Total Maximum Daily Load
For Turbidity and Algae
Little Spirit Lake
Dickinson County, Iowa

2004

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Little Spirit Lake Summary

Waterbody Name:	Little Spirit Lake
County:	Dickinson
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Little Sioux River Basin
Pollutant:	Phosphorus
Pollutant Sources:	Nonpoint external, atmospheric (background), and nonpoint internal (sediment re-suspension and nutrient recycling)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Medium
Watershed Area:	1,430 acres
Lake Area:	620 acres
Lake Volume:	3,716 acre-ft
Detention Time:	4.0 years
TSI Target(s):	Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65
Target Total Phosphorus Load:	See Table 2
Existing Total Phosphorus Load:	1,870 pounds per year
Load Reduction to Achieve Target:	See Table 2
Wasteload Allocation	0
Load Allocation	See Table 2

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. Little Spirit Lake has been identified as impaired by algae and turbidity. The purpose of these TMDLs for Little Spirit 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 Little Spirit Lake water quality that fully supports its designated uses. Phosphorus, which is related through the Trophic State Index (TSI) to chlorophyll and Secchi depth, is targeted to address the algae and turbidity impairments.

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

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

Monitoring is essential to all TMDLs in order to:

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

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

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

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Little Spirit Lake, S8, T100N, R36W, 5 miles northeast of Montgomery, Dickinson County.

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

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

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for Secchi depth, chlorophyll a and total phosphorus based on 2000 - 2003 CLAMP sampling are 0.4 meters, 120 ug/L and 330 ug/L, respectively. Based on these values, a minimum in-lake increase in Secchi transparency of 75% and minimum in-lake reductions of 73% for chlorophyll a and 71% 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 Little Spirit Lake is 1,870 pounds per year. The total phosphorus loading capacity for the lake based on lake response modeling is a function of the relative contribution of internal and external loads as shown in Table 2 and as described by the mathematical relationships given in Appendix E.

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 Little Spirit Lake.

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Little Spirit 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 is shown in Table 2. This includes 200 pounds per year attributable to atmospheric deposition.

Table 2. Little Spirit Lake Total Phosphorus Loads

Total Phosphorus Load Allocation/Target Loads (lbs/year)			**Required Load Reduction (lbs/year)**
Internal	**External**	**Total**	
0	1,170	1,170	700
10	1,110	1,120	750
20	1,060	1,080	790
30	1,010	1,040	830
40	950	990	880
50	900	950	920
60	850	910	960
70	790	860	1,010
80	740	820	1,050
90	690	780	1,090
100	630	730	1,140
110	580	690	1,180
120	530	650	1,220
130	470	600	1,270
140	420	560	1,310
150	370	520	1,350
160	310	470	1,400
170	260	430	1,440
180	210	390	1,480

8. **A margin of safety:** The target total phosphorus loads are calculated using an in-lake concentration 10% below the desired endpoint to ensure that the required load reduction 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 Little Spirit watershed landuse are unlikely except for minor residential development. This potential landuse change could increase or decrease nutrient loading depending on the density of development and type of wastewater treatment. The addition of animal feeding operations within the watershed could increase 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 report.

2. Little Spirit Lake, Description and History

2.1 The Lake

Little Spirit Lake is a natural glacial lake formed during the Wisconsin glaciation of the Des Moines Lobe. The lake is located in northwest Iowa, 5 miles northeast of Montgomery. Public use for Little Spirit Lake is estimated at approximately 23,000 visitors per year. Users of the lake enjoy fishing, swimming, picnicking, hiking, and boating.

Table 3. Little Spirit Lake Features

Waterbody Name:	Little Spirit Lake
Hydrologic Unit Code:	HUC10 1023000301
IDNR Waterbody ID:	IA 06-LSR-02870-L
Location:	Section 8 T100N R36W
Latitude:	43° 30' N
Longitude:	95° 8' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	None
Receiving Waterbody:	Spirit Lake
Lake Surface Area:	620 acres
Maximum Depth:	10 feet
Mean Depth:	6.0 feet
Volume:	3,716 acre-feet
Length of Shoreline:	53,000 feet
Watershed Area:	1,430 acres
Watershed/Lake Area Ratio:	2.3:1
Estimated Detention Time:	4.0 years

Morphometry

Little Spirit Lake has a mean depth of 6.0 feet and a maximum depth of 10 feet. The lake has a surface area of 620 acres and a storage volume of approximately 3,716 acre-feet. Temperature and dissolved oxygen sampling indicate that Little Spirit Lake remains oxic and relatively well mixed throughout the growing season.

Hydrology

Little Spirit Lake is fed by overland flow, direct precipitation, and groundwater. Little Spirit Lake feeds into Spirit Lake. The estimated annual average detention time is 4.0 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Little Spirit Lake watershed has an area of approximately 1,430 acres and has a watershed to lake ratio of 2.3:1. Approximately 1,100 acres of the watershed are in Jackson County, Minnesota. The 2002 landuses and associated areas for the watershed were determined from satellite imagery and are shown in Table 4.

Table 4. 2002 Landuse in Little Spirit Lake watershed

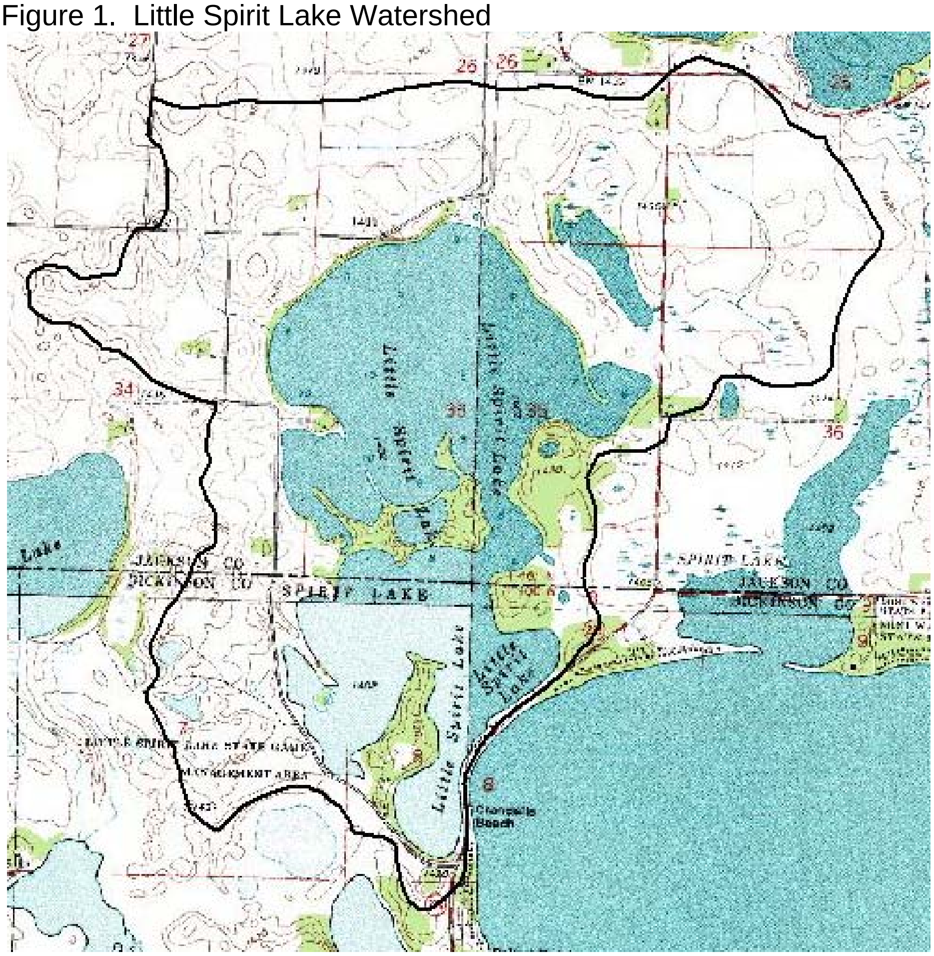
Landuse	Area in Acres	Percent of Total Area
Row Crop	900	62.9
Grassland	300	21.0
Forest	150	10.5
Water/Wetland	40	2.8
Other	40	2.8
Total	1430	100

