Total Maximum Daily Load
For Noxious Aquatic Plants
Lake Smith
Kossuth County, Iowa

2005

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Lake Smith Summary

Waterbody Name:	Lake Smith
County:	Kossuth
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	East Fork Des Moines River Basin
Pollutant:	Phosphorus
Pollutant Sources:	Nonpoint, internal recycle, atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation) B(LW) (aquatic life)
2002 303d Priority:	Medium
Watershed Area:	1,266 acres
Lake Area:	57 acres
Lake Volume:	315 acre-ft
Detention Time:	0.35 years
TSI Target(s):	Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65
Total Phosphorus Load Capacity (TMDL):	670 pounds per year
Existing Total Phosphorus Load:	1,230 pounds per year
Load Reduction to Achieve TMDL:	560 pounds per year
Margin of Safety	70 pounds per year
Wasteload Allocation	0
Load Allocation	600 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. Lake Smith has been identified as impaired by noxious aquatic plants. The purpose of the TMDL for Lake Smith is to calculate the maximum allowable nutrient loading for the lake associated with noxious aquatic plant levels that will meet water quality standards.

This document consists of a single TMDL for noxious aquatic plants designed to provide Lake Smith 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 noxious aquatic plant impairment.

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. 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 TMDL has 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:** Lake Smith, Sec. 36, T96N, R29W, 3 miles north of Algona, Kossuth County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutant causing the water quality impairment is noxious aquatic plants associated with excessive nutrient loading. Designated uses for Lake Smith 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 2002 - 2003 sampling are 2.3 meters, 21 ug/L and 135 ug/L, respectively. Based on these values, both the Secchi depth and chlorophyll targets have been met. A

minimum in-lake reduction of 29% for total phosphorus is required to achieve and maintain lake water quality goals and protect for beneficial uses. The estimated existing annual total phosphorus load to Lake Smith is 1,230 pounds per year. The total phosphorus loading capacity for the lake is 670 pounds per year based on lake response modeling. An average annual load reduction of 560 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 Lake Smith.

6. **Wasteload allocations for pollutants from point sources:** No point sources have been identified in the Lake Smith 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 600 pounds per year including 20 pounds per year attributable to atmospheric deposition.

8. **A margin of safety:** An explicit numerical MOS of 70 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 Lake Smith watershed landuses are unlikely. The shoreline of the lake and a portion of the watershed are part of Lake Smith Park. Most of the remainder of the watershed landuse is dedicated to row crop production. 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 report.

2. Lake Smith, Description and History

2.1 The Lake

Lake Smith is located in north central Iowa, 3 miles north of Algona. Public use for Lake Smith is estimated at approximately 25,000 visitors per year. Users of the lake and of Lake Smith Park enjoy fishing, swimming, boating, camping, and picnicking. Lake Smith Park is a 124-acre park maintained by the Kossuth County Conservation Board. The campground is located to the southwest of the lake.

Table 2. Lake Smith Features

Waterbody Name:	Lake Smith
Hydrologic Unit Code:	HUC10 0710000306
IDNR Waterbody ID:	IA 04-EDM-00610-L
Location:	Section 36 T96N R29W
Latitude:	43° 7’ N
Longitude:	94° 14’ W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	None
Receiving Waterbody:	Unnamed tributary to Black Cat Creek
Lake Surface Area:	57 acres
Maximum Depth:	10 feet
Mean Depth:	5.6 feet
Volume:	315 acre-feet
Length of Shoreline:	10,300 feet
Watershed Area:	1,266 acres
Watershed/Lake Area Ratio:	22:1
Estimated Detention Time:	0.4 years

Morphometry

Lake Smith has a mean depth of 5.6 feet and a maximum depth of 10 feet. The lake surface area is 57 acres and the storage volume is approximately 315 acre-feet. Temperature and dissolved oxygen sampling indicate that Lake Smith may stratify weakly for part of the growing season. The lake has a shoreline development ratio of 1.8.

Hydrology

Lake Smith has no major surface water tributaries. The lake drains into an unnamed tributary of the Black Cat Creek. The estimated annual average detention time for Lake Smith is 0.4 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

