Total Maximum Daily Load
For Algae and Turbidity
Ingham Lake
Emmet County, Iowa

2004

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Ingham Lake Summary

Waterbody Name:	Ingham Lake
County:	Emmet
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Des Moines River Basin
Pollutant:	Phosphorus
Pollutant Sources:	Nonpoint, internal recycle, atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Medium
Watershed Area:	320 acres
Lake Area:	370 acres
Lake Volume:	2,317 acre-ft
Detention Time:	0.5 years
TSI Target(s):	Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65
Total Phosphorus Load Capacity (TMDL):	2,750 pounds per year
Existing Total Phosphorus Load:	9,560 pounds per year
Load Reduction to Achieve TMDL:	6,810 pounds per year
Margin of Safety:	280 pounds per year
Wasteload Allocation:	0
Load Allocation:	2,470 pounds per year

The Federal Clean Water Act requires the Iowa Department of Natural Resources (IDNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's 303(d) list as impaired by a pollutant. Ingham Lake has been identified as impaired by algae and turbidity. The purpose of these TMDLs for Ingham Lake is to calculate the maximum allowable nutrient loading for the lake associated with algae and turbidity levels that will meet water quality standards.

This document consists of TMDLs for algae and turbidity designed to provide Ingham Lake water quality that fully supports its designated uses. Phosphorus, which is related through the Trophic State Index (TSI) to chlorophyll and Secchi depth, is targeted to address the algae and turbidity impairments.

Phasing TMDLs is an iterative approach to managing water quality that becomes necessary when the origin, nature and sources of water quality impairments are not well understood. In Phase 1, the waterbody load capacity, existing pollutant load in excess of this capacity, and the source load allocations are estimated based on the limited information available. A monitoring plan will be used to determine if prescribed load reductions result in attainment of water quality standards and whether or not the target values are sufficient to meet designated uses. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling.

Section 5.0 of this TMDL includes a description of planned monitoring. The TMDL will have two phases. Phase 1 will consist of setting specific and quantifiable targets for total phosphorus, algal biomass and Secchi depth expressed as Carlson's Trophic State Index (TSI). Phase 2 will consist of implementing the monitoring plan, evaluating collected data, and readjusting target values if needed.

Monitoring is essential to all TMDLs in order to:

- Assess the future beneficial use status;
- Determine if the water quality is improving, degrading or remaining status quo;
- Evaluate the effectiveness of implemented best management practices.

The additional data collected will be used to determine if the implemented TMDL and watershed management plan have been or are effective in addressing the identified water quality impairments. The data and information can also be used to determine if the TMDLs have accurately identified the required components (i.e. loading/assimilative capacity, load allocations, in-lake response to pollutant loads, etc.) and if revisions are appropriate.

This TMDL has been prepared in compliance with the current regulations for TMDL development that were promulgated in 1992 as 40 CFR Part 130.7. These regulations and consequent TMDL development are summarized below:

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Ingham Lake, S12, T98N, R33W, 6 miles east of Wallingford, Emmet County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutants causing the water quality impairments are algae and turbidity associated with excessive nutrient (phosphorus) loading. Designated uses for Ingham Lake are Primary Contact Recreation (Class A1) and Aquatic Life (Class B(LW)). Excess nutrient loading has impaired aesthetic and aquatic life water quality narrative criteria (567 IAC 61.3(2)) and hindered the designated uses.

3. **Quantification of the pollutant load that may be present in the waterbody and still allow attainment and maintenance of water quality standards:** The Phase 1 target of this TMDL is a Carlson's Trophic State Index (TSI) of less than 70 for total phosphorus, and TSI values of less than 65 for both chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L respectively, and a Secchi depth of 0.7 meters.

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for Secchi depth, chlorophyll a and total phosphorus based on 2000 - 2003 sampling are 0.5 meters, 62 ug/L and 232 ug/L, respectively. A minimum in-lake increase in Secchi depth of 40% and minimum in-lake reductions of 47% for chlorophyll a and 59% for total phosphorus are required to achieve and maintain lake water quality goals and protect for beneficial uses. The estimated

existing annual total phosphorus load to Ingham Lake is 9,560 pounds per year. The total phosphorus loading capacity for the lake is 2,750 pounds per year based on lake response modeling. An average annual load reduction of 6,810 pounds per year is required.

5. **Identification of pollution source categories:** Nonpoint and atmospheric deposition (background) sources and internal recycling of phosphorus from the lake bottom sediments are identified as the cause of impairments to Ingham Lake.

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Ingham Lake watershed. Therefore, the wasteload allocation will be set at zero.

7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus load allocation for the nonpoint sources and internal recycle is 2,470 pounds per year including 120 pounds per year attributable to atmospheric deposition.

8. **A margin of safety:** An explicit numerical MOS of 280 pounds per year (10% of the calculated allowable phosphorus load) has been included to ensure that the load allocation will result in attainment of water quality targets.

9. **Consideration of seasonal variation:** This TMDL was developed based on the annual phosphorus loading that will result in attainment of TSI targets for the growing season (May through September).

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for increased phosphorus loading was not included in this TMDL. Significant changes in the Ingham Lake watershed landuse are unlikely. A majority of the watershed landuse is dedicated to agricultural production. The addition or deletion of animal feeding operations within the immediate or surrounding watersheds could increase or decrease nutrient loading. Future increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and internal phosphorus loading. Such events cannot be predicted and at this time conditions are not expected to change, therefore, an allowance for their potential occurrence was not included in the TMDL.

11. **Implementation plan:** Although not required by the current regulations, an implementation plan is outlined in the body of the report.

2. Ingham Lake, Description and History

2.1 The Lake

Ingham Lake is a natural, glacial lake located in northwest Iowa, 6 miles east of Wallingford. Public use for Ingham Lake is estimated at approximately 17,000 visitors per year. Users of the lake enjoy fishing, swimming, picnicking, hiking, boating, and snowmobiling.

Table 2. Ingham Lake Features

Waterbody Name:	Ingham Lake
Hydrologic Unit Code:	HUC10 0710000202
IDNR Waterbody ID:	IA 04-UDM-03985-L
Location:	Section 20 T95N R34W
Latitude:	43° 19' N
Longitude:	94° 42' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	Cunningham Slough, High Lake, West Slough
Receiving Waterbody:	East Slough
Lake Surface Area:	370 acres
Maximum Depth:	12 feet
Mean Depth:	6.2 feet
Volume:	2,317 acre-feet
Length of Shoreline:	22,400 feet
Watershed Area:	320 acres
Watershed/Lake Area Ratio:	0.9:1
Estimated Detention Time:	0.5 years

Morphometry

Ingham Lake has a mean depth of 6.2 feet and a maximum depth of 12 feet. The lake has a surface area of 370 acres and a storage volume of approximately 2,317 acre-feet. Temperature and dissolved oxygen sampling indicate that Ingham Lake remains oxic and relatively well mixed throughout the growing season.

