Total Maximum Daily Load
For Algae and Turbidity
North Twin Lake
Calhoun County, Iowa

2004

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. North Twin Lake Summary

Waterbody Name:	North Twin Lake
County:	Calhoun
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Raccoon River Basin
Pollutant:	Phosphorus
Pollutant Sources:	Nonpoint, internal recycle, atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Medium
Watershed Area:	2,420 acres
Lake Area:	460 acres
Lake Volume:	4,975 acre-ft
Detention Time:	2.8 years
TSI Target(s):	Total Phosphorus less than 65; Chlorophyll a less than 65; Secchi Depth less than 65
Total Phosphorus Load Capacity (TMDL):	1,690 pounds per year
Existing Total Phosphorus Load:	3,540 pounds per year
Load Reduction to Achieve TMDL:	1,850 pounds per year
Margin of Safety:	170 pounds per year
Wasteload Allocation:	0
Load Allocation:	1,520 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. North Twin Lake has been identified as impaired by algae and turbidity. The purpose of the TMDL for North Twin 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 North Twin 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. 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:** North Twin Lake, S33, T89N, R32W, 4 miles north of Rockwell City, Calhoun 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 loading. Designated uses for North Twin 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 65 for total phosphorus, chlorophyll a, and Secchi depth. TSI values of 65 are equivalent to total phosphorus and chlorophyll concentrations of 68 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 1.3 meters, 61 ug/L and 108 ug/L, respectively. Based on these values, the Secchi depth target has been met. Minimum in-lake reductions of 46% for chlorophyll a and 37% 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 North Twin Lake is 3,540 pounds per year. The total phosphorus loading capacity for the lake is 1,690 pounds per year based on lake response modeling. An average annual load reduction of 1,850 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 North Twin Lake.

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the North Twin 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 1,520 pounds per year including 160 pounds per year attributable to atmospheric deposition.

8. **A margin of safety:** An explicit numerical MOS of 170 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 North Twin Lake watershed landuse are unlikely. Any new residential development around the lakeshore will be sewered. The addition or deletion of animal feeding operations within the watershed 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. North Twin Lake, Description and History

2.1 The Lake

North Twin Lake is a natural, glacial lake located in north central Iowa, 4 miles north of Rockwell City. Public use for North Twin Lake is estimated at approximately 59,000 visitors per year. Users of the lake and surrounding parks enjoy fishing, swimming, boating, picnicking, hunting, cross-country skiing, and ice skating. Beaches at North Twin Lake are located on the eastern and western shores. In the late 1990's, a gate was installed at the lake spillway. It is believed that this gate has significantly reduced the carp population in the lake by limiting spawning migration to/from South Twin Lake.

Table 2. North Twin Lake Features

Waterbody Name:	North Twin Lake
Hydrologic Unit Code:	HUC10 0710000606
IDNR Waterbody ID:	IA 04-RAC-01390-L
Location:	Section 33 T89N R32W
Latitude:	42° 29' N
Longitude:	94° 38' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	None
Receiving Waterbody:	South Twin Lake
Lake Surface Area:	460 acres
Maximum Depth:	13 feet
Mean Depth:	10.8 feet
Volume:	4,975 acre-feet
Length of Shoreline:	29,000 feet
Watershed Area:	2,420 acres
Watershed/Lake Area Ratio:	5.3:1
Estimated Detention Time:	2.8 years

Morphometry

North Twin Lake has a mean depth of 10.8 feet and a maximum depth of 13 feet. The lake surface area is 460 acres and the storage volume is approximately 4,975 acre-feet. Temperature and dissolved oxygen sampling indicate that North Twin Lake remains oxic and relatively well mixed throughout the growing season. The lake is elongated with a shoreline development ratio of 1.9.

Hydrology

North Twin Lake has no distinct primary surface water inlet. North Twin Lake drains into and is connected to South Twin Lake by an unnamed stream. The estimated annual average detention time for North Twin Lake is 2.8 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The North Twin Lake watershed has an area of approximately 2,420 acres and has a watershed to lake ratio of 5.3:1. 2002 landuses and associated areas for the watershed are shown in Table 3. The 2002 landuse coverages were obtained through satellite imagery.

Table 3. 2002 Landuse in North Twin Lake watershed

Landuse	Area in Acres	Percent of Total Area
Row Crop	1,970	81.4
Grassland	320	13.2
Residential/Commercial	30	1.2
Roads	20	0.8
Other	80	3.3
Total	2,420	100

A more recent field level watershed assessment was completed in June 2004 by the IDNR. The 2004 assessment shows that the major landuse in the watershed is row crop, with 2,130 acres (88%) in either corn or soybeans. Other landuses identified in the 2004 assessment included residential (3%), park (3%), roads (2%), and a church camp (1%).