A field level survey of the watershed by IDNR has not been completed. There are no known animal feeding operations in the watershed. Limited residential development is present on the east (Iowa and Minnesota) shoreline. A campground is located on the north (Minnesota) shoreline.

The watershed is nearly level to gently sloping (0-9%) soils developed from Wisconsin till. The prairie-derived soils are primarily of Clarion, Nicollet, Webster, Stordon, and Canisteo soil types. Average rainfall in the area is 28.3 inches/year.

The 2002 land use map is shown in Appendix D.

Figure 1. Little Spirit 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 Little Spirit Lake as Primary Contact (Class A1) and Aquatic Life (Class B(LW)). In 1999, Little Spirit Lake was included on the impaired water list due to the presence of noxious aquatic plants. The noxious aquatic plant impairment was removed in 2002 based on new data, but the lake remains on the 303(d) list due to algae and turbidity impairments. The Iowa Water Quality Standards (8) do not include numeric criteria for algae or turbidity but they do include narrative standards that are applicable to Little Spirit Lake stating that "such waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor, or other aesthetically objectionable conditions" (8). Therefore, the impaired water quality assessment was made based on measured chlorophyll and transparency values indicating algae and turbidity conditions that are producing objectionable color, odor, or other aesthetically objectionable conditions

In 2002, the Class A and B designated uses were assessed as "partially supporting" for Little Spirit Lake. This assessment was based on the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau. Data from these sources suggest impairments to the Class A (primary contact) uses through presence of aesthetically objectionable blooms of algae and presence of nuisance algal species (e.g., bluegreen algae).

Data Sources

Water quality surveys have been conducted on Little Spirit Lake in 1979, 1990, and 2000-03 (1,2,3,4,5,20,21). Data from these surveys is available in Appendix B.

Two recent sources of lake data were evaluated for this TMDL. These sources are independent, with collection and analyses being done by different institutions; the Iowa State University Limnology Laboratory, and the Iowa Lakeside Laboratory.

The Iowa State University Lake Study began in 2000 and is scheduled to run through 2004. This study by the ISU Limnology Laboratory 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.

The second data source is the Bovbjerg Water Chemistry Laboratory of the Iowa Lakeside Lab. Little Spirit Lake data has been collected and analyzed since 2000 as part of the Cooperative Lakes Area Monitoring Project (CLAMP), which is coordinated by the Iowa Lakeside Lab and the Friends of Lakeside Lab, Inc. The CLAMP program is supported by local lake organizations, the Dickinson County Water Quality Commissions, and ISU.

The CLAMP sampling data focuses on phosphorus, nitrogen, chlorophyll a, and water clarity. For each year during 2000 to 2003, eight samples have been taken at each of two locations in Little Spirit Lake. The CLAMP data represents a much larger sample set than the ISU data (n=62 vs. n=11 for total phosphorus). The CLAMP yearly sampling period also extends over a greater portion of the growing season and gives higher mean and median TSI values for total phosphorus, chlorophyll and Secchi depth. Therefore, this data was used for lake response modeling.

Interpreting Little Spirit Lake Water Quality Data

Based values from both ISU and CLAMP sampling during 2000 - 2003, the ratio of total nitrogen to total phosphorus for this lake is approximately 12. Data on inorganic suspended solids from the ISU survey indicate that this lake is 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 Little Spirit Lake during the same time period was 17.6 mg/l, the seventeenth highest of the 130 lakes, thus suggesting that non-algal turbidity may limit the production of algae as well as impair beneficial uses.

Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for in-lake sampling indicate that a non-phosphorus limitation to algal growth is present (see Figures 2 & 3 and Appendix C). This non-phosphorus limitation is attributable to one or more of three factors. The high levels of inorganic suspended solids may limit algal growth by limiting light penetration to the water column. The relatively low nitrogen to phosphorus ratio may also impose a nitrogen limitation on algal growth during some periods. Finally, ISU data show relatively large populations of zooplankton species at this lake that graze on algae. The average summer mass of these zooplankton grazers (109.3 mg/l) in 2000 was the 11th highest of the 131 lakes sampled, suggesting the potential for these zooplankton grazers to limit algal production.

TSI values for 2000 - 2003 monitoring data are shown in Tables 5 and 6. TSI values for all historical monitoring data and an explanation of Carlson's Trophic State Index are given in Appendix C.

Table 5. ISU TSI Values (1,2,3,4,5,20)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/2000	77	57	84
7/12/2000	77	74	85
8/4/2000	83	66	85
5/16/2001	54	60	74
6/13/2001	67	70	82
7/18/2001	70	75	85
5/22/2002	65	59	78
6/19/2002	67	63	--
7/24/2002	70	76	87
5/21/2003	55	59	82
6/18/2003	55	67	85
7/23/2003	70	61	89

Table 6. CLAMP TSI Values (21)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/24/2000	85	72	73
7/8/2000	73	75	73
7/22/2000	81	83	81
8/5/2000	79	79	82
8/19/2000	77	78	85
9/2/2000	80	73	87
9/16/2000	80	74	85
9/30/2000	75	73	81
6/9/2001	66	73	70
6/27/2001	72	76	81
7/16/2001	81	79	86
7/30/2001	81	83	90
8/11/2001	76	81	92
9/1/2001	--	--	91
9/10/2001	62	57	--
9/26/2001	59	56	91
6/5/2002	57	42	85
6/22/2002	68	72	87
7/3/2002	75	91	90
7/12/2002	68	--	91
7/26/2002	77	--	97
8/7/2002	80	--	90
8/23/2002	69	61	88
9/3/2002	75	75	89
6/11/2003	54	53	85
6/26/2003	73	86	92
7/9/2003	76	90	96
7/21/2003	71	77	91
8/4/2003	79	77	90
8/18/2003	87	79	91
9/8/2003	87	59	87
9/23/2003	90	62	88

Figure 2. 2000 - 2003 ISU Sampling Mean TSI Multivariate Comparison Plot (22)