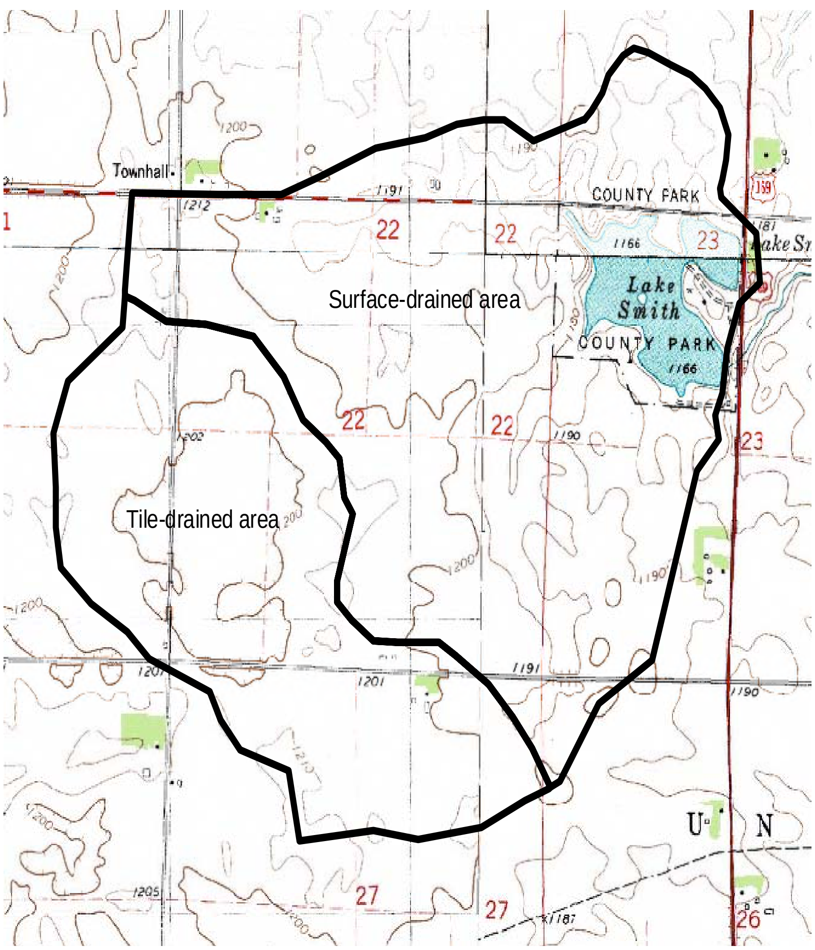
The Lake Smith watershed has an area of approximately 1,266 acres and has a watershed to lake ratio of 22:1. There are about 804 acres of surface drainage and 462 acres of tile-only drainage to the lake. Landuses and associated areas in 2002 for the watershed as listed in Table 3 were obtained through satellite imagery. The 2002 landuse map is shown in Appendix D.

Table 3. 2002 Landuse in Lake Smith watershed

Landuse	Area in Acres	Percent of Total Area
Row Crop	1,113	87.9
Grassland	122	9.6
Water/Wetland	14	1.1
Forest	6	0.5
Other (roads, farmsteads)	11	0.9
Total	1,266	100

The entire shoreline around the lake is maintained by the Kossuth County Conservation Board. There are no known animal feeding operations within the watershed. Topography in the watershed is level to gently sloping (0-5%) with prairie-derived soils developed from Wisconsin till. These soils include Webster, Okoboji, Canisteo, Clarion, Nicollet and Harps. Average rainfall in the area is 29.1 inches/year.

Figure 1. Lake Smith Watershed



3. TMDL for Organic Enrichment and Noxious Aquatic Plants

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (8) list the designated uses for Lake Smith as Primary Contact Recreational Use (Class A) and Aquatic Life (Class B(LW)). In 1998, Lake Smith was included on the impaired water list due to nuisance levels of algae and organic enrichment. At that time, Class A and B uses were assessed as “partially supported.”

In 2002, the Class A and B designated uses were assessed as “fully supporting/threatened” for Lake Smith. This assessment was based upon the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau.

The historical impairment to Class A recreational use is high levels of algal turbidity, aesthetically objectionable blooms of algae and nuisance algal species. The hypereutrophic conditions at Lake Smith, along with information from the IDNR Fisheries Bureau (2002 assessment cycle), suggest that the Class B(LW) aquatic life use is partially supported due to excessive nutrient loading to the water column, nuisance blooms of algae, and organic enrichment in the lake.

Data Sources

Water quality surveys have been conducted on Lake Smith 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 was conducted from 2000 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.

One observed in-lake phosphorus value from the ISU Study data (570 ug/L sampled on 7/25/2002) was excluded from analyses as an outlier based on the unusually low resulting nitrogen to phosphorus ratio it returned (2:1).

Interpreting Lake Smith Water Quality Data

Lake Smith suffered a severe fish kill during the winter of 2000-2001. Populations of sport fish were reduced dramatically. Following this extensive fish kill, Lake Smith was chemically treated in September 2001. This treatment successfully eliminated both common carp and grass carp. The water quality in 2002 substantially improved. The water was clear and submergent vegetation was becoming reestablished. Due to the change in water quality conditions following the lake renovation, the calculations for the existing load included in this TMDL utilize only the 2002 - 2003 data.

