Water Quality Improvement Plan
for

Thayer Lake

Union County, Iowa

Total Maximum Daily Load
for Algae and Turbidity

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General Report Summary

What is the purpose of this report?

This report serves multiple purposes. First, it is a resource for increased understanding of watershed and water quality conditions in and around Thayer Lake. Second, it satisfies the Federal Clean Water Act requirement to develop a Total Maximum Daily Load (TMDL) for impaired waterbodies. Third, it provides a foundation for locally-driven watershed and water quality improvement efforts. Finally, it may be useful for obtaining financial assistance to implement projects to remove Thayer Lake from the federal 303(d) list of impaired waters.

What's wrong with Thayer Lake?

Thayer Lake is listed as impaired on the 2014 303(d) list for not supporting its primary contact recreation designated use. The impairment is due to elevated levels of algae and turbidity, which is caused by overly-abundant nutrients and sediment, including sediment-bound phosphorus in the lake. Preliminary drafts of the 2016 303(d) list show the chl-a limit for aesthetically objectionable algae is recommended for delisting. However, the 2016 303(d) draft is not yet finalized, therefore chl-a TMDL limits will still be included in this document.

What is causing the problem?

The amount of phosphorus transported to the lake from the surrounding watershed is sufficient to cause excessive growth of algae and excessive levels of turbidity, which reduces water clarity. Phosphorus is carried to the lake in two primary forms: (1) attached to eroded soil that is transported to the lake by rainfall runoff and stream flow, and (2) dissolved phosphorus in runoff and subsurface flow (e.g., shallow groundwater). Phosphorus and sediment within the water column and on the lake bed may become resuspended under certain conditions, which can add to algae and turbidity issues. There are no allowable discharging point sources in the Thayer Lake watershed; therefore all phosphorus loads to the lake are attributed to nonpoint sources.

Nonpoint sources are discharged in an indirect and diffuse manner, and often are difficult to locate and quantify. Nonpoint sources of phosphorus in the Thayer Lake watershed include sheet and rill erosion from various land uses, runoff and subsurface flows from lands that receive fertilizer application, grazed pasture land, poorly functioning septic systems, manure deposited by wildlife, and particles carried by dust and wind (i.e., atmospheric deposition). A portion of the phosphorus carried to the lake eventually settles to the lake bottom and accumulates. Under certain conditions, this accumulated phosphorus can become available for algal uptake and growth through an internal recycling process; internal loading was found to be a significant source of phosphorus in Thayer Lake.

What can be done to improve Thayer Lake?

Reducing phosphorus loss from pasture, row crops, and implementing or improving existing structural BMPs such as terraces, grass waterways, and constructed sediment basins in beneficial locations will significantly reduce phosphorus loads to the lake.

Increasing the trapping efficiency of the existing sediment basins may be the most cost effective structural alternative. Additionally, in-lake practices such dredging or phosphorus stabilization may be necessary in order to address algae and turbidity concerns.

Who is responsible for a cleaner Thayer Lake?

Everyone who lives, works, or recreates in the Thayer Lake watershed has a role in water quality improvement. Nonpoint source pollution is unregulated and responsible for the vast majority of sediment and phosphorus entering the lake. Therefore, voluntary management of land, animals, and the lake itself will be required to achieve measurable improvements to water quality. Many of the practices that protect and improve water quality also benefit soil fertility and structure, the overall health of the agroecosystem, and the value and productivity of the land. Practices that improve water quality and enhance the long-term viability and profitability of agricultural production should appeal to producers, land owners, and lake users alike. Improving water quality in Thayer Lake, while also improving the quality of the surrounding land, will continue to require collaborative participation by various stakeholder groups, with land owners playing an especially important role. Additionally, those looking to develop sites within the Thayer Lake watershed should recognize the impact of improved water quality on property values.

Does a TMDL guarantee water quality improvement?

The Iowa Department of Natural Resources (DNR) recognizes that technical guidance and support are critical to achieving the goals outlined in this Water Quality Improvement Plan (WQIP). The TMDL itself is only a document, and without implementation, will not improve water quality. Therefore, a basic implementation plan is included for use by local agencies, watershed managers, and citizens for decision-making support and planning purposes. This implementation plan should be used as a guide or foundation for detailed and comprehensive planning by local stakeholders.

Reducing pollutants from unregulated nonpoint sources requires voluntary implementation of best management practices. Many solutions have benefits to soil health and sustained productivity as well as water quality. However, quantifying the value of those ecosystem services is difficult, and those benefits are not commonly recognized. Consequently, wide-spread adoption of voluntary conservation practices is often difficult to achieve. A coordinated watershed improvement effort for Thayer Lake and surrounding lakes could address some of these barriers by providing financial assistance, technical resources, and information/outreach to landowners to encourage and facilitate adoption of conservation practices.

What are the primary challenges for water quality implementation?

In most Iowa landscapes, implementation requires changes in land management and/or agricultural operations. Management decisions may include changes in the number of acres that are actively tilled and the diversity and rotation of crops produced. These changes present challenges to producers by requiring new equipment (e.g., no-till

planters), narrowing planting, harvesting and fertilization windows, and necessitating more active and complex farm management.

Additionally, potential short-term losses in yields are more easily recognized and quantified than long-term benefits to soil health and sustained productivity. It is not easy to overcome existing incentives and the momentum of current practices. Promoting a longer-term view with an emphasis on long-term soil fertility, production, agroecosystem health, and reduced input costs will be essential for successful, voluntary implementation by willing conservation partners. However, water quality improvement and enhancement of Thayer Lake as a recreational resource are certainly attainable goals, and are appropriate and feasible near-term goals for a coordinated watershed improvement effort.

Technical Elements of the TMDL

Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:	Thayer Lake, Waterbody ID IA 05-GRA-01410-L_0, located in S22, T72N, R28W, 1 mile SW of Thayer
Surface water classification and designated uses:	A1 – Primary Contact B(LW) – Aquatic life HH – Human health (fish consumption)
Impaired beneficial uses:	A1 – Primary Contact (IR 5a) B(LW) – Aquatic Life (IR 3b)
TMDL priority level:	Priority Group 1
Identification of the pollutants and applicable water quality standards (WQS):	Aesthetically objectionable conditions due to algal and non-algal turbidity leading to very poor water transparency
Quantification of the pollutant loads that may be present in the waterbody and still allow attainment and maintenance of WQS:	Excess algae and turbidity are associated with total phosphorus (TP). The allowable average annual TP load = 513 lbs/year; the maximum daily TP load = 4.38 lbs/day.
Quantification of the amount or degree by which the current pollutant loads in the waterbody, including the pollutants from upstream sources that are being accounted for as background loading, deviate from the pollutant loads needed to attain and maintain WQS:	The existing growing season load of 1,019 lbs/year must be reduced by 556 lbs/year to meet the allowable TP load. This is a reduction of 50 percent.
Identification of pollution source categories:	There are no regulated point source discharges of phosphorus in the watershed. Nonpoint sources of phosphorus include fertilizer and manure from row crops, sheet and rill erosion from row crops and pasture, wildlife, septic systems, groundwater, atmospheric deposition, and others.
Wasteload allocations (WLAs) for pollutants from point sources:	There are no allowable point source discharges.
Load allocations (LAs) for pollutants from nonpoint sources:	The allowable annual average TP LA is 462 lbs/year, and the allowable maximum daily LA is 3.94 lbs/day.

A margin of safety (MOS):	An explicit 10 percent MOS is incorporated into this TMDL.
Consideration of seasonal variation:	The TMDL is based on annual TP loading. Although daily maximum loads are provided to address legal uncertainties, the average annual loads are critical to in-lake water quality and lake/watershed management decisions.
Reasonable assurance that load and wasteload allocations will be met:	Reasonable assurances for reductions in nonpoint source pollution are provided by (1) a list of BMPs (see Section 4 of this WQIP) that would provide phosphorus reductions, (2) a group of nonstructural practices that prevent transport of phosphorus, (3) proposed methodology for prioritizing and targeting BMPs on the landscape, and (4) best available data for estimating the efficiency/reduction associated with BMPs.
Allowance for reasonably foreseeable increases in pollutant loads:	Although watershed development may continue in the future, an increase in the pollutant load from land use change is not expected.
Implementation plan:	An implementation plan is outlined in Section 4 of this Water Quality Improvement Plan. Phosphorus loading and associated impairments must be addressed through a variety of voluntary management strategies and structural practices.

1. Introduction

The Federal Clean Water Act requires all states to develop lists of impaired waterbodies that do not meet water quality standards (WQS) and support designated uses. This list of impaired waterbodies is referred to as the state's 303(d) list. In addition to developing the 303(d) list, a Total Maximum Daily Load (TMDL) must be developed for each impaired waterbody included on the list. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can tolerate without exceeding WQS and impairing the waterbody's designated uses. The TMDL calculation is represented by the following general equation:

$$TMDL = LC = \Sigma\ WLA + \Sigma\ LA + MOS$$

Where:
TMDL = total maximum daily load
LC = loading capacity
Σ WLA = sum of wasteload allocations (point sources)
Σ LA = sum of load allocations (nonpoint sources)
MOS = margin of safety (to account for uncertainty)

One purpose of this Water Quality Improvement Plan (WQIP) for Thayer Lake, located in Union County in southwest Iowa, is to provide a TMDL for algae and turbidity, which has decreased water quality in the lake. Another purpose is to provide local stakeholders and watershed managers with a tool to promote awareness and understanding of water quality issues, develop a comprehensive watershed management plan, obtain funding assistance, and implement water quality improvement projects. Over-abundance of phosphorus is largely responsible for excessive algal growth and inorganic turbidity, which impairs the primary contact designated use of Thayer Lake. The impairments are addressed by development of a TMDL that limits total phosphorus (TP) loads to the lake. Phosphorus reductions should be accompanied by reduced algal growth and increased water clarity.

The plan also includes descriptions of potential solutions to the impairments. This group of solutions is presented as a toolbox of best management practices (BMPs) for improving water quality in Thayer Lake, with the ultimate goal of meeting water quality standards and supporting designated uses. These BMPs are outlined in the implementation plan in Section 4.

The Iowa Department of Natural Resources (DNR) recommends a phased approach to watershed management. A phased approach is helpful when the origin, interaction, and quantification of pollutants contributing to water quality problems are complex and difficult to fully understand and predict. Iterative implementation of improvement practices and additional water quality assessment (i.e., monitoring) will help ensure gradual progress towards water quality standards, maximize cost efficiency, and prevent unnecessary or ineffective implementation of costly BMPs. Implementation guidance is provided in Section 4 of this report, and water quality monitoring guidance is provided in Section 5.

This plan will be of limited value unless additional watershed improvement activities and BMPs are implemented. This will require the active engagement of local stakeholders and land owners. Experience has shown that locally-led watershed plans have the highest potential for success. The Watershed Improvement Section of DNR has designed this plan for stakeholder use and may be able to provide technical support for the improvement of water quality in Thayer Lake.

2. Description and History of Thayer Lake

Thayer Lake was constructed by the Chicago, Burlington, and Quincy Railroad (currently Burlington Northern Santa Fe Railway) sometime in the 1850's to be used as a water supply for steam locomotives in the area. The lake is part of a 47 acre nature area surrounded by legacy oaks and shagbark hickory trees. Thayer Lake is roughly 1 mile southwest of the town of Thayer in Jones Township, Union County. Several habitat and access program (IHAP) areas are located within the Thayer Lake watershed, providing opportunities for hunters and wildlife enthusiasts.

Table 2-1 lists some of the general characteristics of Thayer Lake and its watershed, as it exists today. Figure 2-1 shows the vicinity map for the lake system and its watershed. Estimation of physical characteristics such as surface area, depth, and volume are based on a bathymetric survey conducted by DNR in May of 2014.

Table 2-1. Thayer Lake watershed and lake characteristics

DNR Waterbody ID	ID Code: IA 05-GRA-01410-L_0
12-Digit Hydrologic Unit Code (HUC)	102801020207
12-Digit HUC Name	Fourmile Creek
Location	Union County, S22, T72N, R28W; 1 mi 1SW of Thayer
Latitude	41.02° N (ambient lake monitoring location)
Longitude	94.07° W (ambient lake monitoring location)
Designated Uses	A1 – Primary Recreation B(WW-1) – Aquatic Life HH – Human health (fish consumption, drinking water)
Tributaries	Unnamed streams
Receiving Waterbody	Fourmile Creek, Thompson River
Lake Surface Area	[1]12.7 acres
Length of Shoreline	[1]4,963 feet
Shoreline Development Index	3.34
Maximum Depth	[1]13.0 feet
Mean Depth	[1]5.0 feet
Lake Volume	[1]63.1 acre-feet
Watershed Area	499 acres (includes lake)
Watershed:Lake Ratio	38:1
Lake Residence Time	[2]45 days

[1]Per May 2014 bathymetric survey and subsequent calculations
[2]BATHTUB model prediction for average annual conditions (2002-2016)

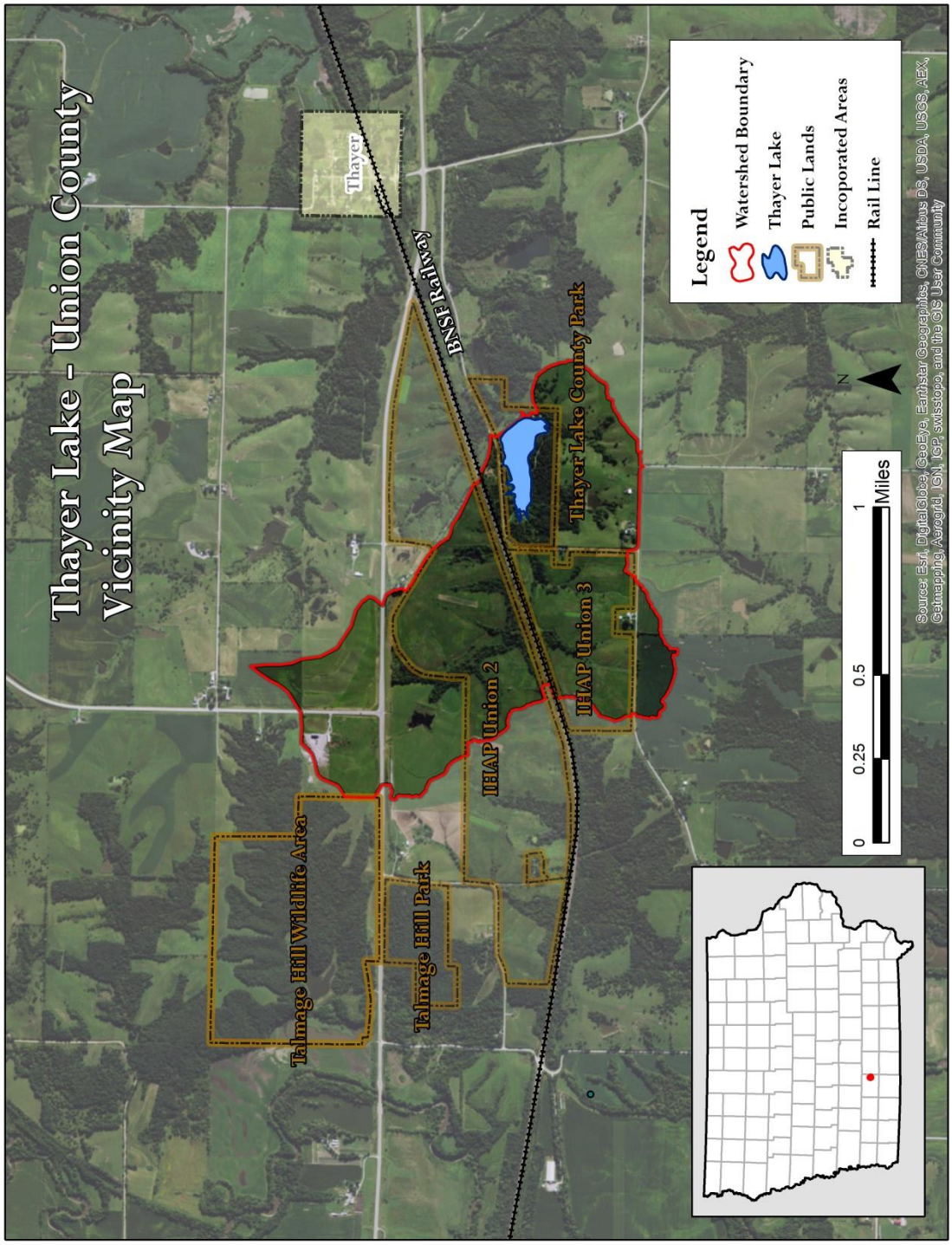

Figure 2-1. Vicinity Map

Water Quality History
Water quality data has been collected through the statewide survey of Iowa Lakes which was conducted from 2000 through 2016 by Iowa State University. A statewide ambient lake monitoring program conducted in 2008 by the State Hygienic Laboratory (SHL) also provided data on the water quality Thayer Lake.

2.1. Thayer Lake

Hydrology
Thayer Lake was created in the 1850's to facilitate the operations of steam locomotives operated by the Chicago Burlington and Quincy Railroad (currently Burlington Northern Sante Fe). Limited bathymetry or renovation history from this period is available for analysis.

The PRISM (**P**arameter-elevation **R**egression on **I**ndependent **S**lopes **M**odel) Climate Group, supported by the USDA Risk Management Agency, provides an interactive tool for analyzing time series rainfall data at a specific location. The dataset output from the data explorer is based on 24 hour rainfall over a 4 km grid cell. By interpolating in between grid cells, the ambient monitoring location was chosen for climatological analysis of rainfall data for watershed and in-lake models.

Daily potential evapotranspiration (PET) data were obtained for 2002-2016 from the Iowa Ag Climate Network, downloadable from the IEM (IEM, 2017b). The Iowa State Climatologist provides quality control of these data, which are downloadable from the Iowa Environmental Mesonet. Daily observations between January 1, 2002 and December 31, 2016 were used in climate assessment and model development. Table 2-2 reports weather station information.

Table 2-2. Weather station information for Thayer Lake

Data	Temperature/Precipitation	Potential ET
Network	PRISM	ISU Ag Climate
Station Name (ID)	Ambient Monitoring Location	Lewis (A134759)
Latitude	Latitude: 41.02°	41.313°
Longitude	Longitude: -94.07°	-95.173°

Average annual precipitation near Thayer Lake was 37.5 inches from 2002-2016. Years 2007, 2010, 2014, and 2015 were, on average, much wetter than normal, with an annual average rainfall amount of 47.3 inches per year. Conversely, years 2002, 2003, 2005, and 2012 were much drier than normal, with an annual average rainfall of only 28.1 inches per year. Figure 2-2 illustrates the annual precipitation totals, along with lake evaporation (estimated as 70 percent of annual PET). This chart shows an inverse relationship between precipitation and lake ET, mainly due to climatological factors such as cloud cover and temperature. Wet years of 2007-2008 and 2014-2015 show a surplus of precipitation, while 2012 shows a precipitation deficit in comparison to lake ET.

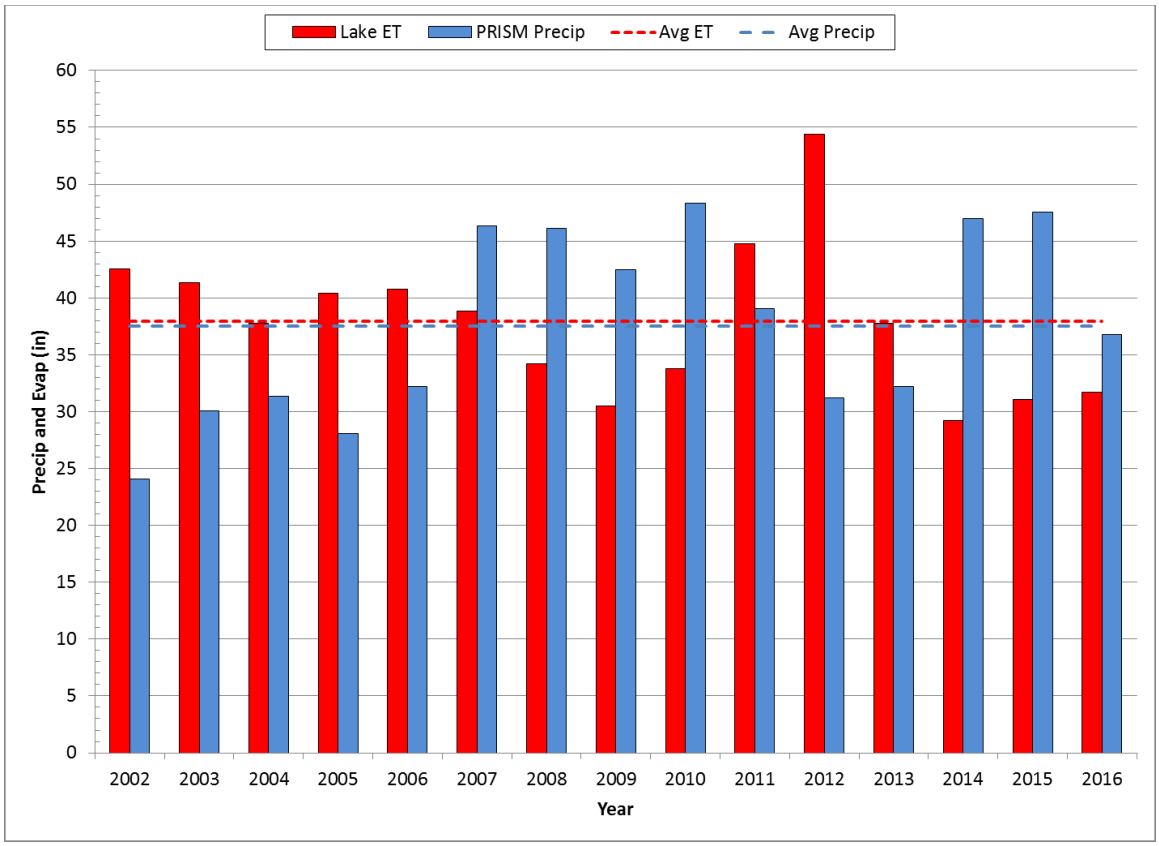

Figure 2-2. Annual precipitation and estimated lake evaporation

Precipitation varies greatly by season in southwestern Iowa, with 75 percent of annual rainfall taking place in half of the year (April through September.) Monthly average precipitation is illustrated in Figure 2-3, along with estimated evapotranspiration (ET) in the watershed based on vegetation cover. Although precipitation is highest during the growing season, so is ET, and a seasonal moisture deficit often occurs between June and September. Note that watershed ET is typically higher than lake evaporation in the summer months, a result of high temperatures and vegetation transpiring large volumes of moisture from the soil during the peak of the growing season. It is often during this period that harmful algal blooms develop in waterbodies, as water heats up and lake flushing is minimal. Additionally, although watershed ET is high, the lake level is supplemented by natural springs in the area. Together, the high watershed ET and natural springs keep the lake water level stable over time.

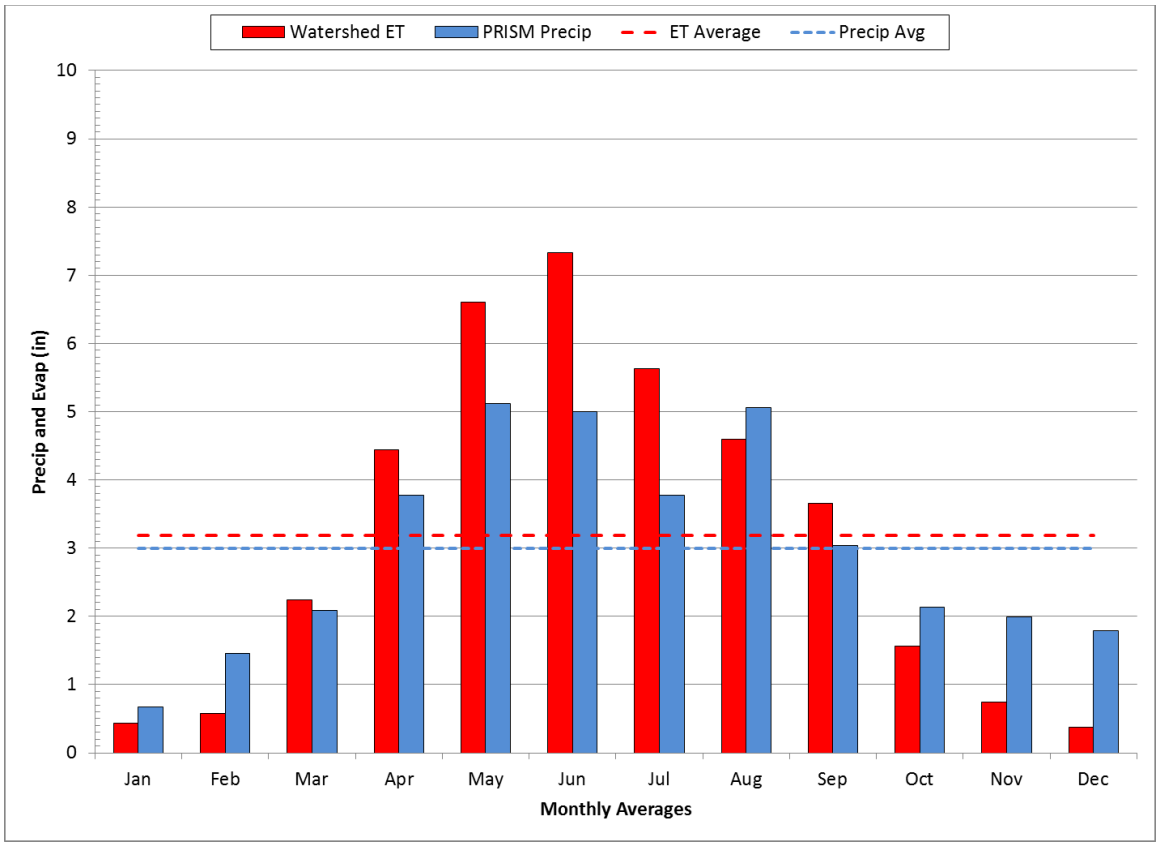

Figure 2-3. Monthly precipitation and estimated ET for the watershed

Rainfall runoff, direct precipitation, evapotranspiration, shallow groundwater flow, and deep aquifer recharge are all part of the lake's hydrologic system. Estimated residence time is based on annual precipitation and evaporation data, Spreadsheet Tool for Estimating Pollutant Load (STEPL) estimates of average annual inflow, and a water balance calculated within the BATHTUB model. The BATHTUB water balance calculation includes: inflows (from STEPL), direct precipitation, evaporation calculated from measured PET at Lewis, Iowa and obtained from the Iowa State University Ag Climate Network on the Iowa Environmental Mesonet (IEM, 2017b), and lake morphometry.

During years of below average precipitation, residence time increases. In wet years, the opposite is true as residence time decreases. In lakes with smaller watershed to lake ratios the residence time may be longer than lakes with higher residence times. The calculated residence time (45 days for average conditions) suggests that internal loading may play a small, intermittent role in algal blooms. In addition, the natural springs in the area help to keep water levels at Thayer Lake relatively stable year to year.

Morphometry
According to the most current bathymetric data (May 2014), the surface area of Thayer Lake is 12.7 acres. Estimated water volume of the main lake is 63.1 acre-feet (ac-ft), with a mean depth of 5.0 ft and a maximum depth of 12.7 ft in the eastern section of the lake

near the outfall. The reservoir, like most man-made stream impoundments, has an irregular shape, with several small dissected arms that lead to upland overland flow paths. Evidence of sedimentation in the lake suggests that the watershed of Thayer Lake has a large impact on water quality. The significance of sediment (and associated phosphorus) loading from the watershed is further evidenced by the shoreline development index of 3.36, which is high. Values greater than 1.0 suggest the shoreline is highly dissected and indicative of a high degree of watershed influence (Dodds, 2000). High indexes are frequently observed in man-made reservoirs, and it is not surprising that watershed processes are critically important for the chemical, physical, and biological processes that take place in Thayer Lake. Lake morphometry and bathymetry data are shown in Figure 2-4.

2.2. The Thayer Lake Watershed

The watershed boundary of Thayer Lake encompasses 499 acres (including the lake) and is illustrated in Figure 2-1. The watershed-to-lake ratio of 38:1 is above the ideal condition of 20:1. This indicates a potential for successful lake restoration based on watershed and lake interactions. Mitigation of watershed influence will be required, and in-lake techniques may have short effective life spans in the absence of watershed improvements and renovations. A prudent watershed management strategy should focus on water quality improvement, problem areas that can be most easily addressed, and implementing alternatives that provide multiple benefits in addition to water quality, such as increased soil health, erosion reduction, and habitat enhancement. Watershed management and implementation strategies are discussed in more detail in Section 4 – Implementation Planning.

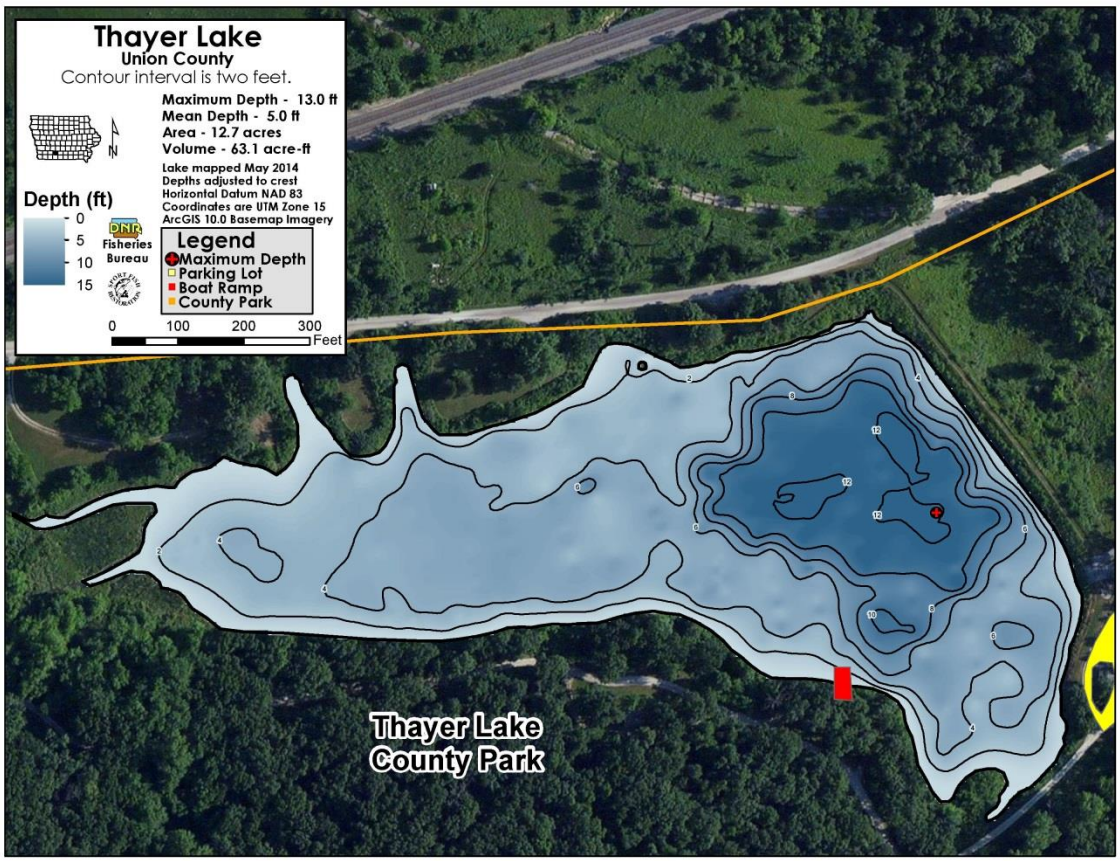

Figure 2-4. Bathymetric map of Thayer Lake

Land Use

A Geographic Information System (GIS) coverage of landuse information was developed using Cropland Data Layer (CDL) for years 2012 and 2014, which was obtained from the United States Department of Agriculture – National Agricultural Statistics Service (USDA-NASS, 2017). The CDL land cover data is summarized by Common Land Units (CLUs). According to the USDA – Farm Service Agency, CLUs are the smallest units of land that have a permanent, contiguous boundary, common land cover, common owner, and common producer (USDA-FSA, 2012).Cropping decisions can change from year to year and several instances were observed where a single CLU had multiple land covers in the same year. In such cases, CLU boundaries were split to incorporate multiple covers in the same year. In addition to landuse, tillage and management information was collected via 2017 windshield survey of the watershed.

Due to annual changes in agricultural management in the watershed, areas with multiple land covers consisting of soybean and corn ground have been aggregated together under a "Row Crop" land cover (1.6 percent total area) with other crops of hay/alfalfa being modeled at 28.0 percent. Wooded grounds around the Thayer Lake Park were modeled as forest area (19.6 percent). Two main types of grassland were modeled: grazed and ungrazed. Areas of perennial grassland that have evidence of grazing of at least two years

within the assessment period (2008-2012) have been added to the "Pasture" land cover. Grazed grassland consists of pasture with livestock present (12.1 percent), while all other grassland, Iowa Habitat and Access Program (IHAP), and conservation reserve program (CRP) lands were modeled as ungrazed (31.6 percent). Farmstead, rail lines, and road areas were modeled as developed areas (3.0 percent). Assessment period land use is shown in Figure 2-5 and itemized in Table 2-3.

Analysis of historical aerial photography data reveals several trends. The size of common land units has increased with the consolidation of land and land owners. Crop diversification has decreased substantially in recent times to mainly consist of corn / soybean rotations.

Table 2-3. Land use composition of Thayer Lake watershed

Land Use	Area (acres)	Percent (%)
Grassland / CRP	144.9	29.0
Hay / Alfalfa	116.1	23.3
Forest / Parkland	97.8	19.6
Pasture	80.2	16.1
[1]Developed	20.4	4.1
Corn / Soybean Rotation	25.0	5.0
[2]Water	14.8	2.9
Total area =	**499.1**	**100.0**

[1]Includes railways, roadways, paved lots, and residential areas
[2]Includes Thayer Lake surface area

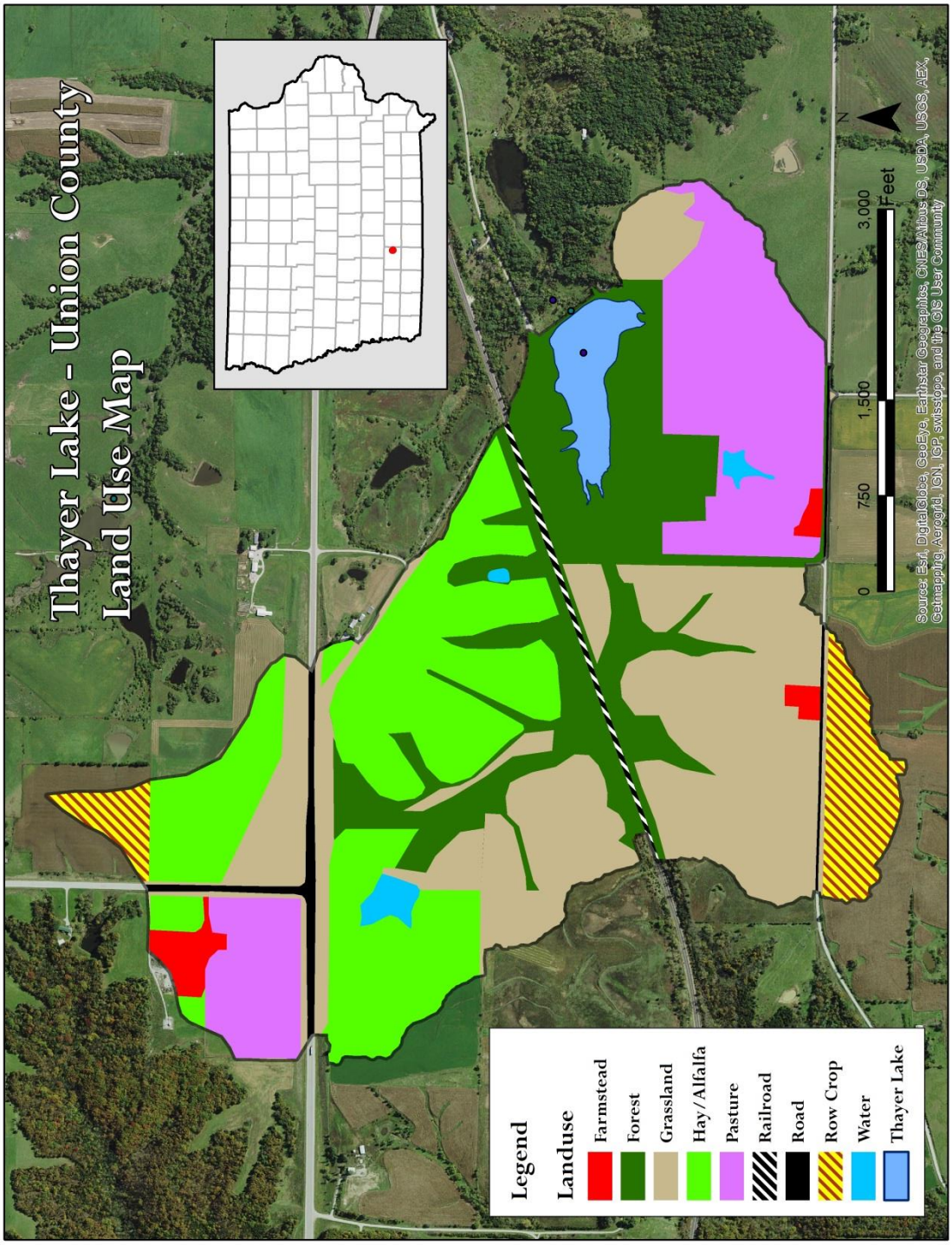

Figure 2-5. Thayer Lake watershed land use map

Soils, Climate, and Topography

The Thayer Lake watershed is in the central region of the Iowan Surface. Four soils series dominate the Thayer Lake watershed, as shown in Figure 2-6 and Table 2-4. Of these, the Sharpsburg / Shelby / Adair soil association and its complexes comprise 30.7 percent of the watershed. These soils are characterized by gently rolling, long slopes of loess on broad ridges and outcrops of till plains (USDA-NRCS, 1979). This association is well drained to somewhat poorly-drained. Table 2-4 and Figure 2-6 show descriptions and percentages of all major soils in the watershed. All other minor classes are listed as "Other."

Table 2-4. Predominant soils of the Thayer Lake watershed

Soil Name	Area (ac)	Area (%)	Description of Surface Soil Layer	Typical Slopes (%)
Nira-Sharpsburg	67.4	13.5	Very deep, moderately well drained soils formed in loess	0-18
Adair-Shelby	57.0	11.4	Very deep, somewhat poorly drained soils formed in loess over till	2-30
Macksburg	50.7	10.2	Very deep, somewhat poorly drained soils formed in loess	0-9
Coly-Ely	47.8	10.0	Very deep, poorly drained soils formed in alluvium and colluvium	0-9
Grundy	34.8	7.0	Very deep, somewhat poorly drained soils formed in loess	0-9
Gara-Armstrong	33.1	6.6	Very deep, somewhat poorly drained soils formed in till	2-25
Shelby	28.9	5.8	Very deep, well drained soils formed in till	1-40
Clarinda	28.1	5.6	Very deep, poorly drained soils formed in a till paleosol	5-18
Clearfield	26.0	5.2	Very deep, poorly drained soils formed loess underlain by paleosol	5-14
Others	109.8	22.0	Varies	Varies
Water	14.1	2.8	---	---
Total	499.2	100.0	Varies	Varies

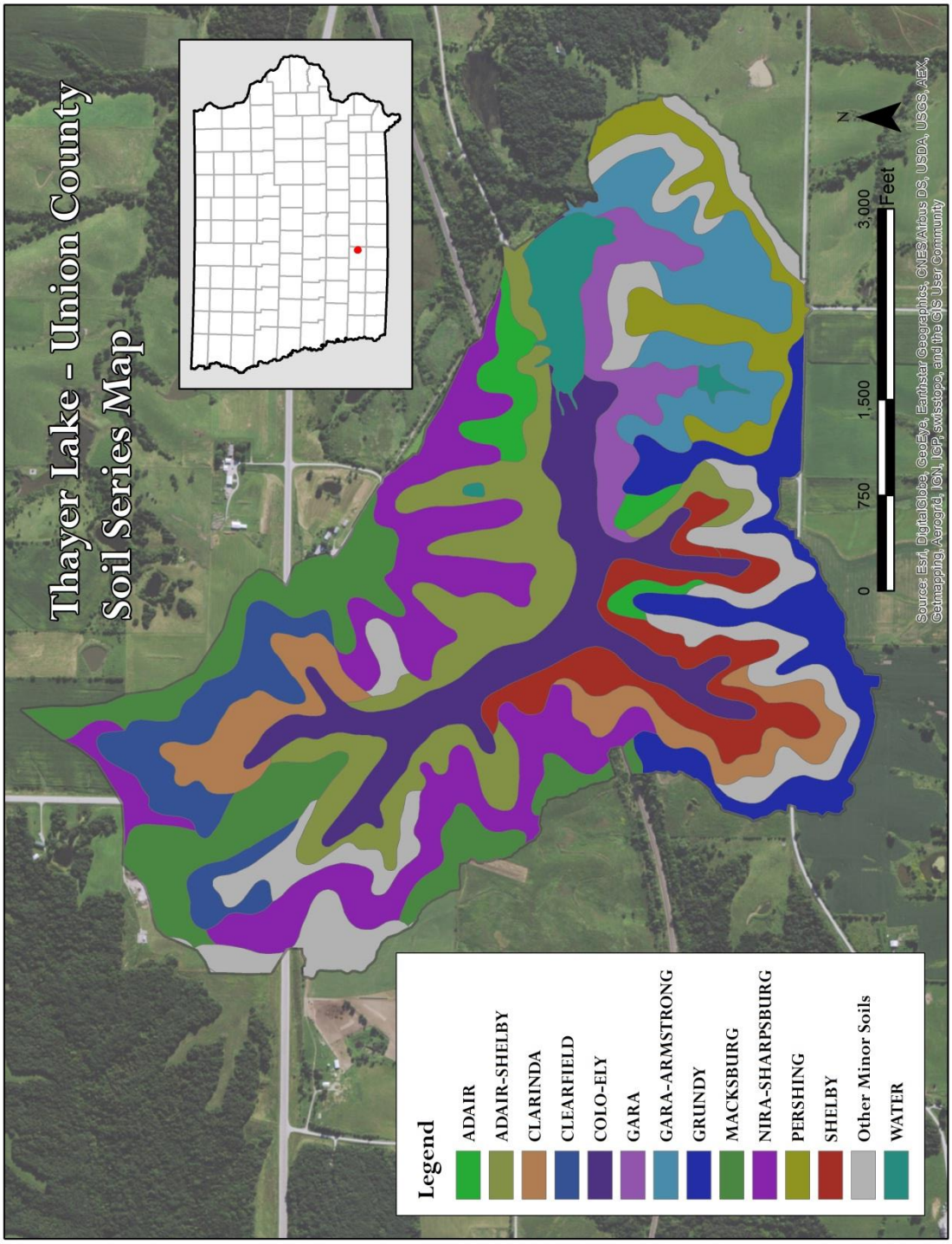

Figure 2-6. Thayer Lake soil classification map

The topography consists of well-defined drainage systems formed by extensive erosion through glacial till, in some areas loess has been deposited over this till. In some areas, prolonged erosion has led to underlying sedimentary rock being exposed. Slopes are therefore mostly gently sloping, to sloping, but there are areas of strongly sloping to moderately steep slopes where the topography transitions to developed areas. Flat to gently sloping (0 – 5 percent slope) regions make up 27 percent of the watershed. Sloping and strongly sloping (5 – 15 percent slope) make up nearly 55 percent of the watershed. Land above 15 percent slope are mainly pasture, forest, and grassland which are unsuitable for row crop production. Table 2-5 shows the percentage breakdown of slope classifications throughout the watershed, and Figure 2-7 illustrates the distribution of the slopes within the Thayer Lake watershed.

Table 2-5. Slope classifications of the Thayer Lake watershed

Slope Class (%)	Area (%)	Description of Slope Class
Class A (0 – 2)	8.1	Flat to very gently sloping
Class B (2 – 5)	18.7	Gently sloping
Class C (5 – 8)	20.0	Sloping
Class D (8 – 15)	34.9	Strongly sloping
Class E (15 – 30)	15.2	Moderately steep
Class F (30 and up)	3.1	Steep to very steep
Total	100.0	---

The combination of soil classification, slope, topography, and hydrologic soil group (discussed more in Appendix D) indicate that the majority of agricultural areas in the Thayer Lake watershed would not be tile drained. The absence of drainage district data and anecdotal data on tile drainage location also indicate that minimal drainage is present in the watershed. However, agricultural management practices related to tile drainage may change in the future, which would lead to changes in watershed loading and its effects on Thayer Lake.

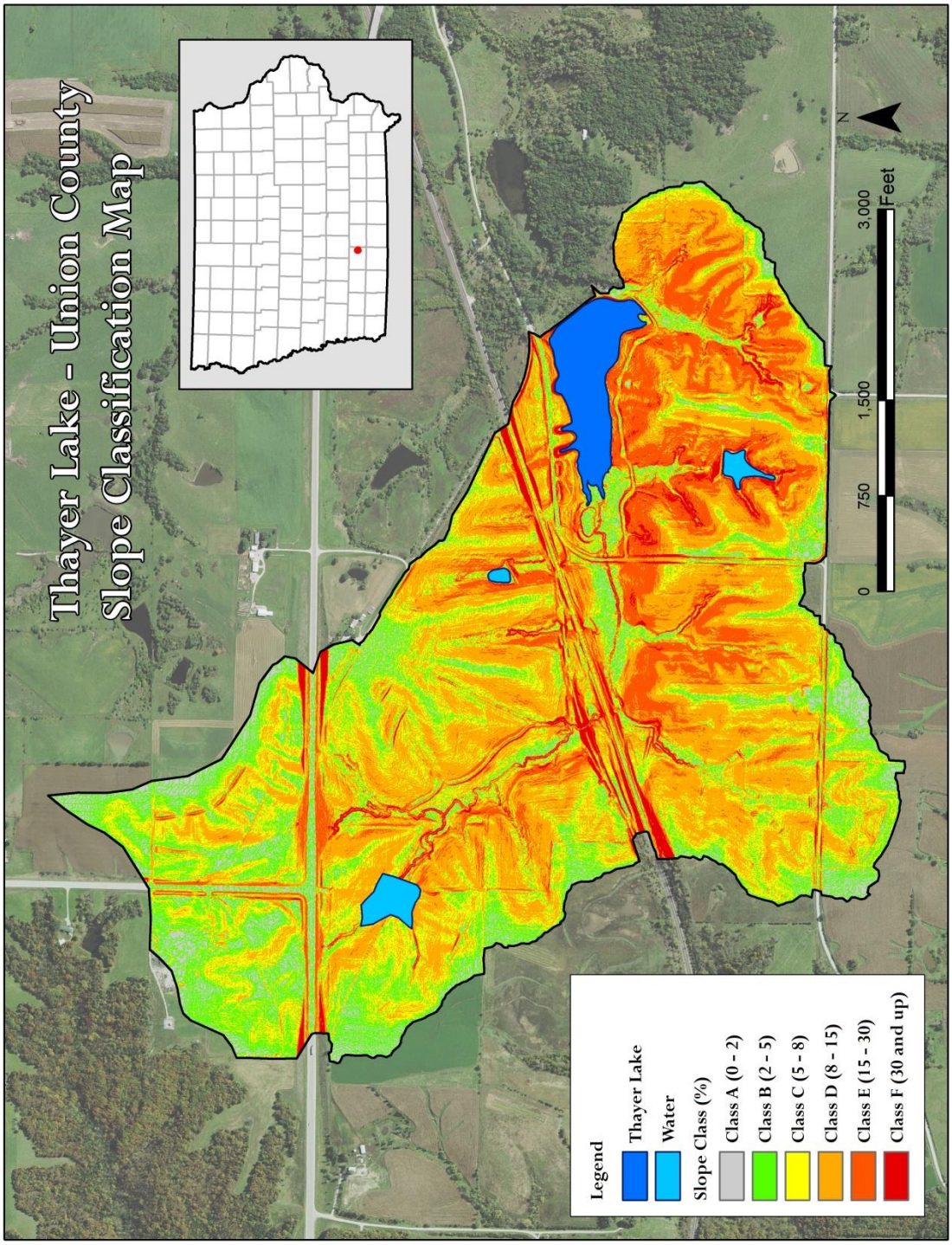

Figure 2-7. Slope classifications in the Thayer Lake watershed

3. TMDL for Algae, Turbidity, and Low DO

A Total Maximum Daily Load (TMDL) is required for Thayer Lake by the Federal Clean Water Act. This section of the Water Quality Improvement Plan (WQIP) quantifies the maximum amount of total phosphorus (TP) the lake can assimilate and still fully support primary contact in Thayer Lake, which is impaired by algae and non-algal turbidity. This section includes an evaluation of Thayer Lake water quality, documents the relationship between algae, turbidity, and TP in Thayer Lake, and quantifies the in-lake target and corresponding TMDL.

3.1. Problem Identification

Thayer Lake is a Significant Publicly Owned Lake, and is protected for the following designated uses:

- Primary Contact – Class A1
- Aquatic life – Class B(LW)
- Fish consumption – Class HH

The 2014 Section 305(b) Water Quality Assessment Report states that primary contact designated use in Thayer Lake is assessed (monitored) as "not supported" due to poor water quality caused by algal and non-algal turbidity. The 2014 assessment is included in its entirety in Appendix H, and can be accessed at https://programs.iowadnr.gov/adbnet/Assessments/Legacy/16533

The preliminary 2016 Section 305(b) Water Quality Assessment report shows a recommended delisting for the chl-a impairment of Thayer Lake based on chl-a TSI values for the 2014 and 2016 assessment reports.

Applicable Water Quality Standards
The State of Iowa Water Quality Standards (WQS) are published in the Iowa Administrative Code (IAC), Environmental Protection Rule 567, Chapter 61 (http://www.legis.iowa.gov/DOCS/ACO/IAC/LINC/Chapter.567.61.pdf) [Note: This link must be copied and pasted into a web browser]. Although the State of Iowa does not have numeric criteria for sediment, nutrients, or algae (chlorophyll-a), general (narrative) water quality criteria below do apply:

61.3(2) General water quality criteria. The following criteria are applicable to all surface waters including general use and designated use waters, at all places and at all times for the uses described in 61.3(1)"a."

a. *Such waters shall be free from substances attributable to point source wastewater discharges that will settle to form sludge deposits.*
b. *Such waters shall be free from floating debris, oil, grease, scum and other floating materials attributable to wastewater discharges or agricultural practices in amounts sufficient to create a nuisance.*

c. *Such waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor or other aesthetically objectionable conditions.*
d. *Such waters shall be free from substances attributable to wastewater discharges or agricultural practices in concentrations or combinations which are acutely toxic to human, animal, or plant life.*
e. *Such waters shall be free from substances, attributable to wastewater discharges or agricultural practices, in quantities which would produce undesirable or nuisance aquatic life.*

For 303(d) listing purposes, aesthetically objectionable conditions are present in a waterbody when Carlson's Trophic State Index (TSI) for the median growing season chlorophyll-a exceeds 65 (DNR, 2008). In order to de-list the algae and turbidity impairments for Thayer Lake, the median growing season chlorophyll-a and Secchi depth TSI must not exceed 63 in two consecutive listing cycles, per DNR de-listing methodology.

Problem Statement
Thayer Lake is impaired because primary contact uses in the lake are not fully supported due to violations of WQS. High levels of algal production and turbidity fueled by phosphorus loads to the lake cause the impairment. TP loads must be reduced in order to reduce algae and fully support the lake's designated uses. Excess nutrients, particularly phosphorus, can cause eutrophic conditions associated with the impairments to Thayer Lake. Phosphorus laden sediment deposits can also cause transparency issues that have been reported in Thayer Lake.

Data Sources
Sources of data used in the development of this TMDL include those used in the 2014 305(b) report, several sources of additional water quality data, and non-water quality related data used for model development. Sources include:

- Ambient Lake Monitoring and / or TMDL monitoring including:
  - results of available statewide surveys of Iowa lakes sponsored by DNR and conducted by Iowa State University 2002-2016
  - available water quality data collected by the State Hygienic Laboratory (SHL) at the University of Iowa from 2008-2012
- Precipitation PRISM network, from Northwest Alliance for Computational Science and Engineering (PRISM, 2017)
- PET data at Lewis, Iowa, the ISU Ag Climate Network (IEM, 2016b)
- 3-m Digital Elevation Model (DEM) available from DNR GIS library
- SSURGO soils data maintained by United States Department of Agriculture – Natural Resource Conservation Service (USDA-NRCS)
- Aerial images (various years) collected and maintained by DNR
- Lake bathymetric data collected in May 2014

Interpreting Thayer Lake Data

The 2014 305(b) assessment was based on results of the ambient monitoring program conducted from 2008 through 2012 by ISU and SHL, and information from the DNR Fisheries Bureau. Assessment of available in-lake water quality in this TMDL utilized available SHL and ISU data from 2002-2016. All data was collected at the ambient monitoring location, which is shown in Figure 3-1. Development of the in-lake target, the TMDL, and impairment status are based on data collected at this location, per DNR assessment methodology. In-lake water quality data is reported in Appendix C.

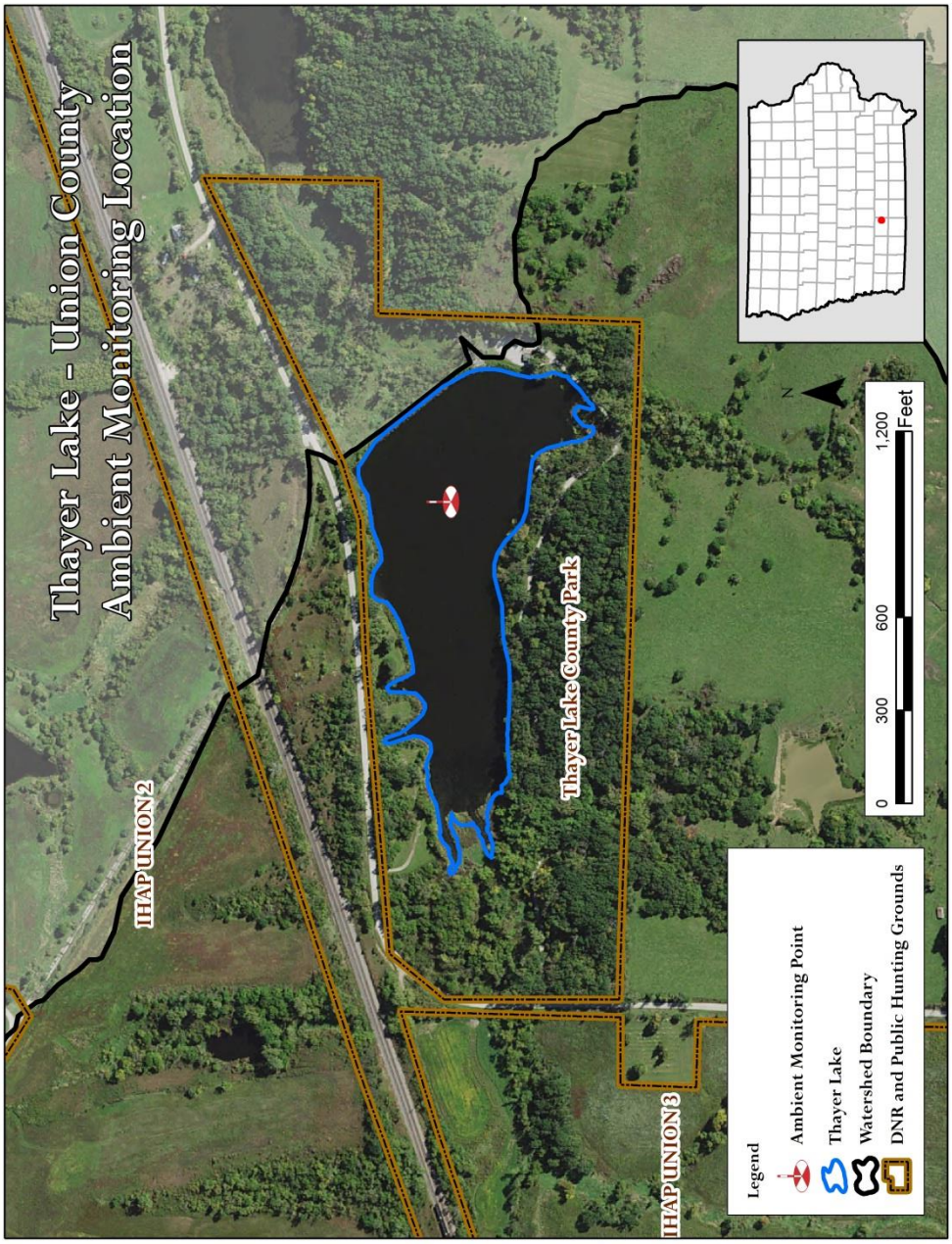

Figure 3-1. Ambient monitoring location for water quality assessment

Carlson's TSI was used to evaluate the relationships between TP, algae (chlorophyll-a), and transparency (Secchi depth) in Thayer Lake. If the TSI values for the three parameters are the same, the relationships between the three are strong. If the TP TSI values are higher than chlorophyll TSI, it suggests there are limitations to algal growth besides phosphorus. Figure 3-2 illustrates each of the individual TSI values throughout the analysis period. TSI values that exceed the 303(d) listing threshold of 65 (for chlorophyll-a) are in the red-shaded box on the top half of Figure 3-2. TSI values within the 2104 305(b) assessment period are highlighted within the blue-shaded box.

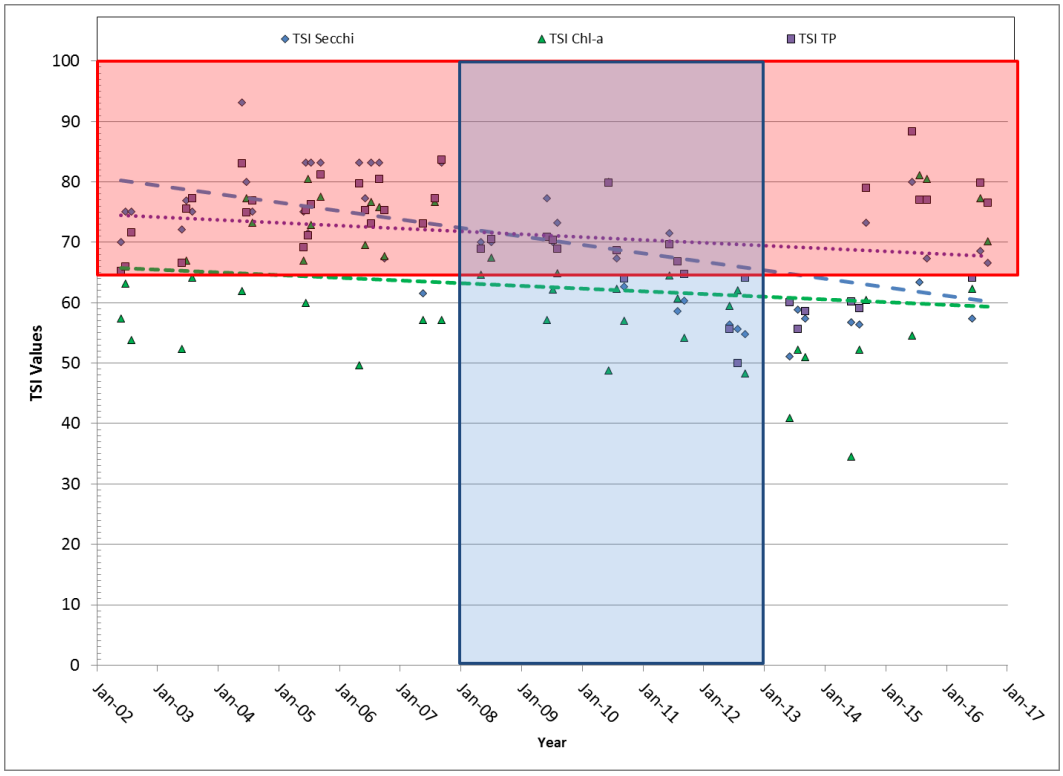

Figure 3-2. Growing season TSI values for individual samples in analysis period

Averaging the growing season TSI values for each year in the analysis period results in overall TSI values of 67 for Secchi depth, 65 for chlorophyll-a, and 72 for phosphorus. These values can be shown in Figure 3-3. The water clarity trend tends to be positive, with decreasing TSI values for TP, and Secchi depth, and chl-a. However, there is as initial increase in TSI values in 2015 and 2016. Averaging growing season TSI values from data used in the 2014 Water Quality Assessment (2008-2012) results in TSI values of 65 for Secchi depth, 61 for chlorophyll-a, and 68 for TP.

Subsequent analyses show the link between the three indices of in-lake water quality. Figure 3-4 shows the relationship between total phosphorus and Secchi depth TSI values. Figure 3-5 shows the relationship between chlorophyll-a and total phosphorus. Figure 3-6 shows the relationship between Secchi depth and total phosphorus. The R^2 values between the various TSI indices are summarized in Table 3-1. There is a strong positive correlation between phosphorus and Secchi depth, and weaker positive correlation

between chlorophyll-a and both TP and Secchi depth. This suggests that transparency issues can be are linked to sediment and sediment bound phosphorus, but can be aggravated by algae in the water column. This also indicates that targeting phosphorus reductions in the watershed should improve Secchi depth TSI values and may also improve chl-a values in Thayer Lake.

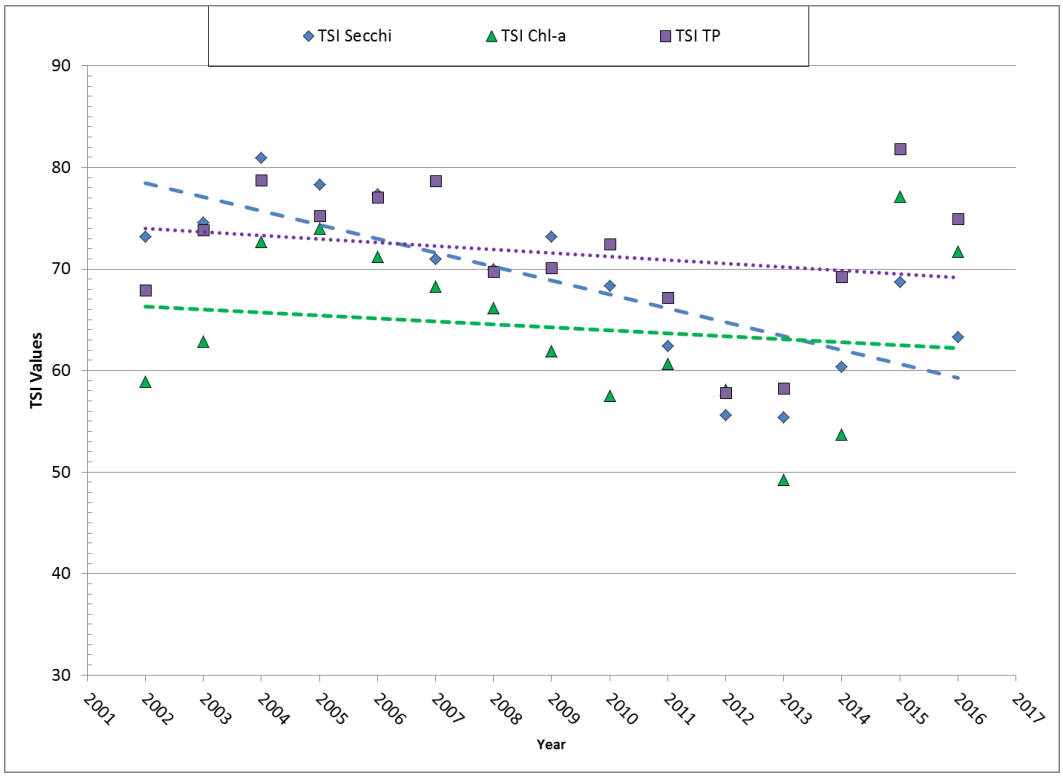

Figure 3-3. Growing season mean TSI values for analysis period

Also shown in Table 3-1 is the relationship between total nitrogen and the three main TSI indicators. Figure 3-7 shows a strong positive relationship with TP and TN with an R^2 value of 0.412. Figure 3-8 shows a weaker positive correlation with TN and chl-a of 0.203. Figure 3-9 shows a strong negative correlation between TN and Secchi depth. This shows that addressing total phosphorus transport may also reduce total nitrogen transport to Thayer Lake, while also related water clarity issues. This also indicates that a shared transport pathway between TP and TN may exist. One such shared pathway may be nutrient rich overland flow from pastoral grounds directly into Thayer Lake.

Table 3-1. Total phosphorus, chl-a, Secchi depth, and total nitrogen relationships and R^2 values

TSI indicator	Total Phosphorus	Chlorophyll-a	Total Nitrogen
Total Phosphorus	---	0.198	0.412
Chlorophyll-a	0.198	---	0.203
Secchi depth	0.615	0.154	0.507

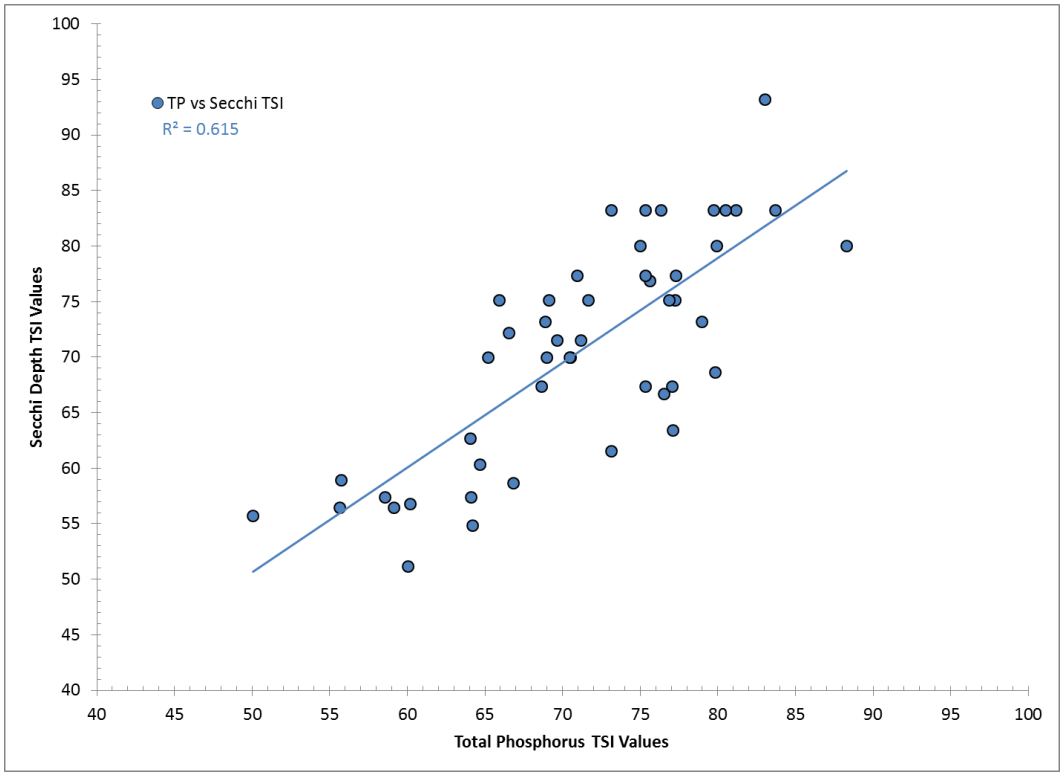

Figure 3-4. Analysis period TSI values for total phosphorus and Secchi depth

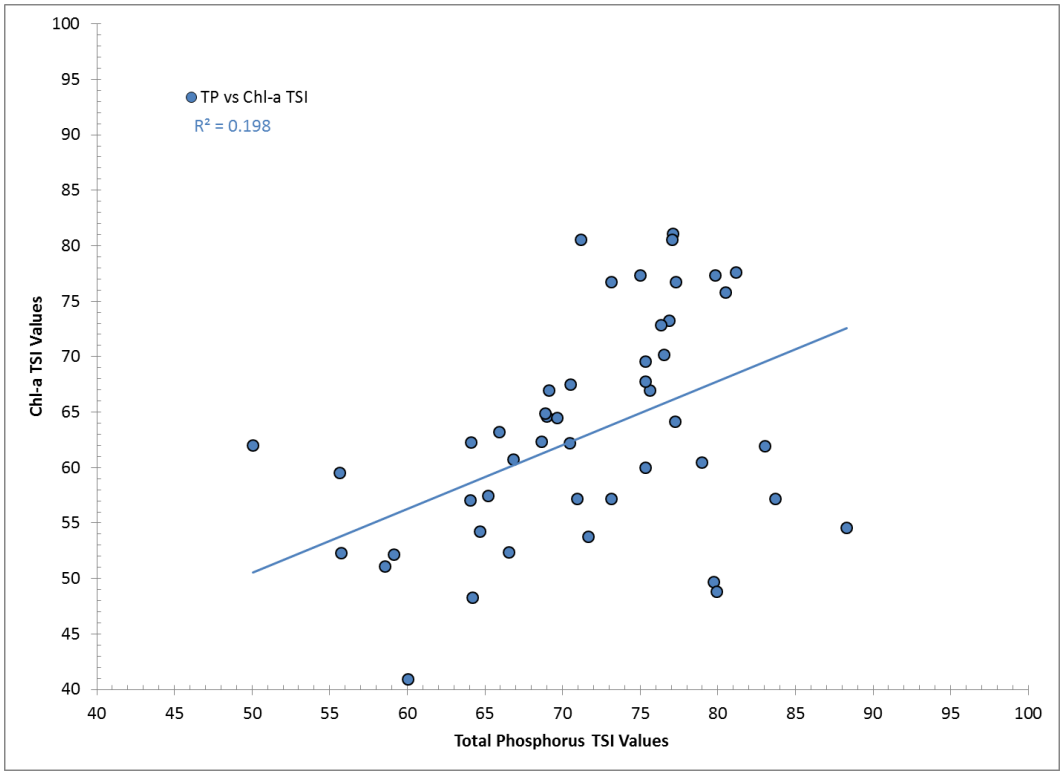

Figure 3-5. Analysis period TSI values for total phosphorus and chlorophyll-a

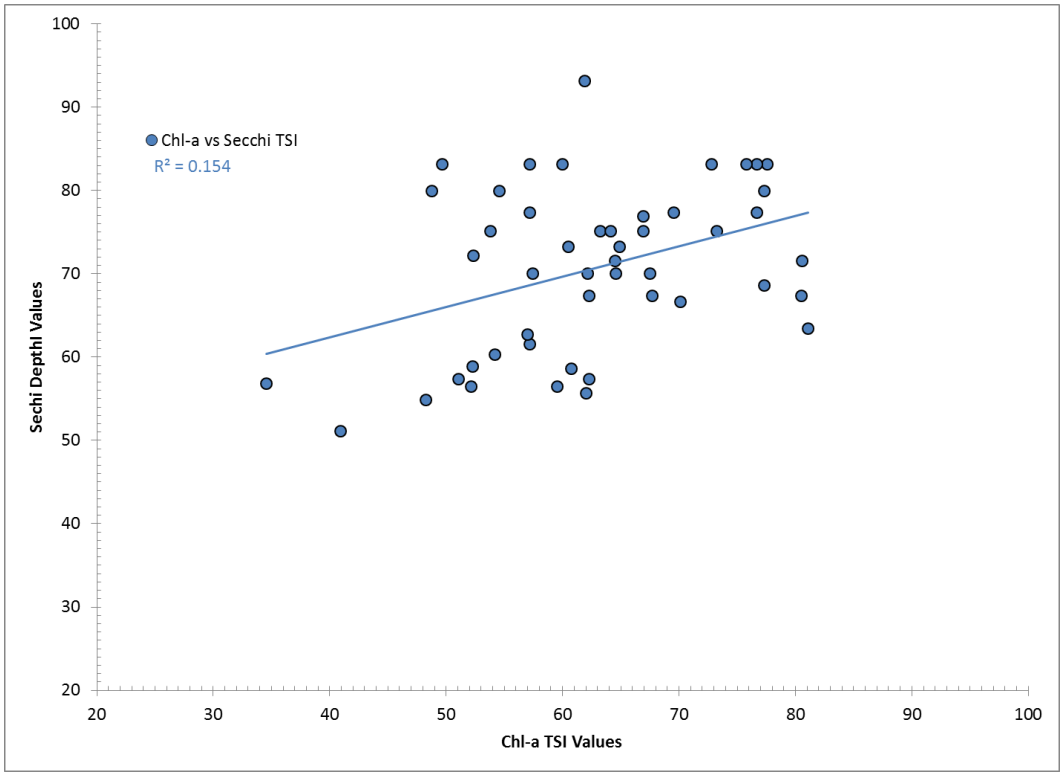

Figure 3-6. Analysis period TSI values for chlorophyll-a and Secchi depth

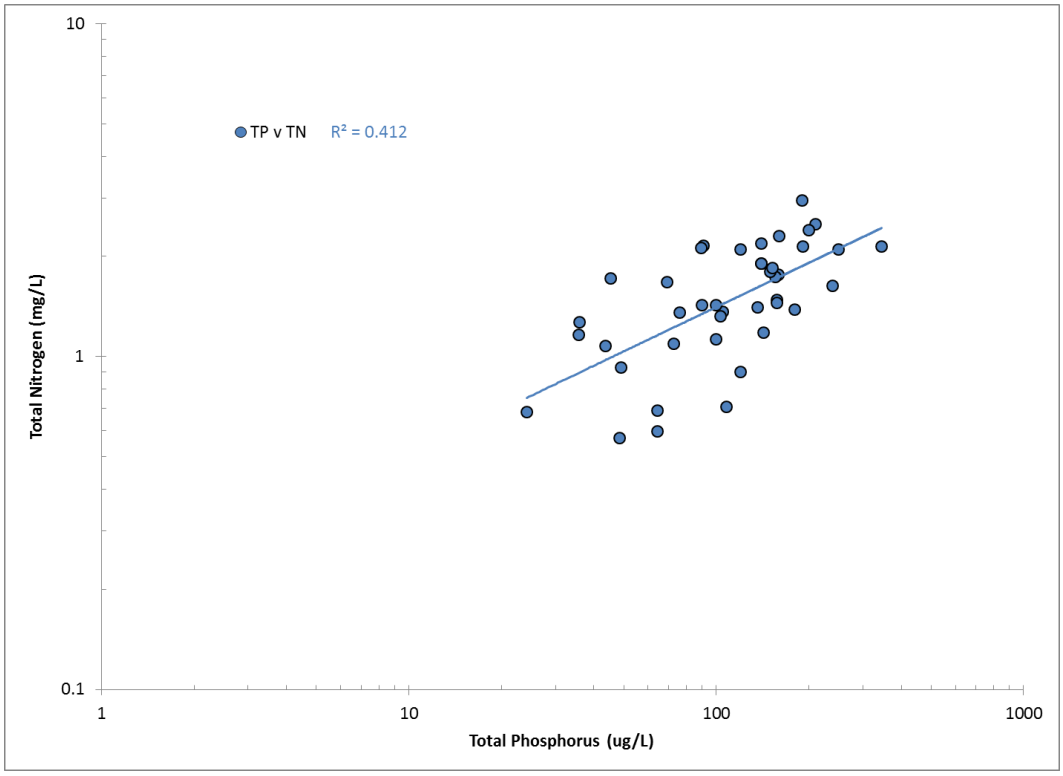

Figure 3-7. Total phosphorus and total nitrogen relationship

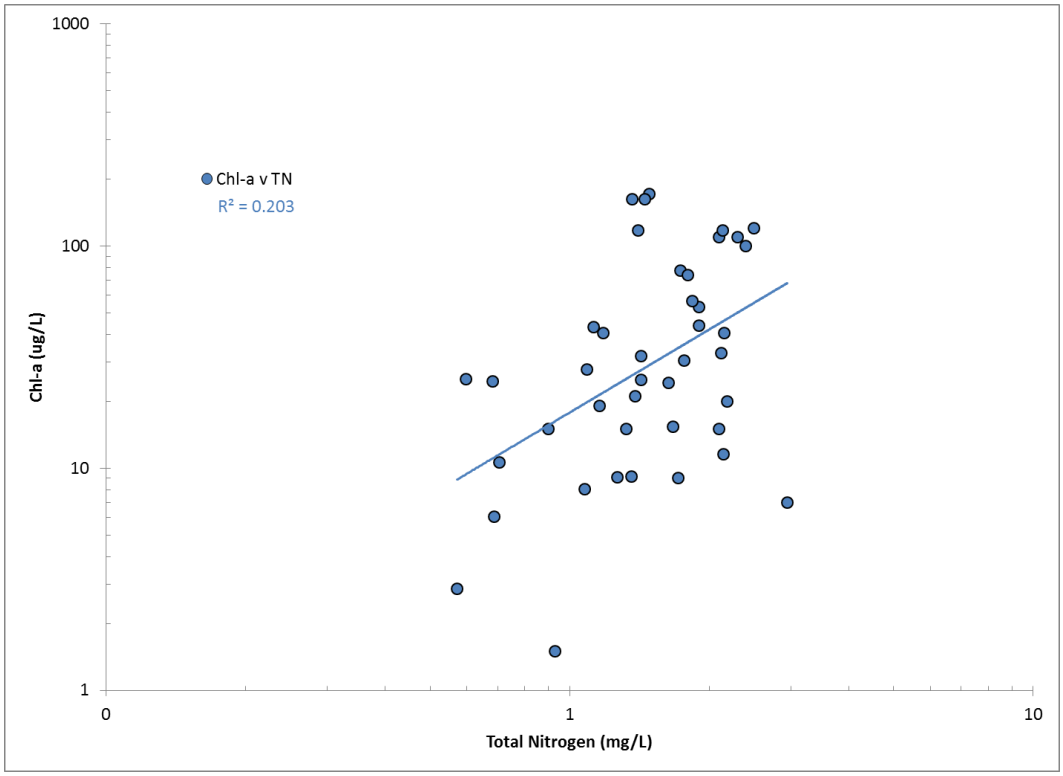

Figure 3-8. Total nitrogen and chl-a relationship

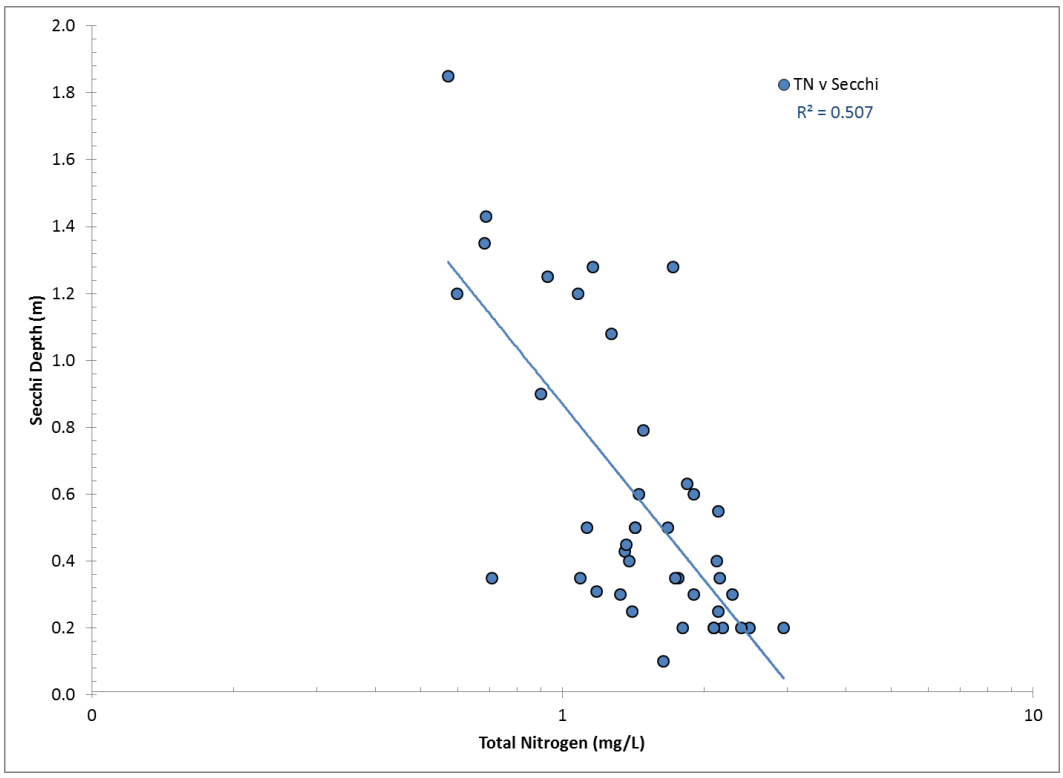

Figure 3-9. Total nitrogen and Secchi depth relationship

Figures 3-10 and 3-11 can be utilized to interpret differences (deviations) between Carlson's TSI values for TP, Secchi depth, and chlorophyll-a. Each quadrant of the chart indicates the potential factors that may limit algal growth in a lake. A detailed description of this approach is available in *A Coordinator's Guide to Volunteer Lake Monitoring Methods* (Carlson and Simpson, 1996). If the deviation between the chlorophyll-a TSI and TP TSI is less than zero (Chl TSI < TP TSI), the data point will fall below the X-axis. Pre-renovation water quality data points are shown in blue, and post-renovation water quality data points are shown in red.

Chlorophyll-a and TP TSI deviations are split between positive and negative deviations, with a majority (41 of 48 samples) lying below the x-axis in Figure 3-7. These metrics are indicative of high turbidity levels and high levels of phosphorus, depending on conditions at the time the water quality sample was collected. In addition, the low number of samples in the upper left quadrant (5 of 48), indicates low levels of finely suspended particles and the low number of samples in the upper right quadrant (2 of 48) show that excess nutrients causing algal blooms may be causing turbidity issues as well.

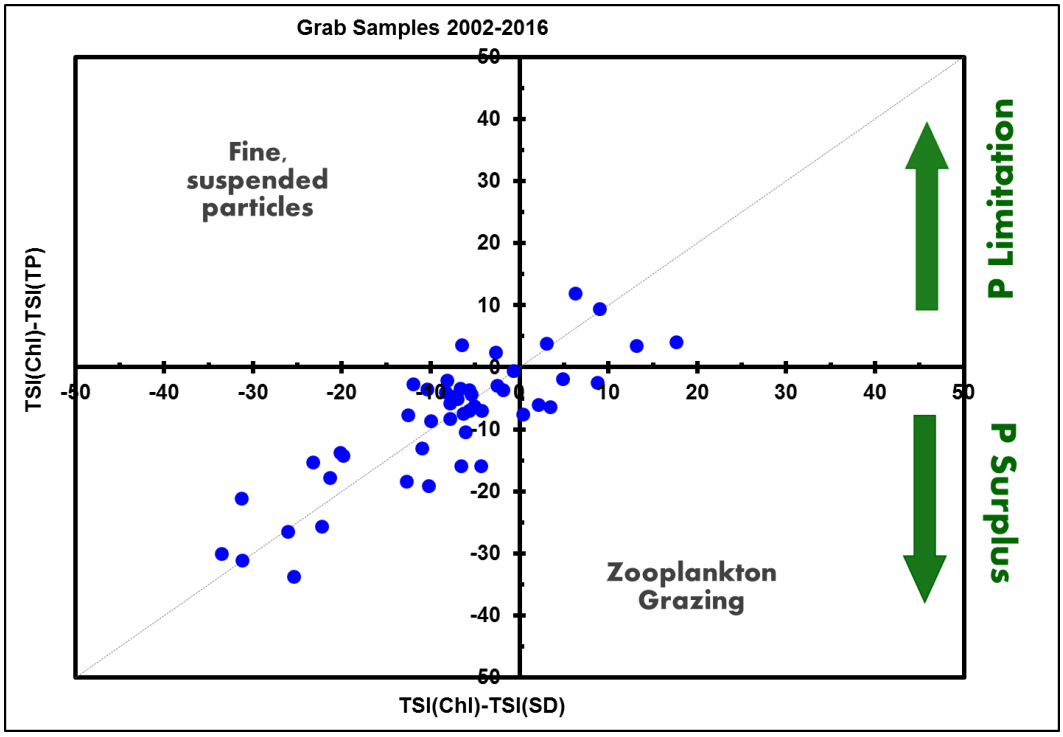

Figure 3-10. Phosphorus TSI deviations grab samples for analysis period

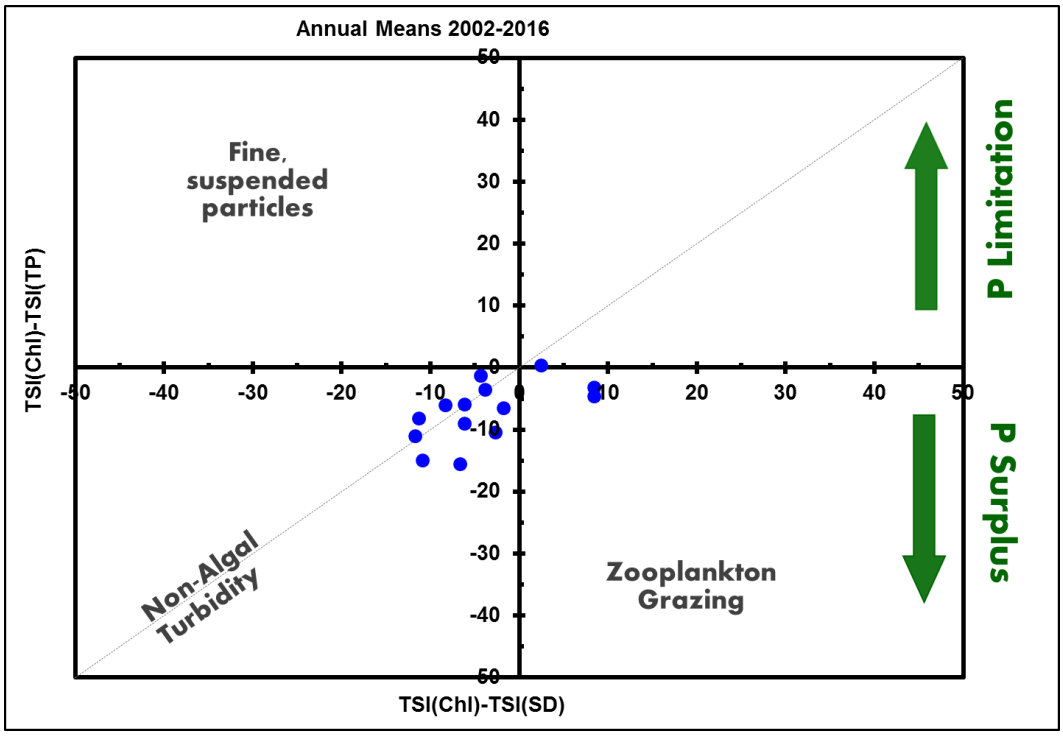

Figure 3-11. Phosphorus TSI deviations annual averages for analysis period

Chl-a, annual average TSI values do not show any correlation to annual or growing season precipitation (Figure 3-13). TP annual average TSI values show a weak positive correlation (Figure 3-12). Secchi depth shows a weak negative correlation to precipitation (Figure 3-14). These relationships may be due to increased overland flow bringing phosphorus laden sediments that can decrease transparency. These analyses reveals that high Secchi depth, chlorophyll-a, and TP levels are observed in both wet and dry years, and that both conditions must be considered when developing the TMDL.

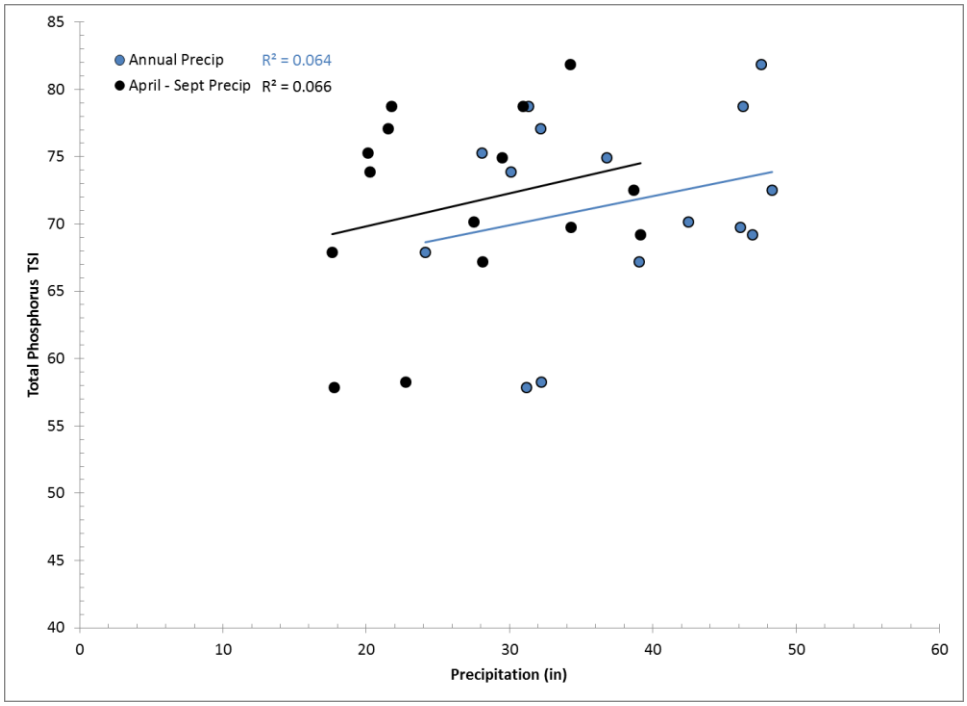

Figure 3-12. TP TSI values plotted against annual and growing season precip

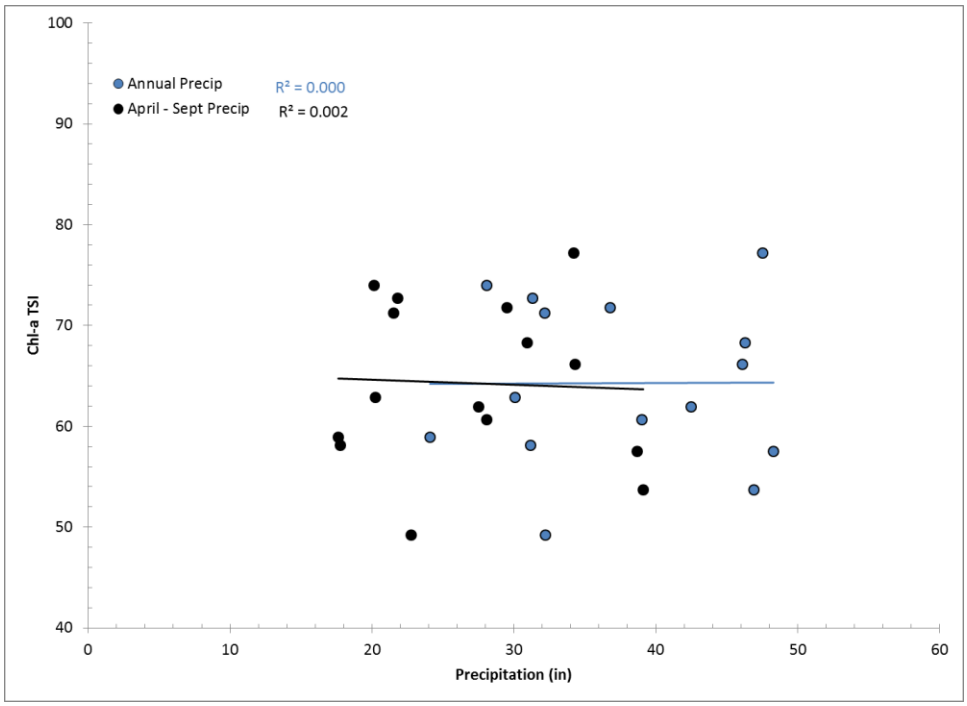

Figure 3-13. Chl-a TSI values plotted against annual and growing season precip

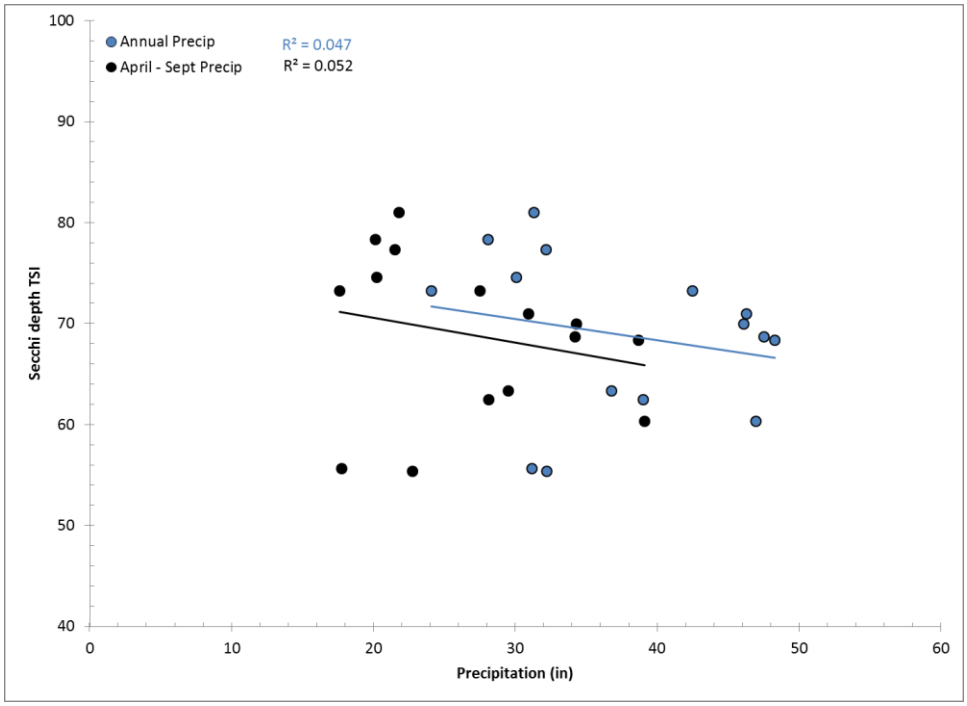

Figure 3-14. Secchi depth TSI values plotted against annual and growing season precip

Within lakes, the main two nutrients necessary for algal bloom development are nitrogen and phosphorus. When one nutrient is in short supply relative to the other, this nutrient supply will be exhausted first during growth. Once this nutrient is no longer available, growth is limited. Generally, in Iowa lakes, phosphorus is the limiting nutrient. Ratios of nitrogen to phosphorus can provide clues as to which nutrient is limiting growth in a given waterbody.

The overall TN:TP ratio in water quality samples from Thayer Lake, using average grab sample concentrations from 2002-2016, is 14. According to a study on blue-green algae dominance in lakes, ratios greater than 17 suggest a lake is phosphorus, rather than nitrogen, limited (MPCA, 2005). Carlson states that phosphorus may be a limiting factor at TN:TP ratios greater than 10 (Carlson and Simpson, 1996). Ratios that fall between 10 to 17 are often considered “co-limiting,” meaning either nitrogen or phosphorus is the limiting nutrient or light is limited due to high non-algal turbidity.

Analysis of the TN:TP ratio in Thayer samples reveals that the lake is P-limited 24 percent of the time and co-limited 47 percent of the time. Table 3-2 lists the mean TSI score for each nutrient limiting condition. The high total phosphorus TSI for N-limiting conditions seems to indicate an oversupply of phosphorus, rather than a limiting quantity of nitrogen. The applicability of the N-limiting concept is questionable at such high eutrophic states, where often light, temperature, or biological constraints on algal growth limit even higher states of productivity. Although a recent study recommends dual control of both N and P to limit eutrophication (Paerl et al., 2016), other studies indicate

that phosphorus-only control is more effective and pushing lakes towards N-limiting conditions (by N reductions) can actually increase the prevalence of nitrogen fixing cyanobacteria (Schindler et al., 2016). Additionally, the positive relationship between phosphorus and nitrogen shown in Figure 3-9 show that targeting phosphorus may reduce nitrogen as well.

Table 3-2. TN:TP ratio summary in Thayer Lake

Samples Collected	# of Samples	N-limited (< 10)	Co-Limited (10-17)	P-limited (>17)
All samples 2002-2016	45	13 (29%)	21 (47%)	11 (24%)
Samples with Chl-a TSI > 65	34	8 (24%)	19 (56%)	5 (15%)
Samples with Secchi TSI > 65	32	10 (31%)	14 (44%)	5 (16%)

When the chl-a TSI exceeds 65, the lake is either P-limited or co-limited 71 percent of the time. When the Secchi depth TSI exceeds 65, the lake is either P-limited or co-limited 69 percent of the time. This analysis reveals that water quailty improvement of algal blooms and turbidity via TP reduction is most feasible. Previous analysis also has shown the high probability of reducing total nitrogen while also reducing total phosphorus.

3.2. TMDL Target

General description of the pollutant
The 2014 305(b) assessment attributes poor water quality in Thayer Lake to excess algae and turbidity, and the data interpretation described in Section 3.1 indicates phosphorus load reduction will best address the impairment. It will be important to continue to assess TSI values for chlorophyll-a and Secchi depth as phosphorus reduction practices are implemented. If phosphorus reductions are not accompanied by reductions in algal blooms and turbidity levels, then reductions of nitrogen may prove necessary to reduce algae to an acceptable level. However, phosphorus should be reduced first, as it is the primary limiting nutrient in algal growth. Additionally, reductions in nitrogen that result in nitrogen limitation favor growth of harmful cyanobacteria, which have the ability to fix nitrogen from the atmosphere. These bacteria, often referred to as blue-green algae, can emit cyanotoxins to the water, which can harm humans, pets, and wildlife if ingested.

Table 3-3 reports the simulated chlorophyll-a, TP, and Secchi depth at the ambient monitoring location for both existing and target conditions. In-lake water quality was simulated using the BATHTUB model, which is described in more detail in Appendix E. The chlorophyll-a TSI target of 63 complies with the narrative “free from aesthetically objectionable conditions” criterion. The Secchi depth target of 63 complies with turbidity impairment. Meeting both of these targets will result in delisting Thayer Lake if attained in two consecutive 303(d) listing cycles. Note that TP values in Table 3-3 are not TMDL targets. Rather, they represent in-lake water quality resulting from TP load reductions required to obtain the chlorophyll-a and Secchi depth TSI targets in Thayer Lake.

Table 3-3. Existing and target water quality (ambient monitoring location)

Parameter	[1]2002-2016	[2]2008-2012	TMDL Target
Secchi Depth	0.6 m	0.7 m	0.8
TSI (Secchi Depth)	67	65	63
Chlorophyll-a	34.1 µg/L	23.1 µg/L	21
TSI (Chlorophyll-a)	65	61	61
TP	109.4 µg/L	85.6 µg/L	72
TSI (TP)	72	68	66

[1]Modeled period
[2]303(b) Assessment period

Selection of environmental conditions
The critical period for poor water clarity is the growing season (April through September). However, long-term phosphorus loads lead to buildup of phosphorus in the reservoir and can contribute to algal growth and turbidity regardless of when phosphorus first enters the lake. Therefore, both existing and allowable TP loads to Thayer are expressed as annual averages. Phosphorus loads are also expressed as daily maximums to comply with EPA guidance.

Waterbody pollutant loading capacity (TMDL)
This TMDL establishes a chlorophyll-a TSI target of 63 and a Secchi depth TSI target of 63 using analyses of existing water quality data and Carlson's trophic state index methodology. The allowable TP loading capacity was developed by performing water quality simulations using the BATHTUB model. BATHTUB is a steady-state water quality model that performs empirical eutrophication simulations in lakes and reservoirs (Walker, 1999). The BATHTUB model was calibrated to available water quality data collected by ISU and SHL from 2002 through 2016, consistent with the assessment period for the 2014 305(b) report and draft 2016 report.

The BATHTUB model is driven by weather, lake morphometry (i.e., size and shape), watershed hydrology, and sediment and nutrient loads predicted by the STEPL model. STEPL utilizes simple equations to predict sediment and nutrient loads from various land use and animal sources, and includes a tool that estimates potential sediment and nutrient reductions resulting from implementation of Best Management Practices (BMPs). STEPL input included local soil, land use, and climate data. A detailed discussion of the parameterization and calibration of the STEPL and BATHTUB models is provided in Appendices D through F.

The annual TP loading capacity was obtained by adjusting the TP loads (tributary concentrations) in the calibrated BATHTUB model until chlorophyll-a and Secchi depth TSIs no greater than 63 were attained for the lake segment in which ambient monitoring data is collected. This model will be used to quantify maximum daily loads, while acknowledging that multiple solutions exist. Modeling reductions in external loading shows the annual loading capacity of Thayer Lake is 186 kg/yr (410.8 lbs/yr).

In November of 2006, The U.S. Environmental Protection Agency (EPA) issued a memorandum entitled *Establishing TMDL "Daily" Loads in Light of the Decision by the*

U.S. Court of Appeals for the D.C. circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits. In the context of the memorandum, EPA

> *"…recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increment. In addition, TMDL submissions may include alternative, non-daily pollutant load expressions in order to facilitate implementation of the applicable water quality standards…"*

As recommended by EPA, the loading capacity of Thayer Lake for TP is expressed as a daily maximum load, in addition to the annual loading capacity of 418.5 lbs/year. The annual average load is applicable to the assessment of in-lake water quality and water quality improvement actions, while the daily maximum load satisfies EPA's recommendation for expressing the loading capacity as a daily load.

The maximum daily load was estimated from the growing season average load using a statistical approach that is outlined in more detail in Appendix G. This approach uses a log-normal distribution to calculate the daily maximum from the long-term (e.g., annual) average load. The methodology for this approach is taken directly from a follow-up guidance document entitled *Options for Expressing Daily Loads in TMDLs* (EPA, 2007), and was issued shortly after the November 2006 memorandum cited previously. This methodology can also be found in EPA's 1991 *Technical Support Document for Water Quality Based Toxics Control*. Using the approach, the annual loading capacity of 418.5 lbs/yr is equivalent to an average daily load of 1.2 pounds per day (lbs/day) and a maximum daily load of 3.6 lbs/day.

Decision criteria for WQS attainment
The narrative criteria in the water quality standards require that Thayer Lake support primary contact for recreation. The metrics for WQS attainment for de-listing the impairments are a chlorophyll-a TSI and Secchi depth TSI of 63 or less in two consecutive 303(d) listing cycles.

Compliance point for WQS attainment
The TSI target for listing and delisting of Thayer Lake is measured at the ambient monitoring location shown in Figure 3-1. To maintain consistency with other Clean Water Act programs implemented by the Iowa DNR, such as the 305(b) assessment and 303(d) listing process, the TMDL target is based on water quality of the main body of the lake in the one BATHTUB segment, which best represents the ambient monitoring location in Thayer Lake.

3.3. Pollution Source Assessment

Existing load
Average annual simulations of hydrology and pollutant loading were developed using the STEPL model (Version 4.1). STEPL was developed by Tetra Tech, for the US EPA Office of Wetlands, Oceans, and Watersheds (OWOW), and has been utilized extensively

in the United States for TMDL development and watershed planning. Model description and parameterization are described in detail in Appendix D.

Using STEPL and BATHTUB to simulate annual average conditions between 2002-2016, the annual TP load to Thayer Lake was estimated to be 829 lbs/yr. The simulation period (for existing conditions) includes assessment period (for the 2014 Integrated Report) where monitoring data was available.

Departure from load capacity
The TP loading capacity for Thayer is 418.5 lbs/yr and 3.6lbs/day (maximum daily load). To meet the target loads, an overall reduction of 49.5 percent of the TP load is required. The implementation plan included in Section 4 describes potential BMPs, potential TP reductions, and considerations for targeted selection and location of BMPs.

Identification of pollutant sources
The existing TP load to Thayer Lake is entirely from nonpoint sources of pollution. Table 3-4 reports estimated annual average TP loads to the lake from all known sources, based on the STEPL simulation of average annual conditions from 2002-2016. The predominant sources of phosphorus to Thayer Lake include erosion from land in grazed pasture and row crop production. Pasture Row crops in various rotations comprise over 68 percent of the land area of the watershed (Table 2-3), and 35.4 percent of the phosphorus load to the lake (Figure 3-13 and Table 3-4). Other contributing sources of phosphorus include row crop (20.4 percent); other non-grazed grassland (19.0 percent) forested areas inside Thayer Lake park ground (18.2 percent); developed areas such as roads, residential, and other urban areas (4.3 percent); and all other loads (2.7 percent).

Internal recycling of phosphorus in the lake was not explicitly simulated or calculated, because predicted phosphorus loads to the lake from the watershed were large enough to fully account for observed phosphorus levels in the lake. The BATHTUB model empirically and indirectly accounts for low to moderate levels of internal loading without the addition of an internal loading input to the model. In lakes with substantial internal loading issues, inclusion of additional internal load inputs is sometimes necessary, but that was not the case for Thayer Lake. The elevated flushing rate, which stems from the large watershed-to-lake ratio of 38-to-1, likely contributes to the low significance of internal loading in Thayer Lake. However, internal recycling of phosphorus may be important in extremely dry conditions, typically late in the growing season, when the water level falls below the spillway crest, creating a stagnant pool in the reservoir. Reduction of internal lake loads is a valid water quality improvement strategy, but watershed loads are more critical to long-term water quality in the lake.

Allowance for increases in pollutant loads
There is no allowance for increased phosphorus loading included as part of this TMDL. A majority of the watershed is in grassland or agricultural row crop production, and is likely to remain in these landuses in the future. Any future residential or urban development may contribute similar sediment loads and therefore will not increase phosphorus to the lake system. Thayer Lake Park, which circumscribes the lake, is

unlikely to undergo significant land use changes. There are currently no incorporated unsewered communities in the watershed; therefore it is unlikely that a future WLA would be needed for a new point source discharge. Any future development of animal feeding operations (AFO) qualifying as large concentrated animal feeding operations (CAFO) or meeting the requirements for NPDES permits as small or medium sized CAFOs will have zero discharge permits.

Table 3-4. Average annual TP loads from each source

Source	Descriptions and Assumptions	TP Load (lb/yr)	Percent (%)
Pastureland	Seasonally grazed grassland	360.6	35.4
Row Crops	Sheet and rill erosion from corn and soybeans dominated agriculture	207.6	20.4
User Defined	All non-grazed grassland, CRP	193.9	19.0
Forest	Forested park grounds surrounding lake	185.1	18.2
Urban	Urban areas, roads, and farmsteads	43.6	4.3
Groundwater	Agricultural tile discharge, natural groundwater flow	18.3	1.8
All others	Wildlife, atmospheric deposition, septics	9.5	0.9
Total		**1018.6**	**100**

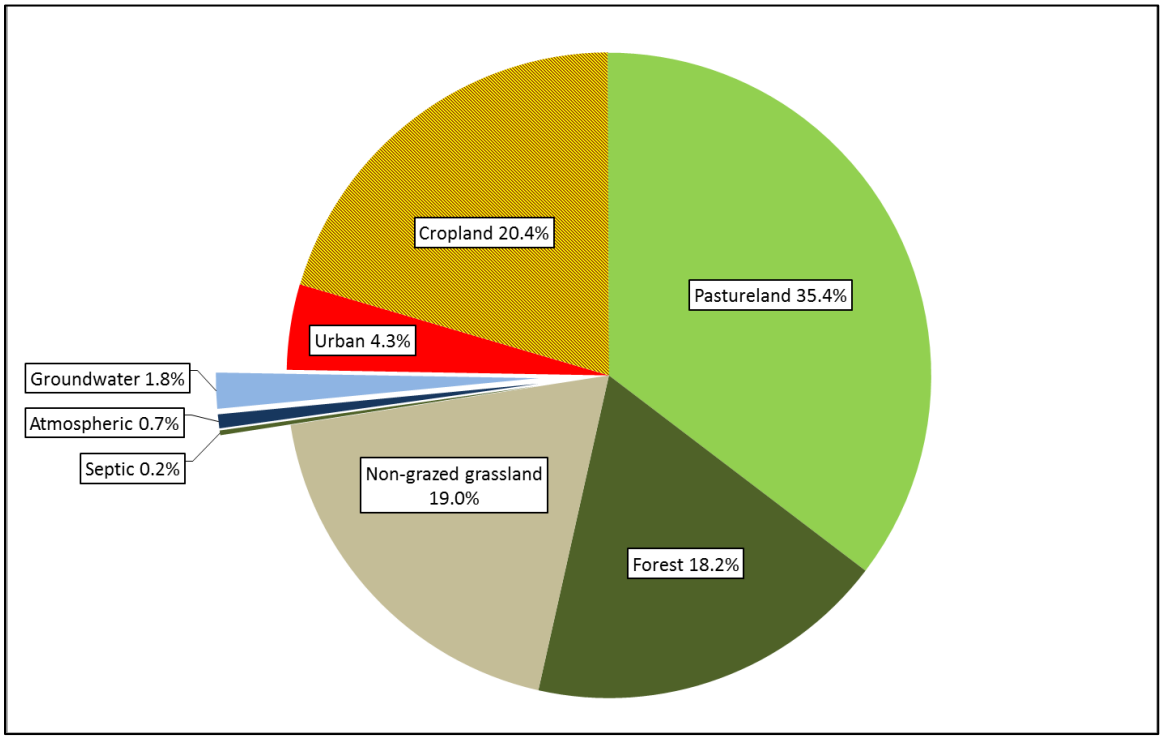

Figure 3-13. Relative TP loads by source

3.4. Pollutant Allocation

Wasteload allocation
There are no permitted point source dischargers of phosphorus in the Thayer Lake watershed.

Load allocation
Nonpoint sources of phosphorus to Thayer Lake include erosion from land in pasture and row crop production, erosion from grasslands, erosion from timber/wooded areas, transport from developed areas (roads, residences, etc.), wildlife defecation, and atmospheric deposition (from dust and rain), and groundwater contributions. Septic systems in this watershed, which are not regulated or permitted under the Clean Water Act, but can fail or drain illegally to ditches, also contributed phosphorus to the lake during the assessment period.

Changes in agricultural land management, implementation of structural best management practices (BMPs), repair or replacement of failing septic systems, and in-lake restoration techniques can reduce phosphorus loads and improve water quality in Thayer Lake. Based on the inventory of sources, management and structural practices targeting surface runoff contributions of phosphorus offer the largest potential reductions in TP loads.

Table 3-5 shows an example load allocation scenario for the Thayer Lake watershed that meets the overall TMDL phosphorus target. The LA is 462 lbs/year, with a maximum daily LA of 3.94 lbs/day. The daily maximum LA was obtained by subtracting the daily WLA and daily MOS from the statistically-derived TMDL (as described in Section 3.2 and Appendix G). The specific reductions shown in Table 3-5 are not required, but provide one of many possible combinations of reductions that would achieve water quality goals.

Table 3-5. Example load allocation scheme to meet target TP load

TP Source	Existing Load (lb/year)	LA (lb/year)	NPS Reduction (%)
Pastureland	360.6	112	69
Row Crops	207.6	100	52
[1]User Defined	193.9	125	36
Forest	185.1	100	46
Urban	43.6	25	43
Groundwater	18.3	0	0
[2]All others	9.5	0	0
Total	**1018.6**	**462**	**55**

[1]Non grazed grassland and CRP
[2]Atmospheric contributions, direct lake contributions by waterfowl

Margin of safety
To account for uncertainties in data and modeling, a margin of safety (MOS) is a required component of all TMDLs. An explicit MOS of 10 percent (51 lbs/year, 0.44 lbs/day) was utilized in the development of this TMDL. These uncertainties may include seasonal

changes in nutrient concentrations of influent to Thayer Lake, changes in internal recycling that may be seasonal in nature, maintenance and efficiency of existing BMPs.

Reasonable Assurance
Under current EPA guidance, when a TMDL is developed for waters impaired by both point and nonpoint sources, and the WLA is based on an assumption that nonpoint source load reductions will occur, the TMDL should provide reasonable assurance that nonpoint source control measures will achieve expected load reductions. There are no permitted or regulated point source discharges contributing phosphorus to Thayer Lake and the WLA is zero, therefore reasonable assurance of point source reductions is not applicable. Reasonable assurance for reduction of nonpoint sources is provided by the list of potential best management practices that would deliver phosphorus reductions, a group of nonstructural practices that prevent transport of phosphorus, a proposed methodology for prioritizing and targeting BMPs on the landscape, and monitoring for best available data for estimating the reductions associated with implemented BMPs.

3.5. TMDL Summary

The following general equation represents the total maximum daily load (TMDL) calculation and its components:

$$TMDL = LC = \Sigma\ WLA + \Sigma\ LA + MOS$$

Where:
TMDL = total maximum daily load
LC = loading capacity
Σ WLA = sum of wasteload allocations (point sources)
Σ LA = sum of load allocations (nonpoint sources)
MOS = margin of safety (to account for uncertainty)

Once the loading capacity, wasteload allocations, load allocations, and margin of safety have all been determined for the Thayer Lake watershed, the general equation above can be expressed for the Thayer Lake algae and turbidity TMDL.

Expressed as the allowable annual average, which is helpful for water quality assessment and watershed management:

TMDL = LC = Σ WLA (0 lbs-TP/year) + Σ LA (462 lbs-TP/year)
+ MOS (51 lbs-TP/year) = **513 lbs-TP/year**

Expressed as the maximum daily load:

TMDL = LC = Σ WLA (0 lbs-TP/day) + Σ LA (3.94 lbs-TP/day)
+ MOS (0.44 lbs-TP/day) = **4.38 lbs-TP/day**

4. Implementation Planning

This implementation plan is not a requirement of the Federal Clean Water Act. However, the Iowa Department of Natural Resources (DNR) recognizes that technical guidance and support are critical to achieving the goals outlined in this Water Quality Improvement Plan (WQIP). Therefore, this implementation plan is included for use by local agencies, watershed managers, and citizens for decision-making support and planning purposes. The best management practices (BMPs) discussed are potential tools that will help achieve water quality goals if appropriately utilized. It is possible that only a portion of BMPs included in this plan will be feasible for implementation in the Thayer Lake watershed. Additionally, there may be potential BMPs not discussed in this implementation plan that should be considered. This implementation plan should be used as a guide or foundation for detailed and comprehensive planning by local stakeholders.

Collaboration and action by residents, landowners, lake users, and local agencies will be essential to improve water quality in Thayer Lake and support its designated uses. Locally-led efforts have proven to be the most successful in obtaining real and significant water quality improvements. Improved water quality results in economic and recreational benefits for people that live, work, and recreate in the watershed. Therefore, each group has a stake in promoting awareness and educating others about water quality, working together to adopt a comprehensive watershed improvement plan, and applying BMPs and land management changes in the watershed.

4.1. Previous Watershed Planning and Implementation

Since the development of the Thayer Lake over 150 years agricultural producers have updated management practices, implemented grassed waterways, riparian corridors and more recently and conservation tillage practices. These practices help prevent and mitigate soil loss from the landscape, which can in turn decrease nutrient and pollutant loading to the lake system. Sediment basins have been installed were high levels of erosion have been documented. Extensive use of these practices can be found throughout the watershed.

4.2. Future Planning and Implementation

General Approach
Future watershed management and BMP implementation efforts in the Thayer Lake watershed should utilize a phased approach. Given the watershed-to-lake ratio and the morphology of this lake system, attainment of existing water quality standards may take considerable time to see improvement in the watershed. Efforts should be targeted to maximize benefits and minimize costs. Emphasis should be placed on non-structural water quality practices that increase organic matter and infiltration (thereby reducing runoff and erosion), keep the soil covered with vegetation, maximize water uptake perennial non-agricultural plant species, along with possible in-lake practices.

Projects with multiple benefits (e.g., wildlife habitat, soil conservation, and water quality) may do more to protect and preserve the use of Thayer Lake for future generations than those focused solely on water quality. Additional funding avenues include, but are not limited to state and federal funding opportunities, which may help facilitate multiple-objective projects, especially in the parkland around the lake.

Timeline
Planning and implementation of future improvement efforts may take several years, depending on stakeholder interest, availability of funds, landowner participation, and time needed for design and construction of any structural BMPs. Realization and documentation of significant water quality benefits may take 5-10 years or longer, depending on weather patterns, amount of water quality data collected, and the successful selection, location, design, construction, and maintenance of BMPs. Sustained improvement may be a more appropriate short term goal than impairment delisting.

Tracking milestones and progress
This WQIP, including the proposed monitoring plan outlined in Section 5, would address several of the elements required for a nine-element plan approved by EPA for the use of 319 funds, or other state and federal funding sources, as available. Establishment of specific short, intermediate, and long-term water quality goals and milestones would also be needed to additional funding from available sources. A path to full attainment of water quality standards and designated uses must be included for most funding sources, but efforts should first focus on documenting water quality improvement resulting from BMPs and elimination of any phosphorus “hot spots” that may exist. Conclude

4.3. Best Management Practices

No stand-alone BMP will be able to sufficiently reduce phosphorus loads to Thayer Lake. Rather, a comprehensive package of BMPs will be required to reduce sediment and phosphorus transport to the lake, which can cause elevated algal growth and turbidity issues- the root of the impairment of designated use in Thayer Lake. The majority of phosphorus enters the lake via nutrient loss from pastureland agricultural fields through sheet / rill erosion. These sources have distinct phosphorus transport pathways and processes; therefore, each requires a different set of BMPs and strategies.

Other sources, although relatively small on an annualized basis, can have important localized and seasonal effects on water quality. It is important that all sources are considered to reduce phosphorus loads in the most comprehensive manner possible. Experience has shown that watershed projects that involve widespread “ownership” of potential solutions have the best chance of success. At the same time, resources to address the various sources of phosphorus should be allocated in a manner that is reflective of the importance to the impairment: algal blooms and turbidity issues caused primarily by excess phosphorus loads to the lake and in the lake. Potential BMPs are grouped into three types: land management (prevention), structural (mitigation), and in-lake alternatives (remediation).

Land Management (Prevention Strategies)
Many agricultural BMPs are designed to reduce erosion and nutrient loss from the landscape. These BMPs provide the highest level of soil conservation and soil health benefits, because they prevent erosion and nutrient loss from occurring. Land management alternatives implemented in row crop areas should include conservation practices such as no-till and strip-till farming, diversified crop rotation methods, utilization of in-field buffers, and cover crops. Incorporation of fertilizer into the soil by knife injection equipment reduces phosphorus levels, as well as nitrogen and bacteria levels, in runoff from application areas. Strategic timing of fertilizer application and avoiding over-application may have even greater benefits to water quality. Application of fertilizer on frozen ground should be avoided, as should application when heavy rainfall is forecasted. Land retirement programs such as the conservation reserve program (CRP), and conservation reserve enhancement program (CREP) constructed wetlands may be considered where appropriate.

Unlike other watersheds, Thayer Lake watershed has a high percentage of land in pasture which can be a large source of phosphorus, even a few acres of pasture with direct access to a stream could impact water quality in the lake. Well-managed pastures can have very little negative impact on water quality, since the ground is covered with vegetation year-round. Stable and diverse pasture forages hold soil in place, filter runoff, and uptake nutrients for growth. Exclusion of livestock from streams and riparian areas can provide additional water quality benefits. Rotational grazing systems can improve water quality in adjacent waterbodies compared with continuously grazed systems. More research is needed, but there is evidence that forage diversity, degree of vegetation coverage or residue, and regrowth rates are higher in rotationally-grazed pastures (Dinnes, 2004). These characteristics increase erosion protection, filter runoff, and provide increased nutrient uptake compared with continually grazed grasses and forages. Table 4-1 summarizes land management BMPs and associated phosphorus reduction estimates.

Structural BMPs (Mitigation Strategies)
Although they do not address the underlying generation of sediment or nutrients, structural BMPs such as sediment control basins, terraces, grass waterways, saturated buffers, riparian buffers, and wetlands can play a valuable role in reduction of sediment and nutrient transport to Thayer Lake. These BMPs attempt to mitigate the impacts of soil erosion and nutrient loss by intercepting them before they reach a stream or lake. Structural BMPs should be targeted to “priority areas” to increase their cost effectiveness and maximize pollutant reductions. Landowner willingness and the physical features of potential sites must also be considered when targeting structural practices. These practices may offer additional benefits not directly related to water quality improvement. These secondary benefits are important to emphasize to increase landowner and public interest and adoption. Potential structural BMPs are listed in Table 4-2, which includes secondary benefits and potential TP reductions.

Table 4-1. Potential land management BMPs (prevention strategies)

BMP or Activity	[1] Potential TP Reduction
Conservation Tillage:	
Moderate vs. Intensive Tillage	50%
No-Till vs. Intensive Tillage	70%
No-Till vs. Moderate Tillage	45%
Cover Crops	50%
Diversified Cropping Systems	50%
In-Field Vegetative Buffers	50%
Pasture/Grassland Management:	
Livestock Exclusion from Streams	75%
Rotational Grazing vs. Constant Intensive Grazing	25%
Seasonal Grazing vs. Constant Intensive Grazing	50%
Phosphorus Nutrient Application Techniques:	
[2]Deep Tillage Incorporation vs. Surface Broadcast	-15%
[2]Shallow Tillage Incorporation vs. Surface Broadcast	-10%
Knife/Injection Incorporation vs. Surface Broadcast	35%
Phosphorus Nutrient Application Timing and Rates:	
Spring vs. Fall Application	30%
Soil-Test P Rate vs. Over-Application Rates	40%
Application: 1-month prior to runoff event vs. 1-day	30%

[1]Adopted from Dinnes (2004) with professional judgment. Actual reduction percentages may vary widely across sites and runoff events.
[2]Note: Tillage incorporation can increase TP in runoff in some cases.

Landowner buy-in, ease of construction, and difficulty implementing preventative land management measures all contribute to the popularity of sediment control structures as a sediment and phosphorus mitigation strategy. This is a proven practice, if properly located, designed, constructed, and maintained. However, if not properly designed and constructed, sediment control basins may trap substantially less sediment and phosphorus than widely-used rules-of-thumb that are often assumed when quantifying reductions in the context of a watershed management plan. There are at least three general criteria that should be considered when designing sediment control basins. First, the area of the basin should be appropriate relative to the size of the drainage area. Effective sediment control basins require a minimum size of at least one percent of the total drainage area to the basin. Second, retention times (i.e., the time it takes for runoff from a storm event to drain from the basin) should be no less than 24 hours, and preferably 40 hours. Shorter retention periods do not adequately settle fine sediments, which carry a large portion of attached phosphorus, which can influence algal blooms and turbidity issues. Third, sediment basins should be shaped such that the length to width ratio is maximized to prevent short-circuiting across the shortest flow-path through the basin. A minimum length to width ratio of 3:1 is commonly cited in the literature.

To obtain reductions in TP load necessary to meet water quality targets, land management strategies and structural BMPs should be implemented to obtain the largest and most cost-effective water quality benefit. Targeting efforts should consider areas with the highest potential phosphorus loads to the lake. Factors affecting phosphorus

contribution include: land cover, steep slopes; proximity to waterbodies; tillage practices, and method, timing, and amount of manure and commercial fertilizer application.

Table 4-2. Potential structural BMPs (mitigation strategies)

BMP or Activity	Secondary Benefits	[1] Potential TP Reduction
Terraces	Soil conservation, prevent in-field gullies, prevent wash-outs	50%
Grass Waterways	Prevent in-field gullies, prevent washouts, some ecological services	50%
[2]Sediment Control Structures	Some ecological services, gully prevention	Varies
[3]Wetlands	Ecological services, potential flood mitigation, aesthetic value	15%
Riparian Buffers	Ecological services, aesthetic value, alternative agriculture	45%
Saturated Buffers	Nitrate removal	[4]Varies

[1]Adopted from Dinnes (2004) with professional judgment. Actual reduction percentages may vary widely across sites and runoff events.
[2]Not discussed in Dinnes (2004). Phosphorus removal in sediment basins varies widely and is dependent upon the size of the structure relative to the drainage area, the length:width ratio, and drawdown time of a specified rainfall/runoff event.
[3]Note: TP reductions in wetlands vary greatly depending on site-specific conditions, such as those listed for sediment control structures. Generally, removal of phosphorus is lower in wetlands than in sediment control structures. Wetland can sometimes be sources, rather than sinks, of phosphorus
[4]Limited research in total phosphorus reduction values

The Spreadsheet Tool for Estimating Pollutant Load (STEPL) model was used in TMDL development to predict phosphorus loads to Thayer Lake. Figure 4-1 shows the annual phosphorus export from each subbasin in the Thayer Lake watershed STEPL model. Red-shaded basins indicate the heaviest phosphorus export and green shaded bars indicate the lowest export rates and loads relative to the sub basins in this study. The figures reveal that more phosphorus is annually exported from Subbasin 2 (690.6 lbs) than Subbasin 1 (320.9 lbs). Figure 4-2 shows TP export rates in for each subbasin after adjusting for drainage area. An annual average of 1.27 lbs/ac/yr and 2.97 lbs/ac/yr are transported from Subbasin 1 and 2, respectively.

Subbasin-level information indicates that best management practices reducing phosphorus export should concentrate efforts on reducing phosphorus and sediment transport from the southern half of the watershed.

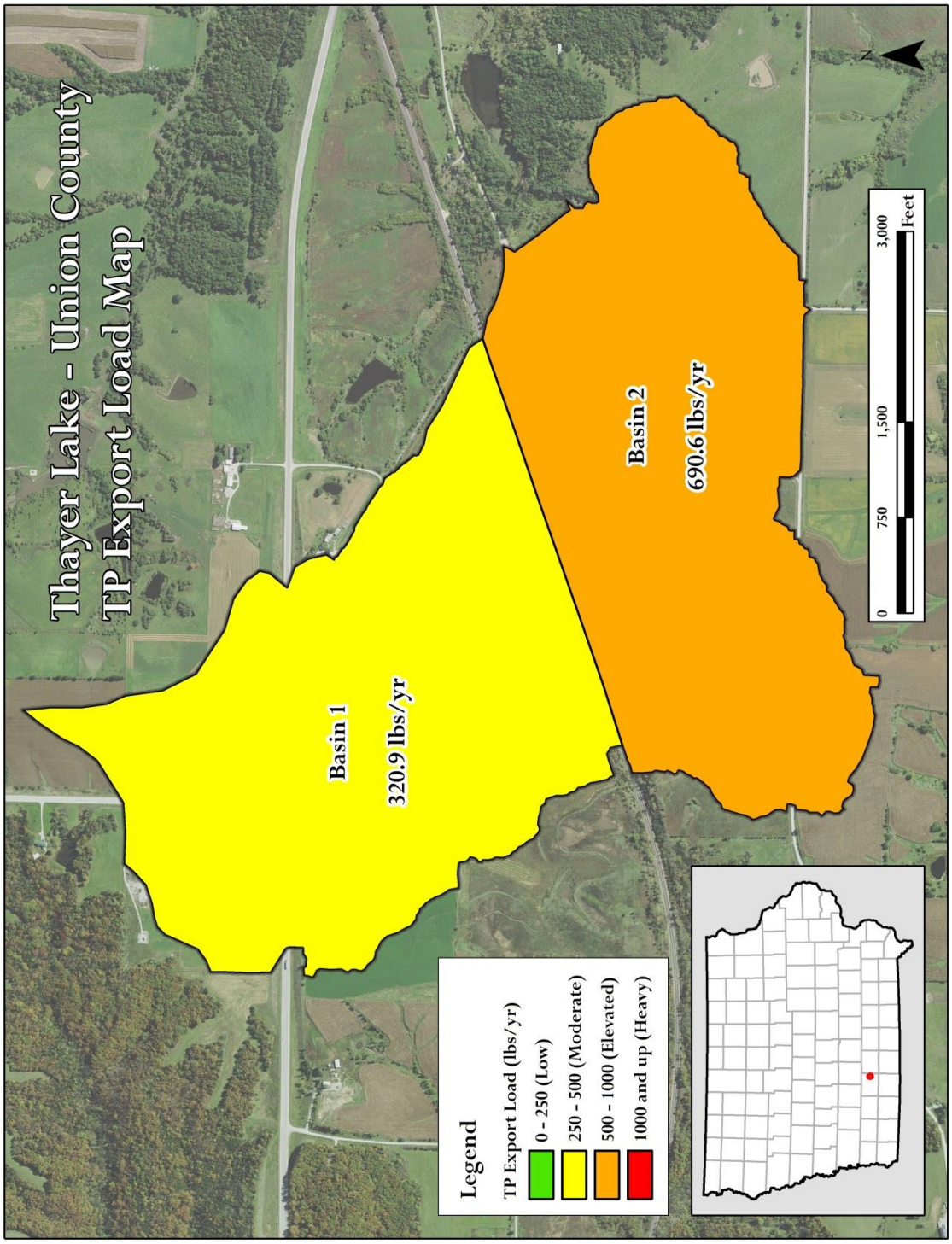

Figure 4-1. Predicted TP load from each STEPL subwatershed

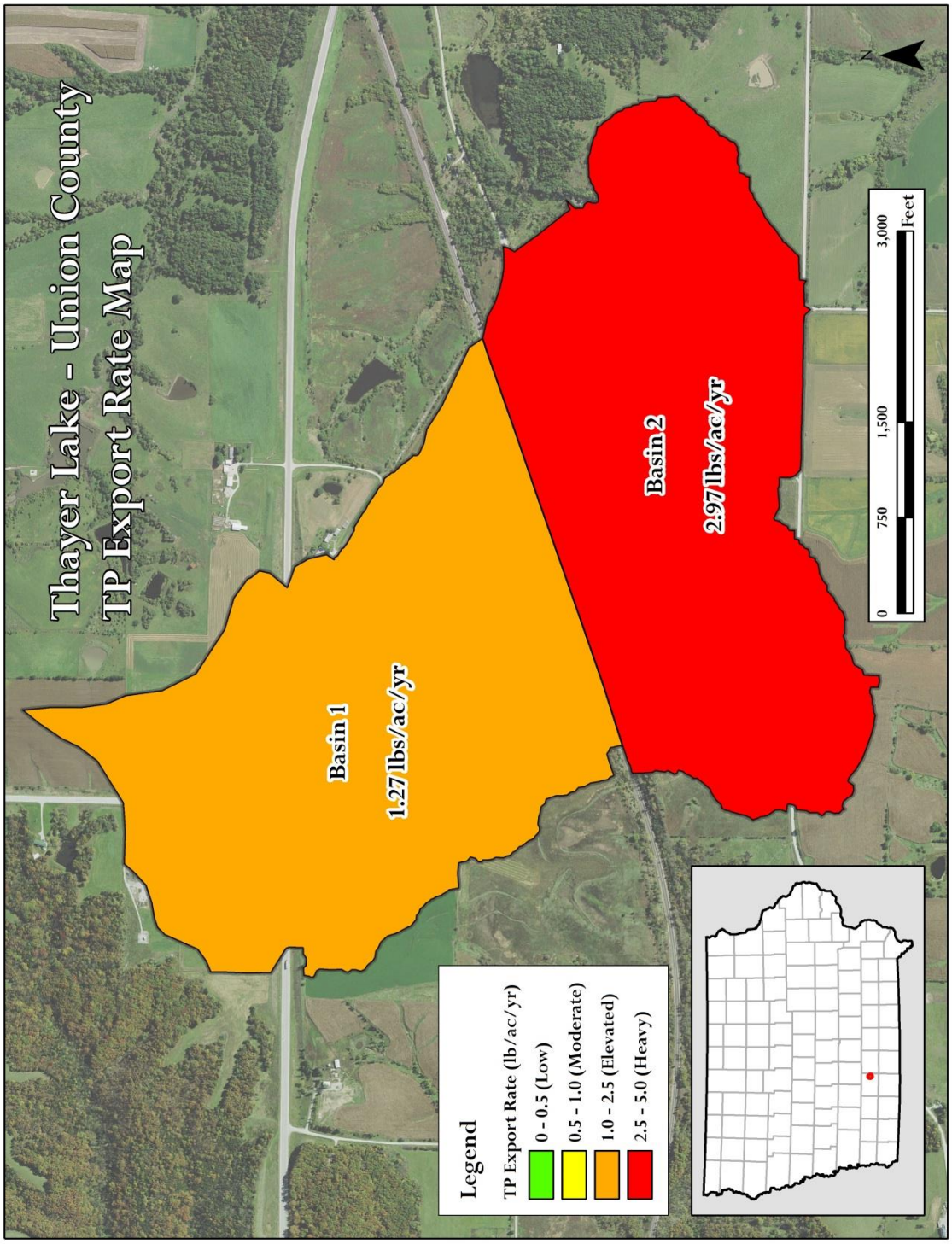

Figure 4-2. Predicted per-acre TP export for each STEPL subwatershed

More detailed information should be collected in order to target specific BMPs to specific areas (e.g., singular fields or waterways) within a subwatershed. This level of detailed targeting is best accomplished by local officials working collaboratively with local stakeholders and land owners.

In-Lake BMPs (Remediation Strategies)
Phosphorus recycled between the bottom sediment and water column of the lake has the potential to be a contributor of bioavailable phosphorus to lakes. The average annual contribution of TP to the system from internal loading appears to be relatively small in Thayer Lake. The reservoir has a large watershed-to-lake ratio, so external inputs typically dwarf internal recycling. However, internal loading may influence in-lake water under certain conditions despite its relatively insignificant average annual phosphorus contribution. Internal loads may exacerbate algal blooms in late summer periods, especially if lake outflow ceases and water temperatures exceed normal levels. It is important to understand that external phosphorus loads from wet weather supply the build-up of phosphorus in the bottom sediments. Estimates of external loads from the Thayer Lake watershed are of large enough magnitude to fully account for observed in-lake phosphorus and subsequent algae levels. Even in lakes with high suspected internal loads, uncertainty regarding the magnitude of internal loads is one of the biggest challenges to TMDL development and lake restoration. Because of these factors, reductions from watershed sources of TP should be given implementation priority. If and when monitoring shows that the external watershed load has been adequately reduced, then additional in-lake measures may be warranted.

Brief descriptions of potential in-lake restoration methods are included in Table 4-3. Phosphorus reduction impacts of each alternative will vary and depend on a number of site-specific factors. It is difficult to determine how much of the internal load is due to each of the contributing factors, and equally difficult to predict phosphorus reductions associated with individual improvement strategies. In-lake measures should be a part of a comprehensive watershed management plan that includes watershed practices in order to enhance, prolong, and protect the effectiveness of in-lake investments.

Table 4-3. Potential in-lake BMPs for water quality improvement

In-Lake BMPs	Comments
Fisheries management	Low to moderate reductions in internal phosphorus load may be attained via continued fisheries management. The reduction of in-lake phosphorus as a result of this practice is variable, but the overall health of the aquatic ecosystem may be improved, which typically improves overall water quality as well. Resident rough fish may be problem and could be controlled through this method.
Targeted dredging and sediment basin improvement	Targeted dredging in shallow inlet areas of the receiving areas would recreate pockets of deep-water habitat for predatory fish that would help control rough fish populations. Strategic dredging would also increase the sediment capacity, thereby reducing sediment and phosphorus loads to the main body where ambient conditions are monitored.
Shoreline stabilization	Helps establish and sustain vegetation, which provides local erosion protection and competes with algae for nutrients. Impacts of individual projects may be small, but cumulative effects of widespread stabilization projects can help improve water quality.
Phosphorus stabilization	Adding compounds, such as alum, to the water column can help stabilize phosphorus that may be resuspended from the lake bottom. This additive precipitates a layer of floc that removes phosphorus as it settles to the lake bottom, and can combine with phosphorus as it is released from sediment

Holistic Approach

An example of a holistic implementation plan would involve prevention, mitigation, and remediation practices across the Thayer Lake watershed. These may include any of the practices from Table 4-3 at any scale. Extending grassed waterways in conjunction with renovation of existing terraces and contour buffers in corn and soybean ground will help mitigate soil loss from row crop ground. Further adoption of agricultural prevention measures like those listed in Table 4-1 will retain topsoil in the soil profile of the fields and prevent erosion. Potential in-lake strategies such phosphorus stabilization treatments in Thayer Lake are included as well.

5. Future Monitoring

Water quality monitoring is critical for assessing the current status of water resources as well as historical and future trends. Furthermore, monitoring is necessary to track the effectiveness of best management practice (BMP) implementation and to document attainment of total maximum daily loads (TMDLs) and progress towards water quality standards (WQS).

Volunteer-based monitoring efforts should include an approved water quality monitoring plan, called a Quality Assurance Project Plan (QAPP), in accordance with Iowa Administrative Code (IAC) 567-61.10(455B) through 567-61.13(455B). The IAC can be viewed here: https://www.legis.iowa.gov/docs/iac/chapter/567.61.pdf

Failure to prepare an approved QAPP will prevent data collected from being used to evaluate waterbody in the 305(b) Integrated Report – the biannual assessment of water quality in the state, and the 303(d) list – the list that identifies impaired waterbodies.

5.1. Routine Monitoring for Water Quality Assessment

Data collection in Thayer Lake to assess water quality trends and compliance with water quality standards (WQS) will include monitoring conducted as part of the DNR Ambient Lake Monitoring Program. This is the same source of data used to develop the TMDL. The Ambient Lake Monitoring Program was initiated in 2000 in order to better assess the water quality of Iowa lakes. Currently, 134 of Iowa's lakes are sampled as part of this program, including Thayer Lake. Typically, one location near the deepest part of the lake is sampled, and many chemical, physical, and biological parameters are measured.

Sampling parameters are reported in Table 5-1. At least three sampling events are scheduled every summer, typically between Memorial Day and Labor Day. While the ambient monitoring program can be used to identify trends in overall, in-lake water quality, it does not lend itself to calculation of watershed loads, identification of individual pollutant sources, or the evaluation of BMP implementation.

Table 5-1. Ambient Lake Monitoring Program water quality parameters

Chemical	Physical	Biological
• Total Phosphorus (TP) • Soluble Reactive Phosphorus (SRP) • Total Nitrogen (TN) • Total Kjeldahl Nitrogen (TKN) • Ammonia • Un-ionized Ammonia • Nitrate + Nitrite Nitrogen • Alkalinity • pH • Total Organic Carbon • Total Dissolved Solids • Dissolved Organic Carbon	• Secchi Depth • Temperature • Dissolved Oxygen (DO) • Turbidity • Total Suspended Solids (TSS) • Total Fixed Suspended Solids • Total Volatile Suspended Solids • Specific Conductivity • Thermocline Depth • Lake Depth	• Chlorophyll a • Phytoplankton (mass and composition) • Zooplankton (mass and composition)

5.2. Expanded Monitoring for Detailed Analysis

Data available from the Iowa DNR Ambient Lake Monitoring Program will be used to assess general water quality trends and WQS violations and attainment. More detailed monitoring data is required to reduce the level of uncertainty associated with water quality trend analysis, better understand the impacts of implemented watershed projects (i.e., BMPs), and guide future water quality modeling and BMP implementation efforts.

If the goal of monitoring is to evaluate spatial and temporal trends and differences in water quality resulting from implementation of BMPs, a more intensive monitoring program will be needed. Table 5-2 outlines potential locations, type of monitoring, parameters collected, and the purpose of each type of data collected as part of an expanded monitoring effort. It is unlikely that available funding will allow collection of all data included in Table 5-2, but the information should be used to help stakeholders identify and prioritize data needs. Locations for expanded monitoring in the Thayer Lake watershed have been chosen to take into account sub basin boundaries and can be used in assigning nutrient concentrations to each sub basin if deployed in such a manner.

Table 5-2. Recommended monitoring plan

Parameter(s)	Intervals	Duration	[1]Location(s)
Routine grab sampling for flow, sediment, P, and N	Every 1-2 weeks	April through October	Ambient location in Thayer Lake, plus secondary locations
Continuous flow	15-60 minute	April through October	Thayer Lake inlet & outlet
Continuous pH, DO, and temperature	15-60 minute	April through October	Ambient location in Thayer Lake
Runoff event flow, sediment, P, and N	15-60 minute intervals during runoff	5 events between April and October	Select tile and/or culvert discharge locations in areas of focused BMP implementation to evaluate efficacy
Event or continuous tile drain flow, N, and P sampling	15-60 minute	10 to 14-day wet weather periods if continuous sampling is not feasible	Select tile and/or culvert discharge locations in areas of focused BMP implementation to evaluate efficacy
Shoreline mapping, bathymetry studies	Before and after dredging or construction, every 5 years	Design lifespan of waterbody	Near dredging operations, or near lake inlets, upstream sediment basins

[1]Tributary, tile drain, and gully site selection to be based on suspected pollutant source location, BMP placement, landowner permission, and access/installation feasibility.

It may be useful to divide the recommended monitoring plan into several tiers based on ease of deployment and cost effectiveness. This will help stakeholders and management personnel best direct their resources. This monitoring plan may be reevaluated at any time to change the management strategy. Data collection should commence before BMPs are renovated or implemented in the watershed to establish baseline conditions. Selection of tributary sites should consider location of BMPs, location of historical data (for comparative purposes), landowner permission (if applicable), and logistical concerns such as site access and feasibility of equipment installation (if necessary). This data could form the foundation for assessment of water quality trends; however, more detailed information will be necessary to make any statements about water quality trends with certainty. Therefore, routine grab sampling should be viewed only as a starting point for assessing trends in water quality.

Advanced Monitoring

Automated data recorded by ISCO devices would provide information on continuous flow, and continuous pH, DO, and temperature. Routine grab sampling for flow, sediment, P, and N will help provide a check on the automated sampling. In addition to routine sampling, runoff event sampling for event flow, sediment, N, and P will help show the effects of high recurrence interval events. Locations and sampling approaches would include the ambient monitoring station, a secondary ambient location in the western area of Thayer Valley, and outlets from upstream tributaries- such as roadway culverts. Reliable long-term flow data is also important because hydrology drives many important processes related to water quality, and a good hydrologic data set will be

necessary to evaluate the success of BMPs such as reduced-tillage, saturated buffers, terraces and grassed waterways, riparian buffers, and wetlands.

To further gather information on erosion in the watershed, a "rapid assessment of stream conditions along length" (RASCAL) procedure would be done on gullies and channels that show significant erosion. An initial assessment will provide a benchmark of current conditions and will allow stakeholders to identify potential problem areas for implementation of BMPs.

Targeted Monitoring
If automated sampling devices cannot be procured, then grab samples should continue on a routine and runoff event based schedule. Flow data may be recorded by area-velocity measurements, or manual flow readings based on developed rating curves. Locations and sampling approaches would include the ambient monitoring station upstream inlets, and the main ditch draining from the pastureland to the southeast.

Basic Monitoring
Targeted grab sampling of the Thayer Lake ambient monitoring point should be continued on a bi-weekly basis. Grab samples on a seasonal basis at the inlet would be done to support data provided by the main lake.

Current Monitoring
With no locally-led effort, only three grab samples would be collected at the ambient location of Thayer Lake between Memorial Day and Labor Day of each year.

The proposed monitoring information would assist utilization of watershed and water quality models to simulate various scenarios and water quality response to BMP implementation. Monitoring parameters and locations should be continually evaluated. Adjustment of parameters and / or locations should be based on BMP placement, newly discovered or suspected pollution sources, and other dynamic factors. The IDNR Watershed Improvement Section may provide technical support to locally led efforts in collecting further water quality and flow monitoring data in the Thayer Lake watershed. A look at how these proposed monitoring plans may be deployed in the Thayer Lake watershed is shown in Figure 5-1.

This expanded monitoring information would improve statistical analysis for evaluating changes and / or trends in water quality over time. Additionally, more detailed data could be used to develop / improve watershed and water quality models for simulation of implementation scenarios and prediction of water quality response. Monitoring parameters and locations should be continually evaluated. Adjustment of parameters and / or locations should be based on BMP placement, newly discovered or suspected pollution sources, and other dynamic factors.

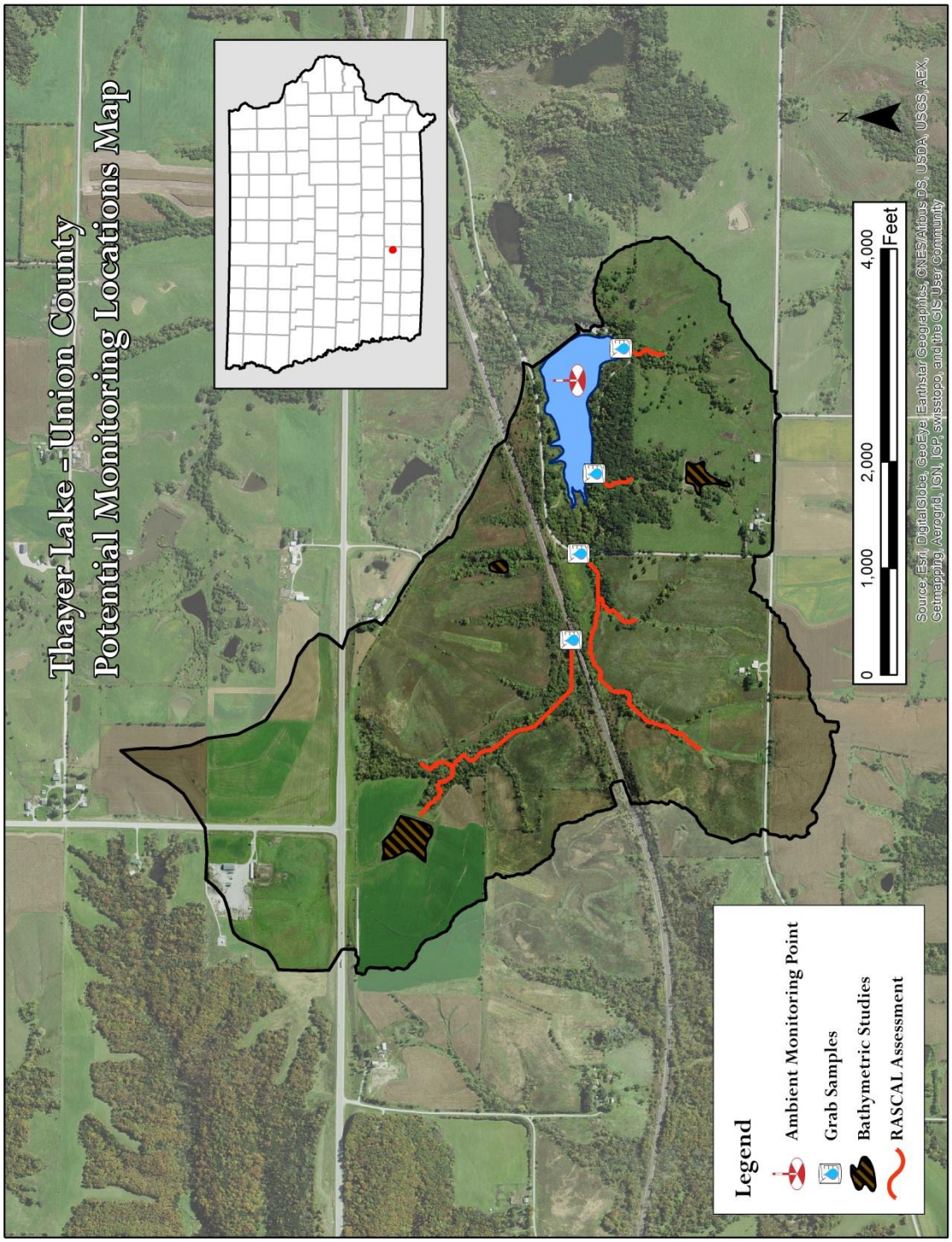

Figure 5-1. Potential monitoring locations

6. Public Participation

Public involvement is important in the Total Maximum Daily Load (TMDL) process since it is the land owners, tenants, and citizens who directly manage land and live in the watershed that determine the water quality in Thayer Lake.

6.1. Public Meeting

Preliminary Meetings

March 30, 2017
Site investigation to ground truth the various land uses, topography, and flow paths of the Thayer Lake and surrounding watershed.

Public Presentations

November 8, 2017
A public meeting to present the results of the TMDL study, obtain stakeholder input, and discuss next steps for community-based watershed planning will be held in the Performing Arts Center, Room 124 of the Southwest Iowa Community College, located at 1201 W. Townline St. in Creston, Iowa. The meeting will be held from 6:00 to 7:30 pm on November 8, 2017.

6.2. Written Comments

The public comment period will begin October 26, and lasts for thirty days. All public comments and the corresponding official response from DNR will be included in Appendix I.

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8. Appendices

Appendix A --- Glossary of Terms, Abbreviations, and Acronyms

303(d) list: Refers to section 303(d) of the Federal Clean Water Act, which requires a listing of all public surface waterbodies (creeks, rivers, wetlands, and lakes) that do not support their general and/or designated uses. Also called the state's "Impaired Waters List."

305(b) assessment: Refers to section 305(b) of the Federal Clean Water Act, it is a comprehensive assessment of the state's public waterbodies' ability to support their general and designated uses. Those bodies of water which are found to be not supporting or only partially supporting their uses are placed on the 303(d) list.

319: Refers to Section 319 of the Federal Clean Water Act, the Nonpoint Source Management Program. Under this amendment, States receive grant money from EPA to provide technical & financial assistance, education, & monitoring to implement local nonpoint source water quality projects.

AFO: Animal Feeding Operation. A lot, yard, corral, building, or other area in which animals are confined and fed and maintained for 45 days or more in any 12-month period, and all structures used for the storage of manure from animals in the operation. Open feedlots and confinement feeding operations are considered to be separate animal feeding operations.

AU: Animal Unit. A unit of measure used to compare manure production between animal types or varying sizes of the same animal. For example, one 1,000 pound steer constitutes one AU, while one mature hog weighing 200 pounds constitutes 0.4 AU.

Benthic: Associated with or located at the bottom (in this context, "bottom" refers to the bottom of streams, lakes, or wetlands). Usually refers to algae or other aquatic organisms that reside at the bottom of a wetland, lake, or stream (see periphyton).

Benthic macroinvertebrates: Animals larger than 0.5 mm that do not have backbones. These animals live on rocks, logs, sediment, debris and aquatic plants during some period in their life. They include crayfish, mussels, snails, aquatic worms, and the immature forms of aquatic insects such as stonefly and mayfly nymphs.

Base flow: Sustained flow of a stream in the absence of direct runoff. It can include natural and human-induced stream flows. Natural base flow is sustained largely by groundwater discharges.

Biological impairment: A stream segment is classified as biologically impaired if one or more of the following occurs, the FIBI and or BMIBI scores fall below biological reference conditions, a fish kill has occurred on the segment, or the segment has seen a > 50% reduction in mussel species.

Biological reference condition: Biological reference sites represent the least disturbed (i.e. most natural) streams in the ecoregion. The biological data from these sites are used to derive least impacted BMIBI and FIBI scores for each ecoregion. These scores are used to develop Biological Impairment Criteria (BIC) scores for each ecoregion. The BIC is used to determine the impairment status for other stream segments within an ecoregion.

BMIBI: Benthic Macroinvertebrate Index of Biotic Integrity. An index-based scoring method for assessing the biological health of streams and rivers (scale of 0-100) based on characteristics of bottom-dwelling invertebrates.

BMP: Best Management Practice. A general term for any structural or upland soil or water conservation practice. For example terraces, grass waterways, sediment retention ponds, reduced tillage systems, etc.

CAFO: Concentrated Animal Feeding Operation. A federal term defined as any animal feeding operation (AFO) with more than 1,000 animal units confined on site, or an AFO of any size that discharges pollutants (e.g. manure, wastewater) into any ditch, stream, or other water conveyance system, whether man-made or natural.

CBOD5: 5-day Carbonaceous Biochemical Oxygen Demand. Measures the amount of oxygen used by microorganisms to oxidize hydrocarbons in a sample of water at a temperature of 20°C and over an elapsed period of five days in the dark.

CFU: A Colony Forming Unit is a cell or cluster of cells capable of multiplying to form a colony of cells. Used as a unit of bacteria concentration when a traditional membrane filter method of analysis is used. Though not necessarily equivalent to most probably number (MPN), the two terms are often used interchangeably.

Confinement feeding operation: An animal feeding operation (AFO) in which animals are confined to areas which are totally roofed.

Credible data law: Refers to 455B.193 of the Iowa Administrative Code, which ensures that water quality data used for all purposes of the Federal Clean Water Act are sufficiently up-to-date and accurate. To be considered "credible," data must be collected and analyzed using methods and protocols outlined in an approved Quality Assurance Project Plan (QAPP).

Cyanobacteria (blue-green algae): Members of the phytoplankton community that are not true algae but are capable of photosynthesis. Some species produce toxic substances that can be harmful to humans and pets.

Designated use(s): Refer to the type of economic, social, or ecological activities that a specific waterbody is intended to support. See Appendix B for a description of all general and designated uses.

DNR: Iowa Department of Natural Resources.

Ecoregion: Areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources based on geology, vegetation, climate, soils, land use, wildlife, and hydrology.

EPA (or USEPA): United States Environmental Protection Agency.

Ephemeral gully erosion: Ephemeral gullies occur where runoff from adjacent slopes forms concentrated flow in drainage ways. Ephemerals are void of vegetation and occur in the same location every year. They are crossable with farm equipment and are often partially filled in by tillage.

FIBI: Fish Index of Biotic Integrity. An index-based scoring method for assessing the biological health of streams and rivers (scale of 0-100) based on characteristics of fish species.

FSA: Farm Service Agency (United States Department of Agriculture). Federal agency responsible for implementing farm policy, commodity, and conservation programs.

General use(s): Refer to narrative water quality criteria that all public waterbodies must meet to satisfy public needs and expectations. See Appendix B for a description of all general and designated uses.

Geometric Mean (GM): A statistic that is a type of mean or average (different from arithmetic mean or average) that measures central tendency of data. It is often used to summarize highly skewed data or data with extreme values such as wastewater discharges and bacteria concentrations in surface waters. In Iowa's water quality standards and assessment procedures, the geometric mean criterion for *E. coli* is measured using at least five samples collected over a 30-day period.

GIS: Geographic Information System(s). A collection of map-based data and tools for creating, managing, and analyzing spatial information.

Groundwater: Subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated.

Gully erosion: Soil movement (loss) that occurs in defined upland channels and ravines that are typically too wide and deep to fill in with traditional tillage methods.

HEL: Highly Erodible Land. Defined by the USDA Natural Resources Conservation Service (NRCS), it is land, which has the potential for long-term annual soil losses to exceed the tolerable amount by eight times for a given agricultural field.

IDALS: Iowa Department of Agriculture and Land Stewardship

Integrated report: Refers to a comprehensive document that combines the 305(b) assessment with the 303(d) list, as well as narratives and discussion of overall water quality trends in the state's public waterbodies. The Iowa Department of Natural Resources submits an integrated report to the EPA biennially in even numbered years.

LA: Load Allocation. The portion of the loading capacity attributed to (1) the existing or future nonpoint sources of pollution and (2) natural background sources. Wherever possible, nonpoint source loads and natural loads should be distinguished. (The total pollutant load is the sum of the wasteload and load allocations.)

LiDAR: Light Detection and Ranging. Remote sensing technology that uses laser scanning to collect height or elevation data for the earth's surface.

Load: The total amount of pollutants entering a waterbody from one or multiple sources, measured as a rate, as in weight per unit time or per unit area.

Macrophyte: An aquatic plant that is large enough to be seen with the naked eye and grows either in or near water. It can be floating, completely submerged (underwater), or partially submerged.

MOS: Margin of Safety. A required component of the TMDL that accounts for the uncertainty in the response of the water quality of a waterbody to pollutant loads.

MPN: Most Probable Number. Used as a unit of bacteria concentration when a more rapid method of analysis (such as Colisure or Colilert) is utilized. Though not necessarily equivalent to colony forming units (CFU), the two terms are often used interchangeably.

MS4: Municipal Separate Storm Sewer System. A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) owned and operated by a state, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to state law) having jurisdiction over disposal of sewage, industrial wastes, stormwater, or other wastes, including special districts under state law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the Clean Water Act (CWA) that discharges to waters of the United States.

Nonpoint source pollution: Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related either to land or water use including failing septic tanks, improper animal-keeping practices, forestry practices, and urban and rural runoff.

NPDES: National Pollution Discharge Elimination System. The national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under Section 307, 402, 318, and 405 of the Clean Water Act. Facilities subjected to NPDES permitting regulations include operations such as municipal wastewater treatment plants and industrial waste treatment facilities, as well as some MS4s.

NRCS: Natural Resources Conservation Service (United States Department of Agriculture). Federal agency that provides technical assistance for the conservation and enhancement of natural resources.

Open feedlot: An unroofed or partially roofed animal feeding operation (AFO) in which no crop, vegetation, or forage growth or residue cover is maintained during the period that animals are confined in the operation.

Periphyton: Algae that are attached to substrates (rocks, sediment, wood, and other living organisms). Are often located at the bottom of a wetland, lake, or stream.

Phytoplankton: Collective term for all photosynthetic organisms suspended in the water column. Includes many types of algae and cyanobacteria.

Point source pollution: Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources are generally regulated by a federal NPDES permit.

Pollutant: As defined in Clean Water Act section 502(6), a pollutant means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water.

Pollution: The man-made or man-induced alteration of the chemical, physical, biological, and/or radiological integrity of water.

PPB: Parts per Billion. A measure of concentration that is the same as micrograms per liter (µg/L).

PPM: Parts per Million. A measure of concentration that is the same as milligrams per liter (mg/L).

RASCAL: Rapid Assessment of Stream Conditions Along Length. RASCAL is a global positioning system (GPS) based assessment procedure designed to provide continuous stream and riparian condition data at a watershed scale.

Riparian: Refers to areas near the banks of natural courses of water. Features of riparian areas include specific physical, chemical, and biological characteristics that differ from upland (dry) sites. Usually refers to the area near a bank of a stream or river.

RUSLE: Revised Universal Soil Loss Equation. An empirical model for estimating long term, average annual soil losses due to sheet and rill erosion.

Scientific notation: See explanation on page 107.

Secchi disk: A device used to measure transparency in waterbodies. The greater the Secchi depth (typically measured in meters), the more transparent the water.

Sediment delivery ratio: A value, expressed as a percent, which is used to describe the fraction of gross soil erosion that is delivered to the waterbody of concern.

Seston: All particulate matter (organic and inorganic) suspended in the water column.

SHL: State Hygienic Laboratory (University of Iowa). Provides physical, biological, and chemical sampling for water quality purposes in support of beach monitoring, ambient monitoring, biological reference monitoring, and impaired water assessments.

Sheet & rill erosion: Sheet and rill erosion is the detachment and removal of soil from the land surface by raindrop impact, and/or overland runoff. It occurs on slopes with overland flow and where runoff is not concentrated.

Single-Sample Maximum (SSM): A water quality standard criterion used to quantify *E. coli* levels. The single-sample maximum is the maximum allowable concentration measured at a specific point in time in a waterbody.

SI: Stressor Identification. A process by which the specific cause(s) of a biological impairment to a waterbody can be determined from cause-and-effect relationships.

Storm flow (or stormwater): The discharge (flow) from surface runoff generated by a precipitation event. *Stormwater* generally refers to runoff that is routed through some artificial channel or structure, often in urban areas.

STP: Sewage Treatment Plant. General term for a facility that treats municipal sewage prior to discharge to a waterbody according to the conditions of an NPDES permit.

SWCD: Soil and Water Conservation District. Agency that provides local assistance for soil conservation and water quality project implementation, with support from the Iowa Department of Agriculture and Land Stewardship.

TDS: Total Dissolved Solids: The quantitative measure of matter (organic and inorganic material) dissolved, rather than suspended, in the water column. TDS is analyzed in a laboratory and quantifies the material passing through a filter and dried at 180 degrees Celsius.

TMDL: Total Maximum Daily Load. As required by the Federal Clean Water Act, a comprehensive analysis and quantification of the maximum amount of a particular pollutant that a waterbody can tolerate while still meeting its general and designated uses. A TMDL is mathematically defined as the sum of all individual wasteload allocations (WLAs), load allocations (LAs), and a margin of safety (MOS).

Trophic state: The level of ecosystem productivity, typically measured in terms of algal biomass.

TSI (or Carlson's TSI): Trophic State Index. A standardized scoring system developed by Carlson (1977) that places trophic state on an exponential scale of Secchi depth, chlorophyll, and total phosphorus. TSI ranges between 0 and 100, with 10 scale units representing a doubling of algal biomass.

TSS: Total Suspended Solids. The quantitative measure of matter (organic and inorganic material) suspended, rather than dissolved, in the water column. TSS is analyzed in a laboratory and quantifies the material retained by a filter and dried at 103 to 105 degrees Celsius.

Turbidity: A term used to indicate water transparency (or lack thereof). Turbidity is the degree to which light is scattered or absorbed by a fluid. In practical terms, highly turbid waters have a high degree of cloudiness or murkiness caused by suspended particles.

UAA: Use Attainability Analysis. A protocol used to determine which (if any) designated uses apply to a particular waterbody. (See Appendix B for a description of all general and designated uses.)

USDA: United States Department of Agriculture

USGS: United States Geologic Survey (United States Department of the Interior). Federal agency responsible for implementation and maintenance of discharge (flow) gauging stations on the nation's waterbodies.

Watershed: The land area that drains water (usually surface water) to a particular waterbody or outlet.

WLA: Wasteload Allocation. The portion of a receiving waterbody's loading capacity that is allocated to one of its existing or future point sources of pollution (e.g., permitted waste treatment facilities).

WQS: Water Quality Standards. Defined in Chapter 61 of Environmental Protection Commission [567] of the Iowa Administrative Code, they are the specific criteria by which water quality is gauged in Iowa.

WWTF: Wastewater Treatment Facility. General term for a facility that treats municipal, industrial, or agricultural wastewater for discharge to public waters according to the conditions of the facility's NPDES permit. Used interchangeably with wastewater treatment plant (WWTP).

Zooplankton: Collective term for all animal plankton suspended in the water column which serve as secondary producers in the aquatic food chain and the primary food source for larger aquatic organisms.

Scientific Notation

Scientific notation is the way that scientists easily handle very large numbers or very small numbers. For example, instead of writing 45,000,000,000 we write 4.5E+10. So, how does this work?

We can think of 4.5E+10 as the product of two numbers: 4.5 (the digit term) and E+10 (the exponential term).

Here are some examples of scientific notation.

10,000 = 1E+4	24,327 = 2.4327E+4
1,000 = 1E+3	7,354 = 7.354E+3
100 = 1E+2	482 = 4.82E+2
1/100 = 0.01 = 1E-2	0.053 = 5.3E-2
1/1,000 = 0.001 = 1E-3	0.0078 = 7.8E-3
1/10,000 = 0.0001 = 1E-4	0.00044 = 4.4E-4

As you can see, the exponent is the number of places the decimal point must be shifted to give the number in long form. A **positive** exponent shows that the decimal point is shifted that number of places to the right. A **negative** exponent shows that the decimal point is shifted that number of places to the left.

Appendix B --- General and Designated Uses of Iowa's Waters

Introduction

Iowa's water quality standards (Environmental Protection Commission [567], Chapter 61 of the Iowa Administrative Code) provide the narrative and numerical criteria by which waterbodies are judged when determining the health and quality of our aquatic ecosystems. These standards vary depending on the type of waterbody (lakes vs. rivers) and the assigned uses (general use vs. designated uses) of the waterbody that is being dealt with. This appendix is intended to provide information about how Iowa's waterbodies are classified and what the use designations mean, hopefully providing a better general understanding for the reader.

All public surface waters in the state are protected for certain beneficial uses, such as livestock and wildlife watering, aquatic life, non-contact recreation, crop irrigation, and other incidental uses (e.g. withdrawal for industry and agriculture). However, certain rivers and lakes warrant a greater degree of protection because they provide enhanced recreational, economical, or ecological opportunities. Thus, all public bodies of surface water in Iowa are divided into two main categories: *general* use segments and *designated* use segments. This is an important classification because it means that not all of the criteria in the state's water quality standards apply to all water ways; rather, the criteria which apply depend on the use designation & classification of the waterbody.

General Use Segments

A general use segment waterbody is one that does not maintain perennial (year-round) flow of water or pools of water in most years (i.e. ephemeral or intermittent waterways). In other words, stream channels or basins that consistently dry up year after year would be classified as general use segments. Exceptions are made for years of extreme drought or floods. For the full definition of a general use waterbody, consult section 61.3(1) in the state's published water quality standards, which became effective on March 22, 2006 (Environmental Protection Commission [567], Chapter 61 of the Iowa Administrative Code).

General use waters are protected for the beneficial uses listed above, which are: livestock and wildlife watering, aquatic life, non-contact recreation, crop irrigation, and industrial, agricultural, domestic and other incidental water withdrawal uses. The criteria used to ensure protection of these uses are described in section 61.3(2) in the state's published water quality standards, which became effective on March 22, 2006 (Environmental Protection Commission [567], Chapter 61 of the Iowa Administrative Code).

Designated Use Segments

Designated use segments are waterbodies that maintain flow throughout the year, or at least hold pools of water that are sufficient to support a viable aquatic community (i.e. perennial waterways). In addition to being protected for the same beneficial uses as the general use segments, these perennial waters are protected for more specific activities such as primary contact recreation, drinking water sources, or cold-water fisheries. There are thirteen different designated use classes (Table B-1) that may apply, and a waterbody

may have more than one designated use. For definitions of the use classes and more detailed descriptions, consult section 61.3(1) in the state's published water quality standards, which became effective on March 22, 2006 (Environmental Protection Commission [567], Chapter 61 of the Iowa Administrative Code).

Table B-1. Designated use classes for Iowa waterbodies

Class prefix	Class	Designated use	Brief comments
A	A1	Primary contact recreation	Supports swimming, water skiing, etc.
	A2	Secondary contact recreation	Limited/incidental contact occurs, such as boating
	A3	Children's contact recreation	Urban/residential waters that are attractive to children
B	B(CW1)	Cold water aquatic life – Type 2	Able to support coldwater fish (e.g. trout) populations
	B(CW2)	Cold water aquatic life – Type 2	Typically unable to support consistent trout populations
	B(WW-1)	Warm water aquatic life – Type 1	Suitable for game and nongame fish populations
	B(WW-2)	Warm water aquatic life – Type 2	Smaller streams where game fish populations are limited by physical conditions & flow
	B(WW-3)	Warm water aquatic life – Type 3	Streams that only hold small perennial pools which extremely limit aquatic life
	B(LW)	Warm water aquatic life – Lakes and Wetlands	Artificial and natural impoundments with "lake-like" conditions
C	C	Drinking water supply	Used for raw potable water
Other	HQ	High quality water	Waters with exceptional water quality
	HQR	High quality resource	Waters with unique or outstanding features
	HH	Human health	Fish are routinely harvested for human consumption

Designated use classes are determined based on a Use Attainability Analysis, or UAA. This is a procedure in which the waterbody is thoroughly scrutinized, using existing

knowledge, historical documents, and visual evidence of existing uses, in order to determine what its designated use(s) should be. This can be a challenging endeavor, and as such, conservative judgment is applied to ensure that any potential uses of a waterbody are allowed for. Changes to a waterbody's designated uses may only occur based on a new UAA, which depending on resources and personnel, can be quite time consuming.

It is relevant to note that on March 22, 2006, a revised edition of Iowa's water quality standards became effective which significantly changed the use designations of the state's surface waters. Essentially, the changes that were made consisted of implementing a "top down" approach to use designations, meaning that all waterbodies should receive the highest degree of protection applicable until a UAA could be performed to ensure that a particular waterbody did not warrant elevated protection. For more information about Iowa's water quality standards and UAAs, contact the Iowa DNR's Water Quality Bureau.

Appendix C --- Water Quality Data

The following is a summary of the sampling data from the Iowa State University (ISU) Iowa Lakes Information System and University of Iowa State Hygienic Laboratory (SHL) monitoring efforts.

C.1. Individual Sample Results

Table C-1. ISU and SHL water quality sampling data ([1]ambient location)

Source	DATE	Secchi (m)	Chl-a (µg/L)	TP (µg/L)	TN (mg/L)	pH
ISU	28-May-02	0.50	15.42	69.21	1.67	8.33
ISU	24-Jun-02	0.35	27.79	72.80	1.09	8.43
ISU	29-Jul-02	0.35	10.63	108.21	0.71	8.44
ISU	28-May-03	0.43	9.16	75.96	1.36	9.23
ISU	24-Jun-03	0.31	40.62	142.77	1.18	8.86
ISU	29-Jul-03	0.35	30.60	159.69	1.76	8.12
ISU	24-May-04	0.10	24.30	238.64	1.64	7.96
ISU	21-Jun-04	0.25	117.42	136.63	1.41	8.45
ISU	26-Jul-04	0.35	77.44	155.79	1.73	8.47
ISU	31-May-05	0.35	40.68	90.94	2.16	7.94
UHL	15-Jun-05	0.20	20.00	140.00	2.19	7.80
ISU	27-Jun-05	0.45	162.72	104.77	1.36	8.70
UHL	13-Jul-05	0.20	74.00	150.00	1.80	9.20
UHL	12-Sep-05	0.20	120.00	210.00	2.50	8.80
UHL	02-May-06	0.20	7.00	190.00	2.95	8.00
UHL	07-Jun-06	0.30	53.00	140.00	1.90	8.30
UHL	12-Jul-06	0.20	110.00	120.00	2.10	8.80
UHL	30-Aug-06	0.20	100.00	200.00	2.40	8.30
UHL	03-Oct-06	0.60	44.00	140.00	1.90	9.10
UHL	23-May-07	0.90	15.00	120.00	0.90	7.60
UHL	01-Aug-07	0.30	110.00	160.00	2.30	9.00
UHL	12-Sep-07	0.20	15.00	250.00	2.10	7.30
UHL	05-May-08	0.50	32.00	90.00	1.43	8.90
UHL	07-Jul-08	0.50	43.00	100.00	1.13	8.60
ISU	08-Jun-09	0.30	15.00	103.10	1.33	7.80
ISU	13-Jul-09	0.50	25.00	99.60	1.43	8.20
ISU	06-Aug-09	0.40	33.00	89.50	2.13	8.90
ISULL	14-Jun-10	0.25	6.39	192.27	*	7.59
ISULL	02-Aug-10	0.60	25.32	87.82	*	7.61
ISULL	15-Sep-10	0.83	14.77	63.97	*	8.28
ISU	13-Jun-11	0.45	31.66	94.14	*	7.67
ISU	01-Aug-11	1.10	21.62	77.49	*	9.24
ISU	12-Sep-11	0.98	11.10	66.83	*	8.83
ISU	11-Jun-12	1.28	19.07	35.70	1.16	7.68
ISU	30-Jul-12	1.35	24.56	24.20	0.68	8.10
ISU	13-Sep-12	1.43	6.04	64.50	0.69	9.18

Source	DATE	Secchi (m)	Chl-a (µg/L)	TP (µg/L)	TN (mg/L)	pH
ISU	10-Jun-13	1.85	2.86	48.45	0.57	8.32
ISU	29-Jul-13	1.08	9.11	35.85	1.27	7.43
ISU	9-Sep-13	1.20	8.04	43.70	1.08	8.82
ISU	16-Jun-14	1.25	1.50	48.90	0.93	8.15
ISU	4-Aug-14	1.28	9.02	45.45	1.72	8.11
ISU	14-Sep-14	0.40	21.04	179.80	1.38	7.27
ISU	15-Jun-15	0.25	11.52	344.05	2.14	7.91
ISU	3-Aug-15	0.79	171.71	157.95	1.48	8.69
ISU	13-Sep-15	0.60	162.40	157.45	1.45	7.62
ISU	13-Jun-16	1.20	25.26	64.20	0.60	8.63
ISU	1-Aug-16	0.55	117.44	191.05	2.14	8.21
ISU	14-Sep-16	0.63	56.32	152.20	1.84	7.66

[1] Ambient monitoring location = STORET ID 22880002
* Data not available

C.2. Annual Mean Data

Table C-2. Precipitation and annual mean TSI values ([1]ambient location)

Date	Annual Precipitation (in)	Apr-Sep Precipitation (in)	Secchi TSI	Chl-a TSI	TP TSI
2002	24.1	17.6	73	59	68
2003	30.1	20.3	75	63	74
2004	31.3	21.8	81	73	78
2005	28.1	20.1	78	74	75
2006	32.2	21.5	77	71	77
2007	46.3	31.0	71	68	79
2008	46.1	34.3	70	66	70
2012	42.5	27.5	73	62	70
2013	48.3	38.7	68	57	72
2014	39.0	28.1	62	61	67
2015	31.2	17.8	56	58	58
2016	32.2	22.8	55	49	58

[1] Ambient monitoring location = STORET 22880002

Appendix D --- Watershed Model Development

Watershed and in-lake modeling were used in conjunction with analysis of observed water quality data to develop the Total Maximum Daily Load (TMDL) for the algae impairment to Thayer Lake in Union County, Iowa. This TMDL targets an allowable phosphorus load that will satisfy the primary contact recreation impairment (see Section 3 of this document for details). Reduction of phosphorus is expected to reduce algal blooms and non-algal turbidity, which decrease water clarity and impair the ability of the public to enjoy the recreational benefits of the lake.

The Spreadsheet Tool for Estimating Pollutant Load (STEPL), version 4.1, was utilized to simulate watershed hydrology and pollutant loading. In-lake water quality simulations were performed using BATHTUB 6.1, an empirical lake and reservoir eutrophication model. The integrated watershed and in-lake modeling approach allows the holistic analysis of hydrology and water quality in Thayer Lake and its watershed. This section of the Water Quality Improvement Plan (WQIP) discusses the modeling approach and development of the STEPL watershed and BATHTUB lake models.

D.1. Modeling Approach

Data from a 15-year period of record, 2002-2016, were analyzed and used to develop watershed and lake models for the simulation and prediction of phosphorus loads and in-lake response. Models representing a variety of conditions (e.g., wet, dry) and various years were developed. This process was instructive in understanding watershed and in-lake processes, and in the validation of model inputs and calibration. This simulation period is supplemental to the water quality assessment period (2008-2012) upon which the 2014 Integrated Report and 303(d) list were generated. As such, it best reflects the long term conditions of the impairment.

D.2. STEPL Model Description

STEPL is a watershed-scale hydrology and water quality model developed for the U.S. Environmental Protection Agency (EPA) by Tetra Tech, Incorporated. STEPL is a long-term average annual model used to assess the impacts of land use and best management practices on hydrology and pollutant loads. STEPL is capable of simulating a variety of pollutants, including sediment, nutrients (nitrogen and phosphorus), and 5-day biochemical oxygen demand (BOD5). Required input data is minimal if the use of county-wide soils and coarse precipitation information is acceptable to the user. If available, the user can modify soil and precipitation inputs with higher resolution and local soil and precipitation data. Precipitation inputs include average annual rainfall and rainfall correction factors that describe the intensity (i.e., runoff producing) characteristics of long-term precipitation. Characteristics that affect STEPL estimates of hydrology and pollutant loading include land cover types, population of agricultural livestock, wildlife populations, population served by septic systems, and urban land uses. STEPL also quantifies the impacts of manure application and best management practices

(BMPs). Almost all STEPL inputs can be customized if site-specific data is available and more detail is desired.

The watershed was divided into 2 subbasins to help quantify the relative pollutant loads stemming from different areas of the watershed and to assist with targeting potential BMP locations. These basins were created to coincide with the topography and interfluvial drainage ways throughout the Thayer watershed. Hydrology and pollutant loadings are summarized for each subbasin and also aggregated as watershed totals.

D.3. Meteorological Input

Precipitation Data
The STEPL model includes a pre-defined set of weather stations from which the user may obtain precipitation-related model inputs. Unfortunately, none of the NWS COOP stations within a reasonable distance of Thayer Lake are included in the STEPL model. Therefore, rainfall data from the PRISM network were used for modeling purposes. Weather station information and rainfall data were reported in Section 2.1 (see Table 2.2 and Figures 2.2 and 2.3.)

Average annual precipitation from 2008-2012 was 41.4 inches/year, higher than the 13-year (2002-2015) annual average of 37.5 inches. Annual rainfall used in the STEPL model coincided with the long term 13-year period in order to simulate dry and wet precipitation patterns.

The STEPL precipitation correlation and rain day correction factors were calculated outside of STEPL and entered directly in the STEPL "Input" worksheet to override the default rainfall data. Precipitation data from the modeling period of 2002-2016 were utilized in parameterization. The rain day correction factor of 0.435 was calculated by dividing the number of days that it rained at least 5 mm by the number of days with at least 1 mm of rainfall. This ratio is intended to estimate the number of days that could potentially generate surface runoff. Precipitation inputs are reported in Table D-1, as entered in the "Input" worksheet of the 2002-2016 Thayer Lake STEPL model.

Table D-1. STEPL rainfall inputs (2002-2016 average annual data)

Rain correction factors			
[1]0.873	[2]0.435		
[3]Annual Rainfall	**[4]Rain Days**	**[5]Avg. Rain/Event**	**Input Notes/Descriptions**
37.5	114	0.660	[1]The percent of rainfall that exceeds 5 mm per event
			[2]The percent of rain events that generate runoff
			[3]Annual average precipitation for modeling period (in)
			[4]Average days of precipitation per year (days)
			[5]Average precipitation per event (in)

D.4. Watershed Characteristics

Topography
The Thayer Lake watershed was delineated into 2 subbasins using ArcGIS (version 10.2) and a 3-meter resolution digital elevation model (DEM) developed by the Iowa Department of Natural Resources (DNR). Figure D-1 illustrates the watershed and subbasin boundaries. The subbasins boundaries were chosen to coincide with internal fluvial boundaries both natural and artificial. These will aide in identifying areas to implement best management practice strategies in water quality improvement programs in the future.

Land Use
A Geographic Information System (GIS) coverage of land use information was developed using the Cropland Data Layer (CDL) for year 2014, which was obtained from the United States Department of Agriculture – National Agricultural Statistics Service (USDA-NASS, 2016). The CDL land cover data is summarized by Common Land Units (CLUs). According to the USDA – Farm Service Agency, CLUs are the smallest units of land that have a permanent, contiguous boundary, common land cover, common owner, and common producer (USDA-FSA, 2016). Cropping decisions can change from year to year and several instances were observed where a single CLU contained multiple land cover types in the same year. In such cases, CLU boundaries were split to incorporate all major land covers into the STEPL model. Because land cover pixels are much smaller than CLU field boundaries, many CLUs have one primary land cover, but small isolated pixels with several minor land cover types. In those cases, the dominant land cover within each CLU boundary was determined using a zonal statistic command within Spatial Analyst. This step served as a land cover "filter" to simplify the data and eliminate small isolated pixels of various land uses within a single field boundary. STEPL land cover classifications are reported in Table D-2, with land use distribution previously illustrated in the map (Figure 2-5) and table (Table 2-3) in Section 2.

Table D-2. STEPL land use inputs

Watershed	[1]Urban	Cropland	Pastureland	Forest	[2]User Defined	[3]Total
W1	12.63	6.2	19.88	37.61	175.89	252.21
W2	7.8	18.8	60.29	60.2	85.17	232.26
[3]Total	20.43	25.0	80.17	97.81	261.06	484.47

[1]Urban includes all developed areas, including roads and farmsteads
[2]Includes hay / alfalfa, non-pasture grassland and conservation reserve programs
[3]Totals exclude open water in STEPL land use inputs

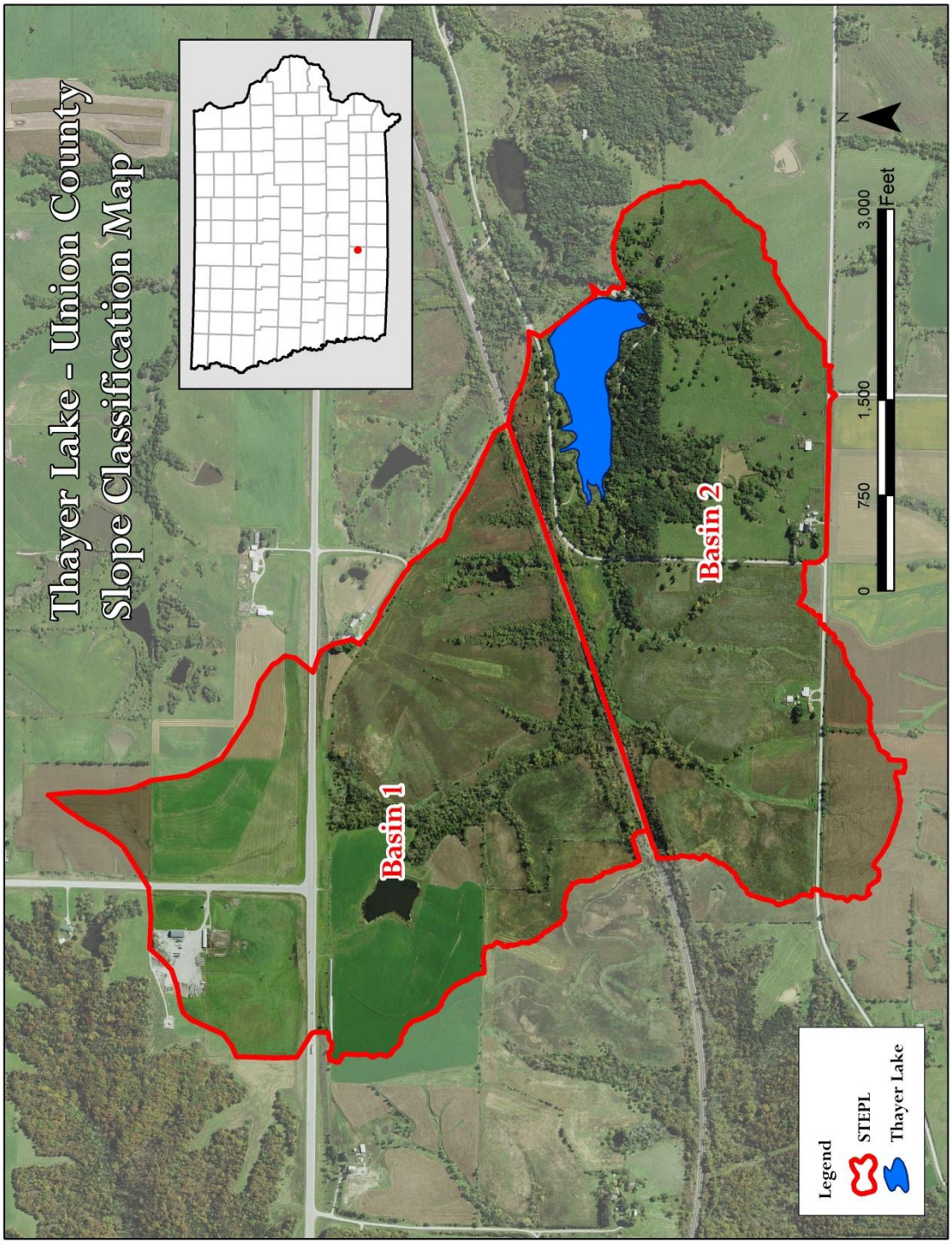

Figure D-1. STEPL subbasin map

Each land cover type was assigned a specific USLE C-factor and P-factor (Table D-3), based on regional estimates developed by DNR and Soil and Water Conservation district personnel for watershed assessments performed in the same ecoregion. C- and P-factors were assigned to each CLU using best available data. P-factors for row crop fields were set at 0.8, with values of 1 representing no existing erosion practices. C-factors vary widely, from 0.0 for paved roads to 0.125 for row crops with conversation tillage and visible plant residue. All USLE parameters were area-weighted and summarized for each subwatershed before input to the STEPL model.

Table D-3. C- and P-factors for each land cover and practice (BMP)

Land Cover Description	C-Factor	Practice	P-Factor
Corn-Soybeans; Conventional-Till	0.260	Terraces	0.6
Corn-Soybeans; Mulch-Till	0.125	Contour Farming	0.7
Corn-Soybeans; No-Till Beans, Mulch-Till Corn	0.080	Contour Buffers	0.7
Corn-Soybeans; No-Till Beans and Corn	0.050	Field Buffers	0.8
Grassland and Pasture	0.008	Ponds/Basins	0.4
Farmstead	0.020		
Timber	0.013		
Road	0.000		

Soils

Soils are discussed in detail in Section 2.2. The hydrologic soil group (HSG) and the USLE K-factor are the critical soil parameters in the STEPL model. Watershed soils are predominantly HSG type C soils, with some B soils interspersed. HSG values were set at group C curve numbers values (CNs) in STEPL as a conservative measure. USLE K-factors are specific to each soil type, and were area-weighted and entered into the “Input” worksheet in the STEPL model.

Slopes

Slopes are described in more detail in Section 2.2. USLE land slope (LS) factors were obtained from the SSURGO data and were assigned at the field-scale, then area-weighted to develop land-use specific LS factors for each STEPL subwatershed. Resulting LS-factors in entered into the “Input” worksheet in the STEPL model vary between 3.58 in row crop areas to 16.17 in the forested region surrounding Thayer Lake. Slopes are heavily influenced by the Southern Iowa Drift Plain. Slopes for each land use in each basin are listed below in Table D-4.

Table D-4. STEPL slopes for land use

Watershed	Cropland	Pastureland	Forest	[1]User Defined
W1	3.58	4.99	15.70	8.20
W2	5.02	13.16	16.17	10.85

[1]Includes hay / alfalfa, non-pasture grassland, and conservation reserve programs

Curve Numbers
The STEPL model includes default curve numbers (CNs) selected automatically based on HSG and land use. In Iowa watershed modeling professionals across multiple agencies have found that standard NRCS curve numbers result in overestimation of surface runoff and flow (IDNR and ISU, unpublished data). Therefore, HSG type C CNs were modified to better reflect conditions in the watershed. Urban land use curve numbers were developed within STEPL based on percent landuse of the urban subcategories. Adjusted CNs were entered in the "Input" worksheet of STEPL, and are reported in Table D-4.

Table D-5. STEPL curve numbers

Subwatershed	[1]Urban	Cropland	Forest	Pastureland	[2]User Defined
W1	92	85	73	79	75
W2	92	85	73	79	75

[1]Urban includes all developed areas, including transportation and farmstead areas
[2]User defined Includes hay / alfalfa, non-pasture grassland, and conservation reserve programs

Sediment Delivery Ratio
The sediment load to each lake in the Thayer Lake watershed will be dependent upon watershed morphology, water velocity, residence time, and other factors. The sediment load to the lake is smaller than total sheet and rill erosion because some of the eroded material is deposited in depressions, ditches, or streams before it reaches the watershed outlet (i.e., the lake). The sediment delivery ratio (SDR) is the portion of sheet and rill erosion that is transported to the watershed outlet. STEPL calculates the SDR for each subbasin using a simple empirical formula based on drainage area (i.e., subbasin area). The resulting SDR values are 34.7 for Basin 1 and 35.2 for Basin 2.

Best Management Practices
STEPL is able to simulate load reduction efficiencies for a variety of urban and agricultural BMPs in each sub basin. Reductions are dependent on the overall efficiency of each practice and the area of the BMP to which it is applied. The main practices modeled in the Thayer Lake watershed were a settling basin that mitigates runoff from pastureland in Basin 2. Each area of row crop was also listed with a filter strip due to flow interception by grassed areas. Percentages for area applied were based on manual delineation within each sub basin. The practices and BMP reduction efficiencies for each sub basin are listed in Tables D-5 and D-6.

Table D-6. BMP reduction efficiencies Cropland

Subwatershed	N	P	BOD	Sediment	BMP	Area Applied (%)
W1	0.14	0.15	ND	0.13	Filter Strip	20
W2	0.14	0.15	ND	0.13	Filter Strip	20

Table D-7. BMP reduction efficiencies Pastureland

Subwatershed	N	P	BOD	Sediment	BMP	Area Applied (%)
W1	0	0	0	0	No BMP	20
W2	ND	0.129	0.14	0.204	Settling Basin	20

D.5. Animals

Agricultural Animals and Manure Application
The STEPL model utilizes livestock population data and the duration (in months) that manure is applied to account for nutrient loading from livestock manure application. There are two main areas of pastureland within the Thayer Lake watershed, as well as large confined animal feeding operations (CAFOs) directly outside of the watershed that may contribute through manure application on cropland within the watershed. Inspection of manure management plans (MMP) showed that these facilities do not directly contribute to manure application within the Thayer Lake watershed. Manure applications to cropland are not expected to occur from pastureland in the Thayer Lake watershed.. Table D-5 lists the number and type of animals, the animal equivalent units (AEU) normalized per acre, and number of months manure is applied.

Table D-8. Agricultural animals and manure application

Watershed	Beef Cattle	Swine (Hog)	AEU (1000lb/ac)	# of months manure applied
W1	40	0	6.45	0
W2	40	0	2.13	0
Total	80	0	3.20	0

Livestock Grazing
There are two cattle grazing operations in the Thayer Lake watershed- one in each sub basin. Erosion and nutrient loss from the pasture landuse in the STEPL model, which likely results in an over-estimate of TP loads from this source. Erosion from pasture (and other grassland that may be in poor condition) carries sediment-bound phosphorus, which is accounted for by using a sediment nutrient enrichment ratio. The STEPL default enrichment ratio is 2.0, but this was changed to 1.3 based on enrichment ratio guidance per the Iowa Phosphorus Index http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_007643.pdf). STEPL simulates nutrient loss in pasture and grassland runoff by assuming a phosphorus concentration of 0.3 mg/L in the runoff. Similarly, a phosphorus concentration of 0.063 was used to simulate phosphorus loads from shallow groundwater in grazed areas.

Open Feedlots
There are no open feedlots in the Thayer Lake watershed in the IDNR Animal Feeding Operations Database. Feedlot operators are not required to report open feedlot information to IDNR for feedlots with less than 1000 animal units (AUs). No active open feedlot operations were observed during the February 2017 windshield survey.

Wildlife
The estimated county-wide average deer density is approximately 5 deer per square mile, but an average of 10 deer per square mile was entered in the “Animals” worksheet of the STEPL model for Thayer Lake watershed to account for increased density of deer around the lake. Population densities of 10 raccoons, 10 beavers, and 10 other per square mile were used to account for other wildlife (e.g., furbearers, upland birds, etc.) for which data is lacking.

Phosphorus contributions from waterfowl in and near the lake by Canada geese were simulated by STEPL. An estimate of goose population and subsequent phosphorus contributions at Thayer Lake were provided by DNR staff and confirmed by Union County staff. On an annual average basis, there are less than 25 geese residing at the lake; however, populations vary throughout the year due to migratory patterns and nesting seasons. Estimates of time spent on the lake are 40 percent of daylight hours due to foraging activity in upland grounds.

Septic Systems
A GIS coverage of rural residences with private onsite wastewater treatment systems (e.g., septic systems) was developed using aerial images and anecdotal data from various state, county, and local agencies. This procedure resulted in the identification of 4 septic systems in this sparsely populated watershed. It is estimated that 5 percent of these systems are not functioning adequately (i.e., are ponding or leaching). This is a fairly common occurrence in some rural parts of the state. This information is included in the "Inputs" worksheet of the STEPL model for Thayer Lake.

D.7. References

U.S. Department of Agriculture – Farm Service Agency (USDA-FSA). 2016. http://www.fsa.usda.gov/Internet/FSA_File/clu_2007_infosheetpdf.pdf. Accessed March 2017.

U.S. Department of Agriculture – National Agricultural Statistical Summary (USDA-NASS). 2016. http://nassgeodata.gmu.edu/CropScape/. Accessed March 2017.

Appendix E --- Water Quality Model Development

Two models were used to develop the Total Maximum Daily Load (TMDL) for Thayer Lake. Watershed hydrology and pollutant loading was simulated using the Spreadsheet Tool for Estimating Pollutant Load (STEPL), version 4.1. STEPL model development was described in detail in Appendix D.

In-lake water quality simulations were performed using BATHTUB 6.14, an empirical lake and reservoir eutrophication model. The BATHTUB model developed for Thayer Lake does not simulate dynamic conditions associated with storm events or individual growing seasons. Rather, the model predicts average water quality in the modeling period of 2002-2016, which includes the 2014 Integrated Report (2008-2012). This appendix discusses development of the BATHTUB model. The integrated watershed and in-lake modeling approach allows the holistic analysis of hydrology and water quality in Thayer Lake and its watershed.

E.1. BATHTUB Model Description

BATHTUB is a steady-state water quality model developed by the U.S. Army Corps of Engineers that performs empirical eutrophication simulations in lakes and reservoirs (Walker, 1999). Eutrophication-related parameters are expressed in terms of total phosphorus (TP), total nitrogen (TN), chlorophyll a (chl-a), and transparency. The model can distinguish between organic and inorganic forms of phosphorus and nitrogen, and simulates hypolimnetic oxygen depletion rates. Water quality predictions are based on empirical models that have been calibrated and tested for lake and reservoir applications (Walker, 1985). Control pathways for nutrient levels and water quality response are illustrated in Figure E-1.

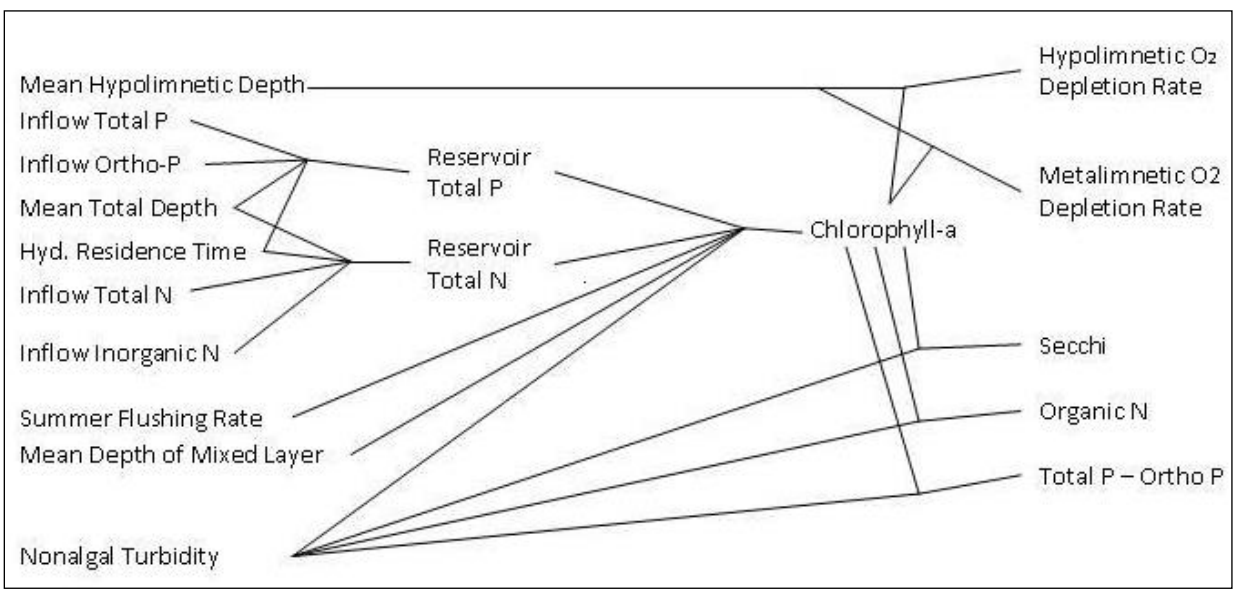

Figure E-1. Eutrophication control pathways in BATHTUB (Walker, 1999)

E.2. Model Parameterization

BATHTUB includes several data input menus and modules to describe lake characteristics, simulation equations, and external (i.e., watershed) inputs. Data menus utilized to develop the BATHTUB model for Thayer Lake include: model selections, global variables, segment data, and tributary data. The model selections menu allows the user to specify which modeling equations (i.e., empirical relationships) are used in the simulation of in-lake nitrogen, phosphorus, chlorophyll-a, transparency, and other parameters. The global variables menu describes parameters consistent throughout the lake such as precipitation, evaporation, and atmospheric deposition. The segment data menu is used to describe lake morphometry, observed water quality, calibration factors, and internal loads in each segment of the lake or reservoir. The tributary data menu specifies nutrient loads to each segment using mean flow and concentration in the averaging period. The following sub-sections describe the development of the Thayer Lake BATHTUB model and report input parameters for each menu.

Model Selections
BATHTUB includes several models and empirical relationships for simulating in-lake nutrients and eutrophication response. For TP, TN, chlorophyll-a, and transparency, Models 1 and 2 are the most general formulations, based upon model testing results (Walker, 1999). Alternative models are provided in BATHTUB to allow use of other eutrophication models, evaluate sensitivity of each model, and facilitate water quality simulation in light of data constraints.

Table E-1 reports the models selected for each parameter used to simulate eutrophication response in Thayer Lake. Preference was given to Models 1 and 2 during evaluation of model performance and calibration of the Thayer Lake model, but final selection of model type was based on applicability to lake characteristics, availability of data, and agreement between predicted and observed data. The default models were left to predict in-lake phosphorus and transparency levels because it provided the best agreement with observed data, and because Thayer Lake is a manmade impoundment and representative of aquatic systems for which these specific models were developed. Chlorophyll model selection was based on observed data agreement and applicability of based on BATHTUB user manual IR-W-96 table 4.2. Model performance is discussed in more detail in Appendix F.

Table E-1. Model selections for Thayer Lake

Parameter	Model No.	Model Description
Total Phosphorus	*01	2nd order, Avail. P
Total Nitrogen	01	2nd order, Avail. N
Chlorophyll-a	01	P, N, Light, T
Transparency	02	vs. Composite Nutrient
Longitudinal Dispersion	*01	Fischer-numeric
Phosphorus Calibration	02	Concentrations
Nitrogen Calibration	02	Concentrations
Availability Factors	01	Use for Model 1 only

* Asterisks indicate BATHTUB defaults

Global Variables
Global input data for Thayer Lake are reported in Table E-2. Global variables are independent of watershed hydrology or lake morphometry, but affect the water balance and nutrient cycling of the lake. The first global input is the averaging period. Both seasonal and annual averaging periods are appropriate, depending on site-specific conditions. An annual averaging period was utilized to quantify existing loads and in-lake water quality, and to develop TMDL targets for Thayer Lake.

Table E-2. Global variables data for simulation period[1]

Parameter	Observed Data	BATHTUB Input
Averaging Period	Annual	1.0 years
[1]Precipitation	37.5 in	0.95 m
[1]Evaporation	37.8 in	0.96 m
[2]Increase in Storage	0	0
[3]Atmospheric Loads:		
TP	0.3 kg/ha-yr	30 mg/m^2-yr
TN	7.7 kg/ha-yr	770.3 mg/m^2-yr

[1]Precip and evaporation data are from 2002 - 2016 in order to provide accurate long term data
[2]Change in lake volume from beginning to end of simulation period.
[3]From Anderson and Downing, 2006.

Precipitation was summarized for the 15-year assessment period of 2002-2016 from PRISM grid data collected and discussed in Chapter 2. Potential evapotranspiration data for the same period was obtained from the Lewis, Iowa weather station via the ISU Ag Climate database (IEM, 2016b). Net change in reservoir storage was assumed to be zero. This 15 year period was chosen in order to reflect the climate during the assessment period when water quality data was collected and analyzed to show the algal and non-algal impairments at Thayer Lake. It was shown in Section 3.1 (Figures 3-9 to 3-11) that precipitation is not highly correlated with total phosphorus and the impairment seen at Thayer Lake. For these reasons, it was assumed the extended assessment period climate conditions may be a more suitable basis for global variable data. These data were summarized and converted to BATHTUB units and entered in the global data menu. Atmospheric deposition rates were obtained from a regional study (Anderson and Downing, 2006). Nutrient deposition rates are assumed constant from year to year.

Segment Data
Lake morphometry, observed water quality, calibration factors, and internal loads are all included in the segment data menu of the BATHTUB model. Separate inputs can be made for each segment of the lake or reservoir system that the user wishes to simulate. In lakes with simple morphometry and one primary tributary, simulation of the entire lake as one segment is often acceptable. If evaluation of individual segments of the lake (or inflowing tributaries) is desirable, the lake can be split into multiple segments. Each segment may have a distinct tributary.

The Thayer Lake BATHTUB model includes one lake segment to facilitate simulation of diffusion, dispersion, and sedimentation that occur in the 12.7 acre lake. The relationship between watershed basins and the BATHTUB segment is shown in Table E-5. The

ambient monitoring location is used for listing and delisting purposes, the TMDL target applies at the ambient monitoring location in that segment.

Segment morphometry was calculated in the model. Bathymetric survey data and ESRI GIS software was used to estimate segment surface area, mean depth, and segment length. Temperature and dissolved oxygen (DO) profiles were used to estimate the mixed layer and hypolimnetic depth at the ambient monitoring location in Thayer Lake. Segment physical parameters input into BATHTUB for the lake system area shown in Table E-3.

Table E-3. Segment morphometry for the Thayer Lake

Segment	Outflow Segment	Segment Group	Surface Area (km^2)	Mean Depth (m)	Length (km)
Segment 1	Out of Reservoir	1	0.051	1.52	0.491

Mean water quality parameters observed for the modeling period (2002-2016) are reported in Table E-4. These data were compared to output in the main segment of the BATHTUB lake model to evaluate model performance and calibrate the BATHUB and STEPL models for each scenario. The TMDL and future water quality assessment and listing will be based solely on water quality data from the ambient monitoring location in Segment 1.

Table E-4. Ambient water quality (2002-2016 annual means)

Parameter	Measured Data	[1]BATHTUB Input
Total Phosphorus	109.4 µg/L	109.4 ppb
Total Nitrogen	1.50 mg/L	1500 ppb
Chlorophyll-a	34.1 µg/L	34.1 ppb
Secchi Depth	0.62 m	0.6 m

[1] Measured or monitored data converted to units required by BATHTUB
ppb = parts per billion = micrograms per liter (ug/L)

Tributary Data

The empirical eutrophication relationships in the BATHTUB model are influenced by the global and segment parameters previously described, but are heavily driven by flow and nutrient loads from the contributing drainage area (watershed). Flow and nutrient loads can be input to the BATHTUB model in a number of ways. Flow and nutrient loads used in the development of the Thayer Lake BATHTUB model utilize watershed hydrology and nutrient loads predicted using the STEPL model described in Appendix D. Output from STEPL includes annual average flow and nutrient loads. Table E-5 summarizes the physical parameters and monitored inputs for Thayer Lake.

Table E-5. Tributary data for the Thayer Lake

Tributary name	BATHTUB Receiving Segment	Total Watershed Area (km^2)	Avg Period Flow Rate (hm^3/yr)	STEPL Total P concentration (ppb)
Tributary 1	Segment 1	1.029	0.306	475.3
Tributary 2	Segment 1	0.991	0.289	1083.9

E.3. References

Anderson, K., and J. Downing. 2006. Dry and wet atmospheric deposition of nitrogen, phosphorus, and silicon in an agricultural region. Water, Air, and Soil Pollution, 176:351-374.

Iowa Environmental Mesonet (IEM). 2016a. Iowa State University Department of Agronomy. Iowa Ag Climate Network. Download available at http://mesonet.agron.iastate.edu/request/coop/fe.phtml
Accessed in March 2017.

Iowa Environmental Mesonet (IEM). 2016b. Iowa State University Department of Agronomy. Iowa Ag Climate Network. Download available at http://mesonet.agron.iastate.edu/agclimate/hist/dailyRequest.php.
Accessed in March 2017.

Appendix F --- Model Performance and Calibration

The Thayer Lake watershed and water quality models were calibrated by comparing simulated and observed local and regional data. The primary source of calibration data is the ambient lake monitoring data collected by Iowa State University (ISU) and the University of Iowa State Hygienic Laboratory (SHL) between 2002 and 2016. Literature values and results from regional studies regarding sediment and phosphorus exports in similar watersheds were also utilized to evaluate model performance. Calibration was an iterative process that involved running both the watershed model (STEPL) and in-lake model (BATHTUB), and refining model parameters to (1) produce simulated values that were within reasonable ranges according to similar studies, and (2) provide good agreement with observed water quality in Thayer Lake.

F.1. STEPL Performance and Calibration

The STEPL model is a long-term average annual simulation model, and is incapable of simulating storm events or short-term fluctuations in hydrology and nutrient loads. There is no long-term monitoring data for tributaries in the Thayer Lake watershed, therefore model calibration relied heavily upon sediment and phosphorus exports reported in similar watersheds in the region. Table F-1 reports estimated sheet and rill erosion rates found in several Iowa watersheds that are similar composition or proximate in location. Values for Thayer Lake watershed are before BMP reductions.

Table F-1. Sheet and rill erosion in Southern Iowa Drift Plain watersheds

Watershed	County	Area (acres)	Proximity (miles)	Erosion (tons/ac/yr)
Lake Hawthorne	Mahaska	3,289	90	5.3
Badger Creek Lake	Madison	11,397	33	3.9 – 4.5
Lake Miami	Monroe	3,595	64	2.2
Miller Creek	Monroe	19,930	73	2.3
Green Valley Lake	Union	5,175	17	2.7
[1]Thayer	**Union**	**484.5**	**--**	**4.5**

[1]Annual sheet/rill erosion estimated for this TMDL using STEPL (2002-2016).

The Thayer Lake STEPL model predicts sheet and rill erosion rates that are consistent with those predicted by DNR for other watersheds in the area. The 2002-2016 simulated annual average sheet and rill erosion rate was 4.5 tons/acre, compared with average estimated rates between 2.2 to 5.3 tons/acre/year estimated in other watersheds in the Southern Iowa Drift Plain. Note that erosion rates in Table F-1 reflect sheet and rill erosion, not sediment delivered to the lake. Sheet and rill erosion rates in the Thayer Lake watershed include erosion from grassland and pasture areas. The extreme slopes in the watershed create conditions which highly favor excessive erosion rates in the watershed.

Table F-2 compares the annual average TP export simulated by the Thayer Lake STEPL model with past study results in other watersheds in Iowa with an emphasis on the Southern Iowa Drift Plain. TP exports in the Thayer Lake watershed are 1.6 pounds per

acre per year. However, this reduced rate takes BMPs throughout the watershed into account when calculating load reductions- reductions which may not occur in other watershed studies. Because the STEPL model predicted sediment and phosphorus loads similar in magnitude to estimates developed for other local and regional watersheds, IDNR has determined the STEPL model to be adequate for estimation of phosphorus loads to Thayer Lake for development of TMDLs and implementation planning.

Table F-2. Comparison of TP exports in Southern Iowa Drift Plain watersheds

Watershed Location	Source	TP Export (lb/ac)
Lake Iowa, Iowa County	IDNR (Previous TMDL)	2.3
Windmill Lake, Taylor County	IDNR (Previous TMDL)	2.5
[1]Black Hawk Lake, Sac County	IDNR (Previous TMDL)	2.1
Badger Creek Lake, Madison County	IDNR (Previous TMDL)	2.2
Green Valley Lake, Union County	IDNR (Previous TMDL)	1.6
Thayer Lake, Union County	**STEPL Model (Current TMDL)**	**2.1**

[1]Black Hawk Lake is at the intersection of the Southern Iowa Drift Plain, Des Moines Lobe, and Northwest Iowa Plain landforms

F.2. BATHTUB Model Performance

Performance of the BATHTUB model was assessed by comparing predicted water quality with observed data collected in Thayer Lake. Simulation of TP concentration and Secchi depth / chlorophyll-a (algae) were critical for TMDL development, and were the focus of calibration efforts.

Calibration
Table F-3 reports observed and predicted annual average TP, chlorophyll-a, and Secchi depths in the open water area of Thayer Lake, along with the dispersion model and calibration coefficients for each parameter of interest. More comprehensive observed data is reported in Appendix C. Predicted water quality is based on BATHTUB simulations, and the calibration coefficients were iteratively adjusted in order to obtain the best possible agreement between observed and predicted water quality, while minimizing changes in the default coefficients. The calibration period was 2002-2016, the period for which water quality data was available.

Calibration coefficients listed alongside the simulated values in Table F-3 were entered in the “Segments” menu of the BATHTUB model, and apply to the ambient monitoring segment of Thayer Lake. Calibration coefficients for Thayer Lake are within the recommended range according to the BATHTUB user guidance (Walker, 1999).

Initial testing showed phosphorus levels from watershed loading were adequate for meeting observed water quality data in Thayer Lake. Internal loading levels were not required and due to lake morphology- not appropriate for Thayer Lake (Filstrup 2016). Once simulated phosphorus levels were calibrated to observed phosphorus levels, other water quality measurements were calibrated by increasing or decreasing model coefficients within the BATHTUB model.

Table F-3. Observed and simulated water quality with calibration factors

Parameter	[1]Observed	[2]Predicted	Calibration Coefficient
Modeling period and TMDL conditions (2002-2016)			
Dispersion coefficient	--	--	--
Total Phosphorus (ug/L)	109.4	109.4	0.538
Chlorophyll-a (ug/L)	34.1	34.1	0.751
Secchi depth (m)	0.6	0.6	0.904

[1]Average concentration observed at ambient monitoring location
[2]Average annual concentration predicted modeled segment of BATHTUB lake model

F.3. References

U.S. Geological Survey (USGS), 2001. Water Quality Assessment of the Eastern Iowa Basins – Nitrogen, Phosphorus, Suspended Sediment, and Organic Carbon in Surface

Walker, W. 1996 (Updated 1999). Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. US Army Corps of Engineers Waterways Experiment Station. Instruction Report W-96-2.

Appendix G --- Expressing Average Loads as Daily Maximums

In November of 2006, The U.S. Environmental Protection Agency (EPA) issued a memorandum entitled *Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits.* In the context of the memorandum, EPA

> *"…recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increments. In addition, TMDL submissions may include alternative, non-daily pollutant load expressions in order to facilitate implementation of the applicable water quality standards…"*

Per the EPA requirements, the loading capacity of Thayer Lake for TP is expressed as both a maximum annual average and a daily maximum load. The annual average load is more applicable to the assessment of in-lake water quality and water quality improvement actions, whereas the daily maximum load expression satisfies the legal uncertainty addressed in the EPA memorandum. The allowable annual average was derived using the BATHTUB model described in Appendix E, and is 513 lbs/year.

The maximum daily load was estimated from the allowable growing season average using a statistical approach. The methodology for this approach is taken directly from the follow-up guidance document titled *Options for Expressing Daily Loads in TMDLs* (EPA, 2007), which was issued shortly after the November 2006 memorandum cited previously. This methodology can also be found in EPA's 1991 *Technical Support Document for Water Quality Based Toxics Control*.

The *Options for Expressing Daily Loads in TMDLs* document presents a similar case study in which a statistical approach is considered the best option for identifying a maximum daily load (MDL) that corresponds to the allowable average load. The method calculates the daily maximum based on a long-term average and considers variation. This method is represented by the equation:

$$MDL = LTA \times e^{[z\sigma - 0.5\sigma^2]}$$

Where: MDL = maximum daily limit
LTA = long term average
z = z statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2 + 1)$
CV = coefficient of variation

The allowable annual average of 513 lbs/year is equivalent to a long-term average (LTA) daily of 4.38 lbs/day. The LTA is the allowable annual load divided by the 365-day averaging period. The average annual allowable load must be converted to a MDL. The 365-day averaging period equates to a recurrence interval of 99.7 percent and corresponding z statistic of 2.326, as reported in Table G-1. The coefficient of variation

(CV) is the ratio of the standard deviation to the mean. However, there is insufficient data to calculate a CV as it relates to TP loads to the lake, because the models are based on annual averages over several years. In cases where data necessary for calculating a CV is lacking, EPA recommends using a CV of 0.6 (EPA, 1991). The resulting σ^2 value is 0.31. This yields a TMDL of 4.38 lbs/day. The TMDL calculation is summarized in Table G-2. An explicit MOS of 10 percent (0.44 lbs) was applied, resulting in a daily LA of 3.94 lbs/day to the daily equation daily TMDL equations. The resulting TMDL, expressed as a daily maximum, is:

TMDL = LC = Σ WLA (0 lbs-TP/day) + Σ LA (3.94 lbs-TP/day)
+ MOS (0.44 lbs-TP/day) = **4.38 lbs-TP/day**

Table G-1. Multipliers used to convert a LTA to an MDL

Parameter	TMDL	Σ WLA	Σ LA	MOS
LTA (lbs/day)	1.41	0.0	1.26	0.14
Z Statistic	2.326	2.326	2.326	2.326
CV	0.6	0.6	0.6	0.6
σ^2	0.31	0.31	0.31	0.31
MDL (lbs/day)				
Seasonal (lbs/day)				

Table G-2. Summary of LTA to MDL calculation for the TMDL

Parameter	Value	Description
LTA	1.41 lbs/day	Annual TMDL (977 lbs) divided by 365 days
Z Statistic	2.326	Based on 180-day averaging period
CV	0.6	Used CV from annual GWLF TP loads
σ^2	0.31	ln (CV^2 + 1)
MDL	**4.38 lbs/day**	**TMDL expressed as daily load**

Appendix H --- 2014 305(b) Water Quality Assessment

Segment Summary

Waterbody ID Code: IA 05-GRA-01410-L_0
Location: Union County, S22, T72N, R28W, 1 mi SW of Thayer.
Waterbody Type: Lake
Segment Size: 12.7 Acres

This is a Significant Publically Owned Lake

Segment Classes:

Class A1
Class B(LW)
Class HH

Assessment Comments

Assessment is based on: (1) results of the statewide survey of Iowa lakes conducted from 2009-2012 by Iowa State University (ISU), (2) results of the statewide ambient lake monitoring program conducted in 2008 by University Hygienic Laboratory (UHL), and (3) information from the IDNR Fisheries Bureau. Note: The fish population of this lake was renovated in fall 2006; a very large population of common carp was eliminated. The IDNR Fisheries Bureau anticipates that, with the removal of the common carp, water clarity of this lake will improve.

Assessment Summary and Beneficial Use Support

Overall Use Support - Not supporting	Assessment Type: Monitored
Aquatic Life Support - Partial	Integrated Report Category: 5a
Fish Consumption - Not assessed	Trend: Stable
Primary Contact Recreation - Not supporting	Trophic Level: Hypereutrophic

Basis for Assessment and Comments

SUMMARY: The Class A1 (primary contact recreation) uses are assessed (monitored) as "not supported" (IR 5a) due to very poor water transparency related mainly to high levels of inorganic turbidity. High levels of algae also contribute to aesthetically objectionable conditions at this lake. The Class B(LW) aquatic life uses remain assessed (evaluated) as "partially supported" (IR 3b) due to siltation, excessive nutrient loading to the water column, and high levels of non-algal turbidity. Fish consumption uses remain "not assessed" due to the lack of fish contaminant monitoring at this lake. Sources of data for this assessment include: (1) results of the statewide survey of Iowa lakes conducted from 2009-2012 by Iowa State University (ISU), (2) results of the statewide ambient lake monitoring program conducted in 2008 by University Hygienic Laboratory (UHL), and (3) information from the IDNR Fisheries Bureau. Note: The fish population of this lake was renovated in fall 2006; a very large population of common carp was eliminated. The IDNR Fisheries Bureau anticipates that, with the removal of the

common carp, water clarity of this lake will improve.

EXPLANATION: Results from the ISU and UHL lake surveys suggest that the Class A1 uses at Thayer Lake are "not supported." Using the median values from these surveys from 2008-2012 (approximately 14 samples), Carlson's (1977) trophic state indices for Secchi depth, chlorophyll a, and total phosphorus were 69, 62, and 69 respectively for Thayer Lake. According to Carlson (1977) the Secchi depth, chlorophyll a, and total phosphorus values place Thayer Lake in between the eutrophic and hypereutrophic categories. These values suggest moderately high levels of chlorophyll a and suspended algae in the water, poor water transparency, and high levels of phosphorus in the water column.

The level of inorganic suspended solids is moderately high at Thayer Lake and suggests that non-algal turbidity causes an impairment at this lake. The median inorganic suspended solids concentration at Thayer Lake was 5.6 mg/L, and ranked 85th of the 134 monitored lakes.

Data from the 2008-2012 ISU and UHL surveys suggest a moderately large population of cyanobacteria exists at Thayer Lake. These data show that cyanobacteria comprised 92% of the phytoplankton wet mass at this lake. The median cyanobacteria wet mass (14.3 mg/L) and ranked 45th of the 134 lakes sampled.

The Class B(LW) (aquatic life) uses are assessed (evaluated) as "partially supported" due to siltation, excessive nutrient loading to the water column, and high levels of non-algal turbidity. Information from the IDNR Fisheries Bureau suggests that water quality has improved after a fishery renovation. No common carp have been sampled in the lake and small areas of rooted aquatic vegetation have appeared. Algae blooms, however, remain a concern at this lake. The ISU and UHL lake surveys results, however, show relatively good chemical water quality at Thayer Lake. During 2008-2012 there were no violations of the Class B(LW) criterion for ammonia in 14 samples. There were two violations of the Class B(LW) criterion for dissolved oxygen in 14 samples (14%) and one violation of the Class A1,B(LW) criteria for pH in 14 samples (7%). Based on IDNR's assessment methodology these violations are not significantly greater than 10% of the samples and therefore do not suggest an impairment of the Class B(LW) uses at Thayer Lake.

Fish consumption uses remain "not assessed" due to the lack of fish contaminant monitoring in this lake.

Monitoring and Methods

Assessment Key Dates

5/5/2008	Fixed Monitoring Start Date
9/13/2012	Fixed Monitoring End Date

Methods

- Surveys of fish and game biologists/other professionals
- Non-fixed-station monitoring (conventional during key seasons and flows)
- Primary producer surveys (phytoplankton/periphyton/macrophyton)

Appendix I --- DNR Project Files and Locations

This appendix is primarily for future reference by DNR staff that may wish to access the original spreadsheets, models, maps, figures, and other files utilized in the development of the TMDL.

Directory\folder path	File name	Description
\\iowa.gov.state.ia.us\...\Data\Raw\	Various files	All raw data received from others
\\iowa.gov.state.ia.us\...\Data\Reduced\	Water_Quality_Data_Thay.xls	Summary of in-lake WQ data
\\iowa.gov.state.ia.us\...\Data\Reduced\Climate	Climate_Precip_ET_Thay.xls	Summary of precipitation and PET data
\\iowa.gov.state.ia.us\...\Documents\Draft_TMDL	Draft TMDL reports	Includes review comments
\\iowa.gov.state.ia.us\...\Documents\Final_TMDL	Final report	Report fir submittal to EPA
\\iowa.gov.state.ia.us\...\Documents\References	Various .pdf and .doc files	References cited in the WQIP and/or utilized to develop model input parameters
\\iowa.gov.state.ia.us\...\GIS\GIS_Data	Various shapefiles (.shp) and raster files (.grd)	Used to develop models and maps
\\iowa.gov.state.ia.us\...\GIS\Projects	ArcGIS project files	Used to develop models and maps
\\iowa.gov.state.ia.us\...\Maps, Figures, Images\Maps	Various .pdf and .jpg files	Maps/figures used in the WQIP document
\\iowa.gov.state.ia.us\...\Modeling	Allocations_Final.xls	Used to develop phosphorus source inventory and potential load allocation scenario
	TMDL_Equation_Calcs_Thay.xls	Used to develop the TMDL equation (LA, WLA, and MOS)
		Load response curve calcs
\\iowa.gov.state.ia.us\...\Modeling\STEPL	Stepl_GVL_2002-2016_.xls	Used to simulated/predict existing watershed loads
	Various .xls files	Used to develop/calculate STEPL model inputs
\\iowa.gov.state.ia.us\...\Modeling\BATHTUB\InputFiles	STEPL_Conversion_Thay.xls	Calculated/converted STEPL outputs to BATHTUB inputs for existing conditions
	BATHTUB _2002-2016.xls	
	Various .btb files	BATHTUB input files for various scenarios

Appendix J --- Public Comments

Public Comment:

All public comments received during the public comment period will be placed in this section, along with Iowa DNR responses.