Hydrology

Ingham Lake is fed by Cunningham Slough, which is in turn fed by High Lake. Other hydrologic inputs include West Slough, overland flow from the immediate watershed, direct precipitation on the lake surface, and groundwater. Ingham Lake discharges to East Slough. The estimated annual average detention time for Ingham Lake is 0.5 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Ingham Lake watershed has an area of approximately 320 acres and has a watershed to lake ratio of 0.9:1. The 2002 landuses and associated areas for the watershed were obtained from satellite imagery and are shown in Table 3. The 2002 landuse map is shown in Appendix D.

Table 3. 2002 Landuse in Ingham Lake watershed.

Landuse	Area in Acres	Percent of Total Area
Row Crop	135	42.2
Forest	80	25.0
Grassland	76	23.8
Water/Wetland	15	4.7
Other	14	4.4
Total	320	100

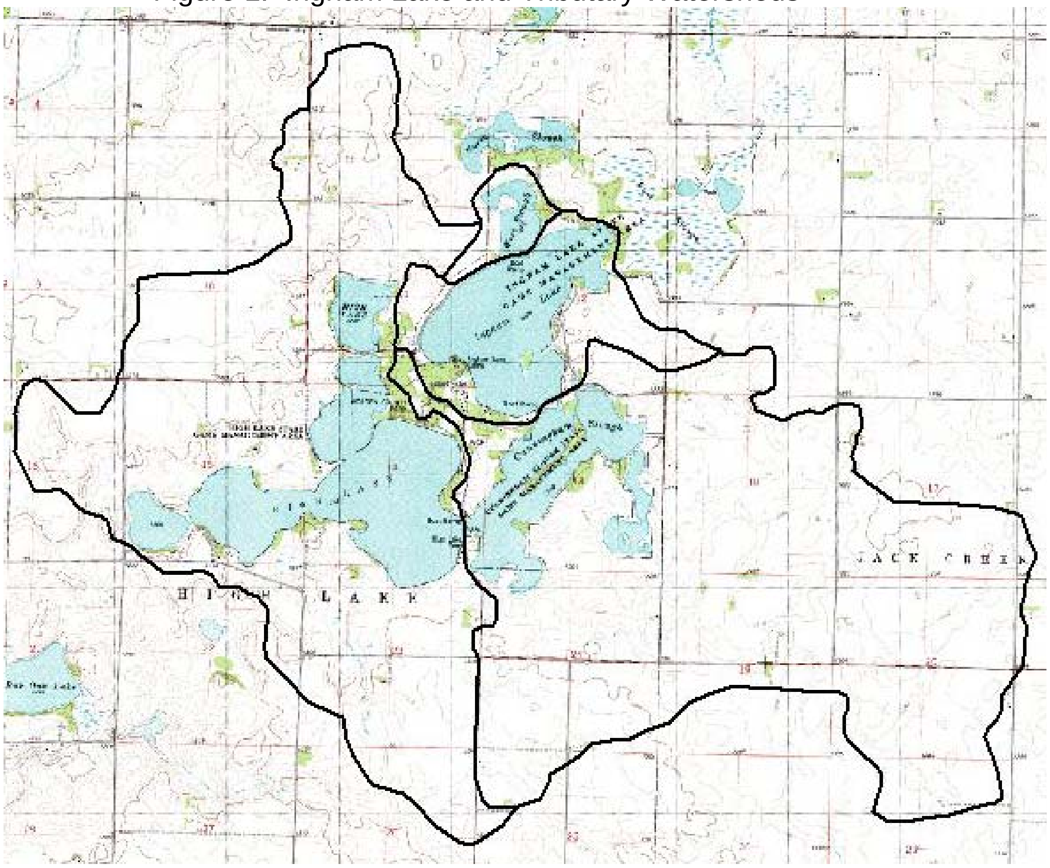
A more recent field-level landuse assessment was completed in June 2004 by the IDNR. The 2004 assessment also shows that the major landuse is row crop and noted the presence of three Confinement Animal Feeding Operations (CAFOs) and four open feedlots (one of which has a manure storage structure) within the immediate and tributary watersheds. The estimated numbers of animal units associated with CAFOs and feedlots within the watershed are 3,200 swine animal units, 790 beef animal units and one sheep animal unit.

Open feedlots are unroofed or partially roofed animal feeding operations in which no crop, vegetation, or forage growth or residue cover is maintained during the period that animals are confined in the operation. Runoff from open feedlots can deliver substantial quantities of nutrients to a waterbody dependent upon factors such as proximity to a water surface, number and type of livestock and manure controls. CAFOs are animal feeding operations in which animals are confined to areas which are totally roofed. CAFOs typically utilize earthen or concrete structures to contain and store manure prior to land application. Nutrients from CAFOs are delivered via runoff from land applied manure or from leaking/failing storage structures.

Limited low-density residential development is present on the east and south shores of the lake. A bible camp is also located on the south shore.

The watershed is predominately level to moderately sloping (0-9%) prairie-derived soils. The most common soil types in the watershed are Clarion, Webster, Canisteo, and Nicollet with some Okoboji and Harps soils.

Figure 1. Ingham Lake and Tributary Watersheds



3. TMDL for Algae and Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (8) list the designated uses for Ingham Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). In 1999, Ingham Lake was included on the impaired water list due to elevated levels of turbidity. In 2002, the lake was also listed for algae impairments.

Since 1994, the Class A designated use has been assessed as “partially supporting” (with the exception of 2000 when this use was not assessed). The Class B(LW) use has been listed as “fully supported/threatened” for Ingham Lake since 1992. The 2002 assessment was based upon the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau.

Impairments to the Class A1 (primary contact) use is through the presence of aesthetically objectionable blooms of algae and of nuisance algal species (e.g., bluegreen algae), as well as through excess turbidity. The turbidity impairment is primarily due to suspended algae but may also be influenced by elevated levels of inorganic suspended solids. Class B(LW) aquatic life uses are assessed as fully supported/threatened due to excessive nutrient loading to the water column, nuisance blooms of algae, and re-suspension of sediment.

Data Sources

Water quality surveys have been conducted on Ingham Lake in 1979, 1990, and 2000-03 (1,2,3,4,5,20). Data from these surveys is available in Appendix B.

Iowa State University Lake Study data from 2000 to 2003 were evaluated for this TMDL. This study is scheduled to run through 2004 and approximates a sampling scheme used by Roger Bachman in earlier Iowa lake studies. Samples are collected three times during the early, middle and late summer. A number of water quality parameters are measured including Secchi disk depth, phosphorus series, nitrogen series, TSS, and VSS.

Interpreting Ingham Lake Water Quality Data

Based on mean values from ISU sampling during 2000 - 2003, the ratio of total nitrogen to total phosphorus for this lake is 11:1. Data on inorganic suspended solids from the ISU sampling suggest that this lake may be subject to episodes of high levels of non-algal turbidity. The median level of inorganic suspended solids in the 130 lakes sampled for the ISU lake survey in 2000 and 2001 was 5.27 mg/L. The median level of inorganic suspended solids at Ingham Lake during the same time period was 9.8 mg/l, the 36th highest of the 130 lakes.