Based on mean values from ISU sampling during 2000 - 2001 (pre-renovation), the ratio of total nitrogen to total phosphorus for this lake is 54:1. For the 2002 - 2003 (post-renovation) data the average total nitrogen to total phosphorus ratio is 61:1. Neither value indicates a nitrogen limitation. Data on inorganic suspended solids from the ISU sampling during 2000 - 2001 suggest that this lake may be subject to occasional 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 Lake Smith during the same time period was 12.7 mg/l, the 27th highest of the 130 lakes. However, the median inorganic suspended solids levels during the 2002 - 2003 sampling period declined significantly to 3.00 mg/L.

Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for both pre- and post-renovation in-lake sampling indicate limitation of algal growth attributable to zooplankton grazing and light attenuation by elevated levels of inorganic suspended solids (see Figures 2 & 3 and Appendix C). The post-renovation comparison plot indicates a shift away from limitation non-algal turbidity and towards limitation due to zooplankton grazing. Data from ISU sampling does show that Lake Smith has moderately large populations of zooplankton that graze on algae. However, this trend may also be partly attributable to establishment of a larger macrophyte population following the lake renovation.

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. Lake Smith TSI Values (3,4,5,20)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/15/2000	77	65	84
7/14/2000	73	71	85
8/7/2000	73	62	82
5/17/2001	56	--	75
6/14/2001	57	58	66
7/19/2001	65	69	69
5/23/2002	56	63	70
6/20/2002	67	70	75
7/25/2002	44	44	96*
5/22/2003	42	36	86
6/19/2003	43	36	64
7/24/2003	50	67	68

*excluded from analysis as outlier

Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) can at times dominate the summertime phytoplankton community of Lake Smith. However, the sampling does not indicate a high level of bluegreen wet mass relative to other lakes. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. The 2000 average summer mass of bluegreen algae at this lake (10.3 mg/l) was the 61st highest of the 131 lakes sampled. The 2001 average summer mass of bluegreen algae declined dramatically to 0.05 mg/L. Sampling for cyanobacterial toxins has not been conducted at Lake Smith for the 2000 - 2003 sampling period. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

Figure 2. Lake Smith 2000 - 2001 Mean TSI Multivariate Comparison Plot (22)

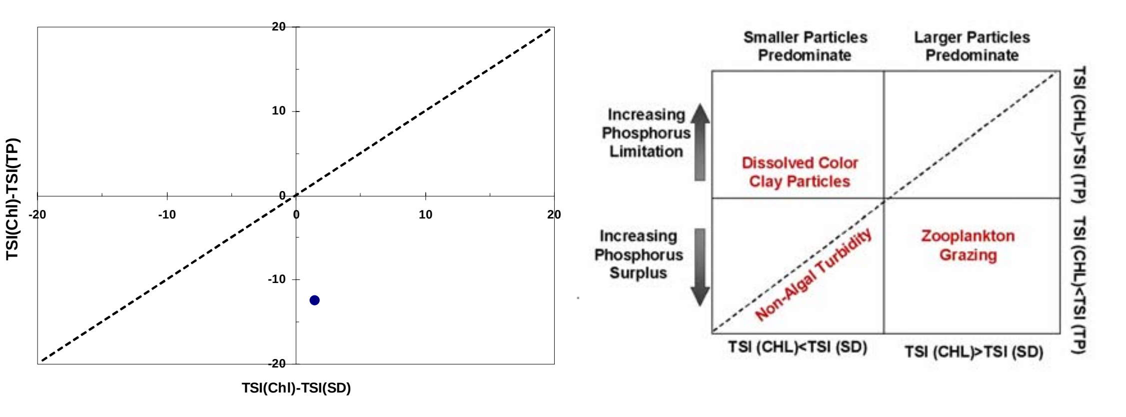
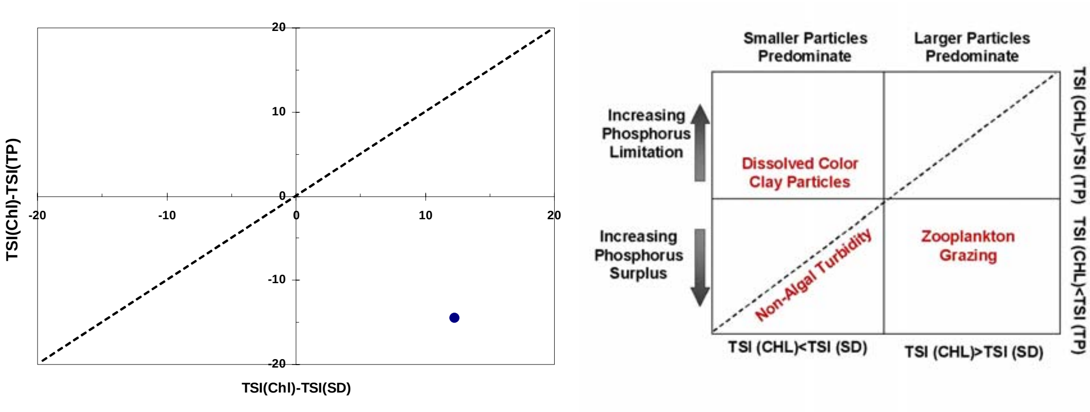


Figure 3. Lake Smith 2002 - 2003 Mean TSI Multivariate Comparison Plot (22)



Both monitoring data and IDNR Fisheries bureau evaluations indicate that water quality conditions have improved and that problems with algal blooms have decreased due to elimination of the rough fish population. Current information suggests that the assessment of both Class A and B designated uses will remain "fully supported/threatened" for the 2004 assessment cycle.