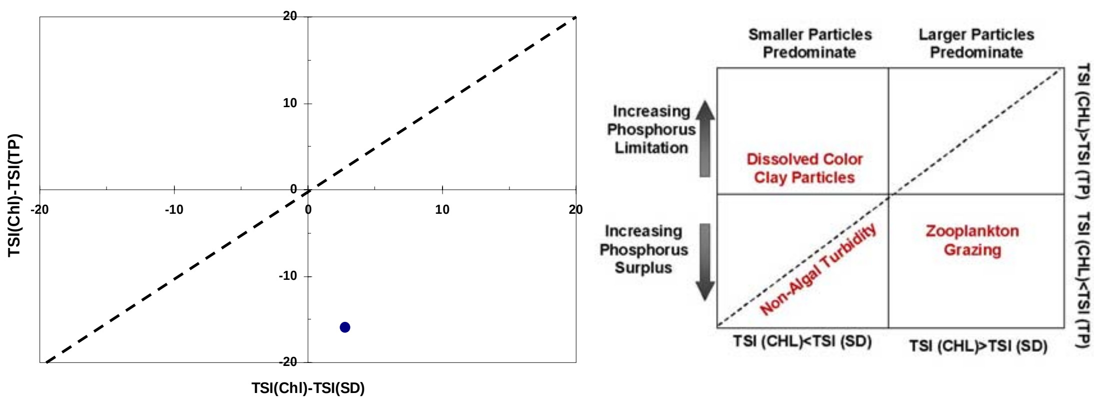
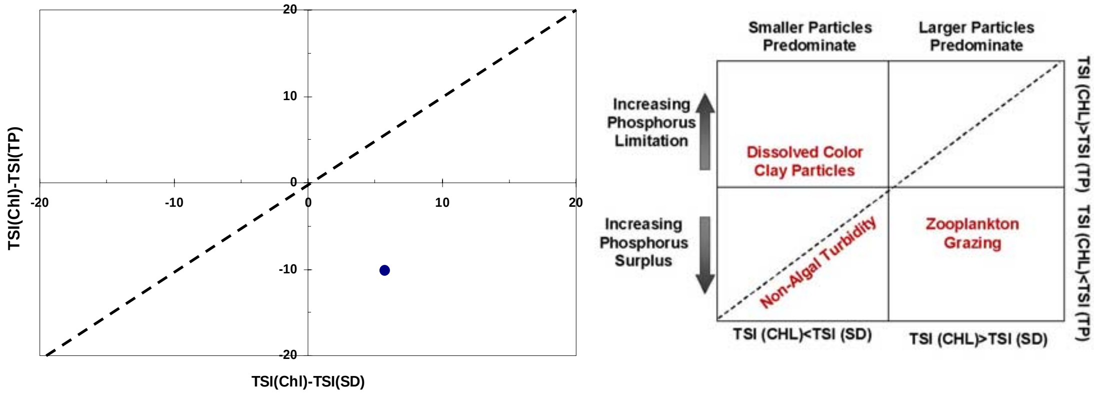


Figure 3. 2000 - 2003 CLAMP Sampling Mean TSI Multivariate Comparison Plot (22)



Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) comprise a significant portion of the summertime phytoplankton community of Little Spirit Lake. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. Sampling in 2000 did not indicate a high level of bluegreen mass relative to other Iowa lakes. Although bluegreens made up a significant portion of total wet mass (36%), the 2000 average summer wet mass (6.9 mg/l) was only the 55th highest of 131 lakes sampled. However, the 2001 summer average wet mass increased dramatically to 80 mg/L with bluegreens comprising approximately 77% of the phytoplankton community. Sampling for cyanobacterial toxins has not been conducted at Little Spirit Lake. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

Potential Pollution Sources

Water quality in Little Spirit Lake is influenced only by watershed nonpoint sources and internal recycling of pollutants from bottom sediments. There are no point source discharges in the watershed.

Other sources of phosphorus capable of being delivered to the water body exist. These sources include septic systems and toilet pits from campsites, individual residences, and seasonal-use businesses and housing units. 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.

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 target of this TMDL is a 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.

Table 7. Little Spirit Lake Existing vs. Target TSI Values

Parameter	ISU 2000-2003 TSI	ISU 2000-2003 Value	CLAMP 2000-2003 TSI	CLAMP 2000-2003 Value	Target TSI	Target Value
Chlorophyll	68	44 ug/L	78	120 ug/L	<65	<33 ug/L
Secchi Depth	65	0.7 meters	72	0.4 meters	<65	>0.7 meters
Total Phosphorus	84	249 ug/L	88	330 ug/L	<70	<96 ug/L

Table 8. In-Lake Increase or Reduction Required

Parameter	Minimum Increase or Reduction Required based on ISU Sampling	Minimum Increase or Reduction Required based on CLAMP Sampling
Chlorophyll	25% Decrease	73% Reduction
Secchi Depth	NA	75% Increase in transparency
Total Phosphorus	61% Decrease	71% Reduction

A second target is the attainment of aquatic life uses as measured by fishery and biological assessments. The aquatic life target for this TMDL will be achieved when the fishery of Little Spirit Lake is determined to be fully supporting the aquatic life uses. This determination will be accomplished through an assessment conducted by the IDNR Fisheries Bureau.

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for algae or turbidity. The algae and turbidity impairments are due to algal blooms caused by excessive nutrient loading to the lake and resuspension of inorganic suspended solids. 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 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. However, the existing and target total phosphorus loadings to the lake are expressed as annual averages. Growing season mean (GSM) in-lake total phosphorus concentrations are used 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 9. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = ANN TP = 330 ug/L, SPO TP = 192 ug/L	Comments
Loading Function	1,280	Reckhow (10)
EPA Export	1,770	EPA/5-80-011
WILMS Export	1,120	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	67,781,470	GSM model
Canfield-Bachmann 1981 Natural Lake	17,100	GSM model
Canfield-Bachmann 1981 Artificial Lake	70,830	GSM model
Reckhow 1977 Anoxic Lake	1,510	GSM Model
Reckhow 1979 Natural Lake	22,020	GSM Model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	5,950	GSM model. P out of range
Nurnberg 1984 Oxic Lake	1,300 (internal load = 590)	Annual model. P out of range
Walker 1977 General Lake	1,240	SPO model.
Vollenweider 1982 Combined OECD	5,240	Annual model.
Vollenweider 1982 Shallow Lake	5,400	Annual model.

The Reckhow Anoxic, Nurnberg and Walker models resulted in values closest to the Loading Function and export estimates. Of these, the Reckhow Anoxic and Walker models are within the parameter ranges used to derive them when applied to Little Spirit Lake. Little Spirit Lake is an oxic lake, making application of the Reckhow Anoxic Model questionable. The Walker Model is a Spring Overturn (SPO) model. The available in-lake phosphorus monitoring for Little Spirit Lake corresponds with the growing season, requiring late spring or early summer sampling values to be used as a surrogate for the early spring phosphorus values used to derive the Walker Model.

The high phosphorus and inorganic suspended solids levels at Little Spirit Lake indicate the likelihood of a significant internal loading. The existing load predicted by the Nurnberg Model also indicates a significant internal load. Therefore, use of the Loading Function estimate with the Nurnberg Oxic Lake Model was selected as the basis for determining the existing load. The Nurnberg Model was also used to determine load targets as a function of the relative contribution from internal and external sources.