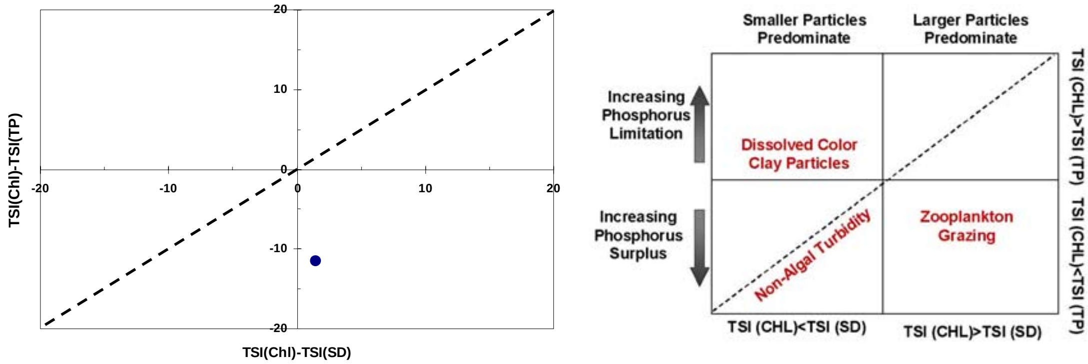
Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for 2000 - 2003 in-lake sampling indicate that algae dominate light attenuation but that some factor other than phosphorus (e.g. nitrogen limitation, zooplankton grazing, or toxics) limits algal biomass (see Figure 2 and Appendix C).

TSI values for 2000 - 2003 monitoring data are shown in Table 4. TSI values for all historical monitoring data and an explanation of Carlson's Trophic State Index are given in Appendix C.

Table 4. Ingham Lake TSI Values (3,4,5,20)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/2000	70	70	76
7/13/2000	73	--	103
8/4/2000	83	71	90
5/16/2001	70	73	72
6/13/2001	50	37	78
7/18/2001	77	79	86
5/22/2002	67	60	71
6/19/2002	77	74	70
7/24/2002	77	80	71
5/21/2003	73	62	76
6/18/2003	73	67	75
7/23/2003	83	63	74

Figure 2. Ingham Lake 2000 - 2003 Mean TSI Multivariate Comparison Plot (22)



Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) tend to dominate the summertime phytoplankton community of Ingham Lake. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. However, the sampling does indicate a high level of bluegreen mass relative to other Iowa lakes. The 2000 average summer wet mass of bluegreen algae at this lake (81.5 mg/l) was the 14th highest of 131 lakes sampled. Sampling for cyanobacterial toxins has not been conducted at Ingham Lake. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

Potential Pollution Sources

Water quality in Ingham Lake is influenced only by nonpoint sources and internal recycling of bottom sediments. Nonpoint source categories identified in this TMDL include inflow from Cunningham Slough and West Slough combined with internal recycle, atmospheric deposition and watershed loads in the immediate Ingham Lake watershed. There are no point source discharges in the watershed.

Natural Background Conditions

For the phosphorus load attributable to atmospheric deposition directly on the lake surface, the annual average concentration of phosphorus in precipitation was assumed to be 0.05 mg/L based on a review of available literature (11,17,18,19) and the default values used in the EUTROMOD and WILMS modeling programs. Contributions of phosphorus attributable to dry atmospheric deposition were not separated from the direct precipitation load. Potential phosphorus contributions from groundwater influx were not separated from the total nonpoint source load.

3.2 TMDL Target

The Phase 1 targets for this TMDL are mean TSI values of less than 70 for total phosphorus, and mean TSI values of less than 65 for both chlorophyll and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L respectively, and a Secchi depth of 0.7 meters.

Table 5. Ingham Lake Existing vs. Target TSI Values

Parameter	2000-2003 Mean TSI	2000-2003 Mean Value	Target TSI	Target Value	Minimum In-Lake Increase or Reduction Required
Chlorophyll	71	62 ug/L	<65	<33 ug/L	47% Reduction
Secchi Depth	70	0.5 meters	<65	>0.7 meters	40% Increase in transparency
Total Phosphorus	83	232 ug/L	<70	<96 ug/L	59% Reduction

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for algae or turbidity. The cause of the algae and turbidity impairments is algal blooms caused by excessive nutrient loading to the lake. The nutrient-loading objective is defined by a mean total phosphorus TSI of less than 70, which is related through the Trophic State Index to chlorophyll a and Secchi depth. The TSI is not a standard, but is used as a guideline to relate phosphorus loading to the algal impairment for TMDL development purposes and to describe water quality that will meet Iowa's narrative water quality standards.

Selection of Environmental Conditions

The critical condition for which the TMDL TSI target values apply is the growing season (May through September). It is during this period that nuisance algal blooms are prevalent. The existing and target total phosphorus loadings to the lake are expressed as annual averages. The model selected for estimating phosphorus loading to the lake utilizes growing season mean (GSM) in-lake total phosphorus concentrations to calculate an annual average total phosphorus loading.

Modeling Approach

A number of different empirical models that predict annual phosphorus load based on measured in-lake phosphorus concentrations were evaluated. In addition, watershed phosphorus delivery using both export coefficients and an annual loading function model as outlined in Reckhow's EUTROMOD User's Manual (10) was calculated. The results from both approaches were compared to select the best-fit empirical model.

Of the empirical models evaluated, the Canfield-Bachmann Natural Lake, Reckhow Anoxic and Vollenweider models resulted in values closest to the Loading Function and export estimates while remaining within the parameter ranges used to derive them. Application of the Reckhow Anoxic Model to Ingham Lake (an oxic lake) is of questionable value. The Vollenweider models are annual models that should ideally be used in combination with annual average in-lake phosphorus estimates. The available in-lake phosphorus monitoring data for Ingham Lake corresponds with the growing season.

The Nurnberg Oxic Lake model indicates an internal loading that is supported by Ingham Lake's high total phosphorus and inorganic suspended solids levels. However, this model must be extrapolated beyond the limits of the data used to derive it for application to Ingham Lake, whereas the Canfield-Bachmann relationship is within parameter ranges. In addition, in-lake monitoring data for Cunningham Slough and West Slough is not available to aid in differentiating internal loading within Ingham Lake from external loading from the tributary water bodies. Therefore, the Canfield-Bachmann Natural Lake relationship was selected as best-fit empirical model.

