Total Maximum Daily Load Report for Lake Manitou

Final TMDL

June 16, 2025

Prepared for: U.S. Environmental Protection Agency Region 5

Prepared by: Indiana Department of Environmental Management

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Executive Summary

Lake Manitou is located in northcentral Indiana, situated in east-central Fulton County southeast of Rochester, Indiana and northwest of Miami County. The lake spans approximately 775 acres or 1.2 square miles and has an average depth of 11 feet. Lake Manitou is heavily influenced by its tributaries Rain Creek/Graham Ditch (HUC 05120106050020) and the Robbin Taylor/Strebe Ditch (HUC 05120106050010). Rain Creek is also home to a small dam that slows down water flow and filtering sediment and other debris before entering Lake Manitou. The primary land use in this area of Indiana is agricultural with moderate development.

The Clean Water Act (CWA) and U.S. Environmental Protection Agency (U.S. EPA) regulations require that states develop Total Maximum Daily Loads (TMDLs) for waters on the Section 303(d) List of Impaired Waters. A TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards. TMDLs are composed of the sum of individual waste load allocations (WLAs) for regulated sources and load allocations (LAs) for sources that are not directly regulated. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this is defined by the equation:

$$TMDL = \sum WLAs + \sum LAs + MOS$$

This TMDL has been developed to address nutrient loading impairments in Lake Manitou for recreational uses, in accordance with the TMDL Program Priority Framework. Parameters chosen for TMDL development include total phosphorus.

After the Indiana Department of Environmental Management (IDEM) identifies a waterbody as having impairments and places the waterbody on Indiana’s Section 303(d) List of Impaired A sampling data is used to determine the extent and the magnitude of the impairment. Sampling on Lake Manitou was completed through collaborations with the Indiana Clean Lakes Program (CLP) administered by Indiana University (IU). Sampling events occurred in 2011, 2013, 2014 2015, and 2020. As a result of the assessments of Lake Manitou, elevated levels of total phosphorus were observed across sampling events resulting in a nutrients impairment. Therefore, a TMDL was developed to address the total phosphorus impairment for the lake.

Potential sources of the phosphorus impairment in the watershed could include both regulated point sources and nonpoint sources. Point sources including wastewater treatment plants (WWTPs) and Public Water Supply (PWS) facilities that discharge wastewater, and stormwater permitted construction activities are regulated through the National Pollutant Discharge Elimination System (NPDES). However, there are no NPDES permitted facilities currently discharging to Lake Manitou. Nonpoint sources such as unregulated urban stormwater, agricultural run-off, wildlife, confined feeding operations (CFOs), pasture animals with access to streams, and faulty and failing septic systems are also potential sources. In-stream runoff can cause eutrophication leading to harmful algae blooms and excessive algae when high levels of phosphorus are present affecting water quality conditions over time. A phosphorus listing on Indiana's 303(d) List suggests that total phosphorus and chlorophyll-a concentrations are at levels which contribute towards lake eutrophication that impacts recreational opportunities causing poor aesthetics. To address this impairment in Lake Manitou, total phosphorus has been identified as a pollutant for TMDL development.

An important step in the TMDL process is the allocation of the allowable loads to individual point sources, as well as sources that are not directly regulated. The Lake Manitou watershed TMDL includes these allocations, which are presented for Lake Manitou.

There are several types of documented and suspected nonpoint sources of pollution located in the Lake Manitou watershed, including unregulated livestock operations with direct access to streams, agricultural row crop land use, leaking or failing septic systems, wildlife, and erosion. Of these, agricultural row crop land use, livestock operations, and erosion are found most often in subwatersheds with elevated levels of total phosphorus. Although Indiana does not have a permitting program for nonpoint sources, many nonpoint sources are addressed through voluntary programs intended to reduce pollutant loads, minimize flow, and improve water quality.

This TMDL report helps identify which locations could most benefit from focusing on implementation activities. It provides recommendations on the types of implementation activities, including the best management practices (BMPs), that stakeholders can consider in achieving the pollutant load reductions necessary. A watershed model, Spreadsheet Tool for Estimating Pollutant Loads (STEPL), was developed to determine existing phosphorus loads entering Lake Manitou. A water quality model, BATHTUB, was developed in conjunction with the STEPL model to determine loading reductions necessary to achieve in-lake target values for total phosphorus and chlorophyll-a. Overall, a 40% reduction in total phosphorus loading in tributaries are needed to Lake Manitou during the critical growing season (June-August) to meet necessary in-lake concentrations.

Table 1: Percent Reduction for Lake Manitou

Percent Reduction	Resulting inflow TP (ppb)	Resulting in-lake TP (ppb)	Resulting in-lake Chl-a Concentration (ppb)
0	488	68	21
10	439.2	64	20
20	390.4	60	19
30	341.6	55	17
40	292.8	50	16
50	244	45	14

Public participation is an important and required component of the TMDL development process. The following public meetings and public comment periods have been held to further develop this project:

- A stakeholder meeting was held in Rochester, IN on October 23, 2017, to introduce the project and solicit public input. IDEM explained the TMDL process and presented initial information regarding the Lake Manitou watershed. Questions were answered from members of the Lake Manitou Association, and information was solicited from stakeholders in the area.
- The public comment period on the draft report was from May 09 2025 to June 09, 2025. IDEM received no public comments during that time period.

1.0 INTRODUCTION

This section of the Total Maximum Daily Load (TMDL) provides an overview of the Lake Manitou location and the regulatory requirements that have led to the development of this TMDL to address impairments in Lake Manitou.

Lake Manitou, shown in Figure 1, is located in north-central Indiana and drains a total of 44 square miles. Tributaries to Lake Manitou originate near the northwest corner of Miami County, and then flows northwest, where it ultimately empties into the southeast corner of Fulton County near Rochester. Land use throughout the watershed is split predominantly between forested areas and agricultural uses. There are no public water supply intakes from Lake Manitou.

The Clean Water Act (CWA) and U.S. Environmental Protection Agency (U.S. EPA) regulations require that states develop TMDLs for waters on the Section 303(d) List of Impaired Waters. U.S. EPA defines a TMDL as the sum of the individual waste load allocations (WLA) for point sources and load allocations (LA) for nonpoint sources, and a margin of safety (MOS) that addressed the uncertainty in the analysis.

The overall goals and objectives of the TMDL study for Lake Manitou are to:

- Assess the water quality of the impaired waterbody and identify key issues associated with the impairments and potential pollutant sources.
- Determine current loads of pollutants to the impaired waterbody.
- Use the best available science and available data to determine the total maximum daily load the waterbody can receive while fully supporting the impaired designated use that is impaired.
- If current loads exceed the maximum allowable loads, determine the load reduction that is needed.
- Inform and involve the public throughout the project to ensure that key concerns are addressed, and the best available information is used.
- Recommend activities for purposes of TMDL implementation.
- Submit a final TMDL report to the U.S. EPA for review and approval.

Watershed stakeholders and partners can use the final approved TMDL report to inform watershed management planning and implementation activities.

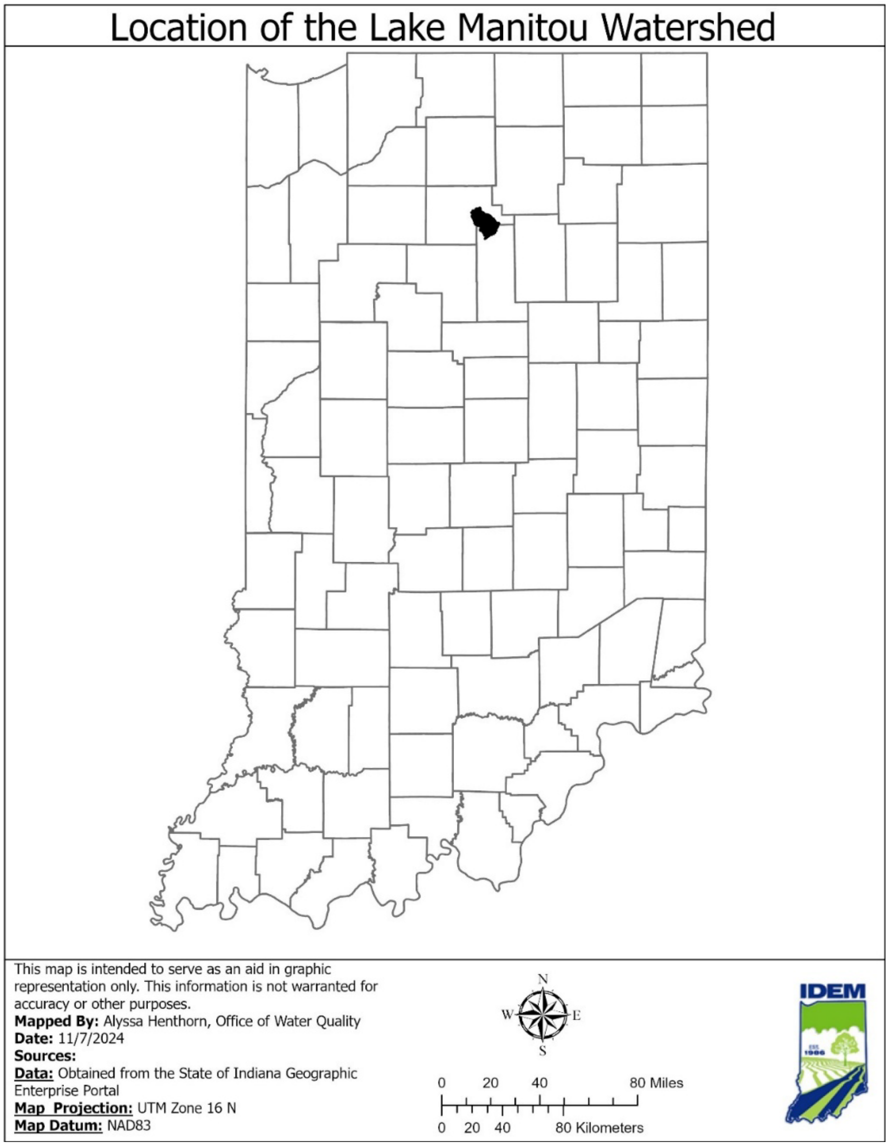

Figure 1: Location of the Lake Manitou Watershed

1.1 Water Quality Standards

Under the CWA, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters. These standards represent a level of water quality that will support the CWA's goal of "swimmable/fishable" waters. Water quality standards consist of three different components:

- **Designated uses** reflect how water can potentially be used by humans and how well it supports a biological community. Examples of designated uses include aquatic life support, drinking water supply, and full body contact recreation. Every waterbody in Indiana has a designated use or uses; however, not all uses apply to all waters. The Lake Manitou TMDL focuses on protecting the designated aesthetic recreational uses of the waterbody.
- Criteria express the condition of the water that is necessary to support the designated uses. **Numeric criteria** represent the concentration of a pollutant that can be in the water and still protect the designated use of the waterbody. **Narrative criteria** are the general water quality criteria ("free froms…") that apply to all surface waters. Target values were used through interpretation of the narrative criteria for nutrients for the Lake Manitou TMDL.
- **Antidegradation** policies provide protection of existing uses and extra protection for high-quality or unique waters.

The minimum surface water quality criteria, 327 IAC 2-1-6, Section 6(a) states the following:

- All surface waters must be free from substances, attributable to municipal, industrial, agricultural, and other land use practices that do any of the following:
    - Produce color or odor to an extent that creates a nuisance
    - Occur in concentrations of combinations that will cause or contribute to the growth of aquatic plants or algae to a degree that creates a nuisance, be unsightly, or otherwise impair the designated uses of the surface waters.

Lake Manitou is impaired based on recreational use assessments for aesthetics, which employs benchmarks for total phosphorus concentrations for both natural lakes and reservoirs that have been found to result in significant increases in algal levels. Because excessive algae can deter use of the resource for recreational purposes, these criteria are used to make recreational use support determinations only and are made within the context of aesthetics. (IDEM 2024, G-23) The water quality standards in Indiana pertaining to nutrients are described in section 1.1.1.

Details on development of assessment methodology and application can be found in IDEM's Consolidated Assessment and Listing Methodology (CALM) (IDEM 2008).

1.1.1 Nutrients

The term "nutrients" typically refers to the various forms of nitrogen and phosphorus found in a waterbody. Both nitrogen and phosphorus are necessary at some level in a waterbody to sustain aquatic life. The natural amount of nutrients in a waterbody varies depending on the type of system. Lakes draining larger areas are expected to have higher nutrient concentrations, however smaller sized lakes may be less resilient to nutrient loadings. On a national scale, the number one impairment of lakes and reservoirs has long been identified as nutrients.

Nutrients generally do not pose a direct threat to the designated uses of a waterbody. However, excess nutrients can cause an undesirable abundance of plant and algae growth through a process called eutrophication. Eutrophication can have many effects on a lake. Excess nutrients promote algal blooms which degrade water clarity and aesthetic quality. They can also lead to phenomena known as Harmful Algal Blooms (HABs) which can produce unpleasant odors, unsightly scums, and toxins harmful to humans and wildlife. Additionally, excess nutrients can lead to an overgrowth of aquatic vegetation leading to a perception of neglect or impede recreational opportunities. Finally, decaying organic matter from algae and/or vegetation can result in foul odors that affect the overall enjoyment of the lake.

Indiana has not adopted numeric water quality criteria for nutrient parameters such as total phosphorus for lakes. However, Indiana Administrative Code 327 IAC 2-1-6(a) contains narrative criteria that apply to all waters of the state:

> *All surface waters at all times and at all places, including waters within the mixing zone, shall meet the minimum conditions of being free from substances, materials, floating debris, oil, or scum attributable to municipal, industrial, agricultural, and other land use practices, or other discharges that do any of the following:" [327 IAC 2-1-6. Sec. 6. (a)(1)] …*
>
> *(a)re in concentrations or combinations that will cause or contribute to the growth of aquatic plants or algae to such degree as to create a nuisance, be unsightly, or otherwise impair the designated uses. [327 IAC 2-1-6. Sec. 6. (a) (1)(D)]*

To protect the recreational use of lakes from the adverse effects of high nutrients and eutrophication, IDEM utilizes certain nutrient benchmarks to "translate" Indiana's narrative standards above into a value that can be used for assessment. In 2008, IDEM developed an assessment method to determine nutrient enrichment impacts for Indiana lakes and their recreational activities, which is based on values for Total Phosphorus (TP) and chlorophyll a (Chl-a) developed by Limno-Tech, Inc (IDEM 2024).

For purposes of determining recreational use support within the context of aesthetics, the following general rules were applied:

- Only TP and Chl-a data, including volunteer-collected data, analyzed in the CLP's laboratory in accordance with the CLP Quality Assurance Project Plan (Indiana CLP, 2019) were used for assessment purposes.

- A minimum of three years' worth of data was considered sufficient for assessment purposes as long as each TP value had a corresponding Chl-a value. For this project, four years' worth of data was collected.

- Multiple results within a given year for TP and Chl-a were averaged to provide a single value for each parameter for that year. One data point per parameter per sampling year was collected for Lake Manitou.

- For consistency in assessments, all samples used in attainment decisions must be collected during the summer season.

1.2 Water Quality Targets

Target values, or benchmarks, are needed for the development of TMDLs because of the need to calculate allowable daily loads. For parameters that have numeric criteria the target equals the numeric criteria. For parameters that do not have numeric criteria, target values must be identified from some other source. The target values used to develop the Lake Manitou TMDL are presented below.

1.2.1 Target Values TMDL

The following sections describe the TMDL target values used for nutrients when developing TMDLs.

Total Phosphorus and Chlorophyll-a

The associated range of Chl-a values represents the range of concentrations expected when TP concentrations are at or below 54 µg/L for natural lakes or 51 µg/L for reservoirs, respectively. These values serve as numeric benchmarks to protect Indiana's designated uses and narrative water quality standards. The targets for both TP and Chl-a must each be met during the recreational season to meet IDEM's water quality benchmarks for lakes and reservoirs and are applied year-round for the purposes of the TMDL.

In some cases, the Chl-a results are not consistent with the expectations shown in Table 3 based on the TP levels measured for a given lake (for example, low Chl-a values associated with high TP values or vice versa). For these situations, IDEM's methodology uses the trophic state index (TSI) score as a surrogate response variable (in addition to Chl-a) to determine impairment status. If the TSI score indicates eutrophic or hypereutrophic conditions, the reservoir is assessed as impaired. The TSI score also provides a good measure of the overall trophic condition of a given lake. Recognizing the connection between trophic status and nutrient enrichment, the U.S. EPA generally considers hypereutrophic conditions as measured by the TSI indicative of impairment (IDEM 2024).

The three indicators used are Secchi depth (SD), total phosphorus (TP), and Chlorophyll-a (Chl-a). The TSI is a scale of 0-100 based on the interrelationships of these three variables using data from northern temperate lakes in North America. The equations used to calculate the Carlson TSI are:

Equation 1: $TSI(SD) = 60 - 14.41 \ln(SD)$

Equation 2: $TSI(CHL) = 9.81 \ln(CHL) + 30.6$

Equation 3: $TSI(TP) = 14.42 \ln(TP) + 4.15$

Tables 2 and 3 reiterate the TMDL target values presented in Section 1.0. These are the target values IDEM uses to assess water quality data collected. Lake Manitou is a human-made lake created by damming the area which was originally a natural wetland. Therefore, it is considered a reservoir for the purposes of recreational uses and assessments.

Table 2: Recreational Use Support-Reservoirs

Fully Supporting	Not Supporting
Not more than 10% of all TP values greater than 51 µg/L and their associated (Chl-a) values are less than or equal to 25 µg/L	Less than 10% of all TP values are greater than 51 µg/L but their associated Chl-a values are greater than 25 µg/L, and the Chl-a trophic state index (TSI) score for the lake indicates eutrophic (50-70) or hypereutrophic (greater than 70) conditions Or More than 10% of TP values are greater than 51 µg/L with associated Chl-a values less than 2 µg/L, but the TSI (Chl-a) score for the lake indicates eutrophic (50-70) or hypereutrophic (greater than 70) conditions Or More than 10% of all TP values are greater than 51 µg/L with associated Chl-a values greater than 2 µg/L

Table 3: Target Values Used for Development of the Lake Manitou TMDLs

Parameter	Corresponding Chl-a values (µg/L)	Target Value for Total Phosphorus (µg/L
Reservoirs	2 - 25	No value should exceed 51

Seasonal conditions and precipitation events may cause tributary loading and resulting in-lake concentration values to fluctuate. Monitoring data used in assessments must be collected during the summer season (June 1 through August 31), therefore target values represent conditions as such. This represents the critical conditions of the lake where known nutrient related issues occur in lakes. For instance, cyanobacterial blooms are seasonal in nature with most occurring during late summer. Meeting these in-lake concentration targets during summer or peak growing conditions ensures recreational uses will be met during all conditions, even outside of the typical recreational season.

1.3 Listing Information

1.3.1 Understanding Subwatersheds and Assessment Units

This section presents information concerning IDEM's segmentation process as it applies to Lake Manitou. IDEM identifies Lake Manitou and its tributaries using a watershed numbering system developed by United States Geological Survey (USGS), Natural Resource Conservation Service (NRCS), and the U.S. Water Resources Council referred to as hydrologic unit codes (HUCs). HUCs are a way of identifying watersheds in a nested arrangement from largest (i.e., those with shorter HUCs) to smallest (i.e., those with longer HUCs) (IDEM, 2010). Figure 2 shows the 14-digit HUCs located in the Lake Manitou watershed. Traditionally, IDEM reports on watersheds that encompus a single 10-digit HUC and break down the watershed into 12-digit HUC subwatershed sections. However, only two 14-digit HUC sections within the whole 10-digit HUC wateshed flows into each other, Rain Creek and Robbin Taylor Ditch. Therefore, this report will only focus on the two 14-digit HUC subwatersheds and delineations will see the two 14-digit HUCs as a reservoir watershed to present an accurate representation of the stream segements that influence Lake Manitou.

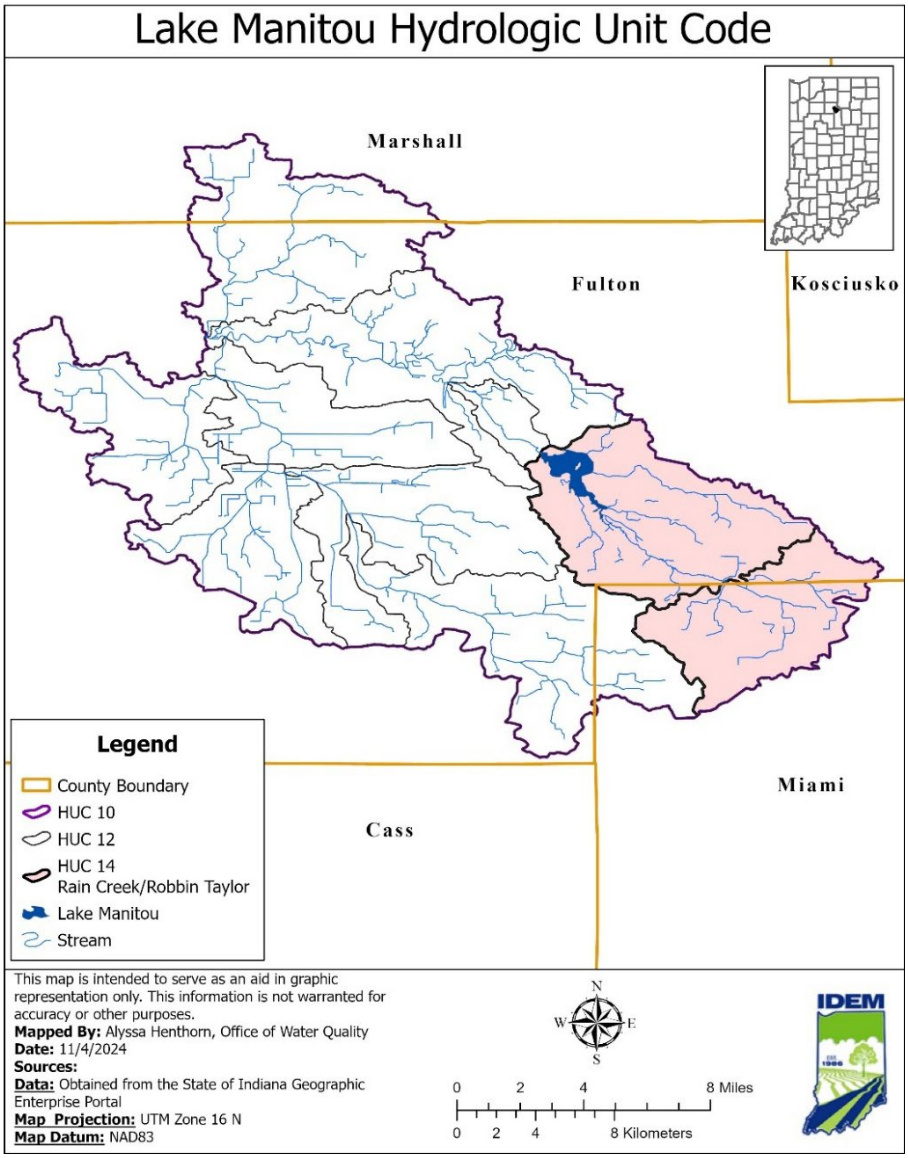

Figure 2: Subwatersheds (14-Digit HUCs) within 10-digit HUC

Within each 14-digit HUC subwatershed, IDEM has identified several AUIDs, which represent individual stream segments. Through the process of segmenting waterbodies into AUIDs, IDEM identifies streams reaches and stream networks that are representative for the purposes of assessment. In practice, this process leads to grouping tributary streams into smaller catchment basins of similar hydrology, land use, and other characteristics such that all tributaries within the catchment basin can be expected to have similar potential water quality impacts. Catchment basins, as defined by the aforementioned factors, are typically very small, which significantly reduces the variability in the water quality expected from one stream or stream reach to another. Given this, all tributaries within a catchment basin are assigned to a single AUID. Grouping tributary systems into smaller catchment basins also allows for better characterization of the larger watershed and more localized recommendations for implementation activities. Variability within the larger watershed will be accounted for by the differing AUIDs assigned to the different catchment basins.

Table 4 contain the AUIDs in the subwatersheds of the Lake Manitou watershed. Subsequent sections of the TMDL report organize information by subwatershed (if applicable) and AUID.

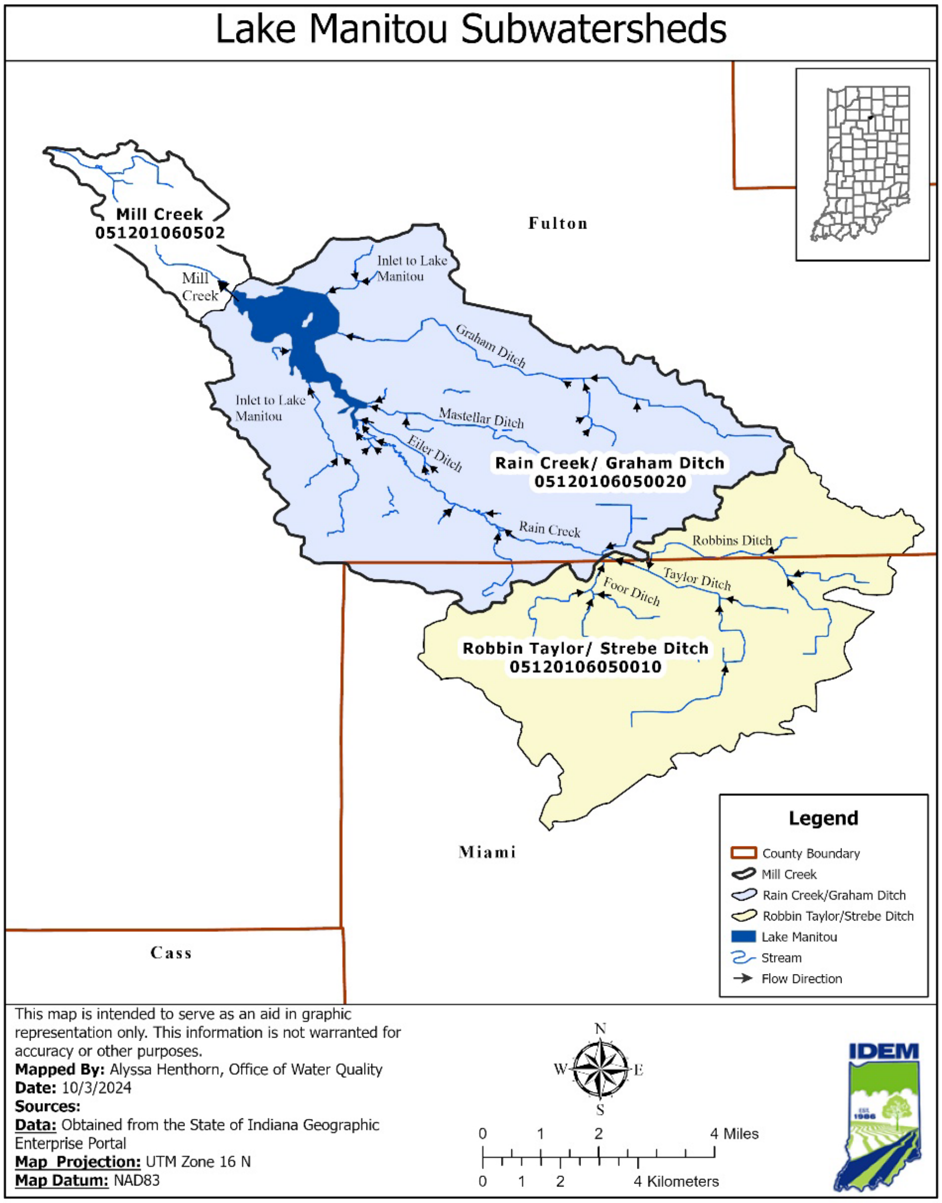

Figure 3: Subwatersheds (14-Digit HUCs) in the Lake Manitou Watershed

1.3.2 Understanding 303(d) Listing Information

The listings and causes of impairments have been determined as a result of assessment data collected at one sampling location in Lake Manitou. Lake Manitou is listed as impaired for nutrients/phosphorus on Indiana's 2024 303(d) List of Impaired Waters (Table 4). Table 4 presents listing information for the Lake Manitou and associated causes of impairments addressed by the TMDL. The reassessment data used in the listings for Lake Manitou watershed are available in Appendix B. Below is an inventory assessment of the available biological and chemistry data for the Lake Manitou watershed.

Table 4: Section 303(d) List Information for the Lake Manitou for 2024

Name	Current AUID	Parameter	Designated Uses
Lake Manitou	INB06P1016_00	*Phosphorus*	Recreation - Aesthetics

Understanding Table 4:

- Column 1: Name of the body of water for the purposes of this report.
- Column 2: Current AUID. Identifies the AUID given to waterbodies within the 14-digit HUC subwatershed for purposes of the 2024 Section 303(d) listing assessment process.
- Column 3: Parameters. Provides the parameter linked to impairment.
- Column 4: Designated Use. Provides the waterbody's impacted designated use.

1.4 Water Quality Data

This section of the TMDL report contains a brief characterization of the Lake Manitou watershed water quality information that was collected in development of this TMDL. Understanding the natural and human factors affecting the watershed will assist in selecting and tailoring appropriate and feasible implementation activities to achieve water quality standards.

1.4.1 Water Quality Data

Data collected by IDEM from June through August in 2011, 2013, 2014, 2015, and 2020 were used for the TMDL analysis. One site was sampled for pathogens, water chemistry, and biological data in the Lake Manitou watershed. Figure 4 shows the sampling site locations and information. Table 6 summarizes the water chemistry data within the Lake Manitou watershed.

Appendix A shows the individual sample results and summarizes all the water quality data for the monitoring site.

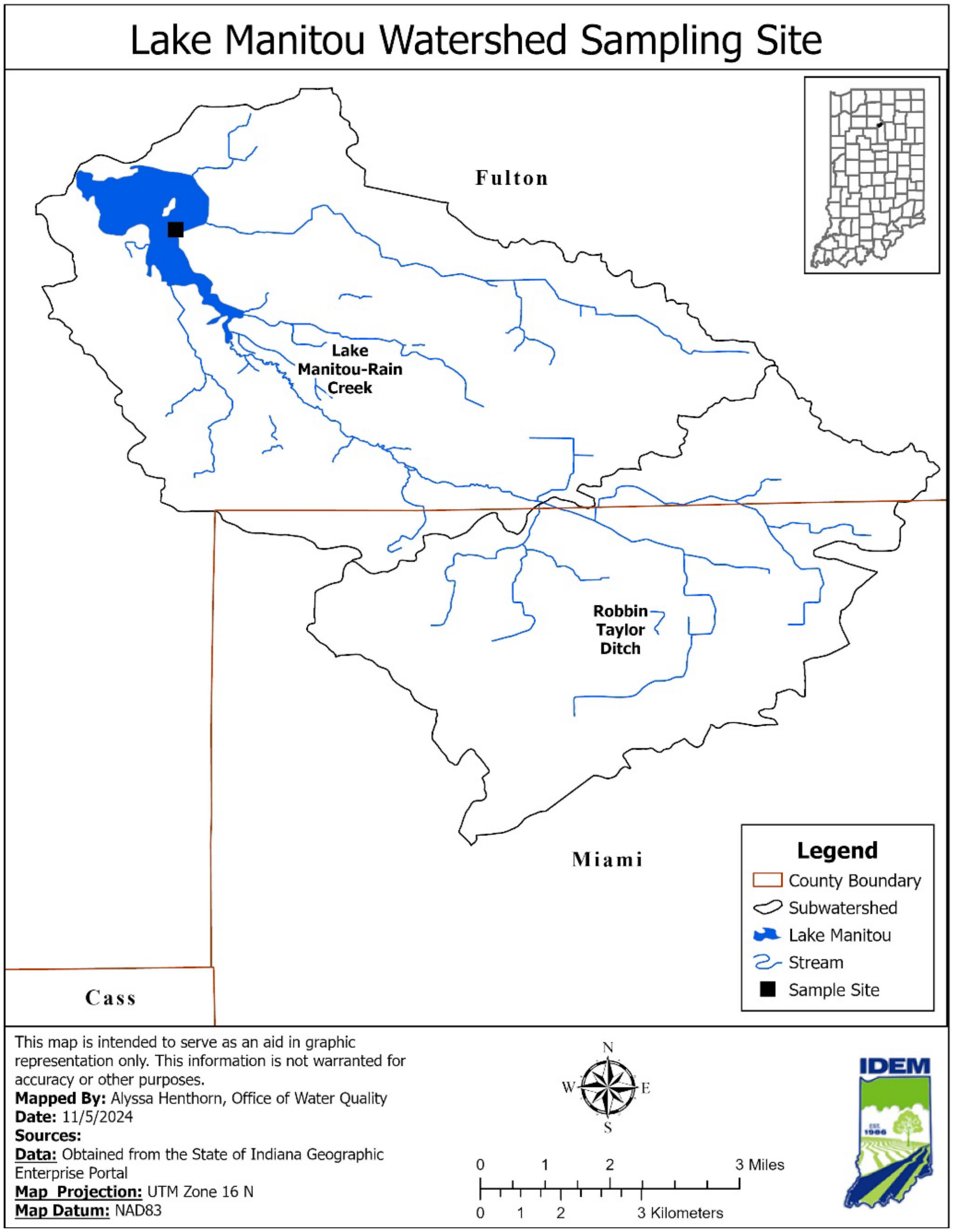

Figure 4: Sampling Locations for the Lake Manitou TMDL Study

1.4.2 Water Chemistry Data

Table 5: Summary Lake Manitou Water Quality Sampling Data

Parameter	Sampling Date					Mean	Standard Deviation	Standard Error
	8/16/2011	8/6/2013	7/7/2014	8/10/2015	7/16/2020			
Ammonia-Epi (mg/L)	0.02	0.03	1.74	0.02	< 0.01	0.36	0.77	0.34
Nitrite plus Nitrate–Epi (mg/L)	0.01	0.04		0.32	< 0.01	0.09	0.15	0.08
TKN–Epi (TN-Nitrite plus Nitrate) (mg/L)	1.11	1.27	0.91	1.43	1.79	1.30	0.33	0.15
Organic N (TKN-NH3)–Epi (mg/L)	1.09	1.24		1.41	1.78	1.38	0.30	0.15
TN–Epi (mg/L)	1.12	1.31		1.75	1.80	1.49	0.33	0.17
Ortho-Phosphorus–Epi (mg/L)	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
TP–Epi (mg/L)	0.03	0.05	0.04		0.03	0.04	0.01	0.00
TP minus OP–Epi (mg/L)	0.02	0.04	0.03		0.02	0.03	0.01	0.00
Ammonia–Avg of Epi and Hypo (mg/L)	2.44	1.19	2.33	1.34	0.55	1.57	0.80	0.36
Nitrite plus Nitrate–Avg of Epi and Hypo (mg/L)	0.01	0.03		0.17	< 0.01	0.05	0.08	0.04
TKN–Avg of Epi and Hypo (mg/L)	3.84	2.61	2.42	2.52	1.29	2.54	0.90	0.40
Organic N (TKN-NH3)–Avg of Epi and Hypo (mg/L)	1.39	1.41	0.09	1.18	0.74	0.96	0.56	0.25
TN–Avg of Epi and Hypo (mg/L)	3.85	2.63		2.69	1.30	2.62	1.04	0.52
Ortho-Phosphorus–Avg of Epi and Hypo (mg/L)	0.02	0.01	0.08	0.21*	0.06	0.04	0.03	0.02
TP–Avg of Epi and Hypo (mg/L)	0.04	0.06	0.11		0.07	0.07	0.03	0.01
TP minus OP–Avg of Epi and Hypo (mg/L)	0.02	0.04	0.03		0.01	0.03	0.01	0.01
Chl-a (µg/L)	15.89	31.69	19.09	22.27	29.69	23.73	6.78	3.03
Total Suspended Solids (mg/L)				6.9		6.90		
Secchi Depth (m)	0.9	0.5	1	0.4	0.80	0.72	0.26	0.15
Non-algal Turbidity	0.71	1.21	0.52	1.94	0.51	0.98	0.61	0.35

Avg=average, Epi=epilimnion, Hypo=hypolimnion, mg/L=milligrams per liter, ug/L=micrograms per liter
"" indicates an outlier and was not accounted for in the calculation of mean, and standard deviation.*
"<" indicates the results were below the equipment's detection limit.

Table 5 provides relevant data collected from the five sampling events, the mean of each parameter, their standard deviations, and their standard errors. These values were used to derive inputs for the BATHTUB model.

An additional calculated parameter was also used in the BATHTUB model: CV, or coefficient of variation. The BATHTUB model requires input of the mean and CV of water quality parameter inputs calculated for the averaging period. The CV of a given parameter reflects the uncertainty in the input value. Therefore, once all available data within the desired time frame are collected, the mean and CV for each parameter for the average period need to be calculated. CV is equivalent to the standard error divided by the mean. The standard error for the sample is calculated as the standard deviation divided by the square root of the number of samples.

Table 6: Summary of Chemistry Data in Lake Manitou

Subwatershed	AUID	Current Inflow Total Phosphorus (ppb)	Total Phosphorus % Reduction Needed
Lake Manitou	INB06P1016_00	488	40%

The inflow TP was determined using the following method:

- The Spreadsheet Tool for Estimating Pollutant Loads (STEPL) was used to calculate Lake Manitou's annual TP load of 22,588.2 lbs/yr or 10,245.8 kg/yr.
- Rainfall during the summer months of June-August (13.82 in) was divided by the annual precipitation data for 2024 (38.3 in), resulting in 0.36.
- Lake Manitou's annual TP load in kilograms (10,245.8) was multiplied by 0.36 to estimate the TP loading within the summer months, resulting in 3,697.1 kg.
- The resulting summer TP loading (3,697.1 kg) was divided by the summer inflow volume of 7,575,675.26 m^3, then converted from kg to ppb, resulting in 488.

- The inflow TP estimate is a lumped sum of all potential TP loading contributors.
- The inflow TP estimate was used as the "starting point" in the BATHTUB model. BATHTUB outputs include in-lake TP and Chl-a concentrations based on inflow TP concentrations and other factors. After the current conditions of TP concentrations were calculated by BATHTUB, reduction scenarios (i.e., 10%, 20%, 30%) were simulated against the current conditions until resulting in-lake benchmarks for TP and Chl-a were achieved by the model outputs. (see Table 1).
- Reductions of 40 percent or greater are needed to meet the TMDL target values for total phosphorus in Lake Manitou.

2.0 WATERSHED AND LAKE DESCRIPTION & SOURCE ASSESSMENT

This section of the TMDL report contains a brief characterization of Lake Manitou and its tributaries to provide a better understanding of the historic and current conditions that affect water quality and contribute to the impairment. Additionally, an assessment of the nonpoint and point sources is introduced for further analysis. Sources of water pollution are defined as either nonpoint or point source pollution by the Clean Water Act. The following describes these sources below:

Point Sources:

The term “point source” refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel, or conduit, by which pollutants are transported to a waterbody. It also includes vessels or other floating crafts from which pollutants are or may be discharged. By law, the term “point source” also includes confined feeding operations (which are places where animals are confined and fed); and illicitly connected “straight pipe” discharges of household waste. Permitted point sources are regulated through the National Pollutant Discharge Elimination System (NPDES).

There are currently no NPDES permitted dischargers or known point sources to Lake Manitou or its tributaries.

Nonpoint Sources:

Nonpoint sources include all other categories not classified as point sources. In urban areas, nonpoint sources can include leaking or faulty septic systems, run-off from lawn fertilizer applications, pet waste, and other sources. In rural areas, nonpoint sources can include run-off from cropland, pastures, groundwater, and animal feeding operations, and inputs from streambank erosion, leaking, failing or leaking septic systems, and wildlife. With lakes, internal-loading and atmospheric deposition are additional sources that are accounted for and analyzed along with other nonpoint sources outlined in this report. Some nonpoint sources are described below in more detail.

Agricultural Sources:

Phosphorus from eroded soil and applied soil amendments (fertilizers) from agricultural land use pose a potentially significant loading source. Regular precipitation and storm events allow for runoff from these areas to enter nearby waterways that connect to Lake Manitou.

Livestock Sources:

Animal feeding operations have the potential to transport phosphorus from feed and manure into the nearby waterways and Lake Manitou via runoff during precipitation events.

Urban/Residential Sources:

Homes and other urban areas placed directly on or near the lake can contribute to the loading of phosphorus from fertilizers, pet waste, and yard litter (grass and leaf) into the lake through runoff.

Atmospheric deposition:

This natural process describes the deposition of particles and substances retained in the atmosphere onto the surface of the Earth. Specifically, phosphorus can be deposited directly into the lake and its connecting tributaries by the atmosphere. Lake Manitou contains significant amount of agricultural drainage areas and as such, atmospheric deposition of nutrient is generally considered insignificant relative to watershed loadings.

Internal Loading:

Internal loading refers to the release of phosphorus back into the water column from sediment within the lake. There can be multiple mechanisms that trigger this phenomenon, the main one being during anoxic conditions where phosphorus is released due to low oxygen concentrations in the water overlying lakebed sediment. Bottom feeding fish and other physical disturbances such as motorized boating in shallow areas can disturb bottom sediments and lead to phosphorus release into the water column as well. Additionally, wind energy in shallow depths can mix the water column and lead to another form of phosphorus release.

Lake Manitou itself is a relatively shallow lake and has many areas of shallow depth. During the summer months/growing period, there is substantial recreational activity where people and boats can contribute to the disruption of the bottom sediment and subsequent internal loading of phosphorus into the water column.

Shoreline Erosion:

Erosion of the shoreline surrounding the lake can lead to phosphorus loading through the transportation of sediment and suspended solids located within the shoreline. Lake Manitou has had some shoreline erosion throughout the years that could be a potential source contributing to the nutrient impairment.

The following section serves to denote the characteristics that make up nonpoint sources, entailing descriptions of land use, topography and geology, soils, wildlife and classified lands, and lastly climate and precipitation to encapsulate nonpoint sources.

Understanding the natural and human factors affecting the watershed and lake will assist in identifying significant sources, informing the selection and tailoring appropriate and feasible implementation activities to achieve water quality standards.

2.1 HUC Description and Target Area

As discussed in Section 1.3.1, contributing drainage to Lake Manitou includes two 14-digit HUC subwatersheds. Examining subwatersheds enables a closer examination of key factors that affect water quality.

The following table contains the names of the two subwatersheds of the Lake Manitou watershed and their associated drainage area.

Table 7: Lake Manitou Subwatershed Drainage Areas

Name of Subwatershed	14-digit HUC	Area Within Watershed (sq. miles)	Percent of Watershed Area	Drainage Area (sq miles)	Percent of Total Drainage Area
Rain Creek	05120106050020	26	59%	44	100%
Robbin Taylor	05120106050010	18	41%	18	41%

Understanding Table 7: Land area helps IDEM to define the pollutant load reductions needed for each AU in each 14-digit HUC subwatershed that comprises the Lake Manitou watershed. Information in each column is as follows:

- Column 1: Name of Subwatershed. Lists the name of the subwatersheds.
- Column 2: 14-digit HUC. Identifies the subwatershed's 14-digit HUC.
- Column 3: Area Within Watershed. Provides the area of each subwatershed within the overall watershed in square miles.
- Column 4: Percent of Watershed Area. Indicates the percent of land area of each subwatershed, providing a relative understanding of the portions of each subwatershed compared to the overall Lake Manitou watershed.
- Column 5: Drainage Area. Quantifies the area the specific subwatershed drains in square miles.
- Column 6: Percent of Total Drainage Area. Indicates the percent of the total drainage area, providing a relative understanding of the portion of the subwatershed in the overall Lake Manitou watershed.

IDEM bases load calculations on the drainage area the Rain Creek 14-digit HUC subwatershed. The information contained in this table is the foundation for the technical calculations found in Sections 3.0 and 4.0 of this report. This table will help watershed stakeholders look at the smaller subwatersheds within the Lake Manitou watershed and understand the smaller areas contributing to the impaired waterbody, helping to quantify the geographic scale that influences source characterization and areas for implementation.

2.2 Land Use

Land use patterns provide important clues to the potential sources of impairments in a watershed. Land use information for the Lake Manitou watershed is available from the National

Agricultural Statistics Service (NASS) cropland data layer. These data categorize the land use for each 30 meters by 30 meters parcel of land in the watershed based on satellite imagery from circa 2024. Figure 5 displays the spatial distribution of the land uses and the data are summarized in Table 8. Additionally, Table 9 displays the breakdown of land uses within each of the two subwatersheds.

Land use in the Lake Manitou watershed is primarily agriculture, comprising 60 percent of the area. Approximately 14 percent of the land is forest. Pasture/hay represents 11 percent of the watershed and could indicate the presence of animal feedlots which can be significant sources of sediment and nutrients. The remaining land use categories represent less than 15 percent of the total area.

The Lake Manitou watershed has a diverse network of streams. Tributaries include Graham Ditch, Lake Manitou inlets, Rain Creek, Taylor Ditch, and Robbins Ditch. Forested areas are more pronounced in the northwestern portions of the watershed around Lake Manitou. Urban areas within the watershed are primarily in the northern portions in the city of Rochester, IN near the headwaters of Robbins Ditch. Robbin Taylor Ditch flows into Rain Creek which drains into Lake Manitou and flows into the Tippecanoe River. Many threatened and endangered species call this watershed home. Various species of darters such as the Spotter Darter (*Etheostoma maculatum*) and Gilt Darter (*Percina evides*) can be found in the watershed and surrounding counties and are dependent upon the health of the aquatic system (IDNR, 2024). Additional information on state endangered, threatened and rare species can be found on the DNR website (www.dnr.IN.gov/nature-preserves/heritage-data-center/endangered-plant-and-animal-species/county).

Table 8: Land Use of the Lake Manitou Watershed

Land Use	Watershed		
	Area		Percent
	Acres	Square Miles	
Agricultural Land	17,093	27	60%
Developed Land	2,119	3	8%
Forested Land	3,916	6	14%
Hay/Pasture	3,221	5	11%
Open Water	908	1	3%
Shrub/Scrub	8	<1	<1%
Wetlands	1,098	2	4%
Total	**28,362**	**44**	**100%**

Understanding 8: The predominant land use types in the Lake Manitou watershed can indicate potential sources of nutrient loadings. Different types of land uses are characterized by different types of hydrology. For example, developed lands are characterized by impervious surfaces that increase the potential of stormwater events during high flow periods delivering nutrients to downstream waterbodies.

Forested land and wetlands allow water to infiltrate slowly thus reducing the risks of polluted water running off into waterbodies. In addition to differences in hydrology, land use types are associated with different types of activities that could contribute pollutants to the watershed. Understanding types of land uses will help identify the type of implementation approaches that watershed stakeholders can use to achieve nutrient load reductions.

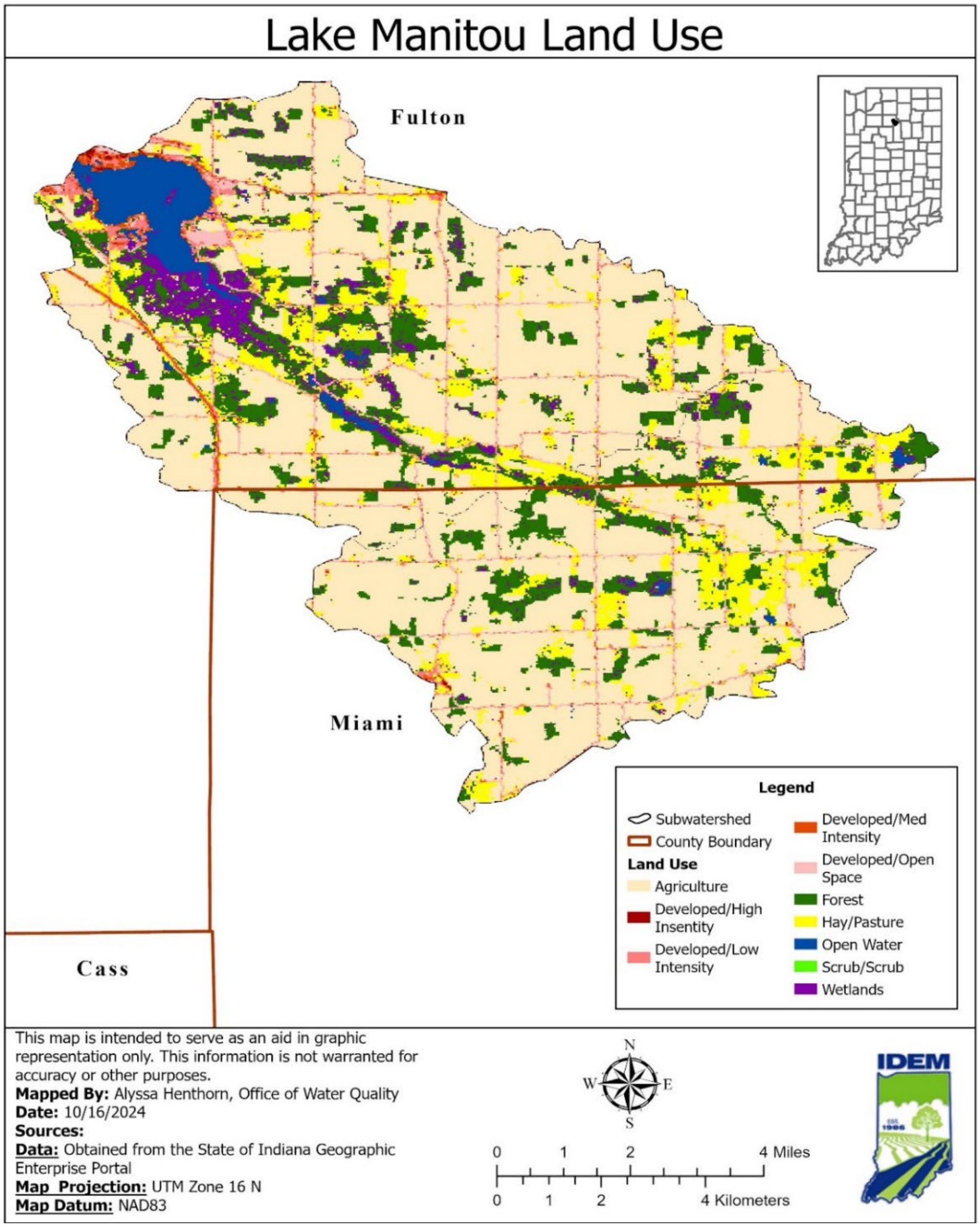

Figure 5: Land use in the Lake Manitou Watershed

Table 9: Land Use in the Lake Manitou Subwatersheds

Subwatershed	Area	Land Use							Total
		Agriculture	Developed	Forest	Hay/ Pasture	Open Water	Shrub/ Scrub	Wetlands	
Rain Creek (05120106050020)	Acres	9,511	1,441	2,298	1,729	860	5	926	16,779
	Sq. Mi.	15	2	4	3	1	<1	2	26
	Percent	57%	9%	14%	10%	5%	<1%	6%	100%
Robbin Taylor (05120106050010)	Acres	7,581	678	1,618	1,482	49	2	173	11,583
	Sq. Mi.	12	1	3	2	<1	<1	<1	18
	Percent	65%	6%	14%	13%	<1%	<1%	2%	100%

2.1.1 Cropland

Croplands can be a source of sediments and nutrients. Accumulation of nutrients on cropland occurs from fertilization with chemical (e.g., anhydrous ammonia) fertilizers, manure fertilizers, inorganic fertilizers, wildlife excreta, irrigation water, and application of waste products from municipal and industrial wastewater treatment facilities. The majority of nutrient loading from cropland occurs from fertilization with commercial and manure fertilizers (Patwardhan, 1997). Use of manure for nitrogen supplementation often results in excessive phosphorus loads relative to crop requirements (Patwardhan, 1997). Data available from the National Agricultural Statistic Service (NASS) were downloaded to estimate crop acreage in the subwatersheds. The 2024 NASS statistics were used in the analysis as shown in 0 and displayed in Figure 6 (USDA, 2017).

Table 10: Major Cash Crop Acreage in the Lake Manitou Watershed

Subwatershed	Crop	Total Acreage	% of Subwatershed Cash Crop Acreage
Rain Creek (05120106050020)	Corn	5,420	57%
	Soybean	3,922	41%
	Winter Wheat	145	2%
	Total	9,487	100%
Robbin Taylor (05120106050010)	Corn	3,861	52%
	Soybean	3,444	46%
	Winter Wheat	193	3%
	Total	7,598	100%

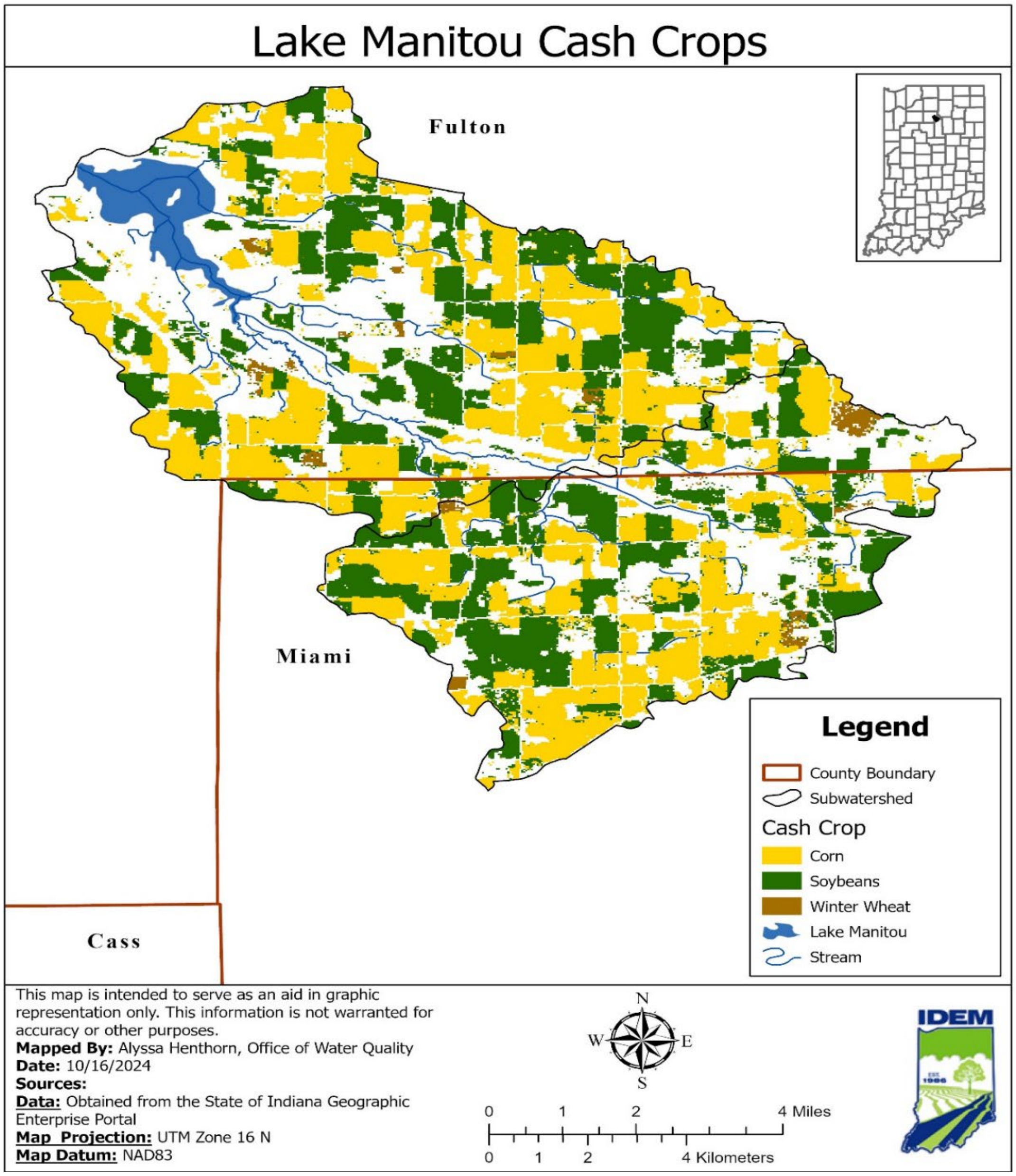

Figure 6: Cash Crop Acreage in the Lake Manitou Watershed

2.1.2 Hay/Pastureland

Run-off from pastures and livestock operations can be potential agricultural sources of nutrients. For example, animals grazing in pasturelands deposit manure directly upon the land surface and, even though a pasture may be relatively large and animal densities low, the manure will often be concentrated near the feeding and watering areas in the field. These areas can quickly become barren of plant cover, increasing the possibility of erosion and contaminated run-off during a storm event.

Livestock animals are potential sources of nutrients to streams, particularly when direct access is unrestricted and/or where feeding structures are located adjacent to riparian areas. Watershed specific data are not available for livestock populations. The amount of hay/pastureland across the landscape can be used as an indicator for potential areas of higher densities from livestock. Information on permitted livestock facilities within the Lake Manitou watershed are presented in Figure 7.

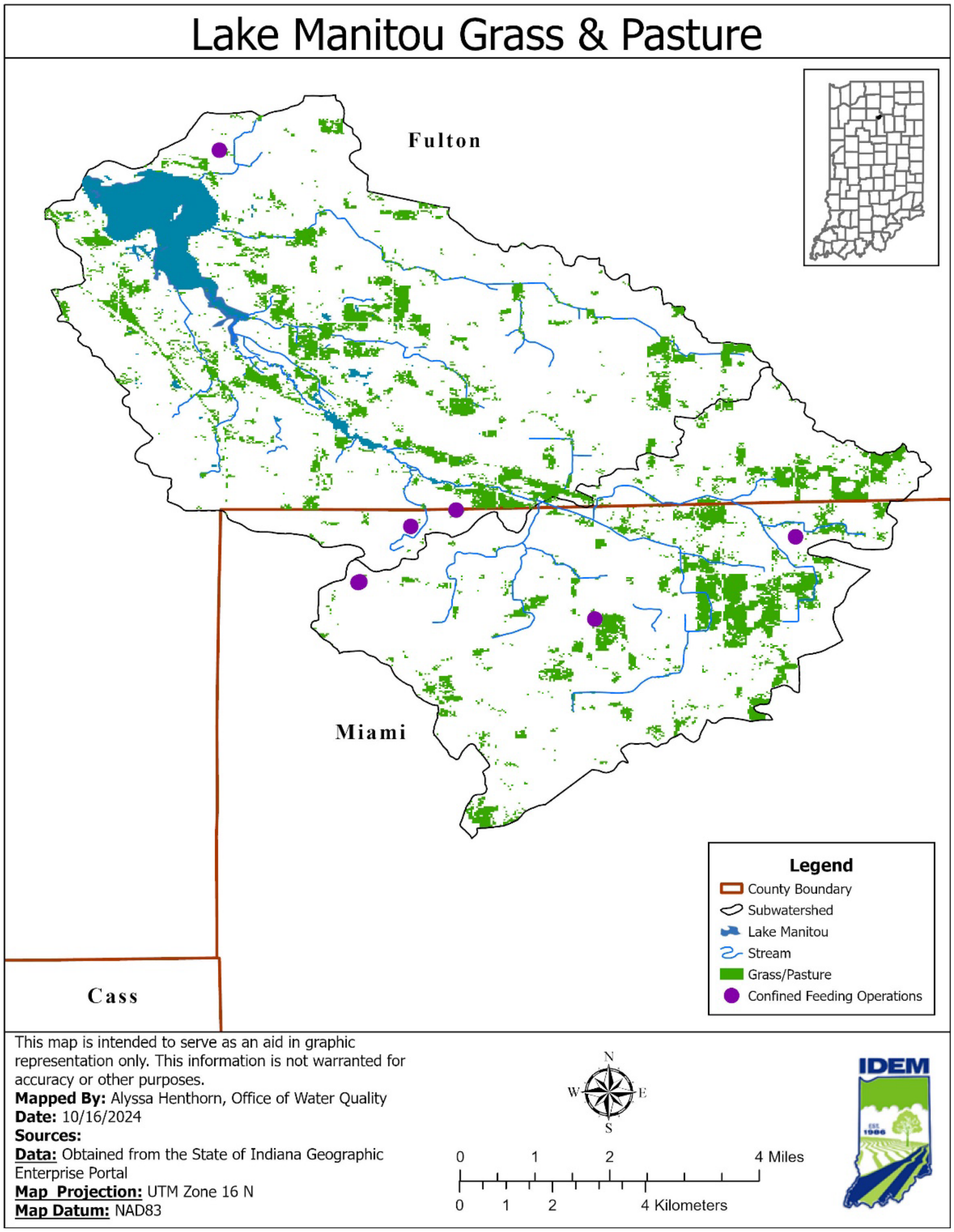

Figure 7: Grassland and Pastureland in the Lake Manitou Watershed

2.1.3 Confined Feeding Operations (CFOs) and Animal Feeding Operations (AFOs)

A CFO is an agricultural operation where animals are kept and raised in confined situations. It 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.
- Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over 50 percent of the lot or facility.
- The number of animals present meets the requirements for the state permitting action.

Feeding operations that are not classified as concentrated animal feeding operations (CAFOs) are known as confined feeding operations (CFOs) in Indiana. There are currently no CAFOs in the Lake Manitou watershed. Non-CAFO animal feeding operations identified as CFOs by IDEM are considered nonpoint sources by U.S. EPA. Indiana's CFOs have state issued permits and are therefore categorized as nonpoint sources for the purposes of this TMDL. CFO permits are "no discharge" permits. Therefore, it is prohibited for these facilities to discharge water of the State.

The CFO regulations (327 IAC 19, 327 IAC 15-16) require that operations "not cause or contribute to an impairment of surface waters of the state." IDEM regulates these confined feeding operations under IC 13-18-10, the Confined Feeding Control Law. The rules at 327 IAC 19, which implement the statute regulating confined feeding operations, were effective on July 1, 2012. The rule at 327 IAC 15-16, which regulates CAFOs and incorporates by reference the federal NPDES CAFO regulations, became effective on July 1, 2012. It should be noted that there are currently zero facilities in Indiana that have an NPDES permit under 15-16.

The animals raised in CFOs produce manure that is stored in pits, lagoons, tanks and other storage devices. The manure can then be applied to area fields as fertilizer. CFO owners can either apply manure to land they own or market and sell manure to other landowners per regulations outlined in 327 IAC 19-14. When stored and applied properly, this beneficial re-use of manure provides a natural source for crop nutrition. It also lessens the need for fuel and other natural resources that are used in the production of fertilizer.

However, CFOs can be a potential source of phosphorus due to the following:

- Improper application of manure can contaminate surface or groundwater.
- Manure over application or improper application can adversely impact soil productivity.

There are multiple AFOs in the Lake Manitou watershed and 7 permitted CFOs in the watershed, as shown below in Table 12 and in Figure 7. Manure used for land application in the Lake Manitou watershed may also originate from AFOs and CFOs in adjacent watersheds.

Table 11: CFOs in the Lake Manitou Watershed

Subwatershed	CFO Permit ID	Operation Name	County	Animal Type and Permitted number
Rain Creek	4039	Don Bauman Farm	Fulton	Nursery Pigs: 850
	5961	James Mark Wildermuth Farm	Miami	Finishers: 1,720 Beef Calves: 30
	2820	Sroufe Farms LLC	Miami	Nursery Pigs: 800 Finishers: 1,400
Robbin Taylor	4881	William C Friend Green Acres Ham LLC	Miami	Finishers: 4,400
	5859	Steven C & Lori Herrell Farm	Miami	Finishers: 4,400
	4551	Eckrote Farms INC	Miami	Finishers: 8,800
	4651	JMD Farms LLC	Miami	Finishers: 4,400

2.3 Topography and Geology

Topographic and geologic features of a watershed play a role in defining a watershed's drainage pattern. Figure 8 below displays the topography of the watershed. Information concerning the topography and geology within the Lake Manitou watershed is available from the Indiana Geological and Water Survey (IGWS). The Lake Manitou watershed originates in Fulton County and travels east into Miami Counties. Lake Manitou Watershed is located in the north middle of the state making it unique in Indiana by not having been covered by glacial till.

Figure 10 displays the depth of Lake Manitou through lines in feet. The depth lines were determined based on a bathymetric study conducted by the Indiana Division of Fish and Wildlife in July 2017. The deepest points in the lake are the most ideal location for sampling to address all impairments in the lake. Additional information on this can be found in Appendix D.

The entire bedrock surface of Indiana consists of sedimentary rocks. The major kinds of sedimentary rock in Indiana include limestone, dolomite, shale, sandstone, and siltstone. The northern two-thirds of Indiana are composed of glacial deposits containing groundwater. These glacial aquifers exist where sand and gravel bodies are present within clay-rich glacial till (sediment deposited by ice) or in alluvial, coastal, and glacial outwash deposits. Groundwater availability is much different in the southern unglaciated part of Indiana. There are few unconsolidated deposits above the bedrock surface, and the voids in bedrock (other than karst dissolution features) are seldom sufficiently interconnected to yield useful amounts of groundwater. Reservoirs in the state, such as Monroe Lake and Patoka Lake, are used for water supply in lieu of water wells in southern Indiana. The IGWS website contains information about the geology of Indiana (https://legacy.igws.indiana.edu/GroundWater).

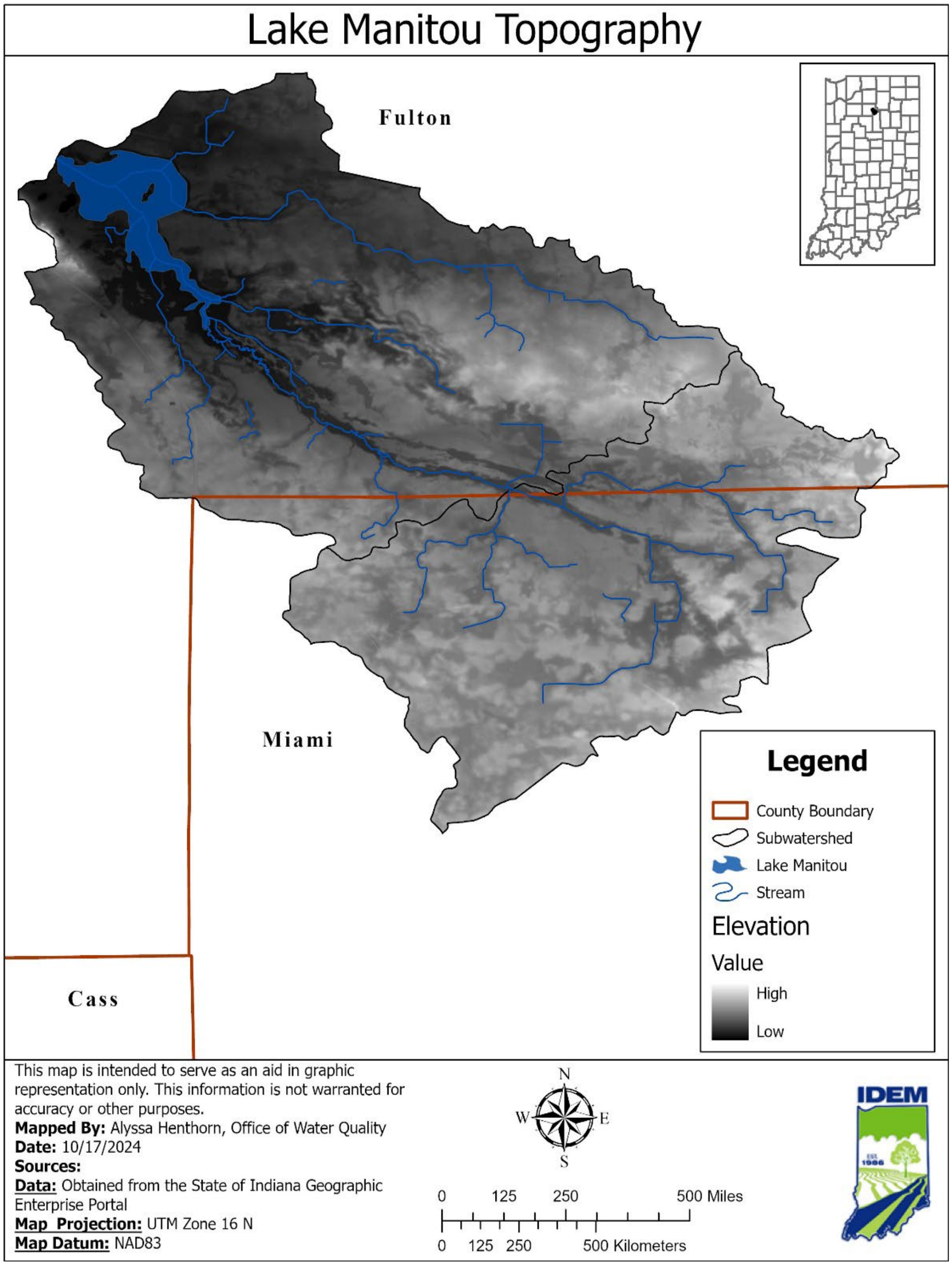

Figure 8: Topography of the Lake Manitou Watershed.

Digital Elevation Data (DEM) was taken from Indiana's Geographic Information Office (GIO).

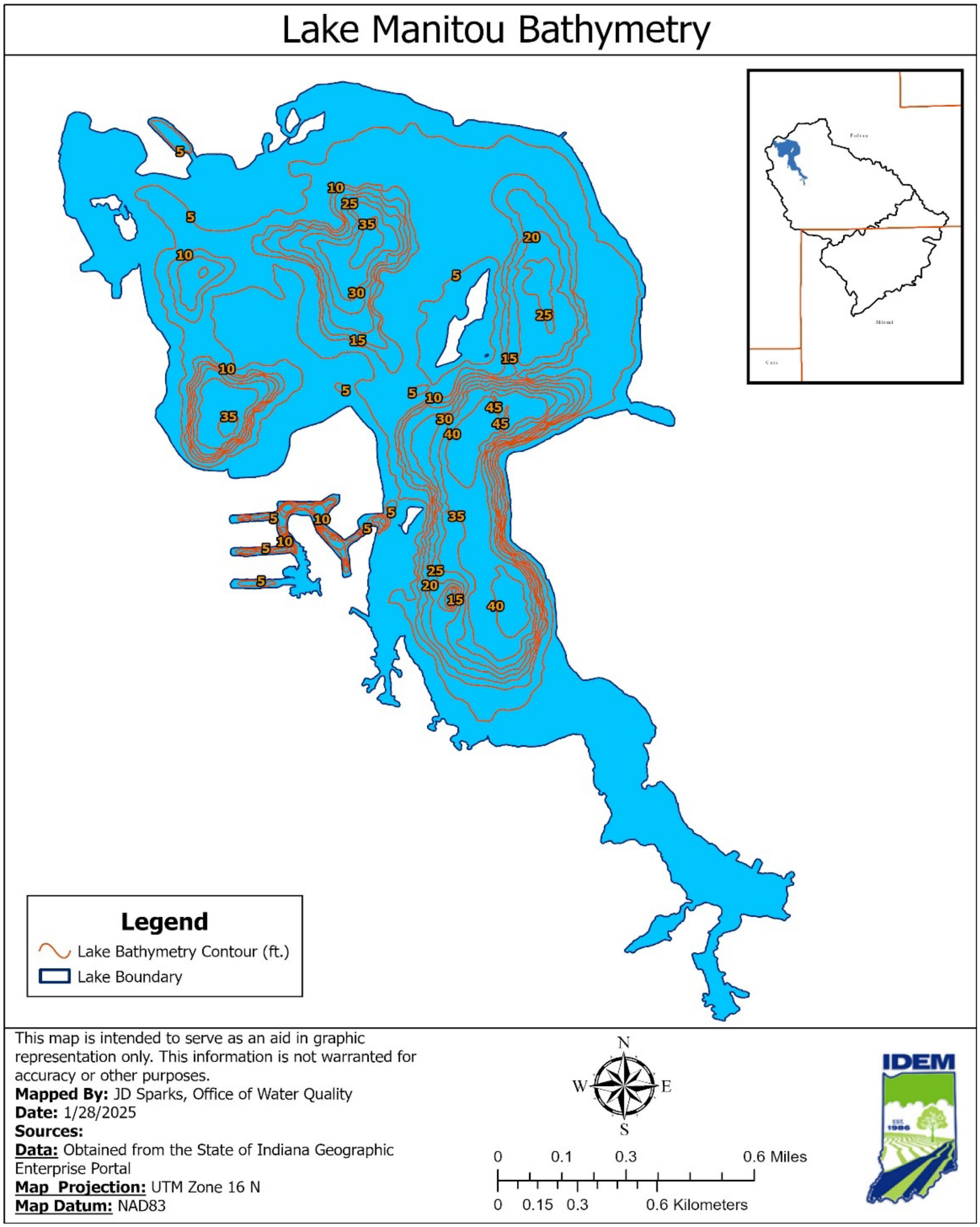

Figure 9: Bathymetry of Lake Manitou

2.4 Soils

There are different soil characteristics that can affect the health of the watershed. Some of these characteristics include soil drainage, septic tank suitability, soil saturation, and soil erodibility.

2.4.1 Soil Drainage

The hydrologic soil group classification is a means for categorizing soils by similar infiltration and run-off characteristics during periods of prolonged wetting. The NRCS has defined four hydrologic groups for soils, described in Table 12 (USDA, 2009). Data for the Lake Manitou watershed was obtained from the USDA Soil Survey Geographic (SSURGO) database. Downloaded data were summarized based on the major hydrologic group in the surface layers of the map unit and are displayed below in Figure 10 and Table 13.

The majority of the watershed is covered by category D soils (52 percent) followed by category B soils (28 percent), category C soils (17 percent), and category A soils (2 percent). Category B soils are moderately deep and well drained, while Category C soils are finer and allow for slower infiltration. This means that regular flooding is likely not typical in much of this watershed but could potentially occur on occasion and transport pollutants across the landscape.

Of the soils identified as category D, 48 percent are specified as dual hydrologic group B/D, 35 percent are specified as dual hydrologic group C/D, and 22 percent are specified as dual hydrologic group A/D. Dual hydrologic groups are identified as certain wet soils that can be adequately drained. The first letter applies to the drained condition, and the second letter applies to the undrained, natural condition. Due to the watershed scale of this report, soils with dual hydrologic groups are classified as category D. However, a site-specific study should consider whether the site has been drained when soils with a dual hydrologic group are present.

Table 12: Hydrologic Soil Groups

Hydrologic Soils Group	Description
A	Soils with high infiltrations rates. Usually deep, well drained sands or gravels. Little run-off.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of run-off.

Understanding Table 12: Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. Soil infiltration rates can affect pollutant loading within a watershed. During high flows, areas with low soil infiltration capacity can flood and therefore discharge high pollutant loads to nearby waterways. In contrast, soils with high infiltration rates can slow the movement of pollutants to streams.

Table 13: Hydrologic Soil Groups in the Lake Manitou Subwatersheds

Subwatershed	Hydrologic Soil Group			
	A	B	C	D
Rain Creek	1%	29%	19%	51%
Robbin Taylor	3%	28%	16%	54%

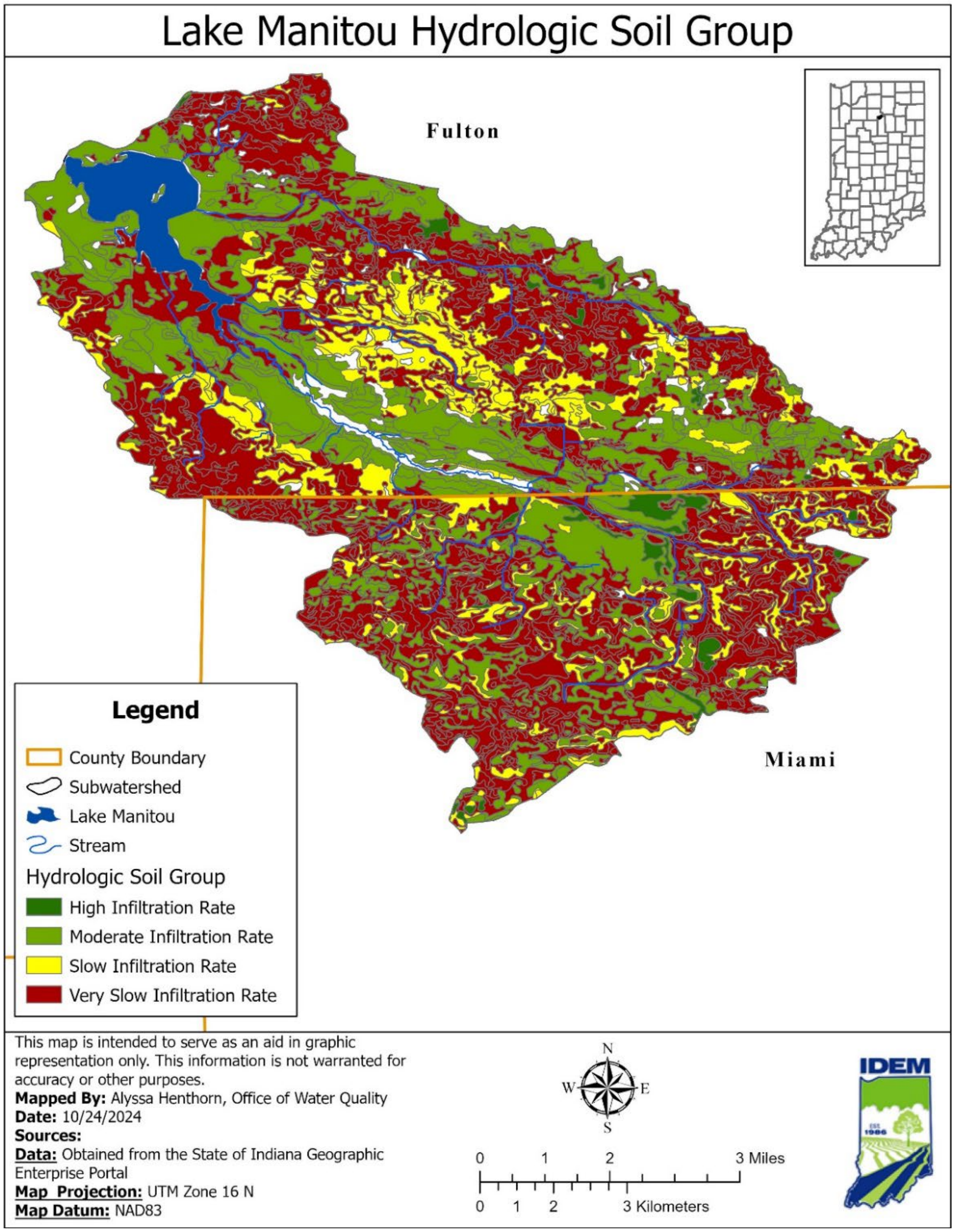

Figure 10: Hydrological Soil Groups in the Lake Manitou Watershed

2.4.2 Septic Tank Absorption Field Suitability

Septic systems require soil characteristics and geology that allow gradual seepage of wastewater into the surrounding soils. Seasonal high-water tables, shallow compact till, and coarse soils present limitations for septic systems. Heavy clay soils require larger (and therefore more expensive) absorption fields; while sandier, well-drained soils are often suitable for smaller, more affordable gravity-flow trench systems. Hydrologic soil group A and B soils have good infiltration rates and have less risk of failing septic systems due to this factor. Group C and D soils have slow infiltration rates with finer textures and slow water movement. Table 13 illustrates the hydrologic soil groups for the Lake Manitou subwatersheds.

While system design can often overcome these limitations (i.e., perimeter drains, mound systems or pressure distribution), sometimes the soil characteristics prove to be unsuitable for any type of traditional septic system. Common soil type limitations which contribute to septic system failure are seasonal water tables, compact glacial till, bedrock, coarse sand and gravel outwash, and fragipan. When these septic systems fail hydraulically (surface breakouts) or hydrogeological (inadequate soil filtration), there can be adverse effects to surface waters due to nutrients (Horsley and Witten, 1996). Refer to Section 2.7.1 for additional information regarding septic systems within the Lake Manitou watershed.

Figure 11 shows ratings that indicate the extent to which the soils are suitable for septic systems within the Lake Manitou watershed. Only that part of the soil between depths of 24 and 60 inches is evaluated for septic system suitability. The ratings are based on the soil properties that affect absorption of the effluent, construction, maintenance of the system, and public health.

Soils labeled “very limited” indicate that the soil has at least one feature that is unfavorable for septic systems. Approximately 86 percent of the Lake Manitou watershed is considered “very limited” in terms of soil suitability for septic systems. These limitations generally cannot be overcome without major soil reclamation or expensive installation designs. Approximately less than 2 percent of the soils within the Lake Manitou watershed are “not rated,” meaning these soils have not been assigned a rating class because it is not industry standard to install a septic system in these geographic locations or are part of the body of water that is Lake Manitou. Approximately 12 percent of the soils in the Lake Manitou watershed are designated “somewhat limited,” meaning that the soil type is suitable for septic systems. According to the History of Rochester, Lake Manitou and the residents surrounding the lake were annexed in 1987. This annex includes sewer and sanitation services through the City Water department. However, residents outside the community surrounding Lake Manitou are not privy to these services. https://www.rochester.in.us/category/subcategory.php?categoryid=9

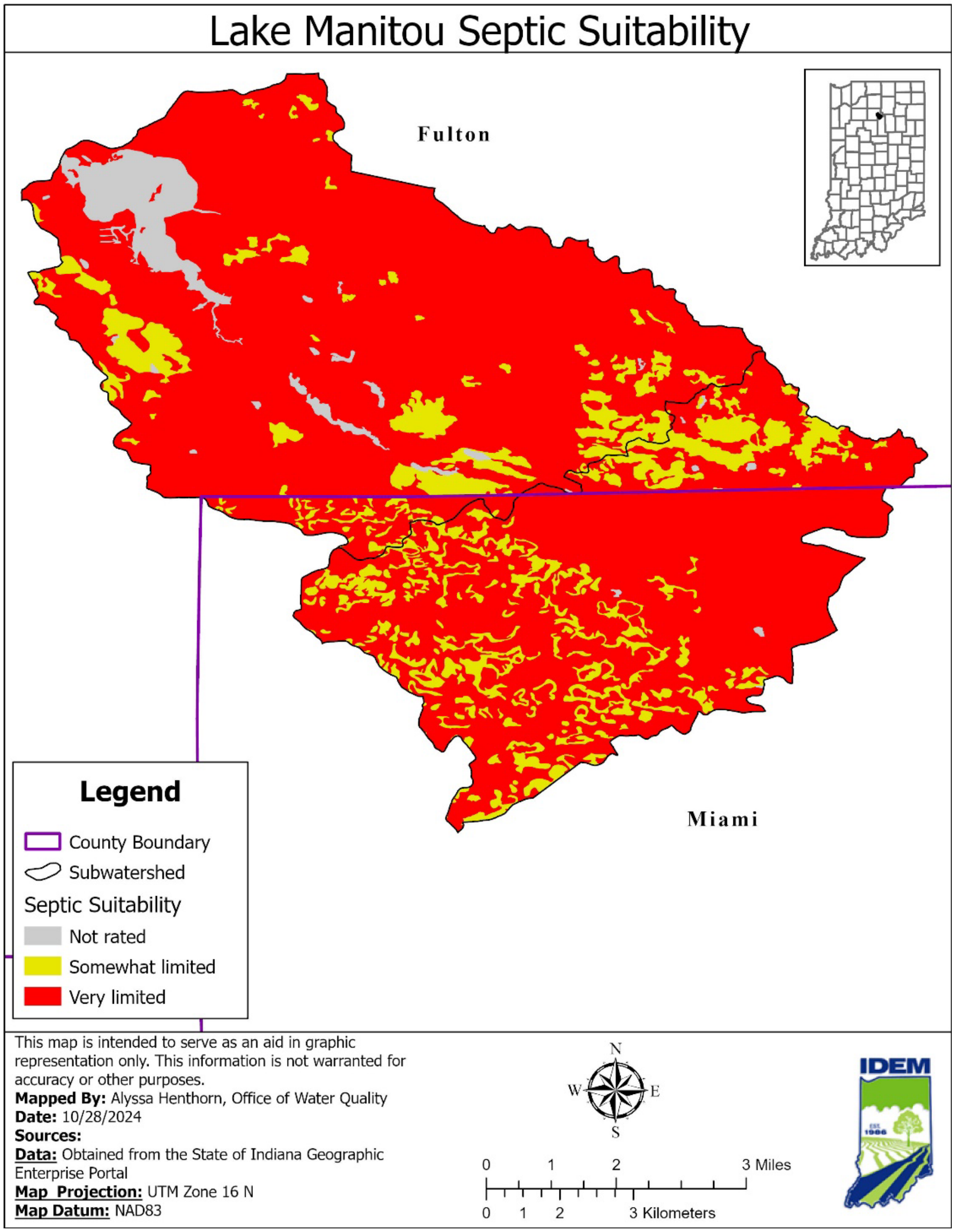

Figure 11: Suitability of Soils for Septic Systems in the Lake Manitou watershed

2.4.3 Soil Saturation and Wetlands

Soils that remain saturated or inundated with water for a sufficient length of time become hydric through a series of chemical, physical, and biological processes. Once a soil takes on hydric characteristics, it retains those characteristics even after the soil is drained. Hydric soils have been identified in the Lake Manitou watershed and are important in consideration of wetland restoration activities. Approximately 9,746 acres or 85 percent of the Lake Manitou watershed area contains soils that are considered hydric or have hydric inclusions. Table 14 includes a list of each map unit within the Lake Manitou watershed with a hydric rating greater than 0. Hydric ratings indicate the percentage of the map unit that meets the criteria for hydric soils. For example, map units with a hydric rating of 6 or less likely have small areas of hydric soils, and map units with a hydric rating of 95 or more have more significant coverage of hydric soils. Figure 12 displays the hydric ratings for each map unit within the Lake Manitou watershed. The Lake Manitou subwatershed appears to have the most significant hydric soil coverage in the watershed. However, a large majority of these soils have been drained for either agricultural production or urban development and would no longer support a wetland. The location of remaining hydric soils can be used to consider possible locations of wetland creation or enhancement. There are many components in addition to soil type that must be considered before moving forward with wetland design and creation.

Table 14: Hydric Ratings for Map Units with Hydric Soils in the Lake Manitou Watershed

Subwatershed	Map Symbol	Map Unit Name	Hydric Rating	Map Unit Acreage
Rain Creek	Ad	Adrian muck, drained, 0 to 1 percent slopes	100	5
	Au	Aubbeenaubbee sandy loam, 0 to 2 percent slopes	3	5
	Bb	Barry loam	100	1,389
	Br	Brady sandy loam	4	279
	BsA	Branch loamy sand, 0 to 2 percent slopes	3	75
	ChB	Chelsea fine sand, 2 to 6 percent slopes	0	8
	Cr	Crosier loam, 0 to 2 percent slopes	5	242
	CrA	Crosier loam, 0 to 2 percent slopes	5	2,472
	Ed	Edwards muck, drained	100	45
	FsA	Fox silt loam, till plain, 0 to 2 percent slopes	4	0.5
	FzC3	Fox clay loam, 8 to 15 percent slopes, severely eroded	0	2
	Gf	Gilford fine sandy loam, 0 to 2 percent slopes, gravelly subsoil	95	79
	Hh	Histosols-Aquolls complex, ponded	100	353
	Hk	Homer fine sandy loam, 0 to 2 percent slopes	3	506
	Hm	Houghton muck, drained	100	205
	Ho	Houghton muck, disintegration moraine, 0 to 2 percent slopes	100	660
	Hx	Houghton muck, drained	100	29
	KoA	Kosciusko-Ormas complex, 0 to 2 percent slopes	5	2,114
	KoB	Kosciusko-Ormas complex, 2 to 6 percent slopes	5	1,000
	KoC	Kosciusko-Ormas complex, 6 to 12 percent slopes	5	725
	MaA	Markton loamy sand, 0 to 2 percent slopes	3	197
	MeA	Metea loamy sand, 0 to 2 percent slopes	0	15
	MeB	Metea loamy sand, 2 to 6 percent slopes	0	288
	MeB	Metea loamy fine sand, 2 to 6 percent slopes	0	53
	MeC	Metea loamy sand, 6 to 12 percent slopes	0	56
	Mx	Muskego muck, drained	100	72
	OsB	Ormas-Oshtemo loamy sands, 2 to 8 percent slopes	16	2
	Pk	Pits, gravel	3	14

Subwatershed	Map Symbol	Map Unit Name	Hydric Rating	Map Unit Acreage
	PlC	Plainfield sand, 6 to 12 percent slopes	1	2
	Pm	Palms muck, drained	100	9
	RlA	Riddles fine sandy loam, 0 to 2 percent slopes	5	372
	RlB2	Riddles fine sandy loam, 2 to 6 percent slopes	5	502
	RlC2	Riddles fine sandy loam, 6 to 12 percent slopes, eroded	3	154
	Se	Sebewa sandy clay loam	100	1,094
	Wa	Wallkill silt loam	100	65
	Wh	Washtenaw silt loam	100	153
	WkB	Wawasee fine sandy loam, 2 to 6 percent slopes	4	1,426
	WkC2	Wawasee fine sandy loam, 6 to 12 percent slopes, eroded	2	820
	WkD	Wawasee fine sandy loam, 12 to 18 percent slopes	2	76
	WsB	Wawasee sandy loam, 2 to 6 percent slopes	3	130
	WsC3	Wawasee loam, 6 to 12 percent slopes, severely eroded	0	20
	WsD3	Wawasee loam, 12 to 18 percent slopes, severely eroded	0	6
			Total Acreage:	**15,760**
Robbin Taylor	Ad	Adrian muck, drained, 0 to 1 percent slopes	100	25
	Au	Aubbeenaubbee sandy loam, 0 to 2 percent slopes	3	103
	Bb	Barry loam	100	79
	BlxA	Blount loam, interlobate moraines, 0 to 2 percent slopes	5	597
	Br	Brady sandy loam	4	8
	Br	Brookston loam	92	1,554
	ChB	Chelsea fine sand, 2 to 6 percent slopes	0	58
	Co	Cohoctah fine sandy loam, occasionally flooded	100	0.3
	Cr	Crosier loam, 0 to 2 percent slopes	5	1,144
	CrA	Crosier loam, 0 to 2 percent slopes	5	39
	Ed	Edwards muck, drained	100	11
	FsA	Fox silt loam, till plain, 0 to 2 percent slopes	4	5
	FzC3	Fox clay loam, 8 to 15 percent slopes, severely eroded	0	136
	Gf	Gilford fine sandy loam, 0 to 2 percent slopes, gravelly subsoil	95	72
	Gr	Gilford sandy loam, till plain, 0 to 2 percent slopes	95	215
	Hh	Histosols-Aquolls complex, ponded	100	44
	Hm	Houghton muck, drained	100	102
	Ho	Houghton muck, disintegration moraine, 0 to 2 percent slopes	100	129
	Hx	Houghton muck, drained	100	890
	KoA	Kosciusko-Ormas complex, 0 to 2 percent slopes	5	41
	KoB	Kosciusko-Ormas complex, 2 to 6 percent slopes	5	100
	KoC	Kosciusko-Ormas complex, 6 to 12 percent slopes	5	123
	MaA	Markton loamy sand, 0 to 2 percent slopes	3	12
	MaA	Martinsville sandy loam, 0 to 2 percent slopes	3	601
	MeA	Metea loamy sand, 0 to 2 percent slopes	0	3
	MeB	Metea loamy sand, 2 to 6 percent slopes	0	31
	MeB	Metea loamy fine sand, 2 to 6 percent slopes	0	412
	MeC	Metea loamy sand, 6 to 12 percent slopes	0	13
	MrB	Morley sandy loam, 2 to 6 percent slopes	3	80
	MrB2	Glynwood loam, 2 to 6 percent slopes, eroded	4	150
	MsB	Glynwood silt loam, 2 to 6 percent slopes	4	501
	MsC3	Morley clay loam, 6 to 12 percent slopes, severely eroded	0	130
	MsD	Morley silt loam, 12 to 18 percent slopes	2	8

Subwatershed	Map Symbol	Map Unit Name	Hydric Rating	Map Unit Acreage
	MtC3	Morley silty clay loam, 6 to 12 percent slopes, severely eroded	0	367
	MtD3	Morley silty clay loam, 12 to 25 percent slopes, severely eroded	0	136
	Mx	Muskego muck, drained	100	13
	Ne	Newton fine sandy loam	100	30
	Or	Orthents, loamy	0	1
	OsB	Ormas-Oshtemo loamy sands, 2 to 8 percent slopes	6	24
	OtA	Oshtemo sandy loam, 0 to 4 percent slopes	6	232
	Pe	Pewamo clay loam, 0 to 2 percent slopes	92	39
	PlB	Plainfield sand, 2 to 6 percent slopes	1	3
	PlC	Plainfield sand, 6 to 12 percent slopes	1	4
	Pm	Palms muck, drained	100	239
	Pt	Patton silty clay loam	100	8
	Pw	Pewamo silty clay loam, 0 to 1 percent slopes	91	290
	Re	Rensselaer loam, 0 to 1 percent slopes	88	175
	RlA	Riddles fine sandy loam, 0 to 2 percent slopes	5	152
	RlB2	Riddles fine sandy loam, 2 to 6 percent slopes	5	324
	RlC2	Riddles fine sandy loam, 6 to 12 percent slopes, eroded	3	125
	Se	Sebewa sandy clay loam	100	74
	Se	Sebewa loam, disintegration moraine, 0 to 1 percent slopes	95	31
	Sn	Sleeth loam	6	3
	So	Sloan silty clay loam, 0 to 1 percent slopes, frequently flooded	94	45
	Wa	Wallkill silt loam	100	22
	Wh	Washtenaw silt loam	100	105
	WkB	Wawasee fine sandy loam, 2 to 6 percent slopes	4	68
	WkC2	Wawasee fine sandy loam, 6 to 12 percent slopes, eroded	2	42
	WsB	Wawasee sandy loam, 2 to 6 percent slopes	3	1,368
	WsC	Wawasee sandy loam, 6 to 12 percent slopes	0	105
	WsC3	Wawasee loam, 6 to 12 percent slopes, severely eroded	0	314
	WsD3	Wawasee loam, 12 to 18 percent slopes, severely eroded	0	36
			Total Acreage:	**11,527**

Understanding Table 14: Areas with the most acreage of hydric soils might contain opportunities for wetland restoration activities that could help address water quality impairments. The hydric rating indicates the percentage of the map unit with hydric soils. Map units with a hydric rating of 100 have 100% hydric soils.

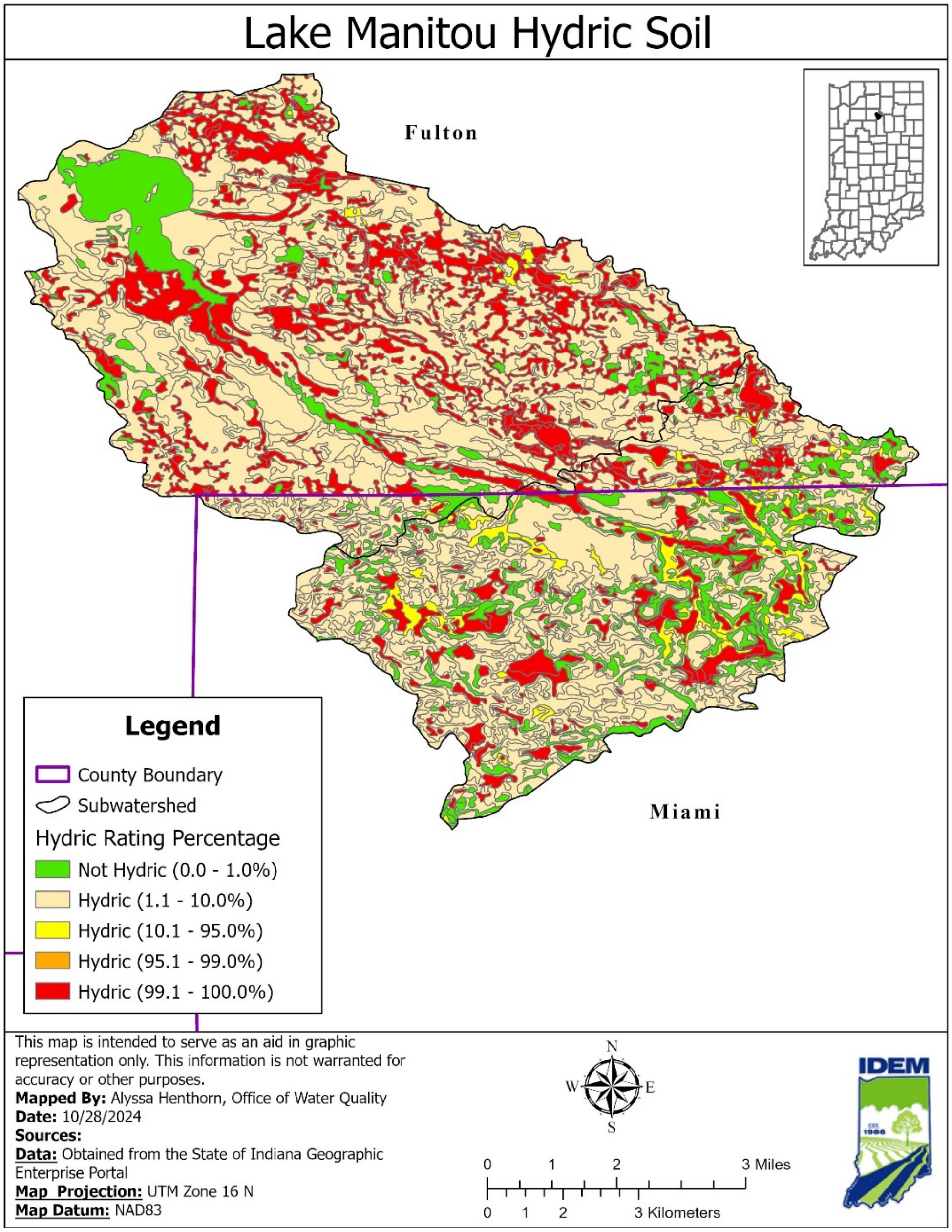

Figure 12: Hydric Soils in the Lake Manitou Watershed
(https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/)

Nationally, since the late 1600s roughly 50 percent of the wetlands in the lower 48 states have been lost. Indiana has lost a large number of its wetlands, approximating over 80 percent (USGS, 1999). In the 1800s and 1900s millions of acres of wetlands were drained or converted into farms, cities, and roads. In the early 1700s, wetlands covered 25 percent of the total area of Indiana. That number has been greatly reduced. By the late 1980s, over 4.7 million acres of wetlands had been lost. Before the conversion of wetlands, there were over 5.6 million acres of wetlands in the state, wetlands such as bogs, fens, wet prairies, dune and swales, cypress swamps, marshes, and swamps. Wetlands now cover less than 4 percent of Indiana. (www.idem.IN.gov/wetlands/importance-of-wetlands)

Wetlands are home to wildlife. More than one-third (1/3) of America's threatened and endangered species live only in wetlands, which means they need them to survive. Over 200 species of birds rely on wetlands for feeding, nesting, foraging, and roosting. Wetlands provide areas for recreation, education, and aesthetics. More than 98 million people hunt, fish, birdwatch, or photograph wildlife. Americans spend $59.5 billion annually on these activities.

Wetland plants and soils naturally store and filter nutrients and sediments. Calm wetland waters, with their flat surface and flow characteristics, allow these materials to settle out of the water column, where plants in the wetland take up certain nutrients from the water. As a result, our lakes, rivers and streams are cleaner, and our drinking water is safer. Constructed wetlands can even be used to clean wastewater, when properly designed. Wetlands also recharge our underground aquifers. Over 70 percent of Indiana residents rely on groundwater for part or all of their drinking water needs.

Wetlands protect our homes from floods. Like sponges, wetlands soak up and slowly release floodwater. This lowers flood heights and slows the flow of water down rivers and streams. Wetlands also control erosion. Shorelines along rivers, lakes, and streams are protected by wetlands, which hold soil in place, absorb the energy of waves, and buffer strong currents.

Wetland areas act to buffer wide variations in flow conditions that result from storm events. They also allow water to infiltrate slowly thus reducing the risks of contaminated water run-off into waterbodies. Agencies such as the USGS and U.S. Fish and Wildlife Service (USFWS) estimate that Indiana has lost approximately 85 percent of the state's original wetlands. Currently, the Lake Manitou watershed contains approximately 1,098 acres of wetlands or 4 percent of the total surface area. Additional information on wetlands can be found on the IDEM website www.idem.IN.gov/wetlands.

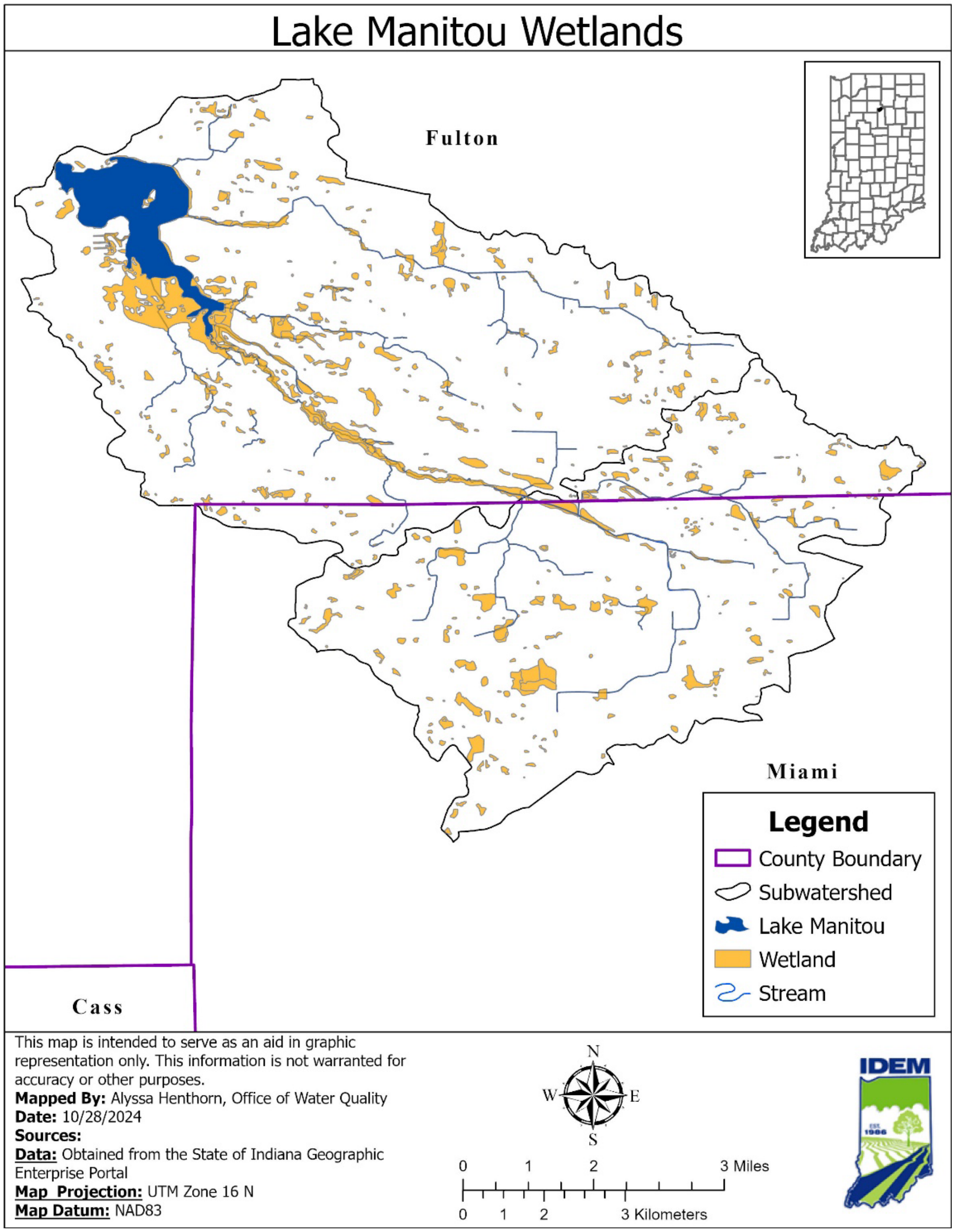

Figure 13: Location of Wetlands in the Lake Manitou Watershed

The USFWS has the responsibility for mapping wetlands in the United States. Those map products are currently held in the Fish and Wildlife Service Wetland Database (sometimes referred to as the National Wetlands Inventory or NWI). Figure 13 shows estimated locations of wetlands as defined by USFWS's NWI. Wetland data for Indiana is available from the U.S. Fish and Wildlife Service's NWI at https://fwsprimary.wim.usgs.gov/wetlands/apps/wetlands-mapper. The NWI was not intended to produce maps that show exact wetland boundaries comparable to boundaries derived from ground soil surveys, and boundaries are generalized in most cases.

Wetlands are identified based on vegetation, visible hydrology and geography. A margin of error is inherent in the use of imagery; thus, detailed on-the-ground inspection of any particular site may result in revision of the wetland boundaries or classification established through image analysis. Therefore, the estimate of the current extent of wetlands in the Lake Manitou watershed from the NWI may not agree with those listed in Section 2.2, which are based upon the National Agricultural Statistics Service. For more information on the wetland classification codes visit http://www.fws.gov/wetlands/Data/Wetland-Codes.html. The USFWS uses data standards to increase the quality and compatibility of its data.

Changes to the natural drainage patterns of a watershed are referred to as hydromodifications. Historically, drain tiles have been used throughout Indiana to drain marsh or wetlands and make it either habitable or tillable for agricultural purposes. While tile drainage is understood to be pervasive – estimated at thousands of miles in Indiana – it is extremely challenging to quantify on a watershed basis because these tiles were established by varying authorities including County Courts, County Commissioners, or County Drainage Boards (www.idem.IN.gov/idem/nps/watershed-restoration).

In addition to tile drainage, regulated drains are another form of hydromodification. A regulated drain is a drain which was established through either a Circuit Court or Commissioners Court of the County prior to January 1, 1966, or by the County Drainage Board since that time. Regulated drains can be an open ditch, a tile drain, or a combination of both. The County Drainage Board can construct, maintain, reconstruct, or vacate a regulated drain.

2.4.4 Soil Erodibility

Although erosion is a natural process within stream ecosystems, excessive erosion negatively impacts the health of watersheds. Erosion increases sedimentation of the streambeds, which impacts the quality of habitat for fish and other organisms. Erosion also impacts water quality as it increases nutrients and decreases water clarity. As water flows over land and enters the stream as run-off, it carries pollutants and other nutrients that are attached to the sediment. Sediment suspended in the water blocks light needed by plants for photosynthesis and clogs respiratory surfaces of aquatic organisms.

The NRCS maintains a list of highly erodible lands (HEL) units for each county based upon the potential of soil units to erode from the land (https://efotg.sc.egov.usda.gov/references/public/NE/HEL_Intro.pdf). HELs are especially susceptible to the erosional forces of wind and water. Wind erosion is common in flat areas where vegetation is sparse or where soil is loose, dry, and finely granulated. Wind erosion damages land and natural vegetation by removing productive topsoil from one place and depositing it in another. The classification for HELs is based upon an erodibility index for a soil, which is determined by dividing the potential average annual rate of erosion by the soil unit's soil loss tolerance (T) value, which is the maximum annual rate of erosion that could occur without causing a decline in long-term productivity. The soil types and acreages in the Lake

Manitou watershed are listed in Table 15. HELs and potential HELs in the Lake Manitou watershed are mapped in Figure 14.

A total of 1,537 acres or 6 percent of the Lake Manitou watershed is considered highly erodible or potentially highly erodible. Rainfall surrounding the Lake Manitou watershed is moderately heavy with an annual average of 39.2 inches. This rainfall and climate data specific to the watershed is available from the Midwestern Regional Climate Center https://mrcc.purdue.edu. Heavy rainfall increases flow rates within streams as the volume and velocity of water moving through the stream channels increases. The velocity of water also increases as streambank steepness increases.

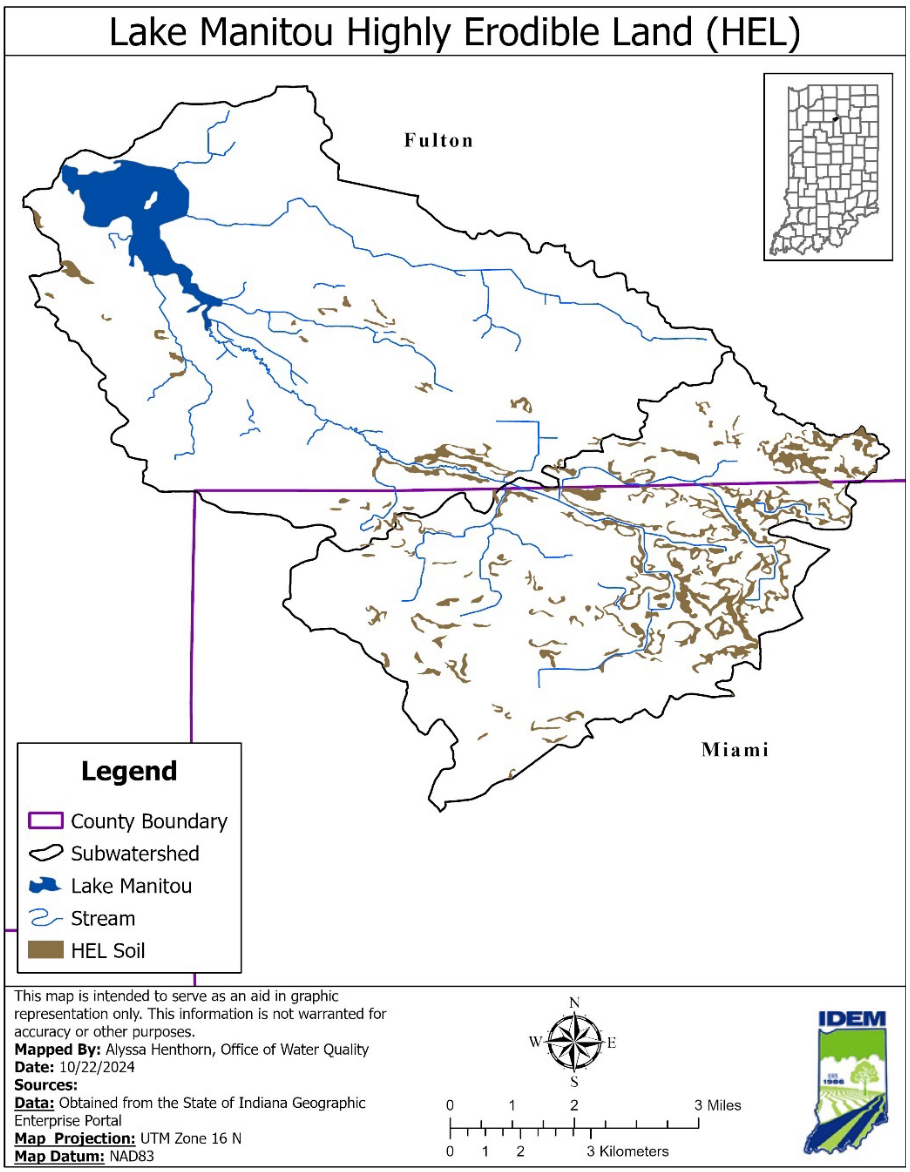

Figure 14: Location of Highly Erodible Lands (HEL) in the Lake Manitou Watershed

Table 15: HEL/Potential HEL Total Acres in the Lake Manitou Watershed

Map Symbol	HEL/Potential HEL Soil Types	Acres
FzC3	Fox clay loam, 8 to 15 percent slopes, severely eroded	137
MsC3	Morley clay loam, 6 to 12 percent slopes, severely eroded	130
MsD	Morley silt loam, 12 to 18 percent slopes	8
MtC3	Morley silty clay loam, 6 to 12 percent slopes, severely eroded	397
MtD3	Morley silty clay loam, 12 to 25 percent slopes, severely eroded	138
RlC2	Riddles fine sandy loam, 6 to 12 percent slopes, eroded	278
WkD	Wawasee fine sandy loam, 12 to 18 percent slopes	75
WsC3	Wawasee loam, 6 to 12 percent slopes, severely eroded	334
WsD3	Wawasee loam, 12 to 18 percent slopes, severely eroded	42
	Total	**1,537**

Understanding Table 15 and Figure 14: Areas with the most acreage of HEL might contribute to water quality impairments associated with excessive erosion, including nutrients, and might contain opportunities for restoration to decrease erosion.

The Indiana State Department of Agriculture (ISDA) tracks trends in conservation and cropland through annual county tillage transects. Data collected through the tillage transect county (https://secure.in.gov/isda/divisions/soil-conservation/cover-crop-and-tillage-transect-data) can help estimate the adoption of conservation practices and the average annual soil loss from Indiana's agricultural lands. The latest figures for the counties in the Lake Manitou watershed are shown in Table 16. Conditions captured in ISDA's conservation transect include the acreage of living cover and the percentage of crop acres where living cover was present. The conservation transect also includes the percentage of crop acres that had not been tilled during the time the survey was conducted. According to ISDA, the conservation survey was conducted in the late winter to early spring of 2024. The early spring survey is not intended to quantify pre-planting tillage. (ISDA, 2024).

Table 16: Tillage Transect Data for 2023 by County in the Lake Manitou Watershed

County	Tillage Practice 2023			
	Living Cover		No Till	
	Corn	Soybean	Corn	Soybean
Fulton	9,685 acres 11%	7,005 acres 9.5%	39%	78%
Miami	3,922 acres 5.5%	9,405 acres 11%	73%	55%

Understanding Table 16: According to the table, in Fulton County and Miami, no till is predominant for corn and soybeans.

2.4.5 Streambank Erosion

Streambank erosion contributes nutrients to streams and lakes by releasing sediment and organic material into the water. As soil is eroded from streambanks, it often carries with it phosphorus and nitrogen, which are bound to soil particles or present in organic matter. These nutrients can fuel agal blooms and disrupt aquatic ecosystems. Streambank erosion is a natural process but can be accelerated due to a variety of human activities including the following:

- Vegetation located adjacent to streams flowing through crops or pasture fields is often removed to promote drainage or cattle access to water. The loss of vegetation makes the streambanks more susceptible to erosion due to the loss of plant roots.
- Extensive areas of agricultural tiles promote much quicker delivery of rainfall into streams than would occur without subsurface drainage, which could potentially contribute to streambank erosion, due to high velocities and shear stress.
- The creation of impervious surfaces (e.g., streets, rooftops, driveways, parking lots) can also lead to rapid run-off of rainfall and higher stream velocities that might cause streambank erosion.

2.5 Wildlife and Classified Lands

2.5.1 Wildlife

The Indiana Department of Natural Resources (IDNR) is the primary entity responsible for monitoring wildlife populations and habitats throughout Indiana. Wildlife such as deer, waterfowl, raccoon, beaver, etc. can be sources nutrients through organic waste. The animal habitat and proximity to surface waters are important factors that determine if animal waste can be transported to surface waters. Waterfowl and riparian mammals deposit waste directly into streams while other riparian species deposit waste in the flood-plain, which can be transported to surface waters by runoff from precipitation events. Animal waste deposited in upland areas can also be transported to streams and rivers; however, due to the distance from uplands to surface streams, only larger precipitation events can sustain sufficient amounts of runoff to transport upland animal waste to surface waters.

Little information exists surrounding feces depositional patterns of wildlife, and a direct inventory of wildlife populations is generally not available. However, based on the *Bacteria Source Load Calculator* developed by the Center for TMDL and Watershed Studies, bacteria production by animal type is estimated as well as their preferred habitat. Higher concentrations of wildlife in the habitats described in Table 17 could contribute nutrients to the watershed, particularly during high flow conditions or flooding events.

Table 17: Bacteria Source Load by Species

Wildlife Type	*E. coli* Production Rate (cfu/day – animal)	Habitat
Deer	1.86×10^8	Entire Watershed
Raccoon	2.65×10^7	Low density on forests in rural areas; high density on forest near a permanent water source or near cropland
Muskrat	1.33×10^7	Near ditch, medium sized stream, pond or lake edge
Goose	4.25×10^8	Near main streams and impoundments
Duck	1.27×10^9	Near main streams and impoundments
Beaver	2.00×10^5	Near streams and impoundments in forest and pastures

2.5.2 Managed Lands

Managed lands shown in Table 18 include natural and recreation areas which are owned or managed by the IDNR, federal agencies, local agencies, non-profit organizations, and conservation easements. Classified lands are public or private lands containing areas supporting the growth of native or planted trees, native or planted grasses, wetlands, or other acceptable types of cover that have been set aside for managed production of timber, wildlife habitat, and watershed protection. Natural areas provide ideal habitat for wildlife. Some of the more common wildlife often found in natural areas include white-tailed deer, raccoon, muskrat, fowl, and beaver. While wildlife is known to contribute nutrients to the surface waters, natural areas provide economic, ecological, and social benefits and should be preserved and protected. Management practices such as impervious surfaces reduction, native vegetation plantings, wetland creation, and riparian buffer maintenance will help in reducing stormwater run-off transporting pollutants to the streams. Table 18 and Figure 15 show the managed lands within the Lake Manitou watershed.

Table 18: Managed Lands within the Lake Manitou Watershed

Unit Name	Manager	Area (acres)
Manitou Islands Wetland Conservation Area	DNR Fish and Wildlife	427
Lake Manitou Public Access Site	DNR Fish and Wildlife	1.4
Manitou Islands Wetland Conservation Area	DNR Fish and Wildlife	22
Bob Kern Wetlands Nature Preserve	DNR Nature Preserves	168
Judy Burton Nature Preserve	DNR Nature Preserves	130
Lake Manitou	DNR Nature Preserves	0.4
Total		**748.8**

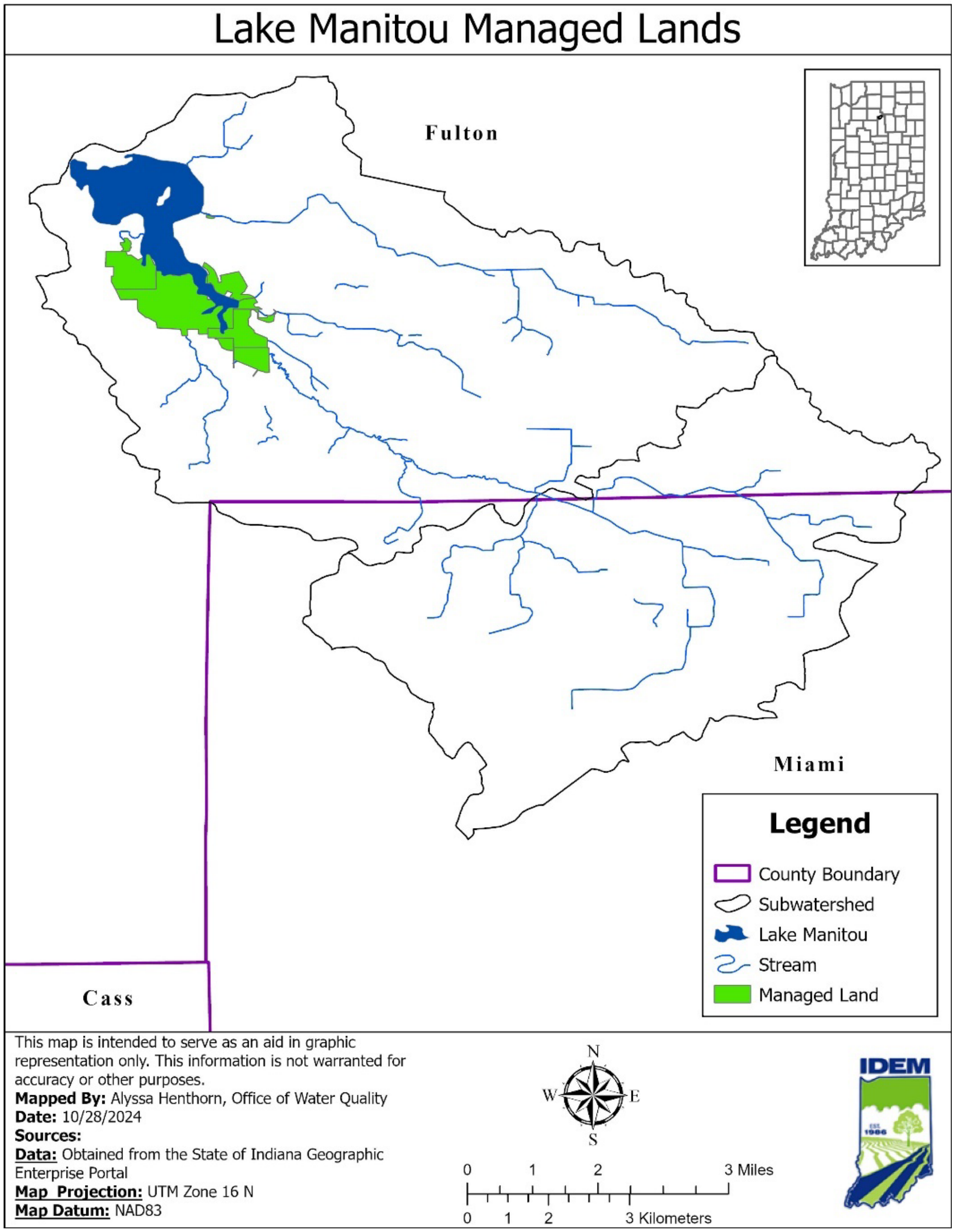

Figure 15: Managed Lands within the Lake Manitou Watershed

2.6 Climate and Precipitation

Climate varies in Indiana depending on latitude, topography, soil types, and lakes. Information on Indiana's climate is available through sources including the Midwestern Regional Climate Center (https://mrcc.purdue.edu).

Climate data from Station USC00127482 located in Rochester, IN were used for climate analysis of the Lake Manitou watershed. Monthly data from 2015 - 2024 were available at the time of analysis. In general, the climate of the region is continental with hot, humid summers and cold winters. From 2014 - 2024, the average winter temperature in Rochester was 33°F and the average summer temperature was 72°F. The average growing season (consecutive days with low temperatures greater than or equal to 32 degrees) is 170 days.

Examination of precipitation patterns is also a key component of watershed characterization because of the impact of run-off on water quality. From 2015 - 2024, the annual average precipitation in Rochester at Station USC00127482 was approximately 38 inches, including approximately 20 inches on average of total annual Lake Manitou snowfall.

Rainfall intensity and timing affect watershed response to precipitation. This information is important in evaluating the effects of stormwater on the Lake Manitou watershed. Using data from USC00127482 during 2015 - 2024, 85 percent of the measurable precipitation events were low intensity (i.e., less than 0.2 inches), while 2 percent of the measurable precipitation events were greater than one inch.

According to the “Impacts of Climate Change for the State of Indiana” report developed by the Purdue Climate Change Research Center, Indiana will face a number of potential impacts if greenhouse gas concentrations continue to increase. The occurrence and duration of extreme hot events is likely to increase in Indiana while the occurrence of extreme cold events is likely to decrease (Purdue Climate Change Research Center, 2008). Indiana could experience a significant reduction in extreme cold temperatures leading to warmer winters (Purdue Climate Change Research Center, 2008). Total annual average precipitation is likely to increase, but there may be a shift in when the precipitation occurs. Winter and spring precipitation are projected to increase by 21 and 30 percent, respectively, by the end of the century, but summer precipitation may decline by 9 percent. Warmer and wetter winters may result in higher streamflow and increased flooding frequency. Total runoff is also projected to increase annually by between 25 and 38 percent by the end of the century with the largest percent increase in total runoff occurring in the winter and spring (Purdue Climate Change Research Center, 2008).

Understanding when precipitation events occur helps in the linkage analysis in Section 4.0, which correlates flow conditions to pollutant concentrations and loads. Data indicates that the wet weather season in the Lake Manitou watershed currently occurs between the months of March and May.

2.7 Human Population

Counties with land located in the Lake Manitou watershed include Fulton and Miami. Major government units with jurisdiction at least partially within the Lake Manitou watershed include Fulton and Miami Counties. U.S. Census data for each county during the past three decades are provided in Table 20 (U.S. Census Bureau, 2020).

Table 19: Population Data for Counties in Lake Manitou Watershed

County	2000	2010	2020
Fulton	20,511	20,836	20,480
Miami	36,082	36,903	35,962
Total	56,593	57,739	56,442

Understanding Table 19: Water quality is linked to population growth because a growing population often leads to more development, translating into more houses, roads, and infrastructure to support more people. The table provides information that shows how population has changed in each of the counties located in the Lake Manitou watershed over time. In addition, understanding population trends can help watershed stakeholders to anticipate where pressures might increase in the future and where action in the Lake Manitou could help prevent further water quality degradation.

Estimates of population within Lake Manitou watershed are based on US Census data 2020 and the percentage of census blocks in urban and rural areas (Table 20). Based on this analysis, the estimated population of the watershed is 2,641 with approximately 58 percent of the population classified as rural residents and 42 percent classified as urban residents. A majority of residents live around Lake Manitou, who's property owner practices can impact water quality within the lake. Figure 16 below indicates population density within the Lake Manitou watershed.

Table 20: Estimated Population in the Lake Manitou Watershed

County	2020 Population	Total Estimated Watershed Urban Population	Total Estimated Watershed Rural Population	Total Estimated Watershed Population	Percent of Total Watershed Population
Fulton	20,480	1,105	1,146	2,251	86%
Miami	35,962	0	390	390	14%
Total	56,442	1,105	1,536	2,641	100%

Understanding Table 20: Understanding where the greatest population is concentrated within the Lake Manitou watershed will help watershed stakeholders understand where different types of water quality pressures might currently exist. In general, watersheds with large urban populations are more likely to have problems associated with lots of impervious surfaces, poor riparian habitat, flashy stormwater flows, and large wastewater inputs. Alternatively, watersheds with mostly a non-urban population are more likely to suffer problems from failing septic systems, agricultural run-off, and other types of poor riparian habitat (e.g., channelized streams). Comparing the information in Table 20 with the information in Table 21 can provide an understanding of how population might change in the Lake Manitou watershed and which counties are experiencing the most growth and shifts in urban and non-urban population. Population change can serve as an indicator for changes in land uses. For example, growing populations might mean more development, resulting in increased impervious surfaces and more infrastructure (e.g., sanitary sewer and storm sewer). Declining population in areas of the Lake Manitou watershed might signify communities with under-utilized infrastructure and indicate opportunities to "right size" existing infrastructure and promote changes to land use that would benefit water quality (e.g., green infrastructure).

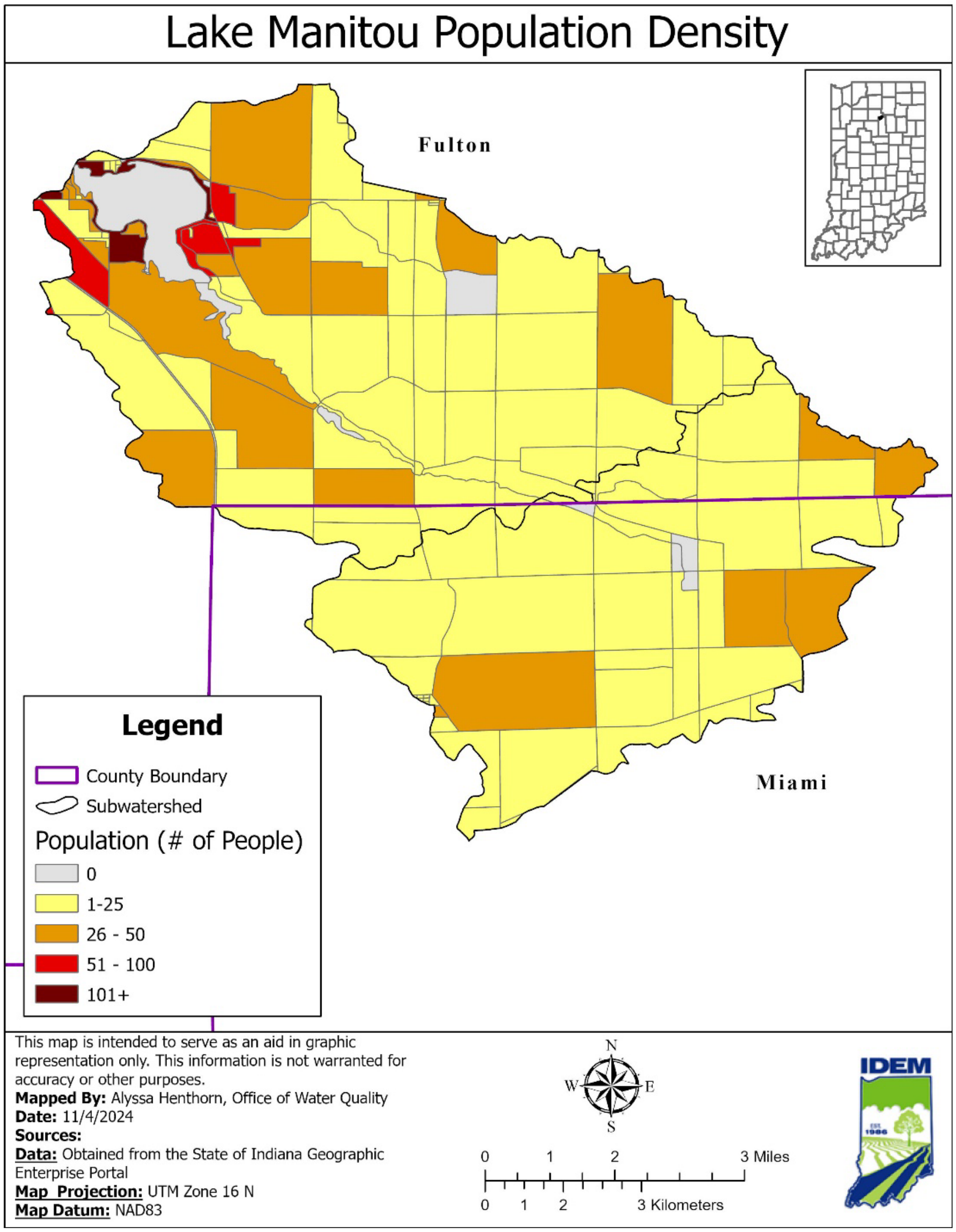

Figure 16: Population Density in the Lake Manitou Watershed

2.7.1 Onsite Sewage Disposal Systems

According to the Fulton County Health Department there are around 252 septic systems within the Lake Manitou area applicable to this study. Onsite sewage disposal systems (i.e., septic systems) are underground wastewater treatment structures most commonly used in rural areas without centralized sewer systems. According to the U.S. EPA's SepticSmart Homeowners program, one in five U.S. homes has a septic system (U.S EPA, 2018). Local health departments regulate onsite residential sewage disposal systems via designated authority from the Indiana Department of Health (IDOH) (410 IAC 6-8.3). More than 800,000 onsite sewage disposal systems are currently used in Indiana. Local health departments issue more than 15,000 permits per year for new systems and about 6,000 permits for repairs (IDOH, 2020).

Septic systems typically consist of a septic tank to settle out and digest sewage solids followed by a system of perforated piping to distribute the treated wastewater for absorption into the soil, also known as the drainfield. The septic tank holds the wastewater to allow for separation of solids, fats, oil, and grease. The septic tank also contains microorganisms that aid in breaking down sludge and removing some contaminants from the wastewater. The drainfield allows for further removal of remaining contaminants through soil filtration.

Regular maintenance of septic systems, such as frequent inspections and pumping of the septic tank, is important to ensure the system is functioning safely and effectively. Septic systems that are properly designed and maintained should not serve as a source of contamination to surface waters. However, a septic system may fail if it is not properly installed or maintained or if it is installed in an unsuitable soil type as discussed in Section 2.4.2. A septic system that is not functioning properly may inadvertently contaminate groundwater and surface water due to elevated levels of nutrients and bacteria that can be found in untreated or inadequately treated household wastewater. A septic system is considered failing when the system exhibits one or more of the following:

1. The system refuses to accept sewage at the rate of design application thereby interfering with the normal use of plumbing fixtures.

2. Effluent discharge exceeds the absorptive capacity of the soil, resulting in ponding, seepage, or other discharge of the effluent to the ground surface or to surface waters.

3. Effluent is discharged from the system causing contamination of a potable water supply, groundwater, or surface water.

The general sewage disposal requirements (410 IAC 6-8.3-52) in the residential onsite sewage systems rule state that:

- No person shall throw, run, drain, seep, or otherwise dispose into any of the surface waters or groundwaters of this state, or cause, permit, or suffer to be thrown, run, drained, allowed to seep, or otherwise disposed into such waters, any organic or inorganic matter from a dwelling or residential onsite sewage system that would cause or contribute to a health hazard or water pollution.
- The: (1) design; (2) construction; (3) installation; (4) location; (5) maintenance; and (6) operation; of residential onsite sewage systems shall comply with the provisions of this rule.

The violations and permit denial and revocation section (410 IAC 6-8.3-55) of the residential onsite sewage system rule states that:

- Should a residential onsite sewage system fail, the failure shall be corrected by the owner within the time limit set by the health officer.
- If any component of a residential onsite sewage system is found to be: (1) defective; (2) malfunctioning; or (3) in need of service; the health officer may require the repair, replacement, or service of that component. The repair, replacement, or service shall be conducted within the time limit set by the health officer.
- Any person found to be violating this rule may be served by the health officer with a written order stating the nature of the violation and providing a time limit for satisfactory correction thereof.

A comprehensive database of septic systems within the Lake Manitou watershed is not available; therefore, the rural population of each subwatershed was calculated to obtain a general representation of the number of systems. The U.S. Census provides the total number of people within a county as well as the total urban and rural population of the county. Subwatershed population is estimated by using the census block population found within each area. It is assumed that the numbers of septic systems in the subwatersheds are directly proportional to rural household density. An additional estimate of septic systems can be made using the 2020 US Census, as that is the last Census that inventoried how household wastewater is disposed. The rural households in the Lake Manitou subwatersheds are shown in Table 21, along with a calculated density (total rural households divided by total area). The rural household density can be used to compare the different subwatersheds within the Lake Manitou watershed (U.S. Census Bureau, 2020).

Table 21: Rural and Urban Household Density in the Lake Manitou Subwatersheds

Subwatershed	County	Area of County in Subwatershed (mi^2)	County Households in Subwatershed	Urban Households	Rural Households	Rural Household Density (Houses/ mi^2)	Urban Household Density (Houses/ mi^2)
Rain Creek	Fulton	25	982	880	4668	26.9	25.3
	Miami	1.2	10	0	11		
	Total	26.2	992	880	477		
Robbin Taylor	Fulton	3.2	35	0	37	21.1	0.0
	Miami	13	112	0	123		
	Total	16.2	147	0	160		

A report by the Indiana Advisory Commission on Intergovernmental Relations (ACIR) surveyed county health department officials statewide from 2023 to 2024. Of the 444 unsewered communities reported statewide, the study was able to identify 192 of those communities where at least 25 percent of the individual wastewater treatment systems were failing. Unsewered communities were defined as “contiguous geographical areas containing at least 25 homes and/or businesses that are not served by sewers” (Palmer et. al, 2019). Table 22 reports unsewered communities by county relevant to the Lake Manitou watershed. The reason why there are no reports for Fulton County is because most residents were annexed into the Rochester water and Sewer treatment services, therefore reducing the concerns for unsewered communities surrounding the lake.

Table 22: Unsewered residences/businesses reported by county in 2023-2024.

County	Unsewered Communities	Residences	Businesses
Fulton	No Report	No Report	No Report
Miami	11	683	13

2.7.2 Urban Stormwater

In areas not covered under the NPDES construction stormwater, industrial stormwater, or MS4 programs. Stormwater run-off from developed areas is not regulated under a permit and is therefore a nonpoint source. Run-off from urban areas can carry a variety of pollutants originating from a variety of sources. Typically, urban sources of nutrients are fertilizer application to lawns and pet waste. Depending on the amount of developed, impervious land in a watershed, urban nonpoint source inputs can result in localized or widespread water quality degradation. The percent and distribution of developed land in the Lake Manitou watershed is discussed in Section 2.2. However, inputs from urban sources are difficult to quantify. Estimates can be made of residential areas that might receive fertilizer treatment. These estimates provide insight into the potential of urban nonpoint sources as important sources of nutrients in the Lake Manitou watershed.

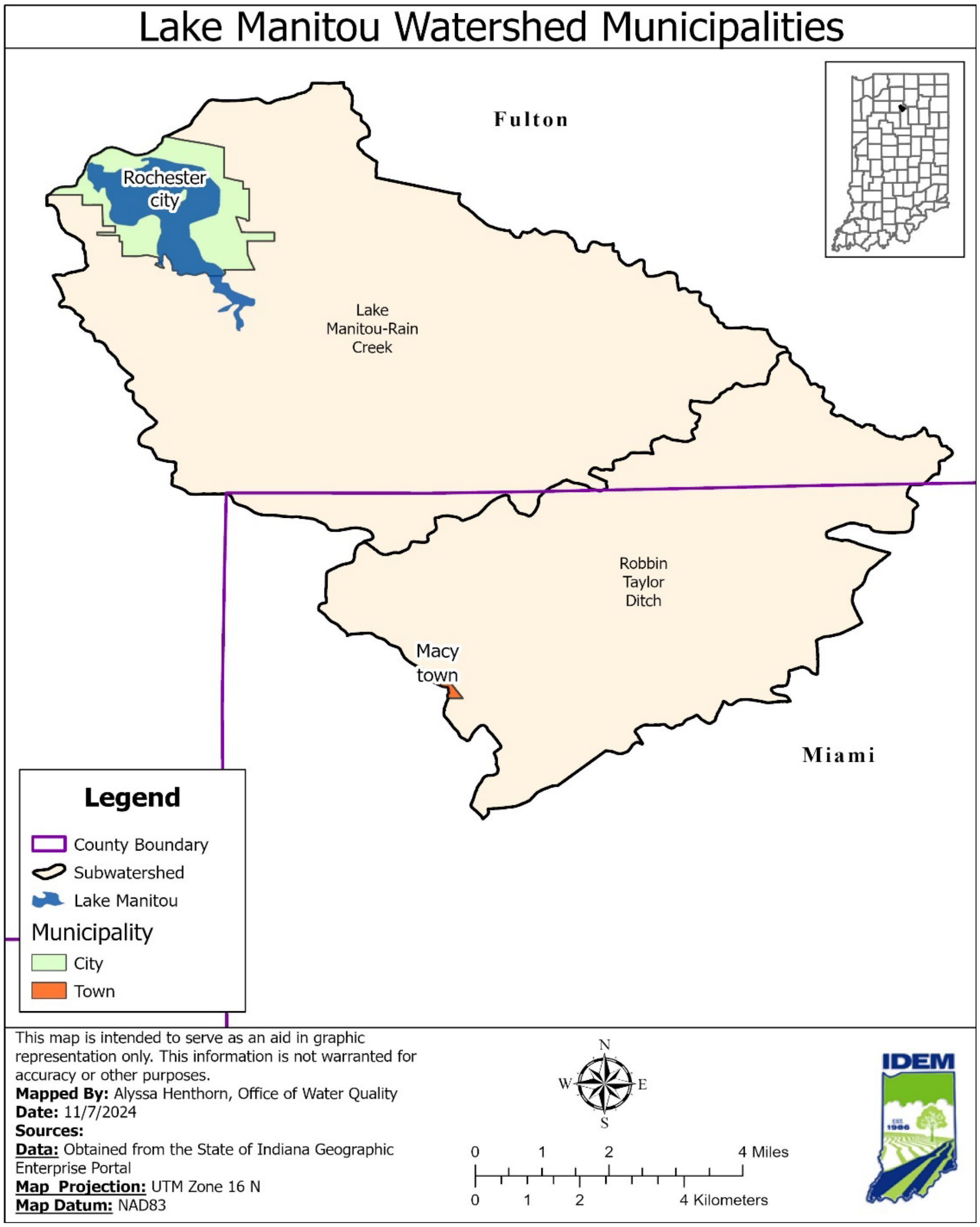

Figure 17: Municipalities in the Lake Manitou Watershed

2.8 Lake Description and Characteristics

The following the description of the watershed, an overview of the Lake Manitou's characteristics and history that contributes to a better identification and understanding of nutrient sources and their loading dynamics to develop insights about potential implementation plans.

Lake Manitou is defined as a man-made lake/reservoir as it was created in 1827 as a by-product of flooding around 5 lakes following the construction of a grist mill and subsequent dam for the Potawatomi Indians by the U.S government. The lake in total is comprised of 775 acres of open water with a maximum depth of 55 ft (17m) and an average depth of 11ft (3m) and is categorized as a shallow lake.

2.8.1 In-Lake Hydrology and Drainage Patterns

Watershed loading of water and subsequent nutrients is described by the previous subsection within this section including land use, topography and geology, soil characteristics, etc. An overview of the water inflows and outflows gives insight into the movement of water through Lake Manitou. The two tributaries, Rain Creek and Robbin Taylor are the main inflow contributions to Lake Manitou. Rain Creek runs 10 miles from the southern tip of the watershed north into the lake, and Robbin Taylor, which runs 3.8 miles west into Rain Creek and into the lake. Minor contributions of inflow include the other tributaries such as Whittenberger/Eiler Ditch, Mastellar Ditch, and Weaver/Kitchen Ditch. Additionally, groundwater offers another potential source of both water and nutrient loading into the lake. Lastly, stormwater runoff from the surrounding land into the lake as well as direct rainfall into the lake contribute to the rest of the inflow of water. Outflow of the lake is situated towards to north-western corner of Lake Manitou across from the inflow locations. The situation of major inflow and outflow points for the lake creates conditions where incoming sediment and nutrients have opportunities to settle and accumulate into the bed of the lake.

2.8.2 Lake Management History

Reclamation Efforts/Dredging History

One of the two major tributaries flowing into Lake Manitou, Rain Creek/Graham Ditch, contains a filtering system designed and implemented in 1995 to control sediment and nutrient runoff. The system comprises of a series of basins, earthen breams, and a small dam to slow down the movement of water and thus allow depositing of sediment and other debris before they enter the lake itself. Over time, the system requires dredging to clear the excess sediment built up allowing the system to function effectively. A challenge with this system is it is located on 3 separate parcels of privately owned property and thus it is not located on state or county owned land that can be easily managed. Additionally, a nearby bridge, White Creek bridge, extends across Rain Creek/Graham Ditch right before the tributary flows into the lake. The bridge provides a means for runoff and sediment to be caught in a filtering system beginning half a mile upstream and enter the lake directly. The system was created in mind that it would need to be dredged every few years, however the accumulated sediment within the filter has the potential to load nutrients including phosphorus into the inflowing water that drains into the lake. The most recent dredging activity for the system was conducted in 2018 by the Lake Manitou Association. Additional information about the Rain Creek/Graham Ditch filtering system can be found in the Lake Manitou Association Webpage (www.lakemanitou.org/conservation).

Dredging Events

Lake Manitou has experienced multiple dredging events that has decreased the amount of bed sediment within the lake that contributes to sources of phosphorus through internal loading. The latest project dredged a total of 20.042 cubic yards between 2017-2021 found in the Lake Manitou Association Webpage (www.lakemanitou.org/events).

In-Lake Vegetation

In 2006 Lake Manitou had an infestation of Hydrilla (*Hydrilla verticillata*), an invasive aquatic plant species. Treatment for the Hydrilla spanned from 2006-2017 where the lake was chemically treated and effectively eradicated by IDEM. Little plant life was left following aggressive management of the invasive species and has initialized the need for monitorization of plant life within the lake.

Aquatic vegetation within the lake has hindered enjoyment and use of designated swimming areas, docks, and other areas where recreational and boat travel occur. Herbicide has been administered to combat this ongoing issue of excess plant growth, attributed to a process known as eutrophication. Per the EPA, "Eutrophication describes the buildup of excess nutrients, such as nitrogen and phosphorus, in a body of water. This buildup can lead to excess plant growth, such as harmful algal blooms (HABs), resulting in deficiency of dissolved oxygen (hypoxia), and in some cases the production of cyanotoxins". These conditions can cause a decrease in aquatic life, disrupt other wildlife and can produce toxins harmful to humans. (EPA. gov/SI/public_record_report).

The information presented in Section 1.0 helps to provide a comprehensive understanding of the conditions and characteristics in the Lake Manitou watershed that, when coupled with the sources presented in Section 2.0, affect both water quality and water quantity. In summary, the predominant land uses in the Lake Manitou watershed of agriculture and forestry serve as indicators as to the type of sources that are likely to contribute to water quality impairments in the Lake Manitou watershed. Human population in the Lake Manitou watershed indicates where more infrastructure-related pressures on water quality might exist. The subsections on topography and geology, as well as soils, provide information on the natural features that affect hydrology in the Lake Manitou watershed. These features interact with land use activities and human population to create pressures on both water quality and quantity in the Lake Manitou watershed. Lastly, the subsection on climate and precipitation provides information on water quantity and the factors that influence flow, which ultimately affects the influence of stormwater on the watershed. Collectively, this information plays an important role in understanding the sources that contribute to water quality impairment during TMDL development and explaining the linkage analysis that connects the observed water quality impairment to pollutants leading to the impairment.

3.0 TECHNICAL APPROACH

Previous sections of the report have provided a description of Lake Manitou, its watershed, and summarize the applicable water quality standards, water quality data, and identified the potential sources of TP for assessment units. This section presents IDEM's technical approach for using water quality sampling data and modeling as described in Section 4.0 to estimate the current aggregated allowable loading of TP. This section focuses on describing the methodology and clarifies subsequent sections of the TMDL report.

3.1 STEPL

The EPA defines the Spreadsheet Tool for Estimating Pollutant Loads (STEPL) as a simple spreadsheet tool that "calculates nutrient and sediment loads from different land uses and the load reductions that would result from the implementation of various best management practices (BMPs)."

Flow and pollutant loading data are crucial for the development and running of the BATHTUB model, yet no USGS flow gauging stations, suitable surrogate flow gauges, or watershed models are available for these purposes. STEPL is thus utilized within this TMDL report to estimate flow and pollutant loadings into Lake Manitou

Additionally, the calculation of phosphorus loading into the lake by land use indicates an inherent link between the pollutant-causing impairment of the waterbody and some potential sources of the pollutant. This creates a foundation upon which the linkage analysis section is built upon. Input data, results, and analysis are further discussed in Section 4.0 with the linkage analysis.

3.1.1 Flow Estimation

Lake Manitou does not have readily available USGS flow gauging stations, suitable surrogate flow gauges from watersheds of nearby and similar characteristics, or a developed watershed model. In this case, STEPL was used to estimate flow.

STEPL has default databases the includes necessary input data regarding precipitation data, default runoff nutrient concentrations for various land use types, default groundwater nutrients concentrations, and default soil erosion parameters.

Data of land use areas, total number of animals by type, number of months per year that manure is applied to croplands, and representative hydrologic soil groups (HSG) were used to complete flow estimation shown in Appendix B.

3.1.2 Pollutant (Nutrient) Loading (Nonpoint sources)

STEPL gives estimates of watershed nonpoint source pollutant loading. The Rain Creek and Robbin Taylor HUC14 subwatersheds were analyzed through STEPL to determine the loading input into the lake. The two subwatersheds were aggregated to determine a singular source of loading input into the lake. STEPL's analysis, which included rainfall, land use, soil hydrologic groups, and other factors, estimated an annual loading of 22,588.2 pounds of phosphorus shown in Table 24.

3.2 BATHTUB Model

"BATHTUB is a steady-state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response" (Walker 2006). The model was developed by the U.S. Army Corps of Engineers (USACE) and provides a means for assessing the potential effects of a variety of management alternatives involving changes in nutrient and/or water input to lakes and reservoirs. The BATHTUB model has been used extensively across the Midwest for lake nutrient loading analysis and lake nutrient TMDLs. The BATHTUB model requires nutrient loading input from the upstream watershed and atmospheric deposition, metric data for the lake, estimates of mixing depth, and in-lake water quality monitoring data, including nonalgal turbidity.

Lakes and reservoirs are represented as a spatially segmented hydraulic network in BATHTUB. The model includes several physical processes such as advective and diffusive transport, and nutrient sedimentation. Each lake segment is represented as a continuous stirred-tank reactor at steady state and the sedimentation of phosphorus as a first-order decay reaction. BATHTUB predicts eutrophication related water quality conditions (parameters such as TP, total nitrogen (TN), chlorophyll-a (Chl-a), transparency, and hypolimnetic oxygen depletion) using empirical relationships derived from assessments of reservoir data.

Although the model is based on theoretical concepts such as mass balance and nutrient limitation of algal growth, it does not simulate explicitly the dynamics of a lake/reservoir in either space or time. Instead, BATHTUB produces spatially and temporally averaged estimates of reservoir water quality conditions. BATHTUB models water quality conditions in a two-stage procedure. First, nutrient concentrations are estimated based on nutrient loads, morphometry, and hydrology. Second, a eutrophication response model is executed to relate pool nutrient concentrations to the water quality measurement standards of Chl-a concentrations and transparency. As a result, the model produces estimates of steady-state, long-term (growing season or annual) water quality conditions in the epilimnion and is not intended to predict or describe short-term, event-related dynamics or to generate vertical profiles of water quality conditions.

Calibrated and verified, models can then be used to evaluate potential responses to selected management decisions. The most significant advantage of BATHTUB is its simplicity, meaning it can provide reasonably realistic results with limited data. The model has simple structures, low resolution, and a limited number of input variables. Initial calibration to data from groups of impoundments results in relatively low data requirements. The simplicity of BATHTUB can also lead to certain limitations. Applications of BATHTUB are limited to steady-state or long-term, nonchanging evaluations of relationships between nutrient loading, transparency, hydrology, and eutrophication responses. Short-term responses to variables other than nutrients, and effects related to structural modifications, such as the constructed Graham Ditch Dam cannot be explicitly evaluated with BATHTUB. However, it can be internally accounted for through calibration alteration as discussed later in this section (Technical Guidance for Applying BATHTUB Model to Indiana Lakes and Reservoirs, p. 6. TetraTech, 2020, Appendix D).

The reasons for using the BATHTUB model to facilitate the TMDL allocation process for Lake Manitou are as follows:

• Lake Manitou is impaired for phosphorus.

• Limited water quality monitoring data are available for Lake Manitou; therefore, a more complex water quality model is unsuitable.

• BATHTUB is a suitable model to predict the cause-and-effect relationship between nutrient loading and lake water quality response.

3.2.1 BATHUB Scheme

The BATHTUB model features several different variations, or schemes of representing a spatially segmented hydraulic network. The number of segments is determined based on the shape and size of the lake, monitoring station locations, and the locations of flow/pollutant loads from tributaries or other sources. Limited amount and variety of monitoring and sampling data leads to a scheme with one segment to be sufficient for modeling. Given this, it is important to note that scheme 1 doesn't consider transport characteristics within the reservoir itself.

Figure 18: BATHTUB Schemes

Lake morphology and hydrologic contributions are considered through segment data. Definitions of segment data requirements for model development can be found in Appendix D.

Physical Characteristic Data Summary

Table 23: Lake Manitou Physical Characteristics

Segment	Segment Length	Segment Surface Area	Segment Mean Depth	Mean Depth of Mixed Layer	Hypolimnetic Thickness
Segment 1 (Spatially Averaged)	2.5 km	3.125 km^2	3.03 m	1.37 m	2.6 m

3.2.2 Determining Averaging Period/Seasonal Variation

The averaging period is a crucial element involved in BATHUB model development. It is defined as the period considered to develop an appropriate TMDL that impacts what tributary inflow data is used as well as the creation of the mass balance calculation within the lake. This inherently means the averaging period is known as the simulation period or time frame that is used for TMDL development and analysis. As such, the units for the averaging period are for a fraction of the calendar year, (averaging period annual= 1, April-September= 0.5, June-August = 0.25). (Appendix D). Determining the averaging period relies on analysis of in-lake water quality data, nutrient mass balance residence time, and external loading of the lake (i.e., what time of the year is external loading the most significant).

Determining the limiting nutrient dictates the biomass (i.e., algal growth) within an ecosystem or a lake. The availability of this nutrient defines the productivity of the lake. Nitrogen and phosphorus are the two limiting nutrients that determine the average condition. A simple calculation of (TN-150)/TP (units of TN and TP are milligrams per cubic meter (mg/m3) or µg/L) is used to determine if Lake Manitou is nitrogen or phosphorus limited (Appendix D). Based on the ranges presented in appendix B, (TN-150)/TP values greater than 15 indicate the lake is phosphorus-limited. From Table 1, for Lake Manitou, TN = 3.06 mg/L (3,060 µg/L) and TP = 0.07 mg/L (70 µg/L). Therefore (TN-150)/TP = 41.6, well above 15, indicating Lake Manitou is phosphorus-limited.

Additionally, stratification of the lake needs to be evaluated to help determine what simulation/averaging period needs to be used. For Lake Manitou, considering its average depth is 3 meters, which indicates it is a shallow lake, [it means] stratification in summer months does not significantly affect the lake's overall water quality conditions (Appendix D).

Because phosphorus is the limiting nutrient for this lake, the turnover ratio for phosphorus during the summer season and annual loading conditions should be evaluated. Steps to calculate the averaging period are shown below.

<u>Steps for Determining Averaging Period:</u>

Step 1: Calculate the nutrient mass in the lake from the mean concentration multiplied by the normal pool volume, converted to kg.

For Lake Manitou, lake volume is 9,477,807 m^3, mean summer TP concentration is 0.07 mg/L, and TP mass is calculated a 0.070 mg/L x 9,477,807 m^3 x 1,000 L/ m^3 /1,000,000 milligrams per kilogram = 663.4 kg.

Step 2: Calculate the external nutrient load, which is equivalent to the tributary load delivered over the averaging period, converter to kg.

Lake Manitou, the annual load is 22,588.2 lbs = 10,245.8 kg.

Step 3: Calculate the mass residence time (mass divided by load). Resulting units are in years.

For Lake Manitou, mass residence time = 663.4 kg/10,245.8 kilograms per year = 0.06 yr.

Step 4: Calculate the length of the averaging period for summer and annual periods. This value entered in years and is equal to the number of days in the period divided by 365 days per year. Assume the summer season is June through August (92 days).

Averaging period for summer simulation = 0.25 yr

Averaging period for annual simulation= 1 yr

Step 5: Calculate the turnover ratio for the annual and summer averaging periods. It equals the length of the averaging period calculated in step 4 divided by the mass residence time calculated in steps 3.

For Lake Manitou, summer turnover ratio = 0.25 yr /0.06 yr = 4.2; annual turnover ratio = 1 yr/0.06 yr = 16.7

3.2.3 Source Loading Methodology

Point sources, internal loading, atmospheric deposition, and evaporation are influences on phosphorus concentrations in Lake Manitou that are accounted for when developing a BATHTUB model for use. However, nonpoint sources were more thoroughly considered and accounted for with the use of STEPL.

The following subsection details the technical approach for the compilation and consideration of source loading information to be used for the BATHTUB model.

Point Source Loading

As mentioned previously, there are no significant point source loadings within the Lake Manitou watershed and therefore were not accounted for in the loading calculations.

Internal Loading

There are multiple mechanisms by which phosphorus can be released back into the water column as internal loading. Low oxygen concentrations (also called "anoxia") in water overlying sediment can lead to phosphorus release. The released phosphorus can mix with surface waters and become available for algal growth. Bottom-feeding fish such as carp and black bullhead forage in lake sediments, which can release phosphorus into the water column. Wind energy in shallow depths can mix the water column and disturb bottom sediments, leading to phosphorus release. Other sources of physical disturbance such as motorized boating in shallow areas can disturb bottom sediments and lead to phosphorus release into the water column from bed sediment (Appendix D).