The equation for the Nurnberg Oxic Lake Model is:

$$P = \frac{L_{Ext}}{q_s}(1-R) + \frac{L_{Int}}{q_s}$$

where

$$R = \frac{15}{18 + q_s}$$

$P =$ predicted in-lake total phosphorus concentration (ug/L)
$L_{Ext} =$ external areal total phosphorus load (mg/m^2)
$L_{Int} =$ internal areal total phosphorus load (mg/m^2)
$q_s =$ areal water loading (m/yr)

The Nurnberg Model represents a possible continuum of internal and external loads for a given in-lake total phosphorus concentration. The Loading Function Model external load estimate was used in combination with the Nurnberg Model to determine the existing loads as follows:

$$P = 330(\mu g/L) = \frac{233(mg/m^2)}{0.46(m/yr)}(1 - \frac{15}{18 + 0.46(m/yr)}) + \frac{108(mg/m^2)}{0.46(m/yr)}$$

An example of a target load calculation for target internal and external loads of 50 and 900 lbs, respectively, is:

$$P = 87(\mu g/L) = \frac{164(mg/m^2)}{0.46(m/yr)}(1 - \frac{15}{18 + 0.46(m/yr)}) + \frac{9.1(mg/m^2)}{0.46(m/yr)}$$

The above calculation includes a margin of safety by using an in-lake concentration 10% below the desired endpoint (P < 96 ug/L) to calculate the target loads. The annual total phosphorus loads are obtained by multiplying the areal loads (L_{Ext}, L_{Int}) by the lake area in square meters and converting the resulting values from milligrams to pounds.

For the in-lake total phosphorus target and any selected target internal load, the corresponding target external load, target total load or target load reduction can be calculated from the relationships shown in Figures E-1 through E-3 in Appendix E.

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 Little Spirit Lake can receive and meet its designated uses. The Phase 1 target TSI (TP) value is less than 70, corresponding to an in-lake total phosphorus concentration of less than 96 ug/L. For the selected lake response model, the target total load is a function of the relative internal and external load contributions as shown in Table 10.

Table 10. Little Spirit Lake Total Phosphorus Target

Total Phosphorus Target Loads (lbs/year)		
Internal	**External**	**Total**
0	1,170	1,170
10	1,110	1,120
20	1,060	1,080
30	1,010	1,040
40	950	990
50	900	950
60	850	910
70	790	860
80	740	820
90	690	780
100	630	730
110	580	690
120	530	650
130	470	600
140	420	560
150	370	520
160	310	470
170	260	430
180	210	390

3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Little Spirit Lake in this TMDL. The first is the phosphorus load from the watershed areas that drain directly into the lake. The second source is internal phosphorus loading from re-suspended sediments. The third 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 Little Spirit Lake is estimated to be 1,870 pounds per year based on the Loading Function and Nurnberg Oxic Lake models. This estimate includes 1,080 pounds per year from external nonpoint sources in the watershed, 590 pounds per year attributable to internal loading, and 200 pounds per year from atmospheric deposition.

Departure from Load Capacity

Table 11 shows the load reductions necessary to achieve and maintain Phase 1 water quality goals.

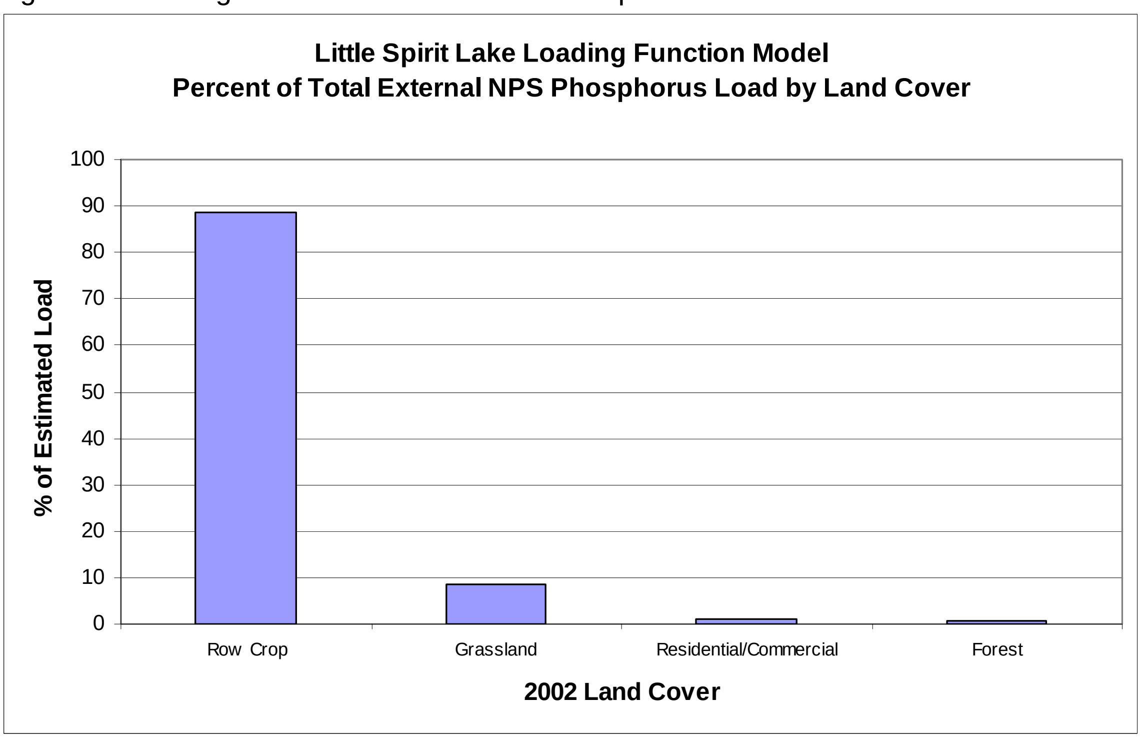
Table 11. Little Spirit Lake Load Reductions to Meet Phase 1 Goals

Total Phosphorus Loads (lbs/year)		**Required Load Reduction (lbs/year)**
Internal	**External**	
0	1,170	700
10	1,110	750
20	1,060	790
30	1,010	830
40	950	880
50	900	920
60	850	960
70	790	1,010
80	740	1,050
90	690	1,090
100	630	1,140
110	580	1,180
120	530	1,220
130	470	1,270
140	420	1,310
150	370	1,350
160	310	1,400
170	260	1,440
180	210	1,480

Identification of Pollutant Sources

There are no significant point source discharges in the Little Spirit Lake watershed. From the Loading Function Model, the most external nonpoint source phosphorus delivered to the lake is from row crop landuse as shown in Figure 4.

Figure 4. Loading Function Model External Nonpoint Source Contributions



The Nurnberg Model indicates that internal loading makes up approximately 32% of the existing total phosphorus mass loading to the lake. However, the internal load has a much greater effect on in-lake total phosphorus concentrations on a pound for pound basis. The model relationship shows that one pound of internal loading is equivalent to 5.3 pounds of external loading. In terms of lake response, the internal load is estimated to comprise approximately 71% of the total load.

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Little Spirit Lake originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source contributions to Little Spirit Lake must be reduced as shown in Table 11 (above).

3.4 Pollutant Allocation

Wasteload Allocation

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

Load Allocation

Table 12 shows the Load Allocation (LA) for this TMDL based on varying internal and external load contributions. The external and total loads shown include 200 pounds per year from atmospheric deposition.