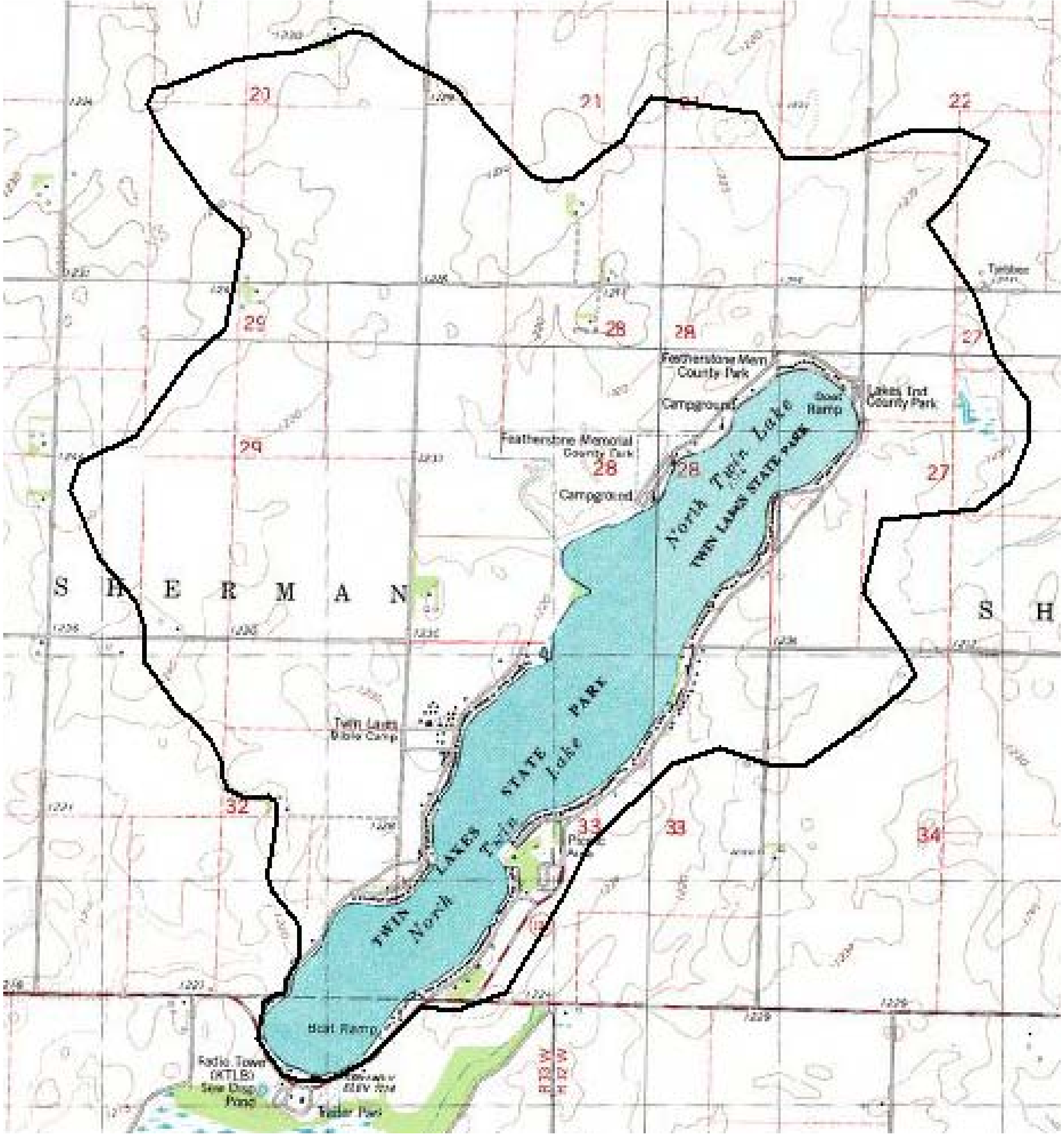
One open feedlot was identified in the 2004 assessment. This feedlot was empty at the time of the assessment. Based on recommended space requirements for feedlot beef, the feedlot has a potential capacity of 35 beef animal units. Open feedlots are unroofed or partially roofed animal feeding operations 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.