Potential Pollution Sources

Water quality in Lake Smith is influenced only by watershed nonpoint sources and internal recycling of pollutants from bottom sediments. 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 is a mean TSI value 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. Based on ISU sampling data for 2000 - 2003 the Secchi and chlorophyll targets have already been achieved. However, the post-renovation TSI value for total phosphorus is still well within the hypereutrophic range. Although an algal impairment is not indicated by current monitoring data, a reduction in the nutrient load to the lake is desirable prevent deterioration of water quality to pre-renovation (algae dominated) conditions.

Table 5. Lake Smith Existing vs. Target TSI Values

Parameter	2002-2003 Mean TSI	2002-2003 Mean Value	Target TSI	Target Value	Minimum In-Lake Increase or Reduction Required
Chlorophyll a	61	21 ug/L	<65	<33 ug/L	N/A
Secchi Depth	48	2.3 meters	<65	>0.7 meters	N/A
Total Phosphorus	75	135 ug/L	<70	<96 ug/L	29% 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 historic 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.

Table 6. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = = ANN TP = 135 ug/L, SPO TP = 196 ug/L	Comments
Loading Function	1,140	Reckhow (10)
EPA Export	1,150	EPA/5-80-011
WILMS Export	860	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	3,195	GSM model
Canfield-Bachmann 1981 Natural Lake	670	GSM model
Canfield-Bachmann 1981 Artificial Lake	1,230	GSM model
Reckhow 1977 Anoxic Lake	330	GSM model
Reckhow 1979 Natural Lake	1,120	GSM model
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	480	GSM model. P out of range
Nurnberg 1984 Oxic Lake	860 (internal load = 0)	Annual model. P out of range
Walker 1977 General Lake	620	SPO model.
Vollenweider 1982 Combined OECD	780	Annual model.
Vollenweider 1982 Shallow Lake	860	Annual model.

Of the empirical models evaluated, the Canfield-Bachmann Artificial Lake Model resulted in the value closest to the Loading Function and export estimates while remaining within the parameter ranges used to derive it. Therefore, the Canfield-Bachmann Artificial Lake relationship was selected as best-fit empirical model.

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

$$P = \frac{L}{z\left[0.114\left(L/z\right)^{0.589} + p\right]}$$

where

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

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

$$P = 135(\mu g/L) = \frac{2{,}420(mg/m^2)}{1.7(m)\left[0.114\left(2{,}420(mg/m^2)/1.7(m)\right)^{0.589} + 2.35(yr^{-1})\right]}$$

The calculations for the total phosphorus load capacity are:

$$P = 96(\mu g/L) = \frac{1{,}320(mg/m^2)}{1.7(m)\left[0.114\left(1{,}320(mg/m^2)/1.7(m)\right)^{0.589} + 2.35(yr^{-1})\right]}$$

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 Lake Smith 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 670 pounds per year.

3.3 Pollution Source Assessment

There are two quantified phosphorus sources for Lake Smith in this TMDL. The first is the phosphorus load from the watershed areas that drain directly into the lake and the phosphorus recycled from lake sediments. The second source is atmospheric deposition. 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 Lake Smith is estimated to be 1,230 pounds per year based on the selected lake response model. This estimate includes 1,210 pounds per year from a combination of nonpoint sources in the watershed and the internal phosphorus load recycled from the lake bottom sediment as well as an estimated load of 20 pounds per year from atmospheric deposition.

Phosphorus delivered from the tile-drained area of the watershed that does not surfically drain to the lake has been estimated. The concentration of phosphorus in tile water from this area was estimated to be 0.02 ppm (25).

The impact of the Canada geese population was specifically requested at the public meeting reviewing the draft TMDL. Therefore, the TMDL staff obtained estimated geese numbers from the Kossuth County Conservation Board staff (23) and obtained average phosphorus content in Canada goose manure from a literature review (24).

The total manure-phosphorus produced by the Canada geese population is:

(160,000 geese-days)(0.49 grams P/goose-day)(1 pound/454 grams) = 170 pounds P/yr

This calculation assumes 100% deposition of manure in the lake. This is a conservative assumption. It should be noted that DNR wildlife biologists are developing a model to better estimate the true contributions of phosphorus from Canada geese and other wildlife to water resources. This model will be used after it has been fully developed and documented in Phase 2 of this TMDL.