Table 12. Little Spirit Lake Load Allocation

Total Phosphorus Load Allocation (lbs/year)		
Internal	**External**	**Total**
0	1,170	1,170
10	1,110	1,120
20	1,060	1,080
30	1,010	1,040
40	950	990
50	900	950
60	850	910
70	790	860
80	740	820
90	690	780
100	630	730
110	580	690
120	530	650
130	470	600
140	420	560
150	370	520
160	310	470
170	260	430
180	210	390

Margin of Safety

The target total phosphorus loads are calculated using an in-lake concentration 10% below the desired endpoint to ensure that the required load reduction 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 Little Spirit Lake water quality. Any projects designed to improve water quality in the lake should include communication with and cooperation from stakeholders in Jackson County, Minnesota. Without a cooperative effort, it will be difficult to substantially improve the condition of the lake.

The estimated existing phosphorus loading from watershed sources is approximately 0.8 pounds/year/acre. Depending on the internal recycle load reduction achieved, the watershed loading would need to be reduced to a maximum of 0.7 pounds/year/acre. Because reductions in internal recycling and watershed loading will require management practices that take time to implement, the following timetable is suggested for improvements:

- Reduce watershed and recycle loading from 1,900 pounds per year to 1,400 pounds per year by 2010.
- Reduce watershed and recycle loading from 1,400 pounds per year to 900 pounds per year by 2015.
- Reduce watershed and recycle loading from 900 pounds per year to 500 pounds per year by 2020.

The final target of 500 pounds per year assumes that reductions in internal and external loads will be roughly proportional. It should be noted that the final total target load may vary depending upon the internal and external load reductions achieved as shown in previous sections of this report.

Although gross soil erosion and sediment delivery in the Little Spirit Lake watershed is relatively minimal, it is believed that phosphorus dissolved in surface runoff and/or attached to fine sediment entering tile through surface inlets is contributing to the phosphorus loading of the lake. The following recommendations are listed, in order of impact, to reduce the nonpoint source delivery of phosphorus to Little Spirit Lake. These practices should be applied even though gross soil erosion may be currently calculated to be less than the tolerable soil loss level "T".

- Nutrient management on production agriculture ground to achieve the optimum soil test range. This soil test range is the most profitable for producers to sustain in the long term.
- Incorporate or subsurface apply phosphorus (manure and commercial fertilizer) while controlling soil erosion. Incorporation will physically separate the phosphorus from surface runoff.
- Continue encouraging the adoption of reduced tillage systems, specifically no till and strip tillage.

- Initiate a fall-seeded cover crop incentive program. Target low residue producing crops (e.g. soybeans) or low residue crops after harvest (e.g. corn silage fields). This practice increases residue cover on the soil surface and improves water infiltration.
- Through incentives, add landscape diversity to reduce runoff volume and/or velocity through the strategic location of contour grass buffer strips, filter strips, and grass waterways, etc.

In addition to the recommended best management practices on agricultural land, there are practices that need to be implemented in the residential areas as well. These include use of low or no-phosphorous fertilizers on lawns and use of appropriate erosion controls on construction sites.

The internal nutrient component is due in large part to wind and wave action continually mixing the lake. Little Spirit Lake is a shallow natural lake and does not readily stratify. Minimizing the impact of wind and wave action on the lake could be accomplished through the installation of a wind break on the northwest edge of the lake to reduce wind fetch across the lake. Increasing the mean depth to at least 3 meters would allow the lake to stratify, reducing the internal mixing. This option may not be feasible due to limitations in the morphometry of the lake as well as cost prohibitive.

In addition to wind and wave action continually stirring the lake, a large rough fish population comprised of bullheads and carp degrade water quality by eliminating aquatic macrophytes that take up available nutrients and by stirring up bottom sediments aiding in sediment and nutrient resuspension. Commercial harvesting of the rough fish population would improve water quality by reducing the impact these fish have on mixing of the water column and macrophyte populations in the lake.

5. Monitoring

Further monitoring is needed at Little Spirit 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. Little Spirit 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.

The phosphorus load due to internal recycling is estimated by the selected lake response model but due to uncertainty inherent in the available data and model predictions further investigation is warranted. 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 estimate will be further refined.

6. Public Participation

TMDL staff met with the East Okoboji Lakes Improvement Corporation on May 20, 2004 to discuss the TMDL process for Little Spirit Lake. The draft TMDL was presented at a public meeting in Arnolds Park, Iowa on November 22, 2004. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

The November 22nd meeting was attended by representatives from several lake associations (including the Dickinson Clean Water Alliance, the Okoboji Protective Association, the Three Lakes Improvement Association, and the East Okoboji Lakes Improvement Corporation), Jackson County (MN) Planning and Environmental Services, DNR Fisheries Bureau, the National Audubon Society, CLAMP volunteer monitors, and Little Spirit Lake landowners.

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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 Little Spirit Lake - Calculations

Table A-5. Little Spirit Lake Hydrology Calculations

Lake	Little Spirit Lake	
Type	Natural w/out inlet	
Inlet(s)	None	
Outlet(s)	Spirit Lake	
Volume	3716	(acre-ft)
Lake Area	615	(acres)
Mean Depth	6.04	(ft)
Drainage Area	1432	(acres)
Mean Annual Precip	28.3	(inches)
Average Basin Slope	--	(%)
%Water	--	
%Forest	--	
%Grass/Hay	--	
%Corn	--	
%Beans	--	
%Urban/Artificial	--	
%Barren/Sparse	--	
Hydrologic Region	--	
Mean Annual Class A Pan Evap	48	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow	1299.81	(acre-ft)
Direct Lake Precip	1451.74	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	1.3505	(yr)
Est. Annual Average Det. Time (outflow)	3.9953	(yr)

9. Appendix B - Sampling Data

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

Parameter	**7/11/1979**	**8/14/1979**	**9/18/1979**
Secchi Depth (m)	0.8	0.7	0.7
Chlorophyll (ug/L)	35.2	62.5	26.2
NO_3+NO_2-N (mg/L)			0.1
Total Phosphorus (ug/l as P)	116	157	71
Alkalinity (mg/L)	228	222	211

Data above is averaged over the upper 6 feet.

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

Parameter	**5/25/1990**	**6/29/1990**	**7/27/1990**
Secchi Depth (m)	0.4	0.3	0.3
Chlorophyll (ug/L)	53.8	65.9	61.7
Total Nitrogen (mg/L as N)	3.5	3.8	2.7
Total Phosphorus (ug/l as P)	170.7	136.6	116.1
Total Suspended Solids (mg/L)	20.6	70	56.3
Inorganic Suspended Solids (mg/L)	9.3	18.3	33.9

Data above is for surface depth.