Approximately 58% of the lake shoreline perimeter landuse is residential. A public sanitary sewer and wastewater treatment system was constructed for the lakeshore residential areas in 1988, eliminating the contributions of residential septic systems.

The watershed is almost entirely gently sloping (0-9%) prairie-derived soils. Clarion, Webster, Canisteo, and Nicollet soils developed from Wisconsin till cover the land. Average rainfall in the area is 31.0 inches/year.

2002 and 2004 landuse maps are shown in Appendix D.

Figure 1. North Twin Lake Watershed



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 North Twin Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). In 1999, North Twin Lake was included on the impaired water list based on water quality data from the Iowa Lakes Survey and on the recommendation of the DNR Fisheries Bureau. The impairments were due to algal blooms and turbidity. At that time, Class A and B uses were assessed as “partially supported.”

In 2002, the Class B aquatic life designated use was assessed as “not supporting” for North Twin Lake. 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 impairment to Class A1 recreational use is the presence of aesthetically objectionable blooms of algae and of nuisance algal species. The hypereutrophic conditions at North Twin Lake, along with information from the IDNR Fisheries Bureau (2002 assessment cycle), suggest that the Class B(LW) aquatic life are partially supported due to excessive nutrient loading to the water column and nuisance blooms of algae.

Data Sources

Water quality surveys have been conducted on North Twin 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 began in 2000 and 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 North Twin Lake Water Quality Data

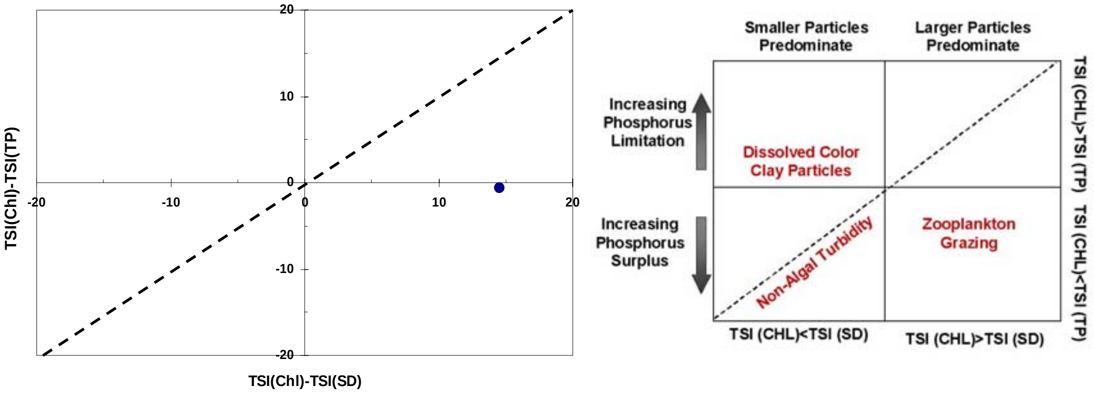
Based on mean values from ISU sampling during 2000 - 2003, the ratio of total nitrogen to total phosphorus for this lake is 21:1. Data on inorganic suspended solids from the ISU sampling during 2000 - 2001 suggest that this lake may be subject to occasional episodes of high levels of non-algal turbidity. 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 North Twin Lake during the same time period was 20.0 mg/l, the eleventh highest of the 130 lakes. However, the median inorganic suspended solids levels during the 2002 - 2003 sampling period declined to 5.35 mg/L.

The 2002 305(b) assessment for North Twin Lake noted that the high levels of inorganic suspended solids observed during the 2000 - 2001 sampling period suggested that non-algal turbidity may limit the production of algae as well as impair beneficial uses. However, based on current comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for all available in-lake sampling, domination of light attenuation by non-algal particles is not indicated (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. North Twin Lake TSI Values (3,4,5,20)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/15/2000	77	77	80
7/14/2000	70	77	76
8/7/2000	73	74	79
5/17/2001	73	81	79
6/14/2001	70	77	72
7/19/2001	56	61	70
5/24/2002	43	41	52
6/20/2002	60	64	64
7/25/2002	67	69	70
5/22/2003	47	54	55
6/19/2003	44	48	63
7/24/2003	53	59	72

Figure 2. North Twin 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 North Twin 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 (202 mg/l) was the 4th highest of 131 lakes sampled. The 2001 average summer wet mass of bluegreen algae declined to 57 mg/L but still comprised over 90% of the total phytoplankton community. Sampling for cyanobacterial toxins has not been conducted at North Twin Lake. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

IDNR Fisheries bureau believes that conditions have improved and that problems with algal blooms have decreased due to both the elimination of septic tank discharges and a recent decline in the rough fish population. Current information suggests that the assessment of Class B(LW) aquatic life uses will be changed from “partially supported” to “fully supported/threatened” for the 2004 assessment cycle. The 2002 - 2003 sampling period TSI values for chlorophyll, Secchi depth and total phosphorus do indicate significant improvement in water quality when compared to the 2000 - 2001 values.