Table 6. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = = ANN TP = 232 ug/L, SPO TP = 121 ug/L	Comments
Loading Function (Ingham watershed / Ingham + tributary watersheds)	320 / 6,300	Reckhow (10)
EPA Export (Ingham watershed / Ingham + tributary watersheds)	400 / 7,520	EPA/5-80-011
WILMS Export (Ingham watershed / Ingham + tributary watersheds)	280 / 5,070	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	394,250	GSM model
Canfield-Bachmann 1981 Natural Lake	9,560	GSM model
Canfield-Bachmann 1981 Artificial Lake	25,360	GSM model
Reckhow 1977 Anoxic Lake	3,400	GSM model
Reckhow 1979 Natural Lake	12,290	GSM model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	6,090	GSM model. P out of range
Nurnberg 1984 Oxic Lake	6,300 (internal load = 860)	Annual model. P out of range
Walker 1977 General Lake	2,360	SPO model.
Vollenweider 1982 Combined OECD	9,300	Annual model.
Vollenweider 1982 Shallow Lake	9,870	Annual model.

The equation for the Canfield-Bachmann Natural Lake Model is:

$$P = \frac{L}{z\left[0.162\left(L/z\right)^{0.458} + p\right]}$$

where

$P =$ predicted in-lake total phosphorus concentration (ug/L)
$L =$ areal total phosphorus load (mg/m^2 of lake area per year)
$z =$ lake mean depth (meters)
$p =$ lake flushing rate (yr^{-1})

The calculations for the existing total phosphorus load to Ingham Lake are as follows:

$$P = 232(\mu g/L) = \frac{2{,}869(mg/m^2)}{1.89(m)\left[0.162\left(2{,}869(mg/m^2)/1.89(m)\right)^{0.458} + 1.91(yr^{-1})\right]}$$

The calculations for the total phosphorus load capacity are:

$$P = 96(\mu g/L) = \frac{825(mg/m^2)}{1.89(m)\left[0.162\left(825(mg/m^2)\big/1.89(m)\right)^{0.458} + 1.91(yr^{-1})\right]}$$

The annual total phosphorus load is obtained by multiplying the areal load (L) by the lake area in square meters and converting the resulting value from milligrams to pounds.

Waterbody Pollutant Loading Capacity

The chlorophyll-a and Secchi depth objectives are related through the Trophic State Index to total phosphorus. The load capacity for this TMDL is the annual amount of phosphorus Ingham Lake can receive and meet its designated uses. Based on the selected lake response model and a target TSI (TP) value of less than 70, the Phase 1 total phosphorus loading capacity for the lake is 2,750 pounds per year.

3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Ingham Lake in this TMDL. The first is the phosphorus load attributable to inflow from Cunningham Slough, West Slough and phosphorus recycled from lake sediments within Ingham Lake. The second source is the watershed area that drains directly into the lake. The third source is atmospheric deposition directly onto the lake. Note that load contributions from groundwater influx have not been separated from the total nonpoint source loads.

Existing Load

The annual total phosphorus load to Ingham Lake is estimated to be 9,560 pounds per year based on the selected lake response model. Of this, 9,240 pounds per year is attributable to inflow from Cunningham Slough, West Slough and internal recycle within Ingham Lake. The remaining 320 pounds per year is divided into inputs from the immediate Ingham Lake watershed (200 pounds per year) and atmospheric deposition (120 pounds per year). In-lake monitoring data for Cunningham Slough and West Slough is not available. Therefore, loads from these tributary water bodies were not separated from each other or the Ingham Lake internal recycle load.

Departure from Load Capacity

The Phase 1 targeted total phosphorus load capacity for Ingham Lake is 2,750 pounds per year. The estimated existing load is 9,560 pounds per year. Therefore, to achieve and maintain Phase 1 water quality goals and protect the designated uses, a nonpoint source load reduction of 6,810 pounds per year is required.

Identification of Pollutant Sources

There are no significant point source discharges in the Ingham Lake watershed. The primary sources of phosphorus are inflow from the tributary water bodies and internal recycle within Ingham Lake. Because average annual flow from West Slough to Ingham

Lake is estimated to be less than 1% of all inflow sources, the phosphorus load from this source is believed to be minor in comparison to that of Cunningham Slough. The combined phosphorus load from these sources was estimated by subtracting the Loading Function phosphorus inputs for the immediate Ingham Lake watershed (200 lbs/yr) and atmospheric deposition (120 lbs/yr) from the in-lake response model total load (9,560 lbs/yr).

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Ingham Lake originates entirely from nonpoint sources (including Cunningham Slough and West Slough) and internal recycling. To meet the TMDL endpoint, the annual nonpoint source contribution to Ingham Lake needs to be reduced by 6,810 pounds per year.

3.4 Pollutant Allocation

Wasteload Allocation

Since there are no significant phosphorus point source contributors in the Ingham Lake watershed, the Waste Load Allocation (WLA) is zero pounds per year.

Load Allocation

The Load Allocation (LA) for this TMDL is 2,470 pounds per year of total phosphorus distributed as follows:

- 2,350 pounds per year allocated to influent from Cunningham Slough and West Slough, internal recycling of phosphorus from lake bottom sediments, and the immediate Ingham Lake watershed.

- 120 pounds per year allocated to atmospheric deposition.

Margin of Safety

An explicit numerical MOS of 280 pounds per year (10% of the calculated allowable phosphorus load) has been included to ensure that the load allocation will result in attainment of water quality targets.

4. Implementation Plan

The following implementation plan is not a required component of a Total Maximum Daily Load but can provide department staff, partners, and watershed stakeholders with a strategy for improving Ingham Lake water quality.

Due to the small size of the immediate Ingham Lake watershed relative to the watersheds of the lake system which feeds it, the major phosphorus loads to the lake are influent from Cunningham Slough (to which High Lake is tributary) and internal recycling. Because monitoring data for Cunningham Slough and West Slough is not available, the loads from these sources have not been separated from the Ingham Lake internal recycling load, which could be significant.

Among the mechanisms of resuspension are bottom feeding rough fish such as carp, wind-driven waves and currents, and boat propellers. Methods are needed to evaluate the magnitude of the phosphorus load from internal recycling, preferably by direct measurement of resuspension and recycling from lake bottom sediment. The department is investigating methods of measuring sediment phosphorus flux by evaluating lake sediment cores. This work is being done at Iowa State University and is supported by an EPA grant.

Because of the uncertainty as to how much of the phosphorus load is attributable to influent from Ingham Lake's tributary water bodies and how much is recycled from lake bottom sediment, an adaptive management approach is recommended. In this approach, management practices to reduce upstream watershed loads and recycled loads are incrementally applied and the results monitored to determine if water quality goals have been achieved. Also, the reductions in watershed loads will require land management changes that take time to implement. For these reasons, the following timetable is suggested for watershed improvements:

- Reduce watershed and recycle loading from 9,600 pounds per year to 7,200 pounds per year by 2010.
- Reduce watershed and recycle loading from 7,200 pounds per year to 4,800 pounds per year by 2015.
- Reduce watershed and recycle loading from 4,800 pounds per year to 2,500 pounds per year by 2020.