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

Parameter	**6/14/2000**	**7/12/2000**	**8/04/2000**
Secchi Depth (m)	0.3	0.3	0.2
Chlorophyll (ug/L)	15	81	38
NH_3+NH_4^+ -N (ug/L)	1038	1139	1349
NH_3 –N (un-ionized) (ug/L)	53	235	168
NO_3+NO_2-N (mg/L)	0.31	0.25	0.28
Total Nitrogen (mg/L as N)	1.73	2.31	2.38
Total Phosphorus (ug/l as P)	253	264	267
Silica (mg/L as SiO_2)	11	15	62
pH	8.1	8.6	8.4
Alkalinity (mg/L)	202	203	209
Total Suspended Solids (mg/L)	55.9	42.9	35.2
Inorganic Suspended Solids (mg/L)	40.6	31.3	23.6
Volatile Suspended Solids (mg/L)	15.3	11.7	11.6

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

Parameter	**5/16/2001**	**6/13/2001**	**7/18/2001**
Secchi Depth (m)	1.5	0.6	0.5
Chlorophyll (ug/L)	20	54	95
NH_3+NH_4^+ -N (ug/L)	584	2452	799
NH_3 –N (un-ionized) (ug/L)	83	268	271
NO_3+NO_2-N (mg/L)	5.98	0.16	0.16
Total Nitrogen (mg/L as N)	6.73	2.72	2.91
Total Phosphorus (ug/l as P)	118	227	275
Silica (mg/L as SiO_2)	11	11	21
pH	8.6	8.5	8.9
Alkalinity (mg/L)	176	186	186
Total Suspended Solids (mg/L)	17.6	15.6	16.3
Inorganic Suspended Solids (mg/L)	11.5	8.1	7.8
Volatile Suspended Solids (mg/L)	6.1	7.5	8.5

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

Parameter	**5/22/2002**	**6/19/2002**	**7/24/2002**
Secchi Depth (m)	0.7	0.6	0.5
Chlorophyll (ug/L)	19	27	103
NH_3+NH_4^+ -N (ug/L)	583	937	494
NH_3 –N (un-ionized) (ug/L)	79	93	169
NO_3+NO_2-N (mg/L)	0.50	0.87	0.27
Total Nitrogen (mg/L as N)	1.91	2.90	2.57
Total Phosphorus (ug/l as P)	172		311
Silica (mg/L as SiO_2)	5	8	16
pH	8.5	8.4	9.0
Alkalinity (mg/L)	216	252	225
Total Suspended Solids (mg/L)	18.0	14.7	21.9
Inorganic Suspended Solids (mg/L)	10.3	10.0	6.5
Volatile Suspended Solids (mg/L)	7.7	4.7	15.3

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

Parameter	**5/21/2003**	**6/18/2003**	**7/23/2003**
Secchi Depth (m)	1.4	1.4	0.5
Chlorophyll (ug/L)	17.5	39.9	21.9
NH_3+NH_4^+ -N (ug/L)	514	566	747
NH_3 –N (un-ionized) (ug/L)	75	141	226
NO_3+NO_2-N (mg/L)	1.05	0.53	0.26
Total Nitrogen (mg/L as N)	2.90	2.50	2.71
Total Phosphorus (ug/l as P)	220	270	351
Silica (mg/L as SiO_2)	7.88	8.02	9.31
pH	8.8	8.8	8.9
Alkalinity (mg/L)	246	180	166
Total Suspended Solids (mg/L)	16	17	30
Inorganic Suspended Solids (mg/L)	8	8	24
Volatile Suspended Solids (mg/L)	8	9	6

Table B-7. CLAMP Data (21)

	Total Phosphorous (mg/L)				Secchi Disc Depth (m)				chlorophyll a (mg/m3)			Total Nitrogen (mg/L)		Nitrate (mg/L)		
	Little Spirit Lake				Little Spirit Lake				Little Spirit Lake			Little Spirit Lake		Little Spirit Lake		
					Sampling Sites - 1,1.2, 2											
	Sampling Sites - 1,1.2, 2				Bachmann 1.2				Sampling Sites - 1,1.2, 2			Sampling Sites - 1,1.2, 2		Sampling Sites - 1,1.2, 2		
					CLAMP 1,2											
Date	**LSL-1-TP**	**LSL-2-TP**	**Avg P**	**ug/L**	**LSL-1.2-S**	**LSL-1-S**	**LSL-2-S**	**Avg S**	**LSL-1-C**	**LSL-2-C**	**Avg C**	**LSL-1-TN**	**LSL-2-TN**	**LSL-1.2-N**	**LSL-1-N**	**LSL-2-N**
7/16/1971					0.6			0.6						0.02		
7/22/1971					0.5			0.5						0.04		
10/7/1971					0.4			0.4						0.04		
**********	**********	**********			**********	**********	**********		**********	**********		**********	**********	**********	**********	**********
1/17/1972					2.0			2.0						0.11		
2/17/1972					1.5			1.5						0.09		
7/16/1972					0.5			0.5						0.02		
7/22/1972					0.5			0.5						0.05		
8/25/1972					0.3			0.3						0.06		
**********	**********	**********			**********	**********	**********		**********	**********		**********	**********	**********	**********	**********
**********	**********	**********			**********	**********	**********		**********	**********		**********	**********	**********	**********	**********
6/24/2000	0.119	0.114	0.117	116.550		0.2	0.2	0.175	81.52	50.05	65.788	2.73	2.26		0.19	0.18
7/8/2000	0.101	0.143	0.122	121.854		0.4	0.4	0.410	115.29	66.98	91.133	2.54	2.55		0.15	0.17
7/22/2000	0.223	0.184	0.203	203.090		0.2	0.2	0.238	260.04	146.82	203.428	4.94	3.70		0.20	0.16
8/5/2000	0.217	0.238	0.227	227.338		0.3	0.3	0.275	99.07	180.59	139.826	3.05	3.60		0.19	0.16
8/19/2000	0.275	0.271	0.273	272.720		0.3	0.3	0.310	112.46	145.74	129.101	3.72	5.59		0.18	0.20
9/2/2000	0.309	0.318	0.314	313.675		0.3	0.2	0.250	49.71	108.47	79.090	3.03	3.65		0.12	0.14
9/16/2000	0.232	0.317	0.275	274.808		0.3	0.3	0.255	48.55	122.46	85.502	2.59	3.48		0.08	0.11
9/30/2000	0.191	0.234	0.213	212.900		0.4	0.3	0.345	46.89	100.22	73.555	2.55	3.19		0.15	0.14
**********	**********	**********			**********	**********	**********		**********	**********		**********	**********	**********	**********	**********
6/9/2001	0.105	0.086	0.095	95.436		0.7	0.7	0.650	108.83	35.61	72.221	2.95	2.25		2.25	1.43
6/27/2001	0.198	0.224	0.211	210.860		0.5	0.5	0.450	80.14	127.62	103.880	2.79	2.81		0.51	0.12
7/16/2001	0.347	0.234	0.291	290.565		0.3	0.2	0.238	126.02	142.27	134.144	2.54	2.46		0.16	0.17
7/30/2001	0.398	0.362	0.380	379.660		0.2	0.2	0.225	185.50	220.58	203.040	3.92	3.42		0.16	0.14
8/11/2001	0.518	0.379	0.448	448.385		0.3	0.4	0.335	221.05	130.74	175.892	5.08	3.52		0.12	0.14
9/1/2001	0.442	0.356	0.399	399.383												
9/10/2001						0.7	1.1	0.888	16.83	11.69	14.259	2.92	2.43		0.17	0.16
9/26/2001	0.439	0.379	0.409	408.788		1.0	1.2	1.055	16.37	10.51	13.437	2.95	2.81		0.18	0.23
**********	**********	**********			**********	**********	**********		**********	**********		**********	**********	**********	**********	**********
6/5/2002	0.248	0.313	0.281	280.640		1.3	1.3	1.250	3.46	3.08	3.268	2.72	3.21		0.30	0.22
6/22/2002	0.241	0.388	0.314	314.340		0.6	0.5	0.575	46.88	94.08	70.482	3.19	4.18		0.87	0.37
7/3/2002	0.253	0.493	0.373	372.518		0.4	0.3	0.350	205.56	706.20	455.882	3.59	7.69		0.22	0.23
7/12/2002	0.400	0.402	0.401	401.243		0.5	0.7	0.575	LE	LE		5.70	5.81		0.27	0.24
7/26/2002	0.830	0.466	0.648	647.825		0.2	0.4	0.305	LE	LE		11.05	5.83		0.29	0.30
8/7/2002	0.354	0.407	0.380	380.425		0.3	0.3	0.250	LE	LE		4.28	5.27		0.20	0.20
8/23/2002	0.320	0.347	0.333	333.423		0.8	0.4	0.550	24.39	20.44	22.416	3.55	3.80		0.22	0.21
9/3/2002	0.404	0.314	0.359	359.085		0.5	0.3	0.350	13.17	163.94	88.553	4.27	3.89		0.26	0.28
**********	**********	**********			**********	**********	**********		**********	**********		**********	**********	**********	**********	**********
6/11/2003	0.263	0.292	0.277	277.323		1.7	1.4	1.525	7.82	12.51	10.167	3.19	3.40		0.59	0.21
6/26/2003	0.437	0.441	0.439	439.093		0.4	0.5	0.413	414.40	158.92	286.656	4.50	4.43		0.20	0.20
7/9/2003	0.611	0.555	0.583	583.225		0.5	0.2	0.319	538.14	353.53	445.837	7.53	8.32		0.48	0.19
7/21/2003	0.387	0.467	0.427	427.030		0.6	0.4	0.463	98.41	117.93	108.172	3.66	5.09		0.16	0.20
8/4/2003	0.360	0.395	0.378	377.663		0.3	0.2	0.269	72.59	153.07	112.827	3.51	4.13		0.16	0.23
8/18/2003	0.480	0.363	0.421	421.135		0.1	0.2	0.156	159.72	106.61	133.164	3.78	3.83		0.19	0.18
9/8/2003	0.351	0.275	0.313	312.643		0.2	0.1	0.150	17.71	18.97	18.336	4.03	4.65		0.22	0.22
9/23/2003	0.362	0.312	0.337	336.848		0.1	0.1	0.125	22.18	25.90	24.037	4.06	4.03		1.36	0.74

