontario Lake Erie Action Plan, Feb 2018	https://www.canada.ca/content/dam/eccc/documents/pdf/great-lakes-protection/dap/action_plan.pdf
	Lake Erie Binational Phosphorus Reduction Strategy, June 2019	https://binational.net/wp-content/uploads/2019/06/19-148_Lake_Erie_Strategy_E_accessible.pdf
Information on new manure nutrient management technologies: - Manure storage and treatment technologies, including nutrient removal efficiency, cost of installation, operation and maintenance - Manure application technologies, efficiency in using manure nutrients, and costs - Funding/incentive opportunities for the implementation of innovative practices	2004 University of Guelph Report on Advanced Manure Management Technologies for Ontario	https://atrium.lib.uoguelph.ca/xmlui/handle/10214/14052
	Application: Effect of tillage on phosphorus loss through tiles	https://atrium.lib.uoguelph.ca/xmlui/handle/10214/14767
	2019 - Manure Treatment Technologies	https://lpelc.org/manure-treatment-technologies/
	OMAFRA Manure Management	https://omafra.gov.on.ca/english/nm/manuremgmt.htm

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Collect information on existing manure management permitting rules and regulations, such as, but not limited to, criteria to be subjected to permitting requirements; nutrient soil testing and frequency requirements; manure nutrient testing and frequency requirements; rules for the construction manure storage structures; application restrictions/bans; acreage requirements for land application of manure; requirements for the preparation of a nutrient management plan; and enforcement protocols	Partnerings on Achieving Phosphorus Loading Reductions in Lake Erie from Canadian Sources: A Draft Canada-Ontario Lake Erie Action Plan	https://www.farmfoodcareon.org/wp-content/uploads/2017/11/DRAFT-DAP-for-November-2017-Engagement.pdf
	Summary of Findings and Strategies to Move Toward a 40% Phosphorus Reduction (includes list of BMPs)	https://mrbplg.org/wp-content/uploads/2018/02/Lake-Erie_Final-Summary-Strategies-WhitePaper.pdf
	Timing Matters (Ontario initiative to promote optimal timing of manure throughout the year)	https://www.farmfoodcareon.org/timing-matters/#ardn-4725013205e9c8475e4b52623837092-1 https://www.farmfoodcareon.org/wp-content/uploads/2021/12/Timing-Matters-Articles_Dec1621.pdf
Collect information on programs and funding for best management practices related to field management practices (such as tillage practices, cropping systems, water/erosion management, drainage practices) and manure land application practices	Clean Water Program (eligible projects include Nutrient Management Plans and Fertilizer, Chemical, and Fuel Storage or Handing. Each as a grant rate of 50% up to a maximum of $500.)	https://www.cleanwaterprogram.ca/eligible-projects/