Potential Pollution Sources

Water quality in North Twin Lake is influenced only by watershed nonpoint sources and internal recycling of pollutants from bottom sediments under normal conditions. There are no point source discharges in the watershed. However, a sewer force main break in July 2003 did result in the discharge of raw municipal wastewater to the lake for approximately two days. The quantity of sewage that entered the lake during this time period is unknown.

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 65 for total phosphorus, chlorophyll, and Secchi depth. TSI values of 65 are equivalent to total phosphorus and chlorophyll concentrations of 68 and 33 ug/L respectively, and a Secchi depth of 0.7 meters. Based on ISU sampling data for 2000 - 2003 the Secchi depth target has already been achieved. The mean TSI values during this time period for total phosphorus, chlorophyll a, and Secchi depth are 72, 71 and 56, respectively.

Table 5. North Twin 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 a	71	61 ug/L	<65	<33 ug/L	46% Reduction
Secchi Depth	56	1.3 meters	<65	>0.7 meters	NA
Total Phosphorus	72	108 ug/L	<65	<68 ug/L	37% 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 65, 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 = 108 ug/L, SPO TP = 82 ug/L	Comments
Loading Function	2,700	Reckhow (10)
EPA Export	3,250	EPA/5-80-011
WILMS Export	2,150	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	96,100	GSM model
Canfield-Bachmann 1981 Natural Lake	3,540	GSM model
Canfield-Bachmann 1981 Artificial Lake	7,230	GSM model
Reckhow 1977 Anoxic Lake	840	GSM model
Reckhow 1979 Natural Lake	5,750	GSM model
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	2,530	GSM model. P out of range
Nurnberg 1984 Oxic Lake	2,400 (internal load = 0)	Annual model. P out of range
Walker 1977 General Lake	930	SPO model.
Vollenweider 1982 Combined OECD	2,280	Annual model.
Vollenweider 1982 Shallow Lake	2,580	Annual model.

Of the empirical models evaluated, the Vollenweider and Canfield-Bachmann Natural Lake Models resulted in values closest to the Loading Function and export estimates while remaining within the parameter ranges used to derive them. Although the Vollenweider models both gave results closely matching the watershed delivery estimates, these 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 North Twin Lake corresponds with the growing season. Therefore, the Canfield-Bachmann Natural Lake relationship was selected as best-fit empirical 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 North Twin Lake are as follows:

$$P = 108(\mu g / L) = \frac{863(mg/m^2)}{3.3(m)\left[0.162\left(\frac{863(mg/m^2)}{3.3(m)}\right)^{0.458} + 0.36(yr^{-1})\right]}$$

The calculations for the total phosphorus load capacity are:

$$P = 68(\mu g / L) = \frac{412(mg/m^2)}{3.3(m)\left[0.162\left(\frac{412(mg/m^2)}{3.3(m)}\right)^{0.458} + 0.36(yr^{-1})\right]}$$

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 North Twin Lake can receive and meet its designated uses. Based on the selected lake response model and a target TSI (TP) value of less than 65, the Phase 1 total phosphorus loading capacity for the lake is 1,690 pounds per year.

3.3 Pollution Source Assessment

There are two quantified phosphorus sources for North Twin Lake 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 North Twin Lake is estimated to be 3,540 pounds per year based on the selected lake response model. This estimate includes 3,380 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 160 pounds per year from atmospheric deposition.

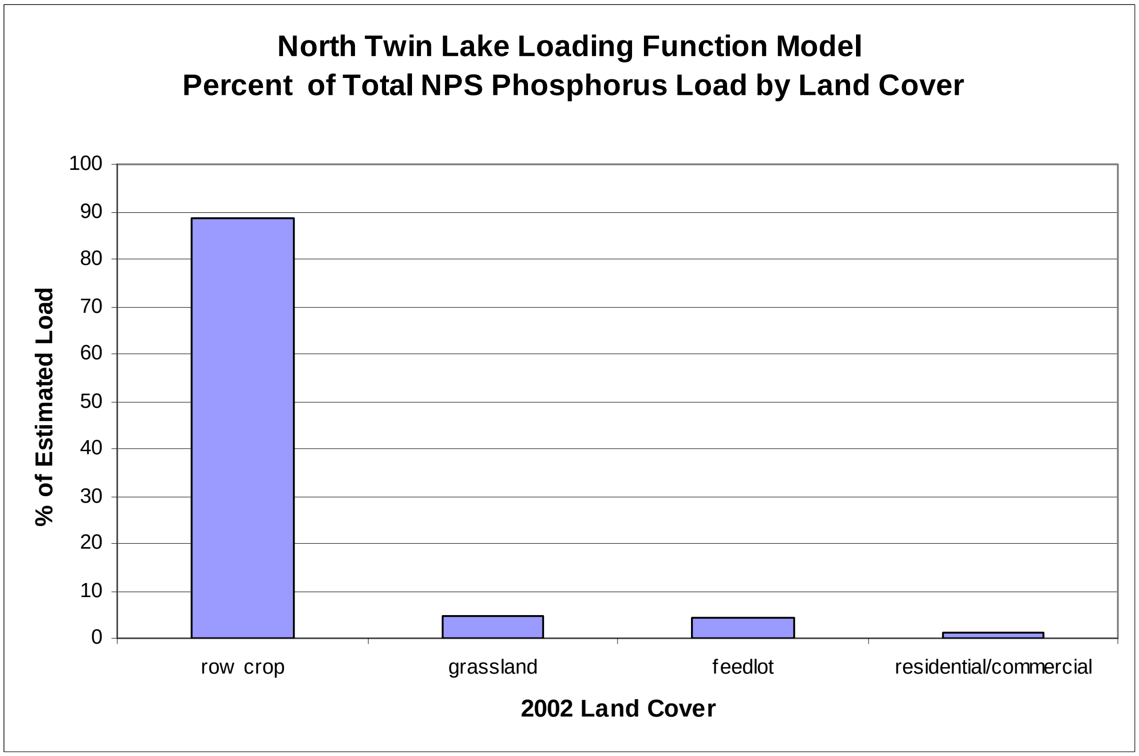
Departure from Load Capacity

The Phase 1 targeted load capacity for North Twin Lake is 1,690 pounds per year or 0.7 pounds per year per acre of watershed area. The estimated existing load is 3,540 pounds per year or 1.5 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 significant point source discharges in the North Twin Lake watershed. From the Loading Function Model, the most nonpoint source phosphorus delivered to the lake is from row crop landuse as shown in Figure 3. Loading from the single open feedlot was estimated based on an export coefficient of 200 lbs/acre/year (21). Actual loading from the feedlot may vary substantially from this estimate depending on the number of animals, extent of use, runoff controls and other factors. 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*. Also, the Loading Function Model estimates only external watershed phosphorus inputs and does not account for internal loading.

Figure 3. Loading Function Model Nonpoint Source Contributions



Other sources of phosphorus capable of being delivered to the water body exist. Potential sources include failing or improperly designed septic systems from residences within the watershed and accidental wastewater releases from the public sewer system such as that mentioned previously. Manure and waste from wildlife, pets, fish cleaning stations, 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.

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to North Twin Lake originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source and internal recycling contribution to North Twin Lake needs to be reduced by 1,850 pounds per year.

3.4 Pollutant Allocation

Wasteload Allocation

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

Load Allocation

The Load Allocation (LA) for this TMDL is 1,520 pounds per year of total phosphorus distributed as follows:

- 1,360 pounds per year allocated to the North Twin Lake watershed and internal recycle.
- 160 pounds per year allocated to atmospheric deposition.

Margin of Safety

An explicit numerical MOS of 170 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 North Twin Lake water quality.

If the entire phosphorus load were attributed to watershed sources, the estimated loading from watershed sources would need to be reduced from 1.5 pounds/year/acre to 0.7 pounds/year/acre to meet the TMDL. However, this does not account for the internally 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. 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 3,500 pounds per year to 2,800 pounds per year by 2010.
- Reduce watershed and recycle loading from 2,800 pounds per year to 2,100 pounds per year by 2015.
- Reduce watershed and recycle loading from 2,100 pounds per year to 1,500 pounds per year by 2020.

Data from the Loading Function Model indicates that the majority of the watershed phosphorous load to North Twin Lake originates on row crop ground. With 88% of the watershed in row crop production, significant improvements need to be made to reduce the external loading to the lake. Although the topography of the North Twin Lake watershed is gently sloping, high rainfall events frequently wash cornstalks and other residue into the lake, highlighting the need for improved management.

To remedy these problems, a number of best management practices could be applied. These include the following:

- Manage agricultural soils for 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 while controlling soil erosion. Incorporation physically separates the phosphorus from surface runoff.
- Continue encouraging the adoption of reduced tillage systems, specifically no till and strip tillage.
- Remove surface tile inlets to force surface water to infiltrate and percolate through the soil.
- Identify key locations in the watershed and construct or restore wetlands to settle out adsorbed and dissolved phosphorus in surface runoff and tile water.
- 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.

In addition to the recommended best management practices on row crop ground, there are practices that need to be implemented in the residential areas adjacent to the lake as well. These include use of low or no-phosphorous fertilizers on lawns and use of appropriate erosion controls on construction sites. These are important sources to address due to the close proximity to the lake.

A major rainfall event in 2001 caused a backup of water at the North Twin Lake spillway. To aid in the drainage of North Twin Lake, the gates were removed from the spillway, allowing the majority of the carp population to flow downstream to South Twin Lake. This loss of rough fish has caused a significant improvement in water quality since 2002. However, as the carp population increases, this improved water quality can be expected to degrade. The use of commercial contracts to remove rough fish may be necessary as part of the management of North Twin Lake.

Although groundwater is not specifically known to be contributing to the phosphorous loading to the lake, North Twin Lake does interact with groundwater and anecdotal evidence from local residents indicates that there are areas within the lake that springs can be identified. Groundwater and tile outlet monitoring should be conducted near North Twin Lake to identify if these are significant sources of phosphorous.

5. Monitoring

Further monitoring is needed at North Twin 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. North Twin 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 North Twin. 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

Presentations were given to members of the North Twin Lake Restoration Association and Homeowners Association on July 19, 2004. The draft TMDL was presented at a public meeting at North Twin Lake on October 28, 2004. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

7. References

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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 North Twin Lake - Calculations

Table A-5. North Twin Lake Hydrology Calculations

Lake	North Twin Lake	
Type	Natural w/out inlet	
Inlet(s)	None	
Outlet(s)	Unnamed (inlet to S. Twin)	
Volume	4975	(acre-ft)
Lake Area	460	(acres)
Mean Depth	10.81	(ft)
Drainage Area	2419	(acres)
Mean Annual Precip	31	(inches)
Average Basin Slope	0.84	(%)
%Water	0.00	
%Forest	2.05	
%Grass/Hay	12.12	
%Corn	35.34	
%Beans	49.64	
%Urban/Artificial	0.27	
%Barren/Sparse	0.59	
Hydrologic Region	4	
Mean Annual Class A Pan Evap	50	(inches)
Mean Annual Lake Evap	37	(inches)
Est. Annual Average Inflow	2019.00	(acre-ft)
Direct Lake Precip	1188.80	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	1.5507	(yr)
Est. Annual Average Det. Time (outflow)	2.7815	(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**	**9/26/1979**
Secchi Depth (m)	0.6	0.4	0.5
Chlorophyll (ug/L)	46	34	48
NO_3+NO_2-N (mg/L)			0.34
Total Phosphorus (ug/l as P)	79	103	56
Alkalinity (mg/L)	180	188	119

Data above is averaged over the upper 6 feet.

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

Parameter	**6/13/1990**	**7/13/1990**	**8/12/1990**
Secchi Depth (m)	0.7	0.4	0.5
Chlorophyll (ug/L)	23	123.3	89.6
Total Nitrogen (mg/L as N)	3.8	3.1	1.9
Total Phosphorus (ug/l as P)	90.2	107.6	96.7
Total Suspended Solids (mg/L)	31.5	64	38.4
Inorganic Suspended Solids (mg/L)	17.6	36.7	11.9

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**	**8/07/2000**
Secchi Depth (m)	0.3	0.5	0.4
Chlorophyll (ug/L)	114	111	81
NH_3+NH_4^+ -N (ug/L)	1903	1661	1677
NH_3 –N (un-ionized) (ug/L)	97	134	193
NO_3+NO_2-N (mg/L)	0.15	0.16	0.16
Total Nitrogen (mg/L as N)	2.21	1.96	2.51
Total Phosphorus (ug/l as P)	187	150	174
Silica (mg/L as SiO_2)	92	78	120
pH	8.1	8.1	8.3
Alkalinity (mg/L)	169	185	146
Total Suspended Solids (mg/L)	37.3	44.1	53.1
Inorganic Suspended Solids (mg/L)	32.0	42.8	26.9
Volatile Suspended Solids (mg/L)	5.3	1.4	26.2

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)	0.4	0.5	1.3
Chlorophyll (ug/L)	173	113	22
NH_3+NH_4^+ -N (ug/L)	901	1634	2362
NH_3 –N (un-ionized) (ug/L)	296	123	130
NO_3+NO_2-N (mg/L)	1.10	0.20	0.17
1Total Nitrogen (mg/L as N)	3.49	3.20	3.45
Total Phosphorus (ug/l as P)	185	108	98
Silica (mg/L as SiO_2)	42	28	23
pH	9.0	8.2	8.0
Alkalinity (mg/L)	105	131	166
Total Suspended Solids (mg/L)	26.9	21.1	9.3
Inorganic Suspended Solids (mg/L)	13.1	3.2	5.1
Volatile Suspended Solids (mg/L)	13.7	17.9	4.1

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

Parameter	**5/24/2002**	**6/20/2002**	**7/25/2002**
Secchi Depth (m)	3.2	1.0	0.6
Chlorophyll (ug/L)	3	29	52
NH_3+NH_4^+ -N (ug/L)	238	261	213
NH_3 –N (un-ionized) (ug/L)		18	37
NO_3+NO_2-N (mg/L)	0.69	0.32	0.20
Total Nitrogen (mg/L as N)	1.46	1.39	1.56
Total Phosphorus (ug/l as P)	27	62	94
Silica (mg/L as SiO_2)	1	10	19
pH	8.4	8.2	8.5
Alkalinity (mg/L)	159	181	182
Total Suspended Solids (mg/L)	4.0	14.3	27.0
Inorganic Suspended Solids (mg/L)	0.7	4.7	9.5
Volatile Suspended Solids (mg/L)	3.3	9.7	17.5

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)	2.5	3.1	1.6
Chlorophyll (ug/L)	10.5	5.9	18.1
NH_3+NH_4^+ -N (ug/L)	116	513	776
NH_3 –N (un-ionized) (ug/L)	20	37	120
NO_3+NO_2-N (mg/L)	1.34	0.36	0.24
Total Nitrogen (mg/L as N)	1.45	1.74	2.07
Total Phosphorus (ug/l as P)	35	58	113
Silica (mg/L as SiO_2)	1.55	7.12	16.62
pH	8.8	8.1	8.5
Alkalinity (mg/L)	122	119	125
Total Suspended Solids (mg/L)	8	10	18
Inorganic Suspended Solids (mg/L)	3	6	6
Volatile Suspended Solids (mg/L)	5	3	12

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

	6/23/2000	**7/20/2000**	**8/10/2000**
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Cyanophyta	7.6E+01	2.5E+02	2.8E+02
Cryptophyta	0.0E+00	0.0E+00	0.0E+00
Chlorophyta	1.7E+00	0.0E+00	3.3E+00
Dinophyta	0.0E+00	0.0E+00	0.0E+00
Chrysophyta	4.6E+00	9.0E+00	0.0E+00
Euglenophyta	0.0E+00	0.0E+00	0.0E+00
TOTAL	**8.3E+01**	**2.6E+02**	**2.8E+02**

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	0.00E+00	1.31E+00	1.08E+01
Chrysophyta	8.60E-01	1.88E-01	1.41E-01
Cryptophyta	0.00E+00	9.68E-01	2.88E-01
Cyanobacteria	9.85E+01	6.83E+01	2.89E+00
Dinophyta	0.00E+00	0.00E+00	1.60E+00
Euglenophyta	0.00E+00	0.00E+00	0.00E+00
Total	9.94E+01	7.08E+01	1.57E+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:

$$\text{TSI (TP)} = 14.42 \ln(\text{TP}) + 4.15$$

$$\text{TSI (CHL)} = 9.81 \ln(\text{CHL}) + 30.6$$

$$\text{TSI (SD)} = 60 - 14.41 \ln(\text{SD})$$

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.

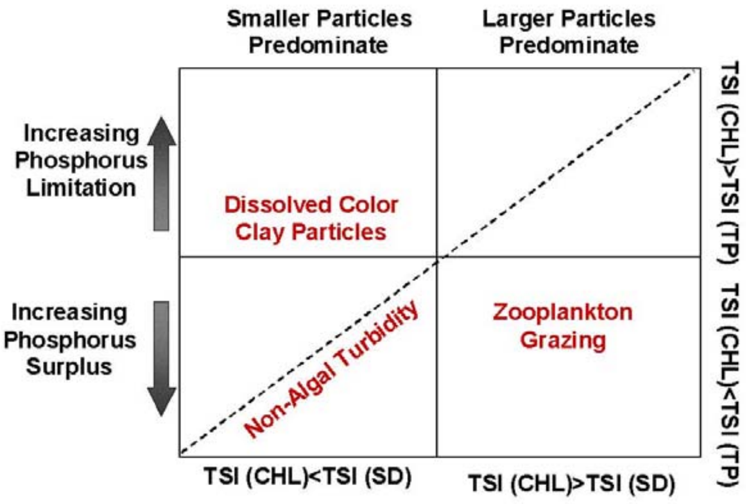
Level of Support	**TSI value**	**Chlorophyll-a (ug/l)**	**Secchi Depth (m)**
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 → 65	*12 → 33*	*1.4 → 0.7*
partially supported (evaluated: in need of further investigation)	65 → 70	*33 → 55*	*0.7 → 0.5*
partially supported (monitored: candidates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



North Twin Lake TSI Values

Table C-4. 1979 North Twin TSI Values (Bachmann)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/26/1979	67.4	68.2	67.2
8/23/1979	73.2	65.2	71.0
9/26/1979	70.0	68.6	62.2

Table C-5. 1990 North Twin TSI Values (Bachmann)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/13/1990	65.1	61.4	69.1
7/13/1990	73.2	77.8	71.6
8/12/1990	70.0	74.7	70.1

Table C-6. 2000 - 2003 North Twin TSI Values (Downing and Ramstack)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/15/2000	77.3	77.1	79.6
7/14/2000	70.0	76.8	76.4
8/7/2000	73.2	73.7	78.5
5/17/2001	73.2	81.2	79.4
6/14/2001	70.0	77.0	71.7
7/19/2001	56.2	60.9	70.3
5/24/2002	43.2	41.4	51.7
6/20/2002	60.0	63.6	63.7
7/25/2002	67.4	69.4	69.7
5/22/2003	46.8	53.7	55.4
6/19/2003	43.7	48.0	62.7
7/24/2003	53.2	59.0	72.3

11. Appendix D - Land Use Maps

Figure D-1. North Twin Lake Watershed 2002 Landuse

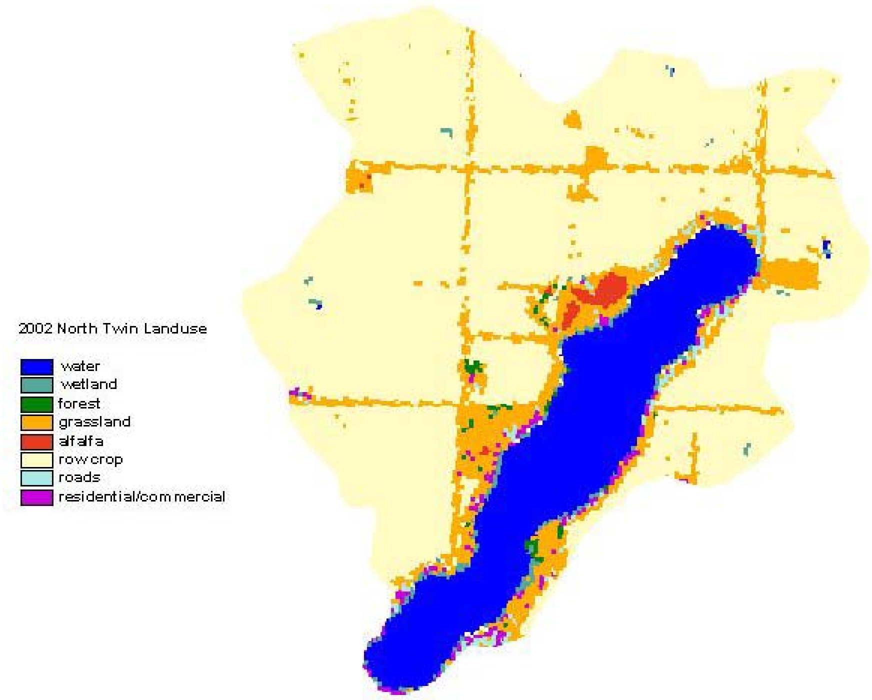


Figure D-2. North Twin Lake Watershed 2004 Site Assessment