Table B-8. 2000 Phytoplankton Data (3)

	6/14/2000	7/12/2000	8/4/2000
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Cyanophyta	2.7E+00	9.3E+00	8.8E+00
Cryptophyta	0.0E+00	0.0E+00	1.6E-01
Chlorophyta	9.1E+00	0.0E+00	0.0E+00
Dinophyta	6.8E-01	0.0E+00	0.0E+00
Chrysophyta	3.9E+00	2.0E+01	1.2E+00
Euglenophyta	0.0E+00	0.0E+00	0.0E+00
Total	**1.6E+01**	**2.9E+01**	**1.0E+01**

Table B-9. 2001 Phytoplankton Data (4)

	5/16/2001	6/13/2001	7/18/2001
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Chlorophyta	1.30E+01	2.04E-01	1.33E-01
Chrysophyta	5.58E+01	0.00E+00	0.00E+00
Cryptophyta	6.73E-01	5.90E-02	1.60E-01
Cyanobacteria	3.51E+01	6.50E+01	1.40E+02
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	0.00E+00	0.00E+00
Total	1.05E+02	6.53E+01	1.40E+02

Additional lake sampling results and information can be viewed at:
http://limnology.eeob.iastate.edu/ and at
http://www.ag.iastate.edu/centers/lakeside/igl/waterqualitydata.html

10. Appendix C - Trophic State Index

Carlson's Trophic State Index

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

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

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

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

$$TSI\ (SD) = 60 - 14.41\ \ln(SD)$$

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

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

SD = lake Secchi depth, meters

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

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

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

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

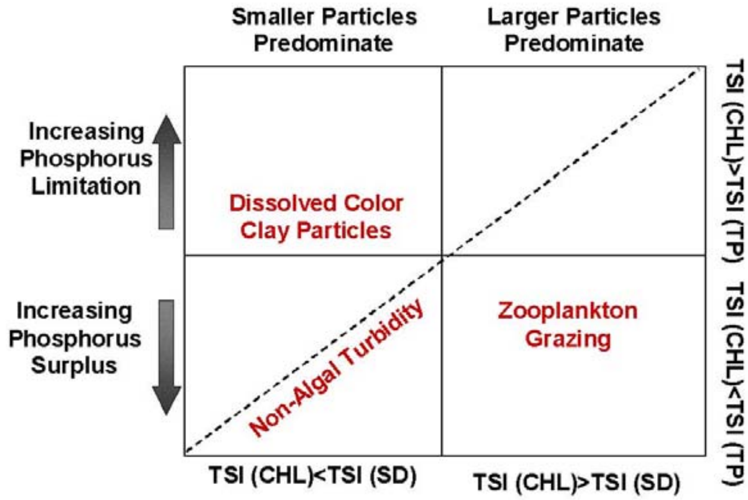
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for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

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

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

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

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



Little Spirit Lake TSI Values

Table C-4. 1979 Little Spirit TSI Values (1)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/11/1979	63	66	73
8/14/1979	65	71	77
9/18/1979	65	63	66

Table C-5. 1990 Little Spirit TSI Values (2)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
5/25/1990	73	70	78
6/29/1990	77	72	75
7/27/1990	77	71	72

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

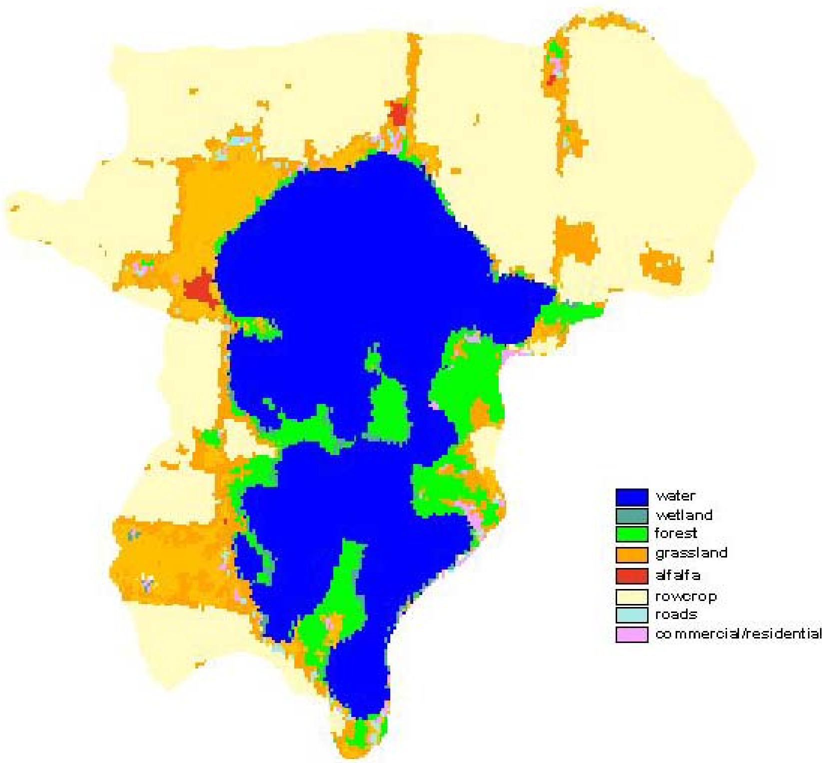
Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/2000	77	57	84
7/12/2000	77	74	85
8/4/2000	83	66	85
5/16/2001	54	60	74
6/13/2001	67	70	82
7/18/2001	70	75	85
5/22/2002	65	59	78
6/19/2002	67	63	--
7/24/2002	70	76	87
5/21/2003	55	59	82
6/18/2003	55	67	85
7/23/2003	70	61	89