Best management practices to reduce nutrient delivery, particularly phosphorus, should be emphasized in both upstream watersheds and the immediate Ingham Lake watershed. These practices include the following:

- Nutrient management on production agriculture ground to achieve the optimum soil test range. This soil test range is the most profitable for producers to sustain in the long term.
- Incorporate or subsurface apply phosphorus (manure and commercial fertilizer) while controlling soil erosion. Incorporation will physically separate the phosphorus from surface runoff.
- Continue encouraging the adoption of reduced tillage systems, specifically no till and strip tillage.
- Initiate a fall-seeded cover crop incentive program. Target low residue producing crops (e.g. soybeans) or low residue crops after harvest (e.g. corn silage fields). This practice increases residue cover on the soil surface and improves water infiltration.
- Through incentives, add landscape diversity to reduce runoff volume and/or velocity through the strategic location of contour grass buffer strips, filter strips, and grass waterways, etc.
- Install terraces, ponds, or other erosion and water control structures at appropriate locations within the watersheds to control erosion and reduce delivery of sediment and phosphorus to the lake.

In addition to the external nutrient loading to Ingham Lake, it is believed there is a significant internal loading component due to rough fish and wind and wave action on the lake. This internal component can be controlled through fish management to control rough fish (i.e., carp), rip rap along the shoreline to reduce shoreline erosion, and dredging to remove nutrients from the lake system.

5. Monitoring

Further monitoring is needed at Ingham Lake to follow-up on the implementation of the TMDL. This monitoring will, at a minimum, meet the minimum data requirements established by Iowa's 305(b) guidelines for a complete water quality assessment (3 lake samples per year over 3 years, 10 lake samples over 2 years, etc.). This data will be collected by 2010. Ingham Lake has been included in the five-year lake study conducted by Iowa State University under contract with the IDNR. Although this lake monitoring program concluded in 2004, it may be extended under a new lake monitoring strategy. The TMDL program is committed to monitoring waters where TMDLs have been completed, and in the absence of a statewide lake monitoring program, follow-up monitoring will be conducted through the TMDL program.

As noted in *Section 4, Implementation*, the phosphorus load due to internal recycling needs to be measured and evaluated. The department is working with Iowa State University to develop a method for quantifying phosphorus sediment flux that will clarify its impact on lakes such as Ingham. When a protocol for measuring phosphorus flux becomes available, coring will be done for this lake and the recycling load component estimated.

6. Public Participation

TMDL staff met with the Emmet County Conservation Board (CCB) on July 1, 2004 to discuss the TMDL process. The draft TMDL was presented at a public meeting in Estherville, Iowa on November 22, 2004. The meeting was attended by representatives from the Emmet CCB, IDNR Fisheries Bureau, the NRCS, and the Okamanpedan Lake Association. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

There are approximately 127 public lakes in Iowa. The contributing watersheds for these lakes range in area from 0.028 mi^2 to 195 mi^2 with mean and median values of 10 mi^2 and 3.5 mi^2, respectively. Few, if any, of these lakes have gauging data available to determine flow statistics for the tributaries that feed into them. A select few have some type of stage information that may be useful in determining historical discharge from the lake itself.

With the large number of lakes on the State's 303(d) list and the requirement for rapid development of TMDLs for these lakes, it was realized that a method to quickly estimate flow statistics for required lake response model inputs would be desirable. In an attempt to achieve this goal, flow data and watershed characteristics for a number of USGS gauging stations with small contributing watershed areas were compiled and evaluated via both simple and multiple linear regressions. The primary focus of this evaluation was estimation of the average annual flow statistic for input to empirical lake response models. However, regression equations for monthly average and calendar year flow statistics were also developed that may be of additional use.

It should be noted that attempts were made to develop regression equations for low-flow streamflow statistics (1Q10, 7Q10, 30Q10, 30Q5 and harmonic mean) but the relationships derived were for the most part considered too weak (R^2 adj.< 70%) to be of practical use. One exception to this is the 30Q5 statistic, which gave an R^2 adj. of 85%. In addition, regression equations were developed for monthly flow prediction models for two months (January and May). Once again, the relationships did not exhibit a high level of correlation and due to the large amount of data required to develop these models, development of equations for additional months was not attempted.

Data

Flow data and watershed characteristics from 26 USGS gauging stations were used to derive the regression equations. The ranges of basin characteristics used to develop the regression equations are shown in Table A-1.

Drainage areas were taken directly from USGS gauge information available at http://water.usgs.gov/waterwatch/ . Precipitation values were obtained through the Iowa Environmental Mesonet IEM Climodat Interface at http://mesonet.agron.iastate.edu/climodat/index.phtml . Where weather and gauging stations were not located in the same town, precipitation information was obtained from the weather station located in the town with the shortest straight-line distance from the gauging station.

Average basin slope and land cover percentages were determined using Arc View and statewide coverages clipped within HUC-12 sub-watersheds. It should be noted that the smallest basin coverages used in determining land cover percentages and average basin slopes were single HUC-12 units (i.e. no attempt was made to subdivide HUC-12 basins into smaller units where the drainage area was less than the area of the HUC-12 basin). Therefore, the regression models assume that for very small watersheds the land cover percentages of the HUC-12 basin are representative of the watershed located within the basin.

The Hydrologic Region for each station was determined from Figure 1 of USGS Water-Resources Investigation Report 87-4132, Method for Estimating the Magnitude and Frequency of Floods at Ungaged Sites on Unregulated Rural Streams in Iowa. None of the stations included in the analyses were located in Regions 1 or 5. This is reflected in the regression equations developed that utilize the hydrologic region as a variable.

Table A-1. Ranges of Basin Characteristics Used to Develop the Regression Equations

Basin Characteristic	Name in equations	Minimum	Mean	Maximum
Drainage Area (mi^2)	DA	2.94	80.7	204
Mean Annual Precip (inches)	$\overline{P}_A$	26.0	34.0	36.2
Average Basin Slope (%)	S	1.53	4.89	10.9
Landcover - % Water	W	0.020	0.336	2.80
Landcover - % Forest	F	2.45	10.3	29.9
Landcover - % Grass/Hay	G	9.91	31.3	58.7
Landcover - % Corn	C	6.71	31.9	52.3
Landcover - % Beans	B	6.01	23.1	37.0
Landcover - % Urban/Artificial	U	0	2.29	7.26
Landcover - % Barren/Sparse	B'	0	0.322	2.67
Hydrologic Region	H	Regions 1 - 5 used for delineation but data for USGS stations in Regions 2, 3 & 4 only.		

Methods

Simple regression models were developed for annual average and monthly average statistics with drainage area as the sole explanatory variable. Multiple linear regression models considering all explanatory variables were developed utilizing stepwise regression in Minitab. All data with the exception of the Hydrologic Region were log transformed. Explanatory variables with regression coefficients that were not statistically different from zero (p-value greater than 0.05) were not utilized.

Equation Variables

Table A-2. Regression Equation Variables

Annual Average Flow (cfs)	$\overline{Q}_A$
Monthly Average Flow (cfs)	$\overline{Q}_{MONTH}$
Annual Flow – calendar year (cfs)	Q_{YEAR}
Drainage Area (mi^2)	DA
Mean Annual Precip (inches)	$\overline{P}_A$
Mean Monthly Precip (inches)	$\overline{P}_{MONTH}$
Antecedent Mean Monthly Precip (inches)	$\overline{A}_{MONTH}$
Annual Precip – calendar year (inches)	P_{YEAR}
Antecedent Precip – calendar year (inches)	A_{YEAR}
Average Basin Slope (%)	S
Landcover - % Water	W
Landcover - % Forest	F
Landcover - % Grass/Hay	G
Landcover - % Corn	C
Landcover - % Beans	B
Landcover - % Urban/Artificial	U
Landcover - % Barren/Sparse	B′
Hydrologic Region	H

Equations

Table A-3. Drainage Area Only Equations

Equation	**R^2 adjusted (%)**	**PRESS (log transform)**
$\overline{Q}_A = 0.832DA^{0.955}$	96.1	0.207290
$\overline{Q}_{JAN} = 0.312DA^{0.950}$	85.0	0.968253
$\overline{Q}_{FEB} = 1.32DA^{0.838}$	90.7	0.419138
$\overline{Q}_{MAR} = 0.907DA^{1.03}$	96.6	0.220384
$\overline{Q}_{APR} = 0.983DA^{1.02}$	93.1	0.463554
$\overline{Q}_{MAY} = 1.97DA^{0.906}$	89.0	0.603766
$\overline{Q}_{JUN} = 2.01DA^{0.878}$	88.9	0.572863
$\overline{Q}_{JUL} = 0.822DA^{0.977}$	87.2	0.803808
$\overline{Q}_{AUG} = 0.537DA^{0.914}$	74.0	1.69929
$\overline{Q}_{SEP} = 0.123DA^{1.21}$	78.7	2.64993
$\overline{Q}_{OCT} = 0.284DA^{1.04}$	90.2	0.713257
$\overline{Q}_{NOV} = 0.340DA^{0.999}$	89.8	0.697353
$\overline{Q}_{DEC} = 0.271DA^{1.00}$	86.3	1.02455

Table A-4. Multiple Regression Equations

Equation	**R^2 adjusted (%)**	**PRESS (log transform)**
$\overline{Q}_A = 1.17 \times 10^{-3} DA^{0.998} \overline{P}_A^{1.54} S^{-0.261} (1+F)^{0.249} C^{0.230}$	98.7	0.177268 (n=26)
$\overline{Q}_{JAN} = 0.213 DA^{0.997} \overline{A}_{JAN}^{0.949}$	89.0	0.729610 (n=26;same for all $\overline{Q}_{MONTH}$)
$\overline{Q}_{FEB} = 2.98 DA^{0.955} \overline{A}_{FEB}^{0.648} G^{-0.594} (1+F)^{0.324}$	97.0	0.07089
$\overline{Q}_{MAR} = 6.19 DA^{1.10} B^{-0.386} G^{-0.296}$	97.8	0.07276
$\overline{Q}_{APR} = 1.24 DA^{1.09} \overline{A}_{APR}^{1.64} S^{-0.311} B^{-0.443}$	97.1	0.257064
$\overline{Q}_{MAY} = 10^{(-3.03+0.114H)} DA^{0.846} \overline{P}_A^{2.05}$ Hydrologic Regions 2, 3 & 4 Only	92.1	0.958859
$\overline{Q}_{MAY} = 1.86 \times 10^{-3} DA^{0.903} \overline{P}_A^{1.98}$	90.5	1.07231
$\overline{Q}_{JUN} = 10^{(-1.47+0.0729H)} DA^{0.891} C^{0.404} \overline{P}_{JUN}^{1.84} (1+F)^{0.326} G^{-0.387}$ Hydrologic Regions 2, 3 & 4 Only	97.0	0.193715
$\overline{Q}_{JUN} = 8.13 \times 10^{-3} DA^{0.828} C^{0.478} \overline{P}_{JUN}^{2.70}$	95.9	0.256941
$\overline{Q}_{JUL} = 1.78 \times 10^{-3} DA^{0.923} \overline{A}_{JUL}^{4.19}$	91.7	0.542940
$\overline{Q}_{AUG} = 4.17 \times 10^{7} DA^{0.981} (1+B')^{-1.64} (1+U)^{0.692} \overline{P}_A^{-7.2} \overline{A}_{AUG}^{4.59}$	90.4	1.11413
$\overline{Q}_{SEP} = 1.63 DA^{1.39} B^{-1.08}$	86.9	1.53072
$\overline{Q}_{OCT} = 5.98 DA^{1.14} B^{-0.755} S^{-0.688} (1+B')^{-0.481}$	95.7	0.375296
$\overline{Q}_{NOV} = 5.79 DA^{1.17} B^{-0.701} G^{-0.463} (1+U)^{0.267} (1+B')^{-0.397}$	95.1	0.492686
$\overline{Q}_{DEC} = 0.785 DA^{1.18} B^{-0.654} (1+U)^{0.331} (1+B')^{-0.490}$	92.4	0.590576
$Q_{YEAR} = 3.164 \times 10^{-4} DA^{0.942} P_{YEAR}^{2.39} A_{YEAR}^{1.02} S^{-0.206} \overline{P}_A^{1.27} C^{0.121} (1+U)^{0.0966}$	83.9	32.6357 (n=716)

General Application

In general, the regression equations developed using multiple watershed characteristics will be better predictors than those using drainage area as the sole explanatory variable. The single exception to this appears to be for the May Average Flow worksheet where the PRESS statistic values indicate that use of drainage area alone results in the least error in the prediction of future observations.

Although 2002 land cover grids for the state are now available with 19 different classifications, the older 2000 land cover grids with 9 different classifications were used in developing the regression equations. The 2000 land cover grids should be used in development of flow estimates using the equations.

The equations were developed from stream gauge data for watersheds with relatively minor open water surface percentages relative to other types of land cover (see Table A-1). For application to lake watersheds, particularly those with small watershed/lake area ratios, the basin slope and land cover percentages taken from HUC-12 basins may need to be adjusted so that the hydraulic budget components of surface inflow and direct precipitation on the lake itself can be treated separately. One method of accomplishing this is by subtraction of lake water surface acreage from the total land cover and slope (lakes will have 0% slope) acreages and recalculation of the % coverages. The watershed (drainage) area used in the equations should not include the area of the lake surface.

Application to Ingham Lake - Calculations

Table A-5. Ingham Lake Hydrology Calculations

	Ingham Lake	
Type	Natural	
Inlet(s)	Cunningham Slough, High Lake	
Outlet(s)	East Slough	
Volume	2317	(acre-ft)
Lake Area	373	(acres)
Mean Depth	6.21	(ft)
Drainage Area	322	(acres)
Mean Annual Precip	28.2	(inches)
Average Basin Slope	1.59	(%)
%Water	0.00	
%Forest	36.31	
%Grass/Hay	15.54	
%Corn	17.28	
%Beans	30.73	
%Urban/Artificial	0.13	
%Barren/Sparse	0.00	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	48.00	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow	313.15	(acre-ft)
Direct Lake Precip	877.23	(acre-ft/yr)
High Lake		
Lake Area	664.32	(acres)
Mean Depth		(ft)
Drainage Area	2737.69	(acres)
Mean Annual Precip	28.2	(inches)
Average Basin Slope	1.85	(%)
%Water	0.07	
%Forest	7.27	
%Grass/Hay	8.07	
%Corn	42.52	
%Beans	42.04	
%Urban/Artificial	0.02	
%Barren/Sparse	0.00	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	48.00	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow	2149.13	(acre-ft)
Direct Lake Precip	1561.15	(acre-ft/yr)
Cunningham Slough		
Lake Area	287.54	(acres)
Mean Depth		(ft)
Drainage Area	3293.95	(acres)
Mean Annual Precip	28.2	(inches)
Average Basin Slope	1.27	(%)
%Water	0.00	
%Forest	5.82	
%Grass/Hay	10.82	
%Corn	43.28	
%Beans	39.94	
%Urban/Artificial	0.01	
%Barren/Sparse	0.13	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	48.00	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow	2727.88	(acre-ft)
Direct Lake Precip	675.72	(acre-ft/yr)
Cunningham Slough -->Ingham Lake	4296.372751	(acre-ft/yr)
West Slough		
Lake Area	52.39	(acres)
Mean Depth		(ft)
Drainage Area	74.15	(acres)
Mean Annual Precip	28.2	(inches)
Average Basin Slope	2.36	(%)
%Water	0.00	
%Forest	47.52	
%Grass/Hay	20.99	
%Corn	25.08	
%Beans	6.41	
%Urban/Artificial	0.00	
%Barren/Sparse	0.00	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	48.00	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow	75.88	(acre-ft)
Direct Lake Precip	123.12	(acre-ft/yr)
West Slough-->Ingham Lake	43.92	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.42	(yr)
Est. Annual Average Det. Time (outflow)	0.52	(yr)

9. Appendix B - Sampling Data

Table B-1. Data collected in 1979 by Iowa State University (1)

Parameter	7/11/1979	8/14/1979	9/18/1979
Secchi Depth (m)	2.1	0.8	0.6
Chlorophyll (ug/L)	11.5	74.5	97.7
NO_3+NO_2-N (mg/L)	--	--	0.1
Total Phosphorus (ug/l as P)	46.5	203	125
Alkalinity (mg/L)	124	110	134

Data above is averaged over the upper 6 feet.

Table B-2. Data collected in 1990 by Iowa State University (2)

Parameter	6/14/1990	7/15/1990	8/13/1990
Secchi Depth (m)	0.2	0.3	0.3
Chlorophyll (ug/L)	80.5	83.2	64.9
Total Nitrogen (mg/L as N)	3.6	3.9	3.9
Total Phosphorus (ug/l as P)	216	206.2	164.3
Total Suspended Solids (mg/L)	79.2	135.5	49.4
Inorganic Suspended Solids (mg/L)	43.7	83.7	17.9

Data above is for surface depth.

Table B-3. Data collected in 2000 by Iowa State University (3)

Parameter	6/14/2000	7/13/2000	8/04/2000
Secchi Depth (m)	0.5	0.4	0.2
Chlorophyll (ug/L)	56		64
NH_3+NH_4^+ -N (ug/L)	891	1960	2001
NH_3 –N (un-ionized) (ug/L)	23	195	322
NO_3+NO_2-N (mg/L)	0.35	0.3	0.33
Total Nitrogen (mg/L as N)	2.19	3.64	2.63
Total Phosphorus (ug/l as P)	147	955	375
Silica (mg/L as SiO_2)	16	53	116
pH	7.8	8.2	8.5
Alkalinity (mg/L)	154	167	146
Total Suspended Solids (mg/L)	25.2	295	56.8
Inorganic Suspended Solids (mg/L)	14.5	207	28.8
Volatile Suspended Solids (mg/L)	10.6	88	28.0

Table B-4. Data collected in 2001 by Iowa State University (4)

Parameter	5/16/2001	6/13/2001	7/18/2001
Secchi Depth (m)	0.5	2.0	0.3
Chlorophyll (ug/L)	79	2.0	135
NH_3+NH_4^+ -N (ug/L)	583	715	914
NH_3 –N (un-ionized) (ug/L)	183	15	109
NO_3+NO_2-N (mg/L)	0.3	0.51	0.14
Total Nitrogen (mg/L as N)	2.19	2.12	2.15
Total Phosphorus (ug/l as P)	114	172	294
Silica (mg/L as SiO_2)	12	7	37
pH	9.0	7.7	8.3
Alkalinity (mg/L)	130	160	180
Total Suspended Solids (mg/L)	20.4	5.4	17.5
Inorganic Suspended Solids (mg/L)	5.0	2.7	3.0
Volatile Suspended Solids (mg/L)	15.4	2.7	14.5

Table B-5. Data collected in 2002 by Iowa State University (5)

Parameter	**5/22/2002**	**6/19/2002**	**7/24/2002**
Secchi Depth (m)	0.6	0.3	0.3
Chlorophyll (ug/L)	21	83	154
NH_3+NH_4^+ -N (ug/L)	367	398	640
NH_3 –N (un-ionized) (ug/L)	87	57	204
NO_3+NO_2-N (mg/L)	0.25	0.23	0.23
Total Nitrogen (mg/L as N)	2.17	2.12	2.58
Total Phosphorus (ug/l as P)	102	98	103
Silica (mg/L as SiO_2)	4	8	15
pH	8.8	8.5	8.9
Alkalinity (mg/L)	137	157	108
Total Suspended Solids (mg/L)		38.4	33.1
Inorganic Suspended Solids (mg/L)		14.2	8.1
Volatile Suspended Solids (mg/L)		24.2	25.0

Table B-6. Data collected in 2003 by Iowa State University (20)

Parameter	**5/21/2003**	**6/18/2003**	**7/23/2003**
Secchi Depth (m)	0.4	0.4	0.2
Chlorophyll (ug/L)	24.3	41.2	27.7
NH_3+NH_4^+ -N (ug/L)	567	373	545
NH_3 –N (un-ionized) (ug/L)	66	60	76
NO_3+NO_2-N (mg/L)	0.21	0.09	0.23
Total Nitrogen (mg/L as N)	2.81	3.25	3.40
Total Phosphorus (ug/l as P)	148	140	131
Silica (mg/L as SiO_2)	14.2	8.5	8.8
pH	8.7	8.6	8.5
Alkalinity (mg/L)	112	91	86
Total Suspended Solids (mg/L)	32	45	43
Inorganic Suspended Solids (mg/L)	8	11	15
Volatile Suspended Solids (mg/L)	24	34	28

Table B-7. 2000 Phytoplankton Data (3)

	6/14/2000	**7/13/200**	**8/4/2000**
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Cyanophyta	8.4E+00	4.6E+01	1.9E+02
Cryptophyta	0.0E+00	0.0E+00	0.0E+00
Chlorophyta	4.3E+00	6.1E+00	2.9E+00
Dinophyta	0.0E+00	0.0E+00	0.0E+00
Chrysophyta	2.0E+00	3.3E+01	1.3E+01
Euglenophyta	0.0E+00	0.0E+00	0.0E+00
TOTAL	**1.5E+01**	**8.5E+01**	**2.1E+02**

Table B-8. 2001 Phytoplankton Data (4)

	5/16/2001	6/13/2001	7/18/2001
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Chlorophyta	7.80E-02	5.00E-03	0.00E+00
Chrysophyta	7.60E-02	3.00E-03	1.92E-01
Cryptophyta	7.80E-02	3.88E-01	0.00E+00
Cyanobacteria	2.88E+01	1.65E-01	5.86E+01
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Total	**2.91E+01**	**5.61E-01**	**5.88E+01**

Additional lake sampling results and information can be viewed at:
http://limnology.eeob.iastate.edu/

10. Appendix C - Trophic State Index

Carlson's Trophic State Index

Carlson's Trophic State Index is a numeric indicator of the continuum of the biomass of suspended algae in lakes and thus reflects a lake's nutrient condition and water transparency. The level of plant biomass is estimated by calculating the TSI value for chlorophyll-a. TSI values for total phosphorus and Secchi depth serve as surrogate measures of the TSI value for chlorophyll.

The TSI equations for total phosphorus, chlorophyll and Secchi depth are:

$$TSI (TP) = 14.42 \ln(TP) + 4.15$$

$$TSI (CHL) = 9.81 \ln(CHL) + 30.6$$

$$TSI (SD) = 60 – 14.41 \ln(SD)$$

TP = in-lake total phosphorus concentration, ug/L

CHL = in-lake chlorophyll-a concentration, ug/L

SD = lake Secchi depth, meters

The three index variables are related by linear regression models and *should* produce the same index value for a given combination of variable values. Therefore, any of the three variables can theoretically be used to classify a waterbody.

Table C-1. Changes in temperate lake attributes according to trophic state (modified from 22,23,24).

TSI Value	Attributes	Primary Contact Recreation	Aquatic Life (Fisheries)
50-60	eutrophy: anoxic hypolimnia; macrophyte problems possible	[none]	warm water fisheries only; percid fishery; bass may be dominant
60-70	blue green algae dominate; algal scums and macrophyte problems occur	weeds, algal scums, and low transparency discourage swimming and boating	Centrarchid fishery
70-80	hyper-eutrophy (light limited). Dense algae and macrophytes	weeds, algal scums, and low transparency discourage swimming and boating	Cyprinid fishery (e.g., common carp and other rough fish)
>80	algal scums; few macrophytes	algal scums, and low transparency discourage swimming and boating	rough fish dominate; summer fish kills possible

Table C-2. Summary of ranges of TSI values and measurements for chlorophyll-a and Secchi depth used to define Section 305(b) use support categories for the 2004 reporting cycle.

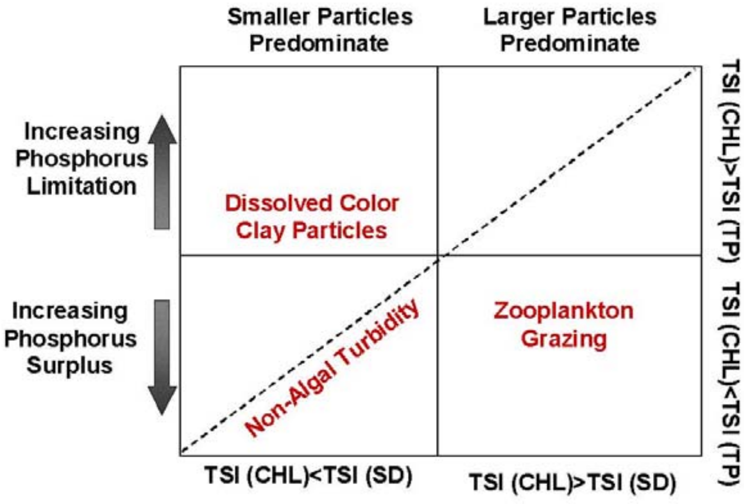
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 → 65	*12 → 33*	*1.4 → 0.7*
partially supported (evaluated: in need of further investigation)	65 → 70	*33 → 55*	*0.7 → 0.5*
partially supported (monitored: candidates for Section 303(d) listing)	65-70	*33 → 55*	*0.7→ 0. 5*
not supported (monitored or evaluated: candidates for Section 303(d) listing)	>70	*>55*	*<0.5*

Table C-3. Descriptions of TSI ranges for Secchi depth, phosphorus, and chlorophyll-a for Iowa lakes.

TSI value	Secchi description	Secchi depth (m)	Phosphorus & Chlorophyll-a description	Phosphorus levels (ug/l)	Chlorophyll-a levels (ug/l)
> 75	extremely poor	< 0.35	extremely high	> 136	> 92
70-75	very poor	0.5 – 0.35	very high	96 - 136	55 – 92
65-70	poor	0.71 – 0.5	high	68 – 96	33 – 55
60-65	moderately poor	1.0 – 0.71	moderately high	48 – 68	20 – 33
55-60	relatively good	1.41 – 1.0	relatively low	34 – 48	12 – 20
50-55	very good	2.0 – 1.41	low	24 – 34	7 – 12
< 50	exceptional	> 2.0	extremely low	< 24	< 7

The relationship between TSI variables can be used to identify potential causal relationships. For example, TSI values for chlorophyll that are consistently well below those for total phosphorus suggest that something other than phosphorus limits algal growth. The TSI values can be plotted to show potential relationships as shown in Figure C-1.

Figure C-1. Multivariate TSI Comparison Chart (Carlson)



Ingham Lake TSI Values

Table C-4. 1979 Ingham Lake TSI Values (1)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/11/1979	49	--	60
8/14/1979	63	73	81
9/18/1979	69	76	74

Table C-5. 1990 Ingham Lake TSI Values (2)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/1990	83	74	82
7/15/1990	77	73	81
8/13/1990	77	72	78

Table C-6. 2000 - 2003 Ingham Lake TSI Values (3,4,5,20)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/2000	70	70	76
7/13/2000	73		103
8/4/2000	83	71	90
5/16/2001	70	73	72
6/13/2001	50	37	78
7/18/2001	77	79	86
5/22/2002	67	60	71
6/19/2002	77	74	70
7/24/2002	77	80	71
5/21/2003	73	62	76
6/18/2003	73	67	75
7/23/2003	83	63	74

11. Appendix D - Land Use Maps

Figure D-1. Ingham Lake and Tributary Watersheds 2002 Landuse