Departure from Load Capacity

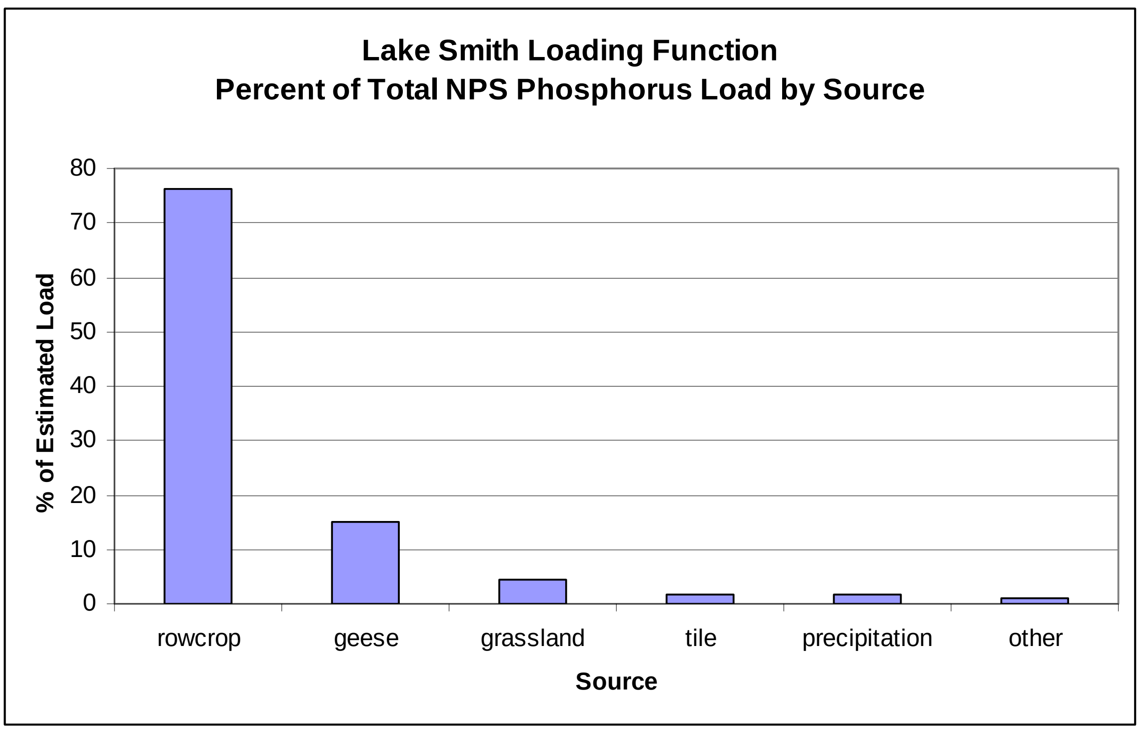
The Phase 1 targeted load capacity for Lake Smith is 670 pounds per year or 0.5 pounds per year per acre of watershed area. The estimated existing load is 1,230 pounds per year or 1.0 pounds per year per acre of watershed area if all loads were attributed to the watershed without any internal recycling of phosphorus.

Identification of Pollutant Sources

There are no point source discharges in the Lake Smith watershed. From the Loading Function Model, the most nonpoint source phosphorus delivered to the lake is from row crop landuse as shown in Figure 4. It should be noted that while the Loading Function Model provides estimates of the primary potential pollutant sources, it was used only for comparison purposes to select an empirical lake response model in the development of existing and target total phosphorus loads identified in this TMDL. Existing and target loads were calculated from measured and target in-lake total phosphorus concentrations using the selected lake response model as shown in *Section 3.2, Modeling Approach*.

Other sources of phosphorus capable of being delivered to the water body exist. These sources include septic systems and toilet pits from campsites and individual residences. Manure and waste from wildlife, pets, etc. also contribute to the phosphorus loading. Unfortunately, the potential phosphorus being contributed from these sources is difficult to quantify. These potential sources have been considered, but are deemed smaller contributors or have less impact than the sources previously identified. However, these sources will be evaluated and quantified as required in Phase II of this TMDL.

Figure 4. Loading Function Model Nonpoint Source Contributions



Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Lake Smith originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source and internal recycling contribution to Lake Smith needs to be reduced by 560 pounds per year.

3.4 Pollutant Allocation

Wasteload Allocation

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

Load Allocation

The Load Allocation (LA) for this TMDL is 600 pounds per year of total phosphorus distributed as follows:

- 580 pounds per year allocated to the Lake Smith watershed and internal recycling of phosphorus from the lake bottom sediments.

- 20 pounds per year allocated to atmospheric deposition.

Margin of Safety

An explicit numerical MOS of 70 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 Lake Smith water quality.