Table C-7. CLAMP TSI Values (21)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/16/1971	**67**	--	--
7/22/1971	70	--	--
10/7/1971	73	--	--
1/17/1972	50	--	--
2/17/1972	54	--	--
7/16/1972	70	--	--
7/22/1972	70	--	--
8/25/1972	77	--	--
6/24/2000	85	72	73
7/8/2000	73	75	73
7/22/2000	81	83	81
8/5/2000	79	79	82
8/19/2000	77	78	85
9/2/2000	80	73	87
9/16/2000	80	74	85
9/30/2000	75	73	81
6/9/2001	66	73	70
6/27/2001	72	76	81
7/16/2001	81	79	86
7/30/2001	81	83	90
8/11/2001	76	81	92
9/1/2001	--	--	91
9/10/2001	62	57	--
9/26/2001	59	56	91
6/5/2002	57	42	85
6/22/2002	68	72	87
7/3/2002	75	91	90
7/12/2002	68	--	91
7/26/2002	77	--	97
8/7/2002	80	--	90
8/23/2002	69	61	88
9/3/2002	75	75	89
6/11/2003	54	53	85
6/26/2003	73	86	92
7/9/2003	76	90	96
7/21/2003	71	77	91
8/4/2003	79	77	90
8/18/2003	87	79	91
9/8/2003	87	59	87
9/23/2003	90	62	88

11. Appendix D - Land Use Map

Figure D-1. Little Spirit Lake 2002 Landuse



12. Appendix E - Little Spirit Lake Loading Relationships

Figure E-1. Little Spirit Lake Target Internal vs. External Load

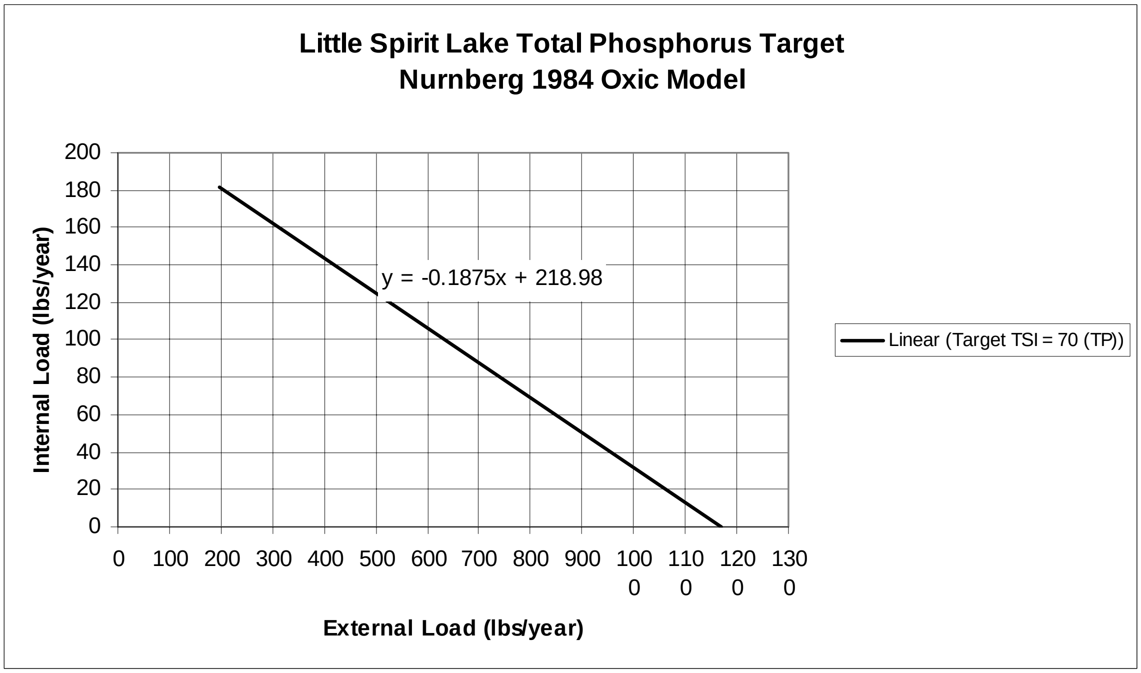


Figure E-2. Little Spirit Lake Target Total Load vs. Internal & External Loads

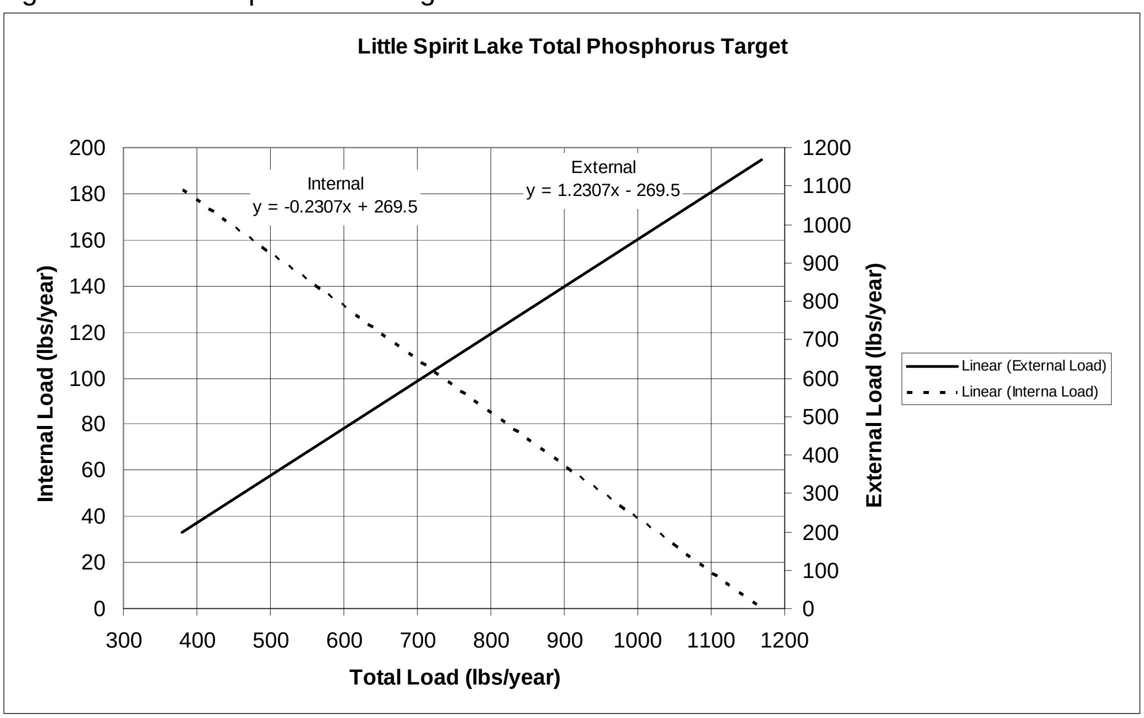


Figure E-3. Little Spirit Lake Load Reduction vs. