Pigeon River Watershed Total Maximum Daily Load Study for E. Coli and Impaired Biotic Community (IBC)

TMDL Report

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EXECUTIVE SUMMARY

The Pigeon River Watershed is located primarily in northeastern Indiana, beginning near Fremont, Indiana and flowing generally to the northwest into the St. Joseph River near Mottville, Michigan. The entire watershed is 395 square miles (253,000 acres) in size and is composed of two HUC 10 watersheds: Pigeon Creek (0405000110, 212 square miles) is the upper portion in Indiana, and Pigeon River (0405000111, 183 square miles) is the lower portion, which extends into Michigan in the furthest downstream HUC 12. Ultimately, the Pigeon River discharges into Lake Michigan, 50 miles west of the Pigeon River Watershed. Land cover in the Pigeon River Watershed is primarily (47%) cultivated crops.

According to the Clean Water Act and U.S. Environmental Protection Agency (EPA), states must develop Total Maximum Daily Loads (TMDLs) for waters on the Section 303(d) list. A TMDL is defined as *the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources* such that the capacity of the waterbody to assimilate pollutant loadings is not exceeded. Seasonal variation must be taken into account, and a margin of safety must be included that addresses the uncertainty in the analysis.

Stream data were collected as a part of this TMDL study between June 9 and September 29, 2010, for the TMDL analysis.

Potential sources of *E. coli*, total nitrogen, and total phosphorus in the watershed include point sources and nonpoint sources. National Pollutant Discharge Elimination System (NPDES) permitted point sources in the Pigeon River Watershed include wastewater treatment plants, combined sewer overflows, and stormwater runoff from stormwater Phase II communities. Nonpoint sources in the Pigeon River Watershed include agriculture (cropland, confined feeding operations, small animal feeding operations, pastured animals, land application of manure, and field tiles), runoff from non-agricultural land uses, onsite wastewater treatment systems, pets, and wildlife.

Source assessments were conducted on a HUC 12 basis for the applicable stream impairments. Load duration analyses were conducted for each HUC 12 to evaluate the flow conditions relative to the observed water quality data. The analyses linked water quality with potential pollutant sources based on the flow regimes under which water quality data exceeded the applicable standard or target value.

TMDLs were determined for each HUC 12 watershed for each of five flow regimes based on load duration analyses. Ultimately, a margin of safety, wasteload allocations, and load allocations were also identified for each HUC 12. Lake TMDLs were not developed as part of this TMDL but the information gathered for the Pigeon River watershed lakes and lake impairments has been compiled in Appendix C.

Implementation strategies for each HUC12 were identified in order to meet the water quality targets. Recommended management practices for regulated point sources, apart from meeting the requirements of the permit, include volume control of stormwater runoff to reduce combined sewer overflows, and volume control and water quality treatment of stormwater from stormwater Phase II communities. Recommended management practices for nonpoint sources include a suite

of agricultural best management practices (operational and structural), volume control of watershed runoff from urban and rural land uses, stream stabilization, and programmatic initiatives that increase public awareness and provide cost-share for failing onsite wastewater treatment systems and pet waste.

Table EX - 1. *E. coli* TMDL summary for HUC 12 watersheds

HUC 12 Watershed	Watershed Area [square miles]	*E. coli* TMDL [billion organisms per day]					Percent Reduction to Meet Geometric Mean Standard of 125 CFU/ 100 mL[1]
		High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows	
040500011001 Pigeon Lake – Pigeon Creek	34	333	138	75	42	20	84%
040500011002 Mud Creek – Pigeon Creek	18	147	63	36	21	12	91%
040500011003 Long Lake – Pigeon Creek	29	218	91	50	28	14	76%
040500011004 Headwaters Turkey Creek	18	155	80	52	34	22	78%
040500011005 Big Turkey Lake – Turkey Creek	17	145	75	48	32	21	89%
040500011006 Silver Lake – Pigeon Creek	20	150	62	34	19	9.3	97%
040500011007 Otter Lake – Pigeon Creek	16	111	57	37	25	16	75%
040500011008 Little Turkey Lake – Turkey Creek	21	162	83	54	36	23	94%
040500011009 Green Lake – Pigeon Creek	21	120	62	40	26	17	32%
040500011010 Mongo Millpond – Pigeon Creek	16	94	49	32	21	14	34%
040500011101 East Fly Creek	24	196	101	66	43	28	80%
040500011102 Fly Creek	19	157	82	53	36	24	92%
040500011103 Cline Lake – Pigeon River	27	193	99	64	42	28	86%
040500011104 Buck Lake – Buck Creek	26	209	108	70	46	30	91%
040500011105 Page Ditch	20	143	74	48	32	21	97%
040500011106 VanNatta Ditch – Pigeon River	32	268	138	89	59	38	89%
040500011107 Stag Lake – Pigeon River	36	240	143	101	67	43	80%

[1] Calculated based on the difference between the maximum geometric mean measured at any monitoring site in the HUC 12 and the water quality standard

Table EX - 2. Nutrients TMDL summary for HUC 12 watersheds

HUC 12 Watershed	Watershed Area [square miles]	Nutrient	Nutrient TMDL [pounds per day]					Percent Reduction to Meet Target[1,2]
			High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows	
040500011002 Mud Creek – Pigeon Creek	18	Total Nitrogen	2601	1116	634	372	213	65%
		Total Phosphorus	78	33	19	11	6.4	87%

[1] Target is 10 mg/L for total nitrogen, and 0.30 mg/L for total phosphorus
[2] Calculated based on the difference between the maximum value observed at the site and the numeric target

1 INTRODUCTION

1.1 Project Objective

The Pigeon River Watershed, located in Indiana and Michigan, contains waterbodies that are impaired due to the following pollutants: *Escherichia coli* (*E. coli*), and Impaired Biotic Communities (IBC). The impaired segments are all located in the Indiana portion of the watershed. The impaired waterbodies are designated for full body contact recreation and for supporting a well-balanced warm-water aquatic community. The impairments in the watershed affect either one or both of these uses.

The primary objective of this project is to develop total maximum daily loads (TMDLs) for the impaired waterbodies within the Pigeon River Watershed (Table 1). The Clean Water Act (CWA) and U.S. EPA regulations require that States develop TMDLs for impaired waterbodies such as those in the Pigeon River Watershed. The TMDL process involves several steps including watershed characterization, loading identification, source assessment, and allocation of loads. The purpose of the TMDL is to identify the allowable loads of each identified pollutant that will result in full attainment of the applicable water quality standards for each impaired resource within the watershed.

The overall goals of the Pigeon River TMDL are to:

- Assess the water quality of waterbodies throughout the watershed in comparison to values appropriate for their designated uses.
- Use available data and the best science to determine the maximum load the waterbodies can receive and fully support their designated uses.
- Determine the load reductions that are needed to meet the maximum allowable loads.
- Involve the public throughout the process for input on key concerns and to inform public on the project.
- Produce a final TMDL report for U.S. EPA approval.

1.2 Project Organization

U.S. Environmental Protection Agency (U.S. EPA) Region 5 provided funding for this project. U.S. EPA also provided technical advice, oversight, and contract administration.

Indiana Department of Environmental Management (IDEM) provided technical advice and oversight on behalf of the State of Indiana. Specifically, IDEM was responsible for the following: collecting monitoring data in 2010, reviewing the monitoring data collected during the 2010 monitoring season, updating the list of impaired waters and pollutants within the watershed, and facilitating meetings in the watershed to introduce the approach and process for the project and to solicit input on the TMDLs.

Michigan Department of Natural Resources and Environment (MDNRE) provided technical advice and oversight on behalf of the State of Michigan.

Emmons & Olivier Resources, Inc. (EOR) was a contractor of the U.S. EPA through a task order under U.S. EPA Contract EP-R5-10-04. EOR defined the goals for the TMDL, assisted in conducting meetings with the public, performed watershed and lake modeling and analysis, and prepared the TMDL report.

1.3 Overview

Section 303(d)(1)(C) of the Clean Water Act and its associated policy and program requirements for water quality planning, management, and implementation (Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require the establishment of a TMDL for the achievement of state water quality standards when a waterbody is water quality-limited. The numeric standards and water quality targets to be used in this TMDL are shown in Table 7 (see page 27). Table 7 makes the distinction as to whether a given parameter is subject to a State standard or if instead a target value has been established, and the table provides these values for both Indiana and Michigan. A TMDL identifies each waterbody's assimilative capacity for a pollutant, and includes an appropriate margin of safety. The focus of the TMDL is reduction of pollutant inputs to a level (*or load*) that fully supports the designated uses of a given waterbody. The mechanisms used to address water quality problems after the TMDL is developed can include a combination of best management practices (BMPs) and/or effluent limits and monitoring required through National Pollutant Discharge Elimination System (NPDES) permits.

The 253,000-acre Pigeon River Watershed is located primarily in Northeastern Indiana, beginning near Fremont, Indiana and flowing generally to the northwest into the St. Joseph River near Mottville, Michigan. The system is referred to as Pigeon Creek in the upper portion in Indiana and then becomes the Pigeon River at the HUC-10 boundary in Indiana. The entire length of the river in Michigan is referred to as the Pigeon River, although locally it may be referred to as the White Pigeon River in portions of Michigan. This document will refer to the entire study area as the Pigeon River Watershed. Distinctions will be made between stream reaches that are referred to as either Pigeon River or Pigeon Creek.

The Indiana portion of the Pigeon River Watershed contains waterbodies that are impaired due to high concentrations of *E. coli*, phosphorus, and nitrogen. The Indiana portion of the Pigeon River Watershed also contains one stream segment that has an impaired biotic community (IBC). The impaired waterbodies are all located in the Indiana portion of the watershed and are designated for full body contact recreation and for supporting a well-balanced warm-water aquatic community. The impairments in the Pigeon River Watershed affect either one or both of these uses. TMDLs will be developed for all impaired segments/pollutants identified in Table 1 and shown in Figures 1 through 4.

The TMDL report includes information that pertains to the entire Pigeon River Watershed, including human population, land use and land cover, topography and soils, and hydrology. The report also includes a description of the permitted and nonpoint sources of pollutants in the watershed, and a detailed source assessment. Allocations are included for each of the 17 distinct HUC 12 hydrologic units shown in Figure 5 and Figure 6.

Table 1. Impairments and associated pollutants within the Pigeon River Watershed

Waterbody	2010 AUID	Impairment			
		E. coli	IBC[1]	Total P	Total N
PIGEON CREEK	INJ01A1_01	yes	no	no	no
RYAN DITCH	INJ01A1_T1001	yes	no	no	no
METZ DITCH	INJ01A1_T1002	yes	no	no	no
BERLIEN DITCH	INJ01A1_T1004	yes	no	no	no
PIGEON CREEK	INJ01A2_01	yes	no	no	no
JACK DITCH	INJ01A2_T1001	yes	no	no	no
PIGEON CREEK - UNNAMED TRIBUTARY	INJ01A2_T1003	yes	no	no	no
MUD CREEK	INJ01A2_T1004	yes	yes	yes	yes
PIGEON CREEK	INJ01A3_01	yes	no	no	no
PIGEON CREEK - UNNAMED TRIBUTARY	INJ01A3_T1001	yes	no	no	no
PIGEON CREEK - UNNAMED TRIBUTARY	INJ01A3_T1003	yes	no	no	no
JOHNSON DITCH	INJ01A3_T1004	yes	no	no	no
JOHNSON DITCH - UNNAMED TRIBUTARY	INJ01A3_T1005	yes	no	no	no
TURKEY CREEK	INJ01A4_02	yes	no	no	no
TURKEY CREEK - UNNAMED TRIBUTARY	INJ01A4_T1003	yes	no	no	no
DEETZ DITCH	INJ01A4_T1005	yes	no	no	no
TURKEY CREEK	INJ01A5_01	yes	no	no	no
MUD CREEK	INJ01A5_T1001	yes	no	no	no
MUD CREEK - UNNAMED TRIBUTARY	INJ01A5_T1002	yes	no	no	no
INLET TO GOLDEN LAKE	INJ01A6_T1002	yes	no	no	no
PIGEON CREEK	INJ01A7_01	yes	no	no	no
INLET TO OTTER LAKE	INJ01A7_T1001	yes	no	no	no
MAUMEE DITCH	INJ01A8_T1001	yes	no	no	no
INLET TO MUD LAKE	INJ01A8_T1002	yes	no	no	no
INLET TO TAYLOR LAKE	INJ01A8_T1002A	yes	no	no	no
INLET TO LITTLE TURKEY LAKE	INJ01A8_T1008	yes	no	no	no
PIGEON CREEK	INJ01A9_01	yes	no	no	no
TURKEY CREEK	INJ01AA_02	yes	no	no	no
TURKEY CREEK	INJ01AA_03	yes	no	no	no
FLY CREEK, EAST	INJ01B1_02	yes	no	no	no
STONER DITCH	INJ01B1_T1004	yes	no	no	no
FLY CREEK	INJ01B2_01	yes	no	no	no
FLY CREEK	INJ01B2_02	yes	no	no	no
PIGEON RIVER	INJ01B3_01	yes	no	no	no
[2]PIGEON RIVER	INJ01B3_02	yes	no	no	no
[2]ONTARIO MILLPOND INLET	INJ01B3_02	yes	no	no	no
PIGEON RIVER	INJ01B3_03	yes	no	no	no
PIGEON RIVER - UNNAMED TRIBUTARY	INJ01B3_T1002	yes	no	no	no
BUCK CREEK	INJ01B4_01	yes	no	no	no
BUCK CREEK DITCH, EAST	INJ01B4_T1002	yes	no	no	no
BUCK CREEK DITCH, EAST	INJ01B4_T1003	yes	no	no	no
PAGE DITCH	INJ01B5_01	yes	no	no	no

Waterbody	2010 AUID	Impairment			
		E. coli	IBC[1]	Total P	Total N
PAGE DITCH - UNNAMED TRIBUTARY	INJ01B5_T1002	yes	no	no	no
TRUSDALE DITCH	INJ01B5_T1003	yes	no	no	no
PIGEON RIVER	INJ01B6_01	yes	no	no	no
PIGEON RIVER	INJ01B6_02	yes	no	no	no
VAN NATTA DITCH	INJ01B6_T1002	yes	no	no	no
FETCH DITCH	INJ01B7_T1001	yes	no	no	no

[1]IBC – Impaired Biotic Community
[2] The waterbodies Pigeon River and Ontario Mill Pond Inlet are both listed as AUID INJ01B3_02

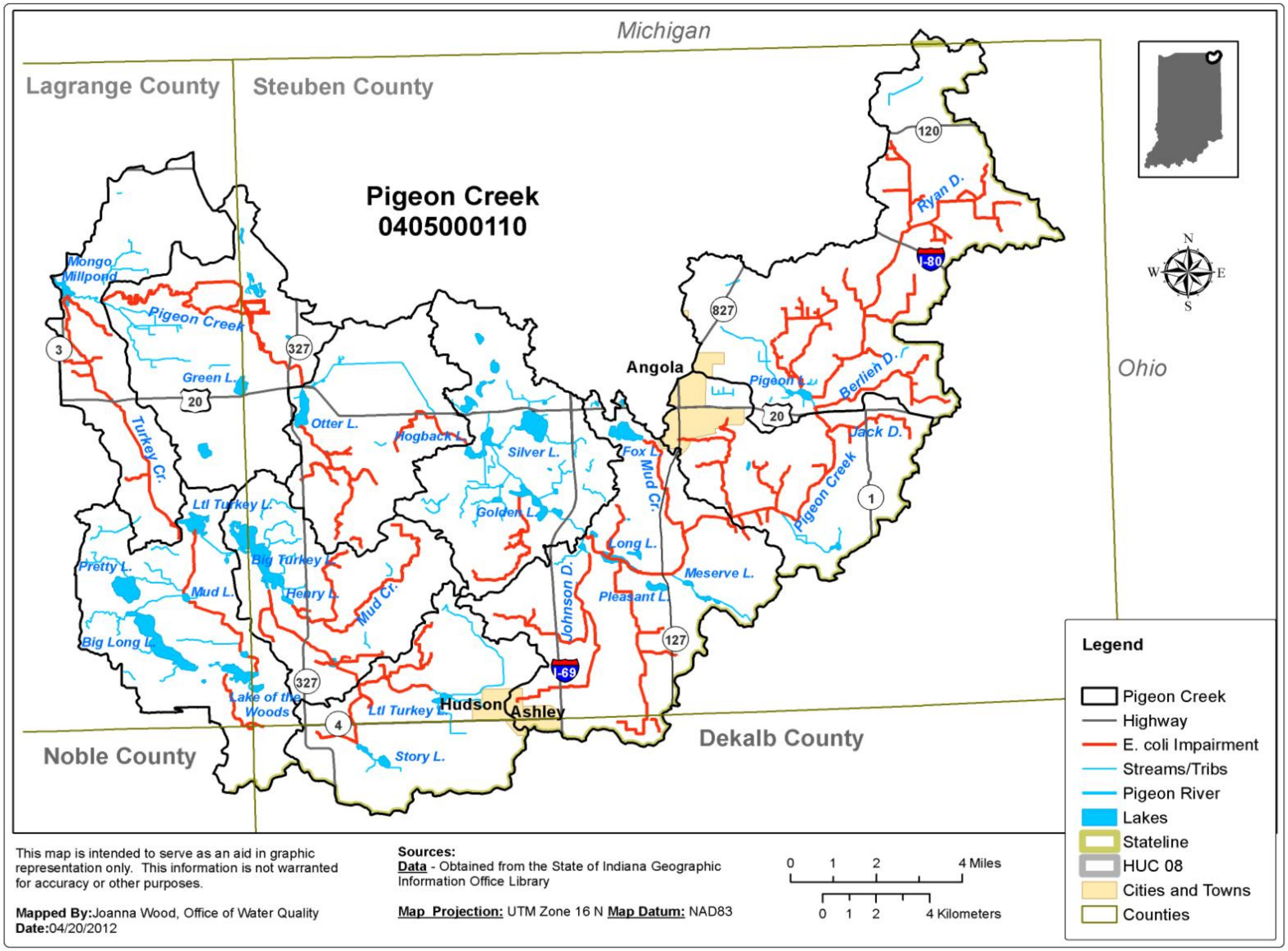

Figure 1. Upper Pigeon River Watershed *E. coli* impairments

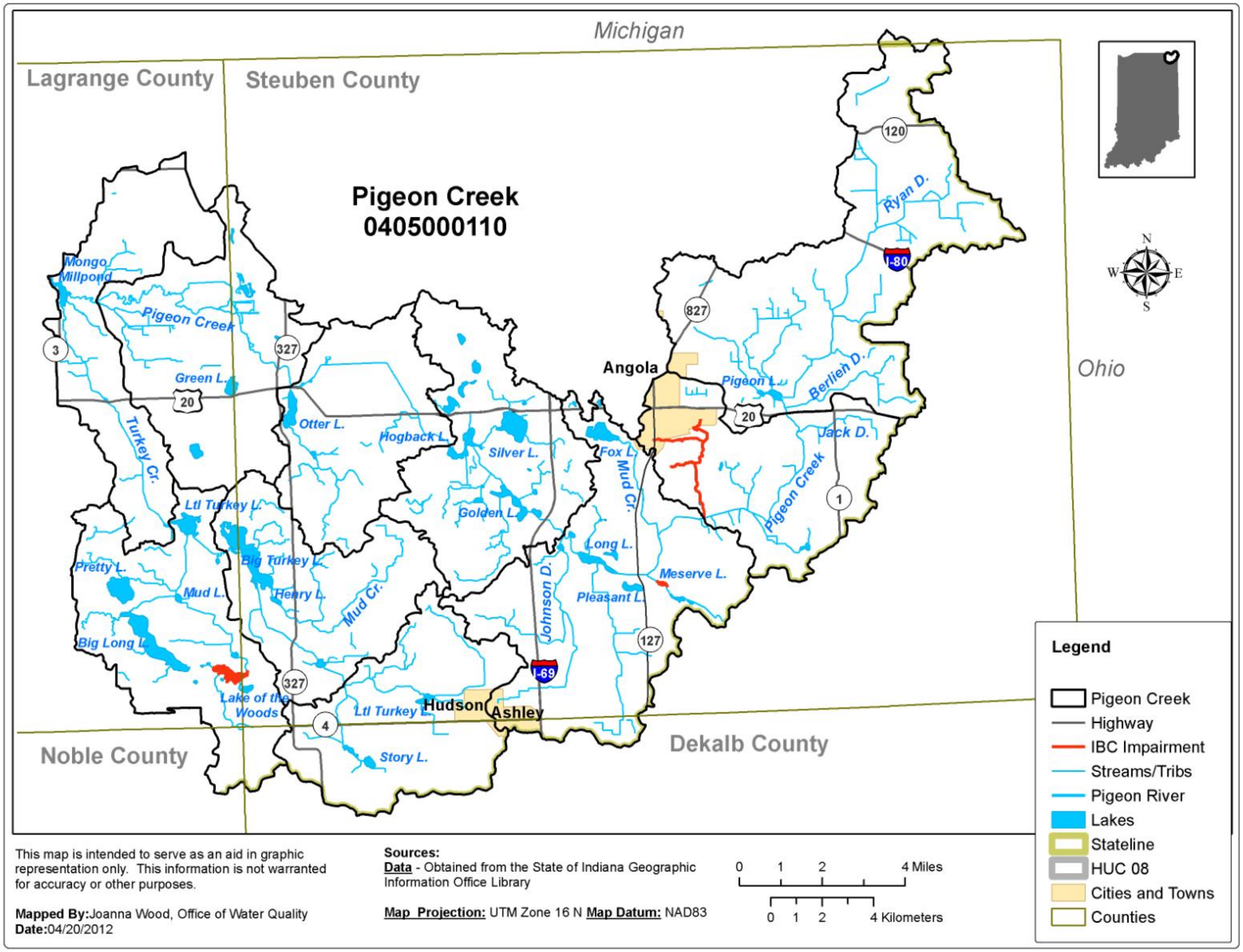

Figure 2. Upper Pigeon River Watershed biotic and nutrient impairments

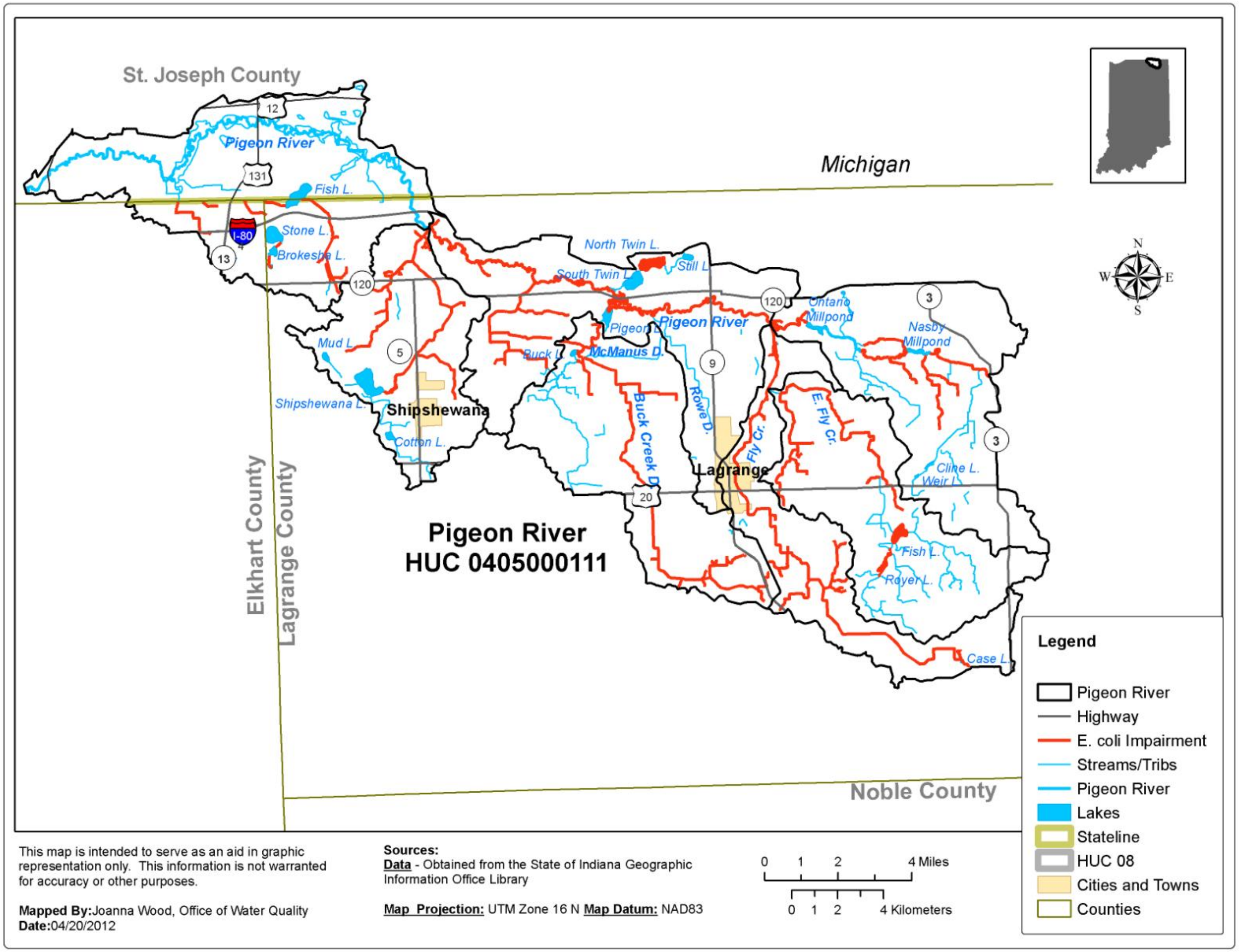

Figure 3. Lower Pigeon River Watershed *E. coli* impairments

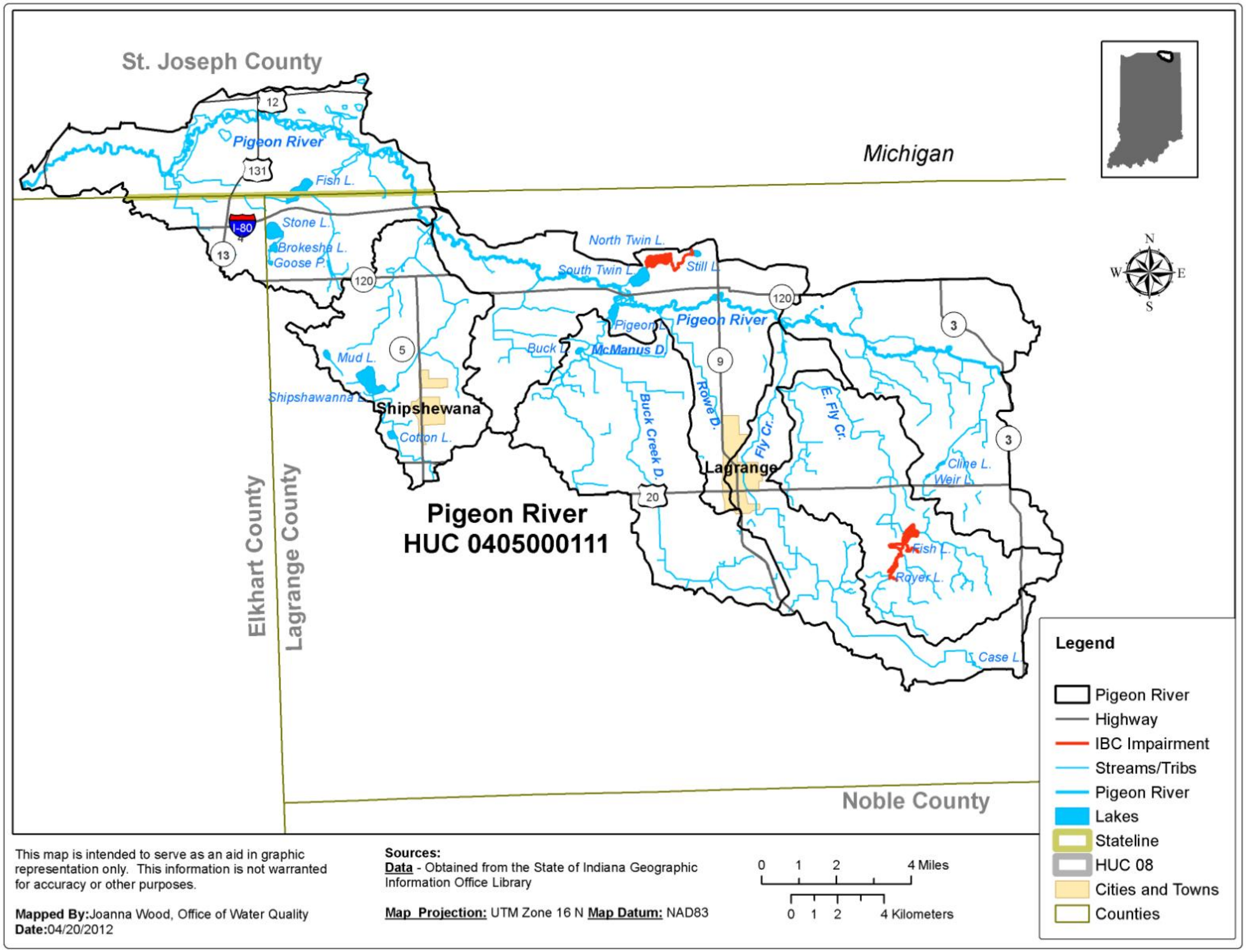

Figure 4. Lower Pigeon River Watershed biotic and nutrient impairments

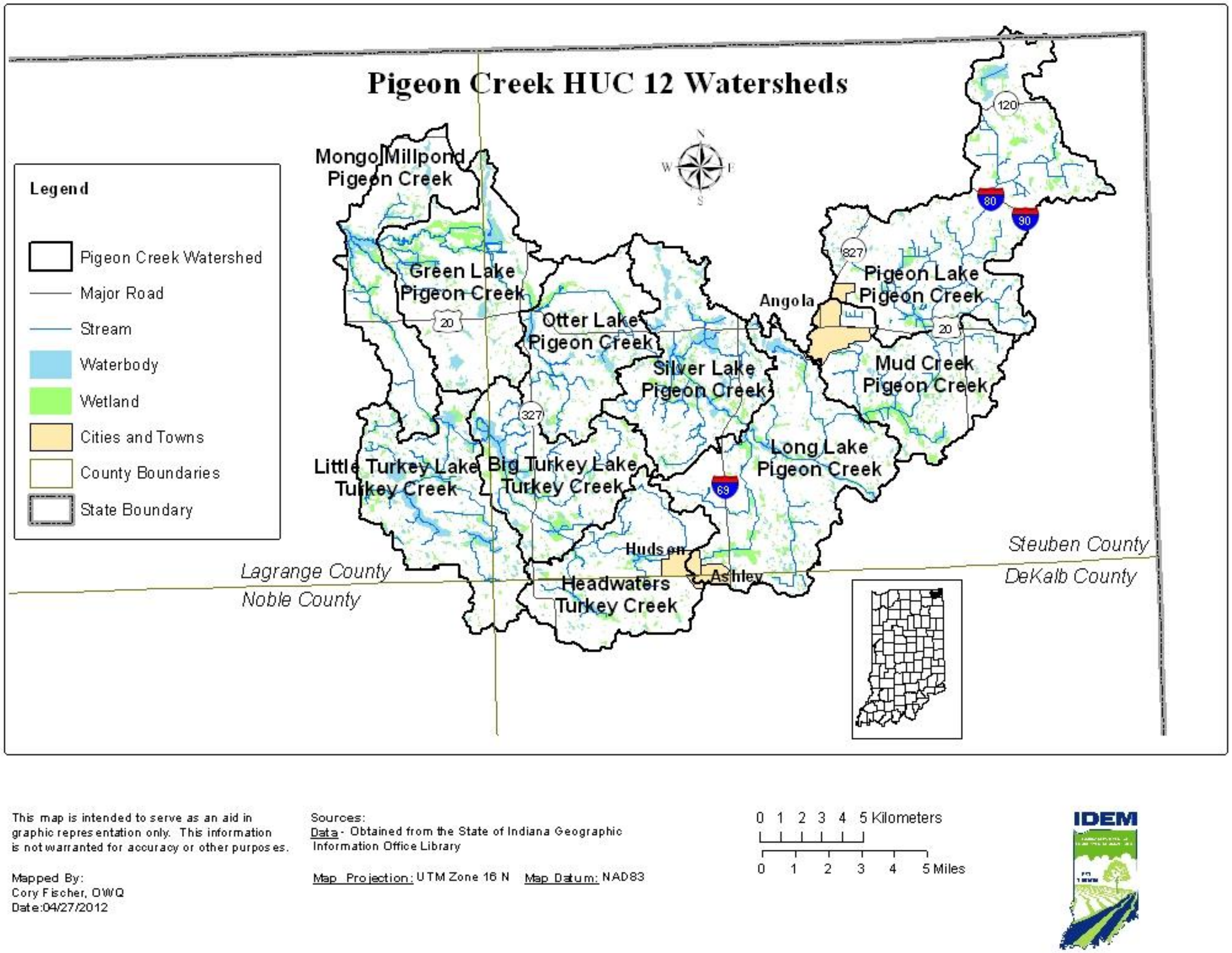

Figure 5. Upper Pigeon River Watershed HUC 12 watersheds

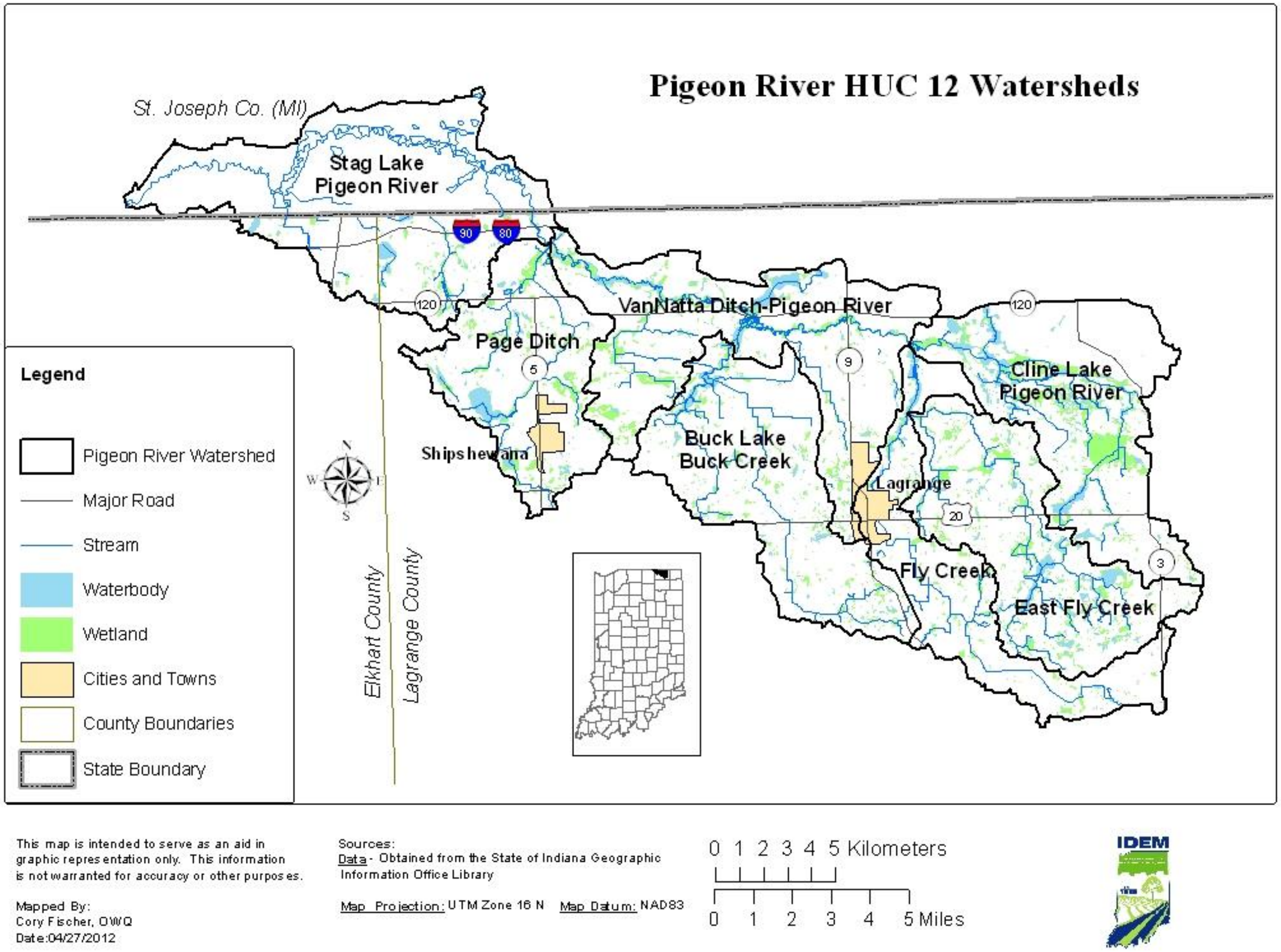

Figure 6. Lower Pigeon River Watershed HUC 12 watersheds

1.4 Priority Ranking

The TMDL development schedule corresponds with IDEM's basin-rotation water quality monitoring schedule. To take advantage of all available resources for TMDL development, impaired waters are scheduled according to the basin-rotation schedule unless there is a significant reason to deviate from this schedule.

2 DESCRIPTION OF THE WATERSHED

2.1 Human Population

The population for the Pigeon River Watershed has been estimated based on U.S. Census 2010 data on the population of the counties within the watershed. The population of the watershed was estimated assuming an even distribution of population throughout the county as census block data for the 2010 Census is not available. The population in the watershed is estimated as the total of each county's population multiplied by the percentage of the county's area covered by the Pigeon River Watershed. The watershed's estimated population is 41,599 (Table 2.)

Table 2. Population of Counties in the Pigeon River Watershed

County	County Population	% of County in Watershed	Estimated Population in Watershed
Steuben	34,185	47	16,067
LaGrange	37,128	53	19,678
Elkhart	197,559	1	1,976
Noble	47,536	0.3	143
DeKalb	42,223	3	1,267
St. Joseph	61,295	4	2,452
Cass	52,293	0.03	16

Total: 41,599

2.2 Land Use and Land Cover

The primary land cover in the Pigeon River Watershed is the cultivated agricultural cropland covering over 47% of the watershed (Table 3). Almost 18% of the watershed area is in hay or pasture. Another almost 17% of the watershed is woody wetlands. The remaining 18% of the watershed is primarily forest, developed open space, and low intensity residential development (Figure 7 and Figure 8).

Table 3. Land cover of the Pigeon River Watershed

Land Cover	Area (acres)	Percent of Watershed Area
Cultivated Crops	119,795	47.3%
Hay/Pasture	44,157	17.5%
Woody Wetlands	41,654	16.5%
Deciduous Forest	12,968	5.1%
Developed, Open Space	12,233	4.8%
Developed, Low Intensity	7,822	3.1%
Open Water	5,513	2.2%
Herbaceous	3,721	1.5%
Developed, Medium Intensity	1,840	0.7%
Evergreen Forest	1,273	0.5%
Developed, High Intensity	764	0.3%
Emergent Herbaceous Wetlands	575	0.2%
Shrub/Scrub	457	0.2%
Mixed Forest	131	0.1%
Barren Land	102	0.0%

Source: National Land Cover Dataset and GIS analysis

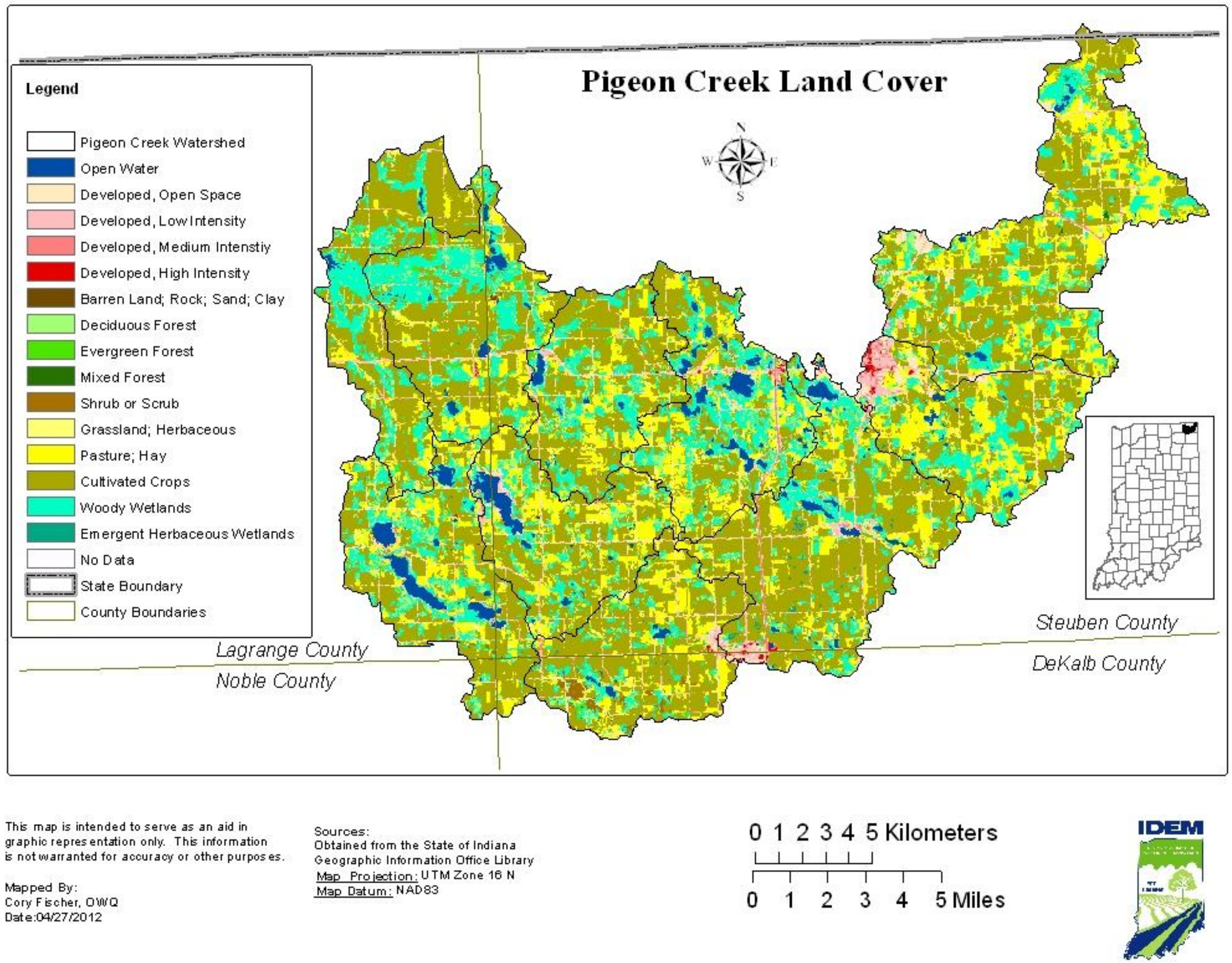

Figure 7. Upper Pigeon River Watershed land cover

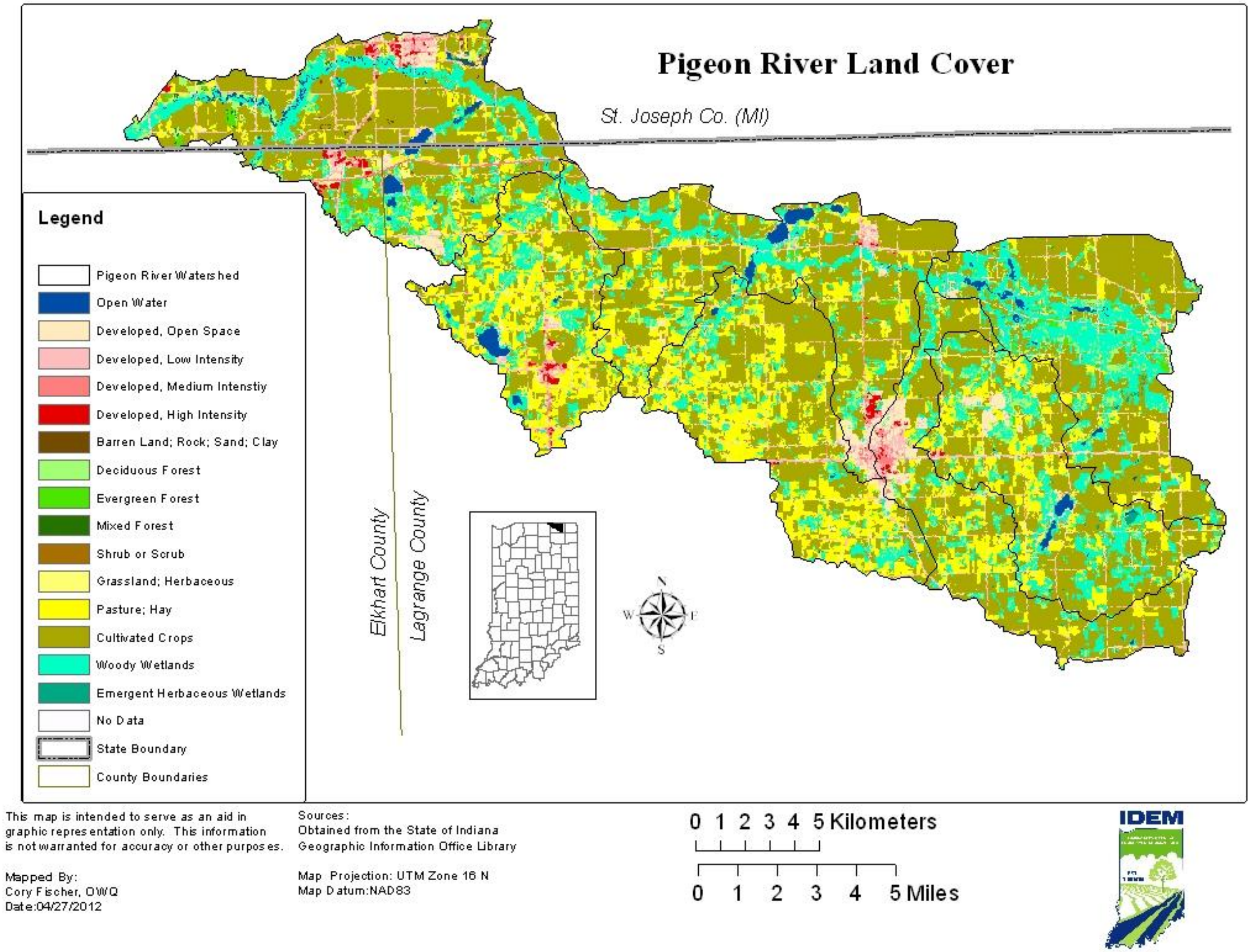

Figure 8. Lower Pigeon River Watershed land cover

2.3 Topography and Soils

The Pigeon River Watershed sits at an elevation of about 1100 feet near the headwaters to about 750 feet near the outlet. Soils in the watershed can be characterized by hydrologic soil group (Figure 9 and Figure 10). The hydrologic soil group is a parameter that generally describes the permeability of the soil by grouping soils into one of four categories (Table 4). Soils in hydrologic soil group A are sandier soils that allow water to filter into the ground fairly quickly and result in lower runoff. Soils in hydrologic soil group D are clayey and limit the movement of water deeper into the soil profile resulting in higher runoff. Group B and C soils fall between these two in their properties. The soil groups that cover the majority of the watershed are A soils with 40% of the watershed, B soils with 30%, and C soils with 18% coverage of the watershed (Table 5).

Table 4. Description of hydrologic soil groups

Hydrologic Soil Group	Description
A	Typically deep, well to excessively drained sands or gravels. High rate of water transmission into the soil. Low runoff potential.
B	Usually moderately deep to deep and moderately well to well drained soils with moderately fine to moderately coarse textures. Moderate rate of water transmission into the soil.
C	Soils with moderately fine to fine structure and a layer that impedes downward movement of water. Lower rate of water transmission into the soil.
D	Chiefly clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material. Low rate of water transmission into the soil. High runoff potential.

Table 5. Area of Pigeon River Watershed by hydrologic soil group

Hydrologic Soil Group	Area (acres)	Percent of Watershed (%)
A	102,425	40%
A/D	1,337	1%
B	75,565	30%
B/D	1,317	1%
C	46,242	18%
D	18,350	7%
Undefined	7,932	3%

2.4 Hydrology

There are two USGS gaging stations within the Pigeon River Watershed and one station outside the watershed that provide information on the hydrology of the watershed (Table 6). The Pigeon Creek station is located about five miles west of the City of Angola and has average daily flows of 98 cubic feet per second (1975-2010). The Pigeon River station is located a little over a half mile south of the state border between Michigan and Indiana. The flows at this station have an average daily flow of 376 cubic feet per second (1975-2010) because of the larger contributing watershed. The St. Joseph River station is outside the watershed, but was used in this study to support modeling efforts.

Table 6. USGS gaging stations within and downstream of Pigeon River Watershed

Station Name	ID	Years*	Average Daily Flow ± Std. Dev. (cfs)	Range of Flows (cfs)
Pigeon Creek near Angola, IN	04099510	1975 - 2010	98 ±97	10 - 996
Pigeon River near Scott, IN	04099750	1975 - 2010	376 ±266	66 - 2,340
St. Joseph River at Elkhart, IN	04101000	1975 - 2010	3,495 ±2,002	613 - 18,500

*The flow record at these sites begins in 1946, 1969, and 1948, respectively, for the order presented in the table. The time period shown was selected as a long-term record for which data are available at all sites. These years of data were used in TMDL modeling.

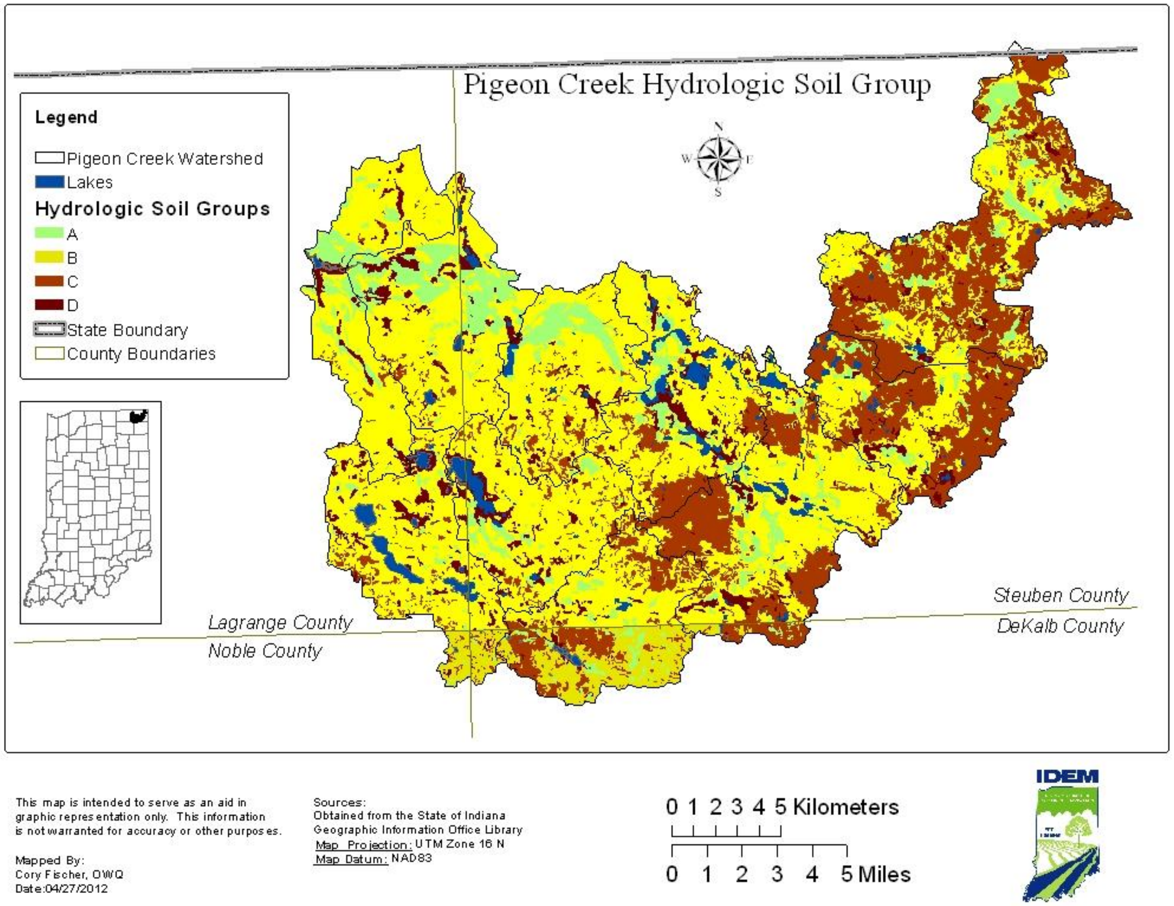

Figure 9. Upper Pigeon River Watershed hydrologic soil groups

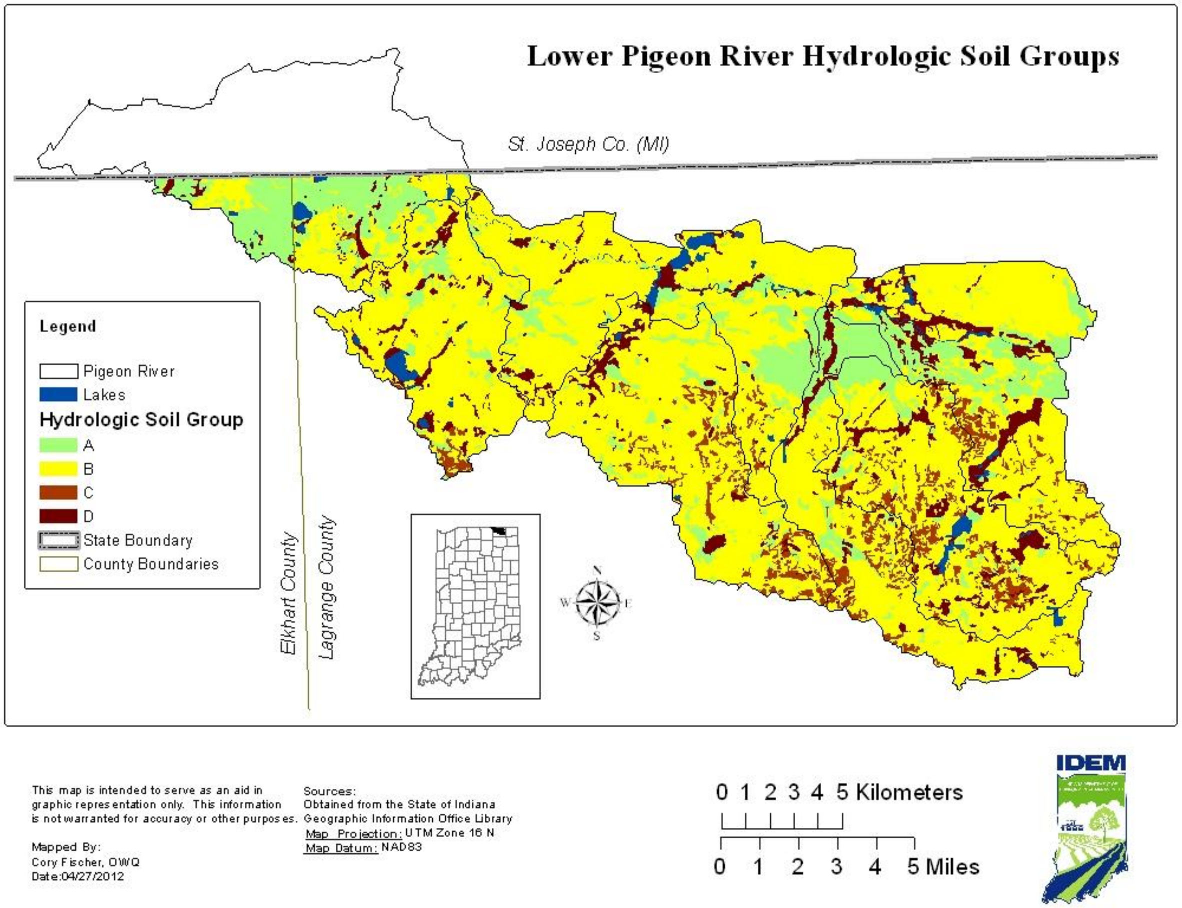

Figure 10. Lower Pigeon River Watershed hydrologic soil groups
*Michigan Soil Data was unavailable

3 INVENTORY AND ASSESSMENT OF WATER QUALITY

3.1 Water Quality Standards and Numeric Targets

3.1.1 Water Quality Standards

Water quality standards are established to protect, maintain, and improve the quality of the nation's waters. Standards consist of two components: designated uses and water quality criteria. Surface waterbodies of the Pigeon River Watershed are designated for full body contact recreation and for supporting a well-balanced warm-water aquatic community.

The State of Indiana (IN) and the State of Michigan (MI) have both narrative and numeric water quality criteria that apply to one or both of the designated uses. Rule 1.5 of the Indiana Administrative Code (IAC) details the water quality criteria that are applicable to waterbodies within the Great Lakes watershed. Rule 323.1041 through 323.1117 of Michigan Administrative Code details the State of Michigan's water quality standards.

This section contains the water quality criteria for the impairments addressed in this TMDL report: *E. coli*, total phosphorus, total nitrogen, and biotic communities.

<u>State of Indiana Water Quality Standards</u>

Biological

The biological narrative criterion in Indiana states that, "all waters, except as described in subdivision (5), will be capable of supporting a well-balanced, warm water aquatic community." Subdivision (5) exempts certain limited use waters. A "well-balanced aquatic community" is defined in IAC 2-1-9(60) as an "aquatic community that is diverse in species composition; contains several different trophic levels; and is not composed mainly of pollution tolerant species."

Bacteria

For full body contact recreational use, during the recreational season of April 1 through October 31, *E. coli* bacteria should not exceed the following [327 IAC 2-1.5-8e(3)]:

- 125 colony forming units (CFU) or maximum probable number (MPN) per 100 mL as a geometric mean based on no fewer than five samples equally spaced over a thirty day period.
- 235 organisms per 100 mL in any one sample in a thirty day period. In cases where there are at least ten samples at a site, up to ten percent of the samples may exceed 235 CFU or MPN per 100 mL where:
    - The *E. coli* exceedances are incidental and attributable solely to *E. coli* resulting from the discharge of treated wastewater from a wastewater treatment plant
    - The 125 CFU per 100 mL criteria is met

State of Michigan Water Quality Standards

The Pigeon River and related tributaries flow into Michigan. Under the Clean Water Act, states are required to ensure that discharges do not impair downstream waters, including those in downstream states.

Biological

The State of Michigan has the following narrative standard for biota:

> At a minimum, all surface waters of the state are designated and protected for all of the following uses: (a) Agriculture, (b) Navigation, (c) Industrial water supply, (d) Warmwater fishery, (e) Other indigenous aquatic life and wildlife, (f) Partial body contact recreation, (g) Fish consumption." [Rule 323.1100(e)]

Bacteria

The State of Michigan has the following numeric criteria for bacteria:

> All surface waters of the state protected for total body contact recreation shall not contain more than 130 *Escherichia coli* (*E. coli*) per 100 milliliters, as a 30-day geometric mean. Compliance shall be based on the geometric mean of all individual samples taken during 5 or more sampling events representatively spread over a 30-day period. Each sampling event shall consist of 3 or more samples taken at representative locations within a defined sampling area. At no time shall the surface waters of the state protected for total body contact recreation contain more than a maximum of 300 *E. coli* per 100 milliliters. Compliance shall be based on the geometric mean of 3 or more samples taken during the same sampling event at representative locations within a defined sampling area. [R 323.1062 Rule 62. (1)]
>
> All surface waters of the state protected for partial body contact recreation shall not contain more than a maximum of 1,000 *E. coli* per 100 milliliters. Compliance shall be based on the geometric mean of 3 or more samples, taken during the same sampling event, at representative locations within a defined sampling area. [R 323.1062 Rule 62. (2)]

Monitoring for Pigeon River Watershed streams consisted of 5 sampling events spread over a 30-day period. Each sampling event consisted of one sample, not the 3 or more samples taken within a defined sampling area as required by the State of Michigan's bacteria standard. Therefore, the *E. coli* data from the sites in MI were not evaluated with respect to numeric criteria.

It is assumed that Michigan's water quality standard for bacteria will be met during the recreational season for flows from the Pigeon River as it crosses from Indiana into Michigan by Indiana meeting their bacteria water quality standards. However, Michigan has a non-recreational (November 1 through April 30) bacteria standard, which Indiana does not have. Under the Clean Water Act, states are required to ensure that discharges do not impair downstream waters. The State of Indiana is responsible for ensuring that the non-recreational seasonal flows from Indiana to Michigan will not exceed Michigan's water quality standard for *E. coli* in the Pigeon River. (There are no data currently available to determine if Michigan's standards are being exceeded.)

3.1.2 Target Values

For parameters that do not have numeric criteria, target values were used to develop the TMDL loading limits.

<u>Biological</u>

Streams

Compliance with the biological narrative standards in Indiana are evaluated with fish community index of biotic integrity (IBI) scores. The IDEM scoring methodology considers that the IBI score should be above 36 in order to be fully supporting of aquatic life.
For IBCs, 327 IAC 2-1-3(a)(2)(A) states that all surface waters, except as described in subdivision (5), will be capable of supporting a well-balanced, warm water aquatic community. Furthermore, at all times, all surface waters outside of mixing zones shall be free of substances in concentrations that on the basis of available scientific data are believed to be sufficient to injure, be chronically toxic to, or be carcinogenic, mutagenic, or teratogenic to humans, animals, aquatic life, or plants (327 IAC 2-1-6(a)(2)).

Parameters contributing to IBC include total nitrogen, and total phosphorus, low dissolved oxygen and habitat are also potential stressors contributing to biotic community impairments. Low dissolved oxygen is often the result of elevated nutrient levels (TP and total nitrogen), while habitat problems generally lead to higher sediment concentrations. One stream (Mud Creek) IBC impairment is address in this TMDL. This is addressed through the total phosphorus and total nitrogen impairments. Additional locations have IBC impairments but pollutants have not been identified as causes for the impairment. The impairment is likely due to stream flow issues caused by lake outfall and the need to keep acceptable lake levels. Therefore these TMDLs have not been addressed.

Total Phosphorus

Streams

The State of Indiana has a numeric target of 0.30 mg/L Total Phosphorus (TP), which is an interpretation of the narrative nutrient criteria (327 IAC 2-1-6). The target value for total phosphorus is intended to limit the negative effects on aquatic ecosystems that can occur due to increasing algal and aquatic plant life production associated with higher nutrient concentrations (Sharpley et al. 1994). Increased plant production increases turbidity, decreases average dissolved oxygen concentrations, and increases fluctuations in diurnal dissolved oxygen and pH levels. Such changes shift aquatic species composition away from functional assemblages composed of intolerant species, benthic insectivores, and top carnivores that are typical of high quality streams towards less desirable assemblages of tolerant species, generalists, omnivores, and detritivores that are typical of degraded streams (OEPA 1999). Such a shift in community structure lowers the diversity of the system.

The State of Michigan does not have a water quality standard or numeric target for TP.

Total Nitrogen - Streams

The State of Indiana has a numeric target of 10 mg/L Total Nitrogen (TN), which is the Indiana drinking water standard. The State of Michigan does not have a water quality standard or numeric target for TN.

Table 7. Summary of target values for stream reaches

Waterbody Type	Parameter	Indiana		Michigan	
		Numeric Standard / Target Value	Source	Numeric Standard / Target Value	Source
Streams	***E. coli*** (Chronic)	**125 CFU / 100 mL** as a geometric mean based on not less than 5 samples over a 30 day period	327 IAC 2-1.5-8(e)(3)	**130 CFU / 100 mL** as a geometric mean based on not less than 5 samples over a 30 day period (Based on a geometric mean of 3 or more samples taken during the same sampling event at a representative location)	Rule 62 (Part 1) of 323.1062 Microorganisms
	E. coli (Maximum)	**235 CFU / 100 mL** in any 1 sample in a 30 day period	327 IAC 2-1.5-8(e)(3)	**300 CFU / 100 mL** as a geometric mean of 3 or more samples taken during the same sampling event at a representative location	Rule 62 (Part 1) of 323.1062 Microorganisms
	E. coli (Non-recreational)	Ensure that non-recreational (Nov 1-Apr 30) flows from IN to MI will not exceed MI's standards		**1,000 CFU / 100 mL** as a geometric mean of 3 or more samples taken during the same sampling event at a representative location	Rule 62 (Part 2) of 323.1062 Microorganisms
	Total Phosphorus (TP)*	No value should exceed **0.30 mg/L**	Interpretation of 327 IAC 2-1-6	No numeric target	--
	Total Nitrogen ((NO2 + NO3) + (TKN))*	No value should exceed **10 mg/L**	Based on drinking water std	No water quality standard	--
	Fish Community Index of Biotic Integrity (IBI) [Scores: Range of possible scores is 6-60]	Fully Supporting**: IBI > 36** Not Supporting**: IBI < 36**	Based on IDEM scoring methodology	No numeric target	--

*Standards/targets in IN are based on single sample exceedances.

3.1.3 Summary Table of Numeric Standards and Target Values

Table 7 summarizes all of the numeric standards and target values presented in Sections 3.1.1 and 3.1.2. These are the numeric targets that will be used to develop the TMDL loading limits for the impaired waters in the Pigeon River Watershed.

3.2 Assessment of Water Quality - Streams

Data for the impaired stream AUIDs are summarized in this section of the report. These data were collected between June 9 and September 29, 2010. For further details regarding 2010 water quality monitoring see the December 8, 2010 report entitled, *Water Quality Monitoring for the Pigeon River Watershed in Support of Total Maximum Daily Load Development: Monitoring Report* prepared for U.S. EPA Region 5 by Emmons & Olivier Resources, Inc. Appendix B.1 (of this report) includes secondary data for streams provided by the Steuben SWCD, which were reviewed for consistency with the TMDL.

3.2.1 Chemistry Data

Table 8 and Table 9 summarize total nitrogen and total phosphorus data, respectively, for AUID INJ01A2_T1004, which is impaired for total nitrogen and total phosphorus. A reach is designated as impaired if at least 1 sample on the reach exceeds the target value.

The total nitrogen target for AUID INJ01A2_T1004 was exceeded at all sites except Site 6; there were a total of five exceedances out of the 12 samples taken along the reach. The total phosphorus target was exceeded only at Site 7; one of the three samples at that site exceeded the target value.

Table 8. Total nitrogen data summary for streams, 2010 growing season

HUC 12	AUID	Site	Sample Size (N)	Mean [mg/L]	Standard Error [mg/L]	Maximum [mg/L]	Percent Reduction to Meet Target of 10 mg/L*
040500011002, Mud Creek – Pigeon Creek	INJ01A2_T1004	6	3	1.44	0.045	1.5	0%
		7	3	13.6	0.108	18.9	65%
		8	3	12.3	0.037	15.8	47%
		10	3	9.79	0.003	13.3	34%

*Calculated based on the difference between the maximum value observed at the site and the numeric target

Table 9. Total phosphorus data summary for streams, 2010 growing season

HUC 12	AUID	Site	Sample Size (N)	Mean [mg/L]	Standard Error [mg/L]	Maximum [mg/L]	Percent Reduction to Meet Target of 0.30 mg/L*
040500011002 Mud Creek – Pigeon Creek	INJ01A2_T1004	6	3	0.11	0.05	0.20	0%
		7	3	0.35	2.84	0.56	87%
		8	3	0.26	2.08	0.30	0%
		10	3	0.21	1.79	0.22	0%

*Calculated based on the difference between the maximum value observed at the site and the numeric target

3.2.2 *E. Coli* Data

Table 10 summarizes *E. coli* data from June 9 through July 7, 2010. The geometric mean, mean, minimum, and maximum values are presented along with the percent reduction needed to meet the TMDL target values. The geometric means ranged from 113 CFU/100 mL at site 31 (HUC 12 040500011007 Otter Lake-Pigeon Creek, AUID INJ01A7_01) to 4,988 CFU/100 mL at site 53 (HUC 12 040500011105 Page Ditch, AUID INJ01B5_T1003). The highest single sample was from site 17 (28,400 CFU/100 mL). The geometric mean exceeded the standard at all sites except sites 27 and 31. Figures illustrating individual sample concentrations, daily precipitation, and daily flow are presented in Appendix A.

Table 10. *E. coli* data summary for streams, 2010 growing season

HUC 12	AUID	Site	Geometric Mean [CFU/ 100mL]	Mean [CFU/ 100mL]	Minimum [CFU/ 100mL]	Maximum [CFU/ 100mL]	Percent Reduction to Meet Geometric Mean Standard of 125 CFU/ 100 mL[1]
040500011001 Pigeon Lake – Pigeon Creek	INJ01A1_01 : INJ010_T1001	1	721	974	290	2,600	83%
	INJ01A1_01	2	758	891	400	1,800	84%
	INJ01A1_T1002	3	699	966	300	2,100	82%
	INJ01A2_01; INJ01A1_T1004	4	273	308	200	660	54%
040500011002 Mud Creek – Pigeon Creek	INJ01A2_01; INJ01A2_T1001	5	286	981	45	4,000	56%
	INJ01A2_T1004	6	546	4,598	109	22,000	77%
		7	824	1,014	470	1,900	85%
		8	696	976	400	2,900	82%
		10	1,366	2,386	720	8,400	91%
	INJ01A2_01; INJ01A3_T1003	11	789	1,279	350	4,200	84%
040500011003 Long Lake – Pigeon Creek	INJ01A3_01	12	518	1,023	45	3,000	76%
	INJ01A3_T1001	13	255	436	45	1,300	51%
	INJ01A3_T1003	15	401	529	164	1,218	69%
	INJ01A3_T1004; INJ01A3_T1005	16	483	496	400	730	74%
040500011004 Headwaters Turkey Creek	INJ01A4_T1005	20	166	278	45	900	25%
	INJ01A4_02	21	252	277	173	520	50%
	INJ01A5_01; INJ01A4_T1003	22	566	612	300	927	78%
040500011005 Big Turkey Lake – Turkey Creek	INJ01A5_T1001; INJ01A5_T1002	23	1,167	1,318	700	2,400	89%
	INJ01A5_01	24	139	144	91	191	10%
040500011006 Silver Lake – Pigeon Creek	INJ01A6_T1002	17	4,125	7,884	1,318	28,400	97%
040500011007 Otter Lake – Pigeon Creek	INJ01A7_01	19	177	485	72	2,000	29%
	INJ01A7_T1001	30	497	736	181	2,200	75%
	INJ01A7_01	31	113	163	45	470	0%
040500011008 Little Turkey Lake – Turkey Creek	INJ01A8_T1002; INJ01A8_T1001; INJ01A8_T1002A; INJ01A8_T1003	25	2,165	4,083	550	13,600	94%
	INJ01A8_T1008	26	591	1,380	118	5,100	79%
040500011009 Green Lake – Pigeon Creek	INJ01A9_01	32	163	240	55	700	23%
		33	183	200	109	380	32%
		34	146	161	82	280	14%
040500011010 Mongo Millpond – Pigeon Creek	INJ01AA_02	27	77	107	27	270	0%
		28	126	138	64	218	1%
		29	188	197	118	290	34%
040500011101 East Fly Creek	INJ01B1_T1004	42	621	642	450	900	80%
040500011102 Fly Creek	INJ01B2_01	40	1,468	1,632	780	2,800	91%
		41	1,583	1,966	760	4,200	92%

HUC 12	AUID	Site	Geometric Mean [CFU/ 100mL]	Mean [CFU/ 100mL]	Minimum [CFU/ 100mL]	Maximum [CFU/ 100mL]	Percent Reduction to Meet Geometric Mean Standard of 125 CFU/ 100 mL[1]
	INJ01B2_02	43	1,593	1,860	690	3,400	92%
040500011103 Cline Lake – Pigeon River	INJ01A9_01	35	910	1,636	220	5,100	86%
	INJ01B3_T1002	36	494	630	240	1,200	75%
	INJ01B3_01	37	335	358	250	640	63%
	INJ01B3_03; INJ01B3_02	44	235	256	136	400	47%
040500011104 Buck Lake – Buck Creek	INJ01B4_T1003; INJ01B4_T1002	47	1,066	1,188	620	2,200	88%
	INJ01B4_T1003	48	1,354	1,724	450	3,700	91%
	INJ01B4_01	49	456	539	200	1,027	73%
040500011105 Page Ditch	INJ01B5_01; INJ01B5_T1002	52	2,019	2,400	700	4,800	94%
	INJ01B5_T1003	53	4,988	6,600	2,700	18,000	97%
	INJ01B5_01	54	1,622	1,938	720	4,100	92%
040500011106 VanNatta Ditch – Pigeon River	INJ01B6_01	45	297	321	145	470	58%
		46	347	575	173	1,927	64%
	INJ01B6_02	50	258	279	127	400	52%
	INJ01B6_T1002	51	1,156	1,558	560	4,200	89%
040500011107 Stag Lake – Pigeon River	INJ01B7_T1001	55	617	796	310	2,100	80%

[1] Calculated based on the geometric mean observed at the site and the standard

3.2.3 Biological Data

Fish data were collected by the USGS and IDEM in mid-September, 2010. Boat electrofishing and backpack electrofishing were used. Electrofishing, which stuns the fish population, allowed staff to collect and count the size, types, and general health of fish before releasing them back into the stream. With boat electrofishing, the boat sweeps upstream along one side of the channel, then upstream along the other side of the channel, covering a length of 15 times the channel width. The number of individuals per species is counted, the total biomass per species is weighed, select large and small individuals are measured, and external anomalies are noted. One to two adults, juveniles, or young of the year per species per site are kept. In backpack electrofishing, the equipment is carried on a backpack while field staff walk through the channel. Electrofishing starts at the downstream end of the reach, and the electrode is swept from side to side as the operator moves upstream covering the entire channel width.

The following fish species were identified in AUID INJ01A2_T1004 (part of the Mud Creek HUC 12 watershed): white sucker, central mudminnow, yellow bullhead, common carp, creek chub, green sunfish, and central stoneroller. The AUID received an IBI score of 28, and it was determined to have 'Poor' habitat status, leading to the listing of an impaired biotic community for this AUID.

4 SOURCE ASSESSMENT

This source assessment provides descriptive information on the general categories of sources identified within the entire watershed. Specifics on sources within each HUC12 watershed, including information on violations where available, are included in Section 6.

4.1 Permitted Point Sources

4.1.1 Wastewater Treatment Plants (WWTPs) and Industrial Facilities

Wastewater treatment plants (WWTPs) and industrial facilities are permitted dischargers authorized to discharge specific pollutants up to regulated thresholds and are a source of *E. coli*, phosphorus, and nitrogen. Wastewater treatment plants and industrial facilities can contribute both pollutants and flow volume to the system. The regulated parameters and thresholds are specified in each permit. Nine existing WWTPs that are regulated for *E. coli*, total nitrogen, or total phosphorus, were identified in the Pigeon River Watershed in Indiana, one was identified in Michigan (Table 1, Figure 11, and Figure 12).

Table 11. Existing wastewater treatment plants regulated for *E. coli,* total nitrogen, or total phosphorus in the Pigeon River Watershed

Site Name	Type	Permit Number	HUC12	Design Flow (MGD)	Average Daily Flow (MGD)[1]
ANGOLA MUNICIPAL STP	WWTP	IN0021296	040500011002	1.70	1.190 (2005-2006)
ASHLEY MUNICIPAL STP	WWTP	IN0022292	040500011003	0.40	0.197 (2005-2007)
FISH AND ROYER LAKE WWTP	WWTP	IN0058505	040500011101	0.05	0.027 (2002-2005)
LAGRANGE MUNICIPAL STP	WWTP	IN0020478	040500011102	1.80	0.385 (1997-1998, 2000-2006)
LAGRANGE REGION B WASTEWATER T	WWTP	IN0060097	040500011010	0.75	0.201 (2004-2009)
PIGEON CREEK REST AREA I-69 SB	WWTP	IN0052043	040500011003	0.01	--[2]
SILVER LAKE GROUP	WWTP	IN0039543	040500011006	0.03	0.024 (2003-2004)
SHIPSHEWANA MUNICIPAL STP	WWTP	IN0040622	040500011105	0.25	0.177 (2001-2006, 2008-2010)
STEUBEN LAKES RWD	WWTP	IN0061557	040500011007	1.00	0.390 (2005-2006, 2008-2010)
WHITE PIGEON SANITARY SYSTEM	WWTP	MIG570102	040500011107	0.45	0.430 (2008-2009)

[1]Average daily flow reported where data were available.
[2]Data not available

4.1.2 Concentrated Animal Feeding Operations

Concentrated animal feeding operations (CAFOs) are confined feeding operations that are large in size or have historical compliance issues and are regulated based on U.S. EPA Clean Water Act regulations under more stringent operational requirements. There is one CAFO in the Pigeon Creek Watershed (Figure 11 and Figure 12).

4.1.3 Combined Sewer Overflows

Combined sewer overflows (CSOs) may discharge *E. coli* and nutrients to waterbodies during combined sewer overflow conditions. These conditions may occur during high flows when the wastewater treatment facility is overwhelmed by high flows such that it cannot treat all flows. The result is that the water, which includes both wastewater and stormwater, is discharged untreated to waterbodies. One permitted site with two CSO locations was identified in the Pigeon River Watershed, located in the City of Angola (Table 22, Figure 11, and Figure 12).

Table 22. Combined sewer overflows in the Pigeon River Watershed

Site Name	Type	Permit Number	HUC 12
ANGOLA MUNICIPAL WWTP (Pipe ID 002)	CSO	IN0021296	040500011002
ANGOLA MUNICIPAL WWTP (Pipe ID 003)	CSO	IN0021296	040500011002

4.1.4 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unintentional and illegal discharges of raw sewage from municipal sanitary sewers. SSOs discharge *E. coli* to waterbodies and may occur due to:

- Severe weather resulting in of excessive runoff of stormwater into sewer lines
- Vandalism
- Improper operation and maintenance
- Malfunction of lift stations
- Electrical power failures

One permitted site with three SSO locations was identified in the Pigeon River Watershed (Table 33, Figure 11, and Figure 12).

Table 33. Sanitary sewer overflows in the Pigeon River Watershed

Site Name		Permit Number	Type	HUC 12
LAGRANGE WWTP	NORTH & CANAL STREETS	IN0020478	SSO	040500011102
LAGRANGE WWTP	SPRING & SYCAMORE STRETS	IN0020478	SSO	040500011102
LAGRANGE WWTP	NEXT TO WWTP	IN0020478	SSO	040500011102

4.1.5 Stormwater Phase II Communities

Municipal separate storm sewer systems (MS4s) permitted dischargers are authorized to discharge specific pollutants up to regulated thresholds. Only one MS4 (permit INR040005), with co-permittees of the City of Angola and Trine University (formerly Tri-State University), is located within the Pigeon River Watershed (Figure 11 and Figure 12). This is a Phase II MS4 that includes land area within three HUC12s: 040500011001 (398 acres), 040500011002 (1308 acres), and 040500011003 (192 acres). The jurisdictional boundaries are used to approximate the regulated area.

4.1.6 Concentrated Animal Feeding Operations

There is one (1) concentrated animal feeding operations (CAFOs) within the Pigeon River Watershed and the CAFO is located in Steuben County (Figure 11).

The removal and disposal of the manure, litter, or processed wastewater that is generated as the result of confined feeding operations falls under the regulations for confined feeding operations CFOs and concentrated animal feeding operations CAFOs. The CFO and CAFO regulations (327 IAC 16, 327 IAC 15) 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 16, which implement the statute regulating confined feeding operations, were effective on March 10, 2002. The rule at 327 IAC 15-15, which regulates concentrated animal feeding operations and complies with most federal CAFO regulations, became effective on March 24, 2004, with two exceptions. 327 IAC 15-15-11 and 327 IAC 15-15-12 became effective on December 28, 2006. Point Source rules can be found at 327 IAC 5-4-3 (effective 12/28/06) and 327 IAC 5-4-3.1 (effective 3/24/04). CAFO loads fall under WLA.

Due to size, some confined feeding operations are defined as CAFOs. For purposes of discussion, it is important to remember that all CAFOs are confined feeding operations. The CAFO regulation, however, contains more stringent operational requirements and slightly different application requirements.

4.1.7 Illicitly Connected Straight Pipe Systems

Illicitly connected straight pipe discharges of household waste are a source of *E. coli*, organic matter, and nutrients. No known illicitly connected straight pipe discharges were identified in the Pigeon River Watershed. One site was identified in past studies and the Steuben County Health Department required that the illicit connection be removed (Steuben SWCD and Steuben County 2006).

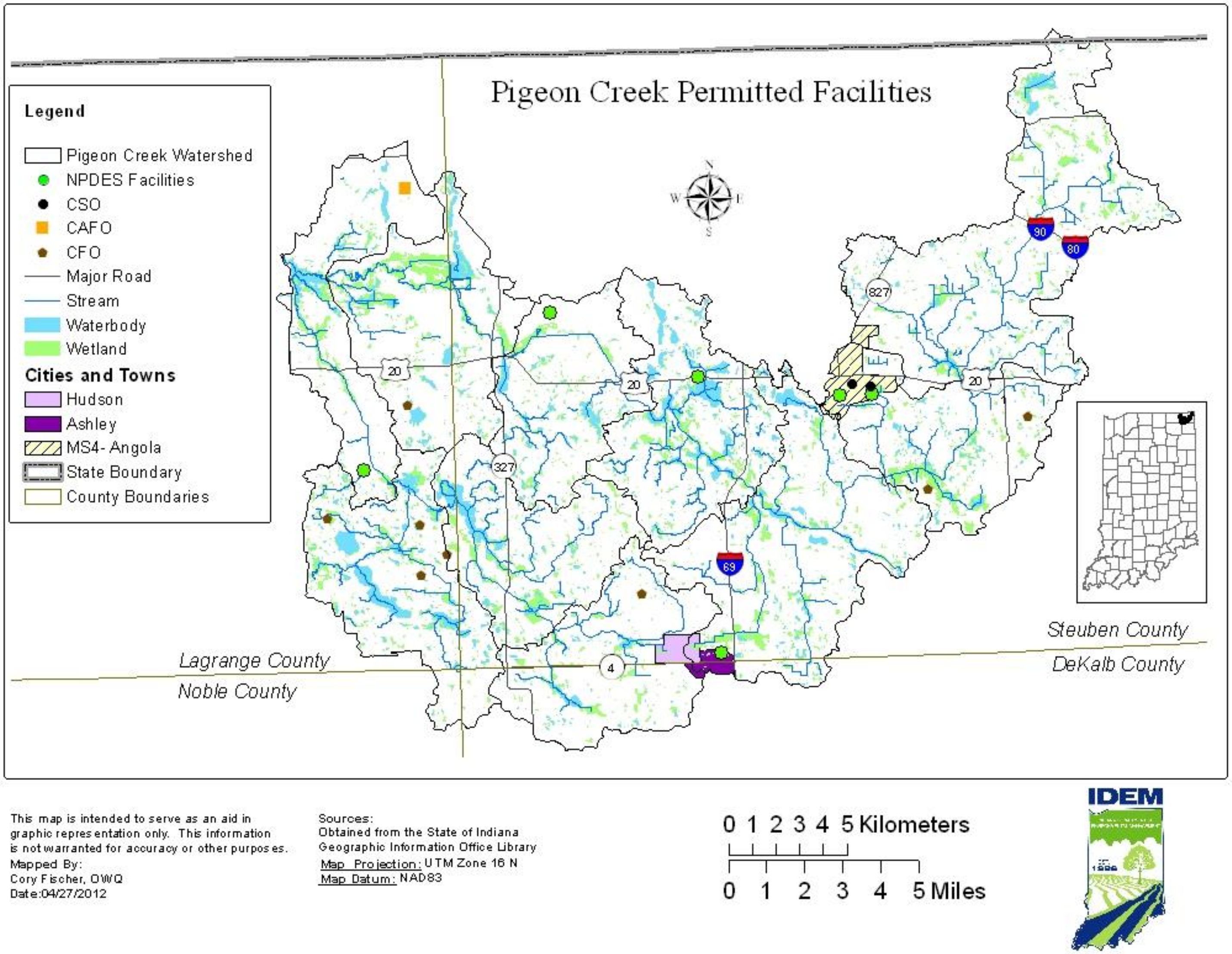

Figure 11. Upper Pigeon River Watershed permitted point sources (regulated for *E. coli*, total nitrogen, or total phosphorus) and regulated nonpoint sources

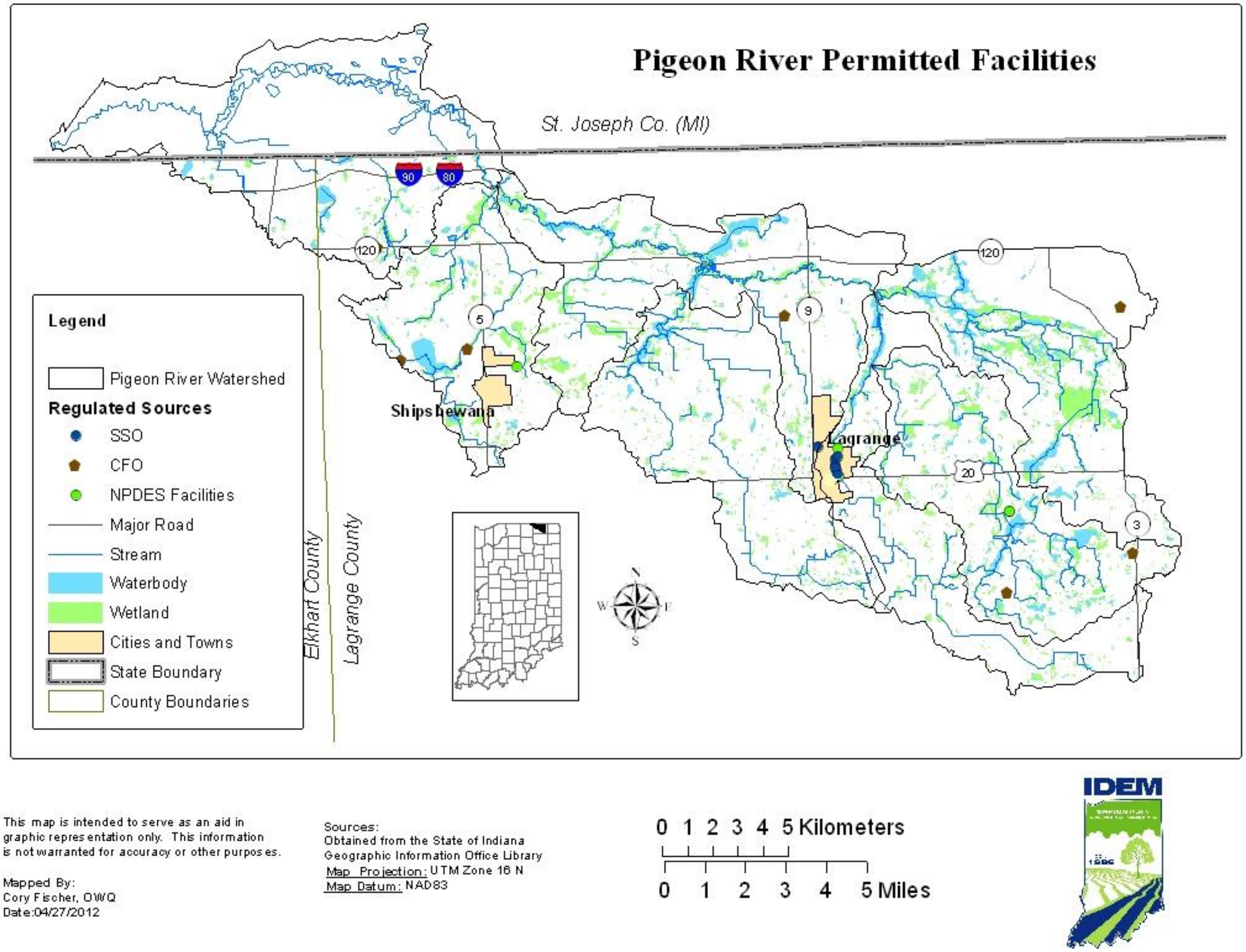

Figure 12. Lower Pigeon River Watershed permitted point sources (regulated for *E. coli*, total nitrogen, or total phosphorus) and regulated nonpoint sources

4.2 Nonpoint Sources

4.2.1 Agriculture

Cropland

Cropland is a source of phosphorus and nitrogen because of fertilizer use and disturbed soils. Rainfall events can cause soils and nutrients to run off the land and be transported to waterways and waterbodies. Additionally, cropland can be a source of *E. coli* if manure is applied to the field (see Land Application of Manure below). Land cover databases provide information on the location and extent of cropland within the Pigeon River Watershed. The Pigeon River Watershed is 47% cropland. Previous studies indicate that agricultural producers in Steuben County have implemented conservation practices more widely than is common in surrounding counties and states (Conservation Technology Information Center 2006; Steuben SWCD and Steuben County 2006). The majority of producers in Steuben County used conservation tillage practices (no-till, mulch-till, and reduced-till) on their agricultural cropland (Steuben SWCD and Steuben County 2006). In 2006, conservation tillage practices were used on 50% to 100% of cropland in Steuben County and on 25% to 50% of cropland in LaGrange County (Conservation Technology Information Center 2006). Cropland with effective conservation practices are expected to have lower rates of nutrient and *E. coli* export than similar areas without these practices.

Confined Feeding Operations

Animal feeding operations can be sources of nutrients and *E. coli* to downstream waterbodies through the mobilization and transportation of phosphorus laden materials from feeding, holding, and manure storage areas. IDEM's Office of Land Quality regulates CFOs and has established and enforced standards that prohibit discharge from CFOs. However, compliance issues may occur that result in discharges, and land application of collected manure is common (see Land Application of Manure below). Confined feeding operations (CFOs) are any animal feeding operations engaged in the confined feeding of at least 300 cattle, or 600 swine or sheep, or 30,000 fowl, such as chickens, turkeys, or other poultry. 14 CFOs were identified in the Pigeon River Watershed (Table 44, Figure 11, and Figure 12). The animals permitted for each site are listed in Table 4. None of these sites are identified as having boars, beef calves, veal calves, layers, pullets, broilers, turkeys, ducks, sheep, or horses.

Table 44. Confined feeding operations in the Pigeon River Watershed

Pigeon River CFO/CAFO (0405000111)	Permit Program	Farm ID #	HUC 12	Nursery Pigs	Finishers	Sows	Beef Cattle	Dairy Cattle	Dairy Calves	Dairy Heifers
FREEMAN YODER	CFO	1031	040500011106	0.00	1,259	0	0	0	0	0
RON KAUFFMAN	CFO	3518	040500011103	600	440	60	0	0	0	0
LOWELL FREED	CFO	3622	040500011101	440	1,360	168	0	0	0	0
ERVIN FRY	CFO	3686	040500011105	0.00	580	0	0	0	0	0
HOG FINISHING SITE	CFO	6507	040500011101	1,064	1,596	0	0	0	0	0
JAMES J LAMBRIGHT	CFO	6555	040500011107	0	0	0	0	0	805	150
Pigeon Creek CFO/CAFO (0405000110)	**Permit Program**	**Farm ID #**	**HUC 12**	**Nursery Pigs**	**Finishers**	**Sows**	**Beef Cattle**	**Dairy Cattle**	**Dairy Calves**	**Dairy Heifers**
TWIN PINES FARM INCORPORATED	CFO	291	040500011008	1300	1,300	0	0	0	0	0
BLT ENTERPRISES	CFO	659	040500011008	0	0	0	1,290	0	0	0
HILLTOP DAIRY LLC	CFO	1005	040500011008	0	0	0	0	220	15	0
SPRINGFIELD SWINE	CFO	4004	040500011009	920	2,376	288.00	0	0	0	0
PERKINS TWIN CREEK FARM	CFO	6390	040500011008	0	0	0	0	516	45.00	0
TOLL TAIL DAIRY LLC	CAFO	6464	040500011010	0	0	0	0	3,630	0	0
JOHN D SMITH & SONS INCORPORATED	CFO	1082	040500011002	2880	0.	0	100	0	0	0
JOHN D SMITH & SONS INCORPORATED	CFO	1108	040500011002	2880	0	0	0	0	0	0
STOCKWELL ACRES INCORPORATED	CFO	6650	040500011004	0	0	0	0	451	85	315

Small Animal Feeding Operations

Small animal feeding operations can also be a source of *E. coli* and nutrients to waterbodies. Operations raising a smaller number of animals are not regulated as a CFO or CAFO, but still result in production of manure onsite. Smaller animal facilities may add bacteria to surface waters via wastewater from these facilities or stormwater runoff from near-stream pastures. Livestock management practices for small operations may include manure storage and application at rates needed for crop growth; collection and treatment of runoff from feeding pens; grazing plans, fencing, and buffers to limit animal access to wetlands, streams, and other waterbodies; and other practices. These types of livestock management practices are expected to reduce the rate of nutrient and *E. coli* export from agricultural properties when compared to similar areas without these practices. Information on the location of smaller animal operations is not available, but smaller animal feeding operations are expected to be associated with agricultural land use throughout the watershed.

Pastured Animals

Pastured animals are a potential source of *E. coli* and nutrients to nearby waterbodies, especially if animals have access to the waterbodies or waterways. Livestock with direct access to stream environments may add bacteria directly to the surfaces waters or resuspend particles that had settled on the stream bottom. Direct deposit of animal wastes can result in high localized bacteria counts and can also contribute to downstream impairments. Stormwater runoff from near-stream pastures may add bacteria and nutrients to nearby waterbodies. The land cover of the Pigeon River Watershed includes hay or pasture land on over 18% of the land area.

Land Application of Manure

Improper land application of manure from animal feeding operations is an additional source of nutrients and *E. coli* to downstream waterbodies. There are no existing records regarding location, volume, and frequency of land application of manure. IDEM assumes that land application of manure occurs within five miles of animal feeding operations, the source of the manure. The Pigeon Creek Watershed study indicated livestock farms, dairy farms near Pigeon Lake, and horse farms along Wood Ditch could be additional areas where land application of manure would occur (Steuben SWCD and Steuben County 2006).

Field Tiles

Drainage tiles in agricultural fields create direct conduits to downstream waterbodies through which nutrients and *E. coli* may be discharged. Data on the specific location of field tiles was not available for the full Pigeon River Watershed. Regulated drainage systems are present throughout the Pigeon River Watershed and some of these systems include portions of tile drainage in addition to open ditches. Additionally, private tiling is expected to be associated with cropland throughout the watershed. Cultivated cropland covers about 47% of the Pigeon River Watershed.

4.2.2 Stream Degradation

Suspended solids and phosphorus can increase in streams due to bank destabilization (e.g. from removal of upland or riparian vegetation or livestock access). Livestock with access to stream environments may cause streambank disturbance and erosion and may resuspend particles that had settled on the stream bottom. Phosphorus adsorbs to sediment particles and often travels through aquatic systems attached to suspended solids. Internally, increases in suspended solids can produce more scouring, introducing additional suspended solids and phosphorus. The sites impacted and the extents of damage depend on stream magnitude, gradient, and whether the site is erosional or depositional.

Many streams in the Pigeon River Watershed are managed as regulated drainage systems and have likely been impacted in the past by straightening and dredging activities. Streambank erosion has been identified in locations along Pigeon Creek, particularly downstream of Hogback Lake and upstream of Long Lake (Steuben SWCD and Steuben County 2006). The following specific areas of sedimentation were noted in the 2006 report: incised channel reaches downstream of Hogback Lake, along Golden Lake Road, at the entrance to Hogback Lake, between Long Lake and Little Bower Lake, and upstream of County Road 150 West (Steuben SWCD and Steuben County 2006).

4.2.3 Onsite Wastewater Treatment Systems

Onsite wastewater treatment systems, commonly referred to as septic systems, provide treatment of wastewater from individual properties. Septic systems are typically only an active source of pollutants when the system is failing. Faulty or leaky septic systems are sources of *E. coli*, nitrogen, and phosphorus. Typical national septic system failure rates are 10-20% and no failure rates are reported specifically for Indiana or Michigan (U.S. EPA 2002). However, reported failure rates vary widely depending on the local definition of failure (U.S. EPA 2002). The number of septic systems was estimated based on land use. Areas identified as developed open space, low intensity development, and medium intensity development are assumed to be served by onsite septic systems at a rate of one system per four acres for open space, one system per acre for low intensity, and five systems per acre for medium intensity. The resulting estimate of number of septic systems is 20,080 in the Pigeon River Watershed. At a 15% failure rate, it is estimated that 3,012 septic systems within the Pigeon River Watershed are failing.

4.2.4 Pets and Horses

Uncollected horse and pet waste is a source of *E. coli* to downstream waterbodies. National average pet ownership rates indicate that 37.2% of households own at least one dog and 1.8% of households own horses. For households with pets, the average number of dogs owned is 1.7 and the average number of horses owned is 3.5 (American Veterinary Medical Association 2007). The average household size in Indiana is 2.53 people (from US Census data, 2000). The estimated number of pets within the Pigeon River Watershed is 10,445 dogs and 1,040 horses. Horses are often used as a primary form of transportation by the relatively large local Amish population; therefore horse waste may be higher than that suggested by the estimated horse population and may not be confined only to rural areas but may also be present on city streets.

4.2.5 Wildlife

Wildlife waste is a source of *E. coli* to waterbodies. The statewide population of greater Canada geese in Indiana was estimated to be 84,215 in 2009 (IN DNR 2009). Steuben and LaGrange counties are expected to have large deer populations as these counties have high deer harvest (IN DNR 2010; IN DNR, 2009).

4.2.6 Soil Erosion

Soil erosion is a source of particulate phosphorus to waterbodies. The Revised Universal Soil Loss Equation (RUSLE) was used as a tool to predict soil erosion in the Mud Creek-Pigeon Creek HUC 12 watershed (040500011002). This equation takes into account slope, soil type and land use to estimate erosion in tons/ac-year. The strength of this tool is that it can be used to target erosion prone areas; however, the tool does not accurately predict sediment yield because much of the soil loss predicted by this equation settles out in flatter or more vegetated areas before leaving a field. Table 55 shows the parameters defined and data sources used in the evaluation.

Table 55. Parameters and data sources used in soil erosion analysis.

Parameter	Defining GIS Layer	Calculation Notes	Description
R	Set as Constant	Defined from figure on page 251 in *Design hydrology and sedimentology for small catchments* (Haan et al. 1994), the 100 isocline transverses the middle of the watershed	Rainfall/runoff factor
K	County Soil Survey	Varies by soil type; value is listed in soil survey; soil types without listed K values were given a median erosivity value of 0.24	Soil erodibility factor
L	Set as Constant	Assume length = to test plot length of 72.6 ft, L = 1	Slope length factor
S	1.5 meter DEM	S = 10.8 sin (theta) + 0.03 if sin (theta) <0.09, S=16.8sin (theta) - 0.50 if sin(theta) >=0.09	Slope steepness factor
C	NLCD Landcover	Defined from tables on 266-267 *Design hydrology and sedimentology for small catchments* (Haan et al. 1994), Book values of C for different land covers	Cover and management factor
P	Set as Constant	Data not available at scale and resolution necessary. Set conservation factor to 0.5.	Supporting conservation practice factor

Average soil loss ranges from zero to 64, representing a range of soil erosion potential, from lowest to highest in tons/ac-year.

5 TECHNICAL APPROACH

5.1 Impaired Stream Reaches

The loading capacity of each HUC 12 watershed (there are 17 HUC 12 watersheds in total) was determined using load duration curves. Load-based TMDLs were developed by HUC 12 for *E. coli*, total phosphorus, and total nitrogen. Load duration curves (Section 6) were used to inform pollutant sources and identify concentration-based percent reductions necessary to meet the TMDL. *E. coli* concentration data at each site are presented graphically with precipitation data in Appendix A.

5.1.1 Load Duration Analysis

Load duration analysis was used to evaluate the flow conditions relative to the observed water quality data. This analysis links water quality with potential pollutant sources.

Flow data for each HUC 12 watershed were downscaled from the nearest downstream USGS gage at the daily time scale on an area-weighted basis (Equation 1); downscaling also accounted for wastewater treatment flows, as applicable, for individual HUC 12 watersheds. Daily mean flow data were available from each of the three USGS gage stations (Station #04099510, Pigeon Creek NR Angola, IN; Station #04099750 Pigeon River near Scott, IN; Station #04101000 St. Joseph River at Elkhart, IN). The gage stations each contain over 40 years of continuous flow data. Data from the years 1975-2010 were used in this analysis; this long record appears to contain the full range of flow conditions. See Table 6 (on page 200) for a summary of flow data from these gage stations.

The flow duration analysis first estimated wastewater treatment plant flows for applicable HUC 12 watersheds on a daily basis based on permitting records. The wastewater treatment plant flows were assigned to their respective HUC 12 watersheds. The total flow of the surrogate USGS gage was reduced by the total wastewater treatment plant flows in upstream HUC 12 watersheds. Next, the drainage area of each HUC 12 watershed was divided by the drainage area of the surrogate USGS gage. The flows for each of the HUC 12 watersheds were then estimated by multiplying the daily flows at the surrogate gage (less the wastewater treatment plant flows) by the drainage area ratios. Flows for HUC 12 watersheds having wastewater treatment plants included previously-estimated wastewater treatment plant flows plus the applicable area-weighted flows. Flows for HUC 12 watersheds without wastewater treatment plants included only the area-weighted flows.

$$Q_{ungaged} = \frac{A_{ungaged}}{A_{gaged}} \left(Q_{gaged} \right) \qquad \text{Equation 1}$$

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

Wastewater treatment plant (and one water treatment plant) flows were estimated based on monthly discharge monitoring reports required by the NPDES permit, electronic copies of permits provided by IDEM, and the EPA's online Permit Compliance System (PCS) detailed reports. No wastewater treatment plant had complete records from the date the plant was put online. Available data were used to estimate average annual flows while the wastewater treatment plant was online during the period January 1, 1975 through December 31, 2010. This period was selected as a long-term record for which data are available at all sites. In many cases, average annual wastewater treatment plant flows were available from discharge monitoring reports for only two to four years, while design flows were available throughout most of each wastewater treatment plant's history. By identifying (for the years where both monitoring data and design flows were available) the percent of design flow under which the wastewater treatment plant operates, average annual flows for periods having no data could be estimated. In many cases, linear interpolation between periods having sufficient data was performed. One additional wastewater treatment plant in White Pigeon, Michigan (HUC 12 40500011107) was identified (NPDES Permit Number MIG570102). For this wastewater treatment plant, flows were estimated based on limited discharge monitoring data from EPA's Enforcement & Compliance History Online (ECHO) database. Flows from all of these wastewater treatment plants were used to downscale the flow data at the nearest downstream USGS gage.

CSOs result in discharge of raw sewage to receiving waters and are a mix of stormwater runoff and raw sewage (see Section 4.1.3 for background information on CSOs). There are two CSO locations in the project area and both are within the Mud Creek-Pigeon Creek HUC 12 watershed (040500011002). The volume of raw sewage from CSOs was assumed to be too small to have significant effects on flows at the downstream point of the HUC 12 watershed. Therefore, CSOs were not specifically accounted for in the downscaling of the flow data.

SSOs also result in discharge of raw sewage to receiving waters, but SSOs originate from potable water sources (not precipitation like CSOs). However, SSOs are typically small in volume and are intermittent. SSOs were assumed to be too small to have significant effects on flows at the downstream point of HUC 12 watersheds.

Table 66. Facilities accounted for in the downscaling of USGS gage station flows

HUC 12	Facility	Dates in Operation within the Period of the Load Duration Analysis (1975-2010)
040500011002	Angola Municipal WWTP (IN0021296)	May 1, 1978 through Dec 31, 2010
040500011003	Ashley Municipal WWTP (IN0022292)	Aug 1, 1985 through Dec 31, 2010
	Pigeon Creek Rest Area I-69 SB (IN0052043)	Jan 1, 1978 through Dec 31, 2010
040500011006	Silver Lake Group WWTP (IN0039543)	Jan 1, 1975 through Dec 31, 2010
	Best Western Angola Inn (IN0042196)	Jan 1, 1975 through Dec 31, 2007
040500011007	Steuben Lakes RWD (IN0061557)	Jul 1, 2005 through Dec 31, 2010
040500011010	LaGrange County Region B WWTP (IN0060097)	Jan 1, 1999 through Dec 31, 2010
040500011101	Fish and Royer Lake WWTP (IN0058505)	Sept 1, 1995 through Dec 31, 2010
040500011102	LaGrange Municipal WWTP (IN0020478)	Jul 1, 1977 through Dec 31, 2010
040500011105	Shipshewana WWTP (IN0062600)	Jan 1, 1977 through Dec 31, 2010
040500011107	White Pigeon Sanitary System (MIG570102)	Jan 1, 1975 through Dec 31, 2010

Downscaling flow data in this manner is typical in the absence of sufficient monitoring locations and hydrologic/hydraulic watershed modeling. It is understood that this approach is not as reliable as monitored or modeled flows due to the spatial variability of rainfall and the differences in hydrologic/hydraulic characteristics of each HUC 12 watershed.

The cumulative frequency of the downscaled flow data was used to develop flow duration curves for the downstream point of each HUC 12 watershed. The compiling of flow data and appropriately downscaling this data based on USGS gage location resulted in a flow duration curve for each HUC 12 watershed that relates flow values to the percent of time those flows have been met or exceeded. Thus for each HUC 12 watershed, the full range of stream flows is considered. Low flows are exceeded a majority of the time, whereas floods are exceeded infrequently.

The flow duration curve was translated into a load duration curve for each HUC 12 watershed by multiplying the flows in the flow duration curve by the applicable water quality criterion or target (Table 7). Conversion factors are used to convert the units of the target (e.g. cfu/100mL) to load (e.g. billion org/d). Equation 2 provides an example calculation. The x-axis remains as the flow duration and the y-axis depicts the load at that flow duration. The curve represents the allowable load (or TMDL) at each flow condition.

Flow (cfs) x TMDL criterion or target (cfu100mL) x conversion factor (0.024463) = Load (billion org/d)

Equation 2

The load duration curves were used to calculate the loading capacity of each HUC 12 watershed across the range of flow conditions. Specifically, the loading capacity (or TMDL) was calculated for five different flow regimes (high flows, moist conditions, mid-range flows, dry conditions, and low flows) that are used as a general indicator of hydrologic conditions. Load duration curve "high flows" are exceeded 0 to 10 percent of the measured time period, "moist conditions" are exceeded 10 to 40 percent of the measured time period, "mid-range flows" are exceeded 40 to 60 percent of the measured time period, "dry conditions" are exceeded 60 to 90 percent of the measured time period, and "low flows" are exceeded 90 to 100 percent of the measured time period. The TMDL for each flow interval was determined by the midpoint of the flow interval (flow regime); it was calculated by multiplying the flow at each midpoint by the water quality criterion or target (Table). The TMDL and allocations are presented in tables as daily loading limits for each of the five flow intervals for each HUC 12 watershed in Section 6 *HUC 12 Watershed Summary of Data and Allocations*.

Monitoring data are plotted on the load duration curves by multiplying the pollutant concentration times the flow that was estimated for the downstream point of the HUC 12 watershed on the day that the sample was taken. Since the estimated flow is from the downstream point of the HUC 12 watershed and not the actual monitoring site that is located upstream, the load presented for each monitoring point is an overestimate of the actual load.

If the concentration exceeded the numeric target, the monitoring point will be above the load duration curve, and if the concentration was lower than the numeric target, the point will be below the curve. In this manner, it is possible to determine if pollutant exceedances are more likely the result of point or continuous sources (exceedances typically associated with low flow conditions) versus nonpoint sources (exceedances typically associated with high flow conditions). For example, impacts from wastewater treatment plants are usually most pronounced during dry and low flow zones because there is less water in the stream to dilute their loads. In contrast, impacts from channel bank erosion are most pronounced during high flow zones because these are the periods during which stream velocities are high enough to cause erosion to occur. Examining water quality data based on flow regimes, when combined with other basic elements of watershed planning, can help guide solutions towards relevant watershed processes, important contributing areas, and key delivery mechanisms. Table 77 provides a simple example of how the flow regime is associated with the pollutant source, which ultimately guides implementation. It is important to note that the load duration curve method can not attribute impairment to any one particular source; instead it determines the flow conditions under which impairment occurs and the probable types of sources contributing to that impairment.

Table 77. Flow regimes associated with pollutant sources

Adapted from Cleland (2007); relative potential of source to contribute loads under given flow regime – H: high, M: medium, L: low.

Pollutant Source	Duration Curve Zone				
	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flow
Point Source				M	H
On-Site Wastewater Systems			H	M	
Riparian Areas		H	H	H	
Stormwater: Impervious Areas		H	H	H	
Combined Sewer Overflows	H	H	H		
Stormwater: Upland	H	H	M		
Bank Erosion	H	M			

The extent of the analyses is limited by the extent of available water quality data. With larger data sets, different conclusions may have been drawn. Despite these limitations, the load duration curve analysis provides a means to visually evaluate data and guide implementation by identifying possible pollutant sources for further examination.

5.1.2 Percent Reduction Analysis

Percent reductions were estimated by comparing the highest violation measured in the 2010 monitoring season in the respective HUC 12 to the numeric standard or the target values shown in Table 7. For nutrients the highest violation is the maximum value measured at any monitoring site in the HUC 12. For *E. coli* the highest violation is the highest 2010 geometric mean of any monitoring site in the HUC 12. Reductions relative to each monitoring site are shown for TN, TP, and *E. coli* in Table 8, Table 9, and Table 10, respectively.

5.2 Wasteload Allocation and Load Allocation Derivation

5.2.1 Wasteload Allocations (WLAs)

NPDES-Permitted Facilities

Within the project area, there are nine known NPDES facilities in Indiana and 1 known NPDES facility in Michigan within the project area, which are regulated for *E. coli*, total nitrogen, or total phosphorus. As required by the Clean Water Act, individual WLAs were developed as part of the TMDL development process for those permittees discharging directly to impaired reaches. No facilities in Michigan discharge to impaired surface waters in the project area; six facilities in Indiana discharge directly to impaired surface waters in the project area. WLAs were calculated based on each facility's design flow and *E. coli* permit limits (125 cfu/100 mL). Angola Municipal WWTP also discharges to streams impaired due to total nitrogen and total phosphorus. WLAs were also calculated for these pollutants based on design flow and permit limits. Table 88 provides detail regarding the derivation of these WLAs.

There are two CSOs within the project area, and they each have the potential to discharge to surface waters impaired for *E. coli*, total nitrogen, and total phosphorus. Both CSOs are in the Indiana portion of the project area and are associated with the Angola Municipal WWTP. Discharge monitoring reports contain the total monthly volume from each CSO, and report the number of CSOs per month (but not the actual days on which they occurred). For each CSO, the highest monthly CSO volume during 2010 was first divided by the number of CSOs in that month to provide an estimate of the discharge volume in each CSO.

Table 88 provides detail regarding the derivation of these WLAs. During the development of the Long-Term Control Plan for the CSO community, the state may decide to modify the WLA if deemed appropriate.

There are three SSOs within the project area. These SSOs are in the Indiana portion of the project area and are associated with the LaGrange Municipal WWTP. SSOs are regulated as zero discharge WWTP outfalls and, therefore, receive a WLA of zero.

MS4s

There is one MS4 permit in the project area, which is a joint permit between the City of Angola and Trine University (formerly Tri-State University). These communities discharge to waters impaired for *E. coli* and, therefore, received WLAs. Within the HUC 12 watershed 040500011002, the MS4 discharges to waters impaired for total nitrogen and total phosphorus and, therefore, for these areas, the MS4 received WLAs for total nitrogen and total phosphorus as well. The WLAs are a percent of the TMDL less the Margin of Safety (MOS). The percent is equal to the proportion of the assessment-location drainage area that is occupied by the regulated MS4 area. The jurisdictional areas of the City of Angola and Trine University were used as surrogates for the regulated areas of the MS4.

Illicit Discharges

WLAs from illicitly connected onsite systems (i.e., straight pipe dischargers) in the watershed are set equal to zero. However, none were identified.

Table 88. Derivation of WLAs for NPDES facilities

HUC 12	Facility Name	Permit ID	Design Flow (mgd) or CSO Volume (mgal/mo)	Permit Limit *E. coli* *(cfu/100mL)* [Total Nitrogen (mg/L), Total Phosphorus (mg/L)]	WLA *E. coli* (billion org/d), [Total Nitrogen (lb/d), Total Phosphorus (lb/d)]
040500011002	Angola Municipal WWTP	IN0021296	1.7	125 [1.6*, 1]	8.0 [23, 14]
040500011003	Ashley Municipal STP	IN0022292	0.4	125	1.9
040500011007	Steuben Lakes RWD	IN0061557	1	125	4.7
040500011010	LaGrange Region B WWTP	IN0060097	0.75	125	3.5
040500011101	Fish and Royer Lake WWTP	IN0058505	0.051	125	0.24
040500011102	LaGrange Municipal STP	IN0020478	1.8	125	8.5
	LaGrange Municipal STP SSOs (3 locations)	IN0020478	0	0	0
040500011105	Shipshewana Municipal STP	IN0040622	0.252	125	1.2

* Based on the ammonia-nitrogen standard, monthly average for December 1 through April 30.

5.2.2 Load Allocations (LAs)

Load allocations represent the portion of the allowable load that is reserved for nonpoint sources. Load allocations are the remainder of the TMDL after subtracting the WLAs and the MOS. CFOs receive a zero discharge permit from the State of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants.

5.3 Margin of Safety

A moderate explicit MOS was applied as part of all the Pigeon River Watershed TMDLs by reserving ten percent of the allowable load. Ten percent is considered an appropriate explicit MOS based on the following considerations:

- The load duration curve approach minimizes uncertainty associated with the development of TMDLs because the loading capacity is a function of monitored flow multiplied by the target value. Uncertainty is associated with the estimated flows in each HUC 12 watershed, which were based on extrapolating flows from the nearest downstream USGS gage.

- The *E. coli* TMDLs are based on the state numeric criteria of 125 cfu/100 mL as a geometric mean based on no fewer than five samples in a thirty day period; the TMDLs were not calculated based on the state numeric criteria of 235 cfu/100 mL in any one sample in a thirty day period. The use of the geometric mean (lower concentration) criteria results in a lower TMDL than if the maximum criteria had been used, thus serving as an implicit margin of safety for *E. coli*.
- The identified percent reduction required for the *E. coli* TMDLs is based on the highest geometric mean of all of the monitoring sites within the HUC 12 watershed, relative to the standard. The use of the maximum geometric mean provides an implicit margin of safety.

5.4 Critical Conditions and Seasonality

The loading capacity for each TMDL takes into account the critical conditions for each impairment. For example, the critical condition of a biotic impairment may be during summer low flows or during the fish spawning season. The use of load duration curves for calculating the loading capacity takes into account any critical conditions that are related to flow.

The loading capacity also takes into account seasonal variation. Symptoms of nutrient enrichment normally are the most severe during the summer months; the water quality targets (and, therefore, the TMDL) were established with this seasonal variability in mind. Seasonal variation of *E. coli* was taken into account by addressing the times of year when the full-body contact recreation standard applies.

6 HUC 12 WATERSHED SUMMARY OF DATA AND ALLOCATIONS

6.1 HUC 12: 040500011001, Pigeon Lake – Pigeon Creek

6.1.1 Source Assessment

A number of *E. coli* sources were identified in the Pigeon Lake – Pigeon Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, one CFO, pasture land use, and septic systems (Table 99). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Available compliance information showed no significant issues associated with the CFO. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed, which include pets and horses, wildlife, field tiles, and illicit discharges.

Table 99. Identified nonpoint sources in the Pigeon Lake – Pigeon Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 45%, Hay/Pasture 24%, Woody Wetlands 15%, Developed Open Space 6%, Deciduous Forest 4%, Herbaceous 2%, Developed Low Intensity 2%, Open Water 1%
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 97% of the Pigeon Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 1,134 septic systems with estimated 170 failing (see Section 4.2.3)
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

The one NPDES-permitted point source of *E. coli* in the Pigeon Lake – Pigeon Creek HUC 12 watershed is a portion of an MS4 (Table20).

Table 20. Identified point sources in the Pigeon Lake – Pigeon Creek HUC 12

Site Name	Type	Permit/ID Number
CITY OF ANGOLA	MS4	INR040005

6.1.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 13 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

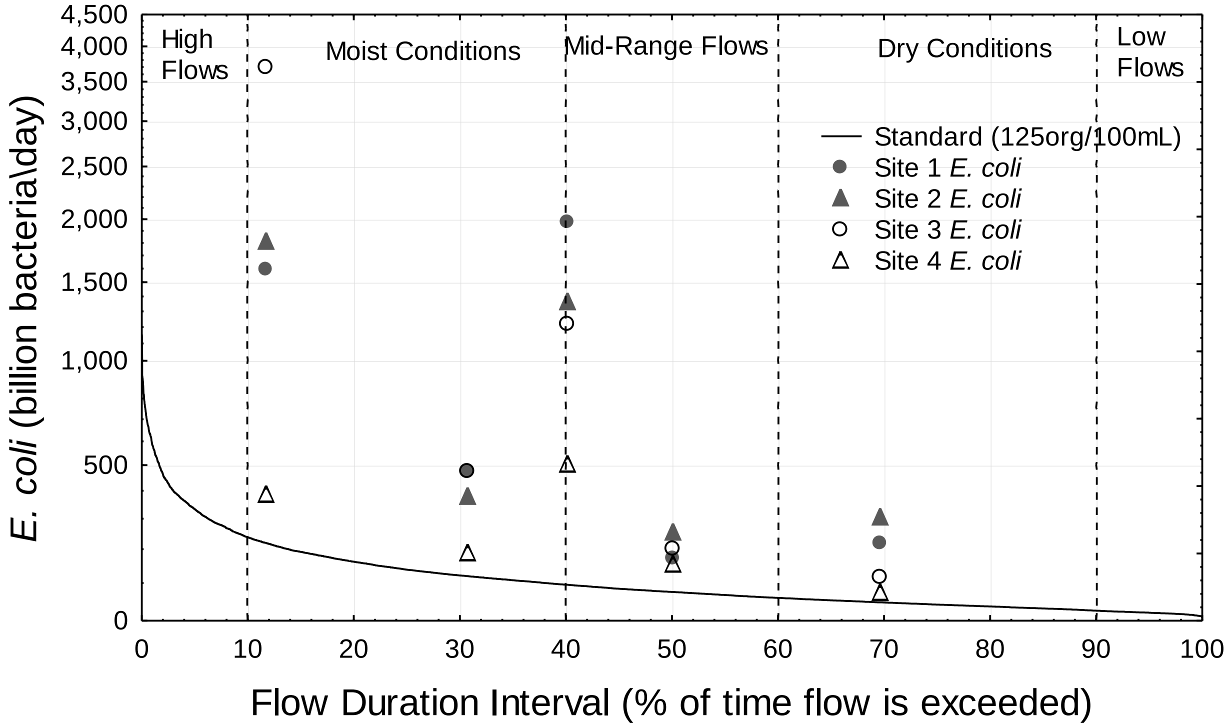

Figure 13. *E. coli* load duration curve for the Pigeon Lake-Pigeon Creek watershed (HUC 040500011001)
IDEM 2010 data; downscaled USGS Gage duration interval; 34 square miles

Exceedances of the *E. coli* standards occur in flow regimes ranging from dry conditions through high flows, with the highest concentrations observed in the mid-range to high flows (Figure 13). *E. coli* sources that were identified in the source assessment (Section 6.1.1) that might lead to high concentrations during dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems. Sources that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, field tiles, and urban stormwater runoff.

6.1.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 101. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). An 84% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 2 at 758 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFO #6067 is in this HUC 12.

Table 101. HUC 12: 040500011001 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	8	8	4	0
TMDL* = MOS + WLA + LA	333	138	75	42	20
MOS (10%)	33	14	7.5	4.2	2.0
WLA: total	5.4	0	0	0	0
City of Angola MS4, INR040005	5.4	0	0	0	0
LA	295	124	68	38	18

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.1.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Pigeon Lake – Pigeon Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 112 with respect to the sources identified in the HUC 12 source summary (Section 6.1.1).

Table 112. Implementation approaches to addresses sources in Pigeon Lake – Pigeon Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 45%, Hay/Pasture 24%**, Woody Wetlands 15%, Developed Open Space 6%, Deciduous Forest 4%, Herbaceous 2%, Developed Low Intensity 2%, Open Water 1%	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 97% of the Pigeon Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 1,134 septic systems with estimated 170 failing (see Section 4.2.3)	7.2.4
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
MS4 stormwater runoff	City of Angola	7.1.4

6.2 HUC 12: 040500011002, Mud Creek – Pigeon Creek

6.2.1 Source Assessment

A number of *E. coli* sources were identified in the Mud Creek – Pigeon Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, two CFOs, pasture land use, and septic systems (Table 123). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Compliance information was not readily available for CFOs. Additional *E. coli* sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Nonpoint phosphorus sources identified in the Mud Creek – Pigeon Creek watershed include crop land use, two CFOs, pasture land use, developed land uses and associated lawn fertilizer, septic systems, golf courses, and stream degradation. IDEM assumes that land application of manure occurs within five miles of any CFO facility. Compliance information was not readily available for CFOs. Additional nonpoint phosphorus sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 123. Identified nonpoint sources in the Mud Creek – Pigeon Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 36%, Hay/Pasture 25%, Woody Wetlands 17%, Developed Open Space 7%, Developed Low Intensity 5%, Deciduous Forest 4%, Developed, Medium Intensity 2%, Herbaceous 2%, Open Water 1%, Developed High Intensity 1%
CFO (#1082, 1108)	ID# 1082 allowed 2880 nursery pigs, 100 beef cattle ID# 1108 allowed 2880 nursery pigs
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Mud Creek – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 1,780 septic systems with estimated 267 failing.
Pets	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)
Lawn Fertilizer	Lawn fertilizer use is expected on developed areas which cover14% of the watershed, or 1,625 acres.
Soil Erosion	Large amount of highly erodible soils throughout the drainage area (see **Error! Reference source not found.Error! Reference source not found.** on page **Error! Bookmark not defined.Error! Bookmark not defined.**)
Stream Degradation	Mud Creek is identified by Steuben County as an open ditch and is estimated to have been impacted by ditching and straightening over the full length of the stream.

NPDES-permitted point sources of *E. coli* and phosphorus in the Mud Creek – Pigeon Creek HUC 12 watershed are one wastewater treatment plant with two combined sewer overflow locations, and a portion of an MS4 (Table 134).

The Angola Wastewater Treatment Plant and CSOs permitted under IN0021296 has recorded 18 effluent exceedances in the past three years, two of which were for *E. coli* exceedances, one was for a phosphorus exceedance, and nine were for exceedance of the ammonia nitrogen standards.

The *E. coli* exceedances were 120% over the permitted *E. coli* standard in the third quarter of 2008 and 502% in the fourth quarter of 2009. The phosphorus exceedance was 29% above the permitted phosphorus concentration standard in the first quarter of 2009. Ammonia nitrogen exceedances for maximum allowed concentration occurred in 10 out of the past 36 months with two of those months also exceeding the average monthly concentration allowed. Exceedances of ammonia nitrogen for over the maximum allowed load occurred in five of the past 36 months with one of those months also exceeding the monthly allowed average. Exceedances of ammonia nitrogen ranged from 3% to 120% over the standard. Of the past 12 quarters, ten were non-compliant for at least one permitted discharge parameter. A notice of non-compliance was issued in 2010, but no formal enforcement actions have been taken.

A study in 2006 noted that the Angola Wastewater Treatment Plant was working with a professor from Indiana University–Purdue University Fort Wayne to conduct bacteria source tracking (Steuben County Soil and Water Conservation District and Steuben County, 2006). Results are not yet available.

Table 134. Identified point sources in the Mud Creek – Pigeon Creek HUC 12

Site Name	Type	Permit/ID Number
ANGOLA MUNICIPAL WWTP	WWTP	IN0021296
ANGOLA MUNICIPAL WWTP (Pipe ID 002)	CSO	IN0021296
ANGOLA MUNICIPAL WWTP (Pipe ID 003)	CSO	IN0021296
CITY OF ANGOLA	MS4	INR040005

6.2.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 14 through Figure 16 are the load duration curves for *E. coli*, total nitrogen, and total phosphorus monitoring sites, respectively, in this HUC 12.

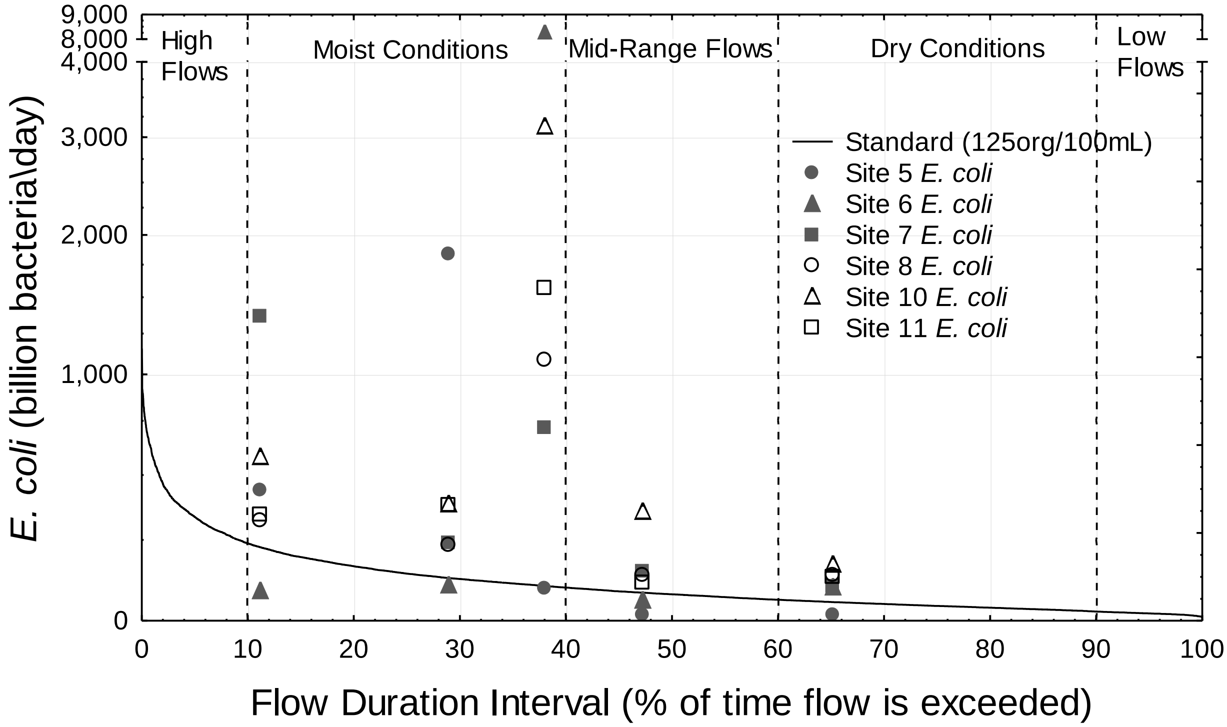

Figure 14. *E. coli* load duration curve for the Mud Creek-Pigeon Creek watershed (HUC 040500011002)
IDEM 2010 data; downscaled USGS Gage duration interval; 18 square miles

Exceedances of the *E. coli* standards occur in flow regimes ranging from dry conditions through high flows, with exceptionally high concentrations observed under moist conditions (Figure 14). *E. coli* sources that were identified in the source assessment (Section 6.2.1) that might lead to high concentrations during dry conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, and discharge from the Angola WWTP. Sources that might lead to high *E. coli* concentrations during higher flows are domesticated and/or wild animals in the watershed, land application of manure, field tiles, CSO events from the Angola WWTP, and urban stormwater runoff.

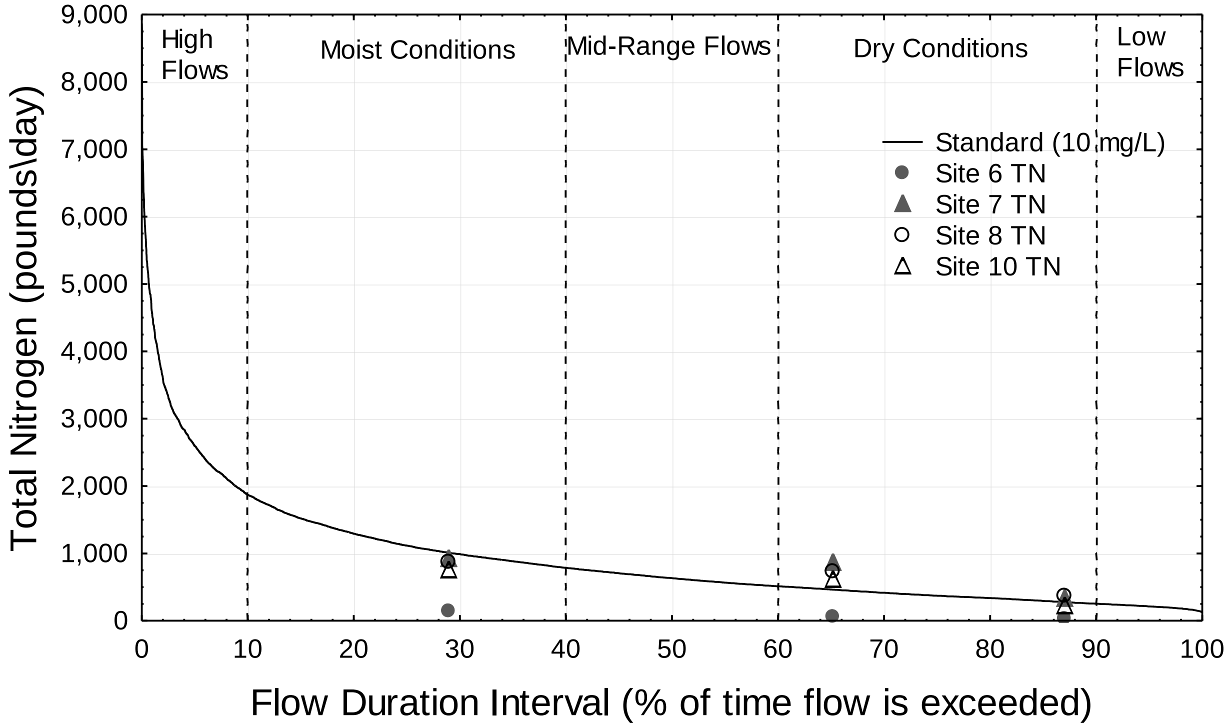

Figure 15. Total nitrogen load duration curve for the Mud Creek-Pigeon Creek watershed (HUC 040500011002)
IDEM 2010 data; downscaled USGS Gage duration interval; 18 square miles

Exceedances of the TN target occur under low flows and moist conditions (Figure 15). TN sources that were identified in the source assessment (Section 6.2.1) that might lead to high concentrations during low flow conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, and discharge from the Angola WWTP.

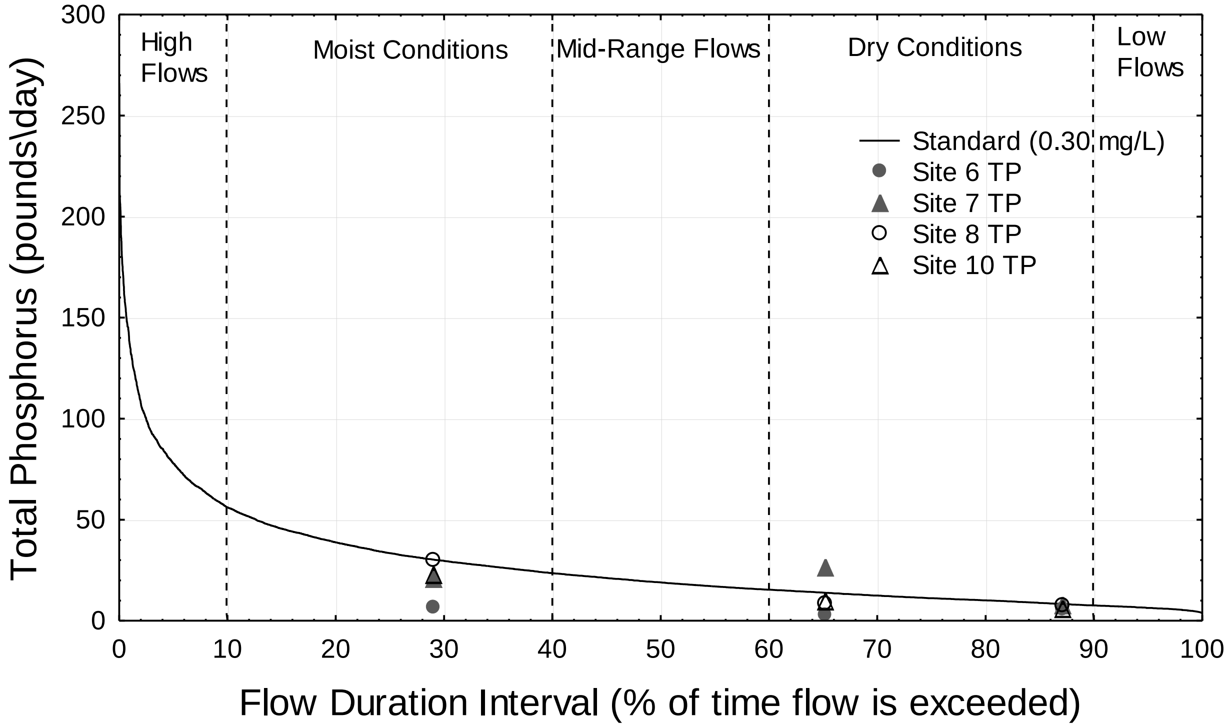

Figure 16. Total phosphorus load duration curve for the Mud Creek-Pigeon Creek watershed (HUC 040500011002)
IDEM 2010 data; downscaled USGS Gage duration interval; 18 square miles

There was one exceedance of the TP target, which occurred under dry conditions on July 7, on the same day that the TN target was also exceeded (Figure 16). TP sources that were identified in the source assessment (Section 6.2.1) that might lead to high concentrations during dry conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, and discharge from the Angola WWTP.

6.2.3 TMDL and Allocations

A summary of the *E. coli*, total nitrogen, and total phosphorus TMDLs at each of five flow intervals is provided in Table 145 through Table 167 respectively. Percent reductions to achieve the TMDLs were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard or the target values shown in Table . A 91% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 10 at 1,366 cfu/100 mL. A 65% reduction in total nitrogen and an 87% reduction in total phosphorus are needed based on the maximum measurements of 18.9 mg/L and 0.56 mg/L, respectively, which were both measured at monitoring Site 7.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFOs #1082 and #1108 are in this HUC 12.

Table 145. HUC 12: 040500011002 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	4	0	8	0
TMDL* = MOS + WLA + LA	147	63	36	21	12
MOS (10%)	15	6.3	3.6	2.1	1.2
WLA: total	25	9.7	9.7	9.7	9.7
Angola Municipal WWTP, IN0021296	8.0	8.0	8.0	8.0	8.0
Angola Municipal WWTP CSO (Pipe ID 002), IN0021296	0.76	0.76	0.76	0.76	0.76
Angola Municipal WWTP CSO (Pipe ID 003), IN0021296	0.92	0.92	0.92	0.92	0.92
Angola and Trine University MS4, INR040005	15	0	0	0	0
LA	107	47	23	9.0	1.1

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Table 156. HUC 12: 040500011002 total nitrogen TMDL summary
Units are lb/d

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	4	0	8	0
TMDL* = MOS + WLA + LA	2601	1116	634	372	213
MOS (10%)	260	112	63	37	21
WLA: total	291	28	28	28	28
Angola Municipal WWTP, IN0021296**	23	23	23	23	23
Angola Municipal WWTP CSO (Pipe ID 002), IN0021296**	2.6	2.6	2.6	2.6	2.6
Angola Municipal WWTP CSO (Pipe ID 003), IN0021296**	2.1	2.1	2.1	2.1	2.1
Angola and Trine University MS4, INR040005	263	0	0	0	0
LA	2050	976	543	307	164

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.
** Based on permit limit for ammonia-nitrogen (also see Table 8).

Table 167. HUC 12: 040500011002 total phosphorus TMDL summary
Units are lb/d

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	4	0	8	0
TMDL* = MOS + WLA + LA	92	47	33	25	20.4
MOS (10%)	9.2	4.7	3.3	2.5	2.04
WLA: total	14	14	14	14	14
Angola Municipal WWTP, IN0021296	14	14	14	14	14
LA	68.8	28.3	15.7	8.5	4.36

6.2.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli*, phosphorus, and nitrogen sources in the Mud Creek – Pigeon Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 178 with respect to the sources identified in the HUC 12 source summary (Section 6.2.1).

Table 178. Implementation approaches to addresses sources in Mud Creek – Pigeon Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 36%, Hay/Pasture 25%**, Woody Wetlands 17%, Developed Open Space 7%, Developed Low Intensity 5%, Deciduous Forest 4%, Developed, Medium Intensity 2%, Herbaceous 2%, Open Water 1%, Developed High Intensity 1%	7.2.1
CFO (#1082, 1108)	ID# 1082 allowed 2880 nursery pigs, 100 beef cattle ID# 1108 allowed 2880 nursery pigs	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Mud Creek – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 1,780 septic systems with estimated 267 failing.	7.2.4
Pets and Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
Lawn Fertilizer	Lawn fertilizer use is expected on developed areas which cover14% of the watershed, or 1,625 acres.	7.2.2, 7.1.4
Soil Erosion	Large amount of highly erodible soils throughout the drainage area	7.2.7
Stream Degradation	Mud Creek is identified by Steuben County as an open ditch and is estimated to have been impacted by ditching and straightening over the full length of the stream.	7.2.3
MS4 stormwater runoff	City of Angola	7.1.4
WWTP	Angola Municipal WWTP	7.1.1
CSO	Angola Municipal WWTP	7.1.2

6.3 HUC 12: 040500011003, Long Lake – Pigeon Creek

6.3.1 Source Assessment

A number of *E. coli* sources were identified in the Long Lake – Pigeon Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, pasture land use, and septic systems (Table 29). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 29. Identified nonpoint sources permit in the Long Lake – Pigeon Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 55%, Woody Wetlands 13%, Hay/Pasture 13%, Developed Open Space 5%, Developed Low Intensity 4%, Deciduous Forest 4%, Open Water 3%, Herbaceous 1%, Developed Medium Intensity 1%, Emergent Herbaceous Wetlands 1%
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 98% of the Long Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 2,101 septic systems with estimated 315 failing.
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

NPDES-permitted point sources of *E. coli* in the Long Lake – Pigeon Creek HUC 12 watershed are two wastewater treatment plants and a portion of an MS4 (Table30).

The Ashley Wastewater Treatment Plant permitted under IN002292 has recorded 12 effluent exceedances in the past three years, none of which were for *E. coli* exceedances. Of the past 12 quarters, seven were non-compliant for at least one permitted discharge parameter. A notice of non-compliance was issued in 2008, but no formal enforcement actions have been taken.

The Pigeon Creek Rest Area Wastewater Treatment Plant permitted under IN0052043 has recorded 13 effluent exceedances in the past three years, none of which were for *E. coli* exceedances. Of the past 12 quarters, four were non-compliant for at least one permitted discharge parameter. No informal or formal enforcement actions have been taken.

Table 30. Identified point sources in the Long Lake – Pigeon Creek HUC 12

Site Name	Type	Permit/ID Number
ASHLEY MUNICIPAL WWTP	WWTP	IN0022292
CITY OF ANGOLA & TRINE UNIVERSITY	MS4	INR040005

6.3.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 17 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

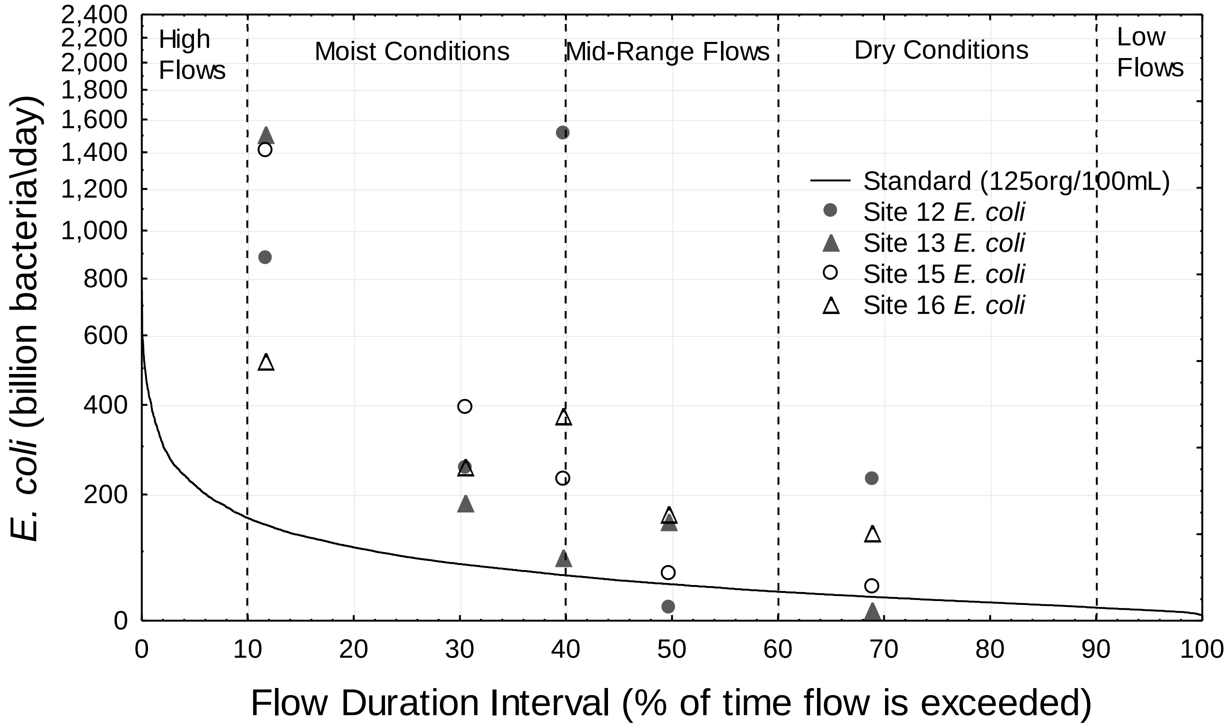

Figure 17. *E. coli* load duration curve for the Long Lake-Pigeon Creek watershed (HUC 040500011003)
IDEM 2010 data; downscaled USGS Gage duration interval; 29 square miles

Exceedances of the *E. coli* standards occur in flow regimes ranging from dry conditions through high flows, with the highest concentrations observed in the mid-range to high flows (Figure 17). *E. coli* sources that were identified in the source assessment (Section 6.3.1) that might lead to high concentrations during dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems. Sources that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, field tiles, discharge from WWTPs, and urban stormwater runoff.

6.3.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 181. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 76% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 12 at 518 cfu/100 mL.

Table 181. HUC 12: 040500011003 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	12	4	4	0
TMDL* = MOS + WLA + LA	218	91	50	28	14
MOS (10%)	22	9.1	5.0	2.8	1.4
WLA: total	3.9	2.8	2.4	2.2	2.0
Ashley Municipal STP, IN0022292	1.9	1.9	1.9	1.9	1.9
Angola and Trine University MS4, INR040005	2.0	0.85	0.47	0.26	0.13
LA	192	79	43	23	11

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.3.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Long Lake – Pigeon Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 192 with respect to the sources identified in the HUC 12 source summary (Section 6.3.1).

Table 192. Implementation approaches to addresses sources in Long Lake – Pigeon Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 55%**, Woody Wetlands 13%, **Hay/Pasture 13%**, Developed Open Space 5%, Developed Low Intensity 4%, Deciduous Forest 4%, Open Water 3%, Herbaceous 1%, Developed Medium Intensity 1%, Emergent Herbaceous Wetlands 1%	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 98% of the Long Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 2,101 septic systems with estimated 315 failing.	7.2.4
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
WWTP	Ashley Municipal WWTP	7.1.1
WWTP	Pigeon Creek Rest Area I-69 SB	7.1.1
MS4 stormwater runoff	City of Angola and Trine University	7.1.4

6.4 HUC 12: 040500011004, Headwaters Turkey Creek

6.4.1 Source Assessment

A number of *E. coli* sources were identified in the Headwaters Turkey Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, one CFO, pasture land use, and septic systems (Table 203). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Available compliance information showed no significant issues associated with the CFO. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 203. Identified nonpoint sources in the Headwaters Turkey Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 56%, Hay/Pasture 16%, Woody Wetlands 9%, Developed Open Space 5%, Deciduous Forest 4%, Shrub/Scrub 3%, Developed Low Intensity 3%, Herbaceous 2%, Open Water 1%, Evergreen Forest 1%
CFO (#6650)	ID# 6650 allowed 451 dairy cattle, 85 dairy calves, 315 dairy heifers
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Headwaters Turkey Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 765 septic systems with estimated 115 failing.
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

No NPDES-permitted point sources of *E. coli* were identified in the Headwaters Turkey Creek HUC 12 watershed.

6.4.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 18 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

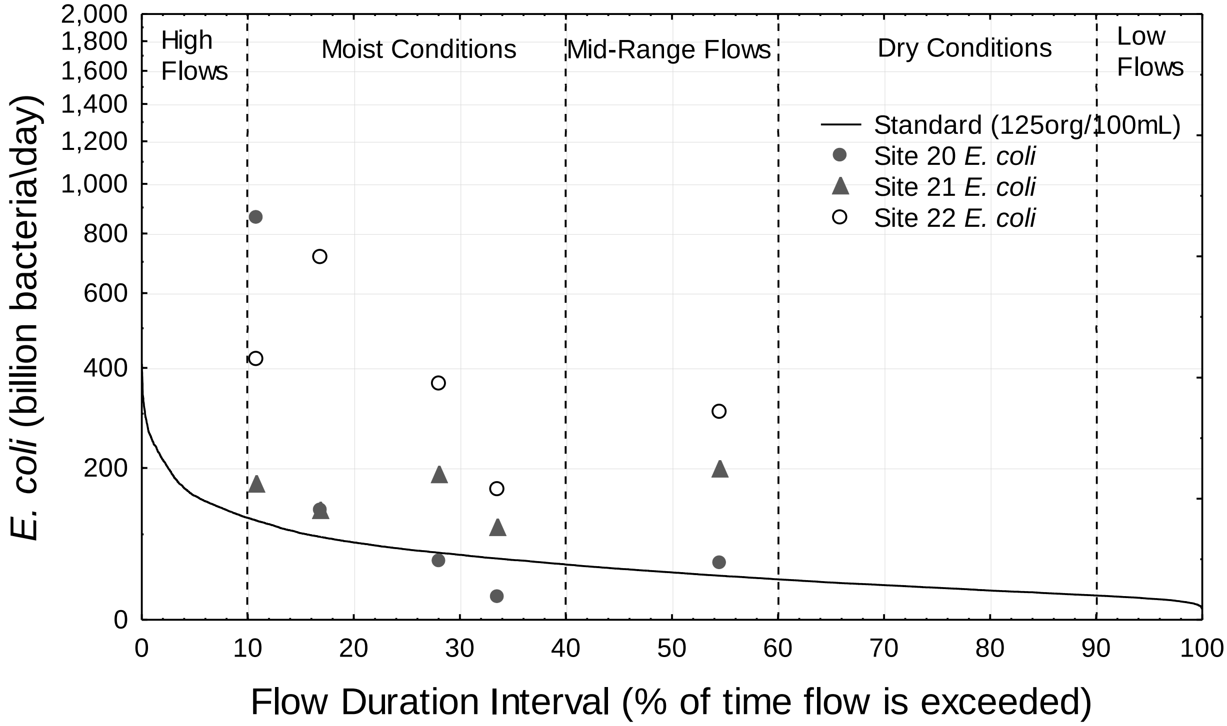

Figure 18. *E. coli* load duration curve for the Headwaters Turkey Creek watershed (HUC 040500011004)
IDEM 2010 data; downscaled USGS Gage duration interval; 18 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range conditions through high flows, with exceedances distributed relatively evenly across those flows (Figure 18). Sources that were identified in the source assessment (6.4.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems.

6.4.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 214. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 78% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 22 at 566 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFO #6650 is in this HUC 12. There are no NPDES-permitted point sources in this HUC 12 watershed.

Table 214. HUC 12: 040500011004 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	12	3	0	0
TMDL* = MOS + WLA + LA	155	80	52	34	22
MOS (10%)	16	8.0	5.2	3.4	2.2
WLA	0	0	0	0	0
LA	139	72	47	31	20

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.4.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Headwaters Turkey Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 225 with respect to the sources identified in the HUC 12 source summary (Section 6.4.1).

Table 225. Implementation approaches to addresses sources in Headwaters Turkey Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 56%, Hay/Pasture 16%**, Woody Wetlands 9%, Developed Open Space 5%, Deciduous Forest 4%, Shrub/Scrub 3%, Developed Low Intensity 3%, Herbaceous 2%, Open Water 1%, Evergreen Forest 1%	7.2.1
CFO (#6650)	ID# 6650 allowed 451 dairy cattle, 85 dairy calves, 315 dairy heifers	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Headwaters Turkey Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 765 septic systems with estimated 115 failing.	7.2.4
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	8.1.5

6.5 HUC 12: 040500011005, Big Turkey Lake – Turkey Creek

6.5.1 Source Assessment

A number of *E. coli* sources were identified in the Big Turkey Lake - Turkey Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, pasture land use, and septic systems (Table 236). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 236. Identified nonpoint sources in the Big Turkey Lake – Turkey Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 45%, Hay/Pasture 20%, Woody Wetlands 13%, Deciduous Forest 6%, Open Water 5%, Developed Open Space 5%, Herbaceous 3%, Developed Low Intensity 3%
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of CFO facilities: 100% of the Big Turkey Lake – Turkey Creek HUC 12 watershed. Land application of manure possible if small animal operations are present.
Septic Systems	Estimated total 530 septic systems with estimated 79 failing.
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

No NPDES-permitted point sources of *E. coli* in were identified in the Big Turkey Lake - Turkey Creek HUC 12 watershed.

6.5.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 19 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

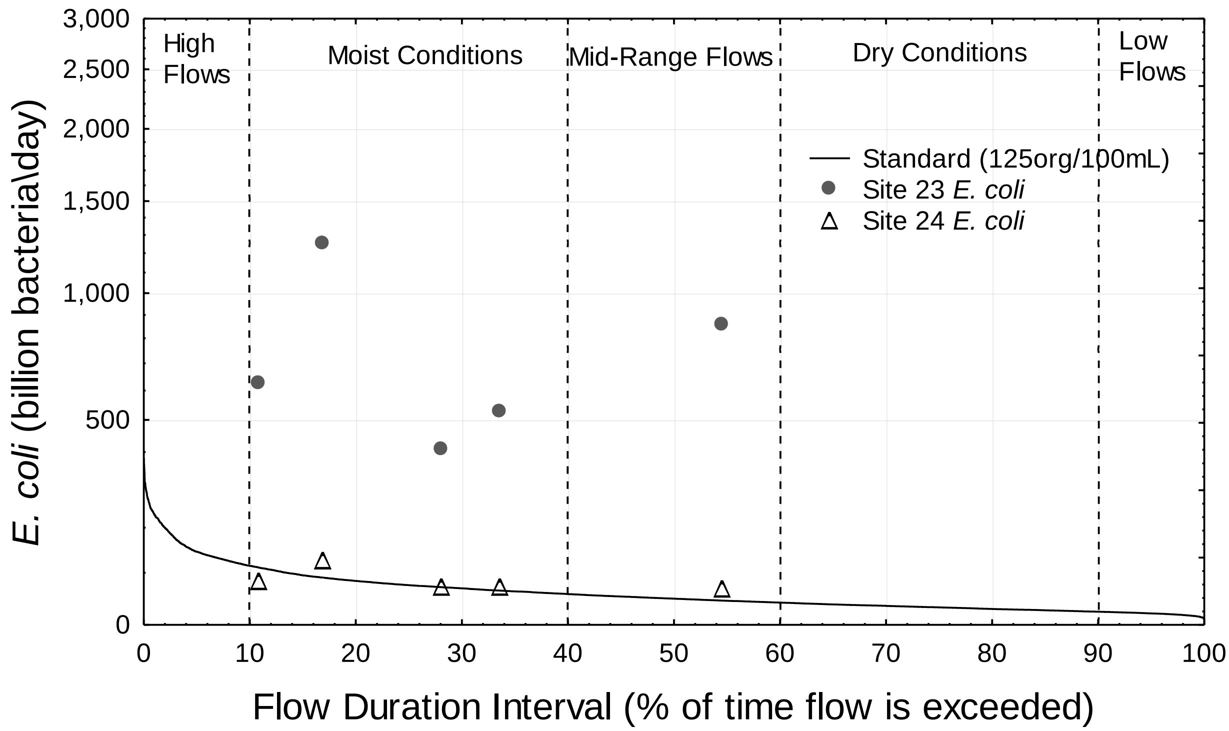

Figure 19. *E. coli* load duration curve for the Big Turkey Lake-Turkey Creek watershed (HUC 040500011005)
IDEM 2010 data; downscaled USGS Gage duration interval; 17 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with exceedances distributed relatively evenly across those flows (Figure 19).

High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.5.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems.

6.5.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 247. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). An 89% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 23 at 1,267 cfu/100 mL. There are no NPDES-permitted sources in this HUC 12 watershed.

Table 247. HUC 12: 040500011005 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	8	2	0	0
TMDL* = MOS + WLA + LA	145	75	48	32	21
MOS (10%)	15	7.5	4.8	3.2	2.1
WLA	0	0	0	0	0
LA	130	68	43	29	19

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.5.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Big Turkey Lake - Turkey Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 258 with respect to the sources identified in the HUC 12 source summary (Section 6.5.1).

Table 258. Implementation approaches to addresses sources in Big Turkey Lake - Turkey Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 45%, Hay/Pasture 20%**, Woody Wetlands 13%, Deciduous Forest 6%, Open Water 5%, Developed Open Space 5%, Herbaceous 3%, Developed Low Intensity 3%	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of CFO facilities: 100% of the Big Turkey Lake – Turkey Creek HUC 12 watershed. Land application of manure possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 530 septic systems with estimated 79 failing.	7.2.4
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5

6.6 HUC 12: 040500011006, Silver Lake – Pigeon Creek

6.6.1 Source Assessment

A number of *E. coli* sources were identified in the Silver Lake – Pigeon Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, pasture land use, and septic systems (Table39). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 39. Identified nonpoint sources in the Silver Lake – Pigeon Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 33%, Woody Wetlands 24%, Hay/Pasture 18%, Deciduous Forest 8%, Open Water 6%, Developed Open Space 5%, Herbaceous 2%, Developed Low Intensity 2%, Developed Medium Intensity 1%
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of CFO facilities: 59% of the Silver Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 1154 septic systems with estimated 173 failing.
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

The one NPDES-permitted point source of *E. coli* in the Silver Lake – Pigeon Creek HUC 12 watershed is a wastewater treatment plant (Table40).

The Silver Lake Group Wastewater Treatment Plant permitted under IN0039543 has recorded 40 effluent exceedances in the past three years, six of which were for *E. coli* exceedances. The *E. coli* exceedances were 26,794% in the second quarter of 2008, 287% in the third quarter of 2008, 15% in the first quarter of 2009, 19% in the third quarter of 2009, 240% in the fourth quarter

2009, and 360% in the second quarter 2010. Of the past 12 quarters, 11 were non-compliant for at least one permitted discharge parameter. Notices of non-compliance were issued in 2009, 2010, and 2011 and formal enforcement actions were taken in 2010.

Table 40. Identified point sources in the Silver Lake – Pigeon Creek HUC 12

Site Name	Type	Permit Number
SILVER LAKE GROUP WWTP	WWTP	IN0039543

Silver Lake WWTP discharges directly to a Silver Lake the WLA would be addressed in a Lake TMDL if needed.

6.6.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 20 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

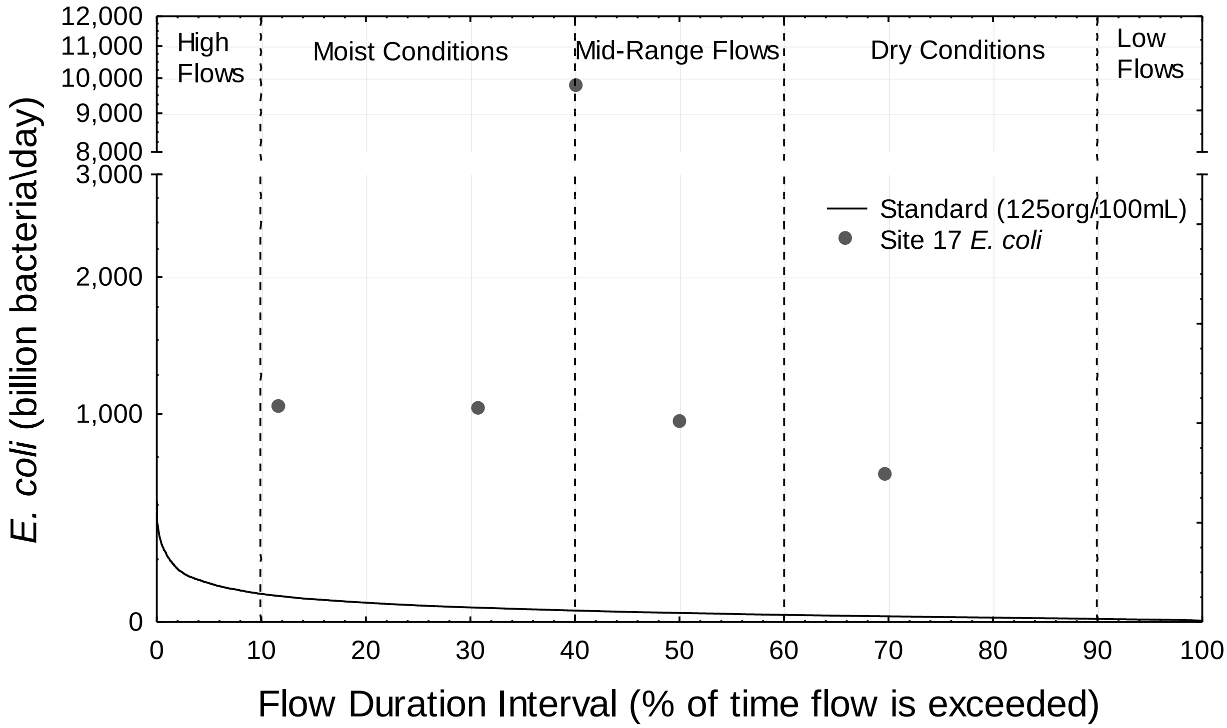

Figure 20. *E. coli* load duration curve for the Silver Lake-Pigeon Creek watershed (HUC 040500011006)

IDEM 2010 data; downscaled USGS Gage duration interval; 20 square miles

Exceedances of the *E. coli* standards occur in flow regimes ranging from dry conditions through moist conditions, with an extremely high concentration observed in the mid-range to moist flows (Figure 20). *E. coli* sources that were identified in the source assessment (6.6.1) that might lead to high concentrations during dry conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, and the WWTP. Sources that might lead to high *E. coli* concentrations during higher flows are domesticated and/or wild animals in the watershed, land application of manure, field tiles, and urban stormwater runoff.

6.6.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 261. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 97% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 17 at 4,125 cfu/100 mL. There are no NPDES-permitted point sources that discharge directly to impaired waters in this HUC 12 watershed.

Table 261. HUC 12: 040500011006 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	3	1	1	0
TMDL* = MOS + WLA + LA	150	62	34	19	9.3
MOS (10%)	15	6.2	3.4	1.9	0.93
WLA	0	0	0	0	0
LA	135	56	31	17	8.4

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.6.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Silver Lake – Pigeon Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 272 with respect to the sources identified in the HUC 12 source summary (Section 6.6.1).

Table 272. Implementation approaches to addresses sources in Silver Lake – Pigeon Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 33%**, Woody Wetlands 24%, **Hay/Pasture 18%**, Deciduous Forest 8%, Open Water 6%, Developed Open Space 5%, Herbaceous 2%, Developed Low Intensity 2%, Developed Medium Intensity 1%	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of CFO facilities: 59% of the Silver Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 1154 septic systems with estimated 173 failing.	7.2.4
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
WWTP	Silver Lake Group WWTP	7.1.1

6.7 HUC 12: 040500011007, Otter Lake – Pigeon Creek

6.7.1 Source Assessment

A number of *E. coli* sources were identified in the Otter Lake - Pigeon Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, pasture land use, and septic systems (Table 283). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 283. Identified nonpoint sources in the Otter Lake – Pigeon Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 52%, Woody Wetlands 17%, Hay/Pasture 16%, Deciduous Forest 5%, Developed Open Space 4%, Developed Low Intensity 2%, Open Water 2%, Herbaceous 1%, Evergreen Forest 1%
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 77% of the Otter Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 366 septic systems with estimated 55 failing.
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

There is one NPDES-permitted point source of *E. coli* in the Otter Lake - Pigeon Creek HUC 12 watershed, a wastewater treatment plant (Table 294).

The Steuben Lakes Wastewater Treatment Plant permitted under IN0061557 has recorded six effluent exceedances in the past three years, none of which were for *E. coli*. Of the past 12 quarters, three were non-compliant for at least one permitted discharge parameter. No informal or formal enforcement actions have been taken.

Table 294. Identified point sources in the Otter Lake – Pigeon Creek HUC 12

Site Name	Type	Permit Number
STEUBEN LAKES RWD	WWTP	IN0061557

6.7.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 21 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

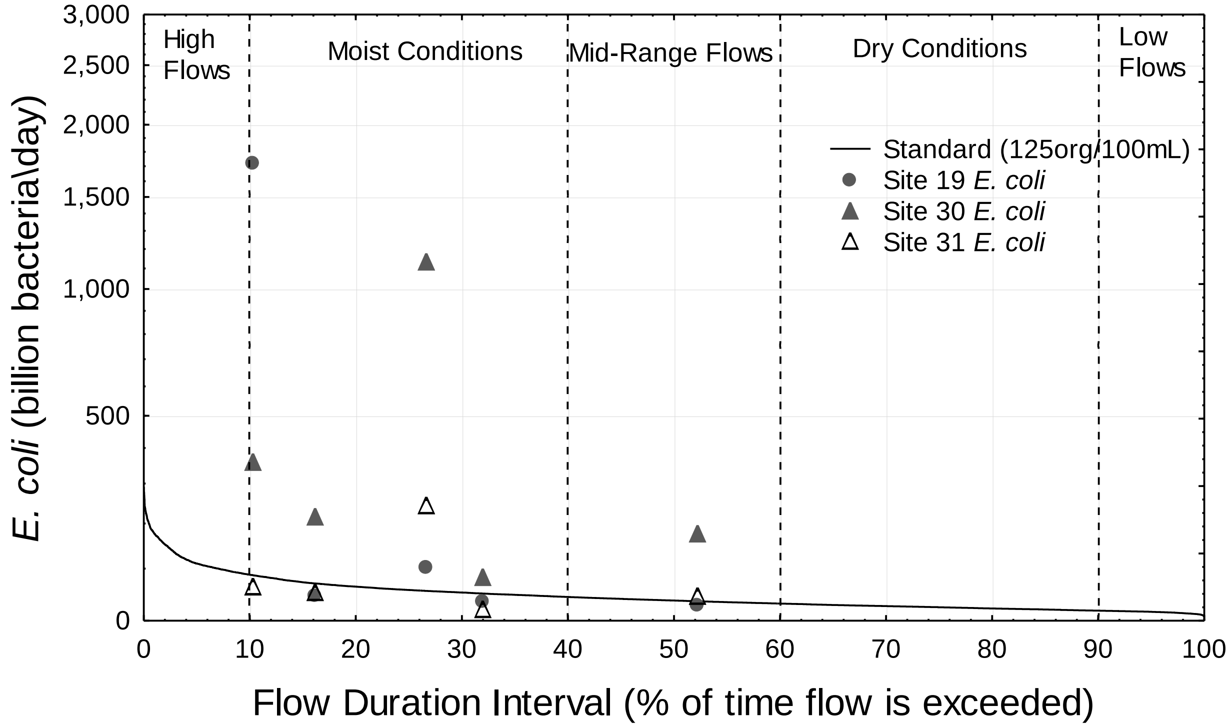

Figure 21. *E. coli* load duration curve for the Otter Lake-Pigeon Creek watershed (HUC 040500011007)
IDEM 2010 data; downscaled USGS Gage duration interval; 16 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with the highest concentrations observed under moist conditions (Figure 21). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.7.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, and the Steuben Lakes WWTP.

6.7.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 305. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 75% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 30 at 497 cfu/100 mL.

Table 305. HUC 12: 040500011007 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	12	3	0	0
TMDL* = MOS + WLA + LA	111	57	37	25	16
MOS (10%)	11	5.7	3.7	2.5	1.6
WLA: total	4.7	4.7	4.7	4.7	4.7
Steuben Lakes RWD, IN0061557	4.7	4.7	4.7	4.7	4.7
LA	95	47	29	18	10

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.7.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Otter Lake – Pigeon Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 316 with respect to the sources identified in the HUC 12 source summary (Section 6.7.1).

Table 316. Implementation approaches to addresses sources in Otter Lake – Pigeon Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 52%**, Woody Wetlands 17%, **Hay/Pasture 16%**, Deciduous Forest 5%, Developed Open Space 4%, Developed Low Intensity 2%, Open Water 2%, Herbaceous 1%, Evergreen Forest 1%	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 77% of the Otter Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 366 septic systems with estimated 55 failing.	7.2.4
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
WWTP	Steuben Lakes RWD	7.1.1

6.8 HUC 12: 040500011008, Little Turkey Lake – Turkey Creek

6.8.1 Source Assessment

A number of *E. coli* sources were identified in the Little Turkey Lake - Turkey Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, four CFOs, pasture land use, and septic systems (Table 327). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Available compliance information showed no significant issues associated with CFOs. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 327. Identified nonpoint sources in the Little Turkey Lake – Turkey Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 44%, Woody Wetlands 17%, Hay/Pasture 16%, Open Water 7%, Deciduous Forest 7%, Developed Open Space 4%, Developed Low Intensity 2%, Herbaceous 2%
CFOs (#291, 659, 1005, 6390)	ID # 291 allowed 1300 finishers ID # 659 allowed 1290 beef cattle ID # 1005 allowed 220 dairy cattle and 15 dairy calves ID # 6390 allowed 516 dairy cattle and 45 dairy calves
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Little Turkey Lake – Turkey Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 547 septic systems with estimated 82 failing.
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

There are no NPDES-permitted point sources of *E. coli* in the Little Turkey Lake - Turkey Creek HUC 12 watershed.

6.8.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 22 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

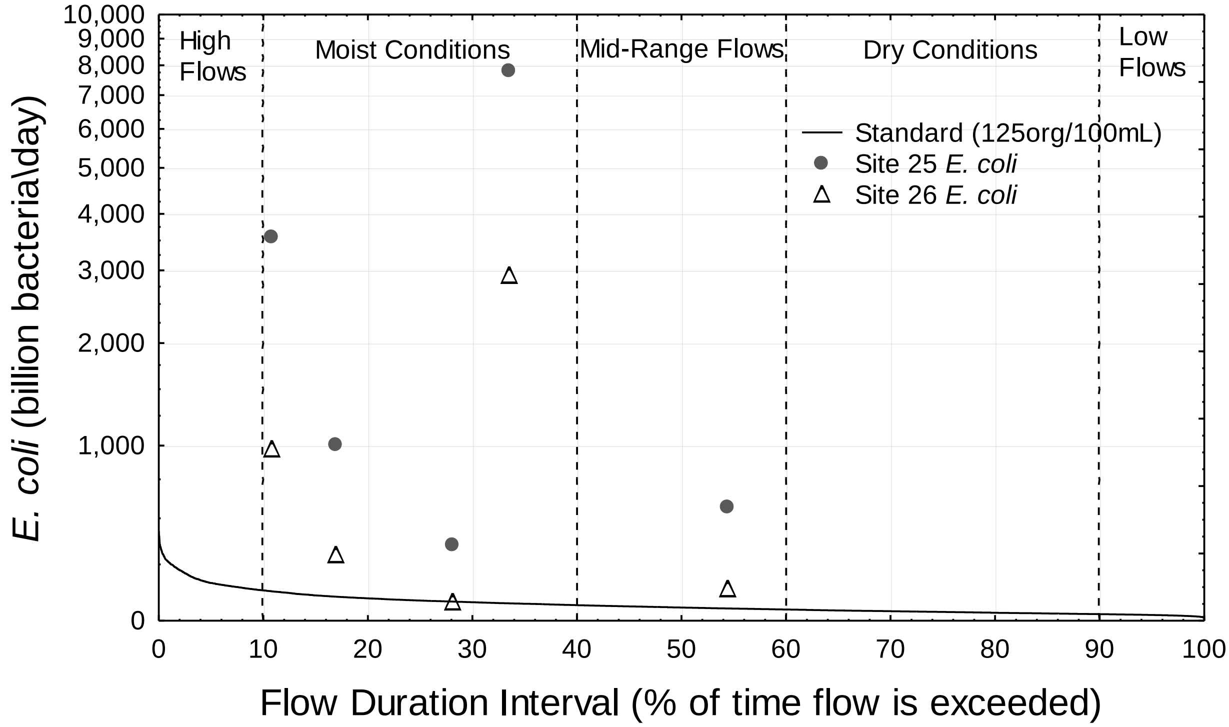

Figure 22. *E. coli* load duration curve for the Little Turkey Lake-Turkey Creek watershed (HUC 040500011008)
IDEM 2010 data; downscaled USGS Gage duration interval; 21 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with higher concentrations observed under moist conditions (Figure 22). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.8.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems.

6.8.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 338. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 94% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 25 at 2,165 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. The following four CFOs are in this HUC 12: #291, #659, #1005, #6390. There are no NPDES-permitted point sources in this HUC 12 watershed.

Table 338. HUC 12: 040500011008 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	8	2	0	0
TMDL* = MOS + WLA + LA	162	83	54	36	23
MOS (10%)	16.2	8.3	5.4	3.6	2.3
WLA	0	0	0	0	0
LA	146	75	49	32	21

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.8.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Little Turkey Lake - Turkey Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 349 with respect to the sources identified in the HUC 12 source summary (Section 6.8.1).

Table 349. Implementation approaches to addresses sources in Little Turkey Lake - Turkey Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 44%**, Woody Wetlands 17%, **Hay/Pasture 16%**, Open Water 7%, Deciduous Forest 7%, Developed Open Space 4%, Developed Low Intensity 2%, Herbaceous 2%	7.2.1
CFOs (#291, 659, 1005, 6390)	ID # 291 allowed 1300 finishers ID # 659 allowed 1290 beef cattle ID # 1005 allowed 220 dairy cattle and 15 dairy calves ID # 6390 allowed 516 dairy cattle and 45 dairy calves	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Little Turkey Lake – Turkey Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 547 septic systems with estimated 82 failing.	7.2.4
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5

6.9 HUC 12: 040500011009, Green Lake – Pigeon Creek

6.9.1 Source Assessment

A number of *E. coli* sources were identified in the Green Lake - Pigeon Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, one CFO, pasture land use, and septic systems (Table50). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Compliance information was not readily available for CFOs. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 50. Identified nonpoint sources in the Green Lake – Pigeon Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 47%, Woody Wetlands 25%, Hay/Pasture 12%, Deciduous Forest 5%, Developed Open Space 4%, Open Water 3%, Developed Low Intensity 2%, Evergreen Forest 2%, Herbaceous 1%
CFO (#4004)	ID # 4004 allowed 920 nursery pigs, 2,376 finishers, and 288 sows
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Green Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 442 septic systems with estimated 66 failing.
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

There are no NPDES-permitted point sources of *E. coli* in the Green Lake - Pigeon Creek HUC 12 watershed.

6.9.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 23 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

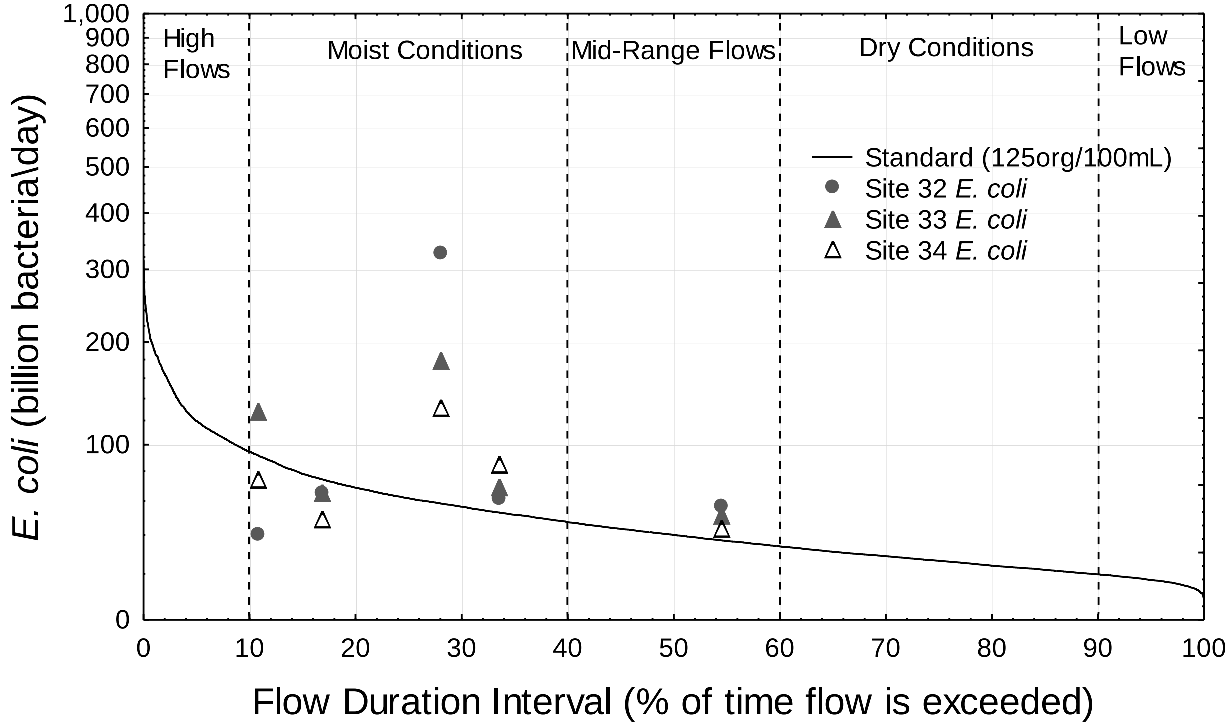

Figure 23. *E. coli* load duration curve for the Green Lake-Pigeon Creek watershed (HUC 040500011009)
IDEM 2010 data; downscaled USGS Gage duration interval; 21 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with higher concentrations observed under moist conditions (Figure 23). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.9.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems.

6.9.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 351. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 32% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 33 at 183 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFO #4004 is in this HUC 12. There are no NPDES permitted point sources in this watershed.

Table 351. HUC 12: 040500011009 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	12	3	0	0
TMDL* = MOS + WLA + LA	120	62	40	26	17
MOS (10%)	12	6.2	4.0	2.6	1.7
WLA	0	0	0	0	0
LA	108	56	36	23	15

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.9.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Green Lake – Pigeon Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 362 with respect to the sources identified in the HUC 12 source summary (Section 6.9.1).

Table 362. Implementation approaches to addresses sources in Green Lake – Pigeon Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 47%**, Woody Wetlands 25%, **Hay/Pasture 12%**, Deciduous Forest 5%, Developed Open Space 4%, Open Water 3%, Developed Low Intensity 2%, Evergreen Forest 2%, Herbaceous 1%	7.2.1
CFO (#4004)	ID # 4004 allowed 920 nursery pigs, 2,376 finishers, and 288 sows	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Green Lake – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 442 septic systems with estimated 66 failing.	7.2.4
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5

6.10 HUC 12: 040500011010, Mongo Millpond – Pigeon Creek

6.10.1 Source Assessment

A number of *E. coli* sources were identified in the Mongo Millpond - Pigeon Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, one CFO, pasture land use, and septic systems (Table 373). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Available compliance information showed no significant issues associated with CFOs. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 373. Identified nonpoint sources in the Mongo Millpond – Pigeon Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 58%, Woody Wetlands 22%, Hay/Pasture 7%, Deciduous Forest 5%, Developed Open Space 3%, Developed Low Intensity 2%, Herbaceous 1%, Open Water 1%, Evergreen Forest 1%
CFO (#6464)	ID # 6464 allowed 3630 dairy cattle
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Mongo Millpond – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 289 septic systems with estimated 43 failing.
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

There is one NPDES-permitted point source of *E. coli* in the Mongo Millpond - Pigeon Creek HUC 12 watershed, a wastewater treatment plant (Table 384).

The LaGrange County Region B Wastewater Treatment Plant permitted under IN0060097 has recorded one effluent exceedance in the past three years. This exceedance was not for *E. coli*. Of the past 12 quarters, one quarter was non-compliant for one permitted discharge parameter. No notices of non-compliance were issued and no formal enforcement actions were taken.

Table 384. Identified point sources in the Mongo Millpond – Pigeon Creek HUC 12

Site Name	Type	Permit/ID Number
LAGRANGE CO REGIONAL UTILITY DISTRICT - REGION B	WWTP	IN0060097

6.10.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 24 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

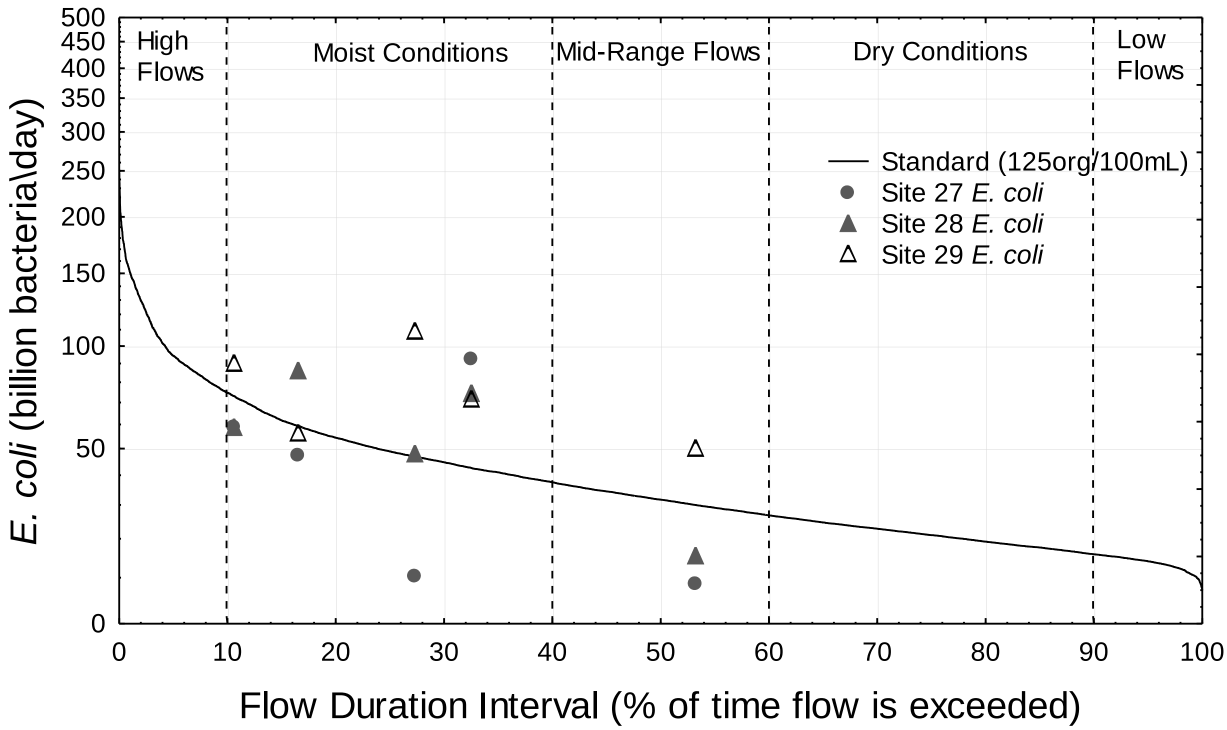

Figure 24. *E. coli* load duration curve for the Mongo Millpond-Pigeon Creek watershed (HUC 040500011010)
IDEM 2010 data; downscaled USGS Gage duration interval; 16 square miles

E. coli exceedances were not as extreme in this HUC 12 watershed, with only two exceedances of the maximum standard, both occurring under moist conditions, and two of the three sites exceeding the geometric mean standard (Figure 24). High concentrations of *E. coli* under moist and mid-flow conditions could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.10.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, and the WWTP.

6.10.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 395. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 34% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 29 at 188 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFO #6464 is in this HUC 12.

Table 395. HUC 12: 040500011010 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	12	3	0	0
TMDL* = MOS + WLA + LA	94	49	32	21	14
MOS (10%)	9.4	4.9	3.2	2.1	1.4
WLA: total	3.5	3.5	3.5	3.5	3.5
LaGrange Co Regional Utility District – Region B, IN0060097	3.5	3.5	3.5	3.5	3.5
LA	81	41	25	15	9.1

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.10.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Mongo Millpond – Pigeon Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 406 with respect to the sources identified in the HUC 12 source summary (Section 6.10.1).

Table 406. Implementation approaches to addresses sources in Mongo Millpond – Pigeon Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 58%**, Woody Wetlands 22%, **Hay/Pasture 7%**, Deciduous Forest 5%, Developed Open Space 3%, Developed Low Intensity 2%, Herbaceous 1%, Open Water 1%, Evergreen Forest 1%	7.2.1
CFO (#6464)	ID # 6464 allowed 3630 dairy cattle	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Mongo Millpond – Pigeon Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 289 septic systems with estimated 43 failing.	7.2.4
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
WWTP	LaGrange County Regional Utility District – Region B	7.1.1

6.11 HUC 12: 040500011101, East Fly Creek

6.11.1 Source Assessment

A number of *E. coli* sources were identified in the East Fly Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, one CFO, pasture land use, and septic systems (Table 417). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Available compliance information showed no significant issues associated with CFOs. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 417. Identified nonpoint sources in the East Fly Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 45%, Woody Wetlands 19%, Hay/Pasture 18%, Deciduous Forest 7%, Developed Open Space 5%, Developed Low Intensity 2%, Herbaceous 1%, Open Water 1%, Evergreen Forest 1%
CFOs (#3622, 6507)	ID # 3622 allowed 440 nursery pigs, 1,360 finishers, and168 sows ID# 6507 allowed 1,064 nursery pigs, and 1,596 finishers
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 94% of the East Fly Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 654 septic systems with estimated 98 failing.
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

There is one NPDES-permitted point sources of *E. coli* in the East Fly Creek HUC 12 watershed, a wastewater treatment plant (Table 428).

The Fish & Royer Wastewater Treatment Plant permitted under IN0058505 has no recorded effluent exceedances in the past three years. No informal or formal enforcement actions have been taken.

Table 428. Identified point sources in the East Fly Creek HUC 12

Site Name	Type	Permit Number
FISH AND ROYER LAKE WWTP	WWTP	IN0058505

6.11.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 25 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

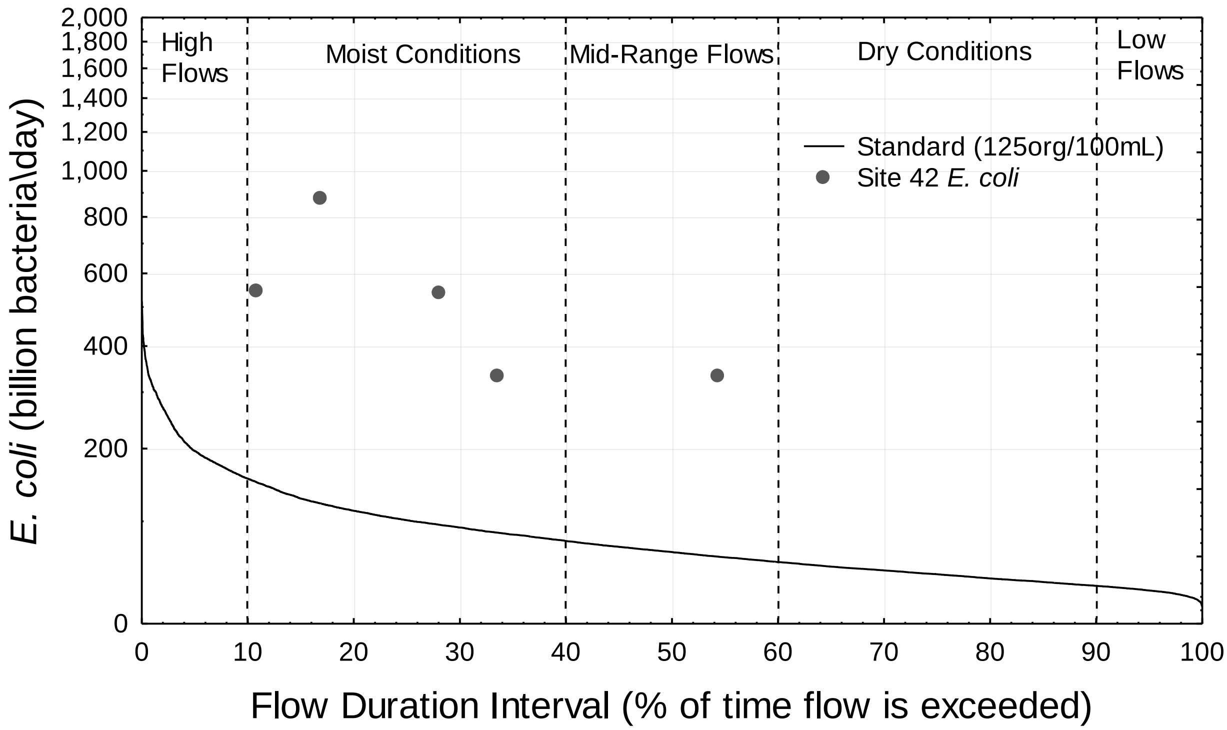

Figure 25. *E. coli* load duration curve for the East Fly Creek watershed (HUC 040500011101)
IDEM 2010 data; downscaled USGS Gage duration interval; 24 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions (Figure 25). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.11.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, and the WWTP.

6.11.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 439. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). An 80% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 42 at 621 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFO #3622 is in this HUC 12. There are no NPDES-permitted point sources that discharge directly to impaired waters in this HUC 12 watershed.

Table 439. HUC 12: 040500011101 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	4	1	0	0
TMDL* = MOS + WLA + LA	196	101	66	43	28
MOS (10%)	20	10	6.6	4.3	2.8
WLA	0.24	0.24	0.24	0.24	0.24
LA	176	91	59	39	25

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.11.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the East Fly Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table60 with respect to the sources identified in the HUC 12 source summary (Section 6.11.1).

Table 60. Implementation approaches to addresses sources in East Fly Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 45%**, Woody Wetlands 19%, **Hay/Pasture 18%**, Deciduous Forest 7%, Developed Open Space 5%, Developed Low Intensity 2%, Herbaceous 1%, Open Water 1%, Evergreen Forest 1%	7.2.1
CFOs (#3622)	ID # 3622 allowed 440 nursery pigs, 1,360 finishers, and168 sows	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 94% of the East Fly Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 654 septic systems with estimated 98 failing.	7.2.4
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
WWTP	Fish and Royer Lake WWTP	7.1.1

6.12 HUC 12: 040500011102, Fly Creek

6.12.1 Source Assessment

A number of *E. coli* sources were identified in the Fly Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, pasture land use, and septic systems (Table 441). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 441. Identified nonpoint sources in the Fly Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 55%, Hay/Pasture 15%, Woody Wetlands 11%, Developed Open Space 7%, Developed Low Intensity 5%, Deciduous Forest 4%, Developed Medium Intensity 2%, Herbaceous 1%
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 73% of the Fly Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 1806 septic systems with estimated 271 failing.
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

NPDES-permitted point sources of *E. coli* in the Fly Creek HUC 12 watershed are one wastewater treatment plant and three associated sanitary sewer overflow locations (SSO) (Table 452).

The LaGrange Wastewater Treatment Plant permitted under IN0020478 has recorded one effluent exceedance in the past three years. This exceedance was not for *E. coli*. Of the past 12 quarters, one was non-compliant for one permitted discharge parameter. No informal or formal enforcement actions have been taken.

Table 452. Identified point sources in the Fly Creek HUC 12

Site Name		Type	Permit Number
LAGRANGE WWTP		WWTP	IN0020478
LAGRANGE WWTP	NORTH & CANAL STREETS	SSO	IN0020478
LAGRANGE WWTP	SPRING & SYCAMORE STRETS	SSO	IN0020478
LAGRANGE WWTP	NEXT TO WWTP	SSO	IN0020478

6.12.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 26 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

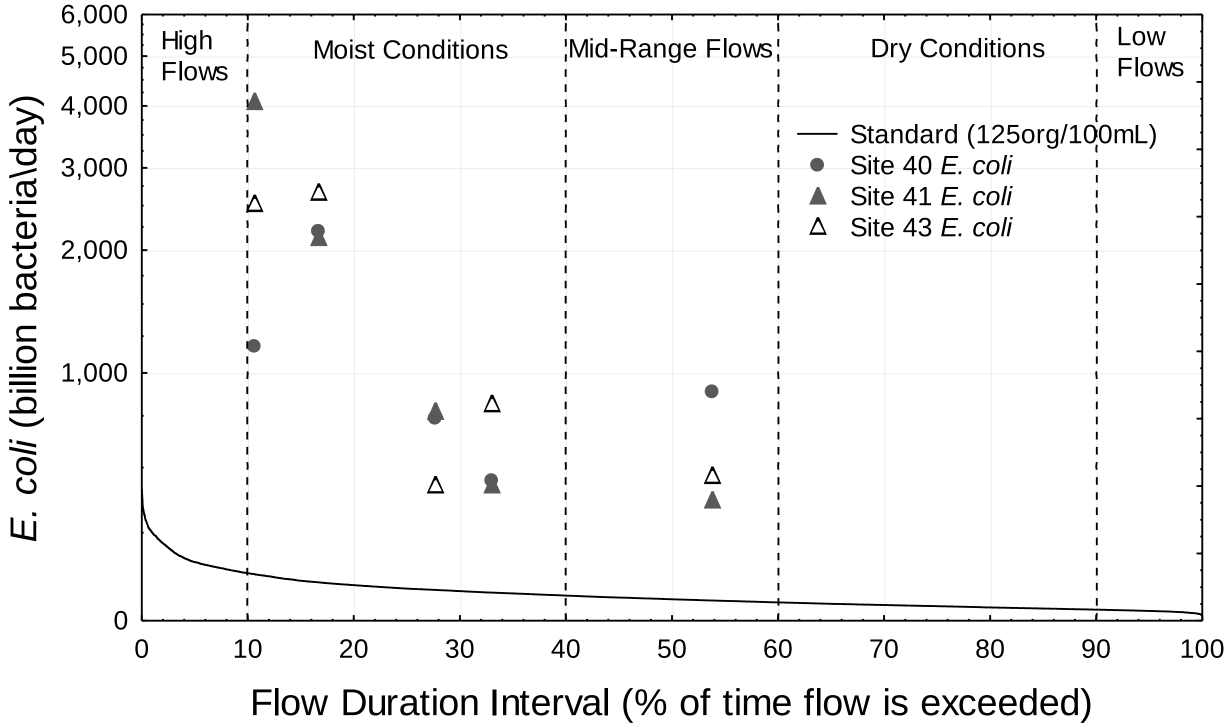

Figure 26. *E. coli* load duration curve for the Fly Creek watershed (HUC 040500011102)
IDEM 2010 data; downscaled USGS Gage duration interval; 19 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with higher exceedances under moist conditions (Figure 26). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.12.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, the WWTP, and the SSOs.

6.12.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 463. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 92% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 43 at 1,593 cfu/100 mL.

Table 463. HUC 12: 040500011102 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	12	3	0	0
TMDL* = MOS + WLA + LA	157	82	54	36	24
MOS (10%)	16	8.2	5.4	3.6	2.4
WLA: total	8.5	8.5	8.5	8.5	8.5
LaGrange Municipal WWTP, IN0020478	8.5	8.5	8.5	8.5	8.5
LaGrange Municipal WWTP SSOs (3locations) IN0020478	0	0	0	0	0
LA	133	65	39	24	13

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.12.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Fly Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 474 with respect to the sources identified in the HUC 12 source summary (Section 6.12.1).

Table 474. Implementation approaches to addresses sources in Fly Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 55%**, **Hay/Pasture 15%**, Woody Wetlands 11%, Developed Open Space 7%, Developed Low Intensity 5%, Deciduous Forest 4%, Developed Medium Intensity 2%, Herbaceous 1%	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 73% of the Fly Creek HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 1806 septic systems with estimated 271 failing.	7.2.4
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
WWTP	LaGrange Wastewater Treatment Plant	7.1.1
SSO	LaGrange Wastewater Treatment Plant	7.1.3

Potential Priority Implementation Areas

- Agricultural practices related to the land application of manure and droppings from working horses.
- Developed areas in the Town of LaGrange, due to the use of horses for transportation and the build-up of horse waste on impervious surfaces.

6.13 HUC 12: 040500011103, Cline Lake – Pigeon River

6.13.1 Source Assessment

A number of *E. coli* sources were identified in the Cline Lake – Pigeon River HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, one CFO, pasture land use, and septic systems (Table 485). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Compliance information was not readily available for CFOs. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 485. Identified nonpoint sources in the Cline Lake – Pigeon River HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 52%, Woody Wetlands 25%, Deciduous Forest 7%, Hay/Pasture 6%, Developed Open Space 4%, Developed Low Intensity 2%, Open Water 1%, Evergreen Forest 1%, Herbaceous 1%
CFO (#3518)	ID # 3518 allowed 600 nursery pigs, 440 finishers, and 60 sows
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Cline Lake – Pigeon River HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 553 septic systems with estimated 83 failing.
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

There are no NPDES-permitted point sources of *E. coli* in the Cline Lake – Pigeon River HUC 12 watershed.

6.13.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 27 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

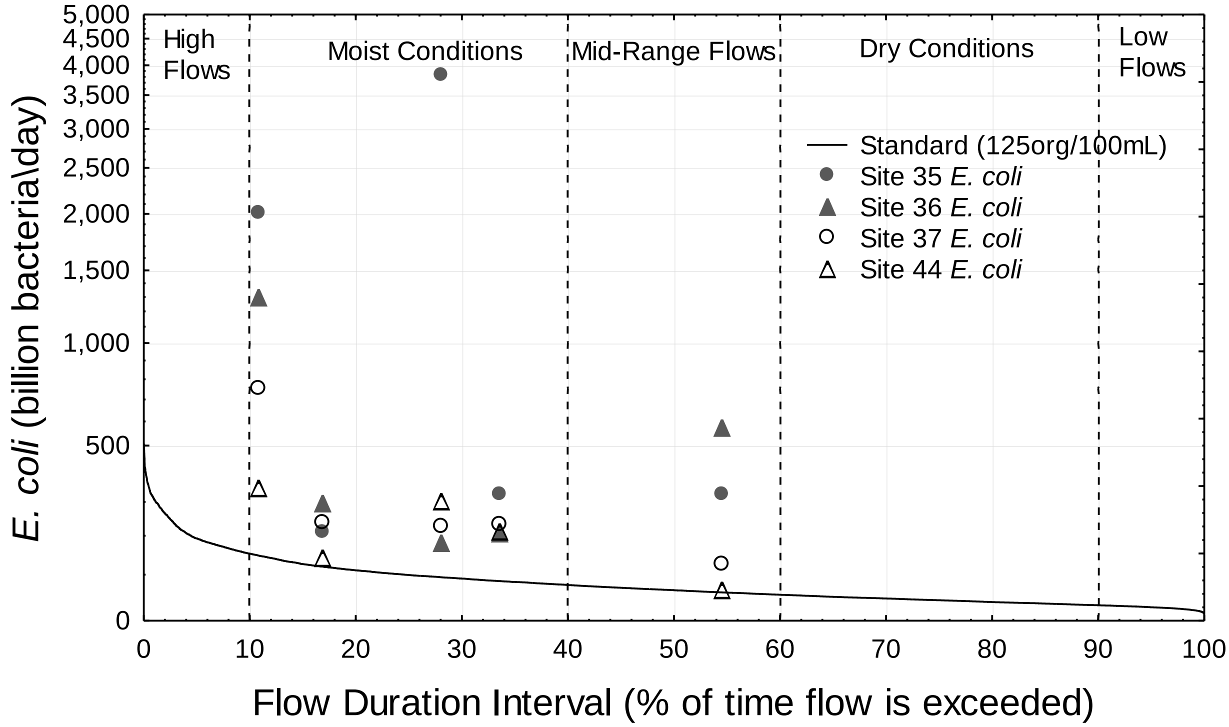

Figure 27. *E. coli* load duration curve for the Cline Lake-Pigeon River watershed (HUC 040500011103)
IDEM 2010 data; downscaled USGS Gage duration interval; 27 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with higher exceedances under moist conditions (Figure 27). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.13.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems.

6.13.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 496. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). An 86% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 35 at 910 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFO #3518 is in this HUC 12. There are no NPDES-permitted point sources in this HUC 12 watershed.

Table 496. HUC 12: 040500011103 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	16	4	0	0
TMDL* = MOS + WLA + LA	193	99	64	42	28
MOS (10%)	19	9.9	6.4	4.2	2.8
WLA	0	0	0	0	0
LA	174	89	58	38	25

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.13.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Cline Lake – Pigeon River HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 507 with respect to the sources identified in the HUC 12 source summary (Section 6.13.1).

Table 507. Implementation approaches to addresses sources in Cline Lake – Pigeon River HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): **Cultivated Crops 52%**, Woody Wetlands 25%, Deciduous Forest 7%, **Hay/Pasture 6%**, Developed Open Space 4%, Developed Low Intensity 2%, Open Water 1%, Evergreen Forest 1%, Herbaceous 1%	7.2.1
CFO (#3518)	ID # 3518 allowed 600 nursery pigs, 440 finishers, and 60 sows	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Cline Lake – Pigeon River HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 553 septic systems with estimated 83 failing.	7.2.4
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5

6.14 HUC 12: 040500011104, Buck Lake – Buck Creek

6.14.1 Source Assessment

A number of *E. coli* sources were identified in the Buck Lake – Buck Creek HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, pasture land use, and septic systems (Table 518). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 518. Identified nonpoint sources in the Buck Lake - Buck Creek HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 45%, Hay/Pasture 32%, Woody Wetlands 10%, Deciduous Forest 4%, Developed Open Space 3%, Developed Low Intensity 3%, Herbaceous 2%
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of CFO facilities: 74% of the Buck Lake – Buck Creek HUC 12 watershed. Land application of manure possible if small animal operations are present.
Septic Systems	Estimated total 773 septic systems with estimated 116 failing.
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

There were no NPDES-permitted point sources of *E. coli* identified in the Buck Lake – Buck Creek HUC 12 watershed.

6.14.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 28 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

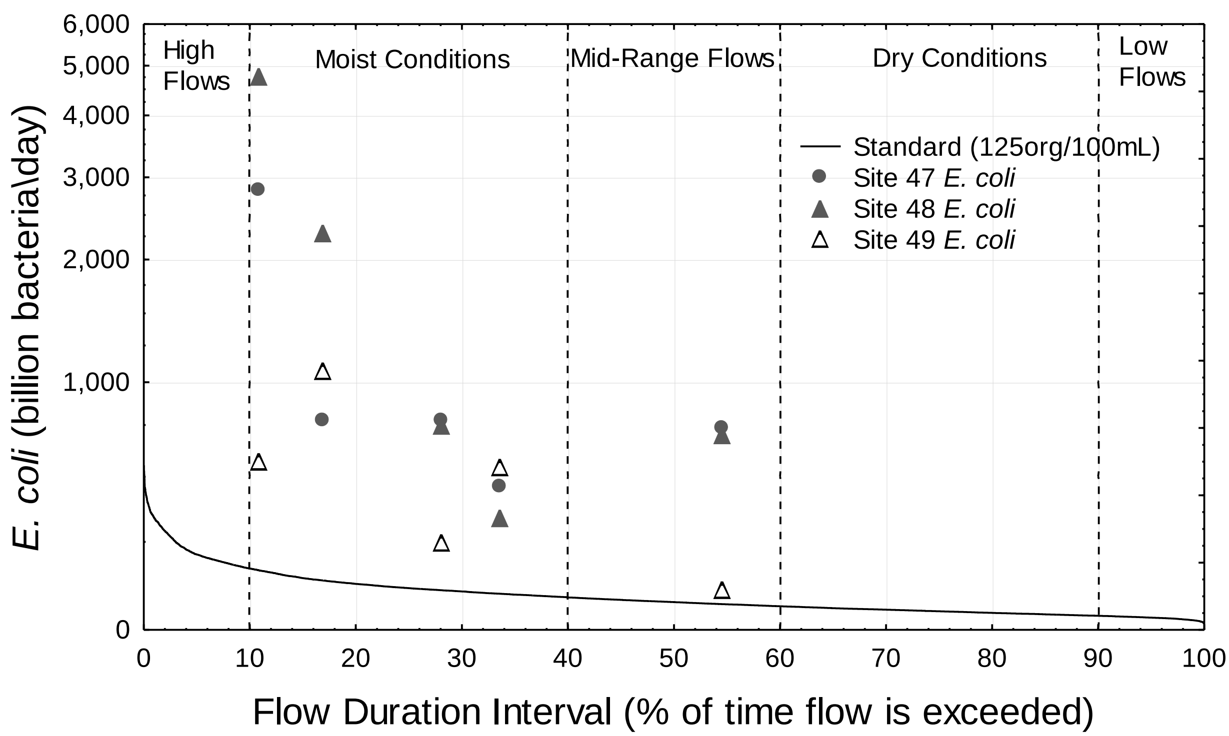

Figure 28. *E. coli* load duration curve for the Buck Lake-Buck Creek watershed (HUC 040500011104)
IDEM 2010 data; downscaled USGS Gage duration interval; 26 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with higher exceedances under moist conditions (Figure 28). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.14.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems.

6.14.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 529. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 91% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 48 at 1,354 cfu/100 mL. There are no NPDES-permitted point sources in this HUC 12 watershed.

Table 529. HUC 12: 040500011104 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	12	3	0	0
TMDL* = MOS + WLA + LA	209	108	70	46	30
MOS (10%)	21	11	7.0	4.6	3.0
WLA	0	0	0	0	0
LA	188	97	63	41	27

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.14.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Buck Lake – Buck Creek HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table70 with respect to the sources identified in the HUC 12 source summary (Section 6.14.1).

Table 70. Implementation approaches to addresses sources in Buck Lake – Buck Creek HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 45%, Hay/Pasture 32%, Woody Wetlands 10%, Deciduous Forest 4%, Developed Open Space 3%, Developed Low Intensity 3%, Herbaceous 2%	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of CFO facilities: 74% of the Buck Lake – Buck Creek HUC 12 watershed. Land application of manure possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 773 septic systems with estimated 116 failing.	7.2.4
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5

6.15 HUC 12: 040500011105, Page Ditch

6.15.1 Source Assessment

A number of *E. coli* sources were identified in the Page Ditch HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, one CFO, pasture land use, and septic systems (Table 531). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Compliance information was not readily available for CFOs. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 531. Identified nonpoint sources in the Page Ditch HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Hay/Pasture 34%, Cultivated Crops 33%, Woody Wetlands 13%, Deciduous Forest 5%, Developed Low Intensity 4%, Developed Open Space 4%, Herbaceous 2%, Open Water 2%, Developed Medium Intensity 1%, Developed High Intensity 1%
CFOs (#3686)	ID # 3686 allowed 580 finishers
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Page Ditch HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 1446 septic systems with estimated 217 failing.
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

The one NPDES-permitted point source of *E. coli* in the Page Ditch HUC 12 watershed is a wastewater treatment plant (Table 542).

The Shipshewana Wastewater Treatment Plant permitted under IN0040622 has recorded 20 effluent exceedances in the past three years, three of which were for *E. coli* exceedances. The *E. coli* exceedances were 21% in the second quarter of 2008, 348% in the third quarter of 2008, and 240% in the second quarter of 2009. Of the past 12 quarters, five were non-compliant for at least one permitted discharge parameter. Notices of non-compliance were issued in 2007, 2008, 2009, and 2010 but no formal enforcement actions were taken.

Table 542. Identified point sources in the Page Ditch HUC 12

Site Name	Type	Permit Number
SHIPSHEWANA MUNICIPAL STP	WWTP	IN0040622

6.15.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 29 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

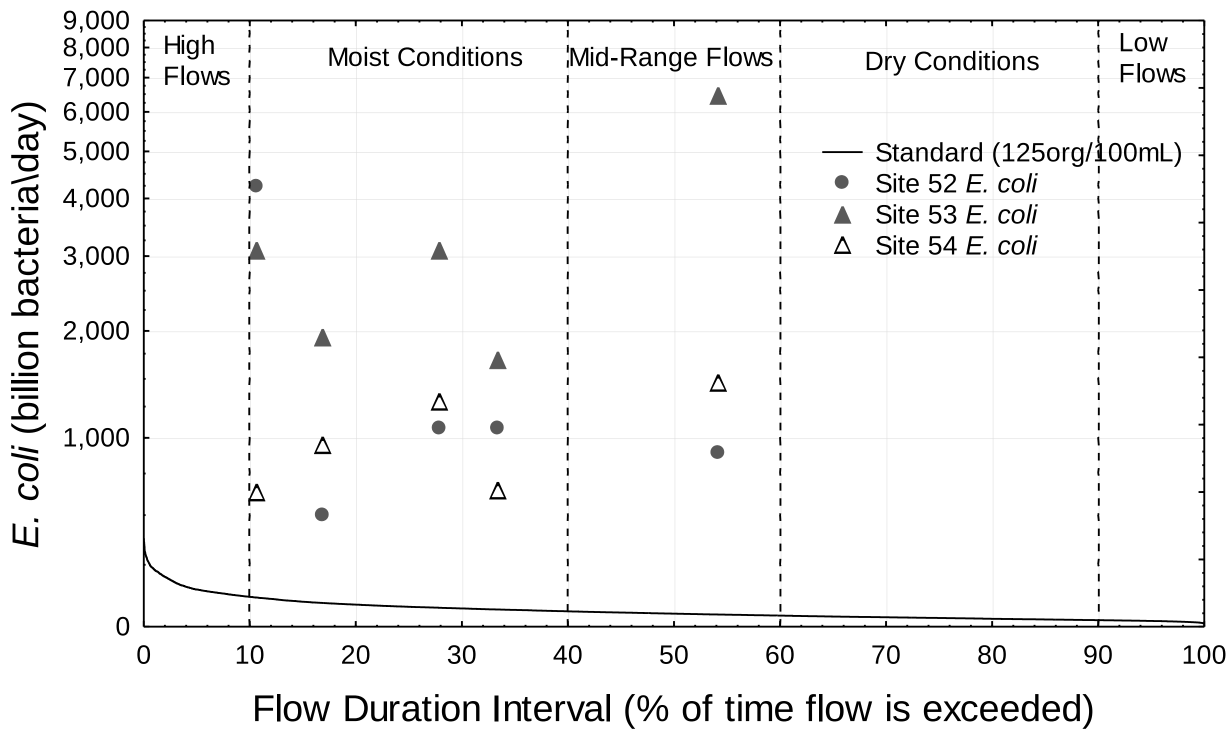

Figure 29. *E. coli* load duration curve for the Page Ditch watershed (HUC 040500011105)
IDEM 2010 data; downscaled USGS Gage duration interval; 20 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with the one relatively high exceedance under mid-range flows (Figure 29). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.15.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, failing septic systems, and the WWTP.

6.15.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 553. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). A 97% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 53 at 4,988 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFO #3686 is in this HUC 12.

Table 553. HUC 12: 040500011105 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	12	3	0	0
TMDL* = MOS + WLA + LA	143	74	48	32	21
MOS (10%)	14	7.4	4.8	3.2	2.1
WLA: total	1.2	1.2	1.2	1.2	1.2
Shipshewana Municipal STP, IN0040622	1.2	1.2	1.2	1.2	1.2
LA	128	65	42	28	18

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.15.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Page Ditch HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 564 with respect to the sources identified in the HUC 12 source summary (Section 6.15.1).

Table 564. Implementation approaches to addresses sources in Page Ditch HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): Hay/Pasture 34%, Cultivated Crops 33%, Woody Wetlands 13%, Deciduous Forest 5%, Developed Low Intensity 4%, Developed Open Space 4%, Herbaceous 2%, Open Water 2%, Developed Medium Intensity 1%, Developed High Intensity 1%	7.2.1
CFOs (#3686)	ID # 3686 allowed 580 finishers	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 100% of the Page Ditch HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 1446 septic systems with estimated 217 failing.	7.2.4
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5
WWTP	Shipshewana Municipal STP	7.1.1

6.16 HUC 12: 040500011106, VanNatta Ditch – Pigeon River

6.16.1 Source Assessment

A number of *E. coli* sources were identified in the VanNatta Ditch – Pigeon River HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, one CFO, pasture land use, and septic systems (Table 575). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Compliance information was not readily available for CFOs. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 575. Identified nonpoint sources in the VanNatta Ditch – Pigeon River HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 52%, Hay/Pasture 17%, Woody Wetlands 14%, Developed Open Space 5%, Developed Low Intensity 4%, Deciduous Forest 4%, Open Water 2%, Herbaceous 1%, Developed Medium Intensity 1%
CFO (#1031)	ID # 1031 allowed 1259 finishers
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 95% of the VanNatta Ditch – Pigeon River HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 1965 septic systems with estimated 295 failing.
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

No NPDES-permitted sources of *E. coli* were identified in the VanNatta Ditch-Pigeon River watershed.

6.16.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 30 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

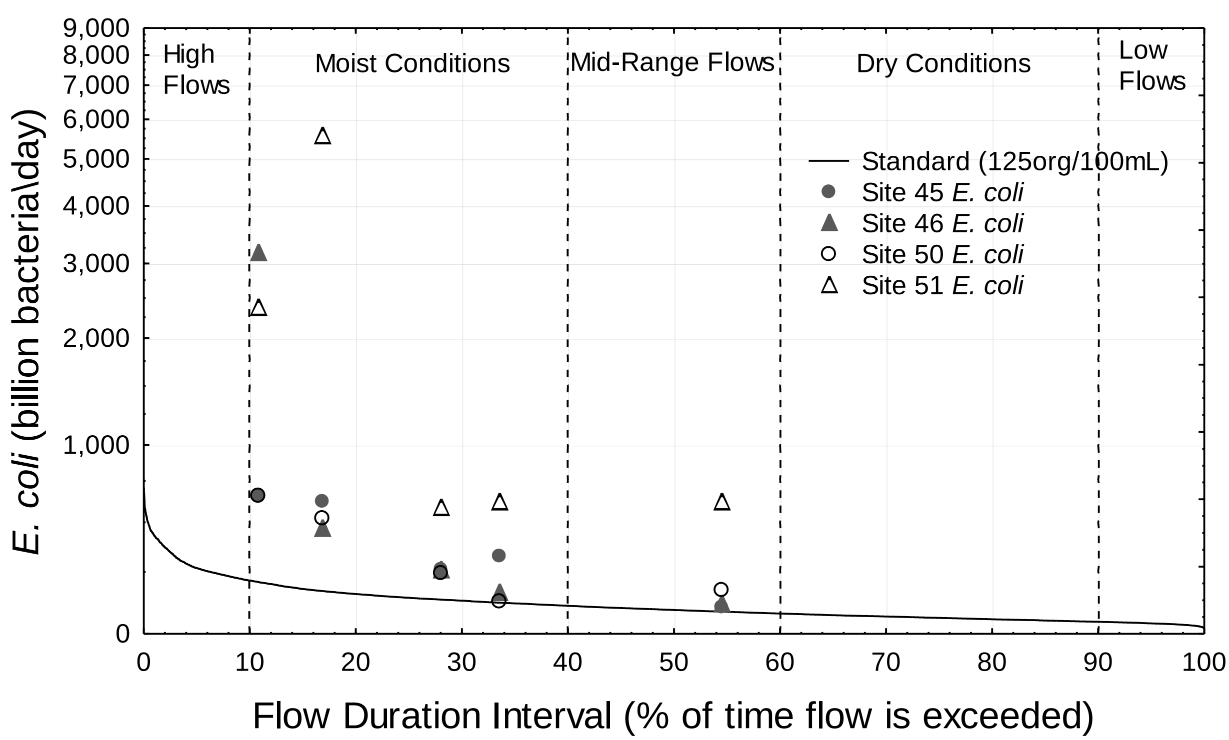

Figure 30. *E. coli* load duration curve for the VanNatta Ditch-Pigeon River watershed (HUC 040500011106)
IDEM 2010 data; downscaled USGS Gage duration interval; 32 square miles

Exceedances of the *E. coli* standards occur under flow regimes ranging from mid-range through moist conditions, with the one relatively high exceedance under moist conditions (Figure 30). High concentrations of *E. coli* under mid-range flows could be due to a combination of sources that lead to high concentrations under both high and low flows. Sources that were identified in the source assessment (6.16.1) that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles. *E. coli* sources that might lead to high concentrations under dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems.

6.16.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 586. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). An 89% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 51 at 1,156 cfu/100 mL.

CFOs receive a zero discharge permit from the state of Indiana. Therefore, CFOs receive a load allocation of zero for all pollutants. CFO #1031 is in this HUC 12. There are no NPDES-permitted point sources in this HUC 12 watershed.

Table 586. HUC 12: 040500011106 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	0	16	4	0	0
TMDL* = MOS + WLA + LA	268	138	90	59	38
MOS (10%)	27	14	9.0	5.9	3.8
WLA	0	0	0	0	0
LA	241	124	80	53	34

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.16.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the VanNatta Ditch – Pigeon River HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 597 with respect to the sources identified in the HUC 12 source summary (Section 6.16.1).

Table 597. Implementation approaches to addresses sources in VanNatta Ditch – Pigeon River HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 52%, Hay/Pasture 17%, Woody Wetlands 14%, Developed Open Space 5%, Developed Low Intensity 4%, Deciduous Forest 4%, Open Water 2%, Herbaceous 1%, Developed Medium Intensity 1%	7.2.1
CFO (#1031)	ID # 1031 allowed 1259 finishers	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 95% of the VanNatta Ditch – Pigeon River HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 1965 septic systems with estimated 295 failing.	7.2.4
Pets & Horses	Typical pet ownership rates; horse ownership likely higher than average (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5

Potential Priority Implementation Areas

- Agricultural practices related to the CFO, the land application of manure, and droppings from working horses.
- Developed areas in the Town of LaGrange, due to the use of horses for transportation and the build-up of horse waste on impervious surfaces.

6.17 HUC 12: 040500011107, Stag Lake – Pigeon River

6.17.1 Source Assessment

A number of *E. coli* sources were identified in the Stag Lake – Pigeon River HUC 12 watershed that do not require an NPDES permit. These unpermitted or state permitted sources are generally nonpoint sources. These sources include cultivated crop land use, pasture land use, and septic systems (Table 608). IDEM assumes that land application of manure occurs within five miles of any CFO facility. Additional nonpoint sources have been estimated for the entire Pigeon River Watershed; these include pets and horses, wildlife, field tiles, and illicit discharges.

Table 608. Identified nonpoint sources in the Stag Lake – Pigeon River HUC 12

Type	Source Summary
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 48%, Woody Wetlands 16%, Hay/Pasture 9%, Developed Low Intensity 6%, Deciduous Forest 6%, Developed Open Space 5%, Open Water 3%, Developed Medium Intensity 2%, Evergreen Forest 1%, Herbaceous 1%, Developed High Intensity 1%
CFO (#6555)	ID # 6555 allowed 805 dairy calves and 150 dairy heifers
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)
Land application of manure	Land application of manure expected within five miles of any CFO facility: 27% of the Stag Lake – Pigeon River HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.
Septic Systems	Estimated total 3775 septic systems with estimated 566 failing.
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)
Wildlife	Geese and deer (see Section 4.2.5)
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)
Illicit Discharges	No records available, but potential source (see Section 0)

Sources were not assessed in Michigan because no impairments are present downstream of Michigan sites. No NPDES-permitted point sources of *E. coli* were identified in the Indiana portion of the Stag Lake-Pigeon River watershed.

6.17.2 Data Assessment

Refer to Appendix A for figures illustrating individual *E. coli* sample concentrations and daily precipitation. Figure 31 is the load duration curve for *E. coli* monitoring sites in this HUC 12.

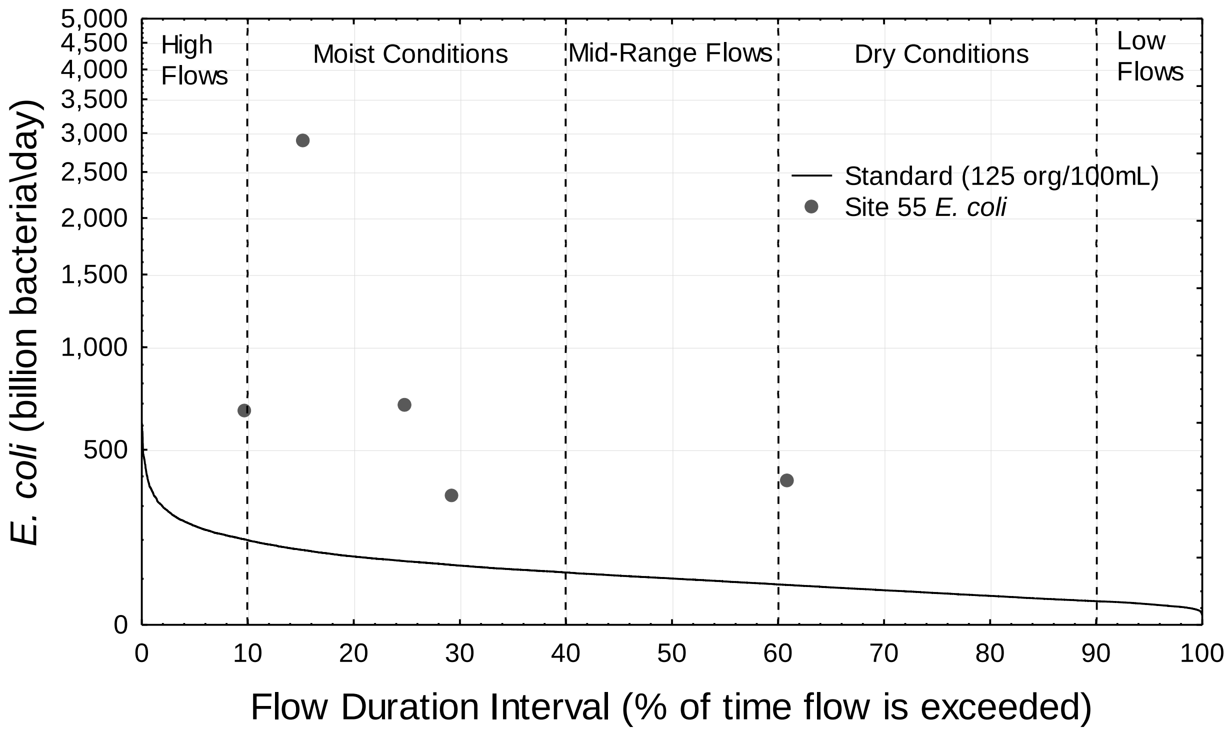

Figure 31. *E. coli* load duration curve for the Stag Lake watershed (HUC 040500011107)
IDEM 2010 data; downscaled USGS Gage duration interval; 36 square miles

Exceedances of the *E. coli* standards occur in flow regimes ranging from dry conditions through high flows, with one relatively high concentration observed under moist conditions (Figure 31). *E. coli* sources that were identified in the source assessment (6.17.1) that might lead to high concentrations during dry conditions are domesticated and/or wild animals with direct access to surface water, and failing septic systems. Sources that might lead to high *E. coli* concentrations during high flows are domesticated and/or wild animals in the watershed, land application of manure, and field tiles.

6.17.3 TMDL and Allocations

A summary of the *E. coli* TMDL at each of five flow intervals is provided in Table 619. Percent reductions to achieve the TMDL were estimated by comparing the highest violation measured in the 2010 monitoring season in the HUC 12 to the numeric standard (geometric mean of 125 cfu/100 mL). An 80% reduction in *E. coli* is needed based on the highest geometric mean, which occurred at Site 55 at 617 cfu/100 mL. There are no NPDES-permitted point sources in this HUC 12 watershed.

Table 619. HUC 12: 040500011107 *E. coli* TMDL summary
Units are billion org/d.

Allocation Category	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Duration Interval	0-10%	10-40%	40-60%	60-90%	90-100%
No. of Samples	1	3	0	1	0
TMDL* = MOS + WLA + LA	240	143	101	67	43
MOS (10%)	24	14	10	6.7	4.3
WLA	0	0	0	0	0
LA	216	129	91	60	39

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

6.17.4 Implementation Strategy

Various approaches to implementation are needed to address the variety of *E. coli* sources in the Stag Lake – Pigeon River HUC 12 watershed. Management practices (discussed in detail in Section 7) are referred to in Table 5980 with respect to the sources identified in the HUC 12 source summary (Section 6.17.1).

Table 80. Implementation approaches to addresses sources in Stag Lake – Pigeon River HUC 12 watershed

Type	Source Summary	Implementation Section
Land Cover/Use	Land Use (Percent of Area): Cultivated Crops 48%, Woody Wetlands 16%, Hay/Pasture 9%, Developed Low Intensity 6%, Deciduous Forest 6%, Developed Open Space 5%, Open Water 3%, Developed Medium Intensity 2%, Evergreen Forest 1%, Herbaceous 1%, Developed High Intensity 1%	7.2.1
CFO (#6555)	ID # 6555 allowed 805 dairy calves and 150 dairy heifers	7.2.1
Small animal feeding operations	Associated with agricultural land uses (see Section 4.2.1)	7.2.1
Land application of manure	Land application of manure expected within five miles of any CFO facility: 27% of the Stag Lake – Pigeon River HUC 12 watershed. Land application of manure is additionally possible if small animal operations are present.	7.2.1
Septic Systems	Estimated total 3775 septic systems with estimated 566 failing.	7.2.4
Pets & Horses	Typical pet and horse ownership rates (see Section 4.2.4)	7.2.5
Wildlife	Geese and deer (see Section 4.2.5)	7.2.6
Field Tiles	Drain tiling likely in areas with cultivated crops (see Section 4.2.1)	7.2.1
Illicit Discharges	No records available, but potential source (see Section 0)	7.1.5

7 MANAGEMENT PRACTICES

7.1 Permitted Point Sources

7.1.1 Wastewater Treatment Plants (WWTPs)

Limits on point source contribution of *E. coli*, ammonia nitrogen, and total phosphorus are included in the NPDES permits for WWTP effluent discharging to stream reaches impaired for the respective pollutants. In the future, the limits on these pollutants are not expected to become less stringent than the current permit requirements. The WWTPs are expected to comply with the permit limit through routine operation of the WWTP and facility upgrades, as necessary. Therefore, specific WWTP technologies for the reduction of *E. coli*, ammonia nitrogen, and total phosphorus are not described in this implementation plan.

Although some NPDES facilities have been found to be in violation of their permit limits for *E. coli,* ammonia-nitrogen, or total phosphorus, the majority of discharges from WWTPs meet effluent water quality standards.

7.1.2 Combined Sewer Overflows

A portion (estimated at 10%) of the sewer system in the City of Angola is combined; both stormwater and sanitary waste are conveyed in the same pipe to the waste water treatment plant. In times of heavy rain, the system becomes overloaded and overflows into Mud Creek and ultimately to Pigeon Creek. Since the mid 1990s Angola has spent approximately $12 million to reduce combined sewer overflows (CSOs) and has reduced the frequency and duration of the bypass of sewage to Mud Creek by 96%. While overflows have been significantly reduced at Angola, there were still three days of CSOs with a total of 163,000 gallons as recent as 2006. It is estimated that CSOs will occur four to five days per year. The Angola CSO is regulated under Permit # IN0021296.

The strategy for addressing CSOs for the City of Angola includes both structural improvements to the system and controlling the volume of stormwater entering the system. Addressing structural improvements to the system consists of building additional capacity within the sanitary system and separating storm sewers from the sanitary system. The system is currently designed for an average daily flow of 1.7 MGD, and building additional capacity in the system would lower the risk of CSOs. The remaining 10% of the city stormsewer could also be separated from the sanitary sewer. This would reduce the volume within the system and would essentially prevent the CSOs that occur during very high rainfalls.

As an alternative to structural improvements to the sanitary sewer system, the City of Angola could reduce the occurrence of CSOs by incorporating volume control practices throughout the drainage areas that contribute to the combined system. Volume control practices are discussed further in Section 7.1.4; these practices consist of disconnecting impervious surfaces from the stormsewer system and encouraging infiltration of rainfall into the ground.

7.1.3 Sanitary Sewer Overflows

SSOs are regulated as zero discharge WWTP outfalls; discharges are not authorized under the NPDES permit. In the future, zero discharge requirements are not expected to change from current permit requirements. In general, SSOs can be prevented by addressing the root causes for their occurrence, namely:

- Excessive infiltration of stormwater into sewer lines
- Vandalism
- Improper operation and maintenance
- Malfunction of lift stations
- Electrical power failures

7.1.4 Stormwater Phase II Communities

There is one Phase II MS4 community in the watershed. The City of Angola, along with Trine University, has an NPDES permit (permit #INR04005) under which it has the following minimum control measures (MCM) for managing stormwater:

MCM 1 - Public Education and Outreach

Distributing educational materials and performing outreach to inform citizens about the impacts that polluted stormwater runoff discharges can have on water quality.

MCM 2 - Public Participation/Involvement

Providing opportunities for citizens to participate in program development and implementation, including effectively publicizing public hearings and/or encouraging citizen representatives on a stormwater management panel.

MCM 3 - Illicit Discharge Detection and Elimination

Developing and implementing a plan to detect and eliminate illicit discharges to the storm sewer system (includes developing a system map and informing the community about hazards associated with illegal discharges and improper disposal of waste).

MCM 4 - Construction Site Runoff Control

Developing, implementing, and enforcing an erosion and sediment control program for construction activities that disturb one or more acres of land (controls could include silt fences and temporary stormwater detention ponds).

MCM 5 - Post-Construction Runoff Control

Developing, implementing, and enforcing a program to address discharges of post-construction stormwater runoff from new development and redevelopment areas. Applicable controls could include preventative actions such as protecting sensitive areas (e.g., wetlands) or the use of structural BMPs such as grassed swales or porous pavement.

MCM 6 - Pollution Prevention/Good Housekeeping

Developing and implementing a program with the goal of preventing or reducing pollutant runoff from municipal operations. The program must include municipal staff training on pollution prevention measures and techniques (e.g., regular street sweeping, reduction in the use of pesticides or street salt, or frequent catch-basin cleaning).

This section describes the pollution prevention activities that may be applicable to a regulated MS4 community. Table 621 identifies the pollution prevention activity by applicable MCM and the primary pollutants removed or prevented. The actual pollutants being addressed depend on the program developed.

Table 621. Pollution prevention activity by minimum control measure and stormwater pollutant addressed

Pollution Prevention Activity	Applicable MCM	Stormwater Pollutants Addressed		
		Runoff Volume	Nutrients	Bacteria
Erosion & Sediment Control Training	1,4,6		●	
Vehicle Washing	3,6		●	
Street & Parking Lot Sweeping	4,6		●	●
Park & Open Space Fertilizer/Chemical Application Programs	1,3,6		●	
Residential Waste Collection & Clean-up Programs	1,2,3,6		●	
Potential Discharge Identification & Risk Reduction	1,2,3,6		●	
Education to Reduce Pet Waste	1		●	●
Septic System Maintenance Programs	1,3		●	●
Open Space Design	5	●	●	
Reducing Impervious Surfaces	5,6	●	●	
Pervious Pavements	5,6	●	●	
Green Roofs	1,2,5,6	●	●	
Rainwater Harvesting/Stormwater Reuse & Rain Barrel Programs	1,2,5,6	●	●	
Urban Forestry & Stormwater Management	5,6	●	●	
Vegetated Swales & Buffer Strips	1,2,5,6	●	●	
Establishing a Buffer Ordinance	1,2	●	●	
Retrofitting: Infiltration, Filtration & Bioretention	1,2,5,6	●	●	
Establishing an Infiltration Standard	1,2,5	●	●	
Volume Control Using Compost Materials / Soil Amendments	1,5,6	●	●	

Erosion & Sediment Control Training

Erosion and sedimentation is the natural process in which soil and rock material is weathered and carried away by wind, water, or ice. Construction activities can increase erosion by removing vegetation, disturbing soil, and exposing sediment to the elements. Eroded soil quickly becomes a sedimentation problem when wind and rain carry the soil off the construction site and nutrient-laden sediment is deposited in surface waters.

Erosion and sediment control best management practices (BMPs) are necessary at all construction sites to keep soil onsite and prevent unnecessary water pollution. Training individuals responsible for installing, constructing, repairing, maintaining, and/or inspecting erosion and sediment control measures and post-construction stormwater management practices at construction sites will result in properly designed, installed, and maintained BMPs, improved compliance with permit regulations, and protection of water quality.

Vehicle Washing

Vehicle washing by MS4 communities involves the removal of dust and dirt from the exterior of trucks, boats, and other vehicles, as well as the cleaning of cargo areas, engines, and other mechanical parts. Washing of vehicles and equipment generates oil, grease, sediment, and metals in the wash water as well as degreasing solvents, cleaning solutions, and detergents used in the cleaning operations.

The impacts of these constituents discharging to downstream waterbodies include increased biochemical oxygen demand, increased temperature and acidity, and reduced oxygen levels. These environmental effects cause potentially fatal physiological disorders and reduced immune status in fish and other aquatic organisms.

The EPA considers wash water to be a non-stormwater discharge (i.e. illicit discharge); therefore, wash water from a facility must be directed to a sanitary sewer or treated on-site prior to discharge. MS4s often own and maintain their own fleet of vehicles that may include cars, tractors, trucks, parks equipment, and other types of vehicles.

Street & Parking Lot Sweeping

Pollutants collect on impervious surfaces in between storm events as a result of atmospheric deposition, vehicle emissions, winter road maintenance, construction site debris, trash, road wear and tear, and litter from adjacent lawn maintenance (grass clippings). Sweeping of materials such as sand, salt, leaves, and debris from city streets, parking lots, and sidewalks prevents them from being washed into storm sewers and surface waters. Timing, frequency, and critical area targeting greatly influence the effectiveness of sweeping.

Park & Open Space Fertilizer / Chemical Application Programs

Fertilizers, herbicides, and insecticides have various ecological effects, toxicity, and chemical fate and transport based on the product's chemical components. Depending on the chemical characteristics, they can have unintended harmful effects on terrestrial and aquatic plants and animals, and can end up in the soil, water, and air. Nitrates from fertilizers can migrate through the soil profile and contaminate groundwater supplies beyond safe drinking water levels. Phosphorus from fertilizers contributes to eutrophication of surface waterbodies that depletes oxygen levels and can lead to fish kills.

A management plan should be developed with the goal of reducing inputs of fertilizers, herbicides, and insecticides, with particular attention to areas where runoff is directed to surface waters.

Residential Waste Collection & Clean-up Programs

Illegal dumping of non-hazardous household waste and improper dumping of yard waste in streets, storm drains, wetlands, lakes, and other waterbodies pollutes surface waters. Non-hazardous household waste includes items such as tires, furniture, common household appliances, and other bulk items. Yard waste includes any organic debris such as grass clippings, leaves, and tree branches.

Although yard waste is composed of natural materials that will eventually decompose, the debris releases nutrients and uses up oxygen that is necessary for a healthy aquatic ecosystem. Non-hazardous household materials should be recycled or disposed of at a proper facility, and yard waste is best minimized and composted.

Potential Discharge Identification & Risk Reduction

Illicit discharges are those wastes and wastewaters from non-stormwater sources that cannot legally be discharged to an MS4 community's storm drains. Sources include the following:

- Sanitary wastewater connected to the storm drain system
- Residential laundry washwaters
- Effluent from septic tanks
- Industrial wastewaters
- Auto and household toxics such as used motor oil
- Liquid fertilizers and pesticides
- Pet waste
- Drained pool water
- Spills from roadways
- Paint waste
- Anything other than stormwater that is discharged to a storm drain is a potential illicit discharge

The result of illicit discharges entering the storm drain is that these untreated discharges reach receiving waters, contributing high levels of pollutants including heavy metals, toxics, oil and grease, solvents, nutrients, viruses, and bacteria.

Education to Reduce Pet Waste

Pet waste left uncollected is unsanitary and disagreeable for users. It contains pathogenic bacteria and other parasites. When pet waste is washed into surface waters it decays in the water, depleting oxygen levels and releasing nutrients, including ammonia, which can be harmful to fish and other aquatic organisms. Other nutrients in pet waste can foster plant and algae growth. The pathogenic micro-organisms in pet waste can cause unsafe conditions for swimming and recreational activities.

Septic System Maintenance Programs

Septic systems, also known as onsite wastewater treatment systems, treat sewage from homes and businesses that are not connected to a centralized wastewater treatment plant. Septic systems can vary in size and the number of dwellings served and include individual and cluster systems. Septic systems can be of conventional design (heavily relying on the soil for treatment along with dispersal) or use pre-soil treatment technologies like constructed wetlands, media filters, or aerobic treatment tanks followed by dispersal (with limited final treatment) in the soil. Soil treatment and dispersal options include in-ground trenches or beds or above ground at-grade or mound systems. The type of soil dispersal system is selected based on the treatment abilities of the native soil in combination with the effectiveness of any pre-soil treatment that may be employed. Septic systems can be protective of public health and water quality if properly planned, sited, designed, constructed, installed, operated, and maintained.

Open Space Design

Open space design is a form of residential development that concentrates development in a compact area of the site to allow for greater conservation of natural areas. This form of development may also be called cluster design, conservation design, or low impact development (LID). Typical management practices associated with open space design and LID include reducing impervious surfaces, pervious pavements, green roofs, rainwater harvesting, urban forestry, vegetated swales and buffers, and establishing an infiltration standard.

Reducing Impervious Surfaces

Impervious areas such as road and parking pavement, building surfaces, and walkways and driveways significantly increase stormwater runoff volumes, which in turn causes flooding and streambank erosion. Impervious surfaces also facilitate the wash-off and transport of pollutants like oil, grease, nutrients, and sediment into downstream waterbodies.

Pervious Pavements

When rainfall hits impervious pavements such as conventional concrete and asphalt, the water runs off of the hard surface, collects pollutants, and enters stormdrains and waterways. Pervious pavements allow water to pass through the surface and infiltrate into the soil below rather than running off impervious surfaces and into surface water.

Pervious pavements include pervious asphalt, pervious concrete, pervious interlocking concrete pavers, plastic grid systems, and amended soils. Pervious pavements have the dual benefit of serving as a parking or drive surface and a stormwater management BMP.

Green Roofs

Green roofs are becoming commonly accepted and installed across the country on buildings of all shapes and sizes. Green roofs are being used as a means to reduce costs associated with the life-cycle of conventional roofs, and associated with heating and cooling. They are being used to address stormwater management, and large green roofs are being used to create spaces for public benefit in urban settings.

Rainwater Harvesting/Stormwater Reuse & Rain Barrel Programs

High intensity land use patterns and increasing pressure on water resources require effective stormwater management solutions in tight spaces. Rainwater harvesting programs collect runoff from rooftops, parking lots, and other surfaces and reuse the water for purposes such as irrigation of gardens and municipal ballparks, washing patio furniture, and lawn watering. Additionally, harvested rainwater when approved could be used indoors for non-potable uses such as toilet and urinal flushing. Indoor use designs are typically subject to review per state plumbing code and would require pretreatment practices including filtration and disinfection. The effect is volume control, reduced flooding and erosion, and less demand for treated potable water.

Urban Forestry & Stormwater Management

High intensity land use patterns and increasing pressure on water resources demand creative stormwater management. Trees dissipate the energy of falling raindrops to help prevent erosion and buffer intense rainfalls. Urban tree roots have the potential to penetrate compacted soils and increase infiltration rates in open space, stormwater basins, and subsurface stormwater storage (structured soil). Uptake of water from trees limits the volume of runoff discharged downstream, and tree canopies offer interception of rainfall and shading (cooling) in an urban environment. Trees also absorb nutrients that could otherwise run off to local receiving waters.

Vegetated Swales & Buffer Strips

Stormwater runoff from residential, commercial, industrial, and agricultural land uses contains pollutants that can contaminate waterbodies. Stormwater runoff from impervious surfaces also can increase runoff velocities and contribute to streambank erosion. Swales and buffer strips are a type of stormwater treatment composed of vegetation and a porous subsoil medium. Buffer strips are vegetated areas adjacent to a waterway that prohibit stormwater runoff from flowing directly into a waterbody.

The vegetation filters pollutants carried by stormwater, decreases the rate of flow and volume of runoff, and stabilizes the soil on the shoreline or bank, lessening erosion caused by runoff. A swale is a long, vegetated depression often used as a water conveyance system which is also designed to infiltrate water and remove sediment and pollutants from runoff. A swale, therefore, assists in recharging groundwater and managing stormwater runoff quantity and quality.

Establishing a Buffer Ordinance

Conservation buffers are small areas or strips of land in permanent vegetation, designed to intercept pollutants and manage other environmental concerns. Examples of buffers include riparian/wetland buffers, filter strips, grassed waterways, and vegetative barriers. An ordinance that requires buffers around water resources can lead to the removal of additional pollutants and can protect downstream resources, as well as provide aquatic and terrestrial habitat.

Retrofitting: Infiltration, Filtration & Bioretention

Retrofitting can be used to achieve highly effective stormwater management that reduces runoff volume, increases groundwater recharge, improves surface water quality, provides thermal benefits, and helps mimic predevelopment hydrology. Retrofits such as rain gardens and swales are versatile because they can be constructed in small areas and easily integrated into existing residential and commercial sites.

Establishing an Infiltration Standard

Infiltration is a highly effective stormwater practice that reduces runoff volume, increases groundwater recharge, improves surface water quality, provides thermal benefits, and helps mimic predevelopment hydrology. While other practices may address stormwater quality and rate control, limiting increased volumes of runoff from development and redevelopment is the most effective way to reduce the cumulative impacts on downstream water resources.

Volume Control Using Compost Materials / Soil Amendments

Land development including landscaping practices damages soil structure and function by removing or compacting topsoil. These land development practices can impact water resources by decreasing infiltration, increasing erosion, impairing fish habitat, and increasing the need for permanent stormwater management. These practices also create chemically dependent landscapes that are difficult and expensive to maintain and contribute to polluted runoff. Soil compaction also reduces the water retention capacity of soil which requires additional irrigation and increased public water supply demand.

Soil improvement techniques have been developed where compost material and other soil amendments are added to native soils to enhance their ability to infiltrate water.

7.1.5 Illicitly Connected Straight Pipe Systems

Currently there are no known illicitly connected straight pipes in the watershed. State and local officials should be trained to identify straight pipes and be encouraged to look for them while they are in the field. If straight pipes are found within the watershed they must be removed as they are illegal. Removal entails determining the source of the straight pipe and installation/re-plumbing of the waste to an appropriate system.

7.2 Nonpoint Sources

7.2.1 Agriculture

Because agriculture encompasses a large portion of the watershed, agricultural management practices are important for improving water quality. The Natural Resource Conservation Service (NRCS) provides assistance to producers to implement these and many other management practices on the ground, and their website contains a wealth of additional information. Table 63 represents a summary of the agricultural conservation practices that will provide the greatest improvements in the impaired waterbodies of the Pigeon River Watershed.

Table 632. Agricultural management practices summary

Management Practice	NRCS #	Sources Addressed							Pollutant Addressed		
		Cropland	Concentrated feeding operations	Small animal feeding operations	Pastured animals	Land application of manure	Field tiles	Erosion	*E. coli*	Nitrogen	Phosphorus
Riparian forested buffer	391	x								x	x
Field border	386	x						x		x	x
Conservation crop rotation	328	x						x		x	x
Alternative tile inlets	NA	x					x	x			x
Grade stabilization structure	410						x	x			x
Wood chip bioreactor	NA	x					x			x	
Tile system design	NA	x					x			x	x
Controlled subsurface drainage	554	x					x			x	x
Contour buffer strips	332	x						x		x	x
Contour farming	330	x						x		x	x
Terrace	600	x						x		x	x
Contour stripcropping	585	x						x		x	x
Conservation cover	327	x						x		x	x
Cover crop	340	x						x		x	x
Critical area planting	342	x						x		x	x
Two-stage ditch	582							x			x
Roof runoff management	558		x	x					x	x	x
Waste facility cover	367		x	x		x			x	x	x
Heavy use protection	561		x	x					x	x	x
Manure and agricultural waste storage	313		x	x		x			x	x	x
Vegetated treatment area	635		x	x		x			x	x	x
Clean runoff water diversion	362		x	x		x			x	x	x
Filter strips	393	x						x		x	x
Grassed waterway	412	x						x			x
Irrigation water management	449	x								x	x
Livestock exclusion - access control	472				x			x	x	x	x
Livestock exclusion - fencing	382				x			x	x	x	x
Rotational grazing	528				x			x	x	x	x
Stream crossing	578				x			x	x	x	x
Nutrient management - timing	590	x				x				x	x
Nutrient management - amount	590	x				x				x	x
Nutrient management - method	590	x				x				x	x
Mulch till	345	x						x		x	x

Management Practice	NRCS #	Sources Addressed							Pollutant Addressed		
		Cropland	Concentrated feeding operations	Small animal feeding operations	Pastured animals	Land application of manure	Field tiles	Erosion	*E. coli*	Nitrogen	Phosphorus
No till / minimum till /strip till	329	x						x		x	x
Seasonal till	344	x						x		x	x
Sediment basin	350	x						x		x	x
Water/sediment control basin	638	x						x			x
Stripcropping	585	x						x		x	x
Wetland, constructed	656	x								x	x
Wetland, creation	658	x								x	x
Wetland, enhancement	659	x								x	x
Wetland, restoration	657	x								x	x
Field windbreak	380	x						x			x
Herbaceous wind barriers	603	x						x			x
Cross wind trap strips	589C	x						x			x
Cross wind ridges	588	x						x			x
Cross wind strip cropping	589B	x						x			x

<u>Agricultural BMP Definitions</u>

- Riparian forested buffer - Trees, shrubs, and other vegetation located in areas adjacent to and upgradient from water bodies.
- Field border - A strip of permanent vegetation established at the edge of a field.
- Conservation crop rotation - Growing crops in a planned sequence on the same field.
- Alternative tile inlets - Using perforated risers, gravel/rock inlets, dense pattern tile, or other alternative techniques rather than flush open inlets.
- Grade stabilization structure - A structure used to control the grade and head cutting in natural or artificial channels.
- Wood chip bioreactor - Trench filled with wood chips placed inline of tile drainage system; microbes use wood chips as a carbon source and reduce nitrate.
- Tile system design - Recognizing tradeoff between cost of tile, yield, and environmental goals by managing tile depth, spacing, and drainage intensity.
- Controlled subsurface drainage - The process of managing water discharges from surface and/or subsurface agricultural drainage systems.
- Contour buffer strips - Narrow strips of permanent, herbaceous vegetative cover established around the hill slope, and alternated down the slope with wider cropped strips that are farmed on the contour.

- Contour farming - Using ridges and furrows formed by tillage, planting, and other farming operations to change the direction of runoff from directly downslope to around the hillslope.
- Terrace - An earth embankment, or a combination ridge and channel, constructed across the field slope.
- Contour stripcropping - Crop rotation and contouring combined with equal-width strips of crops planted on the contour and alternated with strips (buffers) of oats, grass, or legumes.
- Conservation cover - Establishing and maintaining permanent vegetative cover.
- Cover crop - Crops including grasses, legumes, and forbs for seasonal cover and other conservation purposes.
- Critical area planting - Establishing permanent vegetation on sites that have or are expected to have high erosion rates, and on sites that have physical, chemical, or biological conditions that prevent the establishment of vegetation with normal practices.
- Two-stage ditch - Constructing or improving a channel, either natural or artificial, in which water flows with a free surface.
- Roof runoff management - Structures that collect, control, and transport precipitation from roofs.
- Waste facility cover - A fabricated rigid, semi-rigid, or flexible membrane over a waste treatment, storage facility, or feedlot.
- Heavy use protection - The stabilization of areas frequently and intensively used by people, animals, or vehicles by establishing vegetative cover, by surfacing with suitable materials, and/or by installing needed structures.
- Manure and agricultural waste storage - A waste storage impoundment made by constructing an embankment and/or excavating a pit or dugout, or by fabricating a structure.
- Vegetated treatment area - A treatment component of an agricultural waste management system consisting of a strip or area of herbaceous vegetation.
- Clean runoff water diversion - A channel generally constructed across the slope with a supporting ridge on the lower side.
- Filter strips - A strip or area of herbaceous vegetation that removes contaminants from overland flow before they reach water bodies.
- Grassed waterway - A shaped or graded channel that is established with suitable vegetation to carry surface water at a non-erosive velocity to a stable outlet.
- Irrigation water management - Irrigation water management is the process of determining and controlling the volume, frequency, and application rate of irrigation water in a planned, efficient manner.
- Livestock exclusion, access control - The temporary or permanent exclusion of animals, people, vehicles, and/or equipment from an area.
- Livestock exclusion, fencing - A constructed barrier to animals or people.
- Rotational grazing - Livestock are regularly rotated to fresh paddocks at the right time to prevent overgrazing and optimize grass growth.
- Stream crossing - A stabilized area or structure constructed across a stream to provide a travel way for people, livestock, equipment, or vehicles.

- Nutrient management, timing - Managing the timing of the applications of plant nutrients and soil amendments.
- Nutrient management, amount - Managing the amount of the applications of plant nutrients and soil amendments.
- Nutrient management, method - Managing the method of the applications of plant nutrients and soil amendments.
- Mulch till - Managing the amount, orientation, and distribution of crop and other plant residues on the soil surface year round, while limiting soil disturbing activities used to grow crops in systems where the entire field surface is tilled prior to planting.
- No till / minimum till /strip till - Managing the amount, orientation, and distribution of crop and other plant residues on the soil surface year round, while limiting soil disturbing activities to only those necessary to place nutrients, conditions residue, and plant crops.
- Seasonal till - Managing the amount, orientation, and distribution of crop and other plant residues on the soil surface during a specified period of the year, while planting annual crops on a clean-tilled seed bed, or when growing biennial or perennial seed crops.
- Sediment basin - A basin constructed with an engineered outlet, formed by an embankment or excavation or a combination of the two.
- Water/sediment control basin - An earth embankment or a combination ridge and channel generally constructed across the slope and minor watercourses to form a sediment trap and water detention basin.
- Stripcropping - Growing planned rotations of row crops, forages, small grains, or fallow in a systematic arrangement of equal width strips across a field.
- Wetland, constructed - An artificial ecosystem with hydrophytic vegetation for water treatment.
- Wetland, creation - A wetland that has been created on a site location that historically was not a wetland or is a wetland but the site will be converted to a wetland with a different hydrology, vegetation type, or function than naturally occurred on the site.
- Wetland, enhancement - The modification or rehabilitation of an existing or degraded wetland, where specific functions and/or values are modified for the purpose of meeting specific project objectives. Some functions may remain unchanged while others may be degraded.
- Wetland, restoration - The rehabilitation of a degraded wetland or the reestablishment of a wetland so that soils, hydrology, vegetative community, and habitat are a close approximation of the original natural condition that existed prior to modification to the extent practicable.
- Field windbreak - Windbreaks or shelterbelts are single or multiple rows of trees or shrubs in linear configurations.
- Herbaceous wind barriers - Herbaceous vegetation established in rows or narrow strips in the field across the prevailing wind direction.
- Cross wind trap strips - Herbaceous cover resistant to wind erosion, established in one or more strips across the prevailing wind erosion direction.
- Cross wind ridges - Ridges formed by tillage, planting, or other operations and aligned across the direction of erosive winds.

- Cross wind strip cropping - Growing crops in strips established across the prevailing wind erosion direction, and arranged so that strips susceptible to wind erosion are alternated with strips having a protective cover that is resistant to wind erosion.

7.2.2 Runoff from other land uses

Runoff from other land uses refers to developed areas with residential and commercial land uses, which can be in communities that are not regulated through the NPDES phase II stormwater permit. The strategies for addressing runoff from other land uses are similar to those described in Section 7.1.4 for lands in stormwater phase II communities.

7.2.3 Stream degradation

The following discussion is modified from *From Ditching to Stream Restoration*, River Institute Organization.

Many streams and rivers have been directly degraded by channelization and floodplain filling. Furthermore, due to the effects of agriculture and urbanization, many stream channels are becoming incised and are having detrimental effects on infrastructure and ecosystems as they attempt to seek equilibrium. The cumulative watershed effects can be considered in terms of increased flow rates, increased channel instability, and increased loading of pollutants to streams; all contribute to degradation of the water quality of streams.

While restoring the hydrologic function of an altered watershed is frequently complex and often not currently feasible, incremental change must begin to address the true cause of degradation. There are many techniques available for addressing modified channels, including two-stage channel designs, bank stabilization, and channel rehabilitation.

Two-stage channel concepts focus on creating a stable “bench” for ditch systems, which mimics a floodplain. Bank stabilization is a “fix” to erosion problems and focuses on preventing further erosion. While historically being limited to rip-rap, there are now many options for bank stabilization including many bio-engineered solutions.

While bank stabilization normally addresses a very limited portion of any one stream, channel rehabilitation tends to address a larger area and in a more comprehensive manner. Channel rehabilitation starts to address the stream corridor in addition to the stream channel and addresses the relationship between stream channel, floodplain, and vegetation.

7.2.4 Onsite Wastewater Treatment Systems

EPA’s *Handbook for Managing Onsite and Clustered (Decentralized) Wastewater Treatment Systems* describes a step-by-step approach to developing a community management program for decentralized wastewater systems. The handbook is intended to improve the performance of individual and clustered treatment systems through better planning, design, siting, installation, operation, maintenance, and other activities. It includes specific community examples, gives an overview of the elements essential for management of these systems, and provides links to multiple resources (articles, publications, web sites, databases, software, and government programs) for more thorough investigation of particular topics or elements of management. The handbook also includes the steps for developing or enhancing a decentralized wastewater management program.

EPA's *Voluntary National Guidelines for Management of Onsite/Decentralized Wastewater Systems (Guidelines)* are a set of practices recommended to raise the level of performance of onsite/decentralized wastewater systems through improved management programs. Five separate model programs are presented as a progressive series. Management requirements of wastewater systems become more rigorous as the system technologies become more complex or as the sensitivity of the environment increases. Each model program shares the common goal of protecting human health and the environment. Each model approach includes program elements and activities needed to achieve the management objectives. The guidelines address the sensitivity of the environment in the community and the complexity of the system used. The management models are summarized below.

Management Model 1: Homeowner Awareness

Individual property owners in areas of low environmental sensitivity must be aware of their treatment systems and understand proper maintenance schedules. This program is adequate where treatment technologies are limited to conventional systems that require little owner attention. To help ensure that timely maintenance is performed the regulatory authority mails maintenance reminders to owners at appropriate intervals. This model is a starting point for enhancing management programs because it provides communities with a good database of systems and their application for determining whether increased management practices are necessary.

Management Model 2: Maintenance Contracts

This model focuses on the need for maintenance contracts for systems with complex designs and systems employed to enhance the capacity of conventional systems to accept and treat wastewater. Contracts with qualified technicians can be used to ensure proper and timely maintenance of all types of systems, but most commonly are used for large complex systems.

Management Model 3: Operating Permits

Sustained performance of treatment systems is critical to protect public health and water quality. Limited-term operating permits are issued to the owner and are renewable for another term if the owner demonstrates that the system is in compliance with the terms and conditions of the permit. Performance-based designs may be incorporated into programs with management controls at this level.

Management Model 4: Responsible Management Entity (RME) Operations and Maintenance

Under this model, the operating permit is issued to an RME instead of the property owner to provide the needed assurance that the appropriate maintenance is performed. The property owner is responsible for system operations.

Management Model 5: RME Ownership

In contrast to model 4, under this model treatment systems are not only operated and maintained by the RME, but also owned by the RME, which removes the property owner from responsibility for the system. This program is comparable to central sewerage and provides the greatest assurance of system performance in the most sensitive of environments.

7.2.5 Pets and Horses

Programs designed to combat poor management of pet waste fall into three broad categories: awareness campaigns, pet waste control ordinances, and park design features. Municipalities often create programs that overlap these categories for optimal results.

Awareness Campaigns (Pet Owner-Based)

Programs are designed to overcome educational barriers. Owners are educated about the health risks and natural resource impacts associated with not cleaning up their animal's waste and are informed of their responsibility for finding suitable methods to pick up after their pet.

Brochures/fact sheets
Informational sheets are mass-mailed to educate residents of the health risks, natural resource impacts, and applicable ordinances and fines. The brochure should also outline the proper handling and disposal of pet waste. Brochures could be provided at public kiosks or city offices, attached to park signage (see below), as well as displayed at pet supply outlets and veterinarian offices.

Park signage
Park signage is located at park entrances to alert residents of the proper disposal techniques and/or park design features for pet droppings.

Pet Waste Control Ordinances (Management-Based)

A municipality may introduce a law that requires pet owners to pick up after their pets or risk receiving a fine.

Park Design Features (Management-Based)

Collection systems
The simplest additions to a dog-friendly park are pet waste collection systems, which hold plastic bags for owners to use to pick up waste, and which have garbage cans placed in close proximity to bag dispensers and park exits. Bag dispensers should also include educational signage.

Doggy loos
Pet feces disposal units are placed in the ground, which operate by foot-activated lids. Decomposition is quick, and messy cleanup is avoided.

Pooch patch
Upon entrance into the park, the dog is introduced to a telegraph pole, surrounded by a scattering of sand. Dogs are encouraged to defecate on the patch, and bins are close by for owners to dispose of their dog's waste.

Long-grass principle
Parks can have areas where grass is not mowed and where pet owners can take their dogs to defecate. A height of approximately four inches is necessary for the feces to decompose naturally without being washed off during a storm event. Long grass areas, however, should not be placed in close proximity to overland flow paths, stream channels, lakes, drinking water wells, and stormwater drainage inlets.

In portions of the watershed where horses are used extensively for transportation and for tasks associated with farming (plowing, seeding, harvesting, etc.), management practices are needed to minimize the extent that horse waste enters surface waters. Horse waste from animals working in fields can primarily be addressed by the manure management practices described in Section 7.2.1. Horse waste that is deposited directly on impervious surfaces by horses used for transportation should be minimized through the use of droppings collection devices (bags/containers fitted onto horse buggies). Horse waste that accumulates on impervious surfaces should be eliminated by frequent street sweeping.

7.2.6 Wildlife

While wildlife waste is a source of *E. coli* to waterbodies, it appears to be a minor source in this watershed relative to the other sources. Management of wildlife to reduce the delivery of feces to waterbodies is not a priority in the Pigeon River watershed.

7.2.7 Soil Erosion

The source assessment showed that soil erosion was highest in agricultural areas with steep slopes and lowest in forest or wetland areas. Table 63 in Section 7.2.1 contains a list of BMPs that can be used to address soil erosion in agricultural areas.

8 MONITORING PLAN TO TRACK THE EFFECTIVENESS OF IMPLEMENTATION EFFORTS

Future *E. coli*, TN, and TP, fish community index of biotic integrity (IBI) monitoring of the Pigeon River Watershed will take place during IDEM's five-year rotating basin schedule and/or once TMDL implementation methods are in place. Monitoring will be adjusted as needed to assist in continued source identification and elimination. IDEM will monitor at an appropriate frequency to determine whether Indiana's TMDL numeric targets (Table) are being met. When results indicate that the waterbody is meeting the numeric target, the waterbody will be removed from the 303(d) list.

9 REASONABLE ASSURANCE

Reasonable assurance provide a level of confidence that the TMDL allocations will be implemented by federal, state, or local authorities. Implementation of the Pigeon River TMDL will be accomplished by both state and local action on many fronts, both non-regulatory and regulatory. Multiple entities in the watershed already work towards improving water quality. Water quality restoration efforts will be undertaken by IDEM, other government entities, and local groups. Phosphorus reductions from point sources will be made through permit compliance.

9.1 Non-Regulatory

The management practices described in this TMDL (Section 7) have demonstrated to be effective in reducing *E. coli* and nutrient loadings. Participation of landowners will be essential to reducing nonpoint sources of pollution and improving water quality. Educational efforts and cost share programs can increase participation to levels needed to protect water quality. Monitoring will continue and adaptive management will be in place to evaluate progress made towards achieving the beneficial use of each waterbody.

9.2 Regulatory

9.2.1 National Pollutant Discharge Elimination System (NPDES) Permitted Dischargers

Permitted dischargers are required to comply with their discharge limits, which include *E. coli* and nutrient limits. There is one location Mud Creek which also has a violation of Chloride standards. The current NPDES permit has Chloride limits and has received a variance. The following language has been included in the current NPDES permit:

Beginning on the effective date of the permit modification incorporating the chloride variance, the permittee shall comply with the monthly average and daily maximum interim limitations for Chloride in Part I.A.3., Table 4, and the Source Identification requirements in Part I.G.1 of the Chloride PMPP.

Within six (6) months of the effective date of the permit modification incorporating the chloride variance, the permittee shall comply with the Public Awareness Program requirements in Part I.G.2 and the Water Treatment Plants Process Optimization requirements in Part I.G.3 of the Chloride PMPP.

Within twelve (12) months (but no earlier than eleven (11) months) of the effective date of permit modification incorporating the chloride variance, the permittee shall submit the Chloride Variance Annual Report described in Part I.G.5 of the Chloride PMPP.

Within twenty-one (21) months from the effective date of the permit modification incorporating the chloride variance, the permittee shall comply with the Non – Residential Users Program requirements in Part I.G.4 of the Chloride PMPP.

Within twenty-four (24) months of the effective date of the permit modification incorporating the chloride variance, the permittee shall comply with the monthly average and daily maximum variance limitations for chloride in Part I.A.3., Table 4.

If the permittee fails to comply with any deadline contained in the foregoing schedule, the permittee shall, within fourteen (14) days following the missed deadline, submit a written notice of noncompliance to the Compliance Data Section of the Office of Water Quality stating the cause of noncompliance, any remedial action taken or planned, and the probability of meeting the date fixed for compliance with Chloride PMPP requirements and/or chloride variance limitations.

The facility must also have a Chloride Pollutant Minimization Program Plan (PMPP) which shall include; Source Identification, Public Awareness Program, Water Treatment Plants Process Optimization, Chloride Variance Annual Report.

9.2.2 Stormwater General Permit

Stormwater runoff associated with municipal separate storm sewer (MS4) conveyances are regulated by 327 IAC 15-13-1 (Rule 13) in the State of Indiana. There is one regulated MS4 community in the Pigeon River Watershed: the City of Angola (INR040005). Implementation of the permit will improve water quality in the Pigeon River Watershed.

9.2.3 Combined Sewer Overflows

The CSOs in Angola are regulated under a Long Term Control Plan. This plan has a list of conditions and milestones which must be met. The milestones for this LTCP are as follows: separation of two stormwater intakes by 2009, separation of an additional 20 intakes by 2011 and additional monitoring. Removal of CSO outfall starting in 2012 and revision to permit as needed. Also any stormflow that is above treatment capacity at the WWTP will be held in the available tanks at the WWTP.

9.2.4 Confined Feeding Operations

CFOs are permitted by the State of Indiana. Facilities are required to manage their manure, litter, and process wastewater so that they do not cause or contribute to a water quality impairment.

10 PUBLIC PARTICIPATION

Two stakeholder meetings were held during development of the TMDL. The purpose of the meeting was to inform residents and local government representatives of the TMDL process and to gain input on specific issues within the watershed. Attendees at the meetings were also asked to share any information they had in relation to the resources within the watershed. Both meetings were held on April 6, 2011. One meeting was held in LaGrange County in the City of LaGrange, and the second meeting was held in Steuben County in the City of Angola.

Two stakeholder meetings were held for the draft TMDL. The purpose of the meeting was to inform residents and local government representatives of the draft TMDL and its results. Attendees at the meetings were also asked to review and comment on the draft TMDL. Both meetings were held on May 23, 2012. One meeting was held in LaGrange County in the City of LaGrange, and the second meeting was held in Steuben County in the City of Angola.

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APPENDIX A: 2010 *E. COLI* MONITORING DATA AND DAILY PRECIPITATION, BY SITE

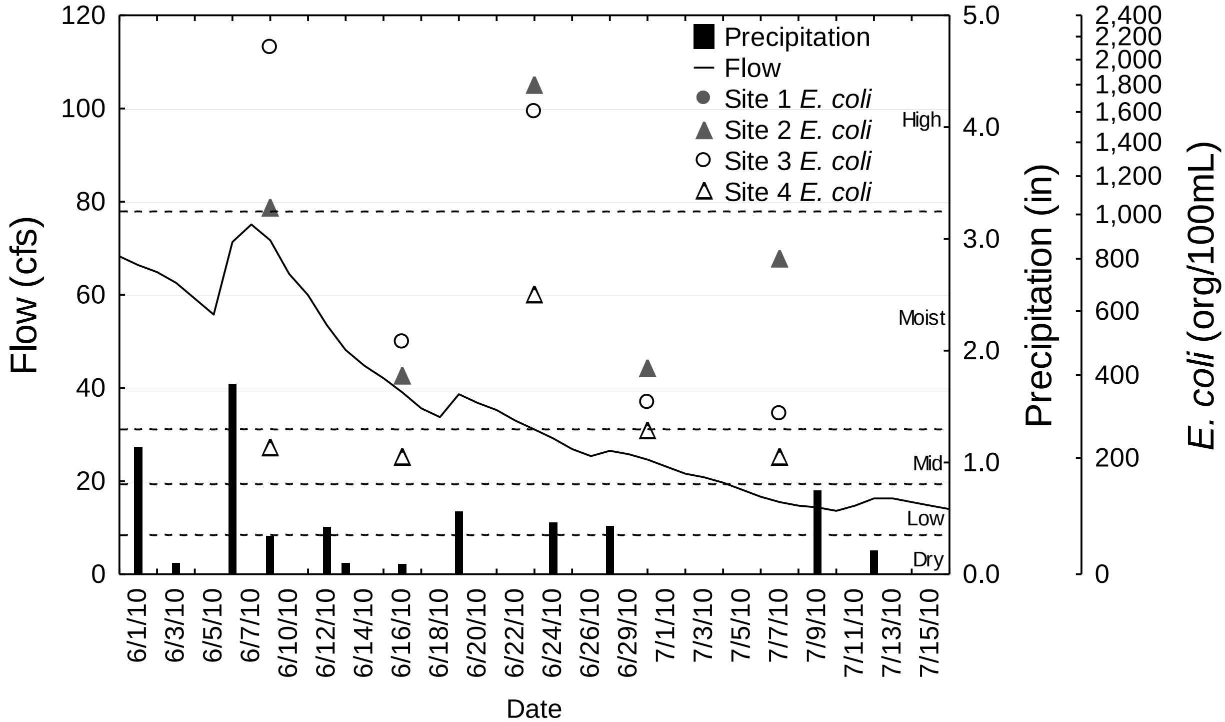

Figure 1. Daily precipitation, daily flow and *E. coli* concentrations in the Pigeon Lake – Pigeon Creek watershed (HUC 040500011001).

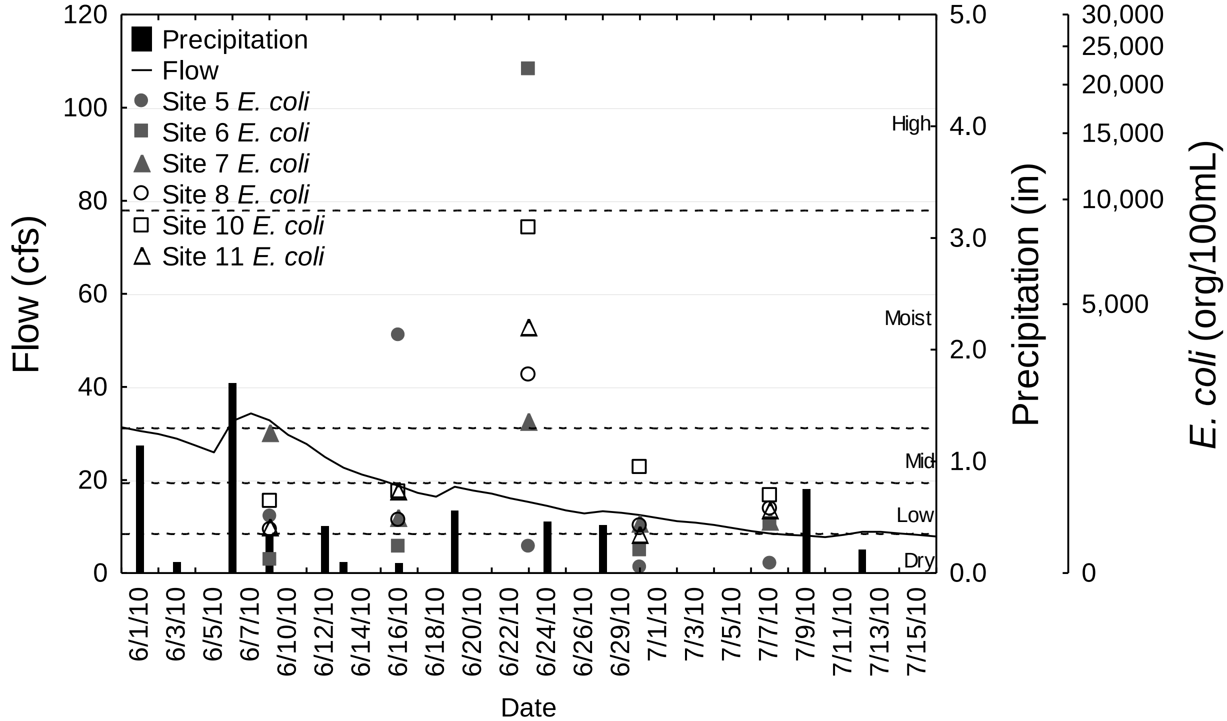

Figure 2. Daily precipitation, daily flow and *E. coli* concentrations in the Mud Creek – Pigeon Creek watershed (HUC 040500011002).

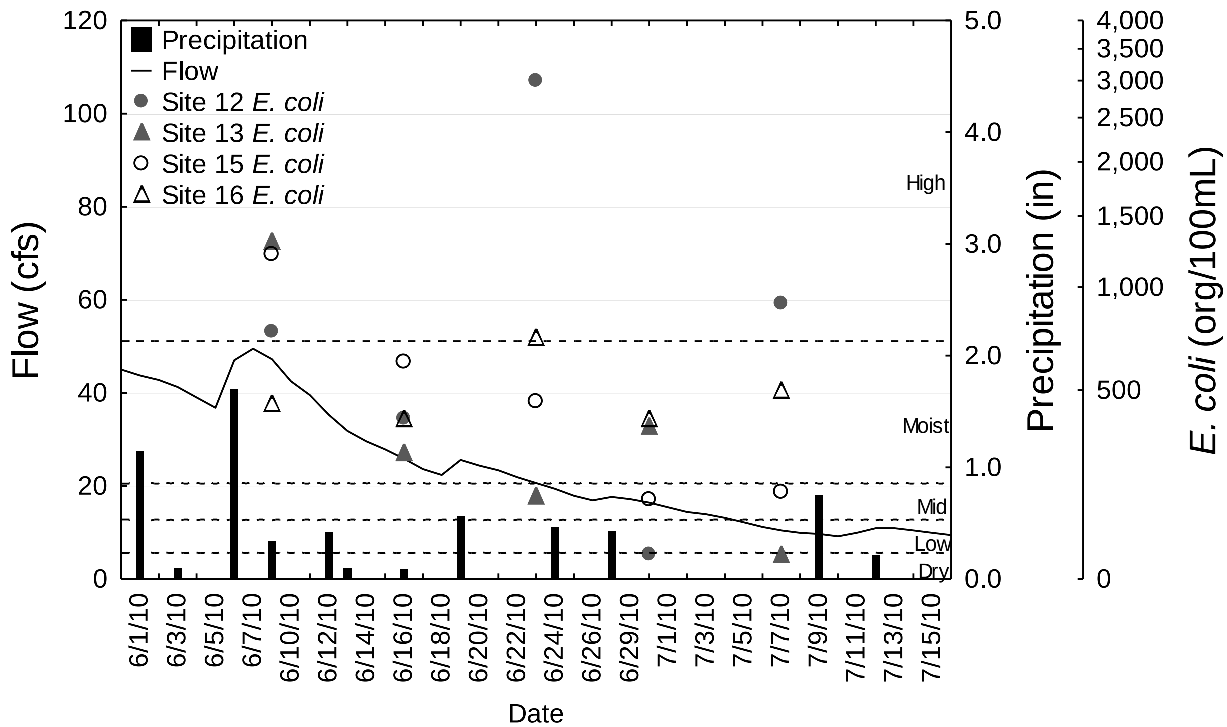

Figure 3. Daily precipitation, daily flow and *E. coli* concentrations in the Long Lake – Pigeon Creek watershed (HUC 040500011003).

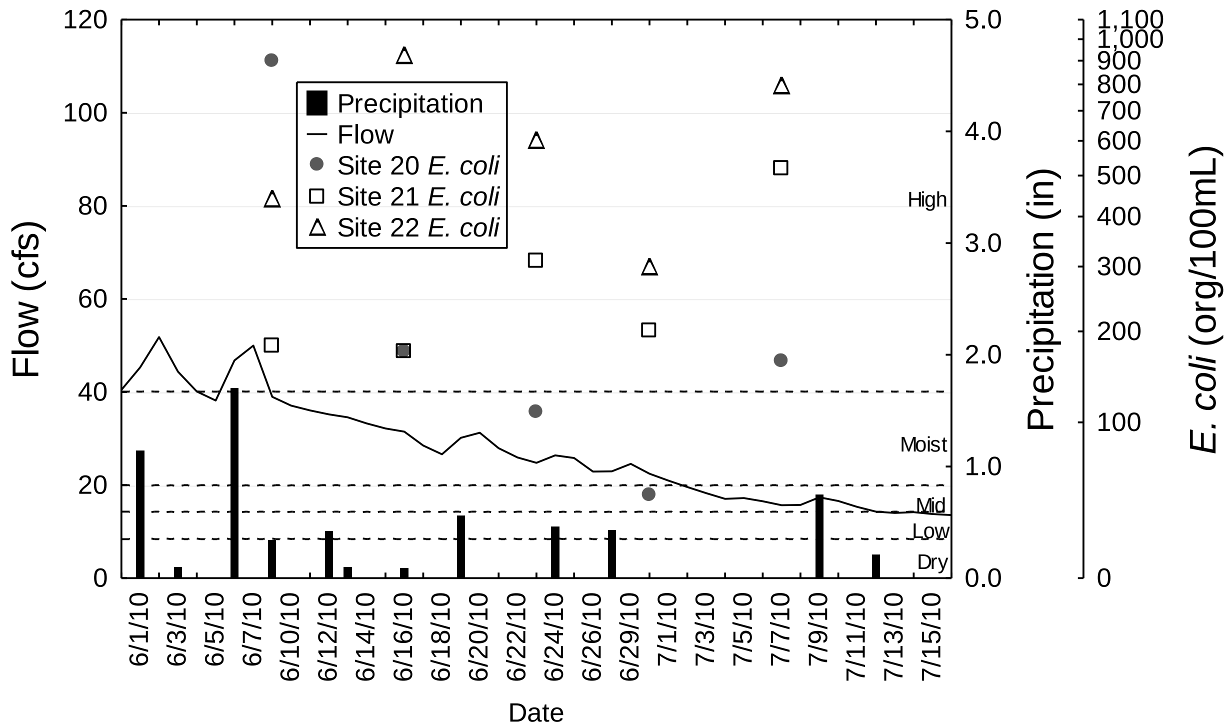

Figure 4. Daily precipitation, daily flow and *E. coli* concentrations in the Headwaters Turkey Creek watershed (HUC 040500011004).

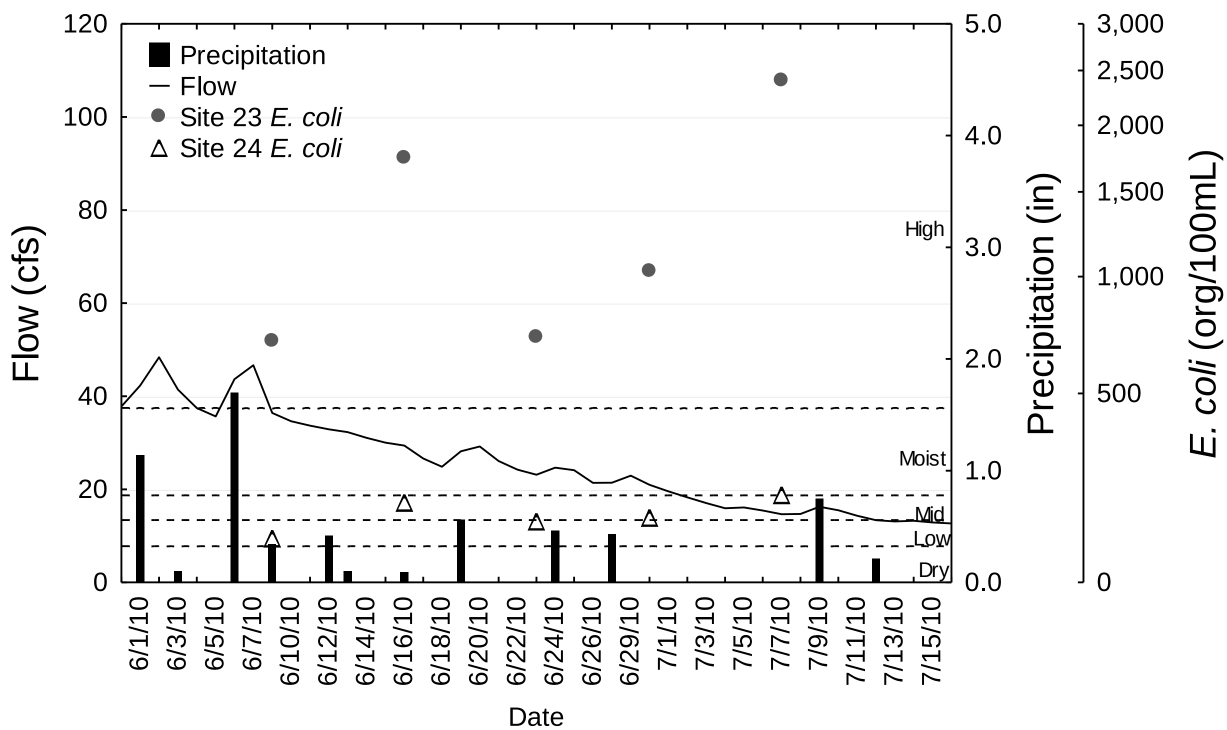

Figure 5. Daily precipitation, daily flow and *E. coli* concentrations in the Big Turkey Lake – Turkey Creek watershed (HUC 040500011005).

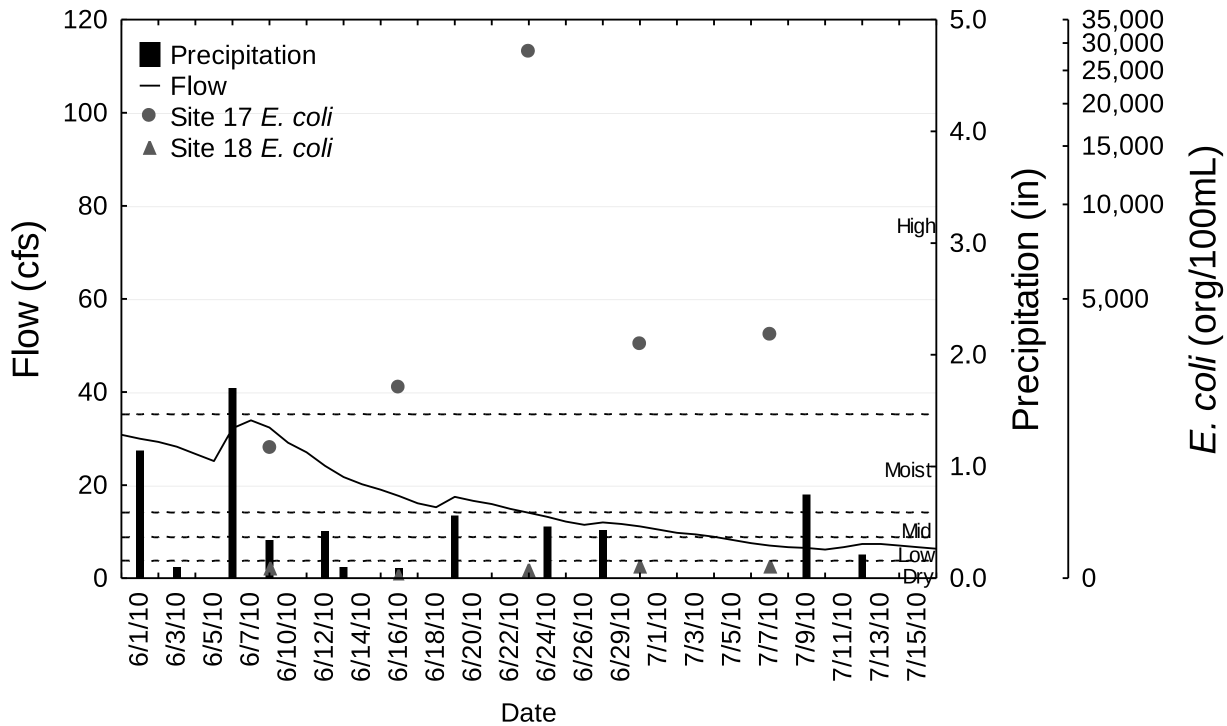

Figure 6. Daily precipitation, daily flow and *E. coli* concentrations in the Silver Lake – Pigeon Creek watershed (HUC 040500011006).

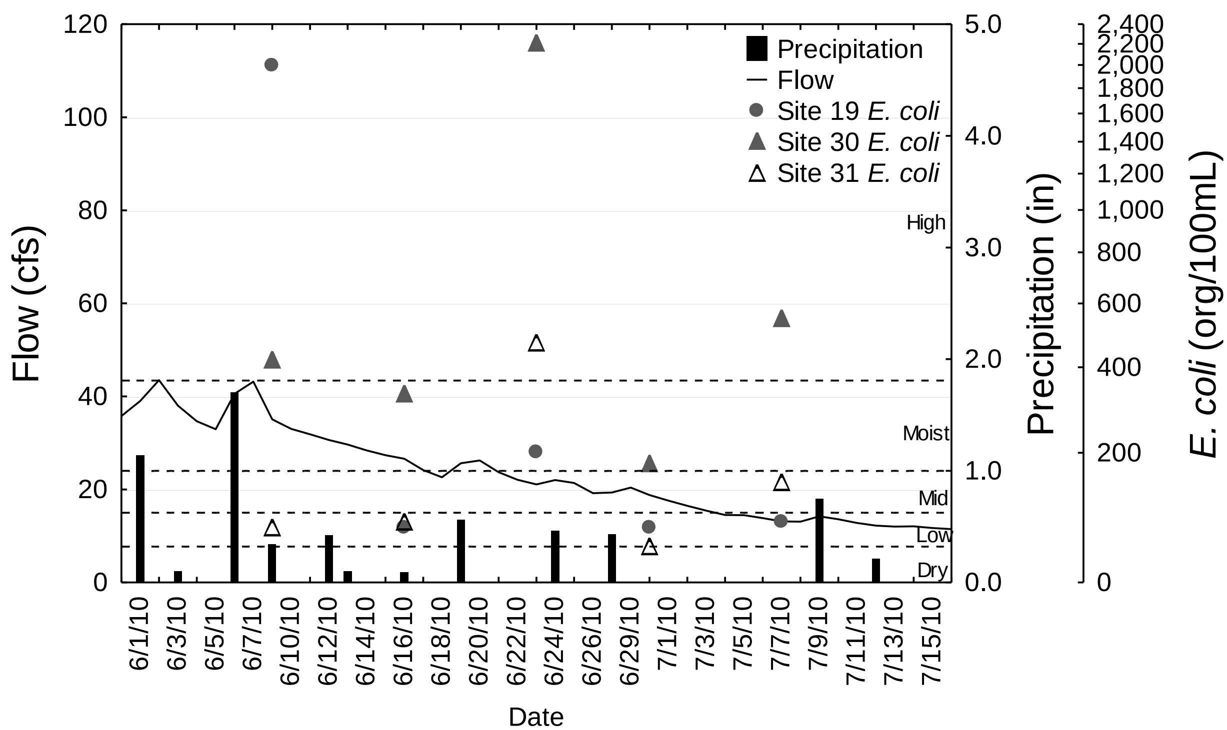

Figure 7. Daily precipitation, daily flow and *E. coli* concentrations in the Otter Lake – Pigeon Creek watershed (HUC 040500011007).

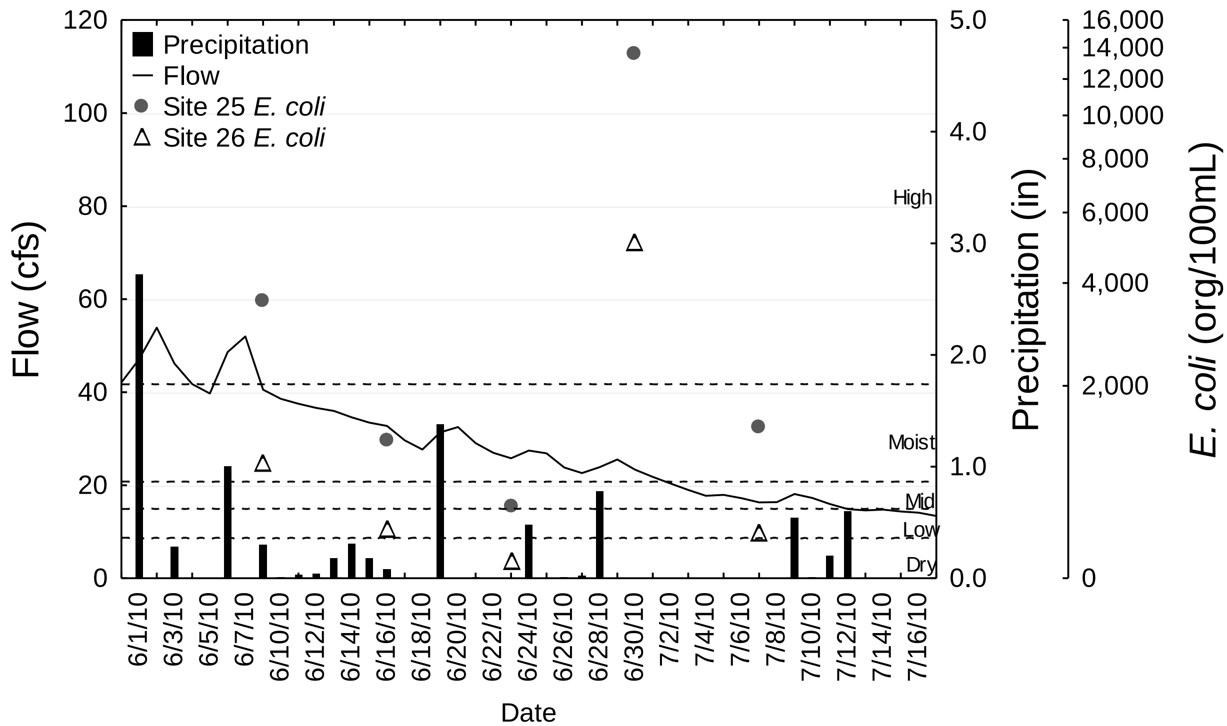

Figure 8. Daily precipitation, daily flow and *E. coli* concentrations in the Little Turkey Lake – Turkey Creek watershed (HUC 040500011008).

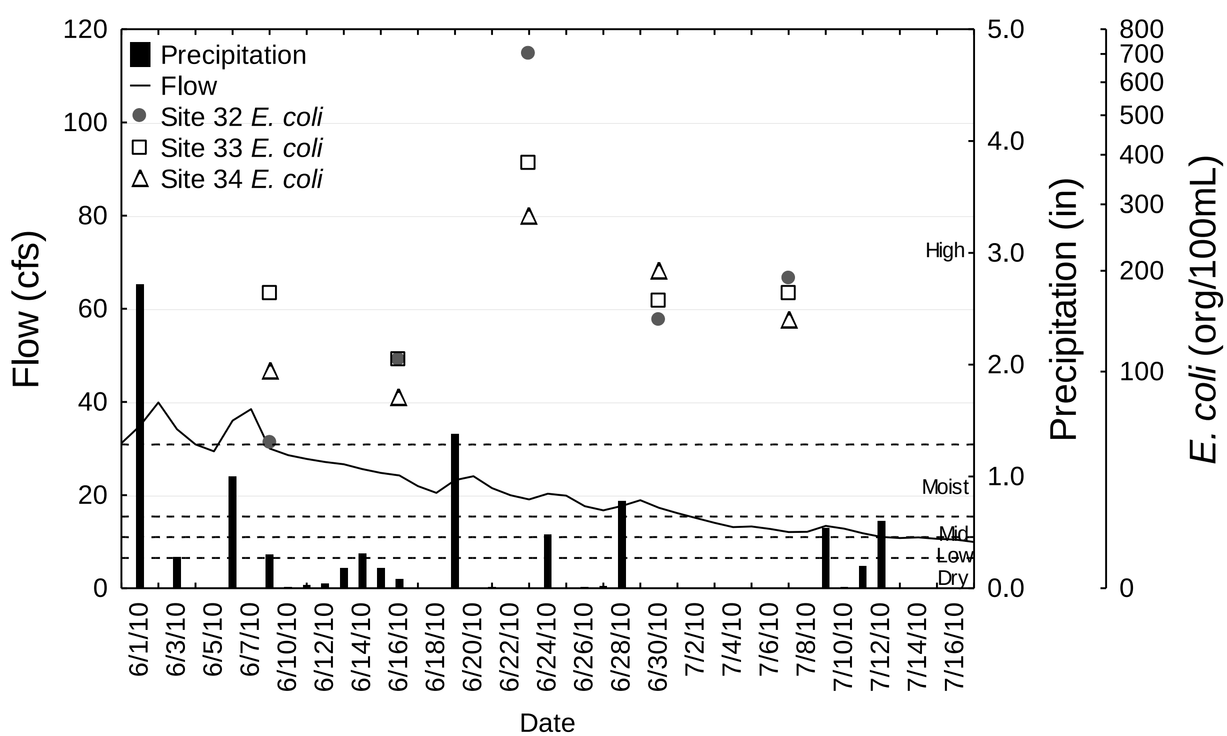

Figure 9. Daily precipitation, daily flow and *E. coli* concentrations in the Green Lake – Pigeon Creek watershed (HUC 040500011009).

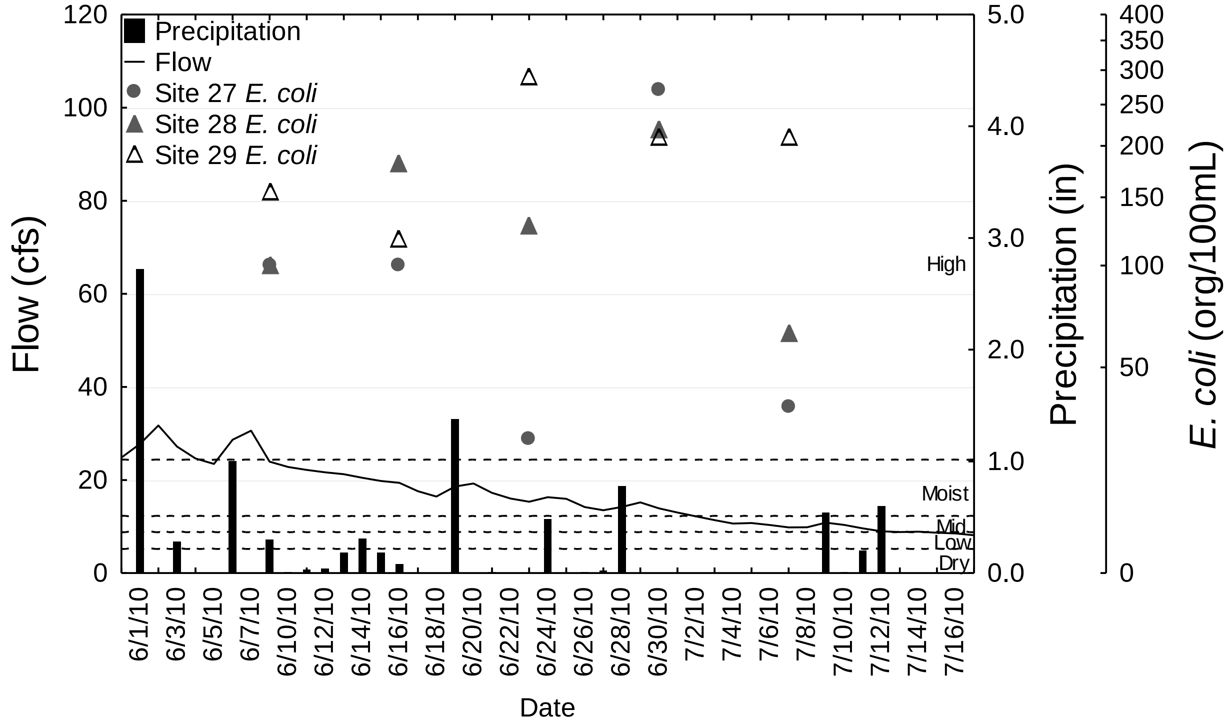

Figure 10. Daily precipitation, daily flow and *E. coli* concentrations in the Mongo Millpond – Pigeon Creek watershed (HUC 040500011010).

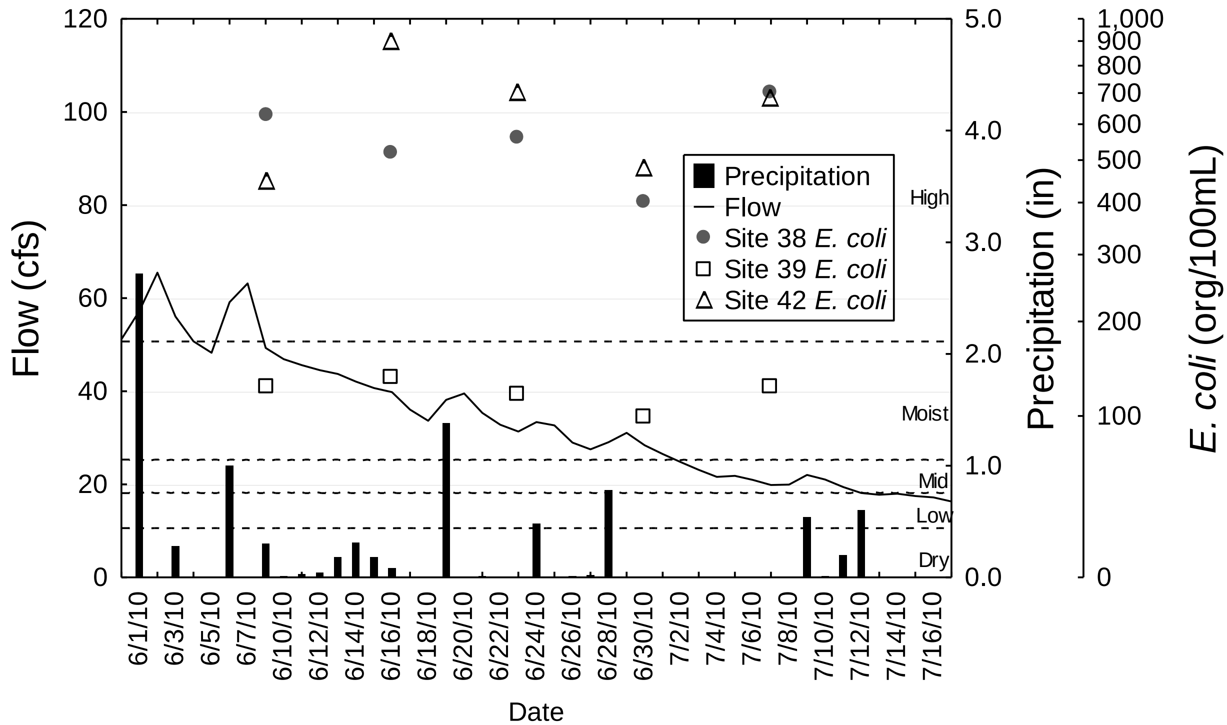

Figure 11. Daily precipitation, daily flow and *E. coli* concentrations in the East Fly Creek watershed (HUC 040500011101).

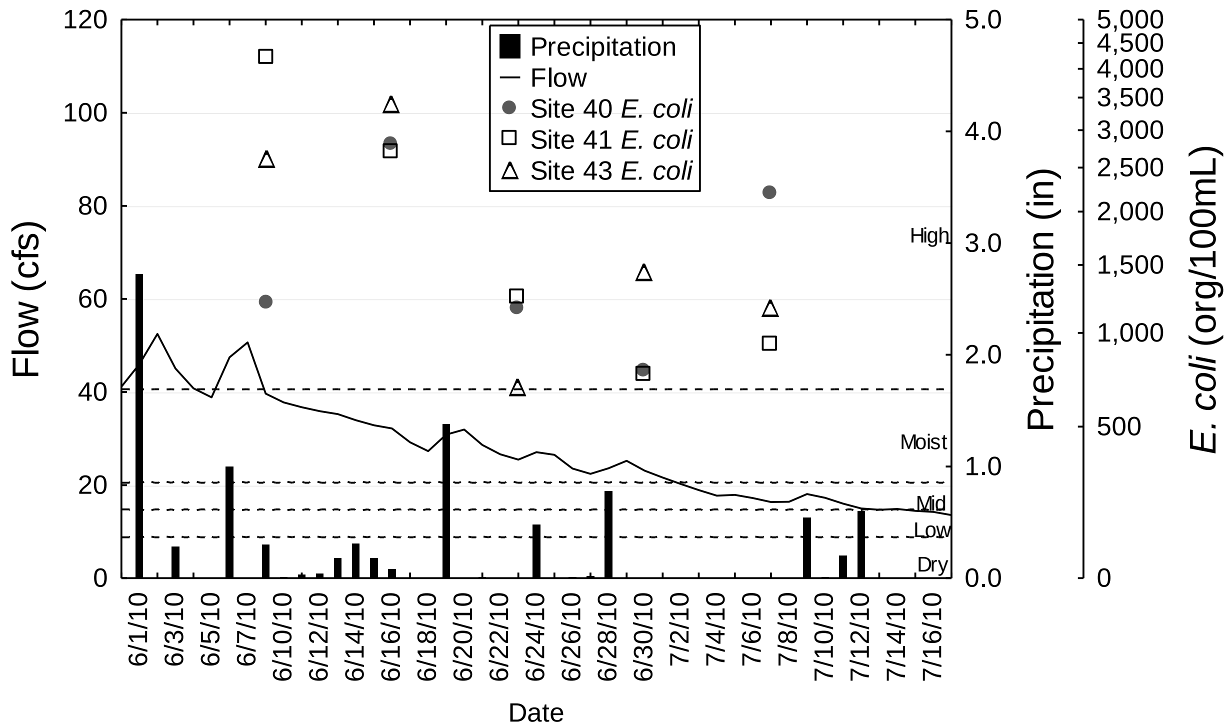

Figure 12. Daily precipitation, daily flow and *E. coli* concentrations in the Fly Creek watershed (HUC 040500011102).

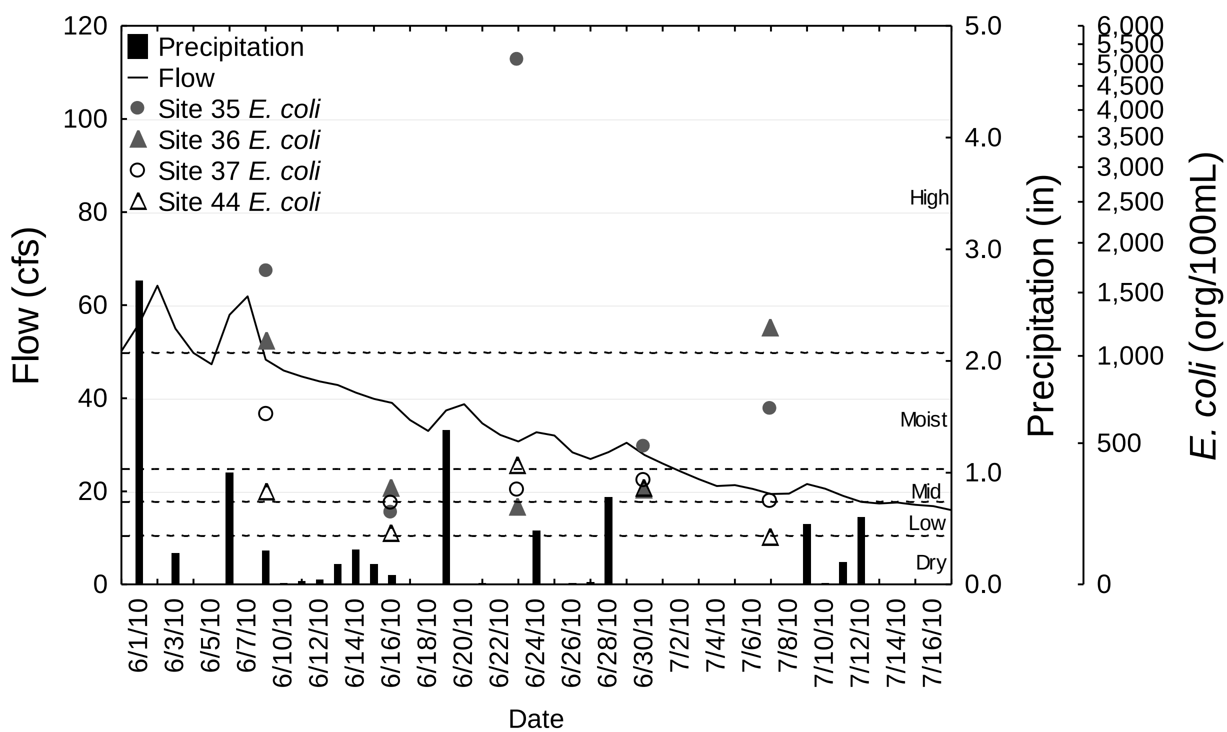

Figure 13. Daily precipitation, daily flow and *E. coli* concentrations in the Cline Lake – Pigeon River watershed (HUC 040500011103).

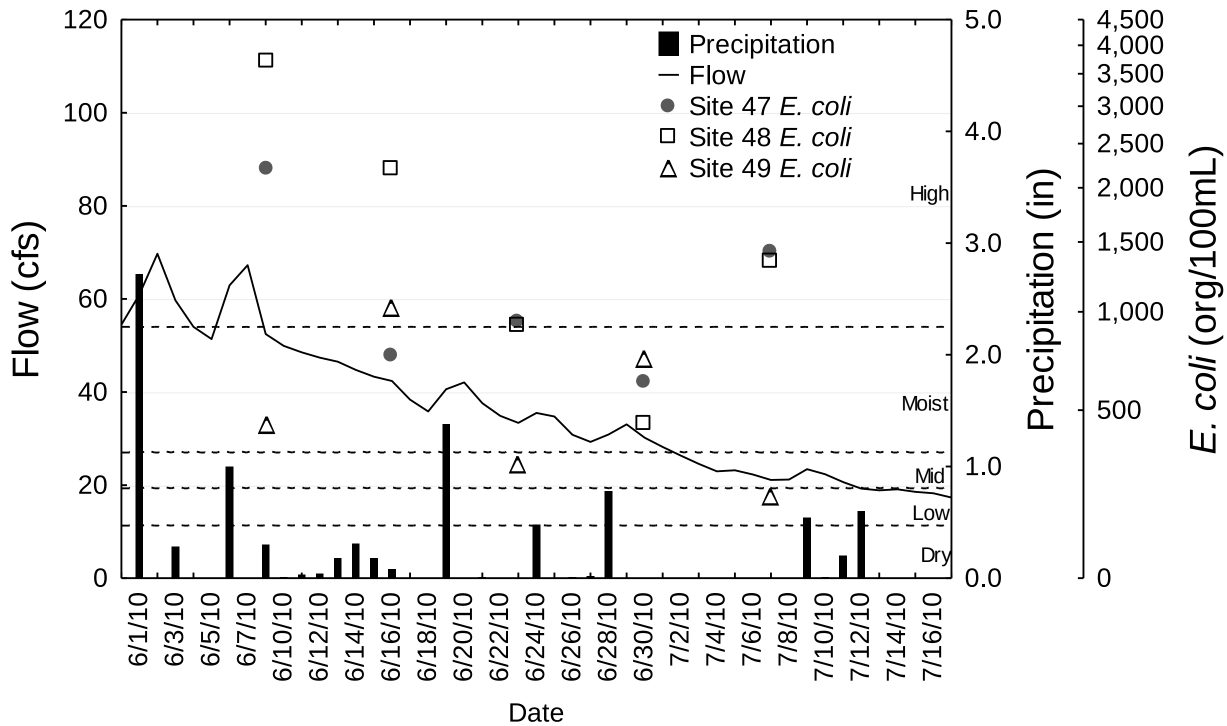

Figure 14. Daily precipitation, daily flow and *E. coli* concentrations in the Buck Lake – Buck Creek watershed (HUC 040500011104).

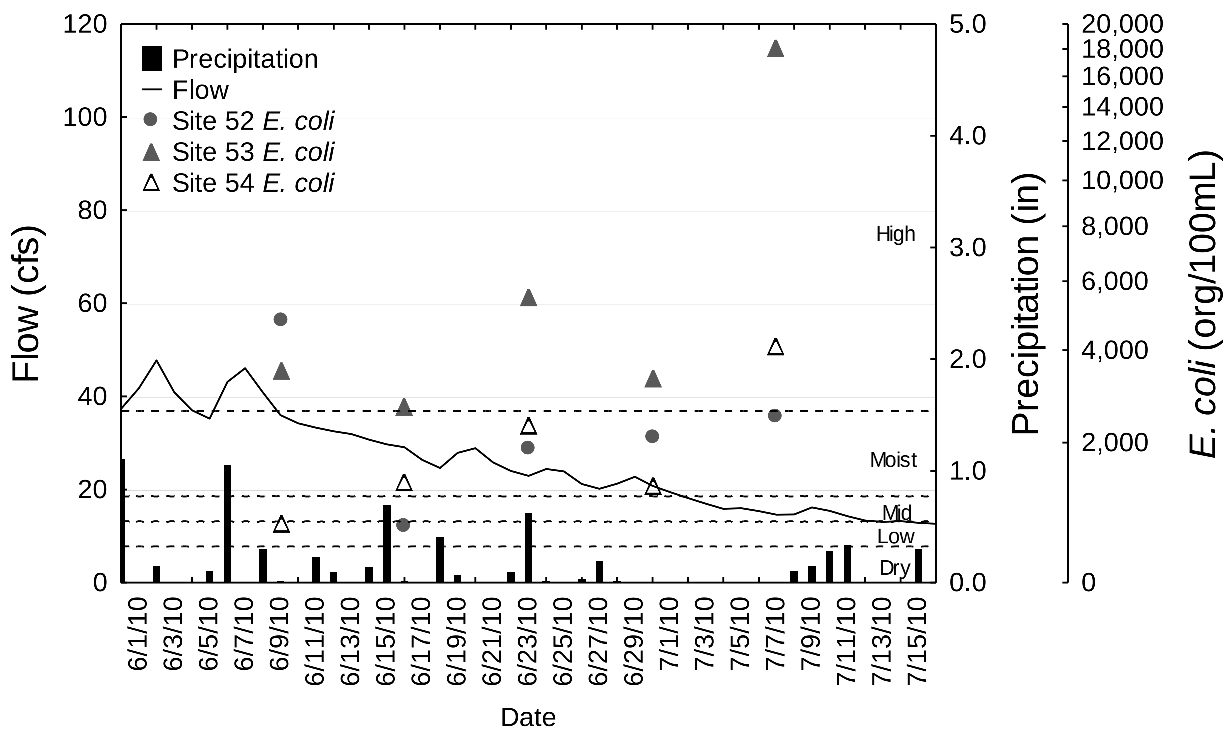

Figure 15. Daily precipitation, daily flow and *E. coli* concentrations in the Page Ditch watershed (HUC 040500011105).

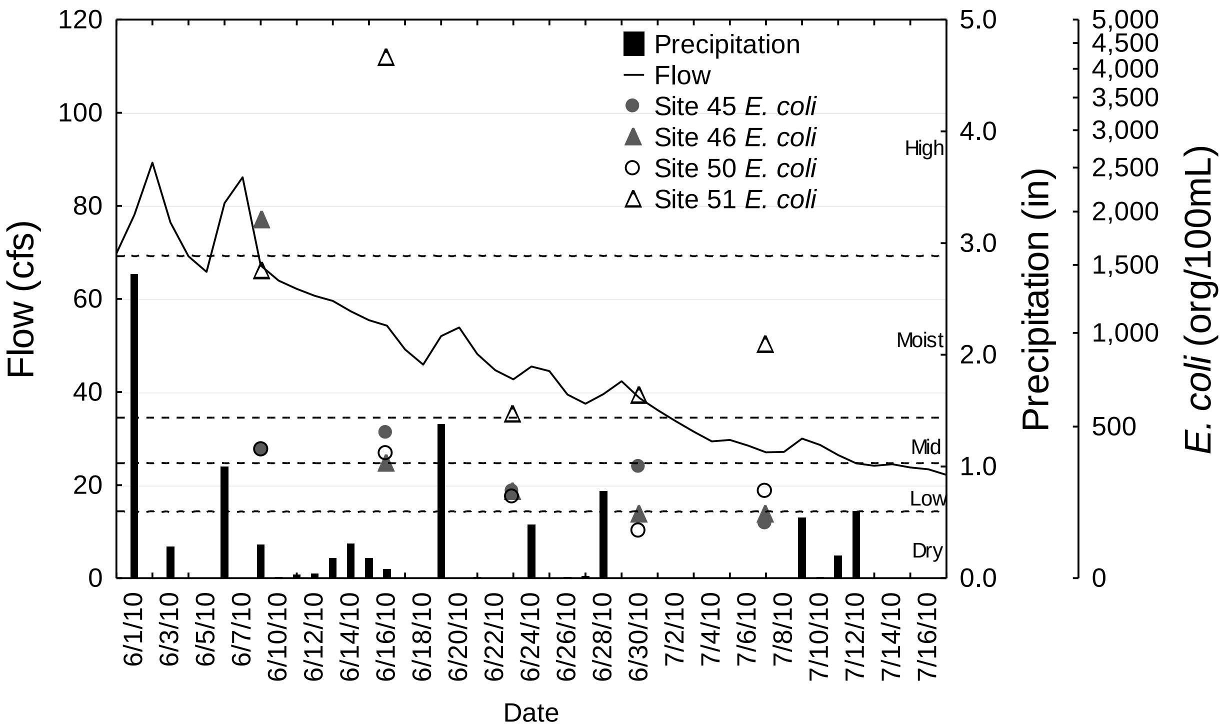

Figure 16. Daily precipitation, daily flow and *E. coli* concentrations in the VanNatta Ditch – Pigeon River watershed (HUC 040500011106).

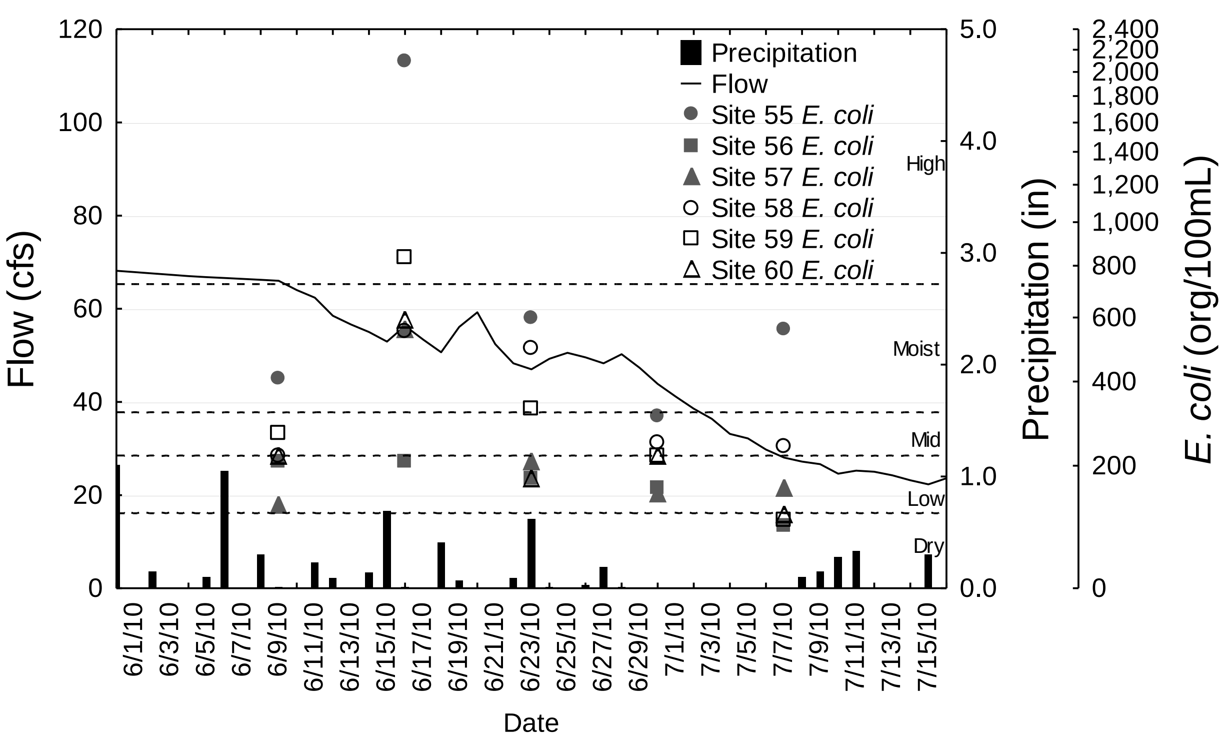

Figure 17. Daily precipitation, daily flow and *E. coli* concentrations in the Stag Lake – Pigeon River watershed (HUC 040500011107).

APPENDIX B: SECONDARY DATA

B.1 Stream data from Steuben SWCD

These secondary stream data were provided from Steuben SWCD. Applicable lake inlet and outlet data were reviewed for consistency with the lake TMDL studies.

Table 1. Steuben SWCD stream water quality data from Site 1 – Pigeon, East Ray Clark Road at culvert, below juncture with the Ryan Ditch

Sampling Date	5/26/2010	7/28/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	142	560	420
E-coli collection date (if different)			
Total Phos. (ppm)	0.16	0.02	0.03
Total Suspended Solids (ppm)	29	3	3
D.O.	5.11	9.32	8.72
pH	7.22	7.95	7.92
Temp. (c)	19.0	22.9	19.5
Specific Conductance	455	758	771
Post Rain Event	*		
CFM Discharge Estimate	2359.67	116.78	337.90
T.S.S. Loading Estimate Kg/day	2788.68	14.28	41.31
Phos. Loading estimate Kg/day	15.39	0.10	0.41

BDL= below detection limit

Table 2. Steuben SWCD stream water quality data from Site 2 – Pigeon Creek, Pigeon Lake Inlet

Parameter	10/31/2007	5/23/2008	7/24/2008	9/14/2008	5/22/2009	7/22/2009	8/19/2009	8/24/2009	5/26/2010	7/28/2010	8/24/2010
E-coli, (CFU or colonies/100 ml)	108	130	382	240	345	512	3400	240	296	254	720
E-coli collection date (if different)		5/22/2008									
total phosphorus (mg/l)	0.018	<.01	<.01	0.02	0.04	<.01		0.02	0.16	0.02	0.03
total suspended solids (mg/l)	2.8	21	9	47	22	<1		20	44	1	6
dissolved oxygen (mg/l)	10.22	8.71	15.04	6.95	8.02	9.08		8.23	6.50	9.17	7.63
pH	8.11	7.37	8.00	7.23	7.59	7.96		7.72	7.40	7.94	7.84
temperature (C)	19.9	12.2	21.8	19.5	18.6	18.8		23.0	19.8	23.5	18.3
specific conductance (µS·cm-1)	n/d	658	721	575	502	754		n/d	481	763	759
conductivity (µS·cm-1)								800			
rain event (yes or no)	no					yes			yes		
discharge estimate (CFM)	720.58	958.99	468.18	754.44	1398.00	776.45		1034.44	2359.67	116.78	337.90
T.S.S. loading estimate (kg/day)	82.22	820.69	171.71	1445.02	1253.37	BDL		843.11	2788.68	14.28	41.31
total phos. loading estimate (kg/day)	0.52	BDL	BDL	0.61	2.28	BDL		0.84	15.39	0.10	0.41
total nitrate loading estimate	17.91										
Biological Oxygen Demand (BOD) (5 day ppm)	3										
nitrate/nitrite	0.61										
nitrate	0.61										
nitrite	0.00										

BDL= below detection limit

Table 3. Steuben SWCD stream water quality data from Site 3 – Pigeon Creek, Pigeon Lake Outlet

Sampling Date	10/31/2007	5/23/2008	7/24/2008	9/14/2008	5/22/2009	7/22/2009	8/19/2009	8/24/2009	5/26/2010	7/28/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	3	10	4	24	579	36	92	118	98	28	38
E-coli collection date (if different)				9/10/2008	5/29/2009						
Total Phos. (ppm)	0.02	<.01	BDL	0.01	0.05	0.02		0.02	0.16	0.02	0.06
Total Suspended Solids (ppm)	4.4	5	6	12	20	<1		17	24	4	3
D.O.	6.81	9.08	12.63	8.08	7.85	12.02		7.97	6.44	9.39	9.84
pH	8.14	7.70	8.31	7.87	7.43	8.35		7.79	7.23	8.28	8.26
Temp. (c)	13.1	15.4	25.9	21.5	18.4	23.0		24.9	21.1	28.1	23.5
Specific Conductance		617	593	*559	418.3	612		*680	418.5	611	581
Post Rain Event						*			*		
CFM Discharge Estimate	503.35	1607.06	1009.80	1736.86	2334.57	3352.80		497.82	flooding	547.25	626.98
T.S.S. Loading Estimate Kg/day	90.26	327.45	246.90	849.36	1902.77	BDL		344.88	flooding	89.21	76.65
Phos. Loading estimate Kg/day	0.47	BDL	BDL	0.70	2.28	2.73		0.41	flooding	0.45	1.53
Total Nitrate Loading Kg/day	5.74										
oxydation reduction potential (mV)	-104										
B.O.D. (5 day ppm)	5										
Nitrate/Nitrite (ppm)	0.28										
Nitrate (ppm)	0.28										
Nitrite (ppm)	0										

BDL= below detection limit

Table 4. Steuben SWCD stream water quality data from Site 4 – Pigeon, U.S. 20 Bridge, Below junction with Berlien Ditch

Sampling Date	8/19/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	4920	68	66	158
E-coli collection date (if different)				
Total Phos. (ppm)		0.17	0.06	0.06
Total Suspended Solids (ppm)		24	12	3
D.O.		6.90	6.13	6.98
pH		7.32	8.07	7.98
Temp. (c)		21.8	24.3	24.4
Specific Conductance		431.1	637	611
Post Rain Event		*		
CFM Discharge Estimate		6765.47	1286.61	1140.86
T.S.S. Loading Estimate Kg/day		6616.95	629.18	139.48
Phos. Loading estimate Kg/day		46.87	3.15	2.79

BDL= below detection limit

Table 5. Steuben SWCD stream water quality data from Site 5 – Pigeon Creek, Metz Road

Sampling Date	8/19/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	14800	120	32	74
E-coli collection date (if different)				
Total Phos. (ppm)		0.16	0.07	0.01
Total Suspended Solids (ppm)		21	10	10
D.O.		6.36	5.57	4.31
pH		7.23	7.84	7.63
Temp. (c)		21.7	24.1	23.3
Specific Conductance		444	655	614
Post Rain Event		*		
CFM Discharge Estimate		6937.57	537.83	542.64
T.S.S. Loading Estimate Kg/day		5937.12	219.18	221.14
Phos. Loading estimate Kg/day		45.24	1.53	2.21

BDL= below detection limit

Table 6. Steuben SWCD stream water quality data from Site 6 – Pigeon Creek between Metz and 275 E

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	10360
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading Estimate Kg/day	

BDL= below detection limit

Table 7. Steuben SWCD stream water quality data from Site 7 – Pigeon Creek at 275 E

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	9800
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 8. Steuben SWCD stream water quality data from Site 8 – Pigeon Creek at Hanselman

Sampling Date	9/19/2009
E-coli (CFU or colonies/100 ml)	9600
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 9. Steuben SWCD stream water quality data from Site 9 – Pigeon Creek between Johnson Ditch and Bill Deller Road

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	5400
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 10. Steuben SWCD stream water quality data from Site 10 – Pigeon Creek downstream of Zabst Ditch

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	6440
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading Estimate Kg/day	
Total Nitrate Loading Kg/day	
oxydation reduction potential (mV)	
B.O.D. (5 day ppm)	
Nitrate/Nitrite (ppm)	
Nitrate (ppm)	
Nitrite (ppm)	

BDL= below detection limit

Table 11. Steuben SWCD stream water quality data from Site 11 – Pigeon Creek, Bill Deller Road

Sampling Date	10/31/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/19/2009	8/24/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	n/d	120	530	324	1200	388	7300	466	110	206	820
E-coli collection date (if different)				9/10/2008	5/28/2009	7/29/2009					
Total Phos. (ppm)	0.019	<.01	0.05	0.02	0.06	0.02		0.04	0.22	0.09	0.06
Total Suspended Solids (ppm)	3.6	11	8	48	16	13		21	16	25	5
D.O.	7.59	7.23	6.76	6.69	7.14	7.81		8.10	4.10	5.57	6.57
pH	8.04	7.45	7.84	7.63	7.59	8.13		7.62	7.32	7.86	7.97
Temp. (c)	11.6	14.1	21.6	20.9	18.0	22.8		20.6	21.9	21.7	22.5
Specific Conductance		663	675	*553	482	670		*690	399.4	665	633
Post Rain Event									*		
CFM Discharge Estimate	903.78	2331.45	1109.36	3095.14	4418.52	1143.24		904.96	14940.45	907.26	689.43
T.S.S. Loading Estimate Kg/day	132.59	1045.12	361.67	6054.39	2881.02	605.66		774.46	9741.65	924.32	140.48
Phos. Loading Estimate Kg/day	0.70	BDL	2.26	2.50	10.80	0.93		1.48	133.95	3.33	1.69
Total Nitrate Loading Kg/day	17.31										
oxydation reduction potential (mV)	-99										
B.O.D. (5 day ppm)	3										
Nitrate/Nitrite (ppm)	0.47										
Nitrate (ppm)	0.47										
Nitrite (ppm)	0										

BDL= below detection limit

Table 12. Steuben SWCD stream water quality data from Site 12 – Pigeon Creek, Meridian Road

Sampling Date	10/31/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/19/2009	8/25/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	n/d	130	642	366	1240	562	7280	684	108	396	880
E-coli collection date (if different)				9/10/2008	5/28/2009	7/29/2009					
Total Phos. (ppm)	0.03	<.01	0.08	0.03	0.06	0.07		0.08	0.18	0.11	0.1
Total Suspended Solids (ppm)	2.8	18	20	49	104	8		44	15	26	15
D.O.	7.57	7.16	6.90	6.55	7.23	7.16		6.56	4.64	5.44	7.00
pH	8.02	7.50	7.83	7.55	7.62	8.01		7.56	7.37	7.84	7.97
Temp. (c)	11.4	14.2	21.6	20.1	17.4	22.3		16.8	22.7	20.8	22.4
Specific Conductance		756	827	*578	509	876		792	462.6	911	862
Post Rain Event									*		
CFM Discharge Estimate	1816.15	3285.46	1438.22	4589.46	4483.74	1591.87		1450.31	18029.40	1978.88	1850.97
T.S.S. Loading Estimate Kg/day	207.23	2410.00	1172.20	16645.63	19003.02	518.97		2600.52	11021.01	2096.73	1131.46
Phos. Loading estimate Kg/day	2.06	BDL	4.69	5.61	10.96	4.54		4.73	132.25	8.87	7.54
Total Nitrate Loading Kg/day	131										
oxydation reduction potential (mV)	-98										
B.O.D. (5 day ppm)	3										
Nitrate/Nitrite (ppm)	1.77										
Nitrate (ppm)	1.77										
Nitrite (ppm)	0										

BDL= below detection limit

Table 13. Steuben SWCD stream water quality data from Site 13 – Pigeon Creek at West 200 South

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	6080
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 14. Steuben SWCD stream water quality data from Site 14 – Pigeon Creek W. Ols US Highway 27

Sampling Date	8/19/2009
E-coli (CFU or colonies/100 ml)	6480
E-coli collection date (if different)	
Total Phos. (ppm)	
Total Suspended Solids (ppm)	
D.O.	
pH	
Temp. (c)	
Specific Conductance	
Post Rain Event	
CFM Discharge Estimate	
T.S.S. Loading Estimate Kg/day	
Phos. Loading estimate Kg/day	

BDL= below detection limit

Table 15. Steuben SWCD stream water quality data from Site 15 – Pigeon Creek, Long Lake Inlet

Sampling Date	10/31/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/19/2009	8/25/2009	5/26/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	238	100	540	388	1120	536	5880	470	100	212	600
E-coli collection date (if different)	11/7/2007			9/10/2008	5/28/2009	7/29/2009					
Total Phos. (ppm)	0.03	<.01	0.09	BDL	0.06	0.04		0.07	0.16	0.10	0.07
Total Suspended Solids (ppm)	1.6	11	12	65	20	10		16	16	19	7
D.O.	8.85	8.13	7.64	7.16	7.85	7.70		7.68	5.80	6.10	7.16
pH	8.06	7.60	7.86	7.46	7.70	7.92		7.56	7.49	7.86	7.97
Temp. (c)	12.1	14.5	21.4	21.1	17.1	21.0		21.2	22.4	22.4	21.6
Specific Conductance		741	806	608	509	856		745	469.9	880	847
Post Rain Event									*		
CFM Discharge Estimate	1304.26	3343.42	1050.60	5609.34	3715.99	1291.98		1034.25	flooding	1852.49	948.87
T.S.S. Loading Estimate Kg/day	85.04	1498.76	513.77	14858.46	3028.68	526.51		1723.54	flooding	1434.36	270.68
Phos. Loading estimate Kg/day	1.51	BDL	3.85	BDL	9.08	2.11		2.95	flooding	7.55	2.71
Total Nitrate Loading Kg/day	89.29										
oxydation reduction potential (mV)	-100										
B.O.D. (5 day ppm)	5										
Nitrate/Nitrite (ppm)	1.68										
Nitrate (ppm)	1.68										
Nitrite (ppm)	0										

BDL= below detection limit

Table 16. Steuben SWCD stream water quality data from Site 16 – Pigeon Creek, Long Lake Outlet

Sampling Date	10/31/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	15	10	8	840	20	104	62	206	10	8
E-coli collection date (if different)	11/7/2007			9/15/2008	6/2/2009	7/29/2009				
Total Phos. (ppm)	0.06	<.01	0.03	0.02	0.04	0.02	0.04	0.12	0.04	0.04
Total Suspended Solids (ppm)	3.2	2	30	13	BDL	4	27	8	15	8
D.O.	6.13	9.90	11.00	10.75	8.98	8.10	11.83	5.30	9.86	11.00
pH	7.92	8.00	8.41	8.93	7.82	8.39	8.06	7.40	8.13	8.50
Temp. (c)	13.5	17.1	25.4	21.2	19.3	24.2	21.6	21.7	26.5	25.7
Specific Conductance		656	651	709	485	755	698	455.2	715	677
Post Rain Event								*		
CFM Discharge Estimate	1596.74	4695.72	1173.05	4699.30	ND	1676.25	1566.42	flooding	2298.81	1849.65
T.S.S. Loading Estimate Kg/day	208.23	382.72	1434.13	2489.58	ND	273.24	1723.54	flooding	1405.22	603.02
Phos. Loading estimate Kg/day	3.64	BDL	1.43	3.83	ND	1.37	2.55	flooding	3.75	3.02
Total Nitrate Loading Kg/day	52.71									
oxydation reduction potential (mV)	-95									
B.O.D. (5 day ppm)	6									
Nitrate/Nitrite (ppm)	0.81									
Nitrate (ppm)	0.81									
Nitrite (ppm)	0									

BDL= below detection limit

Table 17. Steuben SWCD stream water quality data from Site 17 – Pigeon Creek, Mud Lake Outlet just west of Long Lake, Johnson Ditch from Ashley

Sampling Date	5/27/2010	7/29/2010	8/24/2010
E-coli (CFU or colonies/100 ml)	128	36	300
E-coli collection date (if different)			
Total Phos. (ppm)	0.14	0.05	0.04
Total Suspended Solids (ppm)	10	13	6
D.O.	4.87	7.24	7.13
pH	7.35	7.81	8.06
Temp. (c)	21.5	26.1	23.8
Specific Conductance	475.8	840	728
Post Rain Event	*		
CFM Discharge Estimate	flooding	2968.19	1792.11
T.S.S. Loading Estimate Kg/day	flooding	1572.48	438.19
Phos. Loading estimate Kg/day	flooding	6.05	2.92

BDL= below detection limit

Table 18. Steuben SWCD stream water quality data from Site 18 – Pigeon Creek, Big Bower Lake Inlet

Sampling Date	11/2/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/29/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	15	17	72	6	248	200	94	174	104	150
E-coli collection date (if different)				11/26/2008	5/28/2009	7/29/2009				
Total Phos. (ppm)	0.04	<.01	0.04	0.1	0.05	0.02	0.04	0.16	0.06	0.05
Total Suspended Solids (ppm)	3.6	6	12	20	12	3	23	14	11	7
D.O.	4.58	8.87	7.53	7.80	8.12	7.44	9.80	4.85	6.43	7.45
pH	7.87	7.70	7.82	10.19	7.57	7.98	7.82	7.34	7.85	8.03
Temp. (c)	8.5	16.4	25.0	20.7	19.6	24.4	21.5	21.7	26.0	23.5
Specific Conductance		726	683	704	513	781	719	468.7	752	702
Post Rain Event*								*		
CFM Discharge Estimate	1651.69	9414.11	2751.28	3376.52	ND	2660.67	2592.16	flooding	2454.83	2020.12
T.S.S. Loading Estimate Kg/day	242.31	2301.86	1345.44	2752.00	ND	325.29	2429.62	flooding	1100.43	576.27
Phos. Loading estimate Kg/day	2.68	BDL	4.48	13.76	ND	2.17	4.23	flooding	6.00	4.12
Total Nitrate Loading Kg/day	55.19									
oxydation reduction potential (mV)	-90									
B.O.D. (5 day ppm)	4									
Nitrate/Nitrite (ppm)	0.82									
Nitrate (ppm)	0.82									
Nitrite (ppm)	0									

BDL= below detection limit

Table 19. Steuben SWCD stream water quality data from Site 19 – Pigeon Creek, Big Bower Lake Outlet/Golden Lake Inlet

Sampling Date	11/2/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	0	140	30	6	130	94	16	122	26	22
E-coli collection date (if different)				11/26/2008	5/28/2009	7/29/2009				
Total Phos. (ppm)	0.03	<.01	0.05	BDL	0.04	0.04	0.04	0.16	0.04	0.06
Total Suspended Solids (ppm)	3.2	4	13	1	6	<1	22	11	13	11
D.O.	6.42	9.45	10.8	6.41	8.83	11.08	9.65	5.24	8.22	6.45
pH	7.85	7.78	8.22	10.25	7.65	8.26	7.87	7.47	8.04	7.99
Temp. (c)	11.0	17.0	26.8	20.3	20.2	24.3	22.2	22.6	26.3	24.5
Specific Conductance		724	658	710	508	767	711	464.4	751	712
Post Rain Event								*		
CFM Discharge Estimate	2104.95	5720.94	1871.66	6017.44	8582.47	1845.38	2307.81	flooding	2508.24	1417.43
T.S.S. Loading Estimate Kg/day	274.50	932.56	991.56	1471.34	2098.52	BDL	2069.05	flooding	1328.81	635.39
Phos. Loading estimate Kg/day	2.79	BDL	3.81	BDL	13.99	3.01	3.76	flooding	4.09	3.47
Total Nitrate Loading Kg/day	62.62									
oxydation reduction potential (mV)	-90									
B.O.D. (5 day ppm)	6									
Nitrate/Nitrite (ppm)	0.73									
Nitrate (ppm)	0.73									
Nitrite (ppm)	0									

BDL= below detection limit

Table 20. Steuben SWCD stream water quality data from Site 20 – Pigeon Creek, Golden Lake Outlet

Sampling Date	11/2/2007	5/23/2008	7/28/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	3	<3	8	51	40	44	28	84	52	18
E-coli collection date (if different)				11/26/2008	5/28/2009	7/29/2009				
Total Phos. (ppm)	0.04	<.01	0.03	BDL	0.02	<.01	0.03	0.13	0.03	0.04
Total Suspended Solids (ppm)	4.4	2	4	7	8	<1	15	8	15	14
D.O.	6.55	9.08	13.71	4.12	12.59	8.59	13.03	6.22	10.16	7.06
pH	8.07	7.84	8.55	9.79	8.28	8.22	8.26	7.47	8.12	8.16
Temp. (c)	11.5	17.8	30.0	20.2	21.9	26.4	24.0	22.0	27.1	25.9
Specific Conductance		712	585	639	527	713	675	473.9	683	669
Post Rain Event								*		
CFM Discharge Estimate	2596.36	8345.47	1811.42	4371.76	6906.26	ND	ND	flooding	2584.12	1620.56
T.S.S. Loading Estimate Kg/day	465.55	680.19	295.28	9086.06	2251.55	ND	ND	flooding	1579.62	924.57
Phos. Loading estimate Kg/day	4.03	BDL	2.21	BDL	5.63	ND	ND	flooding	3.16	2.64
Total Nitrate Loading Kg/day	37.03									
oxydation reduction potential (mV)	-100									
B.O.D. (5 day ppm)	5									
Nitrate/Nitrite (ppm)	0.35									
Nitrate (ppm)	0.35									
Nitrite (ppm)	0									

BDL= below detection limit

Table 21. Steuben SWCD stream water quality data from Site 21 – Pigeon Creek, Hogback Lake Inlet

Sampling Date	11/2/2007	5/23/2008	7/29/2008	9/14/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	11	3	84	22	48	50	38	128	82	96
E-coli collection date (if different)				10/2/2008	5/28/2009	7/29/2009				
Total Phos. (ppm)	0.04	<.01	0.05	0.05	0.03	0.01	0.03	0.19	0.04	0.04
Total Suspended Solids (ppm)	1.2	3	10	BDL	6	<1	15	9	20	5
D.O.	5.08	9.44	9.72	5.65	11.24	8.70	11.08	5.41	7.64	6.50
pH	7.99	7.83	8.13	7.63	7.95	8.16	8.13	7.37	7.93	8.06
Temp. (c)	10.6	17.3	25.1	15.9	20.3	25.8	23.4	21.7	25.5	24.3
Specific Conductance		711	581	673	512	712	675	476.7	684	670
Post Rain Event								*		
CFM Discharge Estimate	1773.47	6149.28	1863.54	595.57	7563.50	1759.58	2015.38	flooding	2849.12	1273.46
T.S.S. Loading Estimate Kg/day	86.73	751.79	759.43	BDL	1849.37	BDL	1231.96	flooding	2322.15	259.48
Phos. Loading estimate Kg/day	2.90	BDL	3.80	1.21	9.25	0.72	2.46	flooding	4.64	2.08
Total Nitrate Loading Kg/day	29.63									
oxydation reduction potential (mV)	-99									
B.O.D. (5 day ppm)	4									
Nitrate/Nitrite (ppm)	0.41									
Nitrate (ppm)	0.41									
Nitrite (ppm)	0									

BDL= below detection limit

Table 22. Steuben SWCD stream water quality data from Site 22 – Pigeon Creek, Hogback Lake Outlet

Sampling Date	11/2/2007	5/23/2008	7/28/2008	10/2/2008	5/23/2009	7/24/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	1	3	30	18	90	112	14	96	54	10
E-coli collection date (if different)					5/28/2009	7/29/2009				
Total Phos. (ppm)	<.01	<.01	0.04	0.06	0.03	0.04	0.03	0.14	0.04	0.04
Total Suspended Solids (ppm)	4	3	4	BDL	3	5	8	4	9	8
D.O.	8.32	10.93	16.20	5.19	11.66	11.38	11.55	7.43	8.52	7.84
pH	8.49	8.10	8.61	7.57	8.09	8.49	8.16	7.74	8.10	8.17
Temp. (c)	12.2	19	26.6	17.6	23.5	24.9	24.1	22.3	26.8	25.8
Specific Conductance		668	522	306.4	568	622	628	506	610	606
Post Rain Event								*		
CFM Discharge Estimate	2269.32	6613.61	2545.46	539.35	ND	2194.52	ND	flooding	2992.48	2550.94
T.S.S. Loading Estimate Kg/day	369.92	808.55	414.93	BDL	ND	447.16	ND	flooding	1097.55	831.65
Phos. Loading estimate Kg/day	BDL	BDL	4.15	1.32	ND	3.58	ND	flooding	4.88	4.16
Total Nitrate Loading Kg/day	27.74									
oxydation reduction potential (mV)	-122									
B.O.D. (5 day ppm)	6									
Nitrate/Nitrite (ppm)	0.3									
Nitrate (ppm)	0.3									
Nitrite (ppm)	0									

BDL= below detection limit

Table 23. Steuben SWCD stream water quality data from Site 23 – Pigeon Creek at 327

Sampling Date	11/2/2007	5/28/2008	7/29/2008	10/2/2008	5/23/2009	7/29/2009	8/25/2009	5/27/2010	7/30/2010	8/25/2010
E-coli (CFU or colonies/100 ml)	116	86	154	86	740	184	146	88	264	176
E-coli collection date (if different)					5/28/2009					
Total Phos. (ppm)	0.03	<.01	0.02	0.05	0.02	0.02	0.02	0.14	0.04	0.03
Total Suspended Solids (ppm)	0.8	26	6	BDL	6	3	13	14	10	2
D.O.	8.85	8.48	8.69	7.67	9.96	8.23	8.98	6.90	6.25	6.62
pH	8.10	7.77	7.78	7.70	7.86	8.06	7.45	7.77	7.71	7.89
Temp. (c)	11.2	15.8	23.9	15.0	22.5	22.7	22.4	22.3	20.6	21.2
Specific Conductance		677	592	651	550	668	644	521	643	638
Post Rain Event								*		
CFM Discharge Estimate	3696.41	8256.50	3335.60	2888.43	10154.30	3034.33	3914.78	flooding	3657.39	3192.55
T.S.S. Loading Estimate Kg/day	120.51	8748.19	815.60	BDL	2482.85	370.96	2073.96	flooding	1490.46	260.21
Phos. Loading estimate Kg/day	4.50	BDL	2.72	5.89	8.28	2.47	3.19	flooding	5.96	3.90
Total Nitrate Loading Kg/day	109.96									
oxydation reduction potential (mV)	-104									
B.O.D. (5 day ppm)	4									
Nitrate/Nitrite (ppm)	0.73									
Nitrate (ppm)	0.73									
Nitrite (ppm)	0									

BDL= below detection limit

Table 24. Steuben SWCD stream water quality data from Site 43 – Turkey Creek, Tributary to Big Turkey Lake

Sampling Date	7/29/2008	10/6/2008	5/30/2009	7/30/2009	8/27/2009	5/24/2010	7/28/2010	8/23/2010
E-coli (CFU or colonies/100 ml)	132	252	1680	432		228	178	360
E-coli collection date (if different)		10/8/2008	5/28/2009					
Total Phos. (ppm)	0.05	BDL	0.03	0.05	0.05	0.09	0.07	0.09
Total Suspended Solids (ppm)	BDL	BDL	4	<1	7	14	<1	<1
D.O.	7.53	9.65	11.03	7.27	6.61	5.77	5.27	4.66
pH	7.66	7.78	8.06	7.68	7.45	7.47	7.53	7.54
Temp. (c)	25.9	15.1	21.3	18.6	18.9	20.8	23.4	20.4
Specific Conductance	607	651	567	597	508	568	602	619
Post Rain Event					*	*	BDL	
CFM Discharge Estimate	666.77	246.25	1064.15	842.52	1266.26	flooding	801.52	329.03
T.S.S. Loading Estimate Kg/day	BDL	BDL	173.43	BDL	361.22	flooding	2.29	BDL
Phos. Loading estimate Kg/day	1.36	BDL	1.30	1.72	2.58	flooding	BDL	1.21

BDL= below detection limit

Table 25. Steuben SWCD stream water quality data from Site 44 – Pigeon Creek, Fox Lake Outlet

Sampling Date	7/30/2008	10/6/2008	5/30/2009	7/30/2009	8/27/2009	5/24/2010	7/15/2010	8/19/2010
E-coli (CFU or colonies/100 ml)	76	44	16	54	840	12	500	no flow
E-coli collection date (if different)		9/10/2008	5/28/2009					
Total Phos. (ppm)	0.09		BDL	<.01	0.05	0.09	<.01	no flow
Total Suspended Solids (ppm)	BDL		12	6	2	14	4	no flow
D.O.	6.18	no flow	9.79	6.09	4.00	8.57	8.57	no flow
pH	8.05		8.51	7.79	7.90	8.42	8.39	no flow
Temp. (c)	26.2		22.7	18.6	18.6	23.7	30.6	no flow
Specific Conductance	468.9		461.9	482.6	528	488.6	469	no flow
Post Rain Event					*	*	BDL	
CFM Discharge Estimate	14.42	no flow	206.22	3.56	ND	1769.85	43.06	no flow
T.S.S. Loading Estimate Kg/day	BDL	no flow	100.84	0.87	ND	1009.75	7.02	no flow
Phos. Loading estimate Kg/day	0.05	no flow	BDL	BDL	ND	6.49	BDL	no flow

BDL= below detection limit

Table 26. Steuben SWCD stream water quality data from Site 53 – Pigeon Creek, Tributary to West Otter (Between Arrowhead and Otter)

Sampling Date	5/24/2010	7/27/2010	8/20/2010
E-coli (CFU or colonies/100 ml)	116	2280	8300
E-coli collection date (if different)			
Total Phos. (ppm)	0.05	0.12	0.17
Total Suspended Solids (ppm)	10	1	10
D.O.	7.26	5.34	6.17
pH	7.80	7.77	7.95
Temp. (c)	22.1	26.4	21.9
Specific Conductance	440.1	535	521
Post Rain Event	*	0.15	
CFM Discharge Estimate	923.47	31.63	11.91
T.S.S. Loading Estimate Kg/day	376.33	1.29	4.85
Phos. Loading estimate Kg/day	1.88	0.15	0.08

BDL= below detection limit

Table 27. Steuben SWCD stream water quality data from Site 54 – Pigeon Creek, Tributary between Silver and Hogback

Sampling Date	5/24/2010	7/27/2010	8/20/2010
E-coli (CFU or colonies/100 ml)	14	314	124
E-coli collection date (if different)			
Total Phos. (ppm)	0.02	0.01	0.01
Total Suspended Solids (ppm)	9	2	10
D.O.	8.10	6.96	5.96
pH	8.25	8.23	8.08
Temp. (c)	25.1	29.8	26.0
Specific Conductance	457.9	413.6	408.1
Post Rain Event	*	0.05	
CFM Discharge Estimate	678.05	114.81	119.89
T.S.S. Loading Estimate Kg/day	248.69	9.36	48.86
Phos. Loading estimate Kg/day	0.55	0.05	0.05

BDL= below detection limit

Table 28. Steuben SWCD stream water quality data from Site 56 – Pigeon Creek, William Jack Ditch

Sampling Date	7/28/2010	8/17/2010
E-coli (CFU or colonies/100 ml)	860	1400
E-coli collection date (if different)		
Total Phos. (ppm)	0.10	0.11
Total Suspended Solids (ppm)	5	7
D.O.	6.25	7.45
pH	7.75	7.85
Temp. (c)	23.5	21.5
Specific Conductance	774	777
Post Rain Event	0.02	
CFM Discharge Estimate	5.04	4.91
T.S.S. Loading Estimate Kg/day	1.03	1.40
Phos. Loading estimate Kg/day	0.02	0.02

BDL= below detection limit

B.2 Lake data from Indiana's Clean Lakes Program and Volunteer Lake Monitoring Program

These data were used for the in-lake BATHTUB model used for TMDL development. Data in Table 29 were used to estimate phosphorus loading from upstream lakes, as described in *Section 5.2.2 Model Input*. Data in Table 30 and Table 31 are the observed water quality for chlorophyll-*a* and Secchi transparency for the impaired lakes, also used as BATHTUB model input. Total phosphorus data are presented in *Section 3.3 Assessment of Water Quality – Lakes*.

Table 29. Phosphorus data summary for non-impaired lakes used to estimate upstream lake loading for in-lake BATHTUB models

Lake	2008 AUID	Downstream Impaired Lake	Years Data Were Collected	Sample Size (N)	Growing Season Mean [mg/L]	Minimum [mg/L]	Maximum [mg/L]	Standard Error [mg/L]
Big Long	INJ01P1097_00	Little Turkey	1997, 2001-2010	45	0.0267	0.0150	0.0550	0.00335
Big Turkey	INJ01P1102_00	Little Turkey	1982, 1992, 1997, 2002, 2006	7	0.0408	0.0130	0.0770	0.0121
Fox	INJ01P1075_00	Long	1989, 1992, 1997, 2002, 2008	7	0.0195	0.0150	0.0250	0.00240
Gooseneck	INJ01P1084_00	Meserve	1992	1	0.0220	0.0220	0.0220	n/a
McClish	INJ01P1091_00	Lake of the Woods	1989, 1992-1997, 1999-2010	70	0.0327	0.0140	0.0655	0.00293
Pigeon	INJ01P1042_00	Long	1989, 1990, 1992, 1997, 2002, 2009	6	0.0593	0.0330	0.0970	0.0115
Pretty	INJ01P1098_00	Little Turkey	1989, 1993, 1997, 2002, 2006, 2010	6	0.0145	0.0100	0.0210	0.00173
Still	INJ01P1156_00	North Twin	1991, 1993	2	0.109	0.0290	0.189	0.0800

Table 30. Chlorophyll-*a* data summary for impaired lakes

Lake	2008 AUID	Years Data Were Collected	Sample Size (N)	Growing Season Mean [µg/L]	Minimum [µg/L]	Maximum [µg/L]	Standard Error [µg/L]
Fish	INJ01P1133_00	1993, 2000, 2003	3	3.07	1.12	6.17	1.57
Lake of the Woods	INJ01P1093_00	1992-1995, 1997-2002, 2004-2006, 2008-2010	63	3.89	0.375	9.31	0.679
Little Turkey	INJ01P1101_00	1992-2008, 2010	67	6.72	2.58	21.4	1.06
Long	INJ01P1080_00	1992-1999, 2002, 2009, 2010	36	19.2	0.000	30.6	2.50
Meserve	INJ01P1083_00	none	0	n/a	n/a	n/a	n/a
North Twin	INJ01P1157_00	1993, 2000	2	0.650	0.560	32.0	n/a
Royer	INJ01P1132_00	1989, 1993, 2000, 2003	2	4.83	1.25	8.41	3.58

Table 31. Secchi transparency data summary for impaired lakes

Lake	2008 AUID	Years Data Were Collected	Sample Size (N)	Growing Season Mean [m]	Minimum [m]	Maximum [m]	Standard Error [m]
Fish	INJ01P1133_00	1989, 1990, 1992-1994, 1997-2000, 2002, 2003	47	2.19	1.06	3.53	0.637
Lake of the Woods	INJ01P1093_00	1989-1992, 1994-2002, 2004-2010	94	2.12	1.20	2.91	0.520
Little Turkey	INJ01P1101_00	1989-2008, 2010	87	1.51	0.813	2.03	0.347
Long	INJ01P1080_00	1989-1999, 2002, 2009, 2010	85	1.14	0.700	2.00	0.318
Meserve	INJ01P1083_00	1990, 1992	2	3.60	3.30	3.90	0.424
North Twin	INJ01P1157_00	1989, 1993, 2000	3	1.97	1.70	2.40	0.379
Royer	INJ01P1132_00	1989-1994, 1997-2000, 2002, 2003	35	1.93	0.800	3.96	0.926

APPENDIX C: PIGEON RIVER WATERSHED LAKE WATER QUALITY INFORMATION

Since IDEM is in the rulemaking process for a phosphorus standard in lakes, lake TMDLs were not developed as part of this document, but the information gathered for the Pigeon River watershed lakes and lake impairments has been compiled here.

Lake data for the analysis were gathered from Indiana's Clean Lakes Program and Volunteer Lake Monitoring Program. Data were reviewed for consistency with requirements for secondary data as described in the *Pigeon River Watershed TMDL QAPP*. Data were used in calibration of in-lake models and for estimates of reductions needed to meet the lake TMDLs. Five of the lakes are impaired for biotic communities (IBC) and phosphorus has been identified as the pollutant of concern. Two of the lakes have been identified as impaired due to phosphorus alone. A quantitative phosphorus loading analysis and a soil erosion analysis was conducted for each impaired lake's watershed.

Loadings were determined for each impaired lake based on in-lake modeling that identified the phosphorus load that meets the in-lake phosphorus target. Table EX - 1 summarizes the lake watershed for each HUC 12, the watershed area, impairing parameter, and required percent reduction for each impairment.

Table EX - 1. Total phosphorus TMDL summary for impaired lake watersheds

Lake Watershed	Watershed Area [acres]	Total PhosphorusL [pounds per year]	Percent Reduction to Meet Target[1]
Fish	3,525	26	0%
Lake of the Woods	2,413	6.2	30%
Little Turkey	4,870	14	40%
Long	23,520	24	67%
Meserve	77	0.21	8.5%
North Twin	701	1.5	36%
Royer	3,598	9.7	21%

[1] Calculated based on the difference between the phosphorus load that meets the in-lake phosphorus target (growing season mean of 0.03 mg/L) and the existing phosphorus load

Error! Reference source not found. and **Error! Reference source not found.**, and for the watersheds to the seven impaired lakes.

Waterbody	2010 AUID	Impairment			
		E. coli	**IBC[1]**	**Total P**	**Total N**
LONG LAKE	[3]INJ01P1080_00	no	no	yes	no
MESERVE LAKE	[3]INJ01P1083_00	no	yes	yes	no
LAKE OF THE WOODS	[3]INJ01P1093_00	no	yes	yes	no
LITTLE TURKEY LAKE	[3]INJ01P1101_00	no	no	yes	no
ROYER LAKE	[3]INJ01P1132_00	no	yes	yes	no
FISH LAKE	[3]INJ01P1133_00	no	yes	yes	no
NORTH TWIN LAKE	[3]INJ01P1157_00	no	yes	yes	no

[1]IBC – Impaired Biotic Community
[2] The waterbodies Pigeon River and Ontario Mill Pond Inlet are both listed as AUID INJ01B3_02
[3] 2008 AUI

Lakes Criteria

There are currently no Indiana numeric criteria for phosphorus concentration within lakes, although they are currently under development. A growing season (May 1 through September 30) mean phosphorus concentration of 0.03 mg/L will be used as the numeric target for the impaired lakes in the Pigeon River Watershed; this concentration falls within the range of numeric criteria being considered for phosphorus concentrations. The State of Michigan has a narrative standard for total phosphorus, but not a numeric target. The narrative standard reads,

> (Part 1) Consistent with Great Lakes protection, phosphorus which is or may readily become available as a plant nutrient shall be controlled from point source discharges to achieve 1 milligram per liter of total phosphorus as a maximum monthly average effluent concentration unless other limits, either higher or lower, are deemed necessary and appropriate by the department. (Part 2) In addition to the protection provided under subrule (1) of this rule, nutrients shall be limited to the extent necessary to prevent stimulation of growths of aquatic rooter, attached, suspended, and floating plants, fungi or bacteria which are or may become injurious to the designated uses of the surface waters of the state. [Rule 323.1060 Plant Nutrients. Rule 60.]

A.1 Assessment of Water Quality – Lakes

Total phosphorus data for the impaired lakes are summarized in this section of the report. Phosphorus data is summarized in Table 30 on page 28. Appendix B.2 includes a summary of chlorophyll-*a* and Secchi transparency data, which were also used for lake modeling (see Section A.1.6). Appendix B.1 includes additional secondary data for streams provided by the Steuben SWCD. Monitoring locations located near lake outlets were reviewed for consistency with the TMDL.

Table 30 provides a summary of available lake total phosphorus data. These data were collected through Indiana's Clean Lakes Program and Volunteer Lake Monitoring Program[i] and were used in lake model calibration and estimates of the reductions needed to meet the lake TMDLs (addressed in the individual lake TMDL sections (Section B)).

Table 32. Total phosphorus data summary for lakes

Lake	2008 AUID	Years Data Were Collected	Sample Size (N)	Growing Season Mean [mg/L]	Minimum [mg/L]	Maximum [mg/L]	Standard Error [mg/L]
Fish	INJ01P1133_00	1989, 1993, 2000, 2003	4	0.0195	0.0150	0.0250	0.00240
Lake of the Woods	INJ01P1093_00	1989, 1992-2002, 2004-2006, 2008-2010	69	0.0359	0.0175	0.0770	0.00362
Little Turkey	INJ01P1101_00	1989, 1992-2008, 2010	73	0.0422	0.0150	0.0755	0.00331
Long	INJ01P1080_00	1989, 1990, 1992-1999, 2002, 2009, 2010	37	0.0567	0.0200	0.0913	0.00592
Meserve	INJ01P1083_00	1990, 1992	2	0.0340	0.0100	0.0580	0.0240
North Twin	INJ01P1157_00	1989, 1993, 2000	3	0.0403	0.0100	0.0860	0.0232
Royer	INJ01P1132_00	1993, 2000, 2003	4	0.0340	0.0130	0.0450	0.00715

[1] Data provided on IDEM Clean Lakes Program website. Data were reviewed for consistency with requirements for secondary data as described in the Pigeon River Watershed TMDL QAPP.

A.1.1 Source Characterization

A.1.2 Runoff from other land uses

Land uses other than agriculture are also sources of phosphorus and nitrogen. Residential and commercial properties may use fertilizer containing phosphorus and nitrogen, and most land uses result in some level of erosion of sediments carrying phosphorus. For example, areas with maintained lawns along waterbodies, such as are present around Golden Lake, West Otter Lake, and Long Lake (Steuben SWCD and Steuben County 2006), may act as sources of nutrients if lawn fertilizers are used or if soil erosion occurs along the shoreline. Impervious surfaces further act as a conduit to transport sediment and associated nutrients to nearby waterbodies. These sources of nutrients are incorporated into the modeling completed for this study.

A.1.3 Stream Degradation

Suspended solids and phosphorus can increase in streams due to bank destabilization (e.g. from removal of upland or riparian vegetation or livestock access). Livestock with access to stream environments may cause streambank disturbance and erosion and may resuspend particles that had settled on the stream bottom. Phosphorus adsorbs to sediment particles and often travels through aquatic systems attached to suspended solids. Internally, increases in suspended solids can produce more scouring, introducing additional suspended solids and phosphorus. The sites impacted and the extents of damage depend on stream magnitude, gradient, and whether the site is erosional or depositional.

Many streams in the Pigeon River Watershed are managed as regulated drainage systems and have likely been impacted in the past by straightening and dredging activities. Streambank erosion has been identified in locations along Pigeon Creek, particularly downstream of Hogback Lake and upstream of Long Lake (Steuben SWCD and Steuben County 2006). The following specific areas of sedimentation were noted in the 2006 report: incised channel reaches downstream of Hogback Lake, along Golden Lake Road, at the entrance to Hogback Lake, between Long Lake and Little Bower Lake, and upstream of County Road 150 West (Steuben SWCD and Steuben County 2006).

A.1.4 Soil Erosion

Soil erosion is a source of particulate phosphorus to waterbodies. The Revised Universal Soil Loss Equation (RUSLE) was used as a tool to predict soil erosion in the watersheds of the impaired lakes and for the Mud Creek-Pigeon Creek HUC 12 watershed (040500011002). This equation takes into account slope, soil type and land use to estimate erosion in tons/ac-year. The strength of this tool is that it can be used to target erosion prone areas; however, the tool does not accurately predict sediment yield because much of the soil loss predicted by this equation settles out in flatter or more vegetated areas before leaving a field. **Error! Reference source not found.** shows the parameters defined and data sources used in the evaluation.

Parameter	Defining GIS Layer	Calculation Notes	Description
R	Set as Constant	Defined from figure on page 251 in *Design hydrology and sedimentology for small catchments* (Haan et al. 1994), the 100 isocline transverses the middle of the watershed	Rainfall/runoff factor
K	County Soil Survey	Varies by soil type; value is listed in soil survey; soil types without listed K values were given a median erosivity value of 0.24	Soil erodibility factor
L	Set as Constant	Assume length = to test plot length of 72.6 ft, L = 1	Slope length factor
S	1.5 meter DEM	S = 10.8 sin (theta) + 0.03 if sin (theta) <0.09, S=16.8sin (theta) - 0.50 if sin(theta) >=0.09	Slope steepness factor
C	NLCD Landcover	Defined from tables on 266-267 *Design hydrology and sedimentology for small catchments* (Haan et al. 1994), Book values of C for different land covers	Cover and management factor
P	Set as Constant	Data not available at scale and resolution necessary. Set conservation factor to 0.5.	Supporting conservation practice factor

Results are presented in the lake TMDL discussions in Section B. Average soil loss ranges from zero to 64, representing a range of soil erosion potential, from lowest to highest in tons/ac-year.

Impaired Lakes

In addition to assessing the pollutant sources as described in Section **Error! Reference source not found.**, a quantitative phosphorus loading analysis was conducted for each lake. External phosphorus loading to lakes was estimated using:

1) average annual runoff depths from the USGS national dataset (Gerbert et al. 1987),
2) monitoring data from upstream lakes,
3) for the direct watershed, export coefficients based on land use and adjusted for the following watershed characteristics, as applicable: CSOs, SSOs, wastewater treatment plants, CFOs, and septic systems.

Internal (in-lake) phosphorus sources include phosphorus released from sediment due to low oxygen, phosphorus released from sediment due to physical disturbance by rough fish, and phosphorus released during the senescence of curly-leaf pondweed, which occurs during the growing season. Internal phosphorus loading will not be estimated because these data are unavailable. Internal loading is included implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail).

A.1.5 Direct Watershed Runoff

<u>Export Coefficients</u>

Direct watershed runoff was estimated using phosphorus export coefficients. Export coefficients are used to model nutrient export from a watershed in the absence of sufficient monitoring data from the watershed. Land cover data were obtained from the 2001 National Land Cover Dataset (NLCD). Each land cover category was assigned an export coefficient, which serves to estimate the phosphorus export from watershed runoff. Export coefficients were obtained from available, relevant literature (Boelter and Verry 1977; Burton and Pitt 2002; Heiskary and Wilson 1994; King et al. 2001; Kunimatsu et al. 1999; Lee

2003; Lee and Pilgrim 2003; Loehr 1974; Marsalek 1978; McDowell and Omernik 1977; Menzel et al. 1978; Mulla et al. 2002; Olness et al. 1980; Rast and Lee 1983; Reckhow et al. 1980; Robertson 1996; Sonzogni et al. 1980; Timmons and Holt 1977; U.S. EPA 1999; U.S. EPA 2001; Uttormark et al. 1974).

Table 33 identifies the export coefficients assigned to each land use category. Average export coefficients range from 0 lb/ac-yr from wetlands (representing a net zero phosphorus load assuming an equal potential for both source and sink conditions) to 1.5 lb/ac-yr from cultivated crops and barren land. Forests have an estimated average phosphorus export of 0.1 lb/ac-yr. Export coefficients for different land covers take into account management practices that occurred on the sites in the literature datasets. For example, the export coefficient for cultivated crops and developed areas includes phosphorus export due to fertilizers and manure applied to land of that cover type. The lower-than-average and higher-than-average export coefficients are reflective of variations in the landscape including, but not limited to, land management practices. Average values were used in most cases. However, data from CFOs and septic systems were used to adjust export coefficients to the higher-than-average export coefficient.

CFO permits are issued by the state and have at least 300 cattle, 500 horses, 600 swine or sheep, or 30,000 fowl, such as chickens, turkeys, or other poultry. CFOs are zero discharge facilities. However, IDEM assumes that land application of manure occurs within a five-mile radius of each CFO on land covers categorized as *cultivated crops* and *hay/pasture*. All direct lake watersheds are within the five-mile radius of at least one CFO. Five direct lake watersheds are within the five-mile radius of six or more CFOs. Accounting for both the number of CFOs within a five-mile radius of the direct watershed and the area of the direct watershed, Long Lake was determined to have average phosphorus export from land covers categorized as *cultivated crops* and *hay/pasture*, and Fish, Lake of the Woods, Little Turkey, Meserve, North Twin, and Royer Lakes were estimated to have higher-than-average phosphorus export from *cultivated crops* and *hay/pasture* due to an estimated higher-than-average land application of manure.

Septic systems from homes within 500 feet of the shores of impaired lakes are assumed to contribute higher-than-average phosphorus to the lake as compared to septic systems in more remote areas of the direct watershed. Homes within 500 feet of the lake are mostly characterized by *developed, low intensity* and *developed, open space* land covers. The areas of *developed, low intensity* and *developed, open space* land covers within 500 feet of the lake were divided by the coverage of those land covers within the entire direct watershed. For each lake, the calculated percent area of *developed, low intensity* and *developed, open space* land covers existing within 500 feet of the shore was assigned a higher-than-average export coefficient. All other *developed, low intensity* and *developed, open space* land covers in the direct watersheds were assigned average export coefficients.

Table 33. TP export coefficients by NLCD land cover category

Land Cover	Phosphorus Export [lb/ac-yr]		
	Lower-than-Average	Average	Higher-than-Average
Barren Land[1]	0.8	1.5	2.0
Cultivated Crops[2]	0.8	1.5	2.0
Deciduous Forest	0.05	0.1	0.2
Developed, Open Space[2,3]	0.3	0.5	0.9
Developed, High Intensity	0.7	1.0	1.3
Developed, Medium Intensity	0.4	0.8	1.2
Developed, Low Intensity[2]	0.3	0.5	0.9
Emergent Herbaceous Wetlands	0	0	0
Evergreen Forest	0.05	0.1	0.15
Grassland/Herbaceous	0.09	0.1	0.2

Land Cover	Phosphorus Export [lb/ac-yr]		
	Lower-than-Average	Average	Higher-than-Average
Hay/Pasture[2]	0.4	0.7	1.3
Mixed Forest	0.05	0.1	0.2
Open Water	0	0	0
Shrub/Scrub	0.09	0.1	0.2
Woody Wetlands	0	0	0

[1] NLCD metadata: *Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.*
[2] Land covers for which export coefficients other than the average were used in the direct watershed runoff estimates of some lakes.
[3] NLCD metadata: *Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes*.

Point Sources

The direct watershed of Long Lake has one wastewater treatment plant (Angola WWTP, IN0021296) that discharges to surface waters. Trans Guard Industries WWTP (INP000137) discharges to the Angola WWTP, so it was not accounted for as a separate point source. Average annual loading for Angola WWTP was estimated based on average annual flows derived for the flow duration analysis. Average annual flows were used for the same time period for which in-lake phosphorus monitoring data was gathered for in-lake modeling (1989-2010) and the permit limit of 1 mg/L, discharges above which require a degree of reduction in phosphorus.

Angola WWTP has two CSO locations within the direct watershed of Long Lake. Average annual loading for the CSOs were estimated through the use of discharge monitoring report data available from 2008-2010. The in-lake modeling time period (1989-2010) begins earlier than the period for which CSO monitoring data is available. It is possible that CSO flows in the past (prior to significant efforts to manage CSOs) had greater volumes.

Point sources that discharge to upstream lakes are accounted for through the upstream lakes loading analysis described in Section A.1.6.

A.1.6 Developing Loads

A.1.7 Calibration and Validation of In-Lake BATHTUB Models

In-lake BATHTUB models (Version 9.1) were developed for each of the seven impaired lakes (seven impaired for phosphorus and five also having impaired biotic communities) to link phosphorus loads with in-lake water quality. BATHTUB, a publicly available model, was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). It has been used successfully in many lake studies throughout the United States. BATHTUB is limited to steady-state annual or seasonal time steps and predicts a lake's growing season (May 1 through September 30) mean surface water quality. These time-scales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB can be easily calibrated to monitoring data and takes into account the effects of non-algal turbidity on lake transparency and responses of algae to phosphorus. It has built-in statistical calculations that account for data variability and provides a means for estimating confidence in model predictions. The heart of BATHTUB is a mass-balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater. The model accounts for outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

Due to the lack of detailed annual loading and water balance data, the models are considered to represent long term average conditions. Phosphorus loads from direct watershed runoff (see Section A.1.5) and upstream lakes (described in *Model Input - Tributary Data: Flow Rate and Phosphorus Concentration*) were used as inputs to the BATHTUB in-lake models. The models were calibrated to existing water quality data, and then used to determine the phosphorus loading capacity of each lake.

<u>System Representation in Model</u>

In typical applications of BATHTUB, lake and reservoir systems are represented by a set of segments and tributaries. Segments are the basins (lakes, reservoirs, etc.) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined inputs of flow and pollutant loading to a particular segment. Loading from upstream waterbodies can be lumped as a single tributary input or as additional tributary inputs.

Under normal use, internal loading is not represented explicitly in BATHTUB. An average rate of internal loading is implicit in BATHTUB since the model is based on empirical data. The model provides an option to include an additional load identified as an internal load if circumstances warrant, but it is generally not recommended. In the lake models for the Pigeon River TMDL calculations, adjustments to internal loading were not necessary for model calibration.

<u>Model Input</u>

The input required to run the BATHTUB model includes watershed and lake geometry information, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data is also entered into the BATHTUB program in order to facilitate model verification and calibration.

Watershed Delineation

Lake watersheds were delineated based on a 30-m resolution (resampled to 10-m) digital elevation model (DEM) (a regularly spaced grid of elevation points), digital representation of the stream network as defined by the National Hydrography Dataset (NHD)[1] at the 1:24,000-scale, and the NHD watershed boundary dataset. The web-based tool used for delineation was the U.S. Geological Survey (USGS) StreamStats. StreamStats is a Geographic Information System (GIS) application created by the USGS, in cooperation with Environmental Systems Research Institute, Inc. (ESRI). StreamStats is based on ESRI's ArcHydro data model and associated tools. StreamStats was designed so that each state in the U.S. would be implemented as a separate application, with a reliance on local partnerships to fund the individual applications. StreamStats for Indiana was developed in cooperation with the Indiana Department of Natural Resources (IN-DNR). Since the DEM for Indiana has been enhanced by a process that ensures conformity with the existing NHD watershed boundary dataset, delineations obtained form StreamStats are considered to be of greater accuracy than delineations obtained from a standard DEM. Watershed delineations were smoothed and checked for quality against 5-foot DEM and 10-foot topography datasets available through the Indiana Spatial Data Portal.

Watersheds were delineated for impaired lakes as well as adjacent upstream lake(s). Watersheds were delineated for upstream lakes in order to estimate loading from the upstream lake(s) to the impaired lake, which is described in *Model Input - Tributary Data: Flow Rate and Phosphorus Concentration*.

[1] The NHD was developed cooperatively by the USGS and the U.S. EPA.

Precipitation and Evaporation
Estimates of average annual precipitation were provided by the USDA/NRCS National Cartography & Geospatial Center based on the years 1971-2000. Average annual evaporation was obtained from NOAA Technical Report 33 based on the years 1956-1970.

Atmospheric Deposition
Average phosphorus atmospheric deposition loading rates are provided through BATHTUB and were applied over each lake's surface area.

Segment Data: Lake Morphometry and Observed Water Quality
Lake morphometry data were gathered from the IN-DNR. Shapefiles were provided from the IN-DNR for Little Turkey and Meserve Lakes based on data collected on July 31, 2007 and July 8, 2009, respectively. Morphometry data for the other five lakes were based on hydrographic surveys conducted in the 1950s published by the IN-DNR and prepared cooperatively by the U.S. Geological Survey (USGS), Water Resources Division. Observed water quality input model was based on growing season means (May 1 through September 30) of total phosphorus, chlorophyll-*a*, and Secchi transparency. The available data and the period of record for total phosphorus can be found in Table 30. For a given lake, the datasets for chlorophyll-*a* and Secchi transparency were from within the same time period as that of total phosphorus. Due to water quality data from Indiana's Volunteer Lake Monitoring Program, the total records for Secchi transparency tended to be more extensive than for total phosphorus and chlorophyll-*a*. No chlorophyll-*a* measurements were taken for Meserve Lake and, therefore, the Meserve Lake model was not calibrated for this parameter. Appendix B.2 includes a summary of chlorophyll-*a* and Secchi transparency data for impaired lakes (see Section A.1.6).

Tributary Data: Flow Rate and Phosphorus Concentration
External phosphorus loading was compiled into the model tributary inputs. Watershed phosphorus sources consist of the average annual direct watershed runoff as estimated using the export coefficient method described in Section A.1.5 and upstream lake loading.

Little Turkey, North Twin, Lake of the Woods, and Meserve Lakes have upstream lakes that were accounted for explicitly in BATHTUB. In-lake phosphorus data were available for all significant upstream lakes (see Appendix B.2 for a summary of available data), and they are mapped in the individual lake summaries (see Section B). Long-term average phosphorus concentrations were multiplied by average annual runoff depths provided in the USGS national dataset based on the time period from 1951-1980 (Gerbert et al. 1987).

Chlorophyll-Secchi Coefficient
Among the empirical model parameters is non-algal turbidity, a term that reflects turbidity due to the presence of color and inorganic solids in the water column. This parameter uses the chlorophyll-Secchi coefficient, which is the ratio of the inverse of Secchi transparency (the inverse being proportional to the light extinction coefficient) to the chlorophyll-*a* concentration. The default coefficient in BATHTUB (0.025 m^2/mg), which was calibrated to United States Army Corps of Engineers reservoir data, was used.

<u>Selection of Equations</u>

BATHTUB allows choice among several different mass balance phosphorus models. The phosphorus model that best predicted the in-lake TP concentration was selected (Table 34). For other parameters, the default model selections (chlorophyll-*a* model based on phosphorus, light, and flushing; transparency model based on chlorophyll-*a* and turbidity) were used.

Table 34. Selection of in-lake model (BATHTUB) equations

Lake	BATHTUB Phosphorus Model
Fish	Second-Order, Available P
Lake of the Woods	Second-Order, Fixed
Little Turkey	Canfield-Bachman, Reservoirs
Long	Second-Order, Available P
Meserve	Vollenweider (1976)
North Twin	Second-Order, Fixed
Royer	Second-Order, Fixed

<u>Model Calibration</u>

For all lake models, calibration coefficients were then modified so that the predicted values of phosphorus, chlorophyll-*a*, and Secchi transparency matched the observed values. Matches were made to the nearest whole number for phosphorus and chlorophyll-*a* concentrations (µg/L), and to the nearest tenth of a meter for Secchi transparencies. Since chlorophyll-*a* concentrations were not available for Meserve Lake, the Meserve Lake model was not calibrated to chlorophyll-*a*.

A.1.8 Lake Loading Analysis Using BATHTUB

The loading capacity of each lake is the TMDL. The goal of the lake loading analysis is to identify the phosphorus load that meets the in-lake phosphorus target (growing season mean of 0.03 mg/L) and the required reduction in existing phosphorus load to meet the target.

With calibrated existing conditions models completed for the lakes, reductions in phosphorus loading were simulated in order to estimate the effects on lake water quality. The phosphorus concentrations associated with tributaries of the calibrated existing conditions model were reduced until the model indicated that the in-lake phosphorus target was met. Loads from the models that meet the standard were compared to the loads from the existing conditions models; this process determined the amount of load reduction required for each lake.

The TMDLs were determined in terms of annual loads. In-lake water quality models predict growing season averages of water quality parameters based on annual loads. The annual loads were converted to daily loads by dividing the annual loads by 365.

- There are uncertainties in predicting lake phosphorus loads and predicting how lakes respond to changes in phosphorus loading.

B LAKE SUMMARY OF DATA AND ALLOCATIONS

Fish Lake

Physical Characteristics

Fish Lake (Table 35) is located in LaGrange County (Figure 18). Royer Lake, also impaired, discharges to Fish Lake. Highly erodible soils in the drainage area west of Fish Lake show a significant potential for field erosion (Figure 19). The east edge of the drainage area also contains a combination of steep slopes and erodible soils although delivery of these soils to the lake is probably much lower than the areas closer to the lake.

Table 35. Fish Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	100	USGS National Hydrography Dataset
Lake volume (ac-ft)	4055	Indiana DNR August 1956 hydrographic survey prepared cooperatively by the USGS
Mean depth (ft)	41	Calculated (lake area / lake volume)
Maximum depth (ft)	78	Indiana DNR August 1956 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	7211	USGS Indiana StreamStats application & EOR
Watershed area: lake area	72	Calculated (watershed area / lake area)
Upstream lakes*	Royer	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported ‘Drainage area’ in this table.

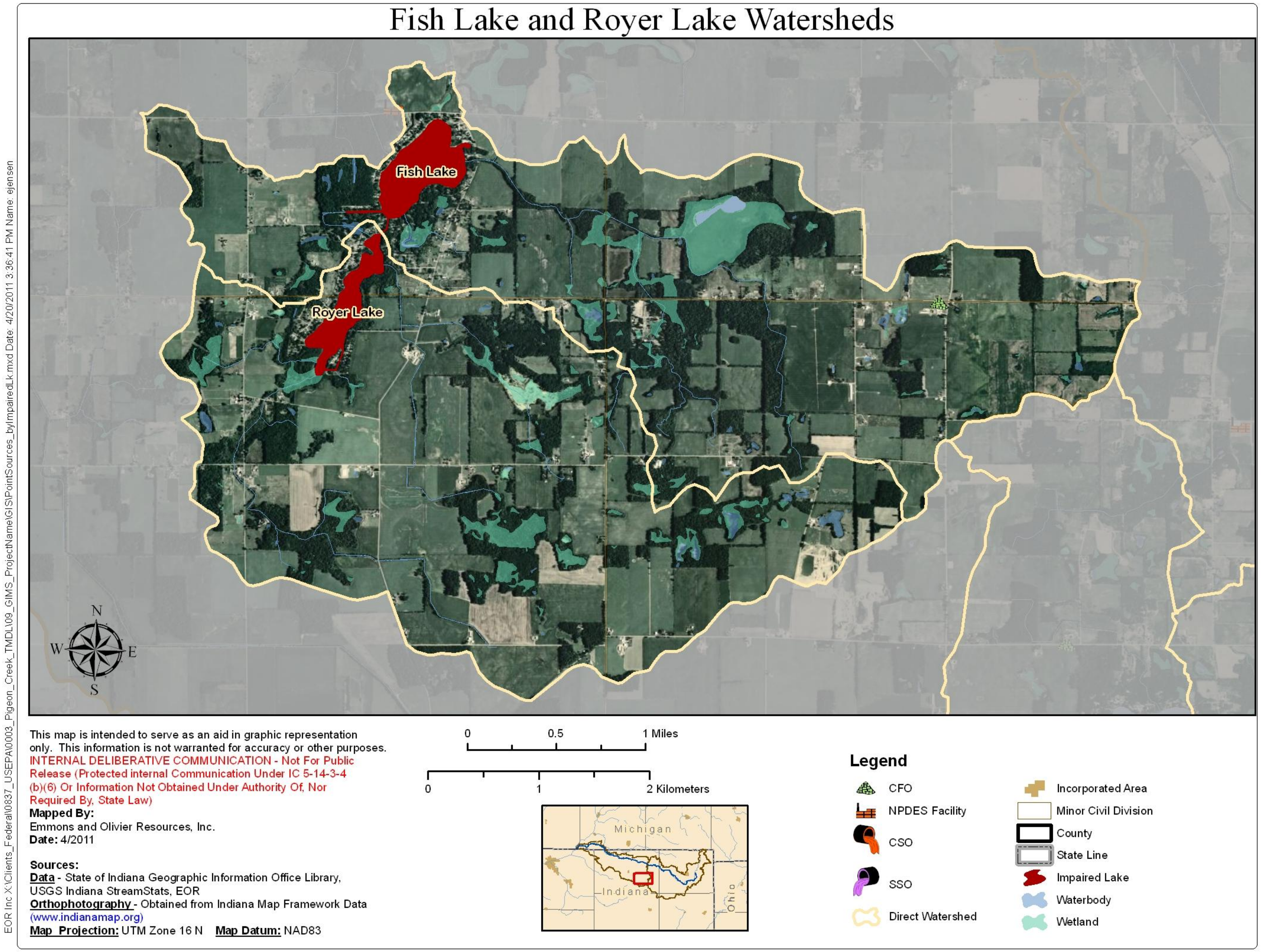

Figure 18. Fish and Royer Lake Watersheds

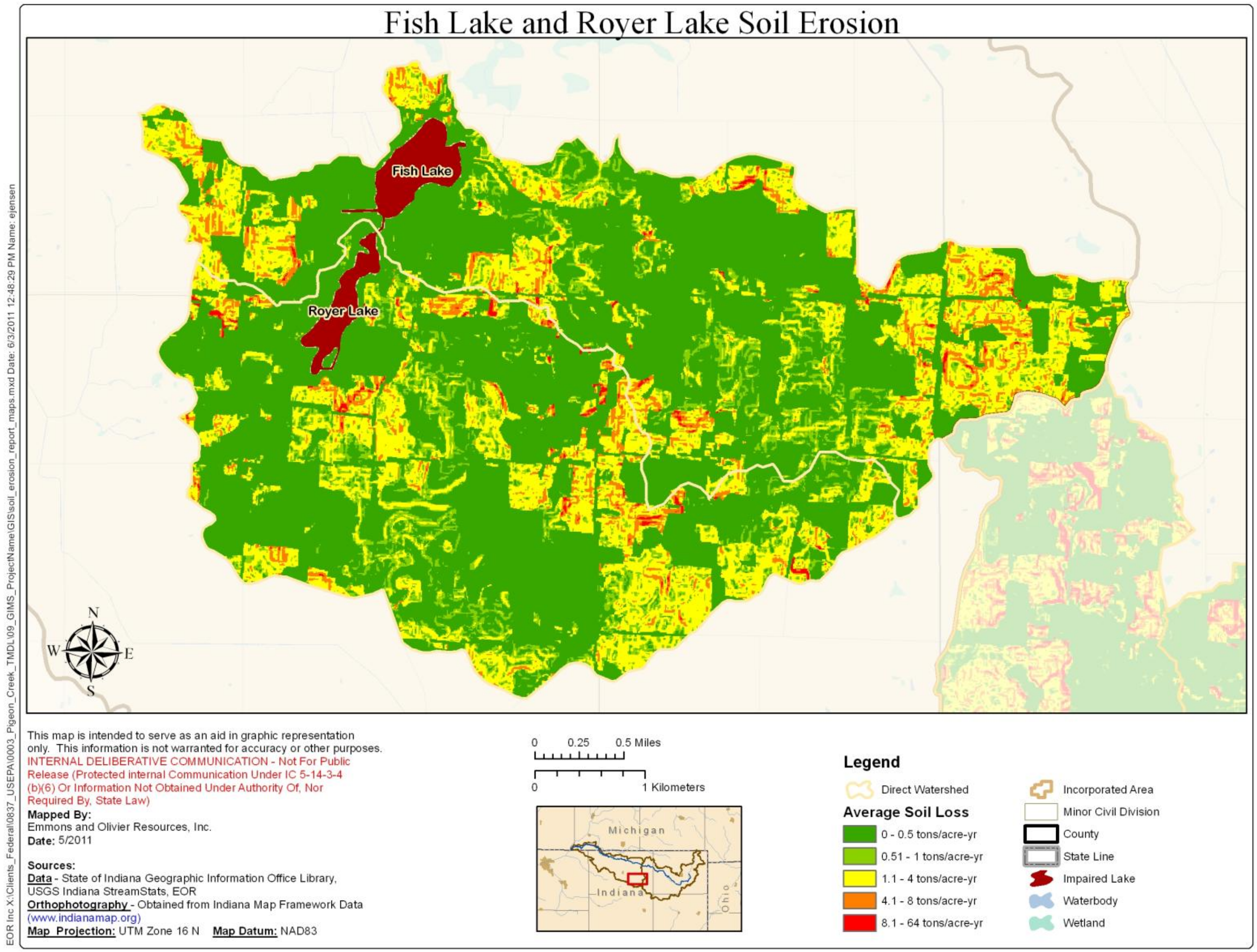

Figure 19. Soil erosion characteristics in Fish and Royer Lake Watersheds

Land Cover

At present, the dominant land cover in the Fish Lake watershed is cultivated crops (Table 36).

Table 36. Fish Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Royer Lake watershed and lake)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	1759	50%	3560	49%
Deciduous Forest	215	6.1%	371	5.1%
Developed, Low Intensity	49	1.4%	105	1.5%
Developed, Medium Intensity	10	0.29%	13	0.18%
Developed, High Intensity	-	-	-	-
Developed, Open Space	174	4.9%	311	4.3%
Emergent Herbaceous Wetlands	58	1.6%	64	0.89%
Evergreen Forest	13	0.37%	44	0.61%
Hay/Pasture	446	13%	999	14%
Herbaceous	55	1.6%	78	1.1%
Mixed Forest	1.2	0.033%	1.2	0.016%
Open Water	16	0.44%	81	1.1%
Shrub/Scrub	-	-	-	-
Woody Wetlands	743	21%	1584	22%
Total*	**3539**	**100%**	**7212**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1989, 1993, 2000, and 2003. The lake is currently meeting lake water quality standards for TP (Table 37). Table 30 shows additional detail regarding the phosphorus monitoring data available for Fish Lake.

Table 37. Fish Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.020	0.030
Chlor-*a* (µg/L)	3.1	none
Secchi transparency (m)	2.2	none

Existing Phosphorus Loading

<u>Watershed Phosphorus Loading</u>

The contributing watershed to Fish Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Royer Lake. It is estimated that Fish Lake receives 4577 pounds of phosphorus annually from external sources (Table 38). Approximately 7% of the phosphorus is coming from Royer Lake.

Table 38. Fish Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	4238	93%
Upstream Lake Loading (Royer Lake)	339	7.4%
Total*	**4577**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Fish Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Fish Lake monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were below 1 mg/l at a depth of 18 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Fish Lake's monitoring data during thermal stratification is evidence of this process occurring; during the two July days that were monitored, hypolimnetic (bottom water) soluble and total phosphorus concentrations were higher than epilimnetic (surface water) concentrations (Table 39). This phosphorus is then available for algal uptake and growth during the following growing season.

Table 39. Fish Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/10/2000	0.01	0.06	0.03	0.06
7/01/2003	0.01	0.05	0.02	0.06

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

Clean Lakes Program data summaries indicate that blue-green algal dominance was high (63-97%), and the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Fish Lake is 9381 lb/yr, to be split among allocations according to Table 40. The lake is currently meeting the TMDL goals. There are no NPDES-permitted sources in the Fish Lake watershed. There is one CFO (#3622) in the Fish Lake watershed; CFOs are zero discharge facilities and receive a LA of zero.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 40. Fish Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	9381	26
MOS	9938	2.6
WLA	0.0	0.0
LA	8443	23

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Fish Lake is in the East Fly Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Fish Lake watershed. The majority of the land use in the watershed is agricultural in nature, and there is one CFO in the watershed. The pollutant sources and management practices for the East Fly Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Fish Lake watershed, in addition to the other sources and implementation approaches identified in Table 41. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 41. Implementation approaches to addresses sources in Fish Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	Highly erodible soils in the drainage area west of Fish Lake and in the east edge of the drainage area (see Figure 19 on page 37)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

<u>Potential Priority Implementation Areas</u>

Fish Lake currently meets water quality standards. However, water quality improvements are still possible, and should focus on the following:

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the CFO, land application of manure and other fertilizers, and droppings from working horses.
- Potential field erosion in the drainage area west of Fish Lake.

Lake of the Woods

Physical Characteristics

Lake of the Woods (Table 42) is located in LaGrange and Steuben Counties (Figure 20). McClish Lake discharges to Lake of the Woods. Highly erodible soils are located in the southern half of the Lake of the Woods drainage area (Figure 21).

Table 42. Lake of the Woods characteristics

Characteristic	Value	Source
Lake total surface area (ac)	117	USGS National Hydrography Dataset
Lake volume (ac-ft)	4,680	Calculated (surface area x mean depth)

Mean depth (ft)	40	Calculated based on Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Maximum depth (ft)	84	Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	2,422	USGS Indiana StreamStats application & EOR
Watershed area: lake area	21	Calculated (watershed area / lake area)
Upstream lakes*	McClish	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported 'Drainage area' in this table.

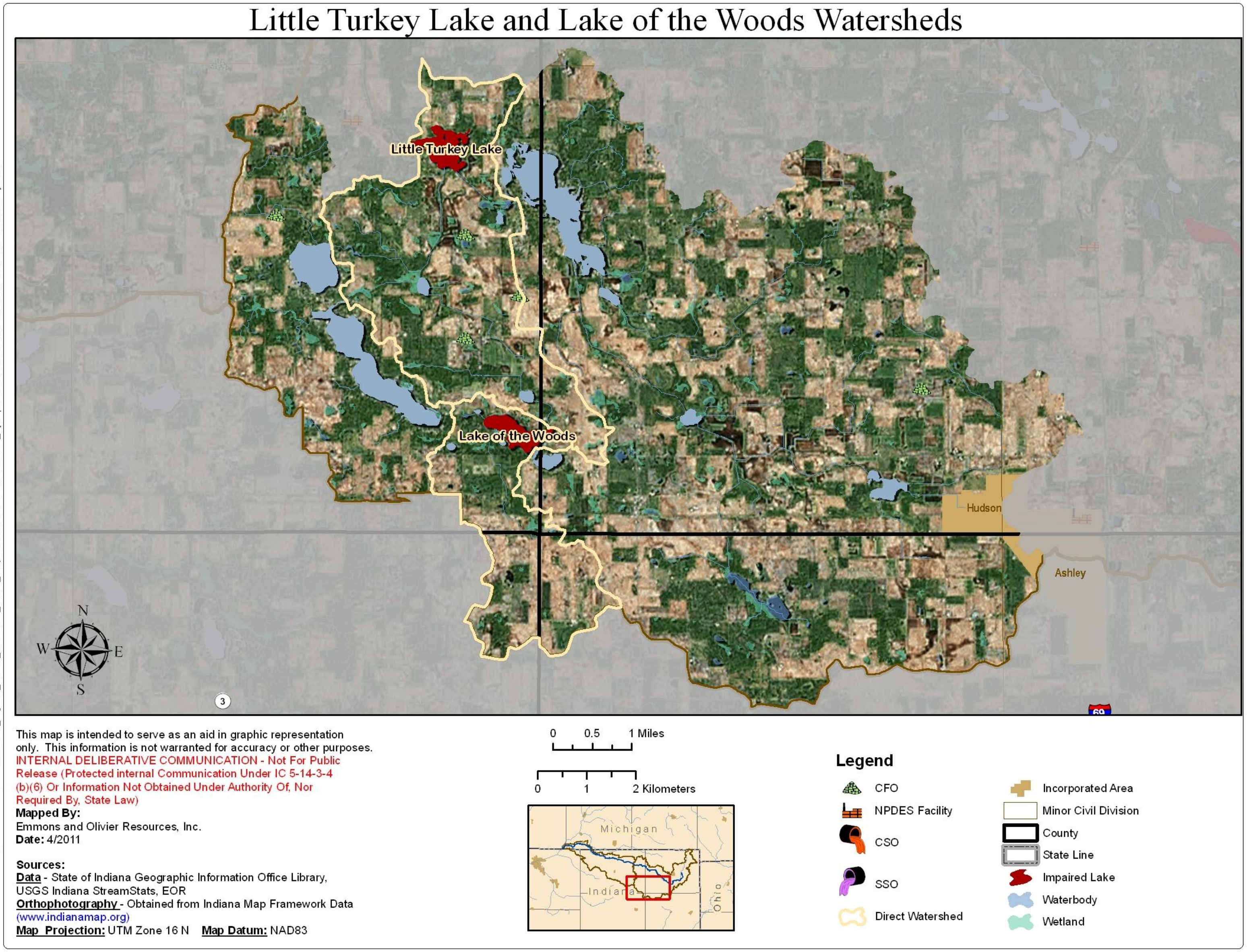

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Figure 20. Little Turkey Lake and Lake of the Woods Watersheds

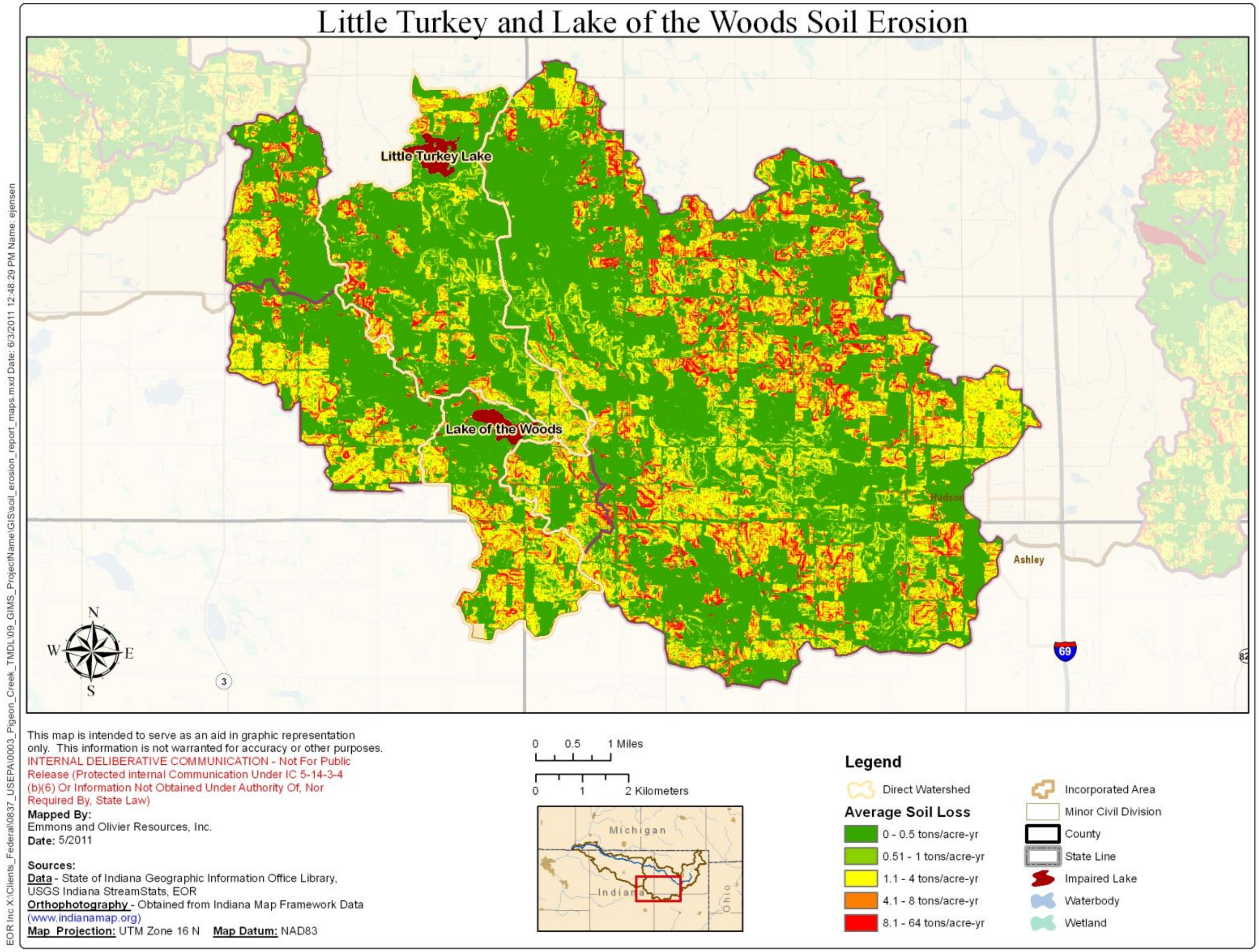

Figure 21. Soil erosion characteristics in Little Turkey Lake and Lake of the Woods Watersheds

Land Cover

At present, the dominant land cover in the Lake of the Woods watershed is cultivated crops (Table 43).

Table 43. Lake of the Woods Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including McClish Lake watershed and lake)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	1302	54%	1779	55%
Deciduous Forest	153	6.3%	206	6.4%
Developed, Low Intensity	53	2.2%	82	2.5%
Developed, Medium Intensity	2.0	0.081%	2.0	0.061%
Developed, High Intensity	-	-	-	-
Developed, Open Space	81	3.3%	99	3.1%
Emergent Herbaceous Wetlands	-	-	1.8	0.055%
Evergreen Forest	17	0.71%	19	0.59%
Hay/Pasture	354	15%	463	14%
Herbaceous	37	1.6%	56	1.7%
Mixed Forest	3.9	0.16%	3.9	0.12%
Open Water	37	1.5%	76	2.3%
Shrub/Scrub	28	1.2%	35	1.08%
Woody Wetlands	354	15%	417	13%
Total*	**2422**	**100%**	**3241**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding

Water Quality

Phosphorus monitoring data are available from 1989, 1992-2002, 2004-2006, 2008-2010. The lake does not meet lake water quality standards for TP (Table 44). Table 30 shows additional detail regarding the phosphorus monitoring data available for Lake of the Woods.

Table 44. Lake of the Woods surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.036	0.030
Chlor-a (µg/L)	3.9	none
Secchi transparency (m)	2.1	none

Existing Phosphorus Loading

<u>Watershed Phosphorus Loading</u>

The contributing watershed to Lake of the Woods includes watershed runoff coming from the direct drainage to the lake and drainage from McClish Lake. It is estimated that Lake of the Woods receives 3213 pounds of phosphorus annually from external sources (Table 45). Approximately 2% of the phosphorus is coming from McClish Lake.

Table 45. Lake of the Woods external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	3146	98%
Upstream Lake Loading (McClish Lake)	67	2.1%
Total*	**3213**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Lake of the Woods is higher than the average of the field datasets used for development of the BATHTUB model.

Lake of the Woods monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were consistently below 1 mg/l at a depth of 17 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Lake of the Woods's monitoring data during thermal stratification is evidence of this process occurring; during four of the five days that the deep hole was monitored, hypolimnetic (bottom water) soluble and total phosphorus concentrations were higher than epilimnetic (surface water) concentrations (Table 46). This phosphorus is then available for algal uptake and growth during the following growing season.

Internal loading in the hypolimnion is not as evident at the other monitoring locations (Table 46).

Table 46. Lake of the Woods water quality data from Clean Lakes Program Data Summary

Date	Site (max depth, m)	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
		Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/19/1989	deep hole (24.7)	0.01	0.33	0.03	0.33
8/25/1992	deep hole (24.7)	0.01	0.01	0.03	0.02
8/26/1997	deep hole (24.7)	0.01	0.24	0.02	0.29
8/5/2002	deep hole (24.7)	0.01	0.20	0.02	0.22
7/24/2006	site 1 (25.3)**	0.01	0.11	0.05	0.17
7/24/2006	site 2 (22.3)	0.01	0.02	0.05	0.04
7/24/2006	site 3 (10.6)	0.01	0.01	0.05	0.05

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l
**It is assumed that site 1 is the site at the deep hole

In the 2006 Clean Lakes Program monitoring, blue-green algal dominance was high (79-94%), and the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Lake of the Woods is 2245 lb/yr, to be split among allocations according to Table 47. To meet the TMDL, the total load to the lake needs to be reduced by 968 lb/yr, or 30%. There are no NPDES-permitted sources of phosphorus in the Lake of the Woods watershed.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 47. Lake of the Woods allocation summary

Allocation*	lb/yr	lb/day
TMDL	2245	6.2
MOS	225	0.62
WLA	0.0	0.0
LA	2020	5.5

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Lake of the Woods is in the Little Turkey Lake – Turkey Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Lake of the Woods watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the Little Turkey Lake – Turkey Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Lake of the Woods watershed, in addition to the other sources and implementation approaches identified in Table 48. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 48. Implementation approaches to addresses sources in Lake of the Woods watershed

Type	Source Summary	Implementation Section
Soil Erosion	Highly erodible soils are located in the southern half of the Lake of the Woods drainage area (see Figure 21 on page 43)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

<u>Potential Priority Implementation Areas</u>

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.
- Potential field erosion in the drainage area south of Lake of the Woods.

Little Turkey Lake

Physical Characteristics

Little Turkey Lake (Table 49) is located in LaGrange County (see Figure 20). Several lakes discharge to Little Turkey Lake: Pretty Lake, Big Long Lake, Lake of the Woods (which is also impaired), and Big Turkey Lake. Patches of highly erodible soils exist throughout the Little Turkey Lake drainage area although they appear to be somewhat isolated (see Figure 21).

Table 49. Little Turkey Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	133	USGS National Hydrography Dataset
Lake volume (ac-ft)	1,317	Calculated (surface area x mean depth)
Mean depth (ft)	9.9	Calculated based on IN-DNR bathymetry data collected on July 31, 2007
Maximum depth (ft)	34	Calculated based on IN-DNR bathymetry data collected on July 31, 2007
Drainage area (acres)	35,942	USGS Indiana StreamStats application & EOR
Watershed area: lake area	270	Calculated (watershed area / lake area)
Upstream Lakes*	Pretty, Big Long, Lake of the Woods, Big Turkey	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported ‘Drainage area’ in this table.

Land Cover

At present, the dominant land cover in the Little Turkey Lake watershed is cultivated crops (Table 50).

Table 50. Little Turkey Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Pretty, Big Long, Lake of the Woods, and Big Turkey Lake watersheds and their lakes)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	2125	44%	17516	49%
Deciduous Forest	361	7.4%	2037	5.7%
Developed, Low Intensity	93	1.9%	933	2.6%
Developed, Medium Intensity	14	0.28%	102	0.28%
Developed, High Intensity	4.1	0.08%	19	0.05%
Developed, Open Space	194	4.0%	1597	4.4%
Emergent Herbaceous Wetlands	4.3	0.089%	56	0.16%
Evergreen Forest	3.7	0.077%	127	0.35%
Hay/Pasture	1032	21%	6228	17%
Herbaceous	75	1.5%	685	2.0%
Mixed Forest	0.082	0.00%	7.9	0.022%
Open Water	69	1.4%	1507	4.2%
Shrub/Scrub	-	-	424	1.2%
Woody Wetlands	905	19%	4702	13%
Total*	**4880**	**100%**	**35942**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1989, 1992-2008, 2010. The lake does not meet lake water quality standards for TP (Table 51). Table 30 shows additional detail regarding the phosphorus monitoring data available for Little Turkey Lake.

Table 51. Little Turkey Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.042	0.030
Chlor-*a* (µg/L)	6.7	none
Secchi transparency (m)	1.5	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to Little Turkey Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Pretty, Big Long, Lake of the Woods, and Big Turkey Lakes. It is estimated that Little Turkey Lake receives 8,684 pounds of phosphorus annually from external sources (Table 52). Approximately 33% of the phosphorus is coming from upstream lakes.

Table 52. Little Turkey Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	5807	67%
Upstream Lake Loading (Pretty, Big Long, Lake of the Woods, and Big Turkey)	2877	33%
Total*	**8684**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Little Turkey Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Little Turkey Lake monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were consistently below 1 mg/l at a depth of 5 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Lake of the Woods's monitoring data during thermal stratification is evidence of this process occurring; during four of the five days that the deep hole was monitored, hypolimnetic (bottom water) soluble and total phosphorus concentrations were higher than epilimnetic (surface water) concentrations (Table 53). On the remaining day (8/6/2002), soluble phosphorus was higher in the hypolimnion whereas total phosphorus was not. However, since Little Turkey Lake has a very short residence time (less than one month), the phosphorus will have flushed downstream by the time that the next growing season has begun. The phosphorus will be available for algal growth in downstream waterbodies.

Internal loading in the hypolimnion is not as evident at the other monitoring locations (Table 53).

Table 53. Little Turkey Lake water quality data from Clean Lakes Program Data Summary

Date	Site (max depth, m)	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
		Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/24/1989	deep hole (8.5)	0.01	0.04	0.03	0.09
7/27/1993	deep hole (8.5)	0.01	0.53	0.02	0.62
8/25/1997	deep hole (10.1)	0.01	0.56	0.08	0.58
8/6/2002	deep hole (10.1)	0.01	0.29	0.03	0.01
7/24/2006	1 (10.3)**	0.01	0.10	0.05	0.14
7/24/2006	2 (3.3)	0.01	0.01	0.03	0.05
7/24/2006	3 (3)	0.01	0.01	0.04	0.06

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l
**It is assumed that site 1 is the site at the deep hole

In the 2006 Clean Lakes Program monitoring, blue-green algal dominance was high (63-88%), and the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Little Turkey Lake is 5236 lb/yr, to be split among allocations according to Table 54. To meet the TMDL, the total load to the lake needs to be reduced by 3448 lb/yr, or 40%. There are no NPDES-permitted sources of phosphorus in the watershed. There are five CFOs (#291, 659, 1005, 6390, and 6650) in the watershed; CFOs are zero discharge facilities and receive a LA of zero.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 54. Little Turkey Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	5236	14
MOS	524	1.4
WLA	0.0	0.0
LA	4712	13

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Little Turkey Lake is in the Little Turkey Lake – Turkey Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Little Turkey Lake watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the Little Turkey Lake – Turkey Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Little Turkey Lake watershed, in addition to the other sources and implementation approaches identified in Table 55. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 55. Implementation approaches to addresses sources in Little Turkey Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	Patches of highly erodible soils exist throughout the Little Turkey Lake drainage area although they appear to be somewhat isolated (see Figure 21 on page 43)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

Potential Priority Implementation Areas

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.
- Potential field erosion in the drainage area south of Little Turkey Lake.

Long Lake

Physical Characteristics

Long Lake (Table 56) is located in Steuben County (Figure 22). Several lakes discharge to Long Lake: Meserve Lake (which is also impaired), Fox Lake, and Pigeon Lake. Upstream of Long Lake are the following landlocked lakes: Gravel Pit and Pleasant. The Long Lake drainage area contains a large amount of highly erodible soils throughout its drainage area (Figure 23).

Table 56. Long Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	92	USGS National Hydrography Dataset
Lake volume (ac-ft)	1,564	Calculated (surface area x mean depth)
Mean depth (ft)	17	Calculated based on Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Maximum depth (ft)	32	Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	44,651	USGS Indiana StreamStats application & EOR
Watershed area: lake area	485	Calculated (watershed area / lake area)
Upstream Lakes*	Meserve, Fox, Pigeon	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported 'Drainage area' in this table.

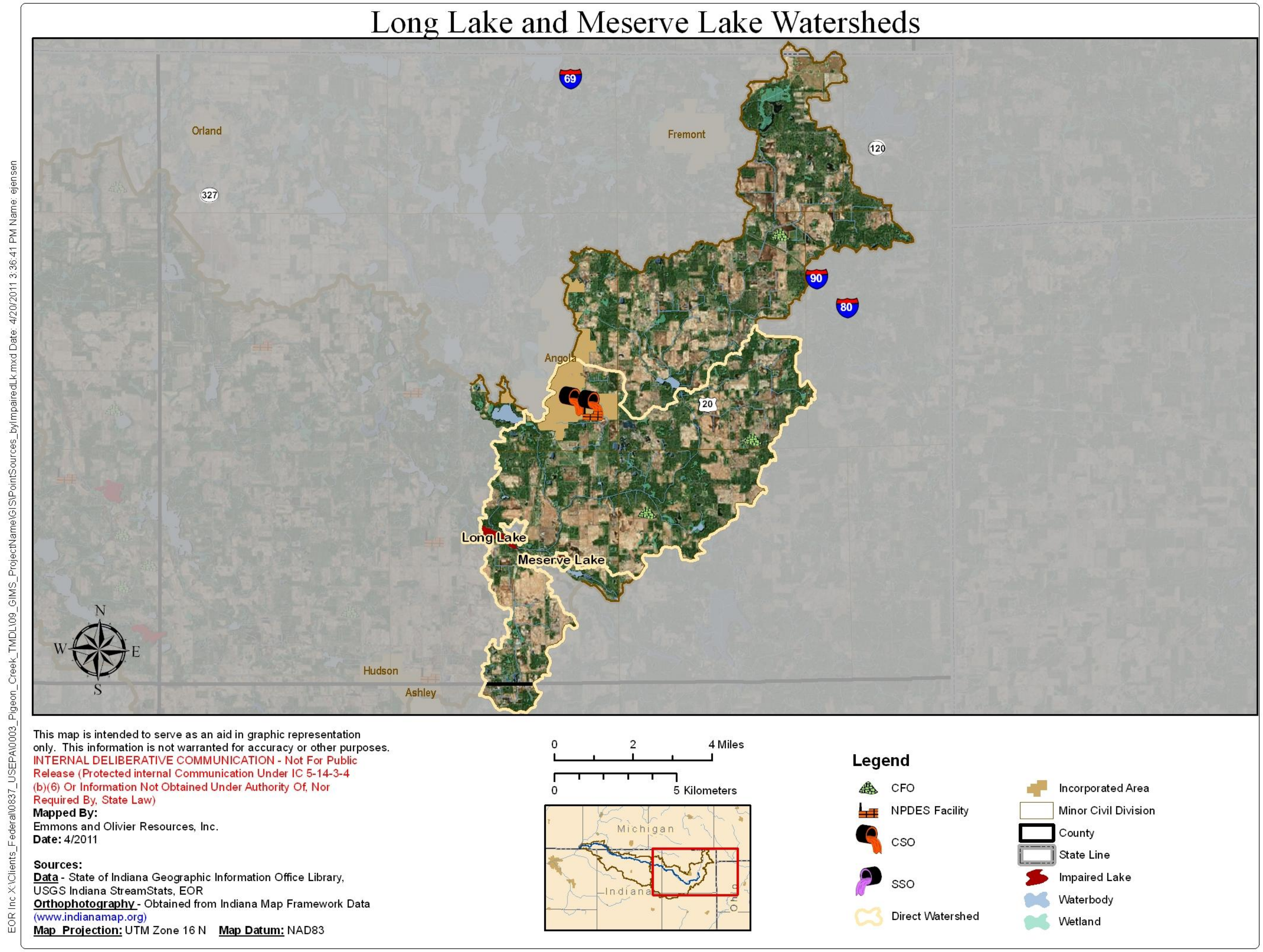

Figure 22. Long and Meserve Lake Watersheds

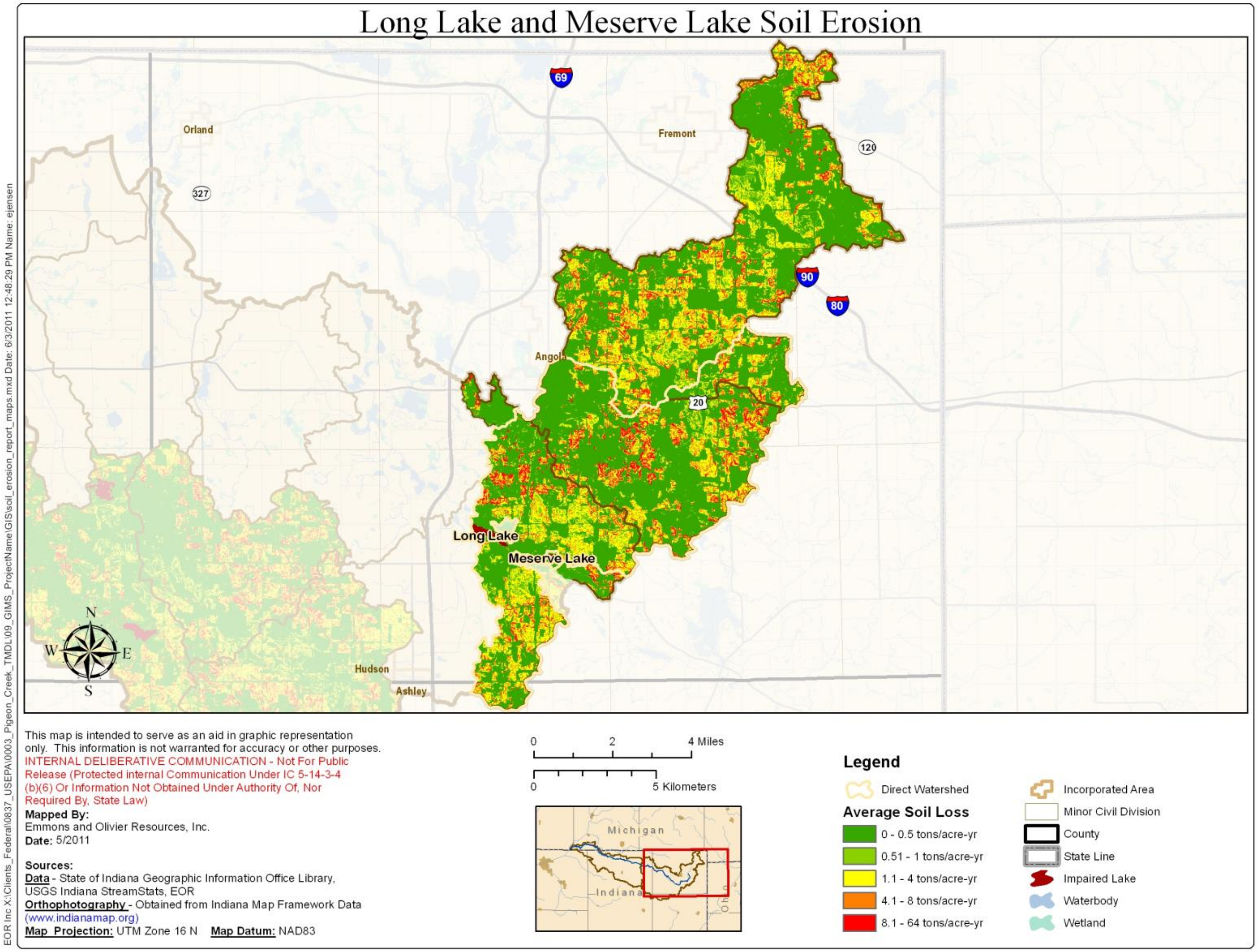

Figure 23. Soil erosion characteristics in Long and Meserve Lake Watersheds and the Mud Creek-Pigeon Creek HUC 12 Watershed

Land Cover

At present, the dominant land covers in the Long Lake watershed are cultivated crops and hay/pasture (Table 57).

Table 57. Long Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Meserve, Fox, and Pigeon Lake watersheds and their lakes)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	2.4	0.0053%
Cultivated Crops	10284	44%	19647	44%
Deciduous Forest	982	4.2%	1839	4.1%
Developed, Low Intensity	860	3.7%	1248	2.8%
Developed, Medium Intensity	239	1.0%	341	0.76%
Developed, High Intensity	105	0.44%	120	0.27%
Developed, Open Space	1276	5.4%	2604	5.8%
Emergent Herbaceous Wetlands	43	0.18%	89	0.20%
Evergreen Forest	23	0.10%	71	0.16%
Hay/Pasture	5210	22%	10091	23%
Herbaceous	349	1.5%	842	1.9%
Mixed Forest	9.0	0.038%	42	0.095%
Open Water	219	0.93%	574	1.3%
Shrub/Scrub	2.8	0.012%	3.9	0.0088%
Woody Wetlands	3952	17%	7136	16%
Total*	**23553**	**100%**	**44651**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1989, 1990, 1992-1999, 2002, 2009, 2010. The lake does not meet lake water quality standards for TP (Table 58). Table 30 shows additional detail regarding the phosphorus monitoring data available for Long Lake.

Table 58. Long Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.056	0.030
Chlor-*a* (µg/L)	19	none
Secchi transparency (m)	1.1	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to Long Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Meserve, Fox, and Pigeon Lakes. It is estimated that Long Lake receives 26,432 pounds of phosphorus annually from external sources (Table 59). Approximately 11% of the phosphorus is coming from upstream lakes. Approximately 11% is coming from Angola Municipal wastewater treatment plant.

Table 59. Long Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	20,617	78%
Upstream Lake Loading (Meserve, Fox, and Pigeon Lakes)	2,996	11%
Angola Municipal WWTP (Permit # IN0021296)	2,786	11%
Angola Municipal WWTP CSOs (Pipe ID 002 and 003, Permit # IN0021296)	33	0.12%
Total*	**26,432**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Long Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Long Lake monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were consistently below 1 mg/l at a depth of 5 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Long Lake's monitoring data during thermal stratification is evidence of this process occurring; during all of the days that the lake was monitored, hypolimnetic (bottom water) total phosphorus concentrations were higher than (at least double) epilimnetic (surface water) concentrations (Table 60). The same was true for soluble phosphorus during four of the five monitoring days. However, since Long Lake has a relatively short residence time (less than one month), the phosphorus will have flushed downstream by the time that the next growing season has begun. The phosphorus will be available for algal growth in downstream waterbodies.

Table 60. Long Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/18/1989	0.01	0.36	0.06	0.37
8/13/1990	0.01	0.27	0.05	0.32
8/17/1992	0.01	0.01	0.06	0.65
8/4/1997	0.01	0.73	0.07	0.78
7/8/2002	0.01	0.03	0.04	0.08
7/6/2009	0.01	0.11	0.02	0.17

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

In the 2009 Clean Lakes Program monitoring, blue-green algal dominance was high (96%), indicating eutrophic conditions.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Long Lake is 8,700 lb/yr, to be split among allocations according to Table 61. To meet the TMDL, the total load to the lake needs to be reduced by 17,732 lb/yr, or 67%. The NPDES-permitted sources in the Long Lake watershed receive individual WLAs (Table 62). There are three CFOs (#1082, 1108, 6067) in the watershed; CFOs are zero discharge facilities and receive a LA of zero.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 61. Long Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	8,700	24
MOS	870	2.4
WLA	5,864	16
LA	1,966	5.4

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Table 62. Long Lake WLAs

Source	Permit #	WLA	
		lb/yr	lb/day
Angola Municipal WWTP	IN0021296	5110	14
Angola Municipal WWTP CSO (Pipe ID 002)	IN0021296	402	1.1
Angola Municipal WWTP CSO (Pipe ID 003)	IN0021296	19	0.053
City of Angola and Trine University MS4	INR040005	333	0.91

Implementation Strategy

Long Lake is in the Long Lake – Pigeon Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Long Lake watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the Long Lake – Pigeon Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Long Lake watershed, in addition to the other sources and implementation approaches identified in Table 63. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 63. Implementation approaches to addresses sources in Long Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	The Long Lake drainage area contains a large amount of highly erodible soils throughout its drainage area (see Figure 23 on page 53)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

<u>Potential Priority Implementation Areas</u>

- City of Angola WWTP: Implementation should address the permit related activities for the WWTP (described in Section **Error! Reference source not found.**). Implementation for the CSOs that are related to the WWTP should focus on minimizing overflow events (described in Section **Error! Reference source not found.**).

- City of Angola MS4: As a phase II community, Angola has an NPDES permit that requires six minimum control measures (MCMs). A description of the MCMs and guidance on the types of activities to comply with the MCMs is provided in Section **Error! Reference source not found.**.
- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.
- Potential field erosion in the drainage area.

Meserve Lake

Physical Characteristics

Meserve Lake (Table 64) is located in Steuben County (see Figure 22). Gooseneck Lake discharges to Meserve Lake. The Meserve Lake drainage area contains no highly erodible soils (see Figure 23).

Table 64. Meserve Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	18	USGS National Hydrography Dataset
Lake volume (ac-ft)	198	Calculated (surface area x mean depth)
Mean depth (ft)	11	Calculated based on IN-DNR bathymetry data collected on July 8, 2009
Maximum depth (ft)	24	Calculated based on IN-DNR bathymetry data collected on July 8, 2009
Drainage area (acres)	620	USGS Indiana StreamStats application & EOR
Watershed area: lake area	34	Calculated (watershed area / lake area)
Upstream Lakes*	Gooseneck	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported ‘Drainage area’ in this table.

Land Cover

At present, the dominant land covers in the Meserve Lake watershed are cultivated crops and hay/pasture (Table 65).

Table 65. Meserve Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Gooseneck Lake watershed and lake)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	14	17%	219	35%
Deciduous Forest	-	-	24	3.8%
Developed, Low Intensity	14	19%	18	3.0%
Developed, Medium Intensity	-	-	-	-
Developed, High Intensity	-	-	-	-
Developed, Open Space	8.6	11%	40	6.4%
Emergent Herbaceous Wetlands	1.2	1.5%	1.2	0.19%
Evergreen Forest	-	-	3.7	0.60%
Hay/Pasture	15	19%	177	29%
Herbaceous	0.69	0.88%	29	4.7%
Mixed Forest	-	-	-	-
Open Water	1.6	2.1%	30	4.8%
Shrub/Scrub	-	-	-	-
Woody Wetlands	23	30%	78	13%
Total*	**78**	**100**	**620**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1990 and 1992. Chlorophyll-*a* data were not available for Meserve Lake. The lake does not meet lake water quality standards for TP (Table 66). Table 30 shows additional detail regarding the phosphorus monitoring data available for Meserve Lake.

Table 66. Meserve Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.034	0.030
Chlor-*a* (µg/L)	n/a	none
Secchi transparency (m)	3.6	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to Meserve Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Gooseneck Lake. It is estimated that Meserve Lake receives 82 pounds of phosphorus annually from external sources (Table 67). Approximately 36% of the phosphorus is coming from Gooseneck Lake.

Table 67. Meserve Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	52	64%
Upstream Lake Loading (Gooseneck Lake)	30	36%
Total*	**82**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

<u>Internal Phosphorus Loading</u>

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Meserve Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Meserve Lake monitoring data indicate that internal loading might be a source of phosphorus to the lake. During one of the monitoring days (7/10/1990), hypolimnetic (bottom water) total phosphorus concentrations were higher than epilimnetic (surface water) concentrations (Table 68). However, hypolimnetic soluble phosphorus concentrations were the same as epilimnetic concentrations. The bottom waters remained oxic, so it is not clear why the total phosphorus concentration was so high in the hypolimnion. On the other monitoring day (8/18/1992), hypolimnetic soluble and total phosphorus concentrations were not higher than epilimnetic concentrations.

Table 68. Meserve Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/10/1990	0.01	0.01	0.01	0.36
8/18/1992	0.01	0.01	0.06	0.04

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

Clean Lakes Program data summaries indicate that the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Meserve Lake is 75 lb/yr, to be split among allocations according to Table 69. To meet the TMDL, the total load to the lake needs to be reduced by 7 lb/yr, or 8.5%. There are no NPDES-permitted sources in the Meserve Lake watershed; therefore, there are no individual WLAs.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 69. Meserve Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	75	0.21
MOS	7.5	0.021
WLA	0.0	0.0
LA	68	0.19

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Meserve Lake is in the Long Lake – Pigeon Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Meserve Lake watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the Long Lake – Pigeon Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Meserve Lake watershed, in addition to the other sources and implementation approaches identified in Table 70. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 70. Implementation approaches to addresses sources in Meserve Lake watershed

Type	Source Summary	Implementation Section
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Internal Loading	Control of curly-leaf pondweed	B.1.1

Starting in approximately 2006, the aquatic plant parrot feather (*Myriophyllum aquaticum*) was found in Meserve Lake. Parrot feather is a type of milfoil that is native to South America, and it often becomes invasive in waters such as small lakes and drainage ditches outside of its native range. It is used in aquaria and was likely introduced into the lake by an owner of an aquarium or garden pond. If not controlled, the plant has the potential to spread throughout the lake and other waterbodies, impairing recreational and ecological functions.

An aquatic plant management plan is detailed in the Meserve Lake Aquatic Vegetation Management Plan Update (Aquatic Enhancement & Survey, Inc. 2009). Areas of the lake containing parrot feather plant were treated in 2008, and management activities for 2009 and beyond were detailed in the plan with the goal of 1) achieving eradication of parrot feather in Meserve Lake by the end of the 2009 season, and 2) increasing awareness among lake residents and users that parrot feather is invasive and that measures should be taken to prevent the re-introduction and spread of the plant in the lake. For 2010, planned activities included hand removal of free floating plants and herbicide application.

Curly-leaf pondweed was also found in low abundance in Meserve Lake. Its presence in the lake is minimal and it was determined in the Aquatic Vegetation Management Plan Update that it does not warrant treatment, but that it should be monitored.

<u>Potential Priority Implementation Areas</u>

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.

North Twin Lake

Physical Characteristics

North Twin Lake (Table 71) is located in LaGrange County (Figure 24). Still Lake discharges to North Twin Lake. The North Twin Lake drainage area contains only small portions of highly erodible soils, just to the east of the lake (Figure 25).

Table 71. North Twin Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	136	USGS National Hydrography Dataset
Lake volume (ac-ft)	2,176	Calculated (surface area x mean depth)
Mean depth (ft)	16	Calculated based on Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Maximum depth (ft)	40	Indiana DNR August 1958 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	1,011	USGS Indiana StreamStats application & EOR
Watershed area: lake area	7.4	Calculated (watershed area / lake area)
Upstream Lakes*	Still	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported ‘Drainage area’ in this table.

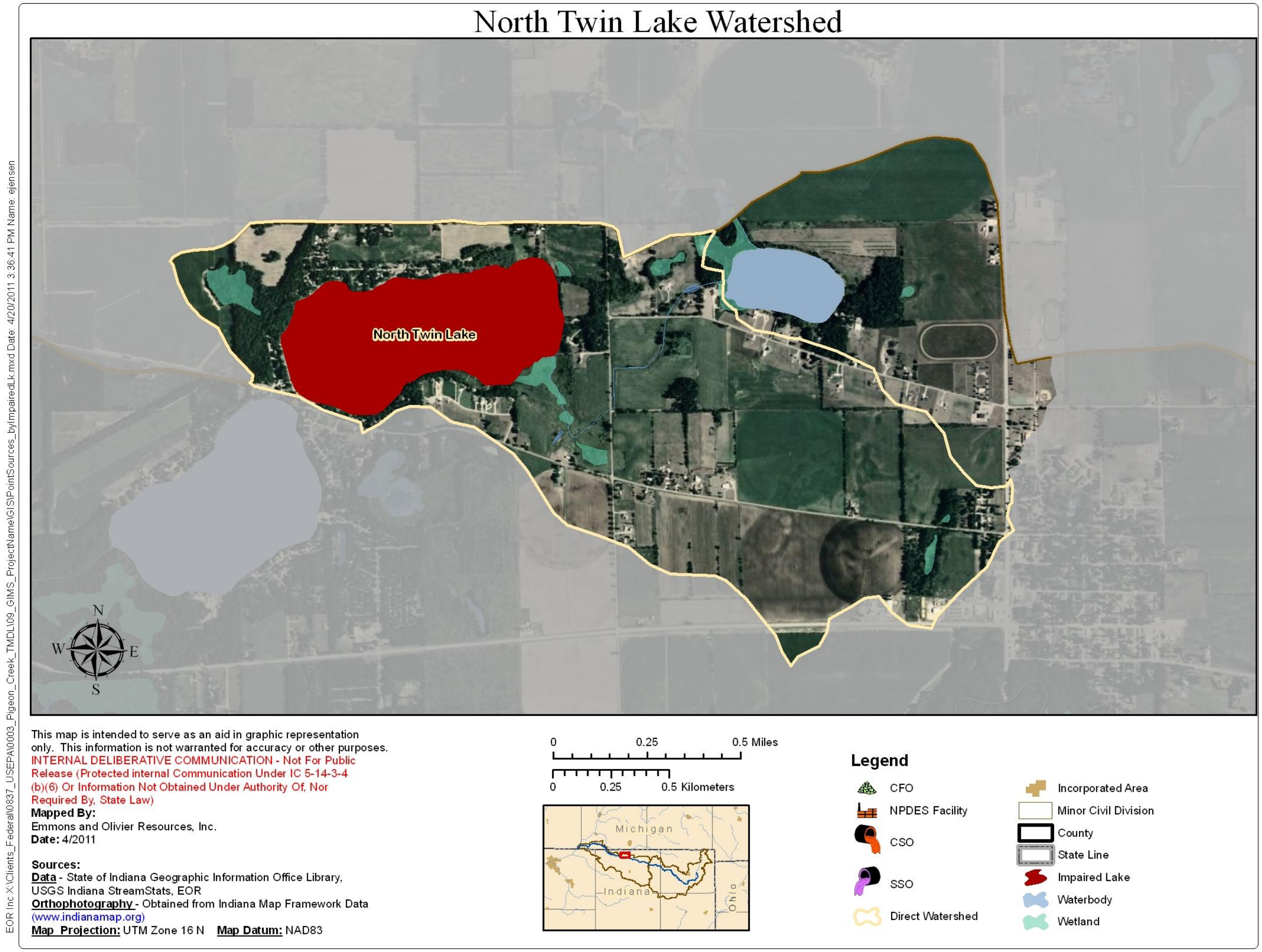

Figure 24. North Twin Lake Watershed

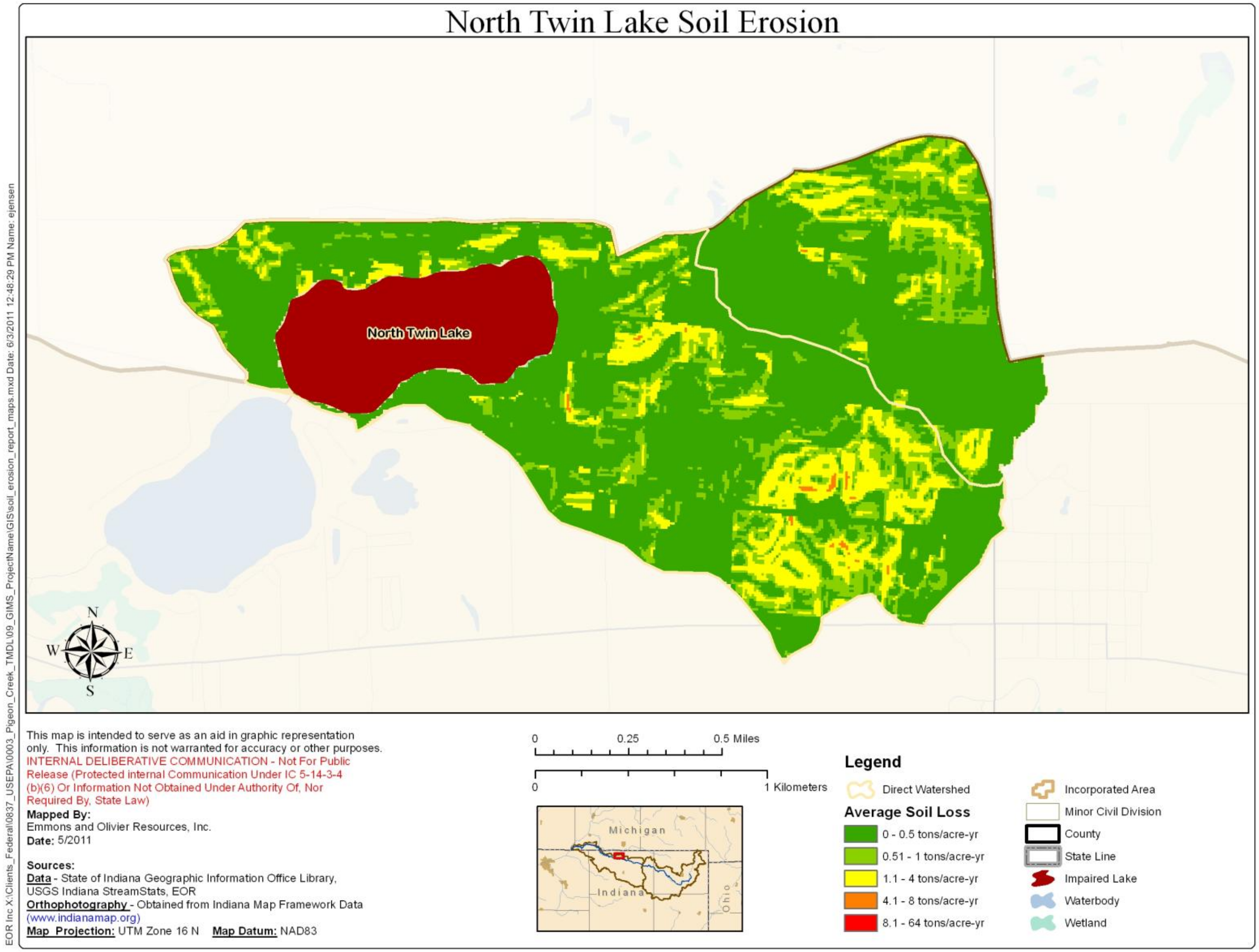

Figure 25. Soil erosion characteristics in North Twin Lake Watershed

Land Cover

At present, the dominant land cover in the North Twin Lake watershed is cultivated crops (Table 72).

Table 72. North Twin Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage		Entire Drainage (including Still Lake watershed and lake)	
	Acres	% of Watershed	Acres	% of Watershed
Barren Land	-	-	-	-
Cultivated Crops	412	58%	552	55%
Deciduous Forest	13	1.8%	17	1.7%
Developed, Low Intensity	51	7.2%	64	6.3%
Developed, Medium Intensity	0.40	0.057%	3.3	0.33%
Developed, High Intensity	1.3	0.19%	1.3	0.13%
Developed, Open Space	28	3.9%	46	4.5%
Emergent Herbaceous Wetlands	-	-	-	-
Evergreen Forest	-	-	-	-
Hay/Pasture	94	13%	150	15%
Herbaceous	3.1	0.44%	16	1.6%
Mixed Forest	1.3	0.19%	1.3	0.13%
Open Water	7.3	1.0%	38	3.7%
Shrub/Scrub	-	-	-	-
Woody Wetlands	97	14%	122	12%
Total*	**709**	**100%**	**1011**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1989, 1993, and 2000. The lake does not meet lake water quality standards for TP (Table 73). Table 30 shows additional detail regarding the phosphorus monitoring data available for North Twin Lake.

Table 73. North Twin Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.040	0.030
Chlor-*a* (µg/L)	0.65	none
Secchi transparency (m)	2.0	none

Existing Phosphorus Loading

<u>Watershed Phosphorus Loading</u>

The contributing watershed to North Twin Lake includes watershed runoff coming from the direct drainage to the lake and drainage from Still Lake. It is estimated that North Twin Lake receives 82 pounds of phosphorus annually from external sources (Table 74). Approximately 10% of the phosphorus is coming from Still Lake.

Table 74. North Twin Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	792	90%
Upstream Lake Loading (Still Lake)	90	10%
Total*	**882**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in North Twin Lake is higher than the average of the field datasets used for development of the BATHTUB model.

North Twin Lake monitoring data indicate that internal loading due to anoxia in bottom waters is likely not a source of phosphorus to the lake. There was no difference in the hypolimnetic (bottom water) soluble and total phosphorus concentrations and epilimnetic (surface water) concentrations (Table 75).

Table 75. North Twin Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
7/31/1989	0.01	0.01	0.09	0.08
7/20/1993	0.01	0.01	0.01	0.01
7/6/2000	0.01	0.01	0.03	0.03

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

Clean Lakes Program data summaries indicate that the zooplankton community was skewed towards smaller zooplankton (rotifers, as opposed to cladocera) that have less ability to control algal densities.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of North Twin Lake is 565 lb/yr, to be split among allocations according to Table 76. To meet the TMDL, the total load to the lake needs to be reduced by 317 lb/yr, or 36%. There are no NPDES-permitted sources in the North Twin Lake watershed; therefore, there are no individual WLAs.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 76. North Twin Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	565	1.5
MOS	57	0.16
WLA	0.0	0.0
LA	508	1.4

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

North Twin Lake is in the VanNatta Ditch – Pigeon River HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the North Twin Lake watershed. The majority of the land use in the watershed is agricultural in nature. The pollutant sources and management practices for the VanNatta Ditch – Pigeon River HUC 12 watershed (**Error! Reference source not found.**) apply to the North Twin Lake watershed, in addition to the other sources and implementation approaches identified in Table 77. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 77. Implementation approaches to addresses sources in North Twin Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	The North Twin Lake drainage area contains only small portions of highly erodible soils, just to the east of the lake (see Figure 25 on page 63)	**Error! Reference source not found.**
Internal Loading	Potential imbalanced in-lake ecological interactions	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

Potential Priority Implementation Areas

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the land application of manure and other fertilizers.

Royer Lake

Physical Characteristics

Royer Lake (Table 78) is located in LaGrange County (see Figure 18). There are no upstream lakes in the Royer Lake watershed. Highly erodible soils with the occasional steep slope in the area just south of Royer Lake show a significant potential for field erosion (see Figure 19).

Table 78. Royer Lake characteristics

Characteristic	Value	Source
Lake total surface area (ac)	65	USGS National Hydrography Dataset
Lake volume (ac-ft)	1,560	Calculated (surface area x mean depth)
Mean depth (ft)	24	Calculated based on Indiana DNR August 1956 hydrographic survey prepared cooperatively by the USGS
Maximum depth (ft)	56	Indiana DNR August 1956 hydrographic survey prepared cooperatively by the USGS
Drainage area (acres)	3,608	USGS Indiana StreamStats application & EOR
Watershed area: lake area	56	Calculated (watershed area / lake area)
Upstream Lakes*	none	USGS Indiana StreamStats application & EOR

* These are the significant adjacent upstream lakes, which were accounted for explicitly in phosphorus modeling through the use of monitoring data (see Section A.1.6). These lakes and their drainage areas are included in the reported 'Drainage area' in this table.

Land Cover

At present, the dominant land cover in the Royer Lake watershed is cultivated crops (Table 79).

Table 79. Royer Lake Watershed land cover
(2001 National Land Cover Dataset)

Land Cover	Direct Drainage	
	Acres	% of Watershed
Barren Land	-	-
Cultivated Crops	1801	50%
Deciduous Forest	155	4.3%
Developed, Low Intensity	56	1.6%
Developed, Medium Intensity	2.6	0.071%
Developed, High Intensity	-	-
Developed, Open Space	138	3.8%
Emergent Herbaceous Wetlands	6.7	0.19%
Evergreen Forest	31	0.87%
Hay/Pasture	552	15%
Herbaceous	23	0.65%
Mixed Forest	-	-
Open Water	9.1	0.25%
Shrub/Scrub	-	-
Woody Wetlands	833	23%
Total*	**3608**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Water Quality

Phosphorus monitoring data are available from 1993, 2000, and 2003. The lake does not meet lake water quality standards for TP (Table 80). Table 30 shows additional detail regarding the phosphorus monitoring data available for Royer Lake.

Table 80. Royer Lake surface water quality means and targets

Parameter	Growing Season Mean (May 1 – September 30)	Lake Target
TP (mg/L)	0.040	0.030
Chlor-*a* (µg/L)	0.65	none
Secchi transparency (m)	2.0	none

Existing Phosphorus Loading

Watershed Phosphorus Loading

The contributing watershed to Royer Lake includes watershed runoff coming from the direct drainage to the lake. There are no upstream lakes in Royer Lake watershed. It is estimated that Royer Lake receives 4,448 pounds of phosphorus annually from external sources (Table 81).

Table 81. Royer Lake external phosphorus source summary

Phosphorus Source	Annual TP Load [lb/yr]	Percent of External TP Load (%)
Direct Watershed Runoff	4448	100%
Upstream Lake Loading (none)	-	-
Total*	**4448**	**100%**

* Totals do not necessarily equal the sum of the rows above due to rounding.

Internal Phosphorus Loading

Internal (in-lake) loading is accounted for implicitly in in-lake BATHTUB modeling (see Section A.1.6 *Calibration and Validation of In-Lake BATHTUB Models: System Representation in Model* for more detail). During calibration of the in-lake models, there was no indication that internal loading in Royer Lake is higher than the average of the field datasets used for development of the BATHTUB model.

Royer Lake monitoring data indicate that internal loading is a source of phosphorus to the lake. Dissolved oxygen concentrations were below 1 mg/l at a depth of 4 meters and below. At these low dissolved oxygen concentrations, phosphorus is released from the sediment to the hypolimnion and mixes with the surface water when the water column mixes during fall turnover. Royer Lake's monitoring data during thermal stratification is evidence of this process occurring; during three of the four days that were monitored, hypolimnetic (bottom water) soluble and total phosphorus concentrations were higher (at least double) than epilimnetic (surface water) concentrations (Table 82). This phosphorus is then available for algal uptake and growth during the following growing season.

Table 82. Royer Lake water quality data from Clean Lakes Program Data Summary

Date	Soluble Reactive Phosphorus, (mg/l*)		Total Phosphorus (mg/l*)	
	Epilimnion	Hypolimnion	Epilimnion	Hypolimnion
1989	0.001	0.32	0.04	0.34
1993	0.003	0.25	0.05	0.30
7/10/2000	0.01	0.01	0.04	0.05
7/01/2003	0.01	0.17	0.01	0.18

*Units were not reported in the Clean Lakes Program data summary, but are assumed to be mg/l

Clean Lakes Program data summaries indicate that blue-green algal dominance was high (96% in 2000 and 2003), indicating eutrophic conditions.

TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Royer Lake is 3536 lb/yr, to be split among allocations according to Table 83. To meet the TMDL, the total load to the lake needs to be reduced by 912 lb/yr, or 21%. There are no NPDES-permitted sources in the North Twin Lake watershed; therefore, there are no individual WLAs.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily allocations were derived from this analysis.

Table 83. Royer Lake allocation summary

Allocation*	lb/yr	lb/day
TMDL	3536	9.7
MOS	354	0.97
WLA	0.0	0.0
LA	3182	8.7

* MOS+WLA+LA do not necessarily equal TMDL due to rounding.

Implementation Strategy

Royer Lake is in the East Fly Creek HUC 12 watershed. Various approaches to implementation are needed to address the variety of phosphorus sources in the Royer Lake watershed. The majority of the land use in the watershed is agricultural in nature, and there is one CFO in the watershed. The pollutant sources and management practices for the East Fly Creek HUC 12 watershed (**Error! Reference source not found.**) apply to the Royer Lake watershed, in addition to the other sources and implementation approaches identified in Table 84. Management practices are discussed in detail in Section **Error! Reference source not found.**.

Table 84. Implementation approaches to addresses sources in Royer Lake watershed

Type	Source Summary	Implementation Section
Soil Erosion	Highly erodible soils with the occasional steep slope in the area just south of Royer Lake show a significant potential for field erosion (see Figure 19 on page 37)	**Error! Reference source not found.**
Internal Loading	Phosphorus release due to anoxic hypolimnion	B.1.1
Watershed Runoff	Runoff from lakeshore properties	**Error! Reference source not found.**, **Error! Reference source not found.**

<u>Potential Priority Implementation Areas</u>

- Lakeshore properties where impervious surfaces and/or fertilized lawns drain directly to the lake.
- Lakeshore properties where septic systems have a more direct connection to the lake.
- Agricultural practices related to the CFO, land application of manure and other fertilizers, and droppings from working horses.
- Potential field erosion in the drainage area south of Royer Lake.

B.1.1 Lake Internal Loading

Once watershed runoff gets into a lake, some of the phosphorus is directly available for algae and plant uptake, while another portion, bound to soil particles present in the watershed runoff, settles to the lake bottom and can be recycled to a form that can be used for algal and plant growth at a later date. Decaying algae also falls out of the water column and is deposited on the lake bottom, where it becomes another source of phosphorus that can be recycled back into the water column.

Over time, a considerable amount of phosphorus can accumulate in the bottom sediment of a lake. This phosphorus can be recycled back to the water through a variety of processes. Insect larvae, bottom feeding fishes, wave action, and disturbance from boats can physically stir and resuspend phosphorus-bound sediment into the water. Resuspended phosphorus can chemically release from sediment particles and become available for algal and plant uptake. Plants can also recycle sediment phosphorus by taking it up through their roots and then releasing it into the water column as they decay.

Internal loading control techniques are those that are conducted in the lake itself and may include physical, chemical, and biological components. No single management practice or approach will resolve the problem of internal loading. The following is a description of internal loading control techniques generally recommended for the lakes in the Pigeon River Watershed. Further data collection will be needed for many of the lakes to determine the applicability of these practices to each lake.

Aquatic Plant Management

Shallow lakes depend on the aquatic macrophyte community to provide refuge for zooplankton and fish and maintain a healthy lake. Invasive aquatic plant species can increase phosphorus recycling within a lake and harm ecosystems. Once introduced, invasive species can spread to new areas and can rarely be eliminated.

Curly-leaf pondweed is an invasive aquatic macrophyte that disrupts the natural phosphorus cycle in the lake by dying off in the mid-summer, releasing phosphorus that is then available for algal growth. This plant also has a competitive advantage over other aquatic plant species because it starts to grow well before ice off, outcompeting the other plants for light. This invasive plant should be controlled immediately to prevent an infestation. Herbicide treatments are generally the most cost-effective method of control and are applied when water temperatures reach 50 to 55˚F.

In lakes with dense curly-leaf pondweed, there are often no other aquatic macrophytes present. In other cases, a lake does not have an established macrophyte community at all. There are many reasons for this, including use of herbicides, abundance of rough fish (which can cause uprooting of vegetation), lack of a viable seed bed, wind mixing, and sedimentation within the lake. The establishment of a healthy macrophyte community may require an evaluation of the seed bed to ensure adequate viability, and analysis of alternatives to establish macrophytes, including lake drawdown, fish management, and transplanting of vegetation. Establishing a healthy macrophyte community will require education of the shoreland owners and other stakeholders as well as costs associated with implementation.

In approximately 2006, the aquatic plant parrot feather (*Myriophyllum aquaticum*) was found in Meserve Lake. Parrot feather can be invasive, impairing recreational and ecological functions. Information on parrot feather and its control in Meserve Lake is included in the implementation strategy for Meserve Lake in Section 0.

Fish Management

The typical lake biological community consists of a broad base of primary producers (plants and algae) and consumers (animals). The primary producers support overlying levels of consumers, including herbivores (such as zooplankton), planktivores (which eat zooplankton), and much smaller numbers of piscivores (which eat other fish). Benthic organisms are consumers that live in, on, or near the lake bottom and forage in/near the sediments. Consumers often shift trophic levels throughout their life cycle.

Water quality can be affected if there is a disproportionate amount of any one of these biological communities.

Biomanipulation is the practice of undergoing lake improvement procedures that alter the food web to favor grazing on algae by zooplankton, or that eliminate fish species that disturb the bottom sediments. Biomanipulation can involve eliminating certain fish species or restructuring the fish community to favor a balance that allows sufficient survival of zooplankton.

Benthic fish management is one type of biomanipulation. An over abundance of benthivorous fish species such as carp and black bullhead can significantly degrade water quality by continually stirring up the lake sediment and re-suspending pollutants, especially phosphorus. One management strategy is to install fish barriers on a lake inlet and/or outlet, which prevents fish migration into areas of concern, coupled with a fish kill. Another management technique is to remove these species by conducting a water level drawdown, netting, or treating the lake with rotenone. Benthic fish removal typically occurs after fish barriers are constructed.

Zooplanktivore management is another type of biomanipulation. Overpopulation of zooplanktivores (such as crappie, sunfish, and bluegill) within a lake is a common problem because they can over-graze the zooplankton community, which causes increases in algal density. Reductions in densities of zooplanktivorous fish can be accomplished by adding predatory fish, conducting a water level drawdown, chemical (e.g. rotenone) treatment, and/or trapping.

Phosphorus Inactivation

Aluminum sulfate (alum) is a chemical addition that binds with phosphorus to form a non-toxic precipitate (floc). Alum reduces internal loading by binding with P and preventing its release, thereby forming a type of barrier between lake sediments and the water. In-lake alum treatments are often proposed to treat the deepest area of a lake and are not typically effective in shallow lakes or lakes that do not stratify. Alum treatments are only effective after external phosphorus inputs are significantly reduced, benthic fish have been removed, and fish barriers are installed to prevent their re-introduction.

Lake Drawdown

Drawdowns lower water levels in a lake in order to improve water quality and aquatic habitat. Lowering the water level in the winter exposes the sediment to both freezing and loss of water. A drawdown of lake levels can improve a lake's littoral vegetation through aeration of the sediments to allow the germination of certain native plant seeds; winter freeze-out of curly-leaf pondweed turions (dormant vegetative propagules); consolidation of the sediments to improve the sediment's ability to support rooted macrophytes; and promotion of oxygenation and consolidation of organic debris.

Summer drawdowns expose and consolidate the sediments, enhance conditions for the growth of perennial emergent species of aquatic vegetation, and consolidate the undesirable fish species for more efficient removal.