If the entire phosphorus load were attributed to watershed sources, the estimated loading from watershed sources would need to be reduced from 1.0 pounds/year/acre to 0.5 pounds/year/acre to meet the TMDL. However, this does not account for the internal recycled 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. Rough fish have historically been a problem at Lake Smith. The recent elimination of rough fish has improved water quality and it is suspected that a significant portion of the internal loading at this lake was due to the large rough fish population. However, some internal loading may remain due to resuspension of accumulated sediments by wind and wave action on the lake.

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 originates in the watershed and how much is recycled from lake bottom sediment, an adaptive management approach is recommended. In this approach management practices to reduce both 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 1,230 pounds per year to 1,000 pounds per year by 2010.
- Reduce watershed and recycle loading from 1,000 pounds per year to 800 pounds per year by 2015.
- Reduce watershed and recycle loading from 800 pounds per year to 670 pounds per year by 2020.

Best management practices to reduce external nutrient delivery, particularly phosphorus, should be emphasized in the Lake Smith watershed. These practices include the following:

- Nutrient management on production agriculture ground to achieve the optimum soil test category. This soil test category 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 filter strips and grass waterways, etc.
- Install terraces, ponds, or other erosion and water control structures at appropriate locations within the watershed to control erosion and reduce delivery of sediment and phosphorus to the lake.

Internal loading 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 Lake Smith 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. Lake Smith 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. 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

The draft TMDL was presented at a public meeting at Lake Smith Park on December 14, 2004. 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)	$\bar{P}_A$	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 Lake Smith- Calculations

Table A-5. Lake Smith Hydrology Calculations

Lake	Lake Smith	
Type	Impoundment	
Inlet(s)	none	
Outlet(s)	unnamed tributary to Black Cat Creek	
Volume	315	(acre-ft)
Lake Area	57	(acres)
Mean Depth	5.56	(ft)
Drainage Area	1267	(acres)
Mean Annual Precip	29.14	(inches)
Average Basin Slope	1.18	(%)
%Water	0.00	
%Forest	0.36	
%Grass/Hay	12.56	
%Corn	46.70	
%Beans	39.70	
%Urban/Artificial	0.61	
%Barren/Sparse	0.07	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	47.00	(inches)
Mean Annual Lake Evap	34.78	(inches)
Est. Annual Average Inflow	766.26	(acre-ft)
Direct Lake Precip	137.52	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.3485	(yr)
Est. Annual Average Det. Time (outflow)	0.4259	(yr)

9. Appendix B - Sampling Data

Table B-1. Data collected in 1979 by Iowa State University (Bachmann, 1980)

Parameter	7/26/1979	8/23/1979	9/25/1979
Secchi Depth (m)	0.75	0.35	0.5
Chlorophyll (ug/L)	156	85	87
NO_3+NO_2-N (mg/L)	--	--	4.4
Total Phosphorus (ug/l as P)	84	171	84
Alkalinity (mg/L)	165	157	219

Data above is averaged over the upper 3 feet.

Table B-2. Data collected in 1990 by Iowa State University (Bachmann, 1994)

Parameter	6/14/1990	7/12/1990	8/10/1990
Secchi Depth (m)	0.2	0.3	1.1
Chlorophyll (ug/L)	232.2	214.8	27.2
Total Nitrogen (mg/L as N)	5.1	8.5	5.3
Total Phosphorus (ug/l as P)	274.7	240.1	186.8
Total Suspended Solids (mg/L)	49	51.5	19.3
Inorganic Suspended Solids (mg/L)	19.5	21	13.1

Data above is for surface depth.

Table B-3. Data collected in 2000 by Iowa State University (Downing and Ramstack, 2001)

Parameter	6/15/2000	7/14/2000	807/2000
Secchi Depth (m)	0.3	0.4	0.4
Chlorophyll (ug/L)	35.1	64.3	24.6
NH_3+NH_4^+ -N (ug/L)	--	--	--
NH_3 –N (un-ionized) (ug/L)	--	--	--
NO_3+NO_2-N (mg/L)	0.78	0.91	0.18
Total Nitrogen (mg/L as N)	2.71	2.53	2.06
Total Phosphorus (ug/l as P)	257	278	244
Silica (mg/L as SiO_2)	--	--	--
pH	7.8	8.0	8.2
Alkalinity (mg/L)	179	135	121
Total Suspended Solids (mg/L)	39	93	26
Inorganic Suspended Solids (mg/L)	31	72	17
Volatile Suspended Solids (mg/L)	8	21	9

Table B-4. Data collected in 2001 by Iowa State University (Downing and Ramstack, 2002)

Parameter	5/17/2001	6/14/2001	7/19/2001
Secchi Depth (m)	1.3	1.2	0.7
Chlorophyll (ug/L)	--	16.1	50.1
NH_3+NH_4^+ -N (ug/L)	--	--	--
NH_3 –N (un-ionized) (ug/L)	--	--	--
NO_3+NO_2-N (mg/L)	11.12	9.46	3.11
Total Nitrogen (mg/L as N)	11.93	11.27	4.67
Total Phosphorus (ug/l as P)	224	73	80
Silica (mg/L as SiO_2)	--	--	--
pH	8.4	8.1	8.4
Alkalinity (mg/L)	143	176	118
Total Suspended Solids (mg/L)	7	11	16
Inorganic Suspended Solids (mg/L)	5	7	8
Volatile Suspended Solids (mg/L)	2	4	8

Table B-5. Data collected in 2002 by Iowa State University (Downing et al., 2003)

Parameter	**5/23/2002**	**6/20/2002**	**7/25/2002**
Secchi Depth (m)	1.3	0.6	3.1
Chlorophyll (ug/L)	27.2	52.7	4.0
NH_3+NH_4^+ -N (ug/L)	333	379	335
NH_3 –N (un-ionized) (ug/L)	35	23	34
NO_3+NO_2-N (mg/L)	0.21	0.23	0.28
Total Nitrogen (mg/L as N)	1.65	1.85	1.21
Total Phosphorus (ug/l as P)	95	135	570
Silica (mg/L as SiO_2)	--	--	13.91
pH	8.6	8.1	8.3
Alkalinity (mg/L)	161	151	141
Total Suspended Solids (mg/L)	6	11	8
Inorganic Suspended Solids (mg/L)	<1	7	4
Volatile Suspended Solids (mg/L)	5	4	4

Table B-6. Data collected in 2003 by Iowa State University (Downing et al., 2004)

Parameter	**5/22/2003**	**6/19/2003**	**7/24/2003**
Secchi Depth (m)	3.4	3.2	2.0
Chlorophyll (ug/L)	1.8	1.8	38.9
NH_3+NH_4^+ -N (ug/L)	504	223	276
NH_3 –N (un-ionized) (ug/L)	127	152	158
NO_3+NO_2-N (mg/L)	6.20	6.97	7.35
Total Nitrogen (mg/L as N)	7.89	8.85	9.55
Total Phosphorus (ug/l as P)	297	64	86
Silica (mg/L as SiO_2)	4.37	0.97	2.54
pH	9.1	9.6	9.4
Alkalinity (mg/L)	178	80	73
Total Suspended Solids (mg/L)	6	2	9
Inorganic Suspended Solids (mg/L)	3	<1	3
Volatile Suspended Solids (mg/L)	2	<1	6

Table B-7. 2000 Phytoplankton Data (Downing and Ramstack, 2001)

	6/15/2000	**7/14/2000**	**8/7/2000**
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Cyanophyta	1.6E+00	9.4E+00	2.0E+01
Cryptophyta	5.4E-02	0.0E+00	9.4E-01
Chlorophyta	1.4E+01	2.4E+00	8.1E-01
Dinophyta	0.0E+00	0.0E+00	8.1E-01
Chrysophyta	2.1E+00	7.8E-01	2.7E-01
Euglenophyta	0.0E+00	0.0E+00	0.0E+00
TOTAL	**1.7E+01**	**1.3E+01**	**2.3E+01**

Table B-8. 2001 Phytoplankton Data (Downing and Ramstack, 2002)

	5/17/2001	**6/14/2001**	**7/19/2001**
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Chlorophyta	7.1E+00	2.8E-01	1.3E-01
Chrysophyta	0.6E-02	1.5E+00	1.9E+00
Cryptophyta	0.0E+00	0.0E+00	0.0E+00
Cyanobacteria	1.9E-02	7.5E-02	6.5E-02
Dinophyta	0.0E+00	0.0E+00	1.9E+00
Euglenophyta	0.0E+00	0.0E+00	0.0E+00
Total	**7.1E+00**	**1.9E+00**	**4.0E+00**

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 U.S. EPA 2000, Carlson and Simpson 1995, and Oglesby et al. 1987).

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.

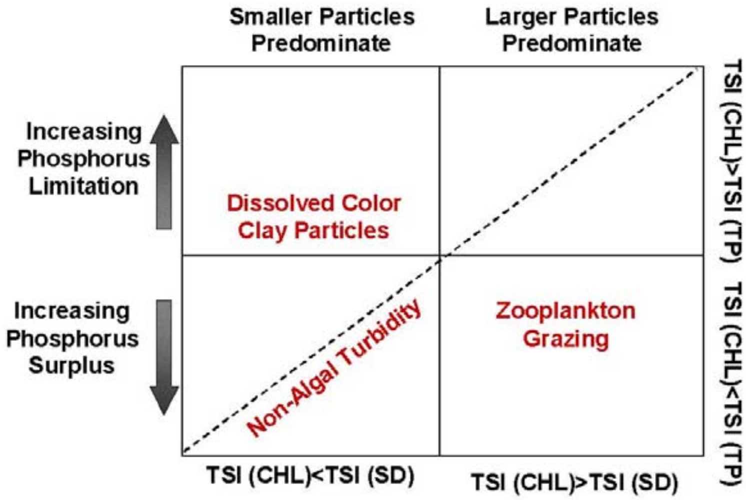
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 → 65	*12 → 33*	*1.4 → 0.7*
partially supported (evaluated: in need of further investigation)	65 → 70	*33 → 55*	*0.7 → 0.5*
partially supported (monitored: candidates for 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)



Lake Smith TSI Values

Table C-4. 1979 Lake Smith TSI Values (Bachmann)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/26/1979	64	80	68
8/23/1979	75	74	78
9/25/1979	70	74	68

Table C-5. 1990 Lake Smith TSI Values (Bachmann)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/1990	83	84	85
7/12/1990	77	83	83
8/10/1990	59	63	80

Table C-6. 2000 - 2003 Lake Smith TSI Values (Downing and Ramstack)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/15/2000	77	65	84
7/14/2000	73	71	85
8/7/2000	73	62	82
5/17/2001	56	--	75
6/14/2001	57	58	66
7/19/2001	65	69	69
5/23/2002	56	63	70
6/20/2002	67	70	75
7/25/2002	44	44	96
5/22/2003	42	36	86
6/19/2003	43	36	64
7/24/2003	50	67	68

11. Appendix D - Land Use Maps

Figure D-1. Lake Smith Watershed 2002 Landuse

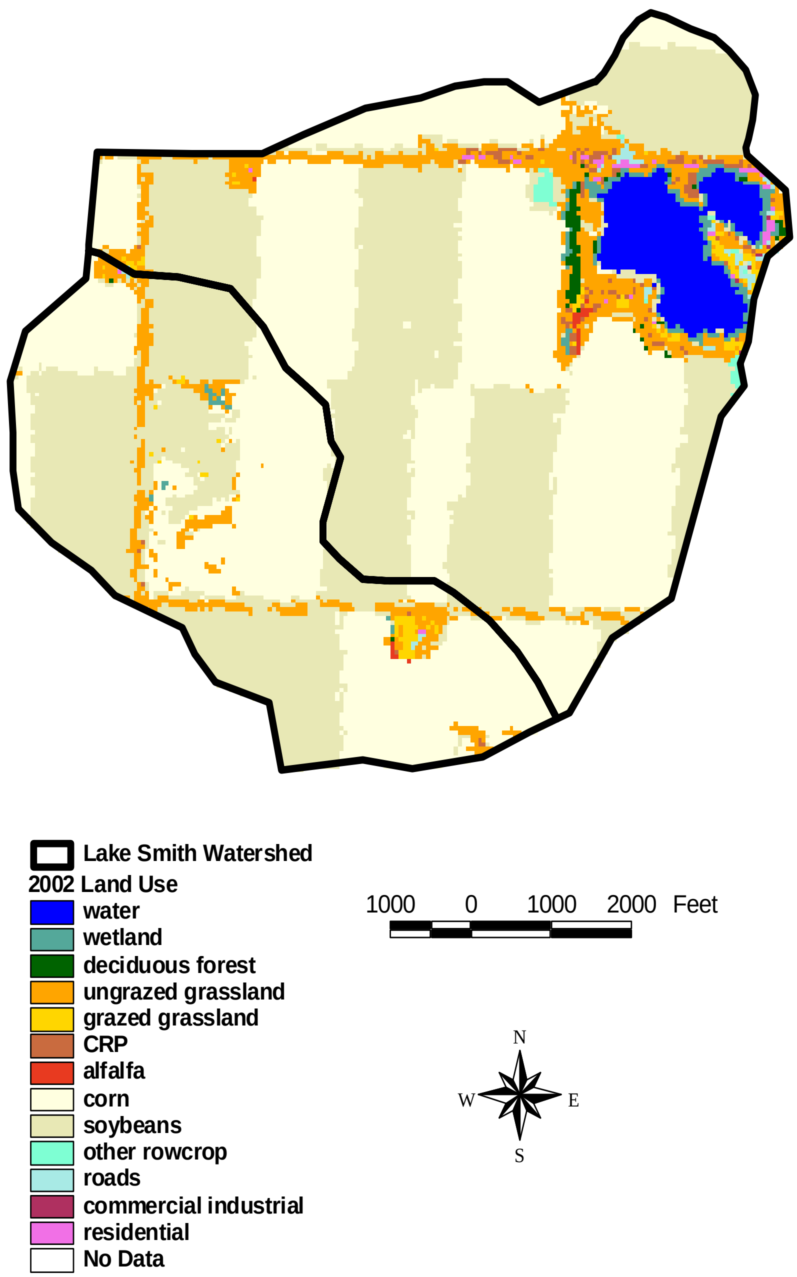


Figure D-2. 2002 aerial infrared photograph of the Lake Smith watershed.