The commonly used Nürnberg method is described below (Nürnberg 1984). The Nürnberg method (1984) uses mean depth, flushing rate, mean inflow concentration, and mean in-lake concentrations to estimate internal load.

$$TP(inlake)= TP(inflow) * (1-R(pred)) + L(int)/Q(s)$$

$$R(pred)- 15/(18+Q(s))$$

Where:

- TP (inlake)= mean summer in-lake phosphorus concentration (mg/ m^3)
- TP (inflow)= mean summer tributary phosphorus concentration (mg/ m^3)
- Q(s)= lake outflow volume divided by lake surface area (meters per year)
- R(pred)= annual retention due to sedimentation
- L(int)= internal phosphorus load (milligrams per square meters per year)

Lake Manitou, the calculation steps are shown below:

- TP(inlake)= 0.07 mg/L= 70 mg/ m^3
- TP(inflow)= 8,150 lbs/6,141,7 ac-ft= 3,697.1 kilograms (kg)/7,575,675.3 m^3= 488 mg/ m^3
- Q(s)= 7,575,675m^3/3.125k m^2= 2.4 m
- Note: The outflow volume is for summer months (June-August) only.
- R(pred)= 15/(18+Q(s))= 0.74

Therefore, 70 mg/ m^3 = 416.5 mg/ m^3 x (1-0.74) + Lint/ 2.2 m, and Lint < 0. Negative internal loading indicates that the lake is acting as a sink for pollutants, mainly due to the sedimentation process. Therefore, internal loading of phosphorus is set to zero for calculating the Lake Manitou phosphorus TMDL.

Atmospheric Deposition:

For lakes with largely agricultural drainage areas, atmospheric deposition of nutrients is generally considered insignificant relative to watershed loadings, particularly related to phosphorus. When no measurements of atmospheric deposition of nutrients are available, default TP and inorganic phosphorus deposition rates as a mean of 10 mg/m2-yr and a CV of 0.1 can be used. These rates were estimated from Robertson (1996), Rast and Lee (1983), and Reinfelder et al. (2004). Note that direct atmospheric deposition of phosphorus to a lake surface is generally considered insignificant compared to watershed loading rates; where no measurements are available, an atmospheric phosphorus deposition input of 0 mg/m2 -yr might be appropriate for a given lake when significant loadings are expected from the watershed. Therefore, atmospheric deposition of phosphorus is set to zero for calculating the Lake Manitou phosphorus.

Evaporation:

For Lake Manitou, the simulation period is summer (June, July, and August). The lake is in northern Indiana; therefore, the monthly evaporation rates for June, July, and August 2024 from NOAA are approximately 95, 95, and 72 millimeters (mm) per month, respectively. Therefore, the total evaporation for the summer period of June–August is 200 mm (0.262 m).

3.2.4 Model Calibration

Input data is used to run and develop a eutrophication response model. Before final conclusions can be drawn, the model must be calibrated to accurately depict conditions within the lake. Mainly, the Graham Ditch Dam sedimentation removal system in place is not inherently accounted for within the BATHTUB model and thus calibration of the model addressed this issue. Once produced, the model is analyzed to determine the lake's loading capacity for phosphorus as well as the loading reduction needed to meet the designated water quality standards for reservoirs.

Calibration

After initial preparation of the model, the model is run and compared with available water quality data for the lake. The initial model results are below in which it does not simulate the observed conditions for the lake. In this case, calibration is needed for completion of the BATHTUB model as the design for BATHUB does not account for the sediment removed by the Graham Ditch Dam sedimental removal system as well as there is a lack of flow and nutrient loading data for the Lake Manitou Watershed, leading to a less accurate model that needs manipulation. This is achieved through changing the model's coefficients for the total phosphorus calibration factor to 0.6, , and Chlorophyll-a to 0.6.

- **Before Calibration:**

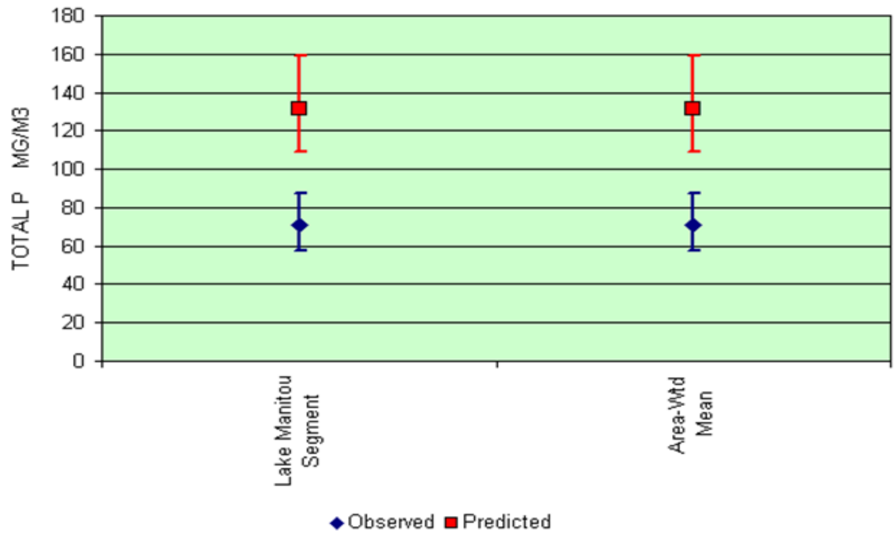

Figure 19: Total Phosphorous pre-calibration

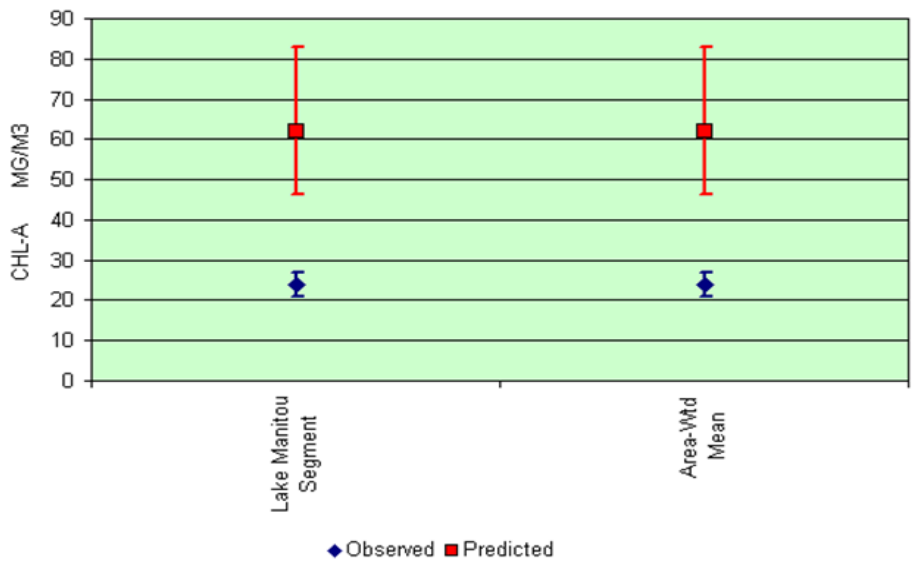

Figure 20: Chl-a pre-calibration

After Calibration:

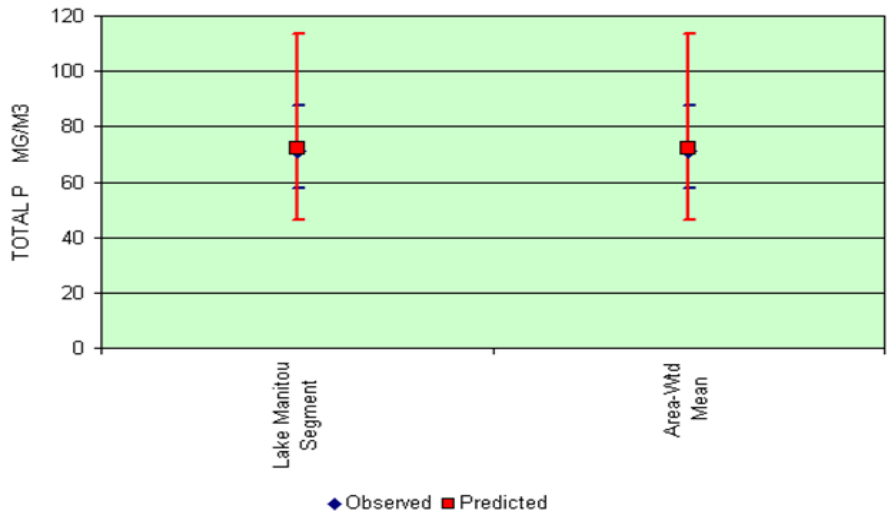

Figure 21: Total Phospherous post-calibration

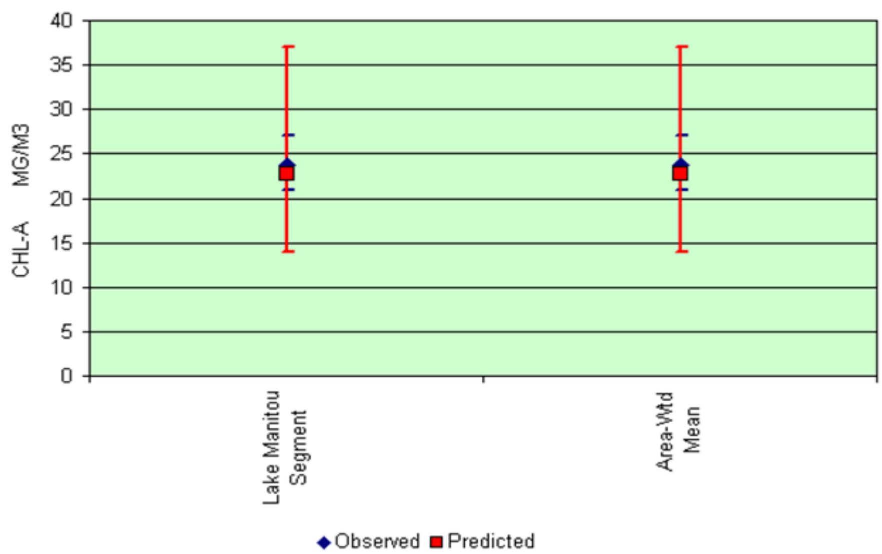

Figure 22: Chl-a post-calibration

3.3 Margin of Safety (MOS)

Section 303(d) of the Clean Water Act and U.S. EPA regulations at 40 CFR 130.7 require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numeric water quality standards with seasonal variations and a MOS which takes into account any lack of knowledge concerning the relationship between limitations and water quality." U.S. EPA guidance explains that the MOS may be implicit (i.e., incorporated into the

TMDL through conservative assumptions in the analysis) or explicit (i.e., expressed in the TMDL as loadings set aside for the MOS). This TMDL uses both implicit and explicit MOS. An implicit MOS was used by applying a couple of conservative assumptions. One assumption includes using the three-month summer averaging period and applying these conditions to calculate the annual phosphorous loading. A moderate explicit MOS has been applied by reserving 10 percent of the allowable load. Ten percent was considered an appropriate MOS based on the following considerations:

- The use of modeling tools like BATHTUB and STEPL minimizes some uncertainty associated with the development of TMDLs because of how the data is set within model. Calibration can help address some uncertainties, however, there is still a margin of unknown that requires the need for MOS.
- These limitations include the models' inability to measure and value the Graham Ditch Dam sediment removal process. The models also do not consider the limited data on flow (estimated using STEPL), seasonal variations, and lack of tributary water quality monitoring data. These details can impact the concluding data for Lake Manitou.
- Modeling efforts were based on limited water quality data (five data points between 2011 and 2020).

Therefore, it is important that an explicit 10 percent MOS, along with an implicit MOS using conservative estimates in modeling inputs, are implemented within the TMDL to help address these uncertainties.

3.4 Future Growth Calculations

Population trends are indicating that this watershed has been decreasing (Table 20) over the past two decades; uncertainty in future populations in the Lake Manitou watershed have led IDEM to choose to allocate 5 percent of the loading capacity toward future growth. IDEM anticipates that land uses will likely be changing in the watershed in the future and, in anticipation of those land use changes, has set aside 5 percent of the loading capacity to address increased loads from those future contributors.

4.0 LINKAGE ANALYSIS

A linkage analysis connects the observed water quality impairment to what has caused that impairment. An essential component of developing a TMDL is establishing a relationship between the source loadings and the resulting water quality. Potential point and nonpoint sources are inventoried in Section 2.0, and water quality data within the Lake Manitou watershed are discussed in Section 1.4. The purpose of this section is to evaluate which of the various potential sources is most likely to be contributing to the observed water quality impairments.

To further investigate sources, water quality precipitation graphs have been created. Elevated levels of pollutants during rain events indicate contributions of pollutants due to run-off. The precipitation data was taken from a weather station in Rockville, IN and managed by the Midwestern Regional Climate Center.

BATHTUB model inherently requires calculation of pollutant loading by source. More information of how this is technically calculated using STEPL is detailed in the previous Section 3.0 as well as Appendix D. The following section serves to investigate these sources further, breaking them down by subwatershed with a concluding analysis of the entire watershed encompassing Lake Manitou.

Each subwatershed and total watershed, analysis includes a summary of the subwatershed, including information regarding sampling sites, land use, and soil characteristics. A summary table of each subwatershed is also provided that includes the load allocations (LAs), wasteload allocations (WLAs), and margin of safety (MOS) values for pollutants of concern. Pollutants of concern for the Lake Manitou identified by sampling data include total phosphorus.

4.1 Pollutant of Concern

4.1.1 Total Phosphorus

Nutrients come in many forms, including nitrogen, phosphorus, ammonia, total Kjeldahl nitrogen (TKN), nitrite, and nitrate. Information presented in the water quality assessment describes nutrient conditions in the Lake Manitou watershed. Additional information is outlined in Section 1.1.1.

Total phosphorus concentrations are naturally low in surface waters but high in rivers and streams located in agricultural and urban areas, or that receive wastewater discharges. High phosphorus levels in streams increase the growth of plants and algae, reducing the quality of the habitat and causing low oxygen levels at night when the plants and algae are respiring but not photosynthesizing.

There are no permitted dischargers for phosphorus within the watershed. Nonpoint sources might include sediment-bound phosphorus that enters the river during erosional processes, as well as the run-off of storms over fertilized fields and residential areas. Septic systems might also be a potential source of phosphorus if the systems are failing and located adjacent to the streams.

4.2 Linkage Analysis by Subwatershed

To further investigate which nonpoint sources are contributing to the observed phosphorus impairment, inherent estimations of nonpoint source loadings provided by the STEPL model were utilized. Table 24 lists Lake Manitou's land-use categories and their relative loads, all calculated by STEPL. Cropland is shown to be the biggest contributor of relative phosphorous load. This is useful information for watershed or lake groups interested in implementing BMPs to reduce TP loading as it can inform the types and locations to implement BMPs.

Table 24: Total Load by Land Uses

Sources	N Load	P Load	BOD Load	Sediment Load
	(lb/yr)	(lb/yr)	(lb/yr)	(t/yr)
Urban	5,407.6	722.0	18,399.5	125.1
Cropland	78,104.7	16,231.6	164,457.7	5,755.3
Pastureland	17,986.8	1,564.7	57,587.2	217.4
Forest	791.5	389.0	1,949.5	18.3
Feedlots	10,138.2	2,027.6	13,517.6	-
Septic	156.7	61.4	639.8	-
Groundwater	36,096.9	1,591.8	-	-
Total	**148,682.3**	**22,588.2**	**256,551.3**	**6,116.1**

4.2.1 Robbin Taylor Subwatershed

The Robbin Taylor subwatershed drains approximately 18 square miles. The subwatershed drains north into the Rain Creek subwatershed. The land use is primarily agriculture (65 percent) followed by forested land (14 percent) and hay and developed land (19 percent). The majority of the subwatershed is rural, indicating homes pump to on-site septic systems. Based on the septic suitability of the soil, this entire subwatershed is very limited. Maintenance and inspections of septic systems in the area are important to ensure proper function and capacity. The landscape in the area is relatively flat leading to its intense conversion to agricultural production and use. In many areas of the subwatershed there are little to no remaining riparian buffers left along its banks due to agricultural practices. Despite its flat nature, the subwatershed does contain significant amounts of highly erodible soil types. These soil types can be susceptible to sheet, rill, and isolated gully erosion and can contribute to sediment loss from agricultural lands, as well as lands from high gradient slopes.

Many of the waterways in this subwatershed are identified as having hydric soil types in their riparian zones. These areas could be potential locations for wetland restoration or high functioning two-stage ditch implementation. With around 13 percent of land used as pastureland a heavy presence of pasture animals is not expected.

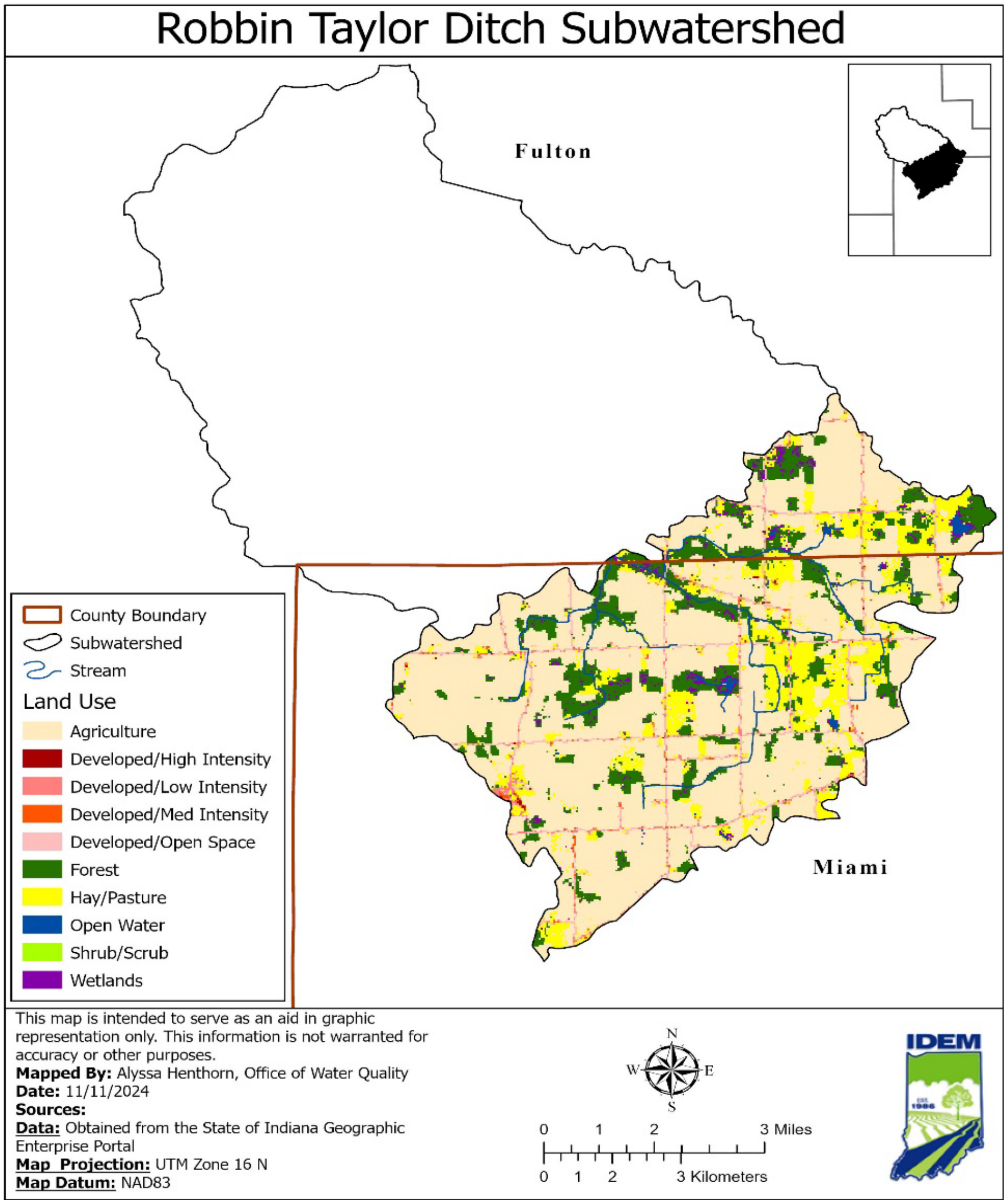

Figure 23: Robbin Taylor Subwatershed with Land Use

4.2.2 Rain Creek Subwatershed

The Rain Creek subwatershed drains approximately 44 square miles with an actual land area of approximately 26 square miles. Water drains into Lake Manitou and continues flowing north into Mill Creek. The land use is primarily agriculture land (57 percent), followed by Forest (14 percent) and hay and pastureland (10 percent). There are no NPDES permitted dischargers in the subwatershed. The majority of the subwatershed is rural, indicating homes pump to on-site septic systems. Based on the septic suitability of the soil, this entire subwatershed is very limited. Maintenance and inspections of septic systems in the area are important to ensure proper function and capacity. The landscape in the area is relatively flat with some low elevation near Lake Manitou leading to its intense conversion to agricultural production and use. In many areas of the subwatershed there are little to no remaining riparian buffers along the stream banks due to agricultural practices. The subwatershed does not contain significant amounts of highly erodible soil types and has hydric properties indicating moderate infiltration rate allowing the water to drain through the soil with minimal erosion.

Many of the waterways in this subwatershed are identified as having hydric soil types in their riparian zones. These areas could be potential locations for wetland restoration or high functioning two-stage ditch implementation. With pastureland use at 10 percent pastureland, a heavy presence of pasture animals is not expected.

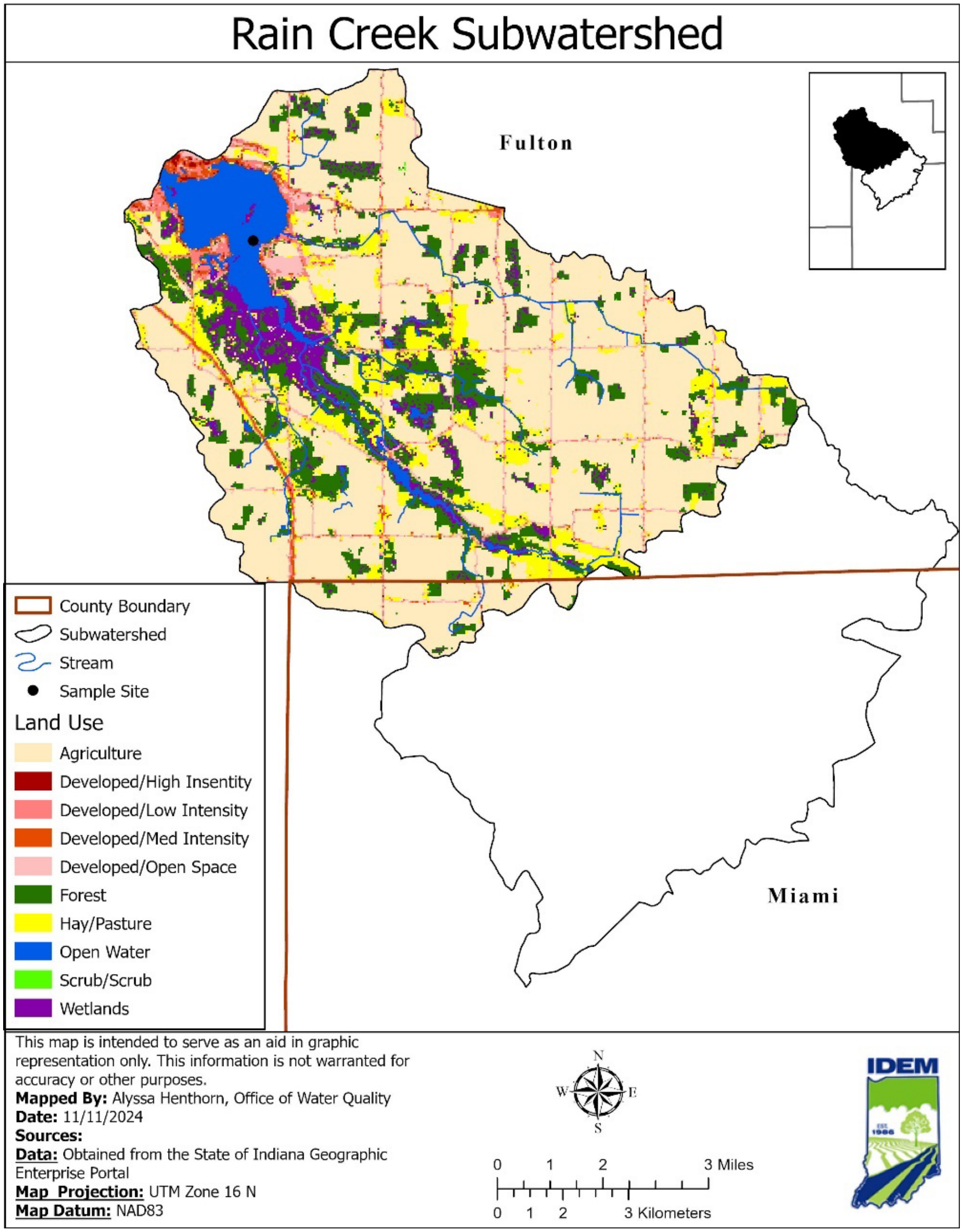

Figure 24: Rain Creek Subwatershed with Land Use

4.2.3 Watershed Linkage Analysis

The linkage analysis connects the water quality impairment to what pollutant has caused the impairment within a watershed. IDEM considers the inflow of Robbin Taylor subwatershed as a potential contributor of phosphorus to Lake Manitou and subsequent potential impacts into the lake. However, TMDL development will be directed towards the Lake Manitou impairment only for this report. These subsections will summarize the results of STEPL and BATHTUB modeling to finalize conclusions on the impairment and the pollutant causes within Lake Manitou.

Table 25: Lake Manitou Water Quality Sampling Data

	Sampling Date								
Parameter	**8/16/2011**	**8/6/2013**	**7/7/2014**	**8/10/2015**	**7/16/2020**	**Mean**	**SD**	**SE**	**CV**
Ammonia-Epi (mg/L)	0.02	0.03	1.74	0.02	< 0.01	0.36	0.77	0.34	0.95
Nitrite plus Nitrate–Epi (mg/L)	0.01	0.04		0.32	< 0.01	0.09	0.15	0.08	0.81
TKN–Epi (TN-Nitrite plus Nitrate) (mg/L)	1.11	1.27	0.91	1.43	1.79	1.30	0.33	0.15	0.11
Organic N (TKN-NH3)–Epi (mg/L)	1.09	1.24		1.41	1.78	1.38	0.30	0.15	0.11
TN–Epi (mg/L)	1.12	1.31		1.75	1.80	1.49	0.33	0.17	0.11
Ortho-Phosphorus–Epi (mg/L)	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.06
TP–Epi (mg/L)	0.03	0.05	0.04		0.03	0.04	0.01	0.00	0.13
TP minus OP–Epi (mg/L)	0.02	0.04	0.03		0.02	0.03	0.01	0.00	0.16
Ammonia–Avg of Epi and Hypo (mg/L)	2.44	1.19	2.33	1.34	0.55	1.57	0.80	0.36	0.23
Nitrite plus Nitrate–Avg of Epi and Hypo (mg/L)	0.01	0.03		0.17	< 0.01	0.05	0.08	0.04	0.72
TKN–Avg of Epi and Hypo (mg/L)	3.84	2.61	2.42	2.52	1.29	2.54	0.90	0.40	0.16
Organic N (TKN-NH3)–Avg of Epi and Hypo (mg/L)	1.39	1.41	0.09	1.18	0.74	0.96	0.56	0.25	0.26
TN–Avg of Epi and Hypo (mg/L)	3.85	2.63		2.69	1.30	2.62	1.04	0.52	0.20
Ortho-Phosphorus–Avg of Epi and Hypo (mg/L)	0.02	0.01	0.08	0.21*	0.06	0.04	0.03	0.02	0.39
TP–Avg of Epi and Hypo (mg/L)	0.04	0.06	0.11		0.07	0.07	0.03	0.01	0.21
TP minus OP–Avg of Epi and Hypo (mg/L)	0.02	0.04	0.03		0.01	0.03	0.01	0.01	0.24
Chl-a (µg/L)	15.89	31.69	19.09	22.27	29.69	23.73	6.78	3.03	0.13
Total Suspended Solids (mg/L)				6.9		6.90			
Secchi Depth (m)	0.9	0.5	1	0.4	0.80	0.72	0.26	0.15	0.21
Non-algal Turbidity	0.71	1.21	0.52	1.94	0.51	0.98	0.61	0.35	0.36

Avg=average, Epi=epilimnion, Hypo=hypolimnion, mg/L=milligrams per liter, ug/L=micrograms per liter
“” indicates an outlier and was not accounted for in the calculation of mean, and standard deviation.*
“< ” indicates the results were below the equipment’s detection limit.
SD=Standard Deviation, SE=Standard Error, CV=Coefficient of Variation (Mean/SE)

4.2.4 Input Data

In-lake monitoring data was used to estimate the internal nutrient source loading. Water quality data for Lake Manitou was sampled on four dates between August 16, 2011, and July 16, 2020, through Clean Lakes Program monitoring. Modeling results and data describe the linkage of total phosphorus to the overall impairment in Lake Manitou.

4.2.5 Lake Manitou Physical Characteristics

The key physical characteristics related to the Lake Manitou waterbody:

- Total volume = 9,477,807 m^3
- Surface area = 3.125 km^2
- Length = 2.5 km
- Mean depth estimated as a function of volume divided by surface area is 9,477,807 m^3 / 3,125,000 m^2 = 3.03 m
- Mean depth of mixed layer estimated as a function of mixed layer volume divided by surface area is 4,276,600 m^3 / 3,125,000 m^2 = 1.37 m.
- Mean hypolimnetic depth estimated as function of hypolimnetic layer volume divided by hypolimnetic surface area is 5,201,207 m^3 / 2,000,000 m^2 = 2.6 m.

4.2.6 Lake Manitou Flow and Pollutant Loadings

Below are the key flow and pollutant loadings to the Lake Manitou waterbody:

- From tributaries (watershed loading):
  - Annual inflow volume is 17,020.8 ac-ft (20,994,816.4 m^3), calculated via STEPL.
  - Summer (June–August) inflow volume is 6,141,7 ac-ft (7,575,675.3 m^3), calculated using the annual inflow volume multiplied by the summer percentage of annual rainfall (36 percent)
- Total annual phosphorus loading is 22,588.2 lbs (10245.8 kg)
- Summer (June–August) loading is 8,150.6 lbs (3,697.1 kg).
  - No significant point sources.
- Total annual precipitation is 38.3 inches (0.97 m); total precipitation for June–August is 13.8 inches (0.35 m).
- Total evaporation rate for the summer period of June–August is 2000 mm (0.2 m).

- The recommended average period is 0.25 years, meaning summer months from June to August

4.2.7 Lake Manitou Linkage Analysis Conclusion

The concluding data indicates that high TP levels within Lake Manitou was not specifically caused by turbidity issues. However, the data does indicate that Lake Manitou has high nutrient loading and high eutrophication potential with limited light causing algal growth. The water quality data analysis for Lake Manitou conclusion that the lake is phosphorus limited due to the increase of algal activity (Appendix A). Therefore, a TMDL was developed to address nutrients impairments associated with total phosphorus. It is necessary to reduce the TP loads by 40 percent to meet water quality standards for reservoirs. Implementation to meet reductions should focus on best management practices (BMPs) that have an impact on runoff during critical conditions.

5.0 ALLOCATIONS

A TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards. TMDLs are composed of the sum of individual WLAs for regulated sources and LAs for sources not directly regulated by a permit. In addition, the TMDL must include a MOS, either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this is defined by the equation:

$$TMDL = \sum WLAs + \sum LAs + MOS$$

Table 26: Total Phosphorous TMDL for Lake Manitou

Unit	TP Load (Current Conditions)	TMDL (TP Load-Target Conditions)	Wasteload Allocation	Load Allocation	Margin of Safety (10%)	Future Growth (5%)	Percent Reduction
lbs/day	61.9	37.1	0	31.6	3.7	1.9	40
lbs/year	22,588.2	13,552.9	0	11,520.0	1,355.3	677.6	

Note: Atmospheric and internal lake loading rates were both allocated at 0 lbs/day.

Reduction scenarios were run in BATHTUB to identify the target inflow concentration reduction needed to meet TP and Chl-a target values (see Table 6 discussion for a more in-depth explanation). Once the reduction simulation outputs met the target TP and Chl-a values, the resulting percent reduction of 40% was applied to the current annual TP load to calculate the target annual (lbs/yr) conditions. The target annual conditions were then divided by 365 to calculate the TMDL.

Refer to page viii for suspected sources of Lake Manitou’s nonpoint-source loading.

5.1 Critical Conditions and Seasonality

TP concentrations in lakes typically vary significantly during the growing season, generally peaking in August. Water quality scenarios using the BATHTUB model were calculated under this assumption, using peripheral data from June, July, and August. Because the growing and recreational seasons occur within these months, this period was identified as the critical conditions for Lake Manitou. The results from these calculations resulted in the worst-case scenario, or critical condition. Implementing the suggested BMPs to meet the reservoir water quality targets should result in Lake Manitou meeting the applicable water quality standards for recreational use and aesthetics. Additionally, the critical conditions were used to determine the annual loading limit for the calculated TMDL.

6.0 REASONABLE ASSURANCES/IMPLEMENTATION

This section of the Lake Manitou watershed TMDL focuses on implementation activities that have the potential to achieve the WLAs and LAs presented in previous sections. The focus of this section is to identify and select the most appropriate structural and non-structural best management practices (BMPs) and control technologies to reduce total phosphorus loads from sources throughout the Lake Manitou watershed, particularly in the critical conditions identified in Section5. This section also addresses the programs that are available to facilitate implementation of structural and non-structural BMPs to achieve the allocations, as well as current ongoing activities in the Lake Manitou watershed at the local level that will play a key role in successful TMDL implementation. Groups like the Lake Manitou Association may not have a current plan in place, but these best management practices are designed to help address nutrient loadings into Lake Manitou. The Lake Manitou Association maintains a list of projects that have occurred in or around their lake on their webpage (www.lakemanitou.org/projects).

To select appropriate BMPs and control technologies, it is important to review the relevant sources in the Lake Manitou watershed.

Nonpoint Sources

- Cropland
- Pastures and livestock operations
- Streambank erosion
- Onsite wastewater treatment systems
- Wildlife
- Urban nonpoint source run-off

6.1 Implementation Activity Options for Sources in the Lake Manitou Watershed

Keeping the list of significant sources in the Lake Manitou watershed in mind, it is possible to review the types of BMPs that are most appropriate for the pollutants and the source type. Table 28 provides a list of implementation activities that are potentially suitable for the Lake Manitou watershed based on the pollutants and the types of sources. The implementation activities are a combination of structural and non-structural BMPs to achieve the assigned WLAs and LAs. IDEM recognizes that actions taken in any individual subwatershed may depend on several factors (including socioeconomic, political, and ecological factors). The recommendations in Table 27 are not intended to be prescriptive. Any number or combination of implementation activities might contribute to water quality improvement, whether applied at sites where the actual impairment was noted or other locations where sources contribute indirectly to the water quality impairment.

Table 27: List of Potentially Suitable BMPs for the Lake Manitou Watershed

Implementation Activities	Pollutant			Nonpoint Sources					
	Bacteria	Nutrients	Sediment	Cropland	Pastures and Livestock Operations	Streambank Erosion	Onsite Wastewater Treatment Systems	Wildlife/Domestic Pets	Urban NPS Run-off
Inspection and maintenance	X	X	X				X		
Outreach and education and training	X	X	X	X	X	X	X	X	
System replacement	X	X					X		
Conservation tillage/residue management	X	X	X	X					
Cover crops	X	X	X	X		X			
Filter strips	X	X	X	X	X	X			
Grassed waterways	X		X	X		X			
Riparian forested/herbaceous buffers	X	X	X	X	X	X		X	
Manure handling, storage, treatment, and disposal	X	X							
Alternative watering systems	X		X		X	X			
Stream fencing (animal exclusion)	X	X	X		X	X			
Prescribed grazing	X	X	X		X	X			
Conservation easements	X	X	X						X
Two-stage ditches		X	X						X
Rain barrel		X	X						X

Implementation Activities	Pollutant			Nonpoint Sources					
	Bacteria	Nutrients	Sediment	Cropland	Pastures and Livestock Operations	Streambank Erosion	Onsite Wastewater Treatment Systems	Wildlife/Domestic Pets	Urban NPS Run-off
Rain garden		X	X						X
Porous pavement		X	X						X
Stormwater planning and management	X	X	X			X	X	X	
Comprehensive Nutrient Management Plan	X	X		X					
Constructed Wetland	X	X	X	X				X	
Critical Area Planting			X		X	X			
Drainage Water Management		X		X					
Nutrient Management Plan		X		X		X			
Land Reconstruction of Mined Land			X			X			
Sediment Basin		X	X						
Pasture and Hay Planting	X	X	X	X	X	X		X	
Streambank and Shoreline Protection			X	X	X	X		X	
Conservation Crop Rotation		X	X	X	X				
Field Border	X	X		X	X			X	
Conservation Crop Rotation	X	X	X	X		X			

The information provided in Section 5.2 assisted in the development of Table 28, which provides a more refined suite of recommended implementation activities targeted to the critical flow condition identified in Section 5.2. Watershed stakeholders can use the implementation activities identified in Table 27 and select activities that are most feasible in the Lake Manitou watershed. This table can also help watershed stakeholders to identify implementation activities for critical areas that they select through the watershed management planning process.

6.2 Implementation Goals and Indicators

For each pollutant in the Lake Manitou watershed, IDEM has identified broad goal statements and indicators. This information is to help watershed stakeholders determine how to track implementation progress over time and provide the information necessary to complete a watershed management plan.

Total Phosphorus Goal Statement: Lake Manitou should meet the 51 ug/L in lake average concentration for total phosphorus target value.

Chlorophyll-a Goal Statement: Lake Manitou should meet the 2-25 ug/L in lake average concentration for Chl-a target value.

Total Phosphorus Indicator: Water quality monitoring will serve as the environmental indicator to determine progress toward the total phosphorus target value.

Total Load: To meet the above goals, total phosphorus loading should be reduced to 37.1 lbs/day.

6.3 Summary of Programs

There are several federal, state, and local programs that either require or can assist with the implementation activities recommended for the Lake Manitou watershed. A description of these programs is provided in this section. The following section discusses how some of these programs relate to the various sources in the Lake Manitou watershed.

6.3.1 Federal Programs

Clean Water Act Section 319(h) Grants

Section 319 of the federal Clean Water Act contains provisions for the control of nonpoint source pollution. The Section 319 program provides for various voluntary projects throughout the state to prevent water pollution and provides for assessment and management plans related to waterbodies in Indiana impacted by NPS pollution. The Watershed Planning and Restoration Section within the Watershed Assessment and Planning Branch of the IDEM Office of Water Quality administers the Section 319 program for the NPS-related projects.

U.S. EPA offers Clean Water Act Section 319(h) grant monies to the state on an annual basis. These grants must be used to fund projects that address nonpoint source pollution issues. Some projects which the Office of Water Quality has funded with this money in the past include developing and implementing Watershed Management Plans (WMPs), BMP demonstrations, data management, educational programs, modeling, stream restoration, and riparian buffer establishment. Projects are usually two to three years in length. Section 319(h) grants are intended to be used for project start-up, not as a continuous funding source. Units of government, nonprofit groups, and universities in the state that have expertise in nonpoint source pollution problems are invited to submit Section 319(h) proposals to the Office of Water Quality.

Clean Water Action Section 205(j) Grants

Section 205(j) provides for planning activities relating to the improvement of water quality from nonpoint and point sources by making funding available to municipal and county governments, regional planning commissions, and other public organizations. The CWA states that the grants are to be used for water quality management and planning, including, but not limited to:

- Identifying the most cost effective and locally acceptable facility and nonpoint source measures to meet and maintain water quality standards;
- Developing an implementation plan to obtain state and local financial and regulatory commitments to implement measures developed under those plans;
- Determining the nature, extent, and cause of water quality problems in various areas of the state.

The Section 205(j) program provides projects that gather and map information on nonpoint and point source water pollution, develop recommendations for increasing the involvement of environmental and civic organizations in watershed planning and implementation activities, and develop watershed management plans.

HUD Community Development Block Grant Program (CDBG)

The Community Development Block Grant Program (CDBG) is authorized under Title I of the Housing and Community Development (HCD) Act of 1974, as amended. The main objective of the CDBG program is to develop viable communities by providing decent housing and suitable living environments and expanding economic opportunities principally for people of low- and moderate-income. The U.S. Department of Housing and Urban Development (HUD) provides federal CDBG funds directly to Indiana annually, through the Office of Community and Rural Affairs (OCRA), which then provides funding to small, incorporated cities and towns with populations less than 50,000 and to non-urban counties.

CDBG regulations define eligible activities and the National Objectives that each activity must meet. OCRA is responsible for ensuring projects that receive funding in Indiana are in accordance with the National Objectives and eligible activities.

OCRA is required to develop a Consolidated Plan that describes needs, resources, priorities, and proposed activities to be undertaken. Indiana’s Consolidated Plan includes four goals for prioritizing fund allocations. These goals include expanding and preserving affordable housing opportunities throughout the housing continuum, reducing homelessness and increasing housing stability for special needs populations, promoting livable communities and community revitalization through addressing unmet community development needs, and promoting activities that enhance local economic development efforts. OCRA has funded a variety of projects, including sanitary sewer and water systems.

USDA Conservation Stewardship Program (CSP)

The Conservation Stewardship Program (CSP) helps landowners build on their existing conservation efforts while strengthening their operation. Whether they are looking to improve grazing conditions, increase crop yields, or develop wildlife habitat, NRCS can custom design a CSP plan to help them meet those goals. NRCS can help landowners schedule timely planting of cover crops, develop a grazing plan that will improve the forage base, implement no-till to reduce erosion or manage forested areas in a way that benefits wildlife habitat. If landowners are already taking steps to improve the condition of the land, chances are CSP can help them find new ways to meet their goals.

USDA Conservation Reserve Program (CRP)

NRCS provides technical assistance to landowners interested in participating in the Conservation Reserve Program (CRP) administered by the USDA Farm Service Agency. The Conservation Reserve Program reduces soil erosion, protects the nation's ability to produce food and fiber, reduces sedimentation in streams and lakes, improves water quality, establishes wildlife habitat, and enhances forest and wetland resources. It encourages farmers to convert highly erodible cropland or other environmentally sensitive acreage to vegetative cover, such as tame or native grasses, wildlife plantings, trees, filter strips, or riparian buffers. Farmers receive an annual rental payment for the term of the multi-year contract. Cost-share funding is provided to establish the vegetative cover practices.

USDA Conservation Reserve Enhancement Program (CREP)

NRCS provides technical assistance to landowners interested in participating in the Conservation Reserve Program administered by the USDA Farm Service Agency. The Conservation Reserve Enhancement Program (CREP), an offshoot of CRP, targets high-priority conservation concerns identified by a state and federal funds are supplemented with non-federal funds to address those concerns. In exchange for removing environmentally sensitive land from production and establishing permanent resource conserving plant species, farmers and ranchers are paid an annual rental rate along with other federal and state incentives as applicable per each CREP agreement. Participation is voluntary, and the contract period is typically 10–15 years.

USDA Environmental Quality Incentives Program (EQIP)

The Environmental Quality Incentives Program provides technical, educational, and financial assistance to eligible farmers and ranchers to address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. The program aids farmers and ranchers in complying with federal, state, and tribal environmental laws, and encourages environmental enhancement. The program is funded through the Commodity Credit Corporation. The purposes of the program are achieved through the implementation of a conservation plan, which includes structural, vegetative, and land management practices on eligible land. Five-to-ten-year contracts are made with eligible producers. Cost-share payments may be made to implement one or more eligible structural or vegetative practices, such as animal waste management facilities, terraces, filter strips, tree planting, and permanent wildlife habitat. Incentive payments can be made to implement one or more land management practices, such as nutrient management, pest management, and grazing land management. Fifty percent of the funding available for the program is targeted at natural resource concerns relating to livestock production. The program is carried out primarily in priority areas that may be watersheds, regions, or multi-state areas, and for significant statewide natural resource concerns that are outside of geographic priority areas.

USDA Farmable Wetlands Program (FWP)

NRCS provides technical assistance to landowners interested in participating in the Conservation Reserve Program administered by the USDA Farm Service Agency. The Farmable Wetlands Program (FWP) is designed to restore previously farmed wetlands and wetland buffer to improve both vegetation and water flow. FWP is a voluntary program to restore up to one million acres of farmable wetlands and associated buffers. Participants must agree to restore the wetlands, establish plant cover, and to not use enrolled land for commercial purposes. Plant cover may include plants that are partially submerged or specific types of trees. By restoring farmable wetlands, FWP improves groundwater quality, helps trap and break down pollutants, prevents soil erosion, reduces downstream flood damage, and provides habitat for water birds and other wildlife. Wetlands can also be used to treat sewage and are found to be as effective as "high tech" methods. The Farm Service Agency runs the program through the Conservation Reserve Program (CRP) with assistance from other government agencies and local conservation groups.

USDA Conservation Technical Assistance (CTA)

The purpose of the CTA program is to assist land users, communities, units of state and local government, and other Federal agencies in planning and implementing conservation systems. The purpose of the conservation systems is to reduce erosion, improve soil and water quality, improve and conserve wetlands, enhance fish and wildlife habitat, improve air quality, improve pasture and range condition, reduce upstream flooding, and improve woodlands.

One objective of the program is to assist individual land users, communities, conservation districts, and other units of state and local government and federal agencies to meet their goals for resource stewardship and assist individuals in complying with state and local requirements. NRCS assistance to individuals is provided through conservation districts in accordance with the Memorandum of Understanding signed by the Secretary of Agriculture, the Governor of the State, and the conservation district. Assistance is provided to land users voluntarily applying conservation practices and to those who must comply with local or state laws and regulations.

Another objective is to provide assistance to agricultural producers to comply with the highly erodible land (HEL) and wetland (Swampbuster) provisions of the 1985 Food Security Act, as amended by the Food, Agriculture, Conservation and Trade Act of 1990 (16 U.S.C. 3801 et. seq.), the Federal Agriculture Improvement and Reform Act of 1996, and wetlands requirements of Section 404 of the Clean Water Act. NRCS makes HEL and wetland determinations and helps land users develop and implement conservation plans to comply with the law. The program also provides technical assistance to participants in USDA cost-share and conservation incentive programs.

NRCS collects, analyzes, interprets, displays, and disseminates information about the condition and trends of the Nation's soil and other natural resources so that people can make good decisions about resource use and about public policies for resource conservation. They also develop effective science-based technologies for natural resource assessment, management, and conservation.

USDA Section 504 Home Repair Program

USDA Rural Development administers the Section 504 Home Repair Program, or Single-Family Housing Repair Loans and Grants. The Section 504 Home Repair Program provides loans to very low-income homeowners to repair, improve, or modernize their home and provides grants to elderly very low-income homeowners to remove health and safety hazards. The purpose of this program is to help families stay in their own home and keep their home in good repair. Applicants must live in a rural area below 50 percent of the area median income. Grant applicants must be age 62 or older and unable to repay a repair loan. Loans may be used to repair, improve, or modernize homes or to remove health and safety hazards. Grants must be used to remove health and safety hazards. For example, repairing a failed septic system may be an applicable health and safety hazard. The maximum loan amount is $20,000, and the maximum grant amount is $7,500.

USDA Watershed Surveys and Planning

The Watershed and Flood Prevention Act, P.L. 83-566, August 4, 1954, (16 U.S.C. 1001-1008) authorized this program. Prior to fiscal year 1996, small watershed planning activities and the cooperative river basin surveys and investigations authorized by Section 6 of the Act were operated as separate programs. The 1996 appropriations act combined the activities into a single program entitled the Watershed Surveys and Planning program. Activities under both programs are continuing under this authority.

The purpose of the program is to assist federal, state, and local agencies and tribal governments to protect watersheds from damage caused by erosion, floodwater, and sediment and to conserve and develop water and land resources. Resource concerns addressed by the program include water quality, opportunities for water conservation, wetland and water storage capacity, agricultural drought problems, rural development, municipal and industrial water needs, upstream flood damage, and water needs for fish, wildlife, and forest-based industries.

Types of surveys and plans include watershed plans, river basin surveys and studies, flood hazard analyses, and flood-plain management assistance. The focus of these plans is to identify solutions that use land treatment and non-structural measures to solve resource problems.

USDA Agricultural Conservation Easement Program (ACEP)

The Agricultural Conservation Easement Program (ACEP) provides financial and technical assistance to help conserve agricultural lands and wetlands and their related benefits. Under the Agricultural Land Easements component, NRCS helps American Indian tribes, state and local governments and nongovernmental organizations protect working agricultural lands and limit non-agricultural uses of the land. Under the Wetlands Reserve Easements component, NRCS helps to restore, protect, and enhance enrolled wetlands.

Agricultural Land Easements protect the long-term viability of the nation's food supply by preventing the conversion of productive working lands to non-agricultural uses. Land protected by agricultural land easements provides additional public benefits, including environmental quality, historic preservation, wildlife habitat, and protection of open space.

Wetland Reserve Easements provide habitat for fish and wildlife, including threatened and endangered species, improve water quality by filtering sediments and chemicals, reduce flooding, recharge groundwater, protect biological diversity, and provide opportunities for educational, scientific, and limited recreational activities.

NRCS provides financial assistance to eligible partners for purchasing Agricultural Land Easements that protect the agricultural use and conservation values of eligible land. In the case of working farms, the program helps farmers and ranchers keep their land in agriculture. The program also protects grazing uses and related conservation values by conserving grassland, including rangeland, pastureland and shrubland. Eligible partners include American Indian tribes, state and local governments and non-governmental organizations that have farmland, rangeland, or grassland protection programs.

Under the Agricultural Land component, NRCS may contribute up to 50 percent of the fair market value of the agricultural land easement. Where NRCS determines that grasslands of special environmental significance will be protected, NRCS may contribute up to 75 percent of the fair market value of the agricultural land easement.

USDA Regional Conservation Partnership Program (RCPP)

The Regional Conservation Partnership Program (RCPP) encourages partners to join in efforts with producers to increase the restoration and sustainable use of soil, water, wildlife, and related natural resources on regional or watershed scales. Through the program, NRCS and its partners help producers install and maintain conservation activities in selected project areas. Partners leverage RCPP funding in project areas and report on the benefits achieved.

USDA Healthy Forests Reserve Program (HFRP)

The Healthy Forests Reserve Program (HFRP) helps landowners restore, enhance, and protect forestland resources on private lands through easements and financial assistance. HRFP aids the recovery of endangered and threatened species under the Endangered Species Act, improves plant and animal biodiversity, and enhances carbon sequestration.

HFRP provides landowners with 10-year restoration agreements and 30-year or permanent easements for specific conservation actions. For acreage owned by an Indian tribe, there is an additional enrollment option of a 30-year contract. Some landowners may avoid regulatory restrictions under the Endangered Species Act by restoring or improving their habitat on their land for a specified period of time.

USDA Voluntary Public Access and Habitat Incentive Program (VPA-HIP)

The Voluntary Public Access and Habitat Incentive Program (VPA-HIP) is a competitive grants program that helps state and tribal governments increase public access to private lands for wildlife-dependent recreation, such as hunting, fishing, nature watching, or hiking.

State and tribal governments may submit proposals for VPA-HIP block grants from NRCS. These governments provide funds to participating private landowners to initiate new or expand existing public access programs that enhance public access to areas previously unavailable for wildlife-dependent recreation. Nothing in VPA-HIP preempts liability laws that may apply to activities on any property related to grants made in this program.

U.S. Army Corps of Engineers

Section 404 of the Clean Water Act establishes a program to regulate the discharge of dredged or fill material into Waters of the United States, including wetlands. Dredge and fill activities are controlled by a permit process administered by the U.S. Army Corps of Engineers and overseen by the U.S. Environmental Protection Agency. In addition, when a project is planned in Indiana that will impact a wetland, stream, river, lake, or other Water of the U.S., the Indiana Department of Environmental Management (IDEM) must also issue a Section 401 Water Quality Certification. Section 401 WQC is a required component of a federal permit and must be issued before a federal permit or license can be granted. Depending on the extent of impact, mitigation may be required to offset the impacts. Stream and wetland mitigation is usually conducted onsite or offsite within the same 8-digit HUC watershed.

6.3.2 State Programs

IDEM Point Source Control Program

Point source pollution is regulated by several IDEM Office of Water Quality branches, including the Wastewater Compliance Branch, the Wastewater Permitting Branch, and the Surface Water, Operations, and Enforcement Branch. The Wastewater Permitting Branch issues NPDES and construction permits to sources that discharge wastewater to streams, lakes, and other waterbodies, including municipal wastewater treatment plants and industrial wastewater dischargers. The Stormwater Program, which is managed under the Surface Water, Operations, and Enforcement Branch, issues NPDES permits for stormwater discharges associated with industrial activities, active construction that results in a land disturbance of an acre or more, and municipal separate storm sewer systems (MS4). NPDES permits are issued in accordance with the Clean Water Act, federal laws, and state laws and regulations. The purpose of the NPDES permit is to control the point source discharge of pollutants into the waters of the state such that the quality of the water of the state is maintained in accordance with applicable water quality standards. The Wastewater Compliance Branch and Stormwater Program conduct inspections of facilities and projects with NPDES permits and review and evaluate compliance data to ensure permittees abide by the requirements of their permit. Control of discharges from point sources consistent with WLAs are implemented through the respective NPDES program.

IDEM Nonpoint Source Control Program

The state's Nonpoint Source Program, administered by the IDEM Office of Water Quality's Watershed Planning and Restoration Section, focuses on the assessment and prevention of nonpoint source water pollution. The program also provides education and outreach to improve the way land is managed. Through the use of federal funding for the installation of BMPs, the development of watershed management plans, and the implementation of watershed restoration pollution prevention activities, the program reaches out to citizens so that land is managed in such a way that less pollution is generated.

Nonpoint source projects funded through the Office of Water Quality are a combination of local, regional, and statewide efforts sponsored by various public and non-for-profit organizations. The emphasis of these projects has been on the local, voluntary implementation of nonpoint source water pollution controls. The Watershed Planning and Restoration Section administers Section 319 funding for nonpoint source-related projects, as well as Section 205(j) grants.

To award 319 grants, Watershed Planning and Restoration Section staff review proposals for minimum 319(h) eligibility criteria and rank each proposal. In their review, members consider such factors as: technical soundness; likelihood of achieving water quality results; strength of local partnerships; and competence/reliability of contracting agency. They then convene to discuss individual project merits and pool all rankings to arrive at final rankings for the projects. All proposals that rank above the funding target are included in the annual grant application to U.S. EPA, with U.S. EPA reserving the right to make final changes to the list. Actual funding depends on approval from U.S. EPA and yearly congressional appropriations.

Section 205(j) projects are administered through grant agreements that define the tasks, schedule, and budget for the project. IDEM project managers work closely with the project sponsors to help ensure that the project runs smoothly, and the tasks of the grant agreement are fulfilled. Site visits are conducted at least quarterly to touch base on the project, provide guidance and technical assistance as needed, and to work with the grantee on any issues that arise to ensure a successful project closeout.

IDEM Hoosier Riverwatch Program

Hoosier Riverwatch (HRW) is a statewide volunteer stream water quality monitoring program administered by the IDEM Office of Water Quality, Watershed Assessment and Planning Branch. The mission of HRW is to involve the citizens of Indiana in becoming active stewards of Indiana's water resources and to increase public awareness of water quality issues and concerns. HRW accomplishes this through watershed education, hands-on training of volunteers, water monitoring, and clean-up activities. HRW collaborates with agencies and volunteers to educate local communities about the relationship between land use and water quality and to provide water quality information to citizens and governmental agencies working to protect Indiana's rivers and streams.

ISDA Division of Soil Conservation

The Indiana State Department of Agriculture (ISDA) Division of Soil Conservation's mission is to ensure the protection, wise use, and enhancement of Indiana's soil and water resources. The Division's employees are part of Indiana's Conservation Partnership, which includes the 92 soil and water conservation districts (SWCDs), the USDA Natural Resources Conservation Service, and the Purdue University Cooperative Extension Service. Working together, the partnership provides technical, educational, and financial assistance to citizens to solve erosion and sediment-related problems occurring on the land or impacting public waters.

ISDA Clean Water Indiana (CWI) Program

The ISDA Division of Soil Conservation administers the Clean Water Indiana (CWI) program under the direction of the State Soil Conservation Board. The CWI program provides financial assistance to landowners and conservation groups to support the implementation of conservation practices which will reduce nonpoint sources of water pollution through education, technical assistance, training, and cost sharing programs. The program is responsible for providing local matching funds, as well as competitive grants for sediment and nutrient reduction projects through Indiana's SWCDs.

ISDA INfield Advantage (INFA) Program

The ISDA Division of Soil Conservation administers Infield Advantage (INFA). INFA is a collaborative opportunity for farmers to collect and understand personalized, on-farm data to optimize their management practices. Participating farmers use precision agricultural tools and technologies, such as aerial imagery and the corn stalk nitrate test, to conduct research on their own farms to determine nitrogen use efficiency in each field that they enroll. Peer to peer group discussions, local aggregated results, and collected data allow participants to make more informed decisions and implement personalized best management practices. INFA is available to farmers as a resource and a conduct to diverse on-farm research, innovative ideas, and technologies. INFA collaborates with local, regional, and national partners to help Indiana farmers improve their bottom line, adopt new management practices, protect natural resources, and benefit their surrounding communities.

IDNR Lake and River Enhancement (LARE) Program

The Lake and River Enhancement program is part of the Aquatic Habitat Unit of the Fisheries Section in the Indiana Department of Natural Resources (IDNR), Division of Fish and Wildlife. The goal of the LARE program is to protect and enhance aquatic habitat for fish and wildlife and to ensure the continued viability of Indiana's publicly accessible lakes and streams for multiple uses, including recreational opportunities. This is accomplished through measures that reduce nonpoint source sediment and nutrient pollution of surface waters to a level that meets or surpasses state water quality standards. The LARE program provides technical and financial assistance to local entities for qualifying projects that improve and maintain water quality in public access to lakes, rivers, and streams.

IFA State Revolving Fund (SRF) Loan Program

The SRF is a fixed rate, 20-year loan administered by the Indiana Finance Authority (IFA). The SRF provides low-interest loans to Indiana communities for projects that improve wastewater and drinking water infrastructure. The program's mission is to provide eligible entities with the lowest interest rates possible on the financing of such projects while protecting public health and the environment. SRF also funds nonpoint source projects that are tied to a wastewater loan. Any project where there is an existing pollution abatement need is eligible for SRF funding.

6.3.3 Local Programs

Programs taking place at the local level are key to successful TMDL implementation. Partners such as Fulton County SWCD and the Lake Manitou Association are instrumental to bringing grant funding into the Lake Manitou watershed to support local protection and restoration projects. This section provides a brief summary of the local programs taking place in the Lake Manitou watershed that will help to reduce pollutant loads, as well as provide ancillary benefits to the Lake Manitou watershed.

Additional monitoring will likely take place in the Lake Manitou watershed. Local groups frequently conduct monitoring in watersheds with watershed management plans to engage the public through Hoosier Riverwatch volunteer monitoring events and through more formal monitoring efforts to determine if implementation activities have been successful in reducing nonpoint source pollutant loads. Supporting groups like the Indiana Lake Management Society can help with these efforts. After best management practices are implemented by local groups, IDEM may also conduct performance monitoring at specific sites in the watershed through the Targeted Monitoring Program. Data collected through performance monitoring is compared to water quality standards and targets, as discussed in Section 1.0, to determine if previously impaired waterbodies can be delisted from the Section 303(d) List of Impaired Waters. Fulton county is active in receiving funding to address issues like invasive plants and water quality concerns within the lake.

Fulton County

Fulton County has received the following funding to improve water quality and conservation in 2020:

- Local: $27,028
- Clean Water Indiana: $106,827
- LARE: $8,800
- Conservation Reserve Program & Conservation Reserve Enhancement Program: $541,751
- Conservation Stewardship Program: $33,614

Total: $718,020

6.4 Implementation Programs by Source

Section 6.3 identified a number of federal, state, and local programs that can support implementation of the recommended management or restoration activities for Lake Manitou watershed. Table 28 and the following sections identify which programs are relevant to the various sources in the Lake Manitou watershed.

Table 28: Summary of Programs Relevant to Sources in the Lake Manitou Watershed

Source	IDEM NPDES program	Local agencies/programs	CWA 319(h) Grants	CWA 205(j) Grants	ISDA Division of Soil Conservation (INFA & CWI)	IDNR Division of Fish and Wildlife (LARE)	IFA State Revolving Fund (SRF) Loan Program)	HUD Community Development Block Grant Program (CDBG)	USDA Conservation Stewardship Program (CSP)	USDA Conservation Reserve Program (CRP)	USDA Conservation Reserve Enhancement Program (CREP)	USDA Conservation Technical Assistance (CTA)	USDA Environmental Quality Incentives Program (EQUIP)	USDA Farmable Wetlands Program	USDA Agricultural Conservation Easement Program (ACEP)	USDA Regional Conservation Partnership Program (RCPP)	USDA Healthy Forests Reserve Program (HFRP)	USDA Voluntary Public Access and Habitat Incentive Program (VPA-HIP)	USDA Watershed Surveys and Planning	USDA Section 504 Program
Illicitly Connected "Straight Pipe" Systems	X	X		X				X												
Cropland		X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	
Pastures and Livestock Operations		X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	
CFOs	X			X		X														
Streambank Erosion		X	X	X	X	X						X	X	X	X	X		X	X	
Onsite Wastewater Treatment Systems		X		X			X	X												X
In-stream Habitat	X	X	X																	

6.4.1 Nonpoint Sources Programs

Cropland

Nonpoint source pollution from cropland areas is typically reduced through the voluntary implementation of BMPs by private landowners. Programs available to support implementation of cropland BMPs, whether through cost-share or technical assistance and education, include:

- Clean Water Act Section 319(h) Grants
- Clean Water Act Section 205(j) Grants
- Indiana State Department of Agriculture Division of Soil Conservation/SWCDs (CWI & INFA)
- Indiana Department of Natural Resources Division of Fish and Wildlife (LARE)
- Indiana Lakes Management Society (ILMS)
- Lake Manitou Association
- USDA Conservation Stewardship Program (CSP)
- USDA Conservation Reserve Program (CRP)
- USDA Conservation Reserve Enhancement Program (CREP)
- USDA Conservation Technical Assistance (CTA)
- USDA Environmental Quality Incentives Program (EQIP)
- USDA Farmable Wetlands Program
- USDA Agricultural Conservation Easement Program (ACEP)
- USDA Regional Conservation Partnership Program (RCPP)
- USDA Healthy Forests Reserve Program (HFRP)
- USDA Voluntary Public Access and Habitat Incentive Program (VPA-HIP)
- USDA Watershed Surveys and Planning

Pastures and Livestock Operations

Nonpoint source pollution from pasture and livestock areas is typically reduced through the voluntary implementation of BMPs by private landowners. Programs available to support implementation of pasture and grazing BMPs, whether through cost-share or technical assistance and education, include:

- Clean Water Act Section 319(h) Grants
- Clean Water Act Section 205(j) Grants

- Indiana State Department of Agriculture Division of Soil Conservation/SWCDs (CWI & INFA)
- Indiana Department of Natural Resources Division of Fish and Wildlife (LARE)
- USDA Conservation Stewardship Program (CSP)
- USDA Conservation Reserve Program (CRP)
- USDA Conservation Reserve Enhancement Program (CREP)
- USDA Conservation Technical Assistance (CTA)
- USDA Environmental Quality Incentives Program (EQIP)
- USDA Farmable Wetlands Program
- USDA Agricultural Conservation Easement Program (ACEP)
- USDA Regional Conservation Partnership Program (RCPP)
- USDA Healthy Forests Reserve Program (HFRP)
- USDA Voluntary Public Access and Habitat Incentive Program (VPA-HIP)
- USDA Watershed Surveys and Planning

CFOs

While CAFOs are regulated by federal law, CFOs are not. However, Indiana has CFO regulations 327 IAC 16 and 327 IAC 15 that require that operations manage manure, litter, and process wastewater in a manner that "does not cause or contribute to an impairment of surface waters of the state." IDEM regulates CFOs under IC 13-18-10, the Confined Feeding Control Law. The rules at 327 IAC 16, which implement the statute regulating CFOs, were effective on March 10, 2002. IDEM's Office of Land Quality administers the regulatory program, which includes permitting, compliance monitoring, and enforcement activities.

Streambank Erosion

Streambank erosion can be the result of changes in the physical structure of the immediate bank from activities such as removal of riparian vegetation or frequent use by livestock, or it can be the result of increased flow volumes and velocities resulting from increased surface run-off throughout the upstream watershed. Therefore, streambank erosion might be addressed through BMPs and restoration targeted to the specific stream reach, and further degradation could be addressed through the use of BMPs implemented to address stormwater issues throughout the watershed. Programs available to support implementation of BMPs to address streambank erosion, whether through cost-share or technical assistance and education, include:

- Clean Water Act Section 319(h) Grants
- Clean Water Act Section 205(j) Grants

- Indiana State Department of Agriculture Division of Soil Conservation/SWCDs (CWI & INFA)
- Indiana Department of Natural Resources Division of Fish and Wildlife (LARE)
- USDA Conservation Technical Assistance (CTA)
- USDA Environmental Quality Incentives Program (EQIP)
- USDA Farmable Wetlands Program
- USDA Agricultural Conservation Easement Program (ACEP)
- USDA Regional Conservation Partnership Program (RCPP)
- USDA Voluntary Public Access and Habitat Incentive Program (VPA-HIP)
- USDA Watershed Surveys and Planning
- Mitigation Funds

Onsite Wastewater Treatment Systems

Local health departments and the Indiana Department of Health (IDOH) regulate septic systems through local ordinances and the Onsite Sewage Disposal Program (410 IAC 6-8.3). Regulations include constraints on the location and design of current septic systems in an effort to prevent system failures. The onsite sewage system rule also prohibits failing systems, requiring that no system will contaminate groundwater, and no system will discharge untreated effluent to the surface. Programs available to address issues related to failing onsite wastewater treatment systems within a community include:

- Clean Water Act Section 319(h) Grants
- Clean Water Act Section 205(j) Grants
- IFA State Revolving Fund Loan Program
- HUD Community Development Block Grant Program (CDBG)
- USDA Section 504 Program

Wildlife/Domestic Pets

Addressing pollutant contributions from wildlife and domestic pets is typically done at the local level through education and outreach efforts. For wildlife, educational programs focus on proper maintenance of riparian areas and discouraging the public from feeding wildlife. For domestic pets, education programs focus on responsible pet waste maintenance (e.g., scoop the poop campaigns) coupled with local ordinances.

6.5 Potential Implementation Partners and Technical Assistance Resources

Agencies and organizations at the federal, state, and local levels will play a critical role in implementation to achieve the WLAs and LAs assigned under this TMDL. Table 29 identifies key potential implementation partners and the type of technical assistance they can provide to watershed stakeholders. IDEM has also compiled a matrix of public and private grants and other funding resources available to fund watershed implementation activities. The matrix is available on IDEM's website at www.idem.IN.gov/nps/funding/non-idem-funding/funding-matrix .

Table 29: Potential Implementation Partners in the Lake Manitou Watershed

Potential Implementation Partner	Funding Source
Federal	
USDA	Conservation Stewardship Program
USDA	Conservation Reserve Program
USDA	Conservation Reserve Enhancement Program
USDA	Conservation Technical Assistance (technical assistance only)
USDA	Environmental Quality Incentives Program
USDA	Farmable Wetlands Program
USDA	Agricultural Conservation Easement Program
USDA	Regional Conservation Partnership Program
USDA	Healthy Forests Reserve Program
USDA	Voluntary Public Access and Habitat Incentive Program
USDA	Watershed Surveys and Planning
USDA	Section 504 Home Repair Program
HUD	Community Development Block Grant Program
State	
ISDA	Division of Soil Conservation – Clean Water Indiana Program
ISDA	Division of Soil Conservation – INfield Advantage Program
IDNR	Division of Fish and Wildlife - Lake and River Enhancement program
IDEM	Clean Water Act Section 319(h) Grants
IDEM	Clean Water Act Section 205(j) Grants
Local	
Soil and Water Conservation Districts	Local funds
Indiana Lake Management Society	Local Lake Group

Potential Implementation Partner	Funding Source
Lake Manitou Association	Local Lake Group

In addition, several tools are available to assist local watershed stakeholders with the estimation of pollutant load reductions from the implementation of various BMPs within the Lake Manitou watershed in order to optimize BMP selection. These tools include BATHTUB, L-THIA, STEPL, and the Region 5 Model.

The Long-Term Hydrologic Impact Assessment (L-THIA) model is an online tool developed by Purdue University that estimates runoff, recharge, and pollutant loads for land use configurations based on precipitation data, soils, and land use data for an area. The L-THIA LID model is an enhancement to the original model, which can be used to simulate runoff and pollutant loads associated with low impact development (LID) practices at lot to watershed scales. The model can be used as a screening tool to evaluate the benefits of implementation of LID practices. LID practices included in the model include, but are not limited to, grass swales, rain barrel/cisterns, rain gardens, and porous pavement. The L-THIA LID tool is available online at https://engineering.purdue.edu/mapserve/LTHIA7/lthianew/lidIntro.php.

The Pollutant Load Estimation Tool (PLET) is a web-based model that calculates long-term nutrient and sediment loads from various land uses and estimates the reductions from best management practices (BMPs). It considers urban, cropland, pastureland, feedlot, forest, and user-defined land uses, focusing on nonpoint sources like runoff and failing septic systems. PLET uses simple algorithms to estimate surface runoff, nutrient loads, and sediment delivery, considering factors like land use and management practices. It also calculates sediment loads using the RUSLE2 methodology.

7.0 PUBLIC PARTICIPATION

Public participation is an important and required component of the TMDL development process. The following public meetings and public comment periods have been held to further develop this project:

- A stakeholder meeting was held in Rochester, IN on October 23, 2017, to introduce the project and solicit public input. IDEM explained the TMDL process and presented initial information regarding the Lake Manitou watershed. Questions were answered from members of the Lake Manitou Association, and information was solicited from stakeholders in the area.
- The public comment period on the draft report was from May 09, 2025 to June 09, 2025. IDEM received no public comments during that time period.

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APPENDIX A. WATER QUALITY DATA FOR THE LAKE MANITOU TMDL

Sample Focus	Sample Date	Event ID	Sample ID	Sample Name	Sample Type	Concentration	Unit	Detection Limit	Detection Limit Unit
NO3	7/16/2020	2904	29041003	2904 Manitou epi	Nothing	<0.008	mg/L	0.008	mg/L
NO3	7/16/2020	2904	29042003	2904 Manitou hypo	Nothing	<0.008	mg/L	0.008	mg/L

Sample Focus	Sample Date	Event ID	Sample ID	Sample Name	Sample Type	Concentration	Unit	Detection Limit	Detection Limit Unit
NH3	7/16/2020	2904	29041003	2904 Manitou epi	Nothing	<0.014	mg/L	0.014	mg/L
NH3	7/16/2020	2904	29042003	2904 Manitou hypo	Nothing	1.086	mg/L	0.014	mg/L

Sample Focus	Sample Date	Event ID	Sample ID	Sample Name	Sample Type	Concentration	Unit	Detection Limit	Detection Limit Unit
SRP	7/16/2020	2904	29041004	2904 Manitou epi	Normal	0.007	mg/L	0.002	mg/L
SRP	7/16/2020	2904	29042004	2904 Manitou hypo	Normal	0.113	mg/L	0.002	mg/L
SRP	7/16/2020	2904	29042004	2904 Manitou hypo SR	Duplicate	0.113	mg/L	0.002	mg/L

Sample Focus	Sample Date	Event ID	Sample ID	Sample Name	Sample Type	Concentration	Unit	Detection Limit	Detection Limit Unit
TN	7/16/2020	2904	29041005	2904 Manitou epi	Normal	0.737	mg/L	0.1	mg/L
TN	7/16/2020	2904	29042005	2904 Manitou hypo	Normal	1.856	mg/L	0.1	mg/L
TN	7/16/2020	2904	29042005	2904 Manitou hypo	Duplicate	1.74	mg/L	0.1	mg/L

Sample Focus	Sample Date	Event ID	Sample ID	Sample Name	Sample Type	Concentration	Unit	Detection Limit	Detection Limit Unit
TP	7/16/2020	2904	29041005	2904 Manitou epi	Normal	0.029	mg/L	0.002	mg/L
TP	7/16/2020	2904	29042005	2904 Manitou hypo	Normal	0.118	mg/L	0.002	mg/L
TP	7/16/2020	2904	29042005	2904 Manitou hypo	Duplicate	0.113	mg/L	0.002	mg/L

Summary	Lake Name	Sample Date	Sample Location	SRP (mg/L)	NO3 (mg/L)	NH3 (mg/L)	TN (mg/L)	TP (mg/L)
	Manitou	7/16/2020	Epi	0.007	<0.008	<0.014	0.737	0.029
			Hypo	0.113	<0.008	1.086	1.798	0.1155
			Avg	0.06			1.2675	0.07225

APPENDIX B. LAND USE DATA FOR THE LAKE MANITOU WATERSHED TMDL

Selected Watershed Information					
State	County	FIPS	Watershed Name	HUC12	Watershed Total Area (acre)
Indiana	Fulton	18049	Lake Manitou-Mill Creek	51201060502	18905.99

Landuse area (acres)									
Watershed Name	HUC12	Urban	Cropland	Pastureland	Forest	User Defined	Feedlots	Water	Others
Lake Manitou-Mill Creek	51201060502	2294.67	12117.39	880.9	2754.14	0	2.434	858.89	0

Agricultural Animals									
Watershed Name	HUC12	Beef Cattle	Dairy Cattle	Swine	Sheep	Horse	Chicken	Turkey	Duck
Lake Manitou-Mill Creek	51201060502	567	266	5139	87	73	122	8	0

Septic System data				
Watershed Name	HUC12	Septic Systems	Population per Septic System	% Septic Failure Rate
Lake Manitou-Mill Creek	51201060502	1178	2	1.09

Hydrologic Soil Group		
Watershed Name	HUC12	Hydrologic Soil Group
Lake Manitou-Mill Creek	51201060502	C

APPENDIX C. STEPL DATA FOR THE LAKE MANITOU WATERSHED TMDL

	Sampling Date							
Parameter	8/16/2011	8/6/2013	7/7/2014	8/10/2015	7/16/2020	Mean	Standard Deviation	SE
Ammonia-Epi (mg/L)	0.02	0.03	1.74	0.02	0.01	0.36	0.77	0.34
Nitrite plus Nitrate–Epi (mg/L)	0.01	0.04		0.32	0.01	0.09	0.15	0.08
TKN–Epi (TN-Nitrite plus Nitrate) (mg/L)	1.11	1.27	0.91	1.43	1.79	1.30	0.33	0.15
Organic N (TKN-NH3)–Epi (mg/L)	1.09	1.24		1.41	1.78	1.38	0.30	0.15
TN–Epi (mg/L)	1.12	1.31		1.75	1.80	1.49	0.33	0.17
Ortho-Phosphorus–Epi (mg/L)	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
TP–Epi (mg/L)	0.03	0.05	0.04		0.03	0.04	0.01	0.00
TP minus OP–Epi (mg/L)	0.02	0.04	0.03		0.02	0.03	0.01	0.00
Ammonia–Avg of Epi and Hypo (mg/L)	2.44	1.19	2.33	1.34	0.55	1.57	0.80	0.36
Nitrite plus Nitrate–Avg of Epi and Hypo (mg/L)	0.01	0.03		0.17	0.01	0.05	0.08	0.04
TKN–Avg of Epi and Hypo (mg/L)	3.84	2.61	2.42	2.52	1.29	2.54	0.90	0.40
Organic N (TKN-NH3)–Avg of Epi and Hypo (mg/L)	1.39	1.41	0.09	1.18	0.74	0.96	0.56	0.25
TN–Avg of Epi and Hypo (mg/L)	3.85	2.63		2.69	1.30	2.62	1.04	0.52
Ortho-Phosphorus–Avg of Epi and Hypo (mg/L)	0.02	0.01	0.08	0.21*	0.06	0.04	0.03	0.02
TP–Avg of Epi and Hypo (mg/L)	0.04	0.06	0.11		0.07	0.07	0.03	0.01
TP minus OP–Avg of Epi and Hypo (mg/L)	0.02	0.04	0.03		0.01	0.03	0.01	0.01
Chl-a (µg/L)	15.89	31.69	19.09	22.27	29.69	23.73	6.78	3.03
Total Suspended Solids (mg/L)				6.9		6.90		
Secchi Depth (m)	0.9	0.5	1	0.4	0.80	0.72	0.26	0.15
Non-algal Turbidity	0.71	1.21	0.52	1.94	0.51	0.98	0.61	0.35

APPENDIX D. TETRA TECH REPORT FOR THE LAKE MANITOU WATERSHED TMDL

Technical Guidance for Applying BATHTUB Model to Indiana Lakes and Reservoirs

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Acronyms

ac-ft	acre-feet
AIMS	Assessment Information Management System
BMP	best management practice
CAFO	concentrated animal feeding operation
Chl-*a*	chlorophyll-*a*
CLP	Clean Lakes Program
CV	coefficient of variation
CWA	Clean Water Act
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
ft	foot, feet
hm^3/yr	cubic hectometers per year
HSG	hydrologic soil group
IDEM	Indiana Department of Environmental Management
kg	kilograms
km	kilometers
km^2	square kilometers
lbs	pounds
m	meters
m^2	square meters
m^3	cubic meters
mg/m^3	milligrams per cubic meter
mm	millimeters
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
SRP	soluble reactive phosphorus
STEPL	Spreadsheet Tool for Estimating Pollutant Load
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
TSI	Trophic State Index
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WQP	Water Quality Portal
WWTP	wastewater treatment plant
Zmix	mixed layer depth

1.0 INTRODUCTION

1.1 Background

Nutrient loading to waterbodies is a significant factor contributing to water quality and biological community impairment in the Midwest. In Indiana, nearly 150 lakes and/or reservoirs are currently listed as impaired on the U.S. Environmental Protection Agency's (EPA's) Clean Water Act (CWA) section 303(d) list. Of those, approximately one third are impaired due to excessive amounts of total phosphorus (TP). Additionally, 10 percent are impaired due to algae, and 20 percent are impaired due to poor biological communities. Thirty percent of all 303(d)-listed waterbodies are impaired as a result of excessive nutrient loading, whether from phosphorus or nitrogen.

Indiana has many partnerships at the state and local levels focusing on nonpoint source issues such as reducing nutrient and other pollutant loadings. As part of the *State Nutrient Reduction Strategy*, the Indiana Conservation Partnership has identified source waters for public water supply as priority waters for action. There have also been various efforts taken in building understanding and technical capacity for accomplishing these goals. For example, there are ongoing efforts to assist in the development of new or improved nutrient criteria related to the health of statewide lakes, rivers, and streams. However, addressing impairments in Indiana lakes and reservoirs has been limited or lacking in key areas such as developing total maximum daily loads (TMDLs) and characterizing pollutant loading. Technical understanding and capacity to analyze sources of nutrient inputs and determine appropriate loading limits and reductions is a key factor in the ability to implement necessary solutions. Local stakeholders have expressed an interest in addressing existing lake impairments; however, the technical capacity of current program staff to support analyses of the issues through a TMDL or alternative approaches are hindering progress. Therefore, it is integral to build technical capacity for modeling nutrients in lakes and reservoirs in Indiana for applications such as TMDL development and watershed management planning efforts.

Determining nutrient loading to lakes and reservoirs in Indiana is important for water quality and watershed managers. This modeling guidance document is tailored for Indiana lakes and reservoirs, and, coupled with hands-on training, will provide value to watershed managers, TMDL developers, and other water quality managers by increasing modeling capacity. As other partnerships and efforts are already moving forward with assessing and understanding nutrients in Indiana lakes and reservoirs, helping to fill the modeling capacity gap will lead to a greatly enhanced ability to implement the necessary actions to reduce nutrient loadings in lakes and reservoirs and meet water quality goals.

1.2 Objective and Report Organization

The objective of this guidance document is to provide detailed instructions on BATHTUB model applications to waterbodies in Indiana.

Specifically, this guidance document is organized into four sections:

Section 1.0 Introduction: Background, objective and report organization, and intended audience.

Section 2.0 BATHTUB Model Simulation Suitability: BATHTUB model description to assist users in understanding its advantages and limitations. Criteria to use in determining if BATHTUB is suitable for performing nutrients analysis and/or nutrient TMDL development for lakes of concern in Indiana.

Section 3.0 Prepare Input Data for Bathtub Model Application: Data requirements and how to prepare BATHTUB model inputs.

Section 4.0 Set Up, Run, and Calibrate: Step-by-step instruction on how to set up, run, and calibrate a BATHTUB model. Also includes interpretation of model output and TMDL allocation.

Appendix A: Unit Conversions: Unit conversions used throughout the document.

Appendix B BATHTUB Diagnostic Variables and Interpretation: Table 4.5 from the BATHTUB User Manual.

Appendix C BATHTUB Model Selection: Full suite of model selection from the BATHTUB Model help file.

Appendix D STEPL Fact Sheet: Fact sheet for the Spreadsheet Tool for Estimating Pollutant Load (STEPL).

Throughout this document, Lake Manitou is presented as an example to demonstrate BATHTUB model application steps.

This document does not replace the *Simplified Procedures for Eutrophication Assessment and Prediction: User Manual* (Walker 1999), which is referred to as “BATHTUB User Manual” in this document and should still be referenced during model application. Rather, this document focuses on in-depth instruction on how to compile required data inputs (based on the Indiana-specific conditions), run the model, and interpret model output. Readers are encouraged to read the BATHTUB User Manual for more information on model background, underlying theory, model structures, and further examples.

1.3 Intended Audience

This document is intended for Indiana watershed managers, TMDL developers, and other water quality managers who are interested in the BATHTUB model application for lake TMDL development and/or nutrient loading analysis. The intended audience is assumed to have basic technical background and knowledge in hydrology, pollutant source assessment, and water quality monitoring and modeling.

2.0 BATHTUB MODEL SIMULATION SUITABILITY

2.1 BATHTUB Description

BATHTUB is a steady-state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1999). The model was developed by the U.S. Army Corps of Engineers (USACE) and provides a means for assessing the potential effects of a variety of management alternatives involving changes in nutrient and/or water input to lakes and reservoirs. The BATHTUB model has been used extensively across the Midwest for lake nutrient loading analysis and lake nutrient TMDLs. The BATHTUB model requires nutrient loading input from the upstream watershed and atmospheric deposition, bathymetric data for the lake, estimates of mixing depth, and in-lake water quality monitoring data, including nonalgal turbidity.

Lakes and reservoirs are represented as a spatially segmented hydraulic network in BATHTUB. The model includes several physical processes such as advective and diffusive transport, and nutrient sedimentation. Each lake segment is represented as a continuous stirred-tank reactor at steady state and the sedimentation of phosphorus as a first-order decay reaction. BATHTUB predicts eutrophication-related water quality conditions (parameters such as TP, total nitrogen (TN), chlorophyll-*a* (chl-*a*), transparency, and hypolimnetic oxygen depletion) using empirical relationships derived from assessments of reservoir data.

Main BATHTUB model features include:

- Nutrient and water balances
- Nutrient sedimentation
- Algal (chl-*a*) response to flushing, light, and nutrient concentration
- Hypolimnetic oxygen depletion

The required input data types include:

- Water and nutrient loads
- Lake or reservoir morphology
- Observed lake or reservoir water quality data

Model outputs include:

- Segment hydraulics
- Water and nutrient balances
- Prediction of nutrient concentrations, transparency, chl-*a* concentrations, and oxygen depletion
- Statistics relating observed and predicted values

Figure 1 summarizes the BATHTUB model input and output variables and control pathways.

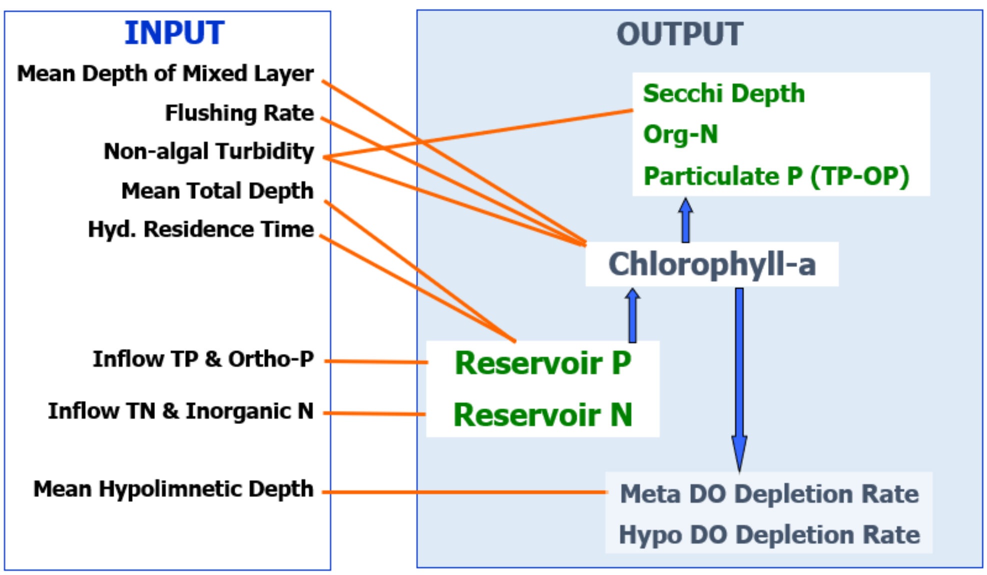


Figure 1. BATHTUB model input and output variables and control pathways.

Although the model is based on theoretical concepts such as mass balance and nutrient limitation of algal growth, it does not simulate explicitly the dynamics of a lake/reservoir in either space or time. Instead, BATHTUB produces spatially and temporally averaged estimates of reservoir water quality conditions. BATHTUB models water quality conditions in a two-stage prodecure. First, nutrient concentrations are estimated based on nutrient loads, morphometry, and hydrology. Second, a eutrophication response model is executed to relate pool nutrient concentrations to chl-*a* concentrations and transparency. As a result, the model produces estimates of steady-state, long-term (growing season or annual) water quality conditions in the epilimnion and is *not* intended to predict or describe short-term, event-related dynamics or to generate vertical profiles of water quality conditions.

Appropriately calibrated and verified, models can then be used to evaluate potential responses to selected management decisions.

The most significant advantage of BATHTUB is its simplicity, meaning it can provide reasonably realistic results with limited data. The model has simple structures, low resolution, and a limited number of input variables. Initial calibration to data from groups of impoundments results in relatively low data requirements.

The simplicity of BATHTUB can also lead to certain limitations. Applications of BATHTUB are limited to steady-state—or long-term, nonchanging—evaluations of relationships between nutrient loading, transparency, hydrology, and eutrophication responses. Short-term responses, responses to variables other than nutrients, and effects related to structural modifications cannot be explicitly evaluated with BATHTUB. The BATHTUB model can be downloaded at http://www.wwwalker.net/bathtub/bathtub_install.zip.

2.2 Criteria for Determining Applicability of BATHTUB Model

BATHTUB is a suitable tool for analyzing and predicting long-term, steady-state, in-lake water quality and algal dynamics. The flowchart in Figure 2 depicts the critical pathway that might be used to determine if the BATHTUB model is applicable based on study objective, desired spatial and temporal resolutions, and data availability.

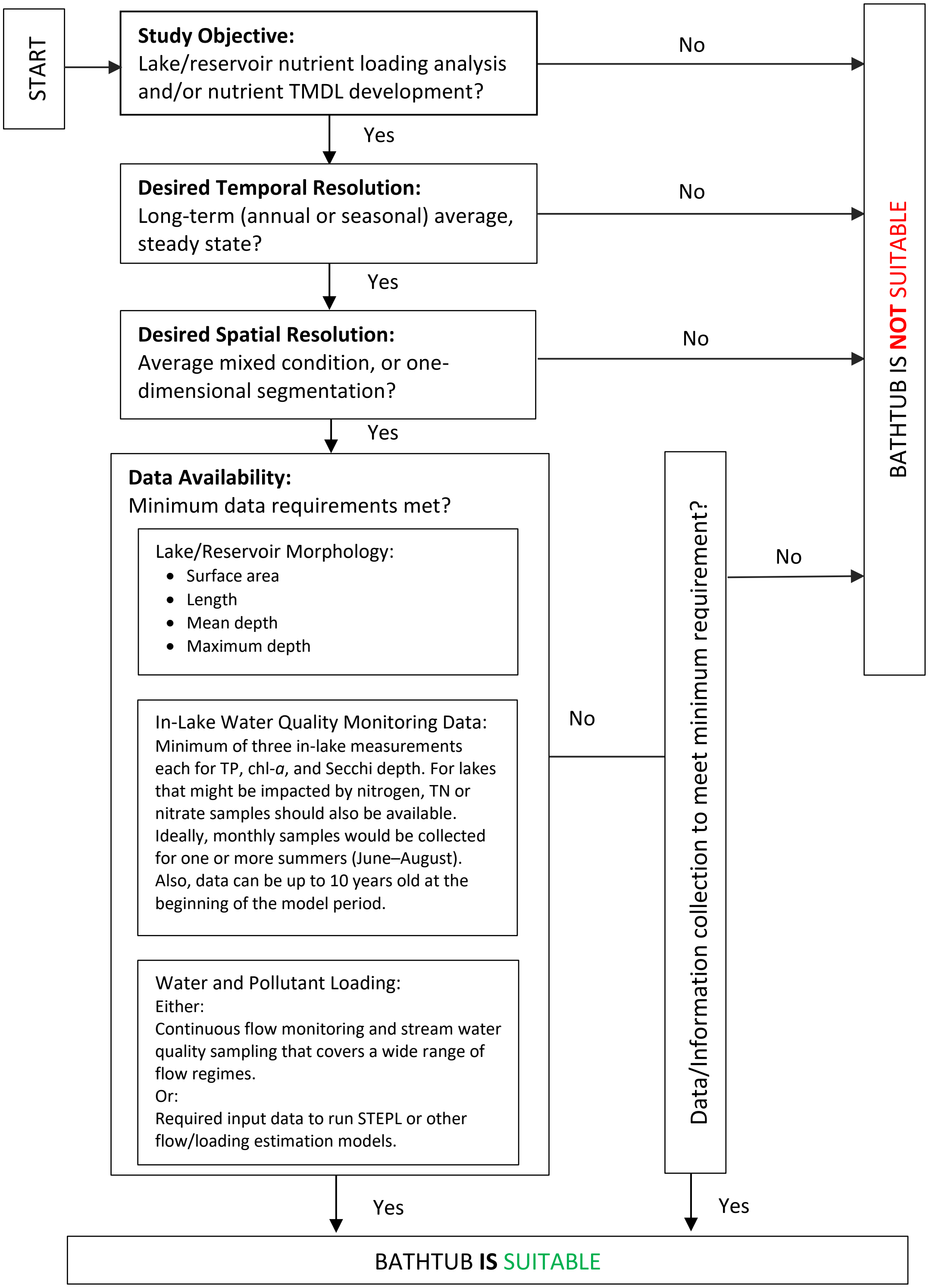


Figure 2. Criteria for determining applicability of BATHTUB model.

3.0 PREPARE INPUT DATA FOR BATHTUB MODEL APPLICATION

Once it is determined that the BATHTUB model is suitable and enough data are available, users can compile the required input data. The essential data needed for performing BATHTUB model applications include (1) physical characteristics of the lake, (2) in-lake water quality data, and (3) flow and pollutant (nutrients) loading to the lake. This section provides detailed guidance on preparing input data for BATHTUB application. Lake Manitou (located in hydrologic unit code 051201060502, Fulton County, IN) is used in this document as a case study to demonstrate the data preparation process.

Lake Manitou is in the city of Rochester, IN. It has a 775-acre open water area and is designated as a recreational lake for fishing, boating, waterskiing, swimming, and kayaking. The Lake Manitou watershed comprises nearly 28,000 acres southeast of Rochester and into Miami County (Figure 3). The drainage area is largely agricultural and contributes excessive sediment and nutrients to the lake. The two main inlets to Lake Manitou are Graham Ditch and Rain Creek. It is important to note that Graham Ditch is one of the lake's filtering systems designed to control sediment and nutrient flow into it. Graham Ditch consists of a series of basins, earthen berms, and a small dam. Every few years, the basins need to be cleaned out, as they fill up with silt.

Lake Manitou is listed as impaired for phosphorus. Sampling data are available from the Clean Lakes Program (CLP). Sampling conducted within the past 10 years (2010–2020) occurred in August 2011, 2013, 2014, and 2015. Sampled relevant parameters include temperature, conductivity, dissolved oxygen (DO), transparency (Secchi depth), plankton, pH, alkalinity, NH_3-N, total Kjeldahl nitrogen (TKN), NO_3-N, TP, soluble reactive phosphorus (SRP), and chl-*a*. Both epilimnion and hypolimnion layers were sampled for most parameters.

There are no active stream flow or water quality gages in the Lake Manitou watershed or nearby watersheds with similar hydrologic and water quality characteristics. Therefore, STEPL was used to estimate the flow and nutrient loadings to the lake. It is recognized that, although STEPL provides reasonable flow and loading estimation, it does not have the capability to account for site-specific conditions like the sedimentation and filtration system installed at Graham Ditch flowing to Lake Manitou. Because detailed information for Graham Ditch is not available, that inlet's pollutant removal efficiencies cannot be quantified. It is anticipated that calibration factors in BATHTUB can be used to account for the pollutant removal provided by Graham Ditch.

The reasons for using the BATHTUB model to facilitate the TMDL allocation process for Lake Manitou are as follows:

- Lake Manitou is impaired for phosphorus.
- Limited water quality monitoring data are available for Lake Manitou; therefore, a more complex water quality model is unsuitable.
- BATHTUB is a suitable model to predict the cause-and-effect relationship between nutrient loading and lake water quality response.

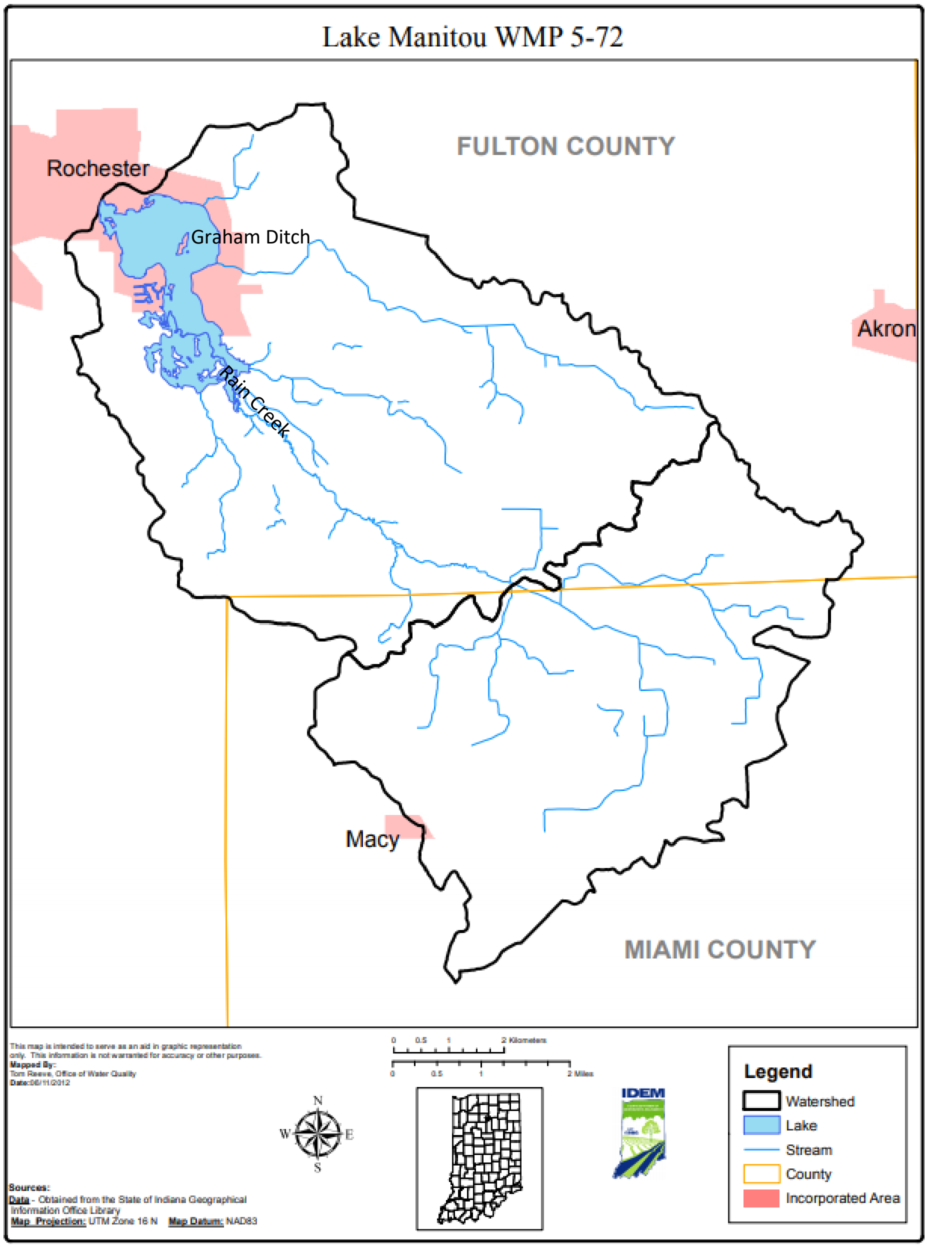


Figure 3. Lake Manitou watershed.

Using Lake Manitou as an example, the following subsections provide detailed guidance for preparing input data for the BATHTUB model.

3.1 Lake/Reservoir Physical Characteristics

The minimum inputs for the BATHTUB model related to lake physical characteristics include:

- Number of segments
- Length along the flow path for each segment
- Surface area for each segment
- Mean depth for each segment

Optional inputs include:

- Mixed layer depth (required if chl-*a* models 1 and 2 are used) (refer to appendix C for information about the specific models).
- Hypolimnetic thickness (required only if estimates of hypolimnetic and oxygen depletion rates are desired).

Surface area, mean depth, mixed layer depth, and length should correspond to the average pool elevation during the period being simulated. Refer to section 3.3.4 Determining Averaging Period for information on simulation period and how to determine it.

3.1.1 Number of Segments

The number of segments is determined based on the shape and size of the lake, monitoring station locations, and the locations of flow/pollutant loads from tributaries or other sources. In most cases, when monitoring data are scarce and/or the water quality data do not exhibit significant variation between stations, one segment is used (shown as scheme 1 in Figure 4). When the user needs to simulate variable water quality conditions across the waterbody, scheme 2 in Figure 4 can be used.

Figure 4. Commonly used segmentation schemes.

As shown in Figure 5, the main tributaries for Lake Manitou are Rain Creek from the south and Graham Ditch from the east, which both flow into the lake. There are three in-lake sampling locations. Within the past 10 years, two locations had one sampling event for water quality monitoring data and one location had two sampling events. Considering the limited amount of sampling data, one segment scheme for Lake Manitou is sufficient. Multiple segments might be appropriate if the in-lake water quality data are spatially variable, however, or if there are distinct physical characteristics with supporting water quality data that suggest multiple segments are valuable (i.e., half the lake is shallow and the other half is far deeper).

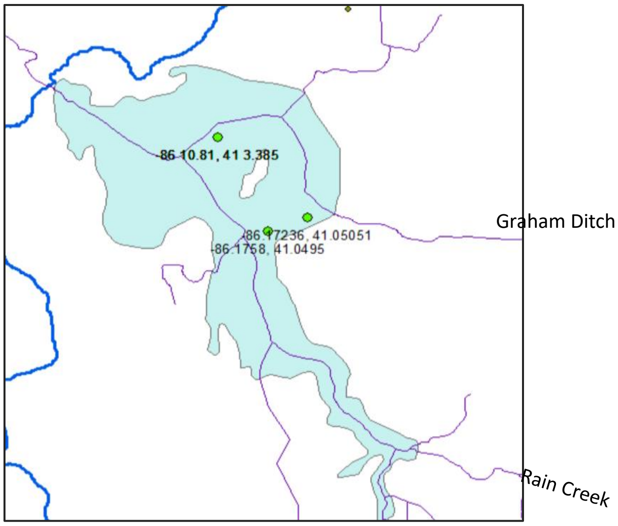


Figure 5. Water quality sampling station locations, Lake Manitou, IN.

3.1.2 Segment Length

Segment length is the distance along the major flow axis (model input in units of kilometers (km)). It is used in estimating diffusive exchange rates (longitudinal dispersion) with downstream segments. The length has no impact on the last reservoir segment (furthest downstream, outflow segment number = 0) or in cases where the simulation employs only one reservoir segment.

In the case of Lake Manitou, because only one segment is used, segment length has no effect on the simulation. For documenting lake dimensions, however, a quick geospatial measure revealed the length along the major flow axis is approximately 2.5 km.

3.1.3 Segment Surface Area

The surface area should correspond to the average pool elevation during the period being simulated. Lake Manitou's surface area is 3.125 km^2. The lake surface area was measured from the lake shapefile provided by the Indiana Department of Environmental Management (IDEM). Lake surface area can also be determined using waterbody shapefiles such as those available through NHDPlusV2 (https://nhdplus.com/NHDPlus/) or in previous reports on the waterbody of interest.

3.1.4 Segment Mean Depth

Lake bathymetry—morphology of the land surface under the water—can be highly complex and is generally not measured with a high degree of accuracy. For the level of resolution required for the average Indiana BATHTUB model application, the mean depth can be coarsely estimated as total volume divided by surface area.

Using the lake bathymetry data provided by IDEM, Lake Manitou's total volume is calculated as 9,477,807 m^3 (cubic meters); therefore, Lake Manitou's mean depth = 9,477,807 m^3 / 3,125,000 square meters (m^2) = 3.03 meters (m).

3.1.5 Mean Depth of Mixed Layer (Optional)

The mean depth of the mixed layer is an optional input and needed only if chl-*a* models 1 and 2 are used. It is calculated as the ratio of mixed layer volume (in cubic hectometers (hm^3)) to surface area (in square kilometers (km^2)), or mean depth if the segment is not vertically stratified. If the user does not have the mixed layer volume data and input mixed layer depth as 0 m, then it is estimated from mean depth using a regression equation developed from USACE reservoir data. A regression model that predicts mixed layer depth as a function of mean depth is used to generate an estimate that appears on the segment data entry screen. This value can be used if a direct estimate of mixed layer depth is not available.

The mean mixed layer depth can be calculated as total mixed layer volume divided by surface area. Based on the temperature and DO profile monitoring data (Figure 6), Lake Manitou's mixed layer depth is approximately 7 feet (ft). Based on the bathymetric contour map provided by IDEM, Lake Manitou's mixed layer volume (the volume with water depth less than or equal to 7 ft) is 4,276,600 m^3. Therefore, <u>Lake Manitou's mean depth of mixed layer = 4,276,600 m^3 / 3,125,000 m^2 = 1.37 m.</u>

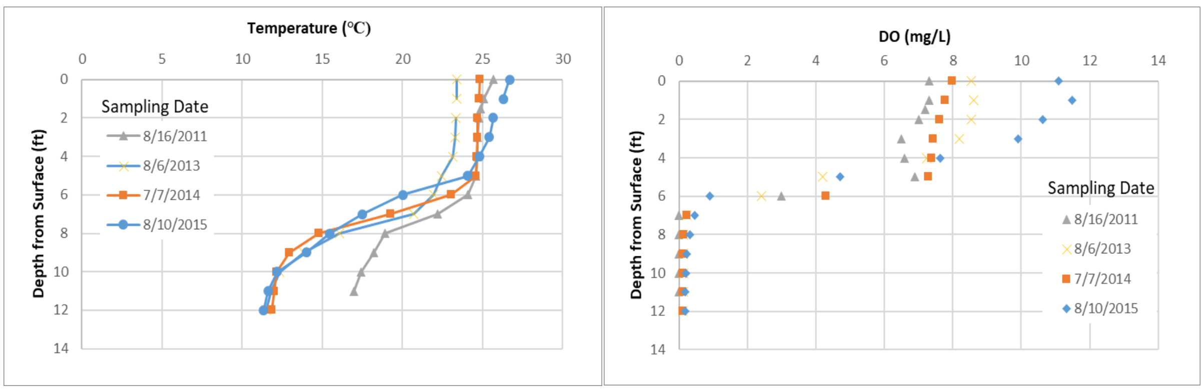


Figure 6. Temperature and DO profiles with depth, Lake Manitou, IN.

3.1.6 Hypolimnetic Thickness

Mean hypolimnetic depth refers to the depth at which stratification occurs during late spring or early summer conditions. This parameter is optional and used only in calculating oxygen depletion rates in stratified waterbodies. Hypolimnetic depth is calculated as hypolimnetic volume / hypolimnetic surface area.

If the mean hypolimnetic depth is set to zero, the segment is assumed to be unstratified and oxygen depletion rates are not calculated. Since the empirical models for predicting the oxygen depletion rate have been developed using data from near-dam stations, hypolimnetic depths should be specified only for near-dam segments. Predictions of depletion rates in upper pool segments (segments not near a dam) are not reliable without being calibrated to site-specific data.

For Lake Manitou, based on the temperature and DO profiles, water deeper than 7 ft is considered the hypolimnion. Based on the bathymetry contour map, hypolimnetic volume is 5,201,207 m^3 and hypolimnetic surface area is approximately 2,000,000 m^2, so <u>the mean hypolimnetic depth for the lake is 5,201,207 m^3 /2,000,000 m^2 = 2.6 m</u>.

3.2 In-Lake Monitoring Data

3.2.1 In-Lake Water Quality Data Requirement

Recommended minimum water quality data requirements for BATHTUB include three in-lake measurements each for TP, chl-*a*, and Secchi depth. For lakes that might be impacted by nitrogen, TN or nitrate samples should also be available. The availability of in-lake monitoring data is critical to ensure adequate calibration of the BATHTUB model. Three samples are the recommended minimum; however, the uncertainty of the calibration will increase as the number of samples decrease or if the samples are spread out over a long time period (e.g., over 5–10 years). Ideally, monthly samples would be collected for one or more summers (June–August). Data collected more frequently would reduce the overall uncertainty of the BATHTUB model and enable a more robust understanding of in-lake water quality and algal dynamics.

IDEM provided data from two sources: the Assessment Information Management System (AIMS) and the CLP. AIMS data were mostly sampled in the 1990s and early 2000s, and relevant sampled parameters include chl-*a*, DO, temp, pH, Secchi depth, NH_3-N, NO_2NO_3-N, TKN, SRP, and TP at various depths. CLP has newer data up to 2018 and relevant sampled parameters include temperature profile, conductivity, DO profile, Secchi depth, transparency, plankton, pH, alkalinity, NH_3-N, TKN, NO_3-N, TP, SRP, and chl-*a*. For deep lakes, both epilimnion and hypolimnion layers were sampled for most parameters in the CLP data.

A publicly available source of lake water quality sampling data is the Water Quality Portal (WQP), a cooperative service sponsored by the U.S. Geological Survey (USGS), EPA, and the National Water Quality Monitoring Council. It serves data collected by over 400 state, federal, tribal, and local agencies and can be accessed at https://www.waterqualitydata.us/.

The BATHTUB model requires input of the mean and coefficient of variation (CV) for water quality parameter inputs calculated for the averaging period. The CV of a given parameter reflects the uncertainty in the input value. Therefore, once all available data within the desired time frame are collected, the mean and CV for each parameter for the average period need to be calculated. The mean, or average, can be calculated in Excel using the AVERAGE function. Based on the definition in the BATHTUB Document (Walker 2006) and how it is used in the model, CV is equivalent to the standard error divided by the mean. The standard error for the sample is calculated as the standard deviation divided by the square root of the number of samples. Standard deviation can be calculated in Excel by using the STDEV function.

The averaging period is the duration of the mass balance calculation within the lake and is also the time period used specifying tributary inflows. The units for the averaging period are for a fraction of a calendar year (e.g., averaging period of 1 = annual, 0.5 = April–September, and 0.25 = June–August). The appropriate averaging period for mass balances depends on the residence time of water and nutrients in the waterbody. Section 3.3.4 describes how to determine the averaging period.

For Lake Manitou, water quality data was sampled on four dates after 2010 and retrieved from the CLP. Table 1 provides water quality data from August and July 2011–2015 as well as calculated mean and CV statistics.

Table 1. Lake Manitou Water Quality Sampling Data Since 2010 from the CLP Dataset (*Source*: IDEM)

Parameter	Sampling Date				Mean	Standard Deviation	CV
	8/16/2011	8/6/2013	7/7/2014	8/10/2015			
Ammonia–Epi (mg/L)	0.02	0.03	1.74	0.02	0.45	0.86	0.95
Nitrite plus Nitrate–Epi (mg/L)	0.01	0.04		0.32	0.12	0.17	0.82
TKN–Epi (mg/L)	1.11	1.27	0.91	1.43	1.18	0.22	0.10
Organic N (TKN-NH_3)–Epi (mg/L)	1.09	1.24		1.41	1.25	0.16	0.08
TN–Epi (mg/L)	1.12	1.31		1.75	1.39	0.32	0.13
Ortho-Phosphorus–Epi (mg/L)	0.01	0.01	0.01	0.01	0.01	0.00	0.00
TP–Epi (mg/L)	0.03	0.05	0.04		0.04	0.01	0.12
TP minus OP–Epi (mg/L)	0.02	0.04	0.03		0.03	0.01	0.20
Ammonia–Avg of Epi and Hypo (mg/L)	2.44	1.19	2.33	1.34	1.83	0.65	0.18
Nitrite plus Nitrate–Avg of Epi and Hypo (mg/L)	0.01	0.03		0.17	0.07	0.08	0.72
TKN–Avg of Epi and Hypo (mg/L)	3.84	2.61	2.42	2.52	2.85	0.66	0.12
Organic N (TKN-NH_3)–Avg of Epi and Hypo (mg/L)	1.39	1.41	0.09	1.18	1.02	0.63	0.31
TN–Avg of Epi and Hypo (mg/L)	3.85	2.63		2.69	3.06	0.69	0.13
Ortho-Phosphorus–Avg of Epi and Hypo (mg/L)	0.02	0.01	0.08	0.21[b]	0.04	0.04	0.54
TP–Avg of Epi and Hypo (mg/L)	0.04	0.06	0.11		0.07	0.03	0.27
TP minus OP–Avg of Epi and Hypo (mg/L)	0.02	0.04	0.03		0.03	0.01	0.22
Chl-*a* (µg/L)	15.89	31.69	19.09	22.27	22.23	6.82	0.16
Total Suspended Solids (mg/L)					6.9[a]		
Secchi Depth (m)	0.90	0.50	1.00	0.40	0.70	0.29	0.21

Notes: [a] Based on the only available sampling data in 2006.
[b] Outlier, not accounted for in the calculation of mean and CV.
Avg = average; Epi = epilimnion; Hypo = hypolimnion; mg/L = milligrams per lit; µg/L = micrograms per liter

3.2.2 Assessing In-Lake Water Quality Data

The BATHTUB User Manual (Walker 1999) provides several diagnostic variables to determine the most important eutrophication response variables (i.e., does algal growth depend more on the availability of nitrogen, phosphorus, or light). Use appendix B from the BATHTUB User Manual (Table 4-5 in the manual) along with water quality data to answer the following questions:

1. Is the lake nitrogen- or phosphorus-limited?
2. Does the lake have a low or high eutrophication potential (i.e., based on the mean in-lake nutrient concentrations and light availability, do we expect excessive algal growth)? Is light an important limiting factor?
3. Is the light availability for this lake high or low?

3.2.2.1 Determine if Lake is Nitrogen- or Phosphorus-Limited

To determine if a lake is nitrogen- or phosphorus-limited, two methods can be used. The applicability of each method depends on the availability of water quality data. Also, for shallow lakes (an average depth less than 3 meters), both epilimnion and hypolimnion layer data should be used; for deep lakes (an average depth more than 3 meters), only the epilimnion layer data should be used to evaluate summer conditions, when the lake is stratified, but both epilimnion and hypolimnion layer data should be used to evaluate annual average conditions for deep lakes.

The first method is a simple calculation of (TN-150)/TP (units of TN and TP are milligrams per cubic meter (mg/m^3) or µg/L). Based on the ranges presented in appendix B, (TN-150)/TP values greater than 15 indicate the lake is phosphorus-limited. From Table 1, for Lake Manitou, TN = 3.06 mg/L (3,060 µg/L); TP = 0.07 mg/L (70 µg/L). Therefore (TN-150)/TP = 41.6, well above 15, indicating Lake Manitou is phosphorus-limited.

The second method is to calculate the ratio of inorganic nitrogen to ortho-phosphorus (units are mg/m^3 or µg/L). A ratio of inorganic nitrogen to ortho-phosphorus greater than 10 indicates the lake is phosphorus-limited. For Lake Manitou, inorganic nitrogen = ammonia nitrogen + nitrite nitrogen + nitrate nitrogen = 1.90 mg/L (1,900 µg/L); ortho-phosphorus = 0.04 mg/L (40 µg/L). The ratio of inorganic nitrogen to ortho-phosphorus is 47.5, which is greater than 10 and indicates that Lake Manitou is phosphorus-limited.

For Lake Manitou, considering its average depth is 3 meters, which indicates it is a shallow lake, meaning stratification in summer months does not significantly affect the lake's overall water quality conditions.

3.2.2.2 Evaluate Lake's Eutrophication Potential and Whether Light is an Important Factor

First and second principal components (PC-1 and PC-2) can be used to evaluate the eutrophication potential of the waterbody. The 1999 BATHTUB User Manual defines equations for PC-1 and PC-2 on page 4-12, and the values of PC-1 and PC-2 are calculated using the equations listed in Figure 7.

<u>Principal Components</u>

With Chl *a*, Secchi, Nutrient, & Organic Nitrogen Data:

$$PC\text{-}1 = 0.554 \log(B) + 0.359 \log(Norg) + 0.583 \log(Xpn) - 0.474 \log(S)$$

$$PC\text{-}2 = 0.689 \log(B) + 0.162 \log(Norg) - 0.205 \log(Xpn) + 0.676 \log(S)$$

With Chl *a* and Secchi Data Only:

$$PC\text{-}1 = 1.47 + 0.949 \log(B) - 0.932 \log(S)$$

$$PC\text{-}2 = 0.13 + 0.673 \log(B) + 0.779 \log(S)$$

Figure 7. Equations for principal components analysis (*Source*: Walker 1999).

For these equations, the variables are defined as:

- B = Chl-*a* concentration (mg/m^3 or µg/L)
- Norg = Organic nitrogen concentration (mg/m3 or µg/L) (calculated as TKN minus ammonia)
- Xpn = Composite nutrient concentration (mg/m3 or µg/L); assume it is equal to TP concentration if phosphorus-limited (see definition of C. NUTRIENT in appendix B)
- S = Secchi depth (m)

For Lake Manitou, based on the observed water quality mean concentrations in Table 1:

- B = 22.23 µg/L
- Norg = 1,020 µg/L
- Xpn = 70 µg/L
- S = 0.7 m

Using the first set of equations in Figure 7 for the Lake Manitou example, PC-1 = 2.98 and PC-2 = 0.932. The second set of equations calculates the antilog of each value for Lake Manitou: Anti Log (PC-1) = 945; Anti Log (PC-2) = 9.

Refer to the range of values listed in appendix B:

- A value of Anti Log (PC-1) greater than 500 indicates high nutrient supply and high eutrophication potential.
- A value of Anti Log (PC-2) greater than 10 indicates plenty of light is available and not a limiting factor, water turbidity is algae-dominated, and there is a high response to nutrient level—meaning algae growth and water turbidity will increase when the nutrient level increases. A value of Anti Log (PC-2) less than 4 means light is a limiting factor, water turbidity is not algae-dominated, and there is a low response to nutrient level—meaning water turbidity will not be significantly affected by nutrient level.

The calculated Anti Log (PC-1) and Anti Log (PC-2) values for Lake Manitou suggest that the lake has a large nutrient load and high eutrophication potential because Anti Log PC-1 = 945, which is greater than 500. Additionally, light is not a limiting factor, because Anti Log PC-2 = 9, much greater than 4. However, because Anti Log PC-2 = 9, which is only slightly less than 10, it indicates water turbidity is somewhat related to algae and can increase as the nutrient level increases.

3.2.2.3 Evaluate Light Availability

There are three ways to evaluate light availability:

- Nonalgal turbidity is an indicator for nonalgal-related light availability. Nonalgal turbidity can be estimated as (1/Secchi − 0.025 x chl-*a*).
    - A value less than 0.4 (1/m) indicates high light availability and high algal response to nutrients.
    - A value greater than 1 (1/m) means low light availability and low algal response to nutrients.

- The product of mixed layer depth (Zmix) and nonalgal turbidity can indicate the effect of turbidity on light intensity in the mixed layer.

- A value of less than 3 indicates high light availability in the mixed layer and high algal response to nutrients.
- A value greater than 6 indicates low light availability in the mixed layer and low algal response to nutrients.

- If chl-*a* data are not available, then Zmix divided by Secchi depth (unitless) can be used to evaluate light availability, as follows:
  - A value of Zmix divided by Secchi depth of less than 3 indicates high light availability and high algal response to nutrients.
  - A value of Zmix divided by Secchi depth greater than 6 indicates low light availability and low algal response to nutrients.

For Lake Manitou, nonalgal turbidity is calculated as 1/0.7 − 0.025 x 22.23 = 0.87(1/m), which is between 0.4 and 1 (1/m), indicating color and/or inorganic suspended solids are in the medium range and medium algal response to nutrients. In addition, Zmix x nonalgal turbidity = 1.37 (m) x 0.87 (1/m) = 1.19, which is less than 3. This indicates the effect of turbidity on light intensity in the mixed layer is low, and the mixed layer has high algal response to nutrients. Also, Zmix/Secchi = 1.37 (m) /0.7 (m) = 1.96, which is less than 3, confirms that high algal response to nutrients is expected.

3.3 Flow and Pollutant Loading Data

Flow and pollutant loading to a waterbody can include inputs associated with major tributaries, septic systems, overland flow from direct drainage areas, and point sources. These sources might be monitored or might be approximated using a statistical method and/or model.

This section includes instructions on how to compile the required flow and pollutant loading data for the BATHTUB model.

3.3.1 Lake Drainage Area Delineation

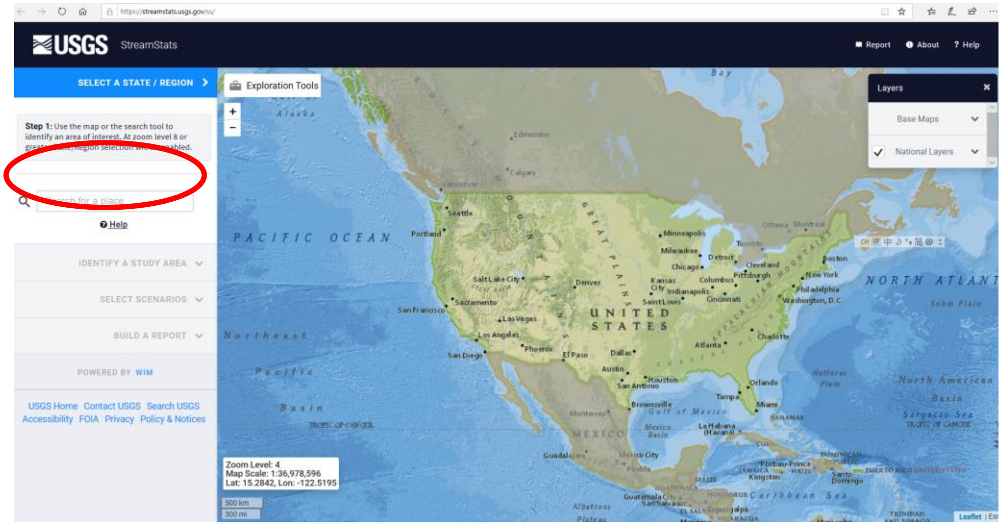
The area that drains to the waterbody must be delineated to determine the entire watershed area that might impact the hydrologic and water quality conditions observed in the lake. The drainage area might consist of several tributary subwatersheds. Depending on the segmentation scheme of the lake BATHTUB model and sediment and nutrients delivery ratio variability of different subwatersheds, the drainage areas of various tributaries may be aggregated.

Occasionally, boundaries for lake drainage areas have been determined in earlier studies or analyses, and if available, these may be used directly. If drainage area boundaries are not available from earlier studies or through online resources, we recommend using the online USGS StreamStats drainage area delineation tool.

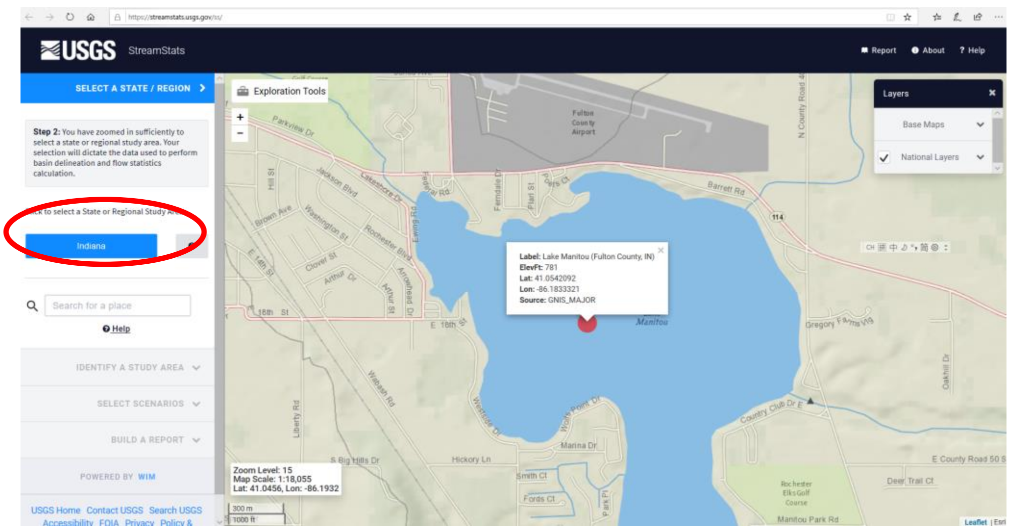
STEPS FOR USING THE USGS STREAMSTATS DRAINAGE AREA DELINEATION TOOL

Step 1: Go to the map-based user interface on the USGS StreamStats website (https://streamstats.usgs.gov/ss/).

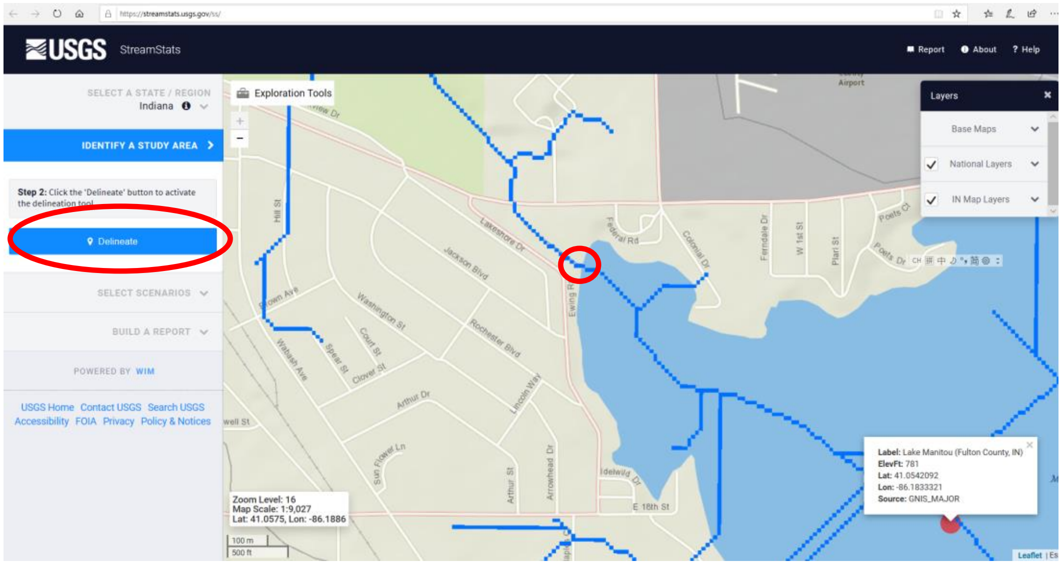
Step 2: Enter the place of interest in the "search for a place" box. For this case study example, enter "Lake Manitou, IN."



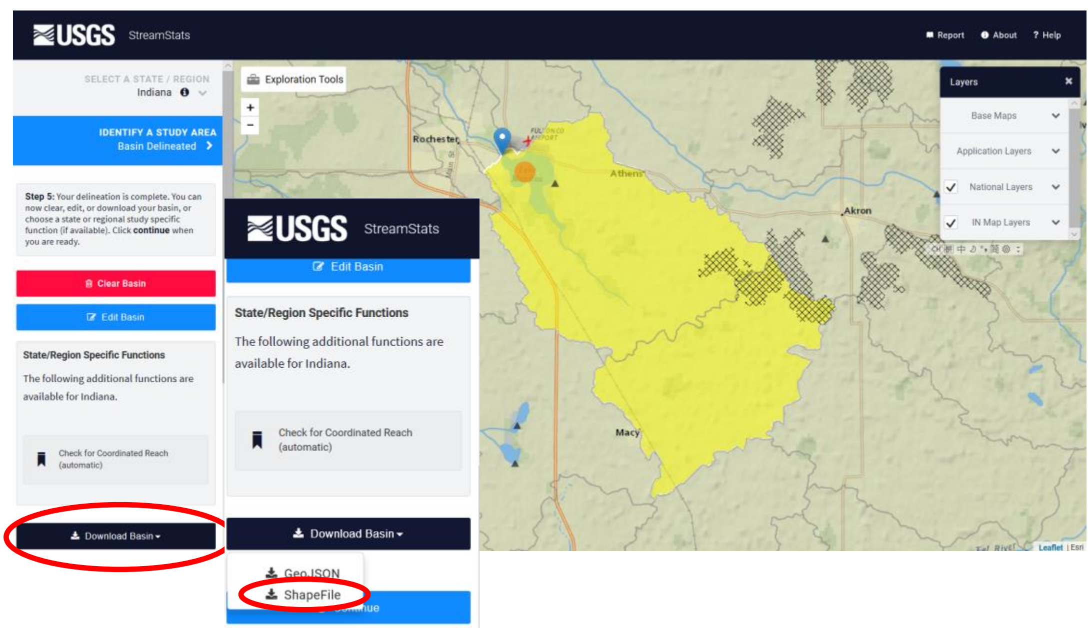
Step 3: Select a state/regional study area. For this case study example, choose "Indiana."



Step 4: Click the blue “Delineate” button and move the cursor to the blue grid at the lake outlet.



Step 5: Click the black “Download Basin” button and choose the “Shapefile” option to download the delineated drainage area boundary shapefile. Then save the shapefile in a desired location.



After the drainage area is delineated, it is often helpful to tabulate the land-use areas in each subwatershed because different land use types are associated with different flow and nutrient loads to the waterbody (for example, a lake watershed that has a lot of agriculture might have higher nutrient loading rates associated with watershed nonpoint source loading than a watershed that is highly forested or natural). Lake Manitou’s drainage area land-use distribution is tabulated in ArcGIS based on the 2018 Cropland Data Layer provided by IDEM and presented in Table 2.

Table 2. Lake Manitou Drainage Area Land Use Distribution

Land Use	Area		Percent
	Acres	km^2	
Agriculture–Corn	9,532	38.6	33.7%
Agriculture–Soybeans	8,290	33.5	29.3%
Agriculture–Other	208	0.8	0.7%
Hay/Pasture	2,941	11.9	10.4%
Developed/Open Space	1,647	6.7	5.8%
Developed/Low Intensity	477	1.9	1.7%
Developed/Med Intensity	101	0.4	0.4%
Developed/High Intensity	29	0.1	0.1%
Open Water	798	3.2	2.8%
Shrubland	189	0.8	0.7%
Wetlands	549	2.2	1.9%
Forest	3,529	14.3	12.5%
TOTAL	28,290	114.5	100.0%

3.3.2 Flow Estimation

There are potentially a number of ways that flow can be estimated for BATHTUB model input. Two flow estimation methods are described in this section. One method is using directly observed flow data from USGS gages. The other is using a land-use-based estimation with STEPL.

3.3.2.1 Using Flow Data from USGS Gages for Flow Estimation

When there are active USGS gages in the watershed or in a neighboring "surrogate" watershed, the measured flow data can be used to estimate flow to the lake/reservoir.

Using a neighboring surrogate watershed is a standard practice for ungaged watersheds and is appropriate when the two watersheds are located close to one another and have similar areas, land use, topography, soil characteristics, and precipitation patterns.

Flows are estimated using the following equation:

$$Q_{ungaged} = \frac{A_{ungaged}}{A_{gaged}} \times Q_{gaged}$$

where:

$Q_{ungaged}$	Flow at the ungaged location
Q_{gaged}	Flow at surrogate USGS gage station
$A_{ungaged}$	Drainage area of the ungaged location
A_{gaged}	Drainage area of the gaged location

In this procedure, the drainage area of interest is divided by the drainage area of the surrogate USGS gage. The flows for each drainage area are then calculated by multiplying the flows at the surrogate gage by the drainage area ratios. Additional flows can be added to certain locations to account for sources such as wastewater treatment plants (WWTPs) that discharge upstream and are not directly accounted for using the drainage area weighting method.

3.3.2.2 Using STEPL for Flow Estimation

For drainage areas that do not have readily available USGS flow gaging stations or suitable surrogate flow gages, or watershed models, simple calculation methods are necessary for estimating the inflow and pollutant loadings. STEPL is a simple spreadsheet tool that can serve this purpose. More information about STEPL is provided in appendix D.

One advantage of STEPL is that it includes a suite of default databases providing the necessary input information (e.g., precipitation data, default runoff nutrients concentrations for various land use types, default groundwater nutrients concentrations, and default soil erosion parameters). The user only needs to provide a minimum of site-specific data, which are:

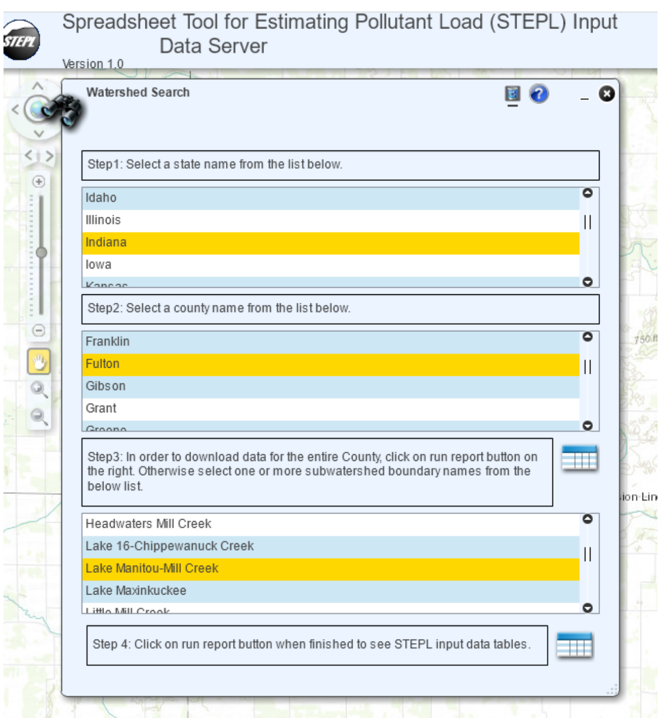
- Land use areas
- Total number of animals by type
- Number of months per year that manure is applied to croplands
- Representative hydrologic soil group (HSG)

The STEPL Input Data Server can further support users in compiling site-specific data. The steps for using the Input Data Server to obtain the data for Lake Manitou are provided below.

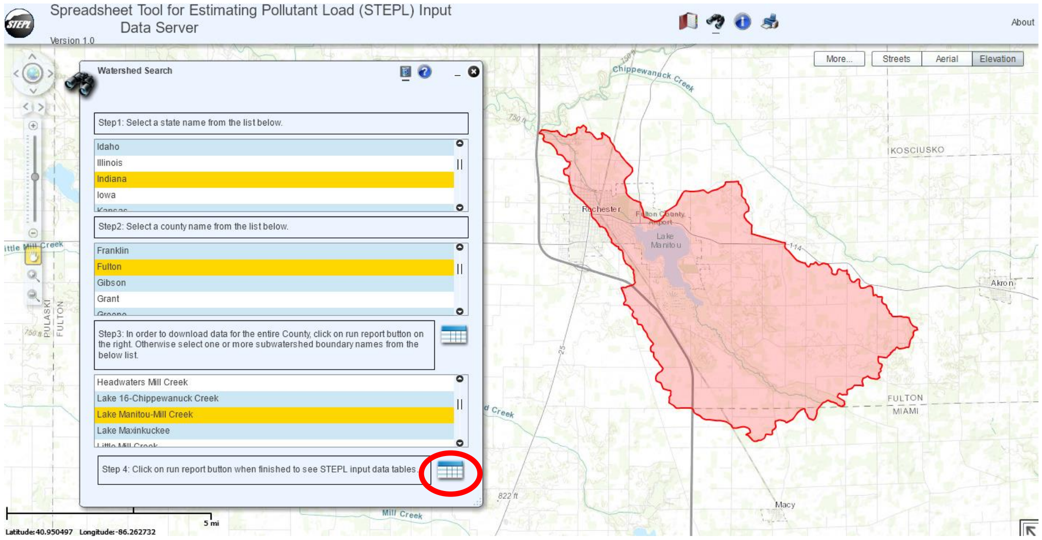
STEPS FOR USING THE STEPL INPUT DATA SERVER

Step 1: Access the Input Data Server at http://it.tetratech-ffx.com/steplweb/steplweb.html.

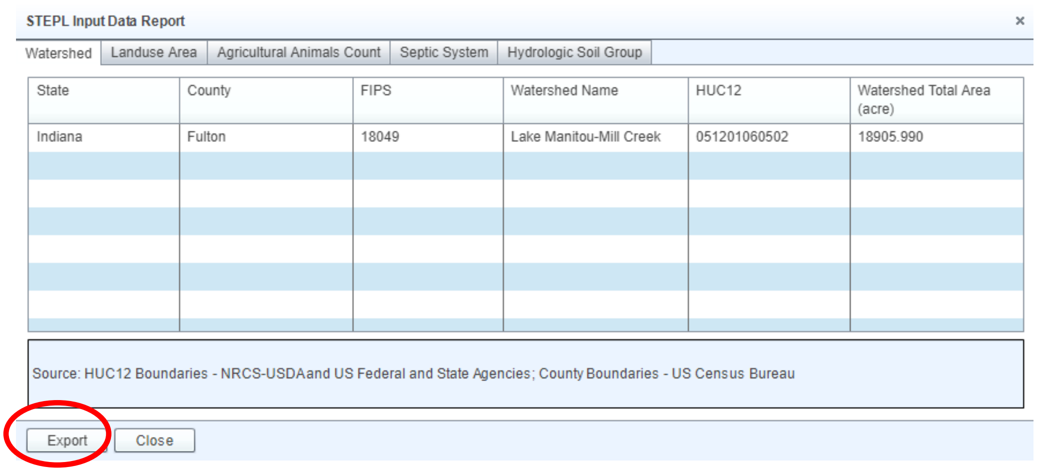
Step 2: Select the state, county, and subwatershed names. For Lake Manitou, select “Indiana,” “Fulton,” and “Lake Manitou-Mill Creek.”



Step 3: Click the "Run Report" button at the bottom of the form to see the STEPL input data tables. This button is shown in the screenshot as the table/chart circled in red.



Step 4: Export the STEPL input data tables by clicking the "Export" button at the bottom of the form shown below, then name and save the file to a user-specified directory.



STEPL Input Data Report

Watershed | Landuse Area | Agricultural Animals Count | Septic System | Hydrologic Soil Group

State	County	FIPS	Watershed Name	HUC12	Watershed Total Area (acre)
Indiana	Fulton	18049	Lake Manitou-Mill Creek	051201060502	18905.990

Source: HUC12 Boundaries - NRCS-USDAand US Federal and State Agencies; County Boundaries - US Census Bureau

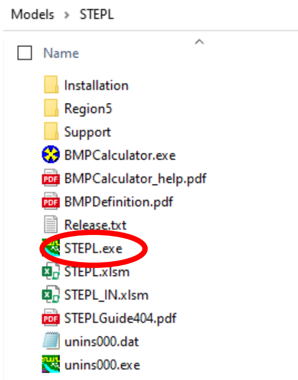
Export Close

As shown on the tabs of the STEPL Input Data Report, the input data tables include watershed information, land-use area, a count of agricultural animals, septic system, and HSG.

STEPS FOR USING STEPL FOR FLOW ESTIMATION

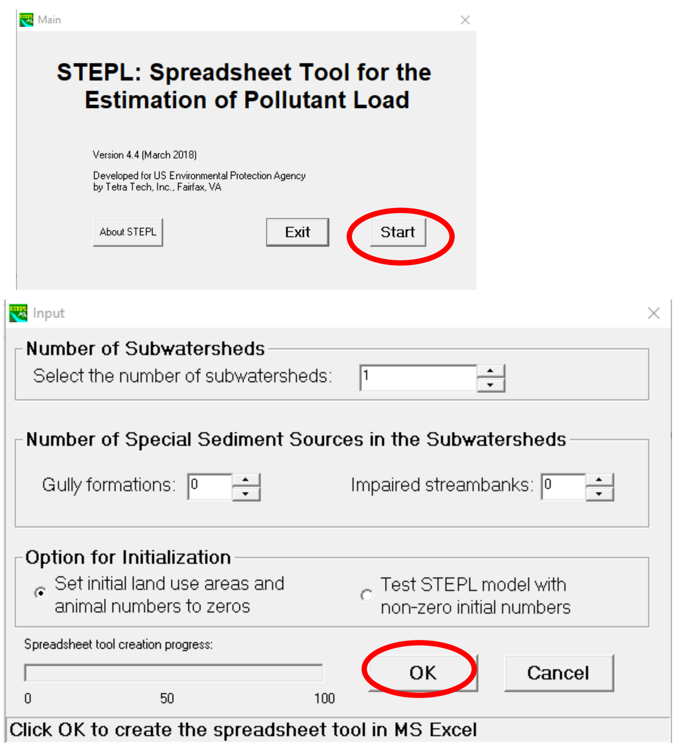
Step 1: Download the installation package from the EPA website (https://www.epa.gov/nps/spreadsheet-tool-estimating-pollutant-loads-stepl) and then install STEPL in a user-specified directory on your computer.

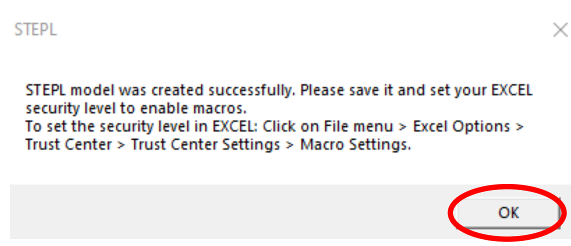
Step 2: Start the model by double-clicking "STEPL.exe" from the list below.



Step 3: Build a new STEPL project by clicking the "Start" button on the STEPL Main screen. On the Input screen, click the "OK" button.

Note: The new STEPL project has one subwatershed, and not considering gully formation and impaired streambanks, and the initial land-use areas and animal numbers are set to zero. Then save the STEPL Excel file. It is recommended the Excel file be renamed for each project. Also follow the instructions on the pop-up window to enable macros.





Step 4: Complete the input sheet following the sequence from #1 to #8 as shown below. The sheet is self-explanatory. **The red text/numbers are user input**, and the black numbers are predefined or calculated.

In the case of Lake Manitou (located in Indiana, Fulton County), the IN-Fulton_Mean weather station is selected. The groundwater load calculation is also included. The watershed land-use areas (#2 and #7) are calculated in ArcGIS using the land-use map and watershed boundary map, with the animal counts (#3), septic data (#4), and HSG (#6) being based on data exported from the STEPL online data server (as described earlier in this section). Note that in the screenshots below, STEPL uses SHG to mean the same as HSG. The Universal Soil Loss Equation parameter numbers (#5) can be obtained based on local knowledge or literature values. Irrigation data (#8) is estimated based on the irrigation water use data from the 2018 Census of Agriculture, which is available from the U.S. Department of Agriculture's National Agricultural Statistics Service. The direct link to the irrigation water use data table is https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris_1_0004_0004.pdf. This table provides the acreage of the irrigated farmland by state. The 2018 irrigated farmland in Indiana is 582,661 acres. The total farmland area in Indiana is estimated as 14,720,396 acres in year 2012 as published on the Farmland Information Center website (https://farmlandinfo.org/statistics/indiana-statistics/#Census%20of%20Agriculture). The ratio of farmland irrigated to the total area is estimated as 582,661 acres divided by 14,720,396 acres, which equals to 4.0%. The ratio (4.0%) was used to estimate the irrigated cropland area (#8).

Export input/output data [Export Data] ☐ Treat all the subwatersheds as parts of a single watershed ☑ Groundwater load calculation

#1

State: Indiana | County: Fulton | Weather Station: _IN-Fulton_Mean | Calculate Manure Application Months [Manure Application]

#2

1. Input watershed land use area (ac) and precipitation (in)

									Rain correction factors 0.880	0.496	
Watershed	Urban	Cropland	Pastureland	Forest	User Defined	Feedlots	Feedlot Percent Paved	Total	Annual Rainfall	Rain Days	Avg. Rain/Event
W1	2254	18030	2941	3529	0	2.434	0-24%	26756.434	38	114	0.595

2. Input agricultural animals

Watershed	Beef Cattle	Dairy Cattle	Swine (Hog)	Sheep	Horse	Chicken	Turkey	Duck	# of months manure applied on Cropland	# of months manure applied on Pastureland
W1	567	266	5139	87	73	122	8	0	1	1
Total	567	266	5139	87	73	122	8	0		

#3

3. Input septic system and illegal direct wastewater discharge data

Watershed	No. of Septic Systems	Population per Septic System	Septic Failure Rate, %	Wastewater Direct Discharge, # of People	Direct Discharge Reduction, %
W1	1178	2	1.09	0	0

#4

4. Modify the Universal Soil Loss Equation (USLE) parameters

Watershed	Cropland					Pastureland					Forest					User Defined				
	R	K	LS	C	P	R	K	LS	C	P	R	K	LS	C	P	R	K	LS	C	P
W1	160.000	0.250	0.150	0.150	1.000	160.000	0.250	0.150	0.040	1.000	160.000	0.250	0.150	0.003	1.000	160.000	0.250	0.150	0.150	1.000

Optional Data Input:

#5

5. Select average soil hydrologic group (SHG), SHG A = highest infiltration and SHG D = lowest infiltration

Watershed	SHG A	SHG B	SHG C	SHG D	SHG Selected	Soil N conc.%	Soil P conc.%	Soil BOD conc.%	Soil E. coli conc. (#/100mg)
W1					C	0.080	0.031	0.160	0.000

#6

6. Reference runoff curve number (may be modified)

SHG	A	B	C	D
Urban	83	89	92	93
Cropland	67	78	85	89
Pastureland	49	69	79	84
Forest	39	60	73	79
User Defined	50	70	80	85

6a. Detailed urban reference runoff curve number (may be modified)

Urban\SHG	A	B	C	D
Commercial	89	92	94	95
Industrial	81	88	91	93
Institutional	81	88	91	93
Transportatio	98	98	98	98
Multi-Family	77	85	90	92
Single-Family	57	72	81	86
Urban-Cultiva	67	78	85	89
Vacant-Deve	77	85	90	92
Open Space	49	69	79	84

7. Nutrient concentration in runoff (mg/l) and E. coli (MPN/100ml)

Land use	N	P	BOD	E. coli
1. L-Croplar	**1.9**	**0.3**	**4**	0
1a. w/ manur	8.1	2	12.3	0
2. M-Cropla	**2.9**	**0.4**	**6.1**	0
2a. w/ manur	12.2	3	18.5	0
3. H-Croplar	**4.4**	**0.5**	**9.2**	0
3a. w/ manur	18.3	4	24.6	0
4. Pastureland (see Table 10 for default values with manure)				
5. Forest	**0.2**	**0.1**	**0.5**	0
6. User Defi	**0**	**0**	**0**	0

7a. Nutrient concentration in shallow groundwater (mg/l) and E. coli (MPN/100ml)(may be modified)

Landuse	N	P	BOD	E. coli
Urban	1.5	0.063	0	0
Cropland	1.44	0.063	0	0
Pastureland	1.44	0.063	0	0
Forest	0.11	0.009	0	0
Feedlot	6	0.07	0	0
User-Defined	0	0	0	0

#7

8. Input or modify urban land use distribution

Watershed	Urban Area (ac.)	Commercial %	Industrial %	Institutional %	Transportation %	Multi-Family %	Single-Family %	Urban-Cultivated	Vacant (develope	Open Space %	Total % Area
W1	2254	0.2	0.2	0.2	0.6	4.5	21.2	0	0	73.1	100

#8

9. Input irrigation area (ac) and irrigation amount (in)

Watershed	Total Cropland (ac)	Cropland: Acres Irrigated	Water Depth (in) per Irrigation - Before	Water Depth (in) per Irrigation - After BMP	Irrigation Frequency (#/Year)
W1	18030	721.2	1	1	5

10. Pastureland Nutrient concentration in runoff (mg/l) and E. coli (MPN/100ml)

Land use	N	P	BOD	E. coli
1. L-Pasture	**4**	**0.3**	**13**	0
1a. w/ manur	4	0.3	13	0
2. M-Pastur	**4**	**0.3**	**13**	0
2a. w/ manur	4	0.3	13	0
3. H-Pasture	**4**	**0.3**	**13**	0
3a. w/ manur	4	0.3	13	0

Input Ends Here.

Step 5: Right-click the workbook bar at the bottom of the screen to unhide the "Land&Rain" worksheet. Go to the "Land&Rain" worksheet and note the "Tot Runoff Vol" in "Table 4. Annual runoff by land uses (ac-ft)." In the case of Lake Manitou, the total annual runoff volume is 18,231.1 acre-feet (ac-ft).

Land Use and Precipitation

You entered 1 subwatersheds in this project.
Areas listed below are in acres, and average annual precipitation is in inches.
SHG: Soil Hydrologic Group

Go to "STEPL" menu for correction factors

1. Input watershed land use area (ac) and precipitation (in)

Watershed	Urban	Cropland	Pastureland	Forest	User Defined	Feedlots	Total	Annual Rainfall	Rain Days	Avg. Rain/event
								0.8800866	0.4959557	0
W1	2254	18030	2941	3529	0	2.434	26756.434	38.1	114	0.595
							Sum= ####			

2. Select average soil hydrologic group

Watershed	SHG A	SHG B	SHG C	SHG D	Selected
W1					C

3. Reference runoff curve number (may be modified)

SHG	A	B	C	D
Urban	83	89	92	93
Cropland	67	78	85	89
Pastureland	49	69	79	84
Forest	39	60	73	79
User Defined	50	70	80	85

4. Annual runoff by land uses (ac-ft)

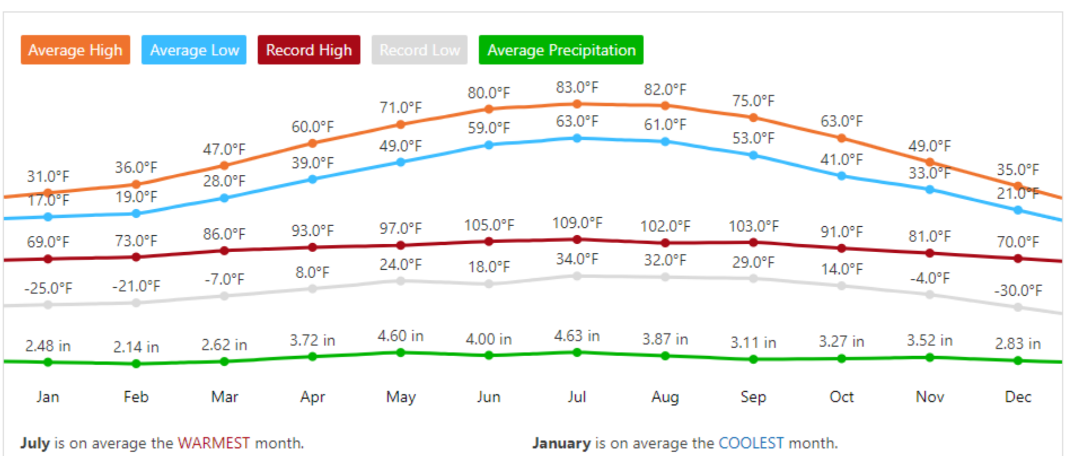
Watershed	Urban	Cropland	Pastureland	Forest	User Defined	Tot Runoff Vol
W1	2557.4	12805.6	1502.3	1365.8	0.0	18231.1

5. Nutrient concentration in runoff (mg/l)

	N	P	BOD	E. coli
Pastureland	0	0	0	0
Forest	0.2	0.1	0.5	0
User Defined	0	0	0	0

Input | Land&Rain | Sheet1 | BMPs | Total Load | Graphs | CountyData

STEPL provides only annual runoff volume. Therefore, to further estimate monthly or summer (June–August) runoff volumes, the user needs average monthly precipitation data. One potential source for monthly precipitation data is www.weather.com. For Lake Manitou (Fulton County, IN), the monthly precipitation is shown as the green line in the screenshot below. The monthly or summer runoff can be calculated using the precipitation monthly distribution. For example, for Lake Manitou, the total precipitation for June–August is 12.5 inches and the total annual precipitation is 40.79 inches. Therefore, the summer runoff volume is 18,231.1 ac-ft x (12.5/40.79) = 18,231.1 x 0.31 = 5,614.5 ac-ft.



3.3.3 Pollutant Loading Estimation

Pollutant sources include the following categories:

- Watershed nonpoint sources from tributaries and direct drainage areas
- Point sources
- Internal loading
- Atmospheric deposition

This section describes the processes for estimating loadings from each potential pollutant loading source.

3.3.3.1 Watershed Nonpoint Source Pollutant Loading

Nonpoint sources include all other categories not classified as point sources and represent more diffuse or not specifically regulated inflows. In rural areas, nonpoint sources can include runoff from cropland, pastures, and animal feeding operations and inputs from streambank erosion, leaking or failing septic systems, and wildlife. In urban areas, nonpoint sources can include leaking or faulty septic systems, runoff from lawn fertilizer applications, pet waste, stormwater runoff, and other sources. Nonpoint sources may be overland flow or occur underground as groundwater inflows into the waterbody from surrounding lands.

Two types of methods for estimating nonpoint sources pollutant loadings are common. If continuous (e.g., daily) flow data and grab sample water quality concentration data are available for the time period of interest, then a flow-weighted loading calculation is recommended. Otherwise, watershed modeling or simple nonpoint source loading estimation is warranted.

For the flow-weighted loading calculation, FLUX32 can be used. FLUX32 is a Windows-based revision to the original DOS-based FLUX. As stated in the FLUX32 help file (Soballe and MPCA 2017):

> It is an interactive software designed for use in estimating the transport (load) of nutrients or other water quality constituents past a tributary sampling station over a given period. These estimates can be used in formulating reservoir nutrient balances over annual or seasonal averaging periods appropriate for application of empirical eutrophication models. Data requirements include (a) grab-sample nutrient concentrations, typically measured at a weekly to monthly frequency for a period of at least 1 year, (b) corresponding flow measurements (instantaneous or daily mean values), and (c) a complete flow record (mean daily flows) for the period of interest. FLUX32 can be viewed as a calculation engine. In general, it uses flow and concentration data to calculate a load (or time series of loads) for a single parameter at a single location over a single period of record. To use it for multiple parameters, multiple sites, and multiple periods of record generally requires multiple instances of Flux to be run and these can be run simultaneously.

The FLUX32 model can be downloaded for free from https://www.pca.state.mn.us/wplmn/flux32. FLUX32 is easy to use and the installation package comes with a comprehensive help file. Therefore, detailed instructions on how to use FLUX32 are omitted here.

For most lakes in Indiana, continuous flow data and grab sample water quality concentration data are not available. In these cases, a watershed model or simple calculation methods are needed to estimate watershed nonpoint source loadings. Developing a comprehensive watershed model requires substantial effort. When a watershed model already exists for the lake of interest, it is recommended as the preferred means for estimating the nonpoint source loadings. For lakes that do not have a watershed model and resources are not available to develop a comprehensive watershed model, a simple calculation method is suggested. STEPL can serve this purpose. As introduced in section 3.3.2, STEPL is a simple spreadsheet tool for watershed flow and pollutant loading estimation. Section 3.3.2.2 detailed the steps of applying STEPL. After completing the input data in step 3 (USING STEPL FOR FLOW ESTIMATION) in section 3.3.2.2, view the watershed loading results on the “Total Load” worksheet, as shown below. Again, the total load is the annual loading. For seasonal or monthly loading, the annual loadings need to be prorated by the precipitation data. For Lake Manitou, the summer (June–August) precipitation is approximately 31 percent of the annual precipitation; therefore, the summer loadings can be estimated by multiplying the annual loading by 31 percent. Specifically, TN loading during the summer (June–August) is 162,231.0 x 31% = 50,291.6 pounds (lbs); TP loading during the summer (June–August) is 24,252.1 x 31% = 7,518.2 lbs. The pollutant loads by land use and other sources are also listed in the second table on the “Total Load” worksheet.

Total Load This is the summary of annual nutrient and sediment load for each subwatershed. This sheet is initially protected.

1. Total load by subwatershed(s)

Watershed	N Load (no BMP)	P Load (no BMP)	BOD Load (no BMP)	Sediment Load (no BMP)	E. coli Load (no BMP)	N Reduction	P Reduction	BOD Reduction	Sediment Reduction	E. coli Reduction	N Load (with BMP)	P Load (with BMP)	BOD (with BMP)	Sediment Load (with BMP)	E. coli Load (with BMP)
	lb/year	lb/year	lb/year	t/year	Billion MPN/ye	lb/year	lb/year	lb/year	t/year	Billion MPN/y	lb/year	lb/year	lb/year	t/year	Billion MPN/ye
W1	162231.9	24252.1	267297.5	2268.8	0.0	0.0	0.0	0.0	0.0	0.(	162231.9	24252.1	267297.5	2268.8	0.0
Total	162231.9	24252.1	267297.5	2268.8	0.0	0.0	0.0	0.0	0.0	0.(	162231.9	24252.1	267297.5	2268.8	0.0

2. Total load by land uses (with BMP)

Sources	N Load (lb/yr)	P Load (lb/yr)	BOD Load (lb/yr)	Sediment Load (t/yr)	E. coli Load (Billion MPN/yr)
Urban	5953.14	794.47	20251.00	137.71	0.00
Cropland	90594.10	17873.57	176259.17	2034.57	0.00
Pastureland	16610.03	1333.54	53628.59	88.50	0.00
Forest	767.69	380.91	1906.48	7.96	0.00
Feedlots	10433.01	2086.60	13910.68	0.00	0.00
User Defined	0.00	0.00	0.00	0.00	0.00
Septic	328.54	128.68	1341.55	0.00	0.00
Gully	0.00	0.00	0.00	0.00	0.00
Streambank	0.00	0.00	0.00	0.00	0.00
Groundwater	37545.44	1654.29	0.00	0.00	0.00
Total	162231.94	24252.07	267297.47	2268.75	0.0(

Input | Land&Rain | Sheet1 | BMPs | Total Load | Graphs | CountyData | WeatherData | CombinedBMPEfficiency

STEPS FOR USING STEPL TO ESTIMATE POLLUTANT LOADING WITH EXISTING BEST MANAGEMENT PRACTICES

In cases in which substantial best management practices (BMPs) are implemented in the watershed, it is necessary to represent the load reductions achieved by those BMPs. For example, crop land nutrient management and conservation tillage can significantly reduce the nutrients concentration in the runoff, thus reduce the watershed nonpoint source pollutant loadings. Based on the "BMPs_Installs_Statewide" GIS data provided by IDEM, a significant number of BMPs have been implemented statewide, although none have been implemented in the Lake Manitou watershed. Therefore, it is important to include instructions on representing BMPs in the pollutant load reduction in this guidance document.

STEPL has a built-in mechanism to represent BMPs. The detailed instructions for estimating pollutant load reduction associated with BMPs in STEPL is included in the STEPL 4.4 User's Guide (http://it.tetratech-ffx.com/steplweb/STEPLmain_files/STEPLGuide404.pdf). A brief step-by-step instruction is provided here for easy reference, for which you may also reference the screenshots below:

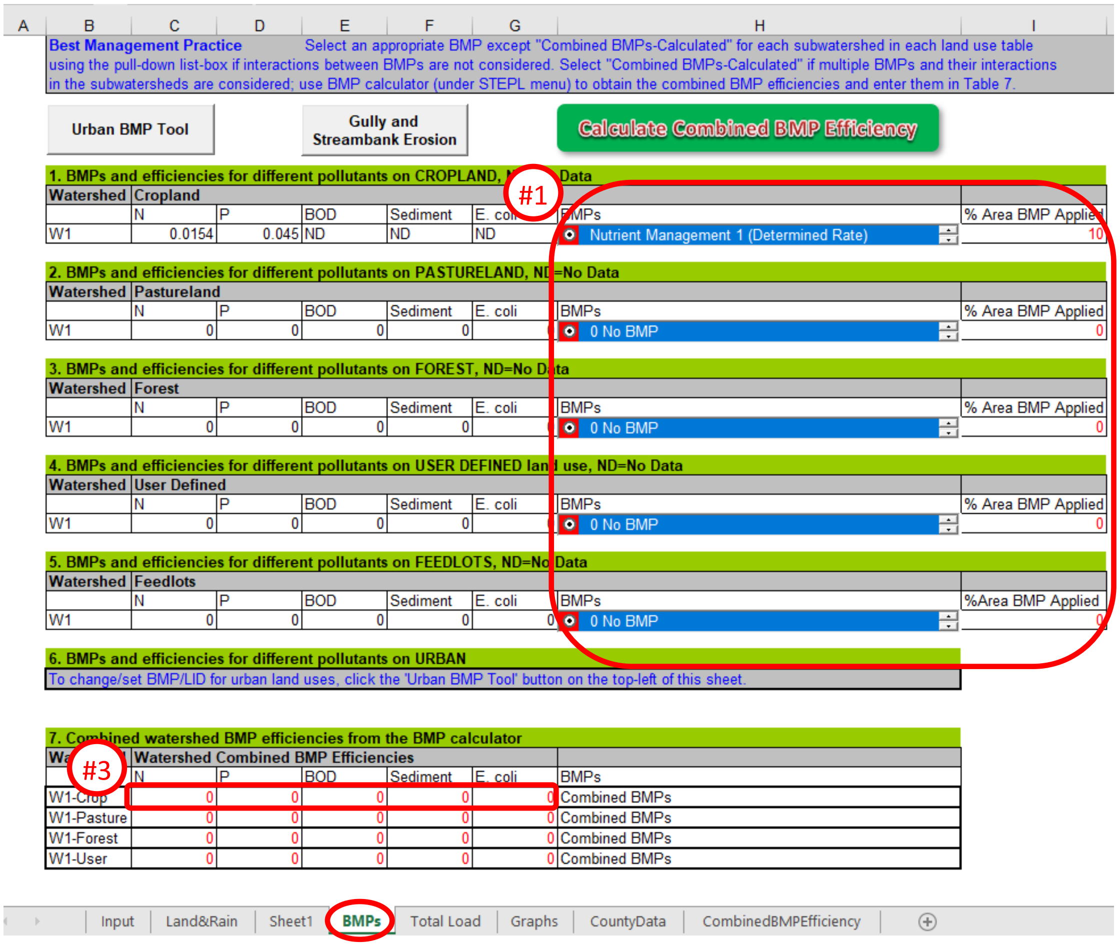
Step 1: Open the "BMPs" tab, select BMPs for different land uses, and specify "% Area BMP Applied."

Note: Only one BMP can be specified for one land-use type in one subwatershed. If there are multiple BMPs for one land use in one subwatershed, then the combined BMP efficiencies need to be calculated in the "CombinedBMPEfficiency" tab in Step 2. Otherwise, this is the only step needed for representing BMPs that are nonurban and not gully- and streambank erosion-related. For urban BMPs and BMPs for gully and streambank erosion prevention, refer to STEPL 4.4 User's Guide.

Step 2: Open the "CombinedBMPEfficiency" worksheet and specify the areas and corresponding BMP types from the BMP pull-down list boxes for the land use to which multiple BMPs are applied.

Step 3: Copy the calculated combined BMP efficiencies (blue numbers) from the bottom of the "CombinedBMPEfficieny" worksheet and paste them into Table 7 of the "BMPs" worksheet for the corresponding subwatershed and land-use combination.

Step 4: View the pollutant reductions with BMPs on the "Total Load" worksheet.



Best Management Practice Select an appropriate BMP except "Combined BMPs-Calculated" for each subwatershed in each land use table using the pull-down list-box if interactions between BMPs are not considered. Select "Combined BMPs-Calculated" if multiple BMPs and their interactions in the subwatersheds are considered; use BMP calculator (under STEPL menu) to obtain the combined BMP efficiencies and enter them in Table 7.

Urban BMP Tool | Gully and Streambank Erosion | Calculate Combined BMP Efficiency

1. BMPs and efficiencies for different pollutants on CROPLAND, ND=No Data

Watershed	Cropland						
	N	P	BOD	Sediment	E. coli	BMPs	% Area BMP Applied
W1	0.0154	0.045	ND	ND	ND	Nutrient Management 1 (Determined Rate)	10

2. BMPs and efficiencies for different pollutants on PASTURELAND, ND=No Data

Watershed	Pastureland						
	N	P	BOD	Sediment	E. coli	BMPs	% Area BMP Applied
W1	0	0	0	0		0 No BMP	0

3. BMPs and efficiencies for different pollutants on FOREST, ND=No Data

Watershed	Forest						
	N	P	BOD	Sediment	E. coli	BMPs	% Area BMP Applied
W1	0	0	0	0		0 No BMP	0

4. BMPs and efficiencies for different pollutants on USER DEFINED land use, ND=No Data

Watershed	User Defined						
	N	P	BOD	Sediment	E. coli	BMPs	% Area BMP Applied
W1	0	0	0	0		0 No BMP	0

5. BMPs and efficiencies for different pollutants on FEEDLOTS, ND=No Data

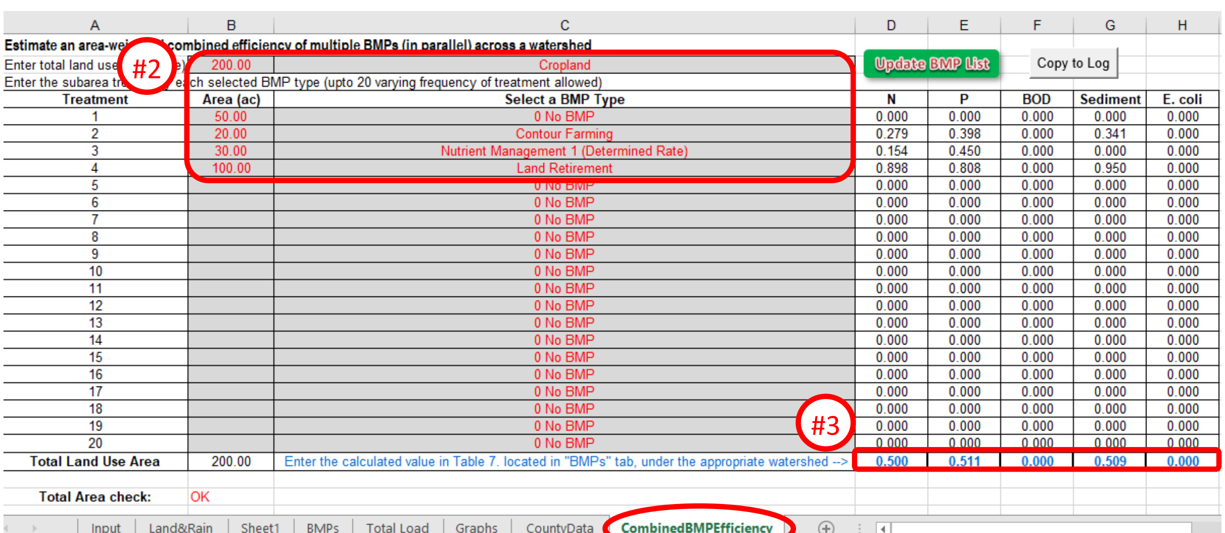
Watershed	Feedlots						
	N	P	BOD	Sediment	E. coli	BMPs	%Area BMP Applied
W1	0	0	0	0	0	0 No BMP	0

6. BMPs and efficiencies for different pollutants on URBAN

To change/set BMP/LID for urban land uses, click the 'Urban BMP Tool' button on the top-left of this sheet.

7. Combined watershed BMP efficiencies from the BMP calculator

Watershed	Watershed Combined BMP Efficiencies					
	N	P	BOD	Sediment	E. coli	BMPs
W1-Crop	0	0	0	0	0	Combined BMPs
W1-Pasture	0	0	0	0	0	Combined BMPs
W1-Forest	0	0	0	0	0	Combined BMPs
W1-User	0	0	0	0	0	Combined BMPs



Estimate an area-weighted combined efficiency of multiple BMPs (in parallel) across a watershed

Enter total land use (...e) 200.00 Cropland

Enter the subarea tr... each selected BMP type (upto 20 varying frequency of treatment allowed)

Update BMP List | Copy to Log

Treatment	Area (ac)	Select a BMP Type	N	P	BOD	Sediment	E. coli
1	50.00	0 No BMP	0.000	0.000	0.000	0.000	0.000
2	20.00	Contour Farming	0.279	0.398	0.000	0.341	0.000
3	30.00	Nutrient Management 1 (Determined Rate)	0.154	0.450	0.000	0.000	0.000
4	100.00	Land Retirement	0.898	0.808	0.000	0.950	0.000
5		0 No BMP	0.000	0.000	0.000	0.000	0.000
6		0 No BMP	0.000	0.000	0.000	0.000	0.000
7		0 No BMP	0.000	0.000	0.000	0.000	0.000
8		0 No BMP	0.000	0.000	0.000	0.000	0.000
9		0 No BMP	0.000	0.000	0.000	0.000	0.000
10		0 No BMP	0.000	0.000	0.000	0.000	0.000
11		0 No BMP	0.000	0.000	0.000	0.000	0.000
12		0 No BMP	0.000	0.000	0.000	0.000	0.000
13		0 No BMP	0.000	0.000	0.000	0.000	0.000
14		0 No BMP	0.000	0.000	0.000	0.000	0.000
15		0 No BMP	0.000	0.000	0.000	0.000	0.000
16		0 No BMP	0.000	0.000	0.000	0.000	0.000
17		0 No BMP	0.000	0.000	0.000	0.000	0.000
18		0 No BMP	0.000	0.000	0.000	0.000	0.000
19		0 No BMP	0.000	0.000	0.000	0.000	0.000
20		0 No BMP	0.000	0.000	0.000	0.000	0.000
Total Land Use Area	200.00	Enter the calculated value in Table 7. located in "BMPs" tab, under the appropriate watershed -->	0.500	0.511	0.000	0.509	0.000

Total Area check: OK

Total Load This is the summary of annual nutrient and sediment load for each subwatershed. This sheet is initially protected.

#4

1. Total load by subwatershed(s)

Watershed	N Load (no BMP)	P Load (no BMP)	BOD Load (no BMP)	Sediment Load (no BMP)	E. coli Load (no BMP)	N Reduction	P Reduction	BOD Reduction	Sediment Reduction	E. coli Reduction	N Load (with BMP)	P Load (with BMP)	BOD (with BMP)	Sediment Load (with BMP)	E. coli Load (with BMP)
	lb/year	lb/year	lb/year	t/year	Billion MPN/ye	lb/year	lb/year	lb/year	t/year	Billion MPN/y	lb/year	lb/year	lb/year	t/year	Billion MPN/y
W1	162231.9	24252.1	267297.5	2268.8	0.0	0.0	0.0	0.0	0.0	0.0	162231.9	24252.1	267297.5	2268.8	0.0
Total	162231.9	24252.1	267297.5	2268.8	0.0	0.0	0.0	0.0	0.0	0.0	162231.9	24252.1	267297.5	2268.8	0.0

2. Total load by land uses (with BMP)

Sources	N Load (lb/yr)	P Load (lb/yr)	BOD Load (lb/yr)	Sediment Load (t/yr)	E. coli Load (Billion MPN/yr)
Urban	5953.14	794.47	20251.00	137.71	0.00
Cropland	90594.10	17873.57	176259.17	2034.57	0.00
Pastureland	16610.03	1333.54	53628.59	88.50	0.00
Forest	767.69	380.91	1906.48	7.96	0.00
Feedlots	10433.01	2086.60	13910.68	0.00	0.00
User Defined	0.00	0.00	0.00	0.00	0.00
Septic	328.54	128.68	1341.55	0.00	0.00
Gully	0.00	0.00	0.00	0.00	0.00
Streambank	0.00	0.00	0.00	0.00	0.00
Groundwater	37545.44	1654.29	0.00	0.00	0.00
Total	162231.94	24252.07	267297.47	2268.75	0.00

Input | Land&Rain | Sheet1 | BMPs | Total Load | Graphs | CountyData | WeatherData | CombinedBMPEfficiency

3.3.3.2 Point Source Loading

Point source pollution is defined by CWA sction 502(14) as:

> …any discernible, confined and discrete conveyance, including any ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation (CAFO), or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agriculture storm water discharges and return flow from irrigated agriculture.

Point sources can include facilities such as municipal WWTPs, industrial facilities, concentrated animal feeding operations (CAFOs), or regulated stormwater, including municipal separate storm sewer systems. Under the CWA, all point sources are regulated under the National Pollutant Discharge Elimination System (NPDES) program. For sources that do not have permits under the NPDES program and are diffuse in nature (e.g., CAFOs and urban stormwater runoff), the associated pollutant loadings should be estimated and included in the watershed nonpoint source loading.

For Lake Manitou, based on the "Facilities" data layer provided by IDEM, there have been four permits issued within the past 10 years, as shown in Figure 8. However, none of the permits has flow and pollutant limit information, and further examination of the records revealed that the facilities are small and do not produce significant loadings as they are permits for stormwater flow. Therefore, the corresponding loadings can be omitted.

PERMIT_NUMBER	FACILITY_NAME	OWNER_TYPE_CODE	OWNER_TYPE_DESCRIPTION	PERMIT_STATUS	TOTAL_AVERAGE_FLOW_MGD	TOTAL_DESIGN_FLOW_MGD	Pollutant Limit	PERMIT_EFFECTIVE_DATE	PERMIT_EXPIRATION_DATE
INR10J215	DAVIS VET CLINC	POF	Privately Owned	Effective				10/10/2014	10/9/2019
INR10N750	2017 ROYAL CENTER TO LAKETON ILI PROJECT - ROCHESTER STATION			Effective				4/26/2017	4/25/2022
INR10M253	PLEASANT CENTER ROAD RECONSTRUCTION	MWD	Municipal or Wat	Effective				6/30/2016	6/29/2021
INR10J908	ROCHESTER JUNCTION TO MACY 6957			Effective				4/15/2015	4/13/2020

Figure 8. Permitted facilities within Lake Manitou watershed.

For other watersheds that have permitted facilities with flow and pollutant limit information (e.g., WWTPs), the point source loadings can be calculated as average flow times pollutant concentration limit. Besides data provided by the state, permitted discharge data available for point sources may be available through discharge monitoring reports that can be obtained from EPA's website. In cases in which a point source discharge location is known, but there is insufficient data to calculate annual average outfall loading of the parameters of interest, assumptions might be appropriate. For example, if there is no available data and a WWTP discharges into a lake, one can use literature values of assumed nutrient concentration depending on the level of treatment of the facility.

3.3.3.3 Internal Loading

There are multiple mechanisms by which phosphorus can be released back into the water column as internal loading. Low oxygen concentrations (also called "anoxia") in water overlying sediment can lead to phosphorus release. The released phosphorus can mix with surface waters and become available for algal growth. Bottom-feeding fish such as carp and black bullhead forage in lake sediments, which can release phosphorus into the water column. Wind energy in shallow depths can mix the water column and disturb bottom sediments, leading to phosphorus release. Other sources of physical disturbance such as motorized boating in shallow areas can disturb bottom sediments and lead to phosphorus release into the water column from bed sediment.

Because the empirical models used to develop the BATHTUB model are calibrated to real datasets, internal loading is inherently accounted for in this model (at least in the collection of reservoirs used for model calibration) (Walker 1999). Therefore, rates are normally set to 0. Nonzero values should be specified with caution and only if independent estimates or measurements are available. Specification of a fixed internal loading rate might be unrealistic for evaluating response to changes in external load. Because they reflect recycling of phosphorus that originally entered the reservoir from the watershed, internal loading rates would be expected to vary with external load. This option is included at the request of model users but is not endorsed by the model developer. In situations in which monitoring data indicate relatively high internal recycling rates to the mixed layer during the growing season, a preferred approach would generally be to calibrate the phosphorus sedimentation rate (specify calibration factors less than 1). There is some risk that apparent internal loads actually reflect underestimation of external loads.

During the TMDL and source assessment process, stakeholders and regulators might request that an estimate of the internal load be calculated. The commonly used Nürnberg method is described below (Nürnberg 1984).

The Nürnberg method (1984) uses mean depth, flushing rate, mean inflow concentration, and mean in-lake concentrations to estimate internal load, as shown below:

$$TP_{inlake} = TP_{inflow} * (1\text{-}R_{pred}) + L_{int} / Q_s$$
$$R_{pred} = 15 / (18 + Q_s)$$

where:

TP_{inlake} = mean summer in-lake phosphorus concentration (mg/m^3)
TP_{inflow} = mean summer tributary phosphorus concentration (mg/m^3)
Q_s = lake outflow volume divided by lake surface area (meters per year)

R_{pred} = annual retention due to sedimentation
L_{int} = internal phosphorus load (milligrams per square meters per year)

For Lake Manitou, the calculation steps are shown below:

TP_{inlake} = 0.07 mg/L = 70 mg/m^3
TP_{inflow} = 7,518.2 lbs / 5,614.5 ac-ft = 3,414.1 kilograms (kg) / 6,925,373.5 m^3 = 492.4 mg/m^3
Q_s = 6,925,373.5 m^3 / 3.125 km^2 = 2.2 m
Note: The outflow volume is for summer months (June-August) only.
R_{pred} = 15 / (18 + Q_s) = 0.74

Therefore, 70 mg/m^3 = 492.4 mg/m^3 x (1-0.74) + L_{int}/ 2.2 m, and L_{int} < 0. Negative internal loading indicates that the lake is acting as a sink for pollutants, mainly due to the sedimentation process. Therefore, for the Lake Manitou example, internal loading of phosphorus is set to zero.

3.3.3.4 Atmospheric Deposition

For lakes with largely agricultural drainage areas, atmospheric deposition of nutrients is generally considered insignificant relative to watershed loadings, particularly related to phosphorus. When no measurements of atmospheric deposition of nutrients are available, default TP and inorganic phosphorus deposition rates as a mean of 10 mg/m2-yr and a CV of 0.1 can be used. These rates were estimated from Robertson (1996), Rast and Lee (1983), and Reinfelder et al. (2004). Note that direct atmospheric deposition of phosphorus to a lake surface is generally considered insignificant compared to watershed loading rates; where no measurements are available, an atmospheric phosphorus deposition input of 0 mg/m^2-yr might be appropriate for a given lake when significant loadings are expected from the watershed.

For lakes that are nitrogen-limited, it is important to incorporate the atmospheric deposition of nitrogen into the BATHTUB model. EPA's CASTNET program provides nationwide atmospheric deposition monitoring data for nitrogen. Step-by-step instructions on how to approximate nitrogen atmospheric deposition from EPA's CASTNET website are provided below.

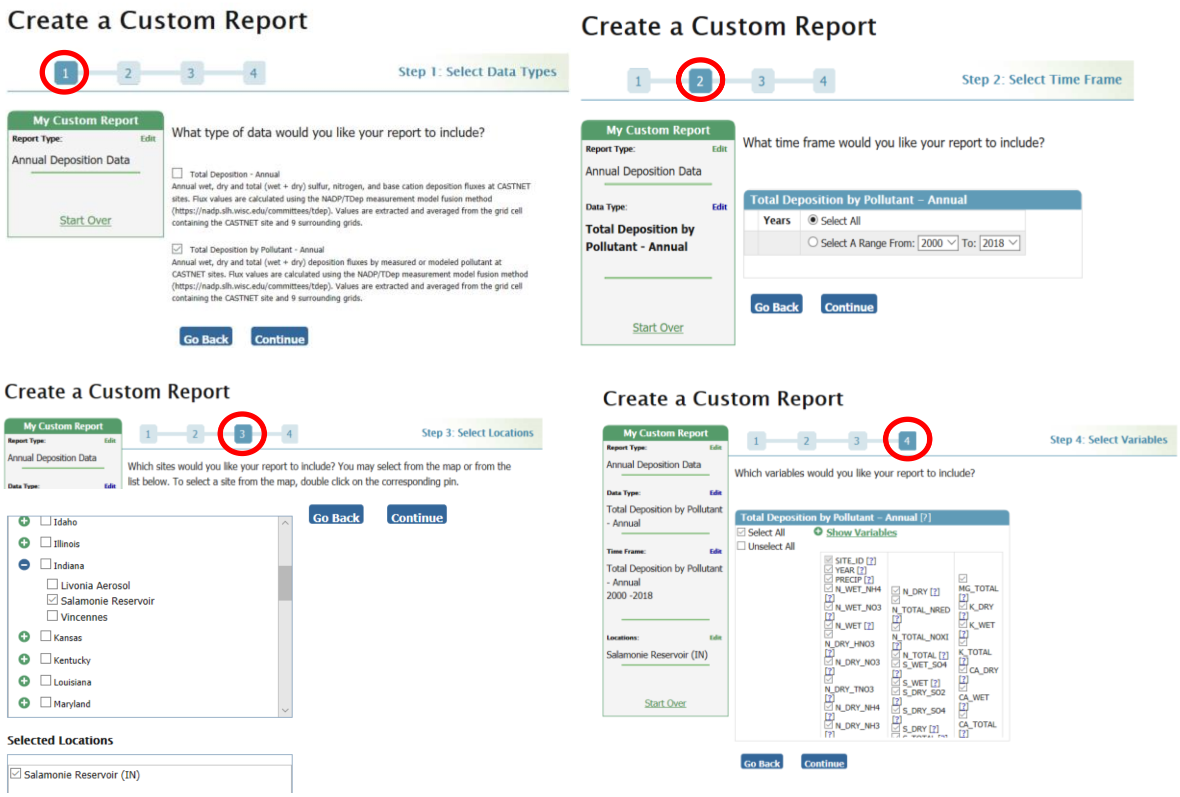
STEPS FOR USING CASTNET TO APPROXIMATE NITROGEN ATMOSPHERIC DEPOSITION

Step 1: Go to the EPA CASTNET website at http://www.epa.gov/castnet/site.html.

Step 2: Click "Site Locations" (https://www.epa.gov/castnet/castnet-site-locations) to identify the closest station to the project watershed. In the case of Lake Manitou, Salamonie Reservoir (Site ID of SAL133) is the closest station.

Step 3: Go back to the "Home" page, and click "Download Data" (https://java.epa.gov/castnet/clearsession.do); then click "Annual Deposition Data" (https://java.epa.gov/castnet/datatypepage.do?reportTypeLabel=Annual%20Deposition%20Data&reportTypeId=REP_003).

Step 4: Follow the instructions for the four steps on the website to create a custom report (shown below).

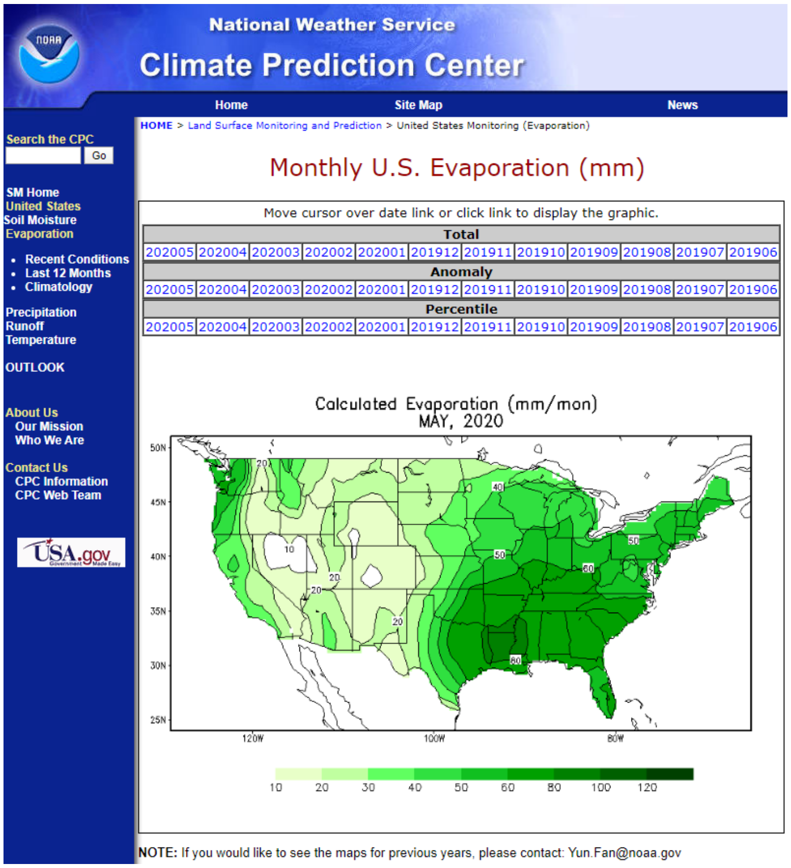


Step 5: Download the data.

Step 6: Calculate the mean and CV of the annual TN deposition. For Lake Manitou, the calculated annual nitrogen atmospheric deposition mean value is 12.76 kg/ha-yr (1,276 mg/m^2-yr) and the CV is 0.125; the summer period (June-August) nitrogen atmospheric deposition mean value is 3.19 kg/ha-yr (319 mg/m^2-yr) and the CV is 0.125.

3.3.3.5 Evaporation

The BATHTUB model requires input for total annual or seasonal evaporation from the lake. Sometimes so-called "pan evaporation" is used to approximate lake evaporation from near a given waterbody. If that level of local data is unavailable, one direct source to obtain monthly evaporation data is from the National Oceanic and Atmospheric Administration's (NOAA's) website (https://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/US_Evaporation-Monthly.php). The NOAA website displays nationwide monthly evaluation maps for the past 12 months, as shown below. The maps on the website may be used to locate the general location of the waterbody and determine the total monthly evaporation rates.



For the Lake Manitou example, the simulation period is summer (June, July, and August). The lake is in northern Indiana; therefore, the monthly evaporation rates for June, July, and August 2019 from the NOAA website are approximately 95, 95, and 72 millimeters (mm) per month, respectively. Therefore, the total evaporation for the summer period of June–August is 262 mm (0.262 m).

3.3.4 Determining Averaging Period

Prior to setting up the BATHTUB model, the user should determine the appropriate averaging period based on the in-lake water quality data and external loading to the lake. This process is outlined on pages 4-25 and 4-26 of the BATHTUB Document (Walker 2006). In this section, Lake Manitou is used as an example to demonstrate the process. As shown in section 3.2.2, phosphorus is the limiting nutrient for this lake, so the turnover ratio for phosphorus under summer season and annual loading conditions should be evaluated. Once the average period is determined, the water quality standard for the same time frame should be used for analysis and TMDL development. The steps for determining the averaging period are detailed below.

STEPS FOR DETERMINING AVERAGING PERIOD

Step 1: Calculate the nutrient mass in the lake from the mean concentration multiplied by the normal pool volume, converted to kg.

For Lake Manitou, lake volume is 9,477,807 m^3, mean summer TP concentration is 0.07 mg/L, and TP mass is calculated as 0.070 mg/L x 9,477,807 m^3 x 1000 L/m^3 / 1,000,000 milligrams per kilogram = 663.4 kg.

Step 2: Calculate the external nutrient load, which is equivalent to the tributary load delivered over the averaging period, converted to kg.

For Lake Manitou, the annual load is 24,252.1 lbs = 11,000.6kg.

Step 3: Calculate the mass residence time (mass divided by load). Resulting units are in years. For Lake Manitou, mass residence time = 663.4 kg/ 11,000.6 kilograms per year = 0.06 yr.

Step 4: Calculate the length of the averaging period for summer and annual periods. This value is entered in years and is equal to the number of days in the period divided by 365 days per year. Assume the summer season is June through August (92 days).

Averaging period for summer simulation =	0.25 yr
Averaging period for annual simulation =	1 yr

Step 5: Calculate the turnover ratio for the annual and summer averaging periods. It equals the length of the averaging period calculated in step 4 divided by the mass residence time calculated in step 3.

For Lake Manitou, summer turnover ratio = 0.25 yr / 0.06 yr = 4.2; annual turnover ratio = 1 yr /0.06 yr = 16.7.

The turnover ratio should be greater than 2 to ensure the simulation period is representative of an averaging condition. As explained in the BATHTUB User Manual (Walker 1999), very high turnover ratios typically indicate large variability in observed water quality, particularly following storm events.

If both the summer and annual turnover ratios are greater than 2, use the mass residence time to decide on the averaging period. Generally, if the mass residence time is relatively low (roughly less than 0.2 year), a seasonal averaging period is appropriate. For Lake Manitou, the summer and annual turnover ratios are 4.2 and 16.7, respectively. The mass residence time is 0.06 yr. Therefore, the averaging period of summer months (June–August), 0.25 year, is recommended, and will be used during the model setup.

3.4 Lake Manitou Data Summary

This section summarizes the prepared input data for the Lake Manitou case study in a single location for quick reference. How this data was prepared and estimated can be found in previous sections of this document.

3.4.1 Lake Manitou Physical Characteristics

The key physical characteristics related to the Lake Manitou waterbody:

- Total volume = 9,477,807 m^3
- Surface area = 3.125 km^2
- Length = 2.5 km
- Mean depth estimated as a function of volume divided by surface area is 9,477,807 m^3 / 3,125,000 m^2 = 3.03 m
- Mean depth of mixed layer estimated as a function of mixed layer volume divided by surface area is 4,276,600 m^3 / 3,125,000 m^2 = 1.37 m.
- Mean hypolimnetic depth estimated as function of hypolimnetic layer volume divided by hypolimnetic surface area is 5,201,207 m^3 / 2,000,000 m^2 = 2.6 m.

3.4.2 Lake Manitou Water Quality Data

Refer to Table 1 for Lake Manitou water quality sampling data since 2010 (from the CLP dataset). The water quality data analysis for Lake Manitou leads to the following conclusions:

- Lake Manitou is phosphorus-limited.
- Lake Manitou has high nutrient loading and high eutrophication potential (Anti Log PC-1 is 605, greater than 500); and light is somewhat important and can potentially limit algal growth; however nutrients are more likely the limiting factor (Anti Log PC-2 is 9, which is slightly less than 10 and much greater than 4).
- Lake Manitou nonalgal turbidity is calculated as 0.87, which is between 0.4 and 1, indicating color and/or inorganic suspended solids are in the medium range and medium algal response to nutrients. In addition, for the mixed layer, high algal response to nutrients is expected.

3.4.3 Lake Manitou Flow and Pollutant Loadings

Below are the key flow and pollutant loadings to the Lake Manitou waterbody:

- From tributaries (watershed loading)
    - Annual inflow volume is 18,231.1 ac-ft (22,487,697 m^3).
    - Summer (June–August) inflow volume is 5,614.5 ac-ft (6,925,373 m^3).
    - Total annual nitrogen loading is 162,231.9 lbs (73,587.2 kg); summer (June–August) loading is 50,291.9 lbs (22,812.0 kg).
    - Total annual phosphorus loading is 24,252.1 lbs (11000.6 kg); summer (June–August) loading is 7,518.2 lbs (3,410.2 kg).
- No significant point sources.
- Total annual precipitation is 40.79 inches (1.04 m); total precipitation for June–August is 12.5 inches (0.32 m).
- Total evaporation rate for the summer period of June–August is 262 mm (0.262 m).
- TN annual atmospheric deposition mean value is 12.76 kg/ha-yr (1,276 mg/m^2-yr) and the CV is 0.125; the summer period TN atmospheric deposition is 3.19 kg/ha-yr (319 mg/m^2-yr) and the CV is 0.125.
- The recommended average period is 0.25 year, meaning summer months from June to August.

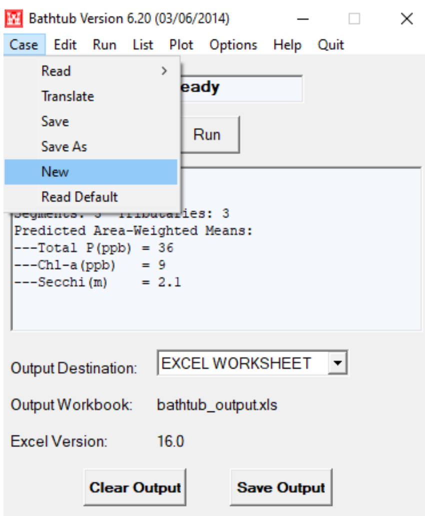
4.0 SET UP, RUN, AND CALIBRATE A BATHTUB MODEL

With all the required data prepared, the BATHTUB model is ready to be set up, run, and calibrated. The case study of Lake Manitou is included here as an example.

4.1 Starting BATHTUB and Creating a New Case

Step 1: Go to the directory where the BATHTUB model is installed and open the model by double-clicking bathtub.exe.

Step 2: From the main menu, click "Case" to open the drop-down menu. Click "New" to create a new BATHTUB project.

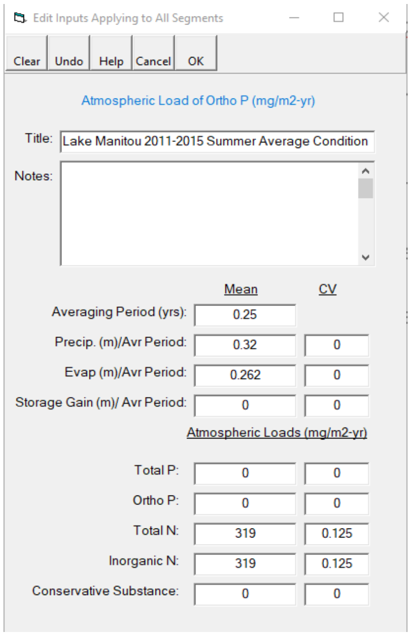


Step 3: Follow the pop-up forms to define the number of segments ("1" for Lake Manitou) and number of tributaries ("1" for Lake Manitou). Provide a title for your model (Lake Manitou 2011–2015 summer average condition).

Step 4: Save the project in the user-specified directory.

4.2 Setting Global Variables

Click "Edit" from the main menu to open the drop-down menu. Click "Global Variables," then provide the following inputs for your lake and refer to the screenshot with the inputs for Lake Manitou.

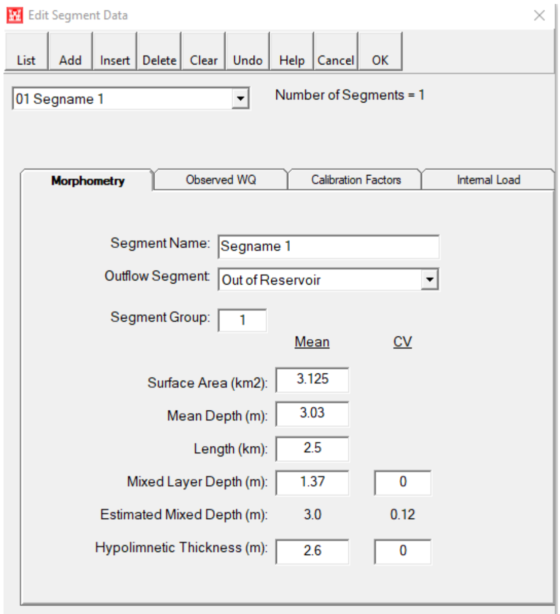


- Title: The name of your waterbody and any relevant naming reference.
- Notes: Any notes you may need for this model run.
- Averaging Period: 0.25 year (i.e., summer growing season as the simulation period).
- Precipitation over averaging period and CV: 0.32 m and 0.
- Evaporation over averaging period and CV: 0.262 m and 0.
- Storage gain over averaging period and CV: 0 and 0.
- Atmospheric Loads:
    - TP and CV: 0 and 0
    - Ortho-phosphorus and CV: 0 and 0
    - TN and CV: 319 mg/m^2-yr (for the summer average period) and 0.125
    - Inorganic nitrogen and CV: 319 mg/m^2-yr (for the summer average period) and 0.125
    - Conservative substance and CV: Leave as 0 unless simulated.

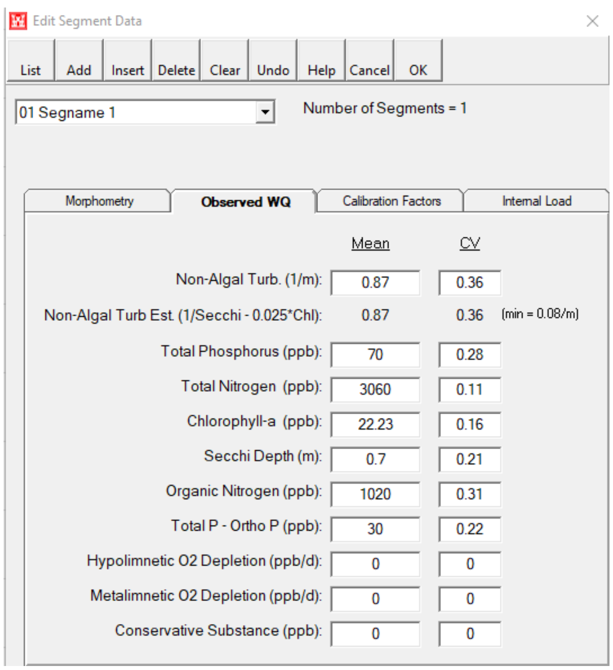
4.3 Segment Data Input

Click “Edit” from the main menu to open the drop-down menu. Click “Segments,” which calls for input for each model segment on four individual tabs: Morphometry, Observed WQ, Calibration Factors, and Internal Load. Because Lake Manitou is simulated as a single segment, each tab is filled out only once based on the drop-down at the top of the screen.

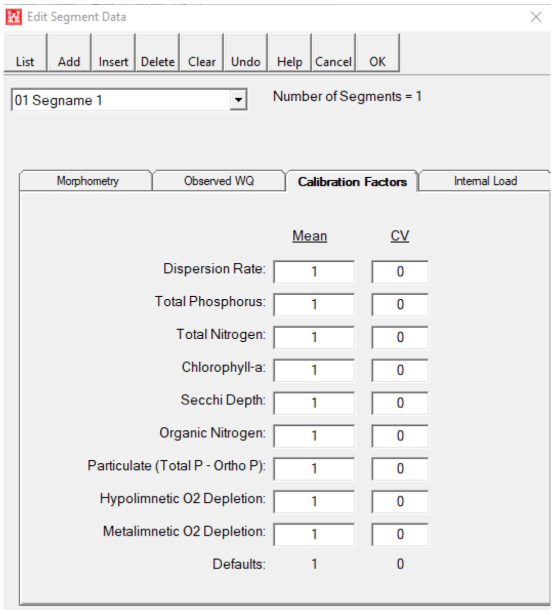
- **Morphometry:** Input physical characters of the waterbody as previously prepared, as shown in the screen shot below.



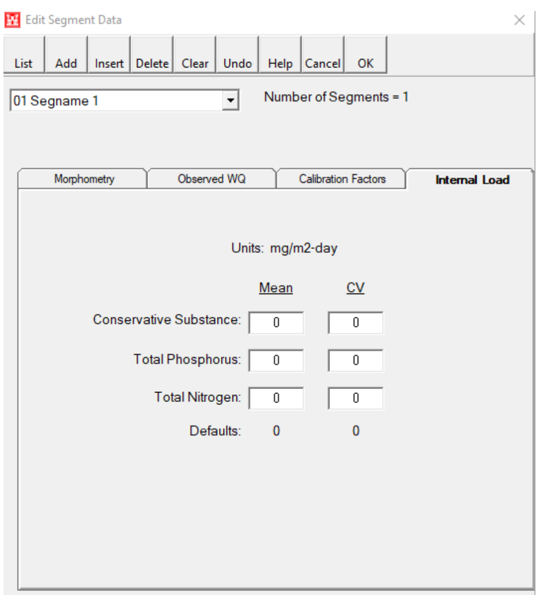
- **Observed WQ:** Input concentrations and CVs for simulated parameters of interest as prepared. The data for Lake Manitou is shown below.



- **Calibration Factors:** These are used to calibrate the simulated values to match with observed data. At the initial setup, keep the default values of “1” for mean and “0” for CV, as shown below.



- **Internal Load:** Input the calculated internal loading data here. For Lake Manitou, the estimated internal load is zero. A caveat for using internal load is that, as mentioned in section 4.1.1.3, the option of manually entering a prescribed internal load is included at the request of model users but is not endorsed by the model developer.



4.4 Tributary Data Input

Click "Edit" from the main menu to open the drop-down menu. Click "Tributaries." For this step, the interface asks for an inflow rate and corresponding pollutant concentrations as well as outflow rate and pollutant concentrations. Inflows are classified into three categories (Types 1–3) and outflows are classified into two categories (Types 4 and 5):

- Type 1: Monitored inflow
- Type 2: Nonpoint inflow
- Type 3: Point source
- Type 4: Reservoir outflow
- Type 5: Downstream boundary

Generally, the nonpoint inflow can be calculated externally and grouped with the monitored inflow. Required inputs depend on the selected model options and parameters simulated, but generally include the associated model segment, flow, total nutrient concentrations, and associated CVs.

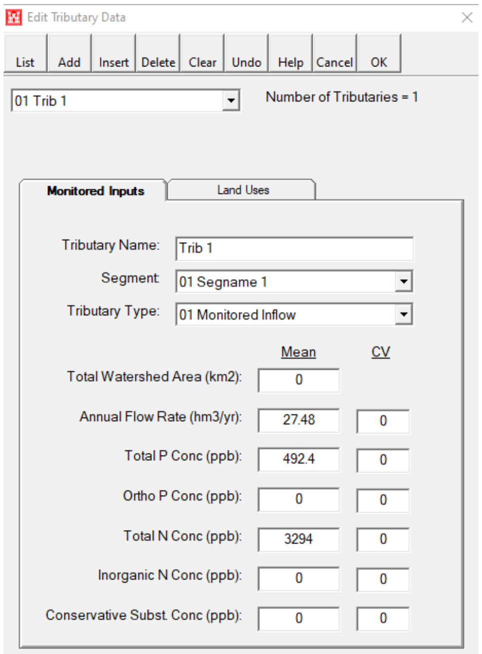
Flow types are described below:

- Type 1 is for tributaries with monitored inflows and concentrations. This type is also often used to represent modeled watershed nonpoint source inflows and concentrations.
- Type 2 is for tributaries or watershed areas that are not monitored; inflow volumes and concentrations are estimated from user-defined land-use categories and export coefficients. To invoke this tributary type, the user must supply independent estimates of export coefficients (runoff [m/year] and typical runoff concentrations for each land use) developed from regional data. This type is normally not used because the nonpoint sources are generally estimated externally and input as Type 1.
- Type 3 describes point sources (e.g., WWTP effluents) that discharge directly to the reservoir.
- Type 4 describes measured outflows or withdrawals; these are optional, since the model predicts outflow from the last segment based upon water balance calculations. Specification of outflow streams is useful for checking water-balance calculations (by comparing observed and predicted outflow volumes).
- Type 5 defines diffusive exchange with downstream waterbodies in simulation.

Required inputs include flow and TP concentration. Requirements for other inputs depend upon the selected model options. Tributary flow rates specified on input screens are expressed in units of cubic hectometers per year (hm^3/yr). These are <u>mean flow rates</u> during the <u>averaging period</u> (<u>not total flow volumes</u>). Special care should be taken in specifying tributary flow rates when the <u>averaging period</u> is less than 1 year. Suppose, for example, that the averaging period is April through September (one-half year) and that a gaged total inflow volume for a given tributary during this period is 40 hm^3. The value specified on the tributary input screen in this case should be 80 hm^3/yr (40 hm^3 / 0.5 year).

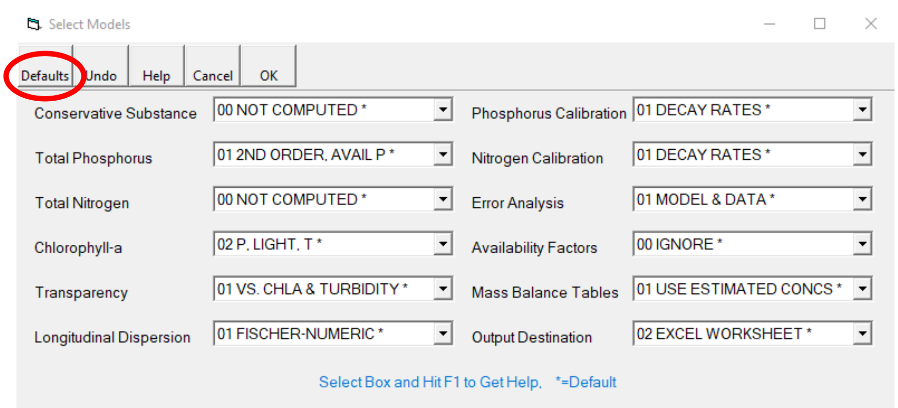
For Lake Manitou, flow, TP, and TN loading are based on the STEPL modeling results and as shown in the screenshot below. As listed in Section 3.4.3 on page 36, the summer (June–August) watershed inflow volume is 5,614.5 ac-ft (6,925,373 m^3), summer (June–August) total nitrogen loading is 50,291.9 lbs (22,812.0 kg), and summer (June–August) total phosphorous loading is 7,518.2 lbs (3,410.2 kg). BATHTUB input requires different units, the unit conversion processes are described below.

- Annual Flow Rate (hm^3/yr) = 6,925,373 m^3 x (hm^3/1,000,000 m^3) x (365 days per yr / 92 days per summer) = 27.48 (hm^3/yr)
- TP Conc (ppb) = 3,410.2 kg / 6,925,373 m^3 x (1,000,000 mg/kg) = 492.4 ppb
- TN Conc (ppb) = 22,812.0 kg / 6,925,373 m^3 x (1,000,000 mg/kg) = 3,294.0 ppb



4.5 Model Selections

Choices must be made to identify what parameters will be modeled and what models will be used, selecting options available from pull-down lists under "Edit," then "Model Selections." It is generally suggested users start with the default options by clicking "Default" on the "Model Selections" form. The default options are marked with an asterisk ("*"), as shown in the screenshot below. The full suite of model selection is provided from the BATHTUB model help file in appendix C.



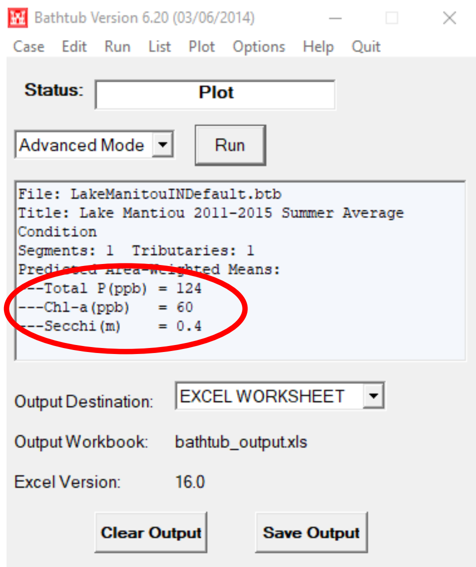
For Lake Manitou, the default model selections are initially suitable choices. Later, some of the model selections can be changed during the calibration process. The reasons for choosing the default model selections for Lake Manitou are listed below. “00 Not Computed” has been selected for Conservative Substance because there is no conservative substance simulated.

- TP: “01 2nd Order, Avail P” is selected because this is the option suitable for phosphorus simulation when inflow ortho-phosphorus load is not available.
- TN: “00 Not Computed” is selected because Lake Manitou is phosphorus-limited and nitrogen simulation is not necessary.
- Chl-*a*: “02 P. Light. T” is selected because Lake Manitou is phosphorus-limited, and light is somewhat important and can potentially limit algal growth.
- Transparency: “01 vs. Chl-*a* & Turbidity” is selected because Lake Manitou’s transparency is mostly related to algal growth and turbidity.
- Longitudinal Dispersion: Since Lake Manitou has only one segment, longitudinal dispersion is not applicable; therefore, the option selection will not affect the model simulation.
- Phosphorus Calibration: “01 Decay Rates” is selected because it is the most commonly used method.
- Nitrogen Calibration: Not applicable, because nitrogen is not computed; therefore, the option selection will not affect the model simulation.
- Error Analysis: Use default option.
- Availability Factors: “00 Ignore” is selected because ortho-phosphorus loading data are not available for Lake Manitou, so the availability factor does not apply.
- Mass Balance Tables: Use default option.
- Output Destination: Use default option.

It is anticipated that a large percentage of lakes in Indiana are phosphorus-limited and have similar water quality characteristics as Lake Manitou because the land use of many watershed drainage areas is largely agricultural. Therefore, it is recommended the user start with the default model selections for applying the BATHTUB model to other Indiana lakes.

4.6 Run Model, Model Output, and Calibration

Once all model inputs are made and the model is set up, it may be run and calibrated to existing data. To run the model, navigate to “Run Model” on the main menu or the “Run” button on the main model interface. There are two run modes: standard and advanced. Under “Advanced Mode,” the model provides more calibration means (e.g., “model coefficients” option, “Sensitivity Analysis,” “Load Response,” and “Calibration” options under “Run” are turned on), which provides more “tuning knobs” for the calibration processes. Therefore, “Advanced Mode” is recommended when the model is run. When the model has run, the display window will produce the predicted area-weighted means for the modeled constituents, as shown in the screenshot below.



To simplify reviewing the simulation results, users can use "Plot" from the main menu, then select the parameter to plot. With the original prepared input data and default model selections and calibration factors, the simulated TP, chl-*a*, and Carlson's Trophic State Index (TSI) chl-*a* are plotted in comparison with observed data in Figure 9. As shown, the simulated TP is much higher than the observed data, while predicted chl-*a* and Carlson's TSI (chl-*a*) are lower than the observed value.

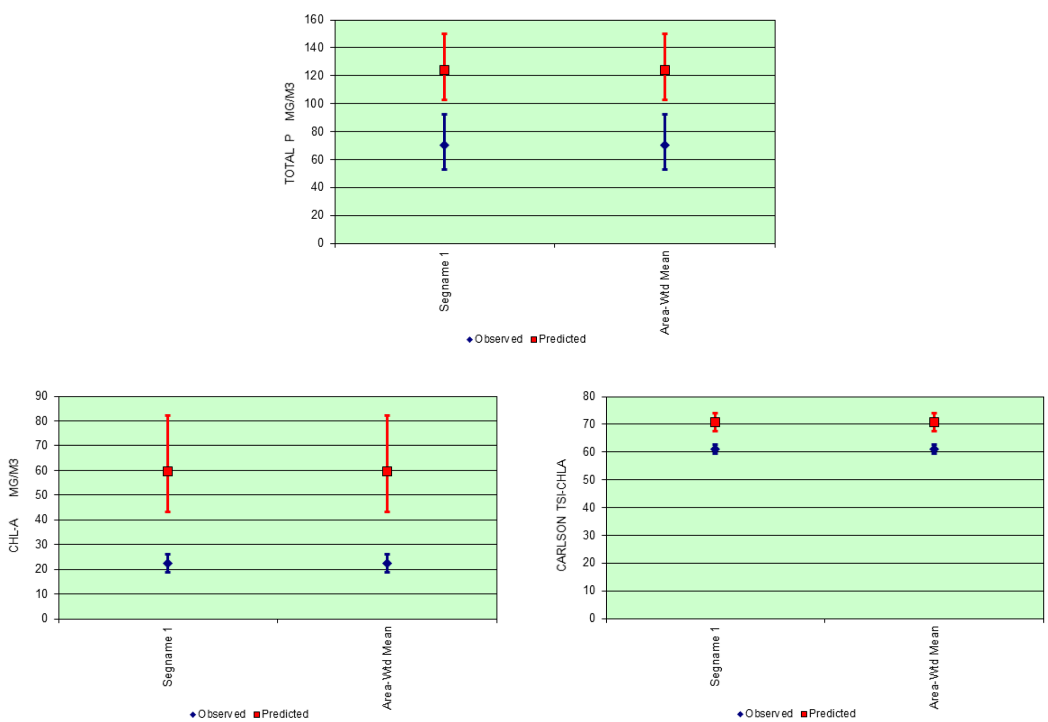
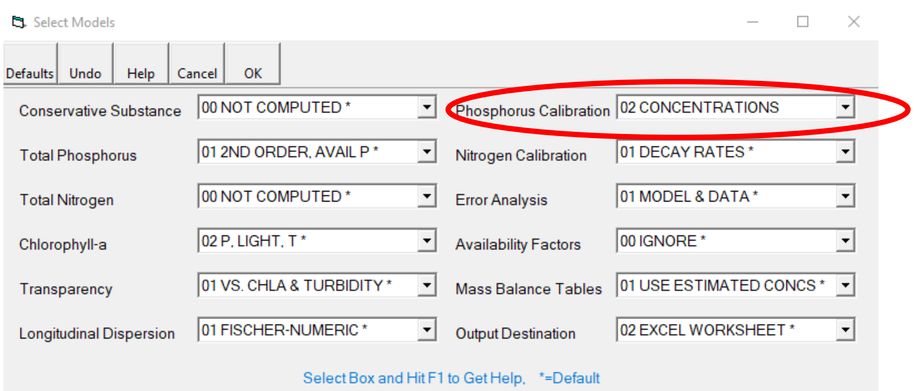
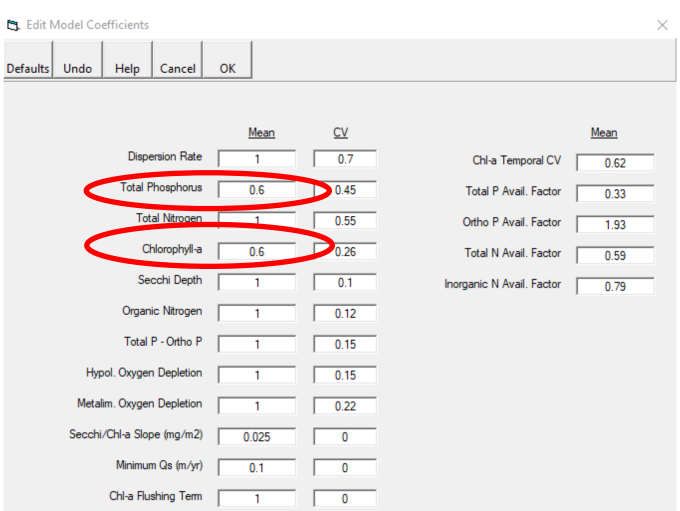


Figure 9. Lake Manitou BATHTUB simulation results (TP, Chl-*a*, and TSI-chl-*a*) with default model selections and calibration factors.

If the predicted concentrations do not match the observed concentrations, especially not within one standard deviation of the observed values, the model requires calibration to fit the data and best simulate the observed conditions of the waterbody. Commonly applied calibration processes include trying different model selections and changing calibration factors for sedimentation rates, phosphorus and/or nitrogen availability factors, and the chl-*a* flushing term.

For Lake Manitou, the first-round modeled TP concentration (using default model selections and calibration factors) is less than two times the observed value, modeled chl-*a* is more than two times the observed value, and modeled TSI-chl-*a* is slighted higher than the observed value. It is suspected that the modeled inflow TP loading using STEPL is higher than the actual value, because the pollutant removal provided by Graham Ditch (one of the two main inflow tributaries) was not accounted for. However, because of the lack of tributary water quality monitoring, it is not feasible to calibrate the inflow TP loading. Instead the BATHTUB calibration factor can be used to match the modeled data to observed values. Lake Manitou calibration consists of two steps, as shown in the screenshots below. The first step is to open the “Model Selections” form (Edit -> Model Selection) to change the Phosphorus Calibration Model to “02 CONCENTRATIONS.” The second step is to open the “Model Coefficients” form (Edit -> Model Coefficients) and change the “Total Phosphorus” calibration factor to 0.6 and “Chlorophyll-*a*” to 0.6. With the calibration, as shown in Figure 10, the simulated results are matching the observed value well.





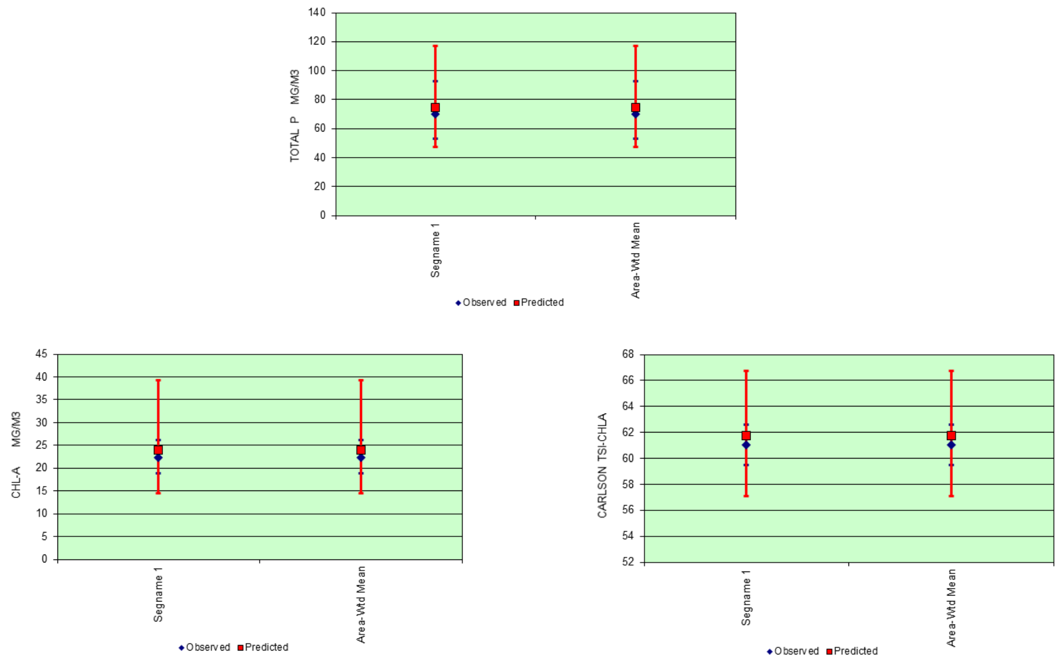


Figure 10. Lake Manitou BATHTUB simulation results (TP, Chl-*a*, TSI-Chl-*a*) with calibration.

It is important to note that the model calibration process is both art and science, requiring some subjectivity, especially for an empirical model like BATHTUB and with limited loading and water quality monitoring data as with the Lake Manitou case study. Calibration is generally not necessary when there is considerable overlap between observed and predicted distributions. When the model simulated results do not match the observed data well during initial model runs, calibration is needed. There are two basic sources of error: data error and model error. Data errors can always occur during model input, including tributary flow and pollutant loads, observed water quality data, and lake morphometry data. They are essentially the outcome of data collection, estimation methods, and data reduction. Model errors reflect true differences between model predictions and lake response. Model calibration is justified to account for model errors, but not recommended to account for data errors. One possible exception to this rule is when data errors are not random but are attributed to differences with a consistent trend in data measurement or estimation methods. For the Lake Manitou BATHTUB model calibration, with the simulated TP concentration from the initial run about two times higher than the observed value, data error with the estimated inflow TP load is suspected. However, it is not feasible to calibrate the inflow TP load due to the lack of inflow tributary water quality data. Therefore, the BATHTUB model is calibrated to compensate for the possible data error.

4.7 TMDL Allocation Exercises

With the calibrated BATHTUB model, allocation exercises can be performed to estimate the load reduction needed to meet a site-specific TMDL target. Essentially, various reduced loads can be simulated by the calibrated BATHTUB model to predict the water quality responses of the lake. The predicted parameters would be compared with water quality standards to evaluate the needed load reduction.

4.7.1 TMDL Target

In 2008, IDEM developed an assessment method for determining the degree to which nutrient enrichment might be impacting the aesthetic value of Indiana lakes and their use for recreational activities, which is based on benchmark values for TP and chl-*a* developed by Limno-Tech, Inc., as shown in Table 3. The associated range of chl-*a* represents the range of concentrations expected when TP concentrations are at or below 54 µg/L for natural lakes or 51 µg/L for reservoirs. In some cases, the chl-*a* results are not consistent with the expectations shown in Table 3, based on the TP levels measured for a given lake (e.g., low chl-*a* values associated with high TP values or vice versa). For these situations, IDEM's methodology uses the TSI score as a surrogate response variable (in addition to chl-*a*) to determine impairment status, as listed in Table 4. Also, Figure 11 is the flow chart showing IDEM's assessment process for determining recreational use support using TP, chl-*a*, and TSI data for lakes within the context of aesthetics.

Table 3. Recommended Phosphorus Thresholds and Their Corresponding Expected Ranges of Chl-*a* Concentrations (*Source*: IDEM 2020)

Waterbody	TP (µg/L)	Associated Range in Chl-*a* (µg/L)
Lakes	54	4-20
Reservoirs	51	2-25

Table 4. Methods Used to Assess Indiana Lakes and Reservoirs for Recreational Use Support within the Context of Aesthetics (*Source:* IDEM 2020)

Waterbody	Fully Supporting	Not Supporting
Lakes	Not more than 10% of all TP values greater than 54 µg/L and their associated (CHL) values are less than or equal to 20 µg/L	Less than 10% of all TP values are greater than 54 µg/L but their associated CHL values are greater than 20 µg/L, and the CHL TSI score for the lake indicates eutrophic (50–70) or hypereutrophic (greater than 70) conditions. Or More than 10% of TP values are greater than 54 µg/L with associated CHL values less than 4 µg/L, but the TSI (CHL) score for the lake indicates eutrophic (50–70) or hypereutrophic (greater than 70) conditions. Or More than 10% of all TP values are greater than 54 µg/L with associated CHL values greater than 4 µg/L.
Reservoirs	Not more than 10% of all TP values greater than 51 µg/L and their associated CHL values are less than 25 µg/L	Less than 10% of all TP values are greater than 51 µg/L but their associated CHL values are greater than 25 µg/L and the TSI (CHL) score for the lake indicates eutrophic (50–70) or hypereutrophic (greater than 70) conditions. Or More than 10% of all TP values are greater than 51 µg/L with associated CHL values less than 2 µg/L, but the TSI (CHL) score for the lake indicates eutrophic (50–70) or hypereutrophic (greater than 70) conditions Or More than 10% of all TP values are greater than 51 µg/L with associated CHL values greater than 2 µg/L.

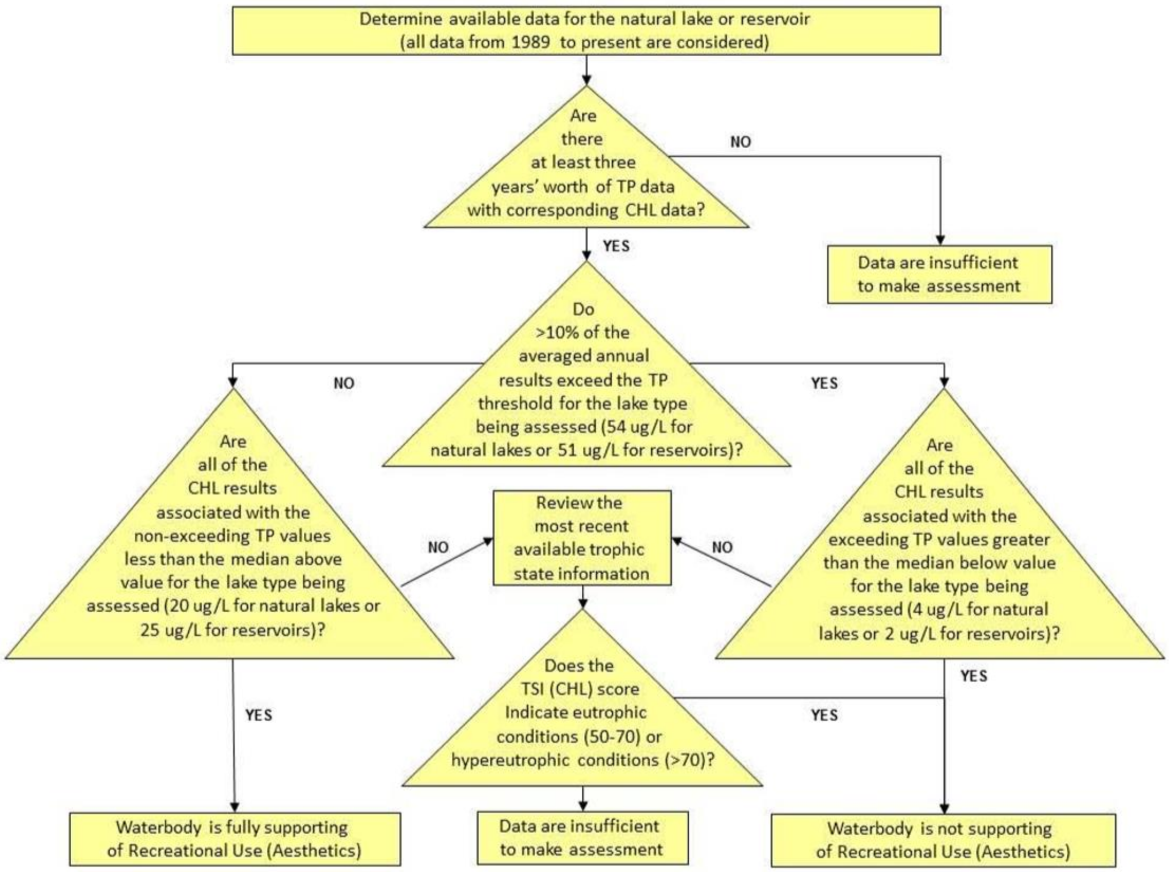
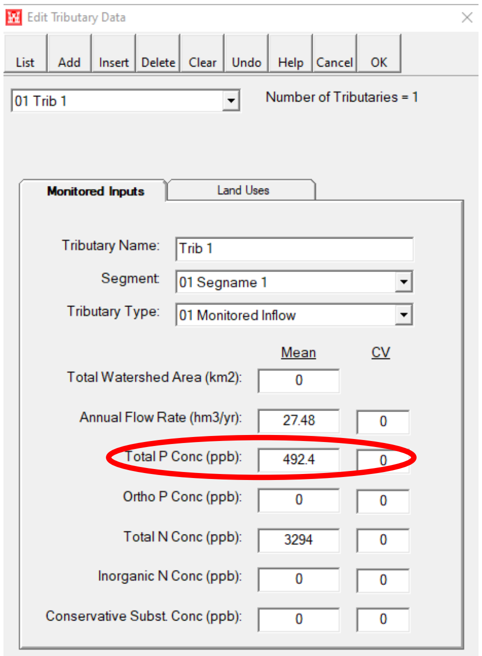


Figure 11. IDEM's Assessment process for determining recreational use support for lakes within the context of aesthetics (*Source*: IDEM 2020).

Based on the monitoring data collected from 2011 to 2015, average TP, chl-*a*, and TSI values are 70 µg/L, 22 µg/L, and 61 respectively. Both the TP and chl-*a* are above the threshold values listed in Table 3 for lakes, indicating Lake Manitou is not meeting the water quality criteria.

4.7.2 Lake Manitou TMDL Allocation Exercise

The calibrated Lake Manitou BATHTUB model can be used to predict the lake's water quality responses to inflow load reduction. Four load reduction scenarios with percent reductions of 20, 30, 45, and 50 percent are simulated. The calibrated BATHTUB model is rerun with the reduced inflow concentration on the "Edit Tributary Data" form as shown in the screenshot below. The predicted in-lake TP and chl-*a* are listed in Table 5.



The scenario with 45 percent load reduction resulted in in-lake TP concentration below 54 µg/L and chl-*a* concentration below 20 µg/L, meeting the water quality criteria. Therefore, this preliminary exercise indicated that reducing the watershed TP load by 45 percent will likely result in meeting the criteria for supporting recreational uses. How that reduction is achieved could involve various implementation practices and parties.

Table 5. Lake Manitou TMDL Allocation Scenarios

Percent Reduction	Resulting In-Flow TP Concentration (ppb)	Resulting In-Lake TP Concentration (ppb)	Resulting In-Lake Chl-*a* Concentration (ppb)
0% (current condition)	492	80	22
20%	394	65	21
30%	345	61	20
45%	***271***	***52***	***17***
50%	247	50	16

Note: ppb = parts per billion.

4.7.3 Summary

Illustrated using the Lake Manitou example, step-by-step instructions were provided to guide users through the input data preparation and model setup processes for a typical BATHTUB model application. The usefulness and accuracy of any model is only as good as the input data provided. For this reason, diligence should be exercised when collecting and synthesizing data. When data are scarce or not available, default and literature values can be used with caution and appropriate attribution to sources.

As a simple lake water quality model, a calibrated BATHTUB model can be used to predict steady-state water quality responses to various nutrient loading scenarios. It is a useful tool for lake/reservoir nutrient-related TMDL development and nutrient loading analyses, and provides valuable information to watershed managers, TMDL developers, and other water quality managers.

5.0 REFERENCES AND RESOURCES

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APPENDIX A. UNIT CONVERSIONS

1. Using Google for Unit Conversions

2. Conversion Factors Used in the Following Exercises:

Length Conversion Factors
1 m = 3.281 ft

Area Conversion Factors
1 ac = 43,560 ft^2
1 ac = 4046.9 m^2
1 ha = 2.47 ac = 10,000 m^2
1 km^2 = 247.1 ac

Volume Conversion Factors
1 ft^3 = 28.317 L
1 m^3 = 35.314 ft^3
1 hm^3 = 1,000,000 m^3

Mass Conversion Factors
1 kg = 1,000,000 mg
1 ton = 907.185 kg
1 ton = 2,000 lbs
1 lb = 453.6 g
1 g = 1,000,000 µg

Time Conversion Factors
1 d = 86,400 s
1 yr = 365 d
May through September = 153 d

Concentration Conversion Factors
1 ppb = 1 µg/L

APPENDIX B. BATHTUB DIAGNOSTIC VARIABLES AND INTERPRETATION

Table 4.5 in BATHTUB User Manual (Walker 1999)

Table 4.5
Diagnostic Variables and Their Interpretation

Variable	Units	Explanation
TOTAL P	mg/m^3	Total phosphorus concentration CE distrib (MEAN = 48, CV = 0.90, MIN = 9.9, MAX = 274) Measure of nutrient supply under P-limited conditions
TOTAL N	mg/m^3	Total nitrogen concentration CE distr (MEAN = 1002, CV = 0.64, MIN = 243, MAX = 4306) Measure of nutrient supply under N-limited conditions
C. NUTRIENT	mg/m^3	Composite nutrient concentration CE distr (MEAN = 36, CV = 0.80, MIN = 6.6, MAX = 142) Measure of nutrient supply independent of N versus P limitation; equals total P at high N/P ratios
CHL A	mg/m^3	Mean chlorophyll *a* concentration CE distrib (MEAN = 9.4, CV = 0.77, MIN = 2, MAX = 64) Measure of algal standing crop based upon photosynthetic pigment
SECCHI	m	Secchi depth CE distrib (MEAN = 1.1, CV=0.76, MIN = 0.19, MAX = 4.6) Measure of water transparency as influenced by algae and nonalgal turbidity
ORGANIC N	mg/m^3	Organic nitrogen concentration CE dist (MEAN = 474, CV = 0.51, MIN = 186, MAX = 1510) Portion of nitrogen pool in organic forms; generally correlated with chlorophyll *a* concentration
P-ORTHOP	mg/m^3	Total phosphorus - Ortho phosphorus CE distrib (MEAN = 30, CV = 0.95, MIN = 4, MAX = 148) Phosphorus in organic or particulate forms correlated with chlorophyll *a* and nonalgal turbidity
HODv	mg/m^3-day	Hypolimnetic oxygen depletion rate CE distrib (MEAN = 77, CV = 0.75, MIN = 36, MAX = 443) Rate of oxygen depletion below thermocline; related to organic supply from settling of algae, external organic sediment loads, and hypolimnetic depth For HOD-V > 100; hypolimnetic oxygen supply depleted within 120 days after onset of stratification
MODv	mg/m^3-day	Metalimnetic oxygen depletion rate CE distrib (MEAN = 68, CV = 0.71, MIN = 25, MAX = 286) Rate of oxygen depletion within thermocline; generally more important than HODv in deeper reservoirs (mean hypolimnetic depth >20 m)
ANTILOG PC-1	--	First principal component of reserv. response variables (Chlorophyll *a*, Secchi, Organic N, Composite Nutrient) CE distrib (MEAN = 245, CV =1.3, MIN = 18, MAX = 2460) Measure of nutrient supply: Low: PC-1 < 50 low nutrient supply low eutrophication potential High: PC-1 > 500 high nutrient supply high eutrophication potential

(Sheet 1 of 3)

Notes: CE distribution based upon 41 reservoirs used in development and testing of the model network (MEAN, CV = geometric mean and coefficient of variation). Low and high values are typical benchmarks for interpretation.

Table 4.5 (Continued)

Variable	Units	Explanation
ANTILOG PC-2	--	Second principal component of reserv. response variables CE distrib (MEAN = 6.4, CV =0.53, MIN = 1.6, MAX = 13.4) Nutrient association with organic vs. inorganic forms; related to light-limited areal productivity Low: PC-2 < 4 turbidity-dominated, light-limited, low nutrient response High: PC-2 > 10 algae-dominated, light unimportant, high nutrient response
(N-150)/P	--	(Total N - 150)/Total P ratio CE distrib. (MEAN = 17, CV = 0.68, MIN = 4.7, MAX = 73) Indicator of limiting nutrient Low: (N-150)/P < 10-12 nitrogen-limited High: (N-150)/P > 12-15 phosphorus-limited
INORGANIC N/P Ratio	--	Inorganic nitrogen/ortho-phosphorus ratio CE distrib. (MEAN = 30, CV = 0.99, MIN = 1.6, MAX = 127) Indicator of limiting nutrient Low: N/P < 7-10 nitrogen-limited High: N/P > 7-10 phosphorus-limited
TURBIDITY	m^{-1}	Nonalgal turbidity (1/SECCHI - 0.025 x CHL-A) CE distrib. (MEAN = 0.61, CV=0.88, MIN = 0.13,MAX = 5.2) Inverse Secchi corrected for light extinction by Chl *a* Reflects color and/or inorganic suspended solids Influences algal response to nutrients: Low: Turbidity < 0.4 allochthonous particulates unimportant high algal response to nutrients High: Turbidity > 1 allochthonous particulates possibly important low algal response to nutrients
ZMIX * TURBIDITY	--	Mixed-layer depth x turbidity CE distrib. (MEAN = 3.2, CV = 0.78, MIN = 1.0, MAX = 17) Effect of turbidity on light intensity in mixed layer Low: < 3 light availability high; turbidity unimportant high algal response to nutrients High: > 6 light availability low; turbidity important low algal response to nutrients
ZMIX/ SECCHI	--	Mixed-layer depth/Secchi depth (dimensionless) CE distrib (MEAN = 4.8, CV = 0.58, MIN = 1.5, MAX = 19) Inversely proportional to mean light intensity in mixed layer for a given surface light intensity: Low: < 3 light availability high high algal response to nutrients expected High: > 6 light availability low low algal response to nutrients expected

(Sheet 2 of 3)

Table 4.5 (Concluded)

Variable	Units	Explanation
CHL A SECCHI	--	Chlorophyll *a* x transparency (mg/m^2) CE distrib (MEAN = 10, CV = 0.71, MIN = 1.8, MAX = 31) Partitioning of light extinction between algae turbidity Measure of light-limited productivity Correlated with PC-2 (second principal component) Low: < 6 turbidity-dominated, light-limited low nutrient response expected High: > 16 algae-dominated, nutrient-limited high nutrient response expected
CHL A TOTAL P	--	Mean Chlorophyll *a* / Mean Total P CE distrib (MEAN = 0.20, CV=0.64, MIN=0.04, MAX = 0.60) Measure of algal use of phosphorus supply Related to nitrogen-limited and light-limitation factors Low: < 0.13 low phosphorus response algae limited by N, light, or flushing rate High: > 0.40 high phosphorus response (northern lakes) N, light, and flushing unimportant P limited (typical of northern lakes)
TSI-P TSI-B TSI-S	--	Trophic State Indices (Carlson 1977) Developed from Northern Lake Data Sets Calculated from P, Chl *a*, and Secchi Depths TSI < 40 "Oligotrophic" 41 < TSI < 50 "Mesotrophic" 51 < TSI < 70 "Eutrophic" TSI > 70 "Hypereutrophic"
FREQ > 10% FREQ > 20% FREQ > 30% FREQ > 40% FREQ > 50% FREQ > 60%		Algal Nuisance Frequencies or Bloom Frequencies Estimated from Mean Chlorophyll *a* Percent of Time During Growing Season that Chl *a* Exceeds 10, 20, 30, 40, 50, or 60 ppb Related to Risk or Frequency of Use Impairment "Blooms" generally defined at Chl *a* > 30-40 ppb

(Sheet 3 of 3)

APPENDIX C. BATHTUB MODEL SELECTIONS

Conservative Substance Balance	
Option	**Description**
0	Do Not Compute (Set Predicted = Observed) [default]
1	Compute Mass Balances

Phosphorus Sedimentation Models (see discussion)

Unit P Net Sedimentation Rate (mg/m^3-year) = CP A1 P^{A2}

Solution for Mixed Segment:

Second-Order Models (A2 = 2):

P = [-1 + (1 + 4 K A1 Pi T)$^{0.5}$] / (2 K A1 T)

First-Order Models (A2 = 1):

P = Pi / (1 + K A1 T)

Option	Model Description	A1	A2
0	Do Not Compute (Set Predicted = Observed) [default]	-	-
1	Second-Order, Available P [default] *Inflow Avail P = 0.33 Pi + 1.93 Pio* See options for specification of available P	*0.17 Qs/(Qs + 13.3)* *Qs = Max(Z/T,4)*	2
2	Second-Order Decay Rate Function *Fot = Tributary Ortho P / Total P Load* *Requires specification of inflow total & ortho P loads*	*0.056 Fot^{-1}Qs/(Qs + 13.3)* *Qs = Max(Z/T,4)*	2
3	Second-Order	*0.10*	2
4	Canfield & Bachmann (1981), Reservoirs	*0.114 (Wp/V)$^{0.589}$*	1
5*	Vollenweider (1976), Northern Lakes	*T$^{-0.5}$*	1
6*	Simple First-Order	*1*	1
7*	First-Order Settling	1/Z	1
8*	Canfield & Bachmann (1981), Natural Lakes	*0.162 (Wp/V)$^{0.458}$*	
9*	Canfield & Bachmann (1981), Reservoirs + Lakes	*0.129 (Wp/V)$^{0.549}$*	1

For purposes of computing effective rate coefficients (A1), Qs, Wp, Fot, T, and V are evaluated separately for each segment group based upon external loadings and segment hydraulics.

** These models are not calibrated to CE reservoir data. They are likely to require calibration by the user to site-specific data.*

Nitrogen Sedimentation Models (see discussion)

Unit N Net Sedimentation Rate (mg/m^3-year) = $CN\ B1\ N^{B2}$

Solution for Mixed Segment:

Second-Order Models (B2 = 2):

$$N = [-1 + (1 + 4\ K\ B1\ Ni\ T\ )^{0.5}\ ] / (2\ K\ B1\ T\ )$$

First-Order Models (B2 = 1):

$$N = Ni / (1 + K\ B1\ T)$$

Option	Model Description	B1	B2
0	Do Not Compute (Set Predicted = Observed) [default]	-	-
1	Second-Order, Available N [default] Inflow Avail N = 0.59 Ni + 0.79 Nin See options for specification of available N	$0.0045\ Qs/(Qs + 7.2)$ $Qs = Max(Z/T,4)$	2
2	Second-Order Decay Rate Function Fin = Tributary Inorganic N/Total N Load Requires specification of inflow total & inorganic N loads	$0.0035\ Fin^{-1} Qs/(Qs + 17.3)$ $Qs = Max(Z/T,4)$	2
3	Second-Order	0.00315	2
4*	Bachmann (1980), Volumetric Load	$0.0159\ (Wn/V)^{0.59}$	1
5*	Bachmann (1980), Flushing Rate	$0.693\ T^{-0.55}$	1
6*	Simple First-Order	1	1
7*	First-Order Settling	1/Z	1

Nitrogen Model 1 differs slightly from that developed in Walker (1985). The coefficients have been adjusted so that predictions will be unbiased if inflow inorganic nitrogen data are not available (inflow available N = inflow total N). These adjustments have negligible influence on model error statistics< /A > .

For purposes of computing effective rate coefficients (B1), Qs, Wn, Fin, T, and V are evaluated separately for each segment group based upon external loadings and segment hydraulics.

** These models are not calibrated to CE reservoir data. They are likely to require calibration by the user to site-specific data.*

Application of Nutrient Availability Factors (see discussion)		
Option	**Description**	**Equations**
0	Do Not Apply Availability Factors [default]	*Select if Ortho P & Inorganic N loadings are not specified* *Inflow Available P = Pi* *Inflow Available N = Ni*
1	Apply to P & N Sedimentation Model 1 Only	*When P Model 1 or N Model 1 is selected, calculate nutrient balances based upon available nutrient loads:* *Inflow Available P = 0.22 Pi + 1.93 Pio* *Inflow Available N = 0.59 Ni + 0.79 Nin* *Require specification of ortho P & inorganic N loadings if P or N sedimentation model 1 is selected.* *Coefficients used to compute availability factors can be edited on the 'Edit Model Coefficients' screen.* *With other P or N models, nutrient balances using Total P and Total N loads (same as Option 0)*
2	Apply to All P & N Sedimentation Models Except Model 2	*Same equations as Option 1* *Requires Specification of Ortho P & Inorganic N Loadings*

Account for differences between dissolved & particulate nutrient forms with respect to sedimentation rates and/or bioavailability.
Although consideration of these factors reduced prediction error in the CE model development data set, the default option (0) ignores them because ortho P and inorganic N loadings are not typically measured.

Chlorophyll-a Models (see discussion)			Applicability Constraints			
Option	**Description / Limiting Factors**	**Equations**	**a**	**(N-150)/P**	**Ninorg/Portho**	**Fs**
0	Do Not Compute	*Predicted = Observed*				
1	P, N, Light, Flushing	$Xpn = [\ P^{-2} + ((N-150)/12)^{-2}\ ]^{-0.5}$ $Bx = Xpn^{1.33} / 4.31$ $G = Zmix\ (0.14 + 0.0039\ Fs)$ $B = K\ Bx / [\ (1 + b\ Bx\ G)\ (1 + Ga)\ ]$				
2	P, Light, Flushing [default]	$Bp = P^{1.37}/4.88$ $G = Zmix\ (0.19 + 0.0042\ Fs)$ $B = K\ Bp / [(1 + b\ Bp\ G)\ (1 + Ga)]$		>12	>7	
3	P, N, Low Turbidity	$B = K\ 0.2\ Xpn^{1.25}$	<0.9			<25
4	P, Linear	$B = K\ 0.28\ P$	<0.9	>12	>7	<25
5	P, Exponential, Jones & Bachmann (1976)	$B = K\ 0.081\ P^{1.46}$	<.4	>12	>7	<25
6	P, Carlson TSI (1977), Lakes	$B = K\ 0.087\ P^{1.45}$	<0.4	>12	>7	<25

Options 1 & 2 require estimates of non-algal turbidity for each model segment. These are entered with observed water quality data on the 'Edit Segments' screen. If non-algal turbidity is not specified, it is estimated from observed Secchi depth and chlorophyll-a. If the latter are not specified, an error message is generated.

Secchi Depth Models (See discussion)			Applicability Constraints	
Option	Description	Equations	(N-150)/P	Ninorg/Portho
0	Do Not Compute	*Predicted = Observed*		
1	Secchi vs. Chl a and Turbidity [default]	$S = K / (a + b\ B)$		
2	Secchi vs. Composite Nutrient	$S = K\ 16.2\ Xpn^{-0.79}$		
3	Secchi vs. Total P, CE Reservoirs	$S = K\ 17.8\ P^{-0.76}$	>12	>7
4*	Carlson TSI (1977) , Lakes	$S = K\ 48 / P$	>12	>7

Longitudinal Dispersion Models (see discussion)		
Option	Description	Equations
0	Do Not Compute	$E = 0$
1	Fischer et al. (1979) Dispersion Equation as adapted by Walker (1985) [default]	Width: $W = As/L$ Cross-Section: $Ac = W\ Z$ Velocity: $U = Q/Ac$ Dispersion (U,1): $D = KD\ 100\ W^2\ Z^{-0.84}$ Maximum Numeric Dispersion: $Dn = U\ L/2$ Exchange: $E = MAX(D - Dn, 0)\ Ac/L$
2	Fixed Dispersion Rate	*Same as Model 1, except with fixed* $D = 1{,}000$ $km^2/year$ $D = 1000\ KD$
3	Input Exchange Rates Directly	$E = KD$
4	Fischer Equation, Not Adjusted for Numeric Dispersion	$E = D\ Ac/L$ (D as defined in Option 1)
5	Constant Dispersion, Not Adjusted for Numeric Dispersion	$E = 1{,}000\ KD\ Ac / L$

Estimate Exchange Flows (E) between Adjacent Segment Pairs.
For all options, E = 0. always for segments discharging out of network (outflow segment number = 0).

Error Analysis (see discussion)	
Option	Description
0	Do Not Perform (Output CV's = 0)
1	Consider Model Error & Input Error [default]
2	Consider Model Error Only (reflect inherent model error only)
3	Consider Input Error Only (reflect uncertainty in user-specified inputs only)

Application of Phosphorus Calibration Factors (see discussion)	
Option	Description
0	Apply Calibration Factors to Predicted Sedimentation Rates [default]
1	Apply Calibration Factors to Predicted Concentrations

Application of Nitrogen Calibration Factors (see discussion)	
Option	**Description**
0	Apply Calibration Factors to Predicted Sedimentation Rates [default]
1	Apply Calibration Factors to Predicted Concentrations

Calculation of Mass Balance Tables (see discussion)	
Option	**Description**
0	Use Observed Segment Concentrations to Calculate Outflow and Storage Terms Mass balance tables are based entirely on observed inflow, outflow, & segment concentrations specified by the user (independent of predicted reservoir or outflow concentrations). If observed outflow or segment concentrations are missing, predicted values are used.
1	Use Predicted Segment Concentrations to Calculate Outflow and Storage Terms [default]

Influences output from the 'List Balances ' procedures. Does not influence predicted concentrations.

APPENDIX D. STEPL FACT SHEET

STEPL employs simple algorithms to calculate nutrient and sediment loads from different land uses and the load reductions that would result from the implementation of various BMPs.

Detailed STEPL information and downloads can be accessed here:
https://www.epa.gov/nps/spreadsheet-tool-estimating-pollutant-loads-stepl#training

STEPL provides a user-friendly Visual Basic interface to create a customized spreadsheet-based model in Microsoft Excel. It computes watershed surface runoff; nutrient loads, including nitrogen, phosphorus, 5-day biological oxygen demand; and sediment delivery based on various land uses and management practices. For each watershed, the annual nutrient loading is calculated based on the runoff volume and the pollutant concentrations in the runoff water, as influenced by factors such as the land-use distribution and management practices.

The annual sediment load (sheet and rill erosion only) is calculated based on the Universal Soil Loss Equation, an equation used to predict the average rate of erosion of an area on the basis of the rainfall, soil type, topography, and management measures of the area and the sediment delivery ratio. The sediment and pollutant load reductions that result from the implementation of BMPs are computed using known BMP efficiencies.

The Online STEPL Input Data Server provided necessary input data for STEPL. For selected 12-digit hydrologic unit code subwatershed(s), the Data Server can generate the hydrologic soil group data, number of septic systems, numbers of livestock, and land-use distribution.

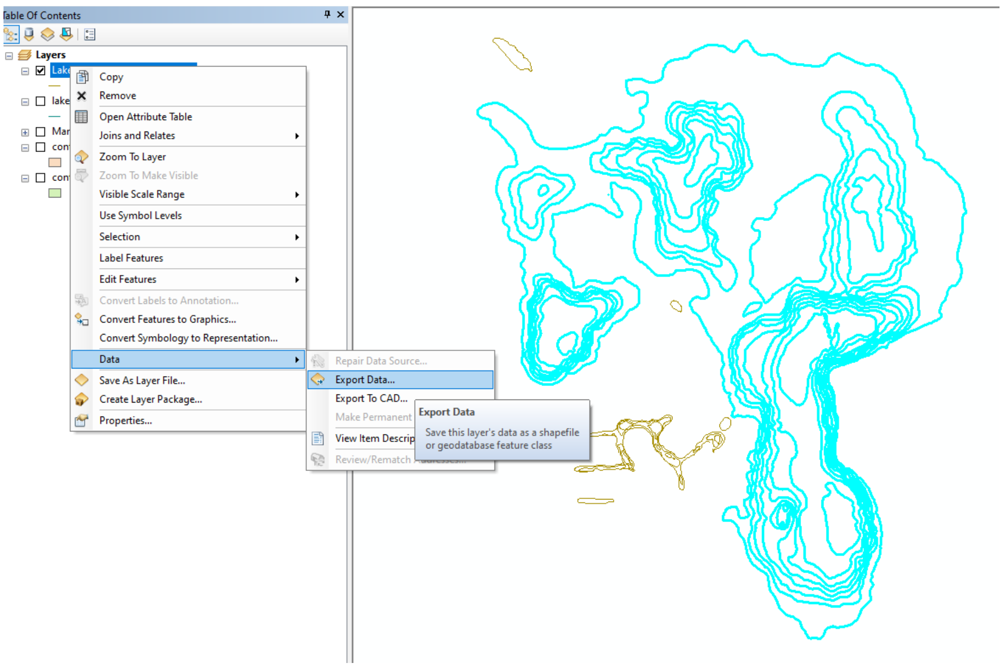
Data Server User's Guide can be accessed here:
https://www.epa.gov/nps/guide-using-stepl-online-data-access-system

Data Server can be accessed here:
http://it.tetratech-ffx.com/steplweb/steplweb.html

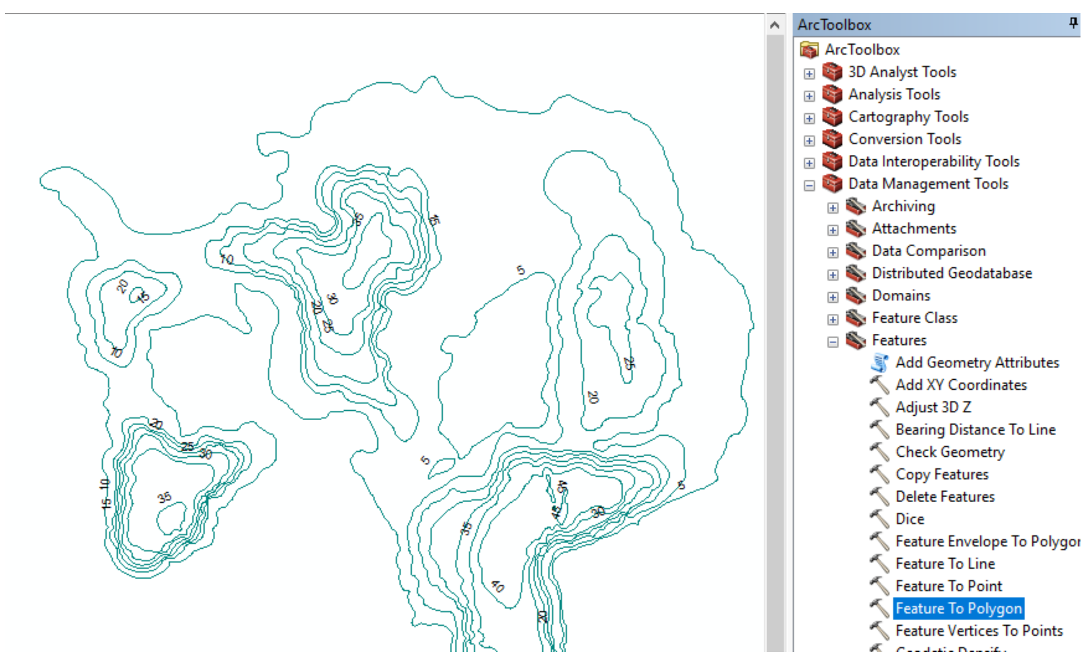
APPENDIX E. ESTIMATING LAKE VOLUME FROM DEPTH CONTOURS

This Appendix provides step-by-step instruction for estimating lake volume using the bathymetry contour data.

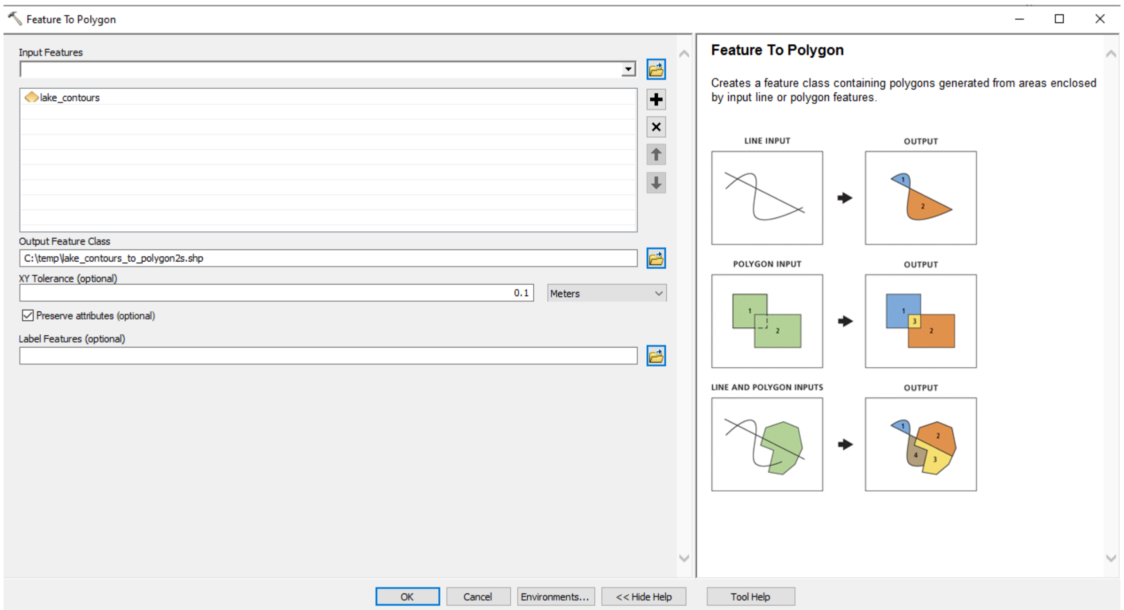
1. Isolate the depth contours for the area of interest. This can be accomplished by selecting the contours of interest, then exporting the selected features to a new shapefile. Add this new shapefile to the map.



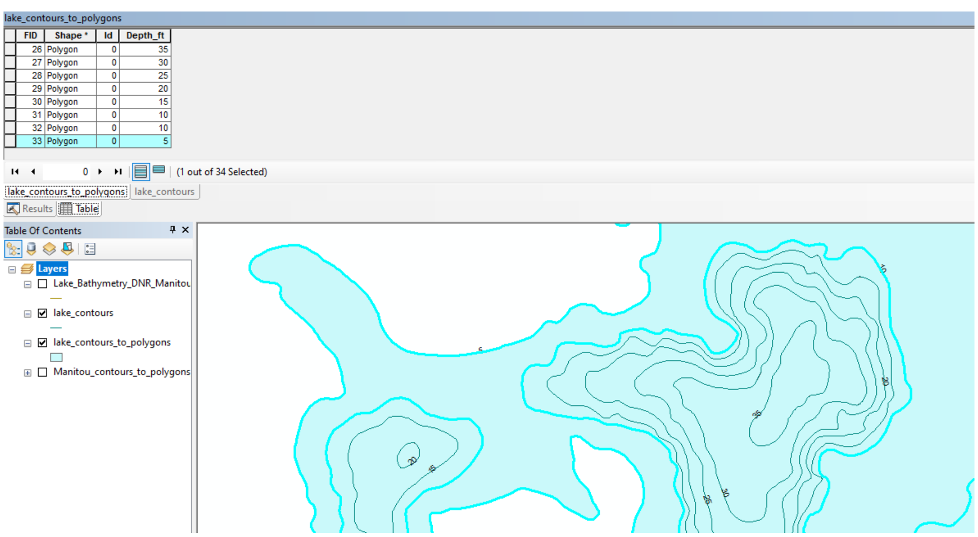
2. Use the Feature to Polygon tool in Data Management Tools/Features to convert the contour lines to polygons.



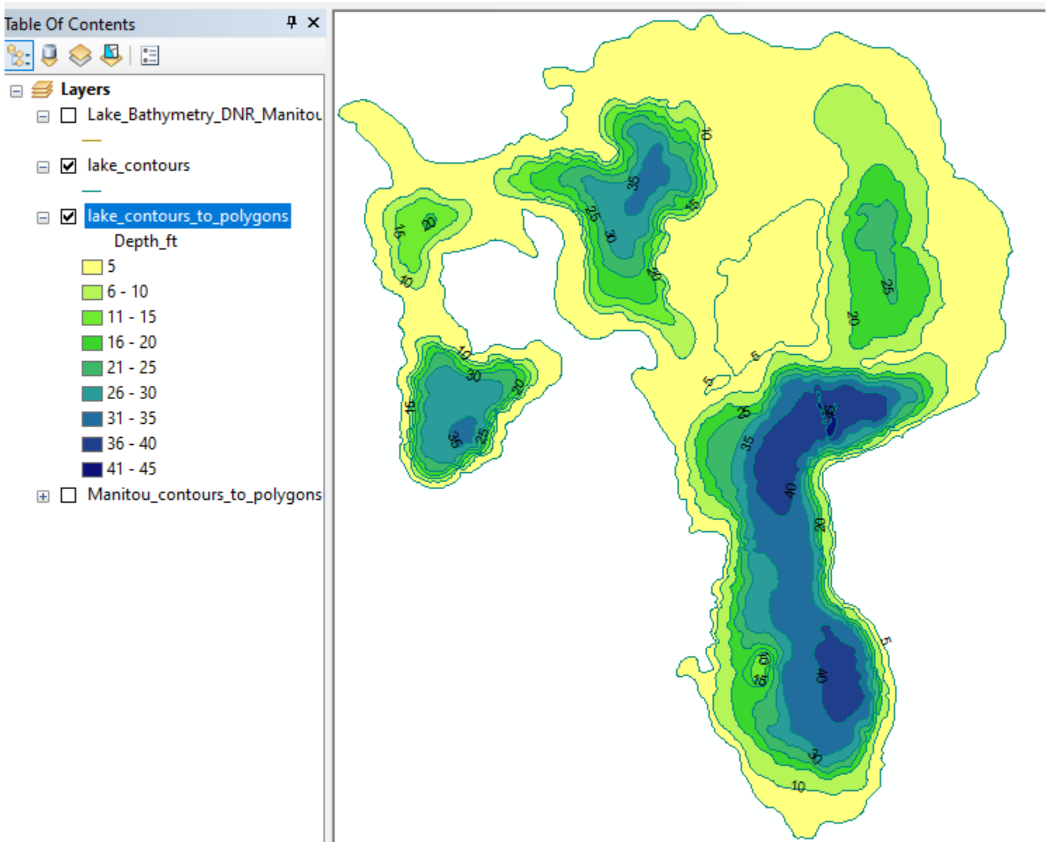
3. Select your shapefile with the isolated lake contours from Step 1 as the Input Feature. You may need to include a small distance for the XY Tolerance. If there are any small gaps in the contours, polygons won't be drawn unless the gap is smaller than the XY Tolerance. If the XY Tolerance is too high, the shapes of the polygons may not accurately reflect the input contour lines. Experiment to find a small value the allows all the polygons to be drawn and does not distort the polygons. This tool will create polygons from the spaces between the lines but will not always associate the attribute data from the original features to the resulting polygons.



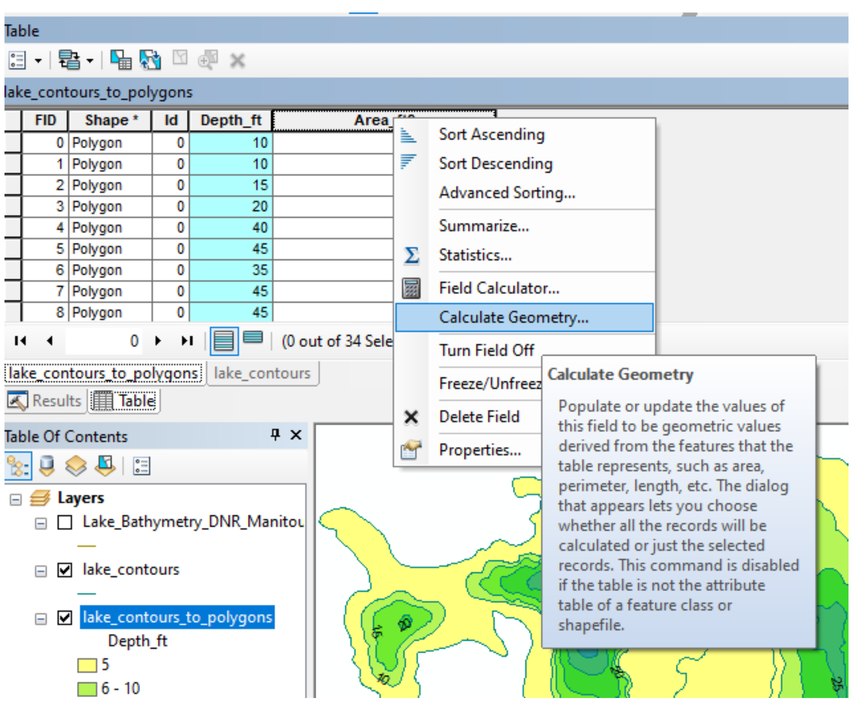
4. For this example, the depth contour data must be manually transferred to the polygon feature. Create a new field for the polygon feature, then begin an edit session. It helps to turn on labeling for the depth contours. The depth of each contour line will be manually assigned to the space contained within the contour line.

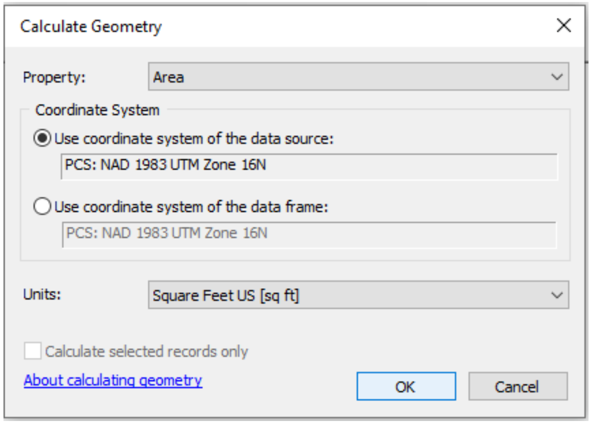


5. Verify the polygon depths against the contour depths. Save edits and stop editing,



6. If the polygon layer was saved to a geodatabase, it will already have a field containing each polygon's area. If not, add a new Double field, and use the Calculate Geometry option to get the area for each polygon in the appropriate units to match the depth contours.





7. To perform the calculations, export the attribute table for the polygon features as a text file, and open it in Excel. Calculate the volume of each contour polygon prism by multiplying its area by its depth. Then sum the volume of all the polygons to get the total approximate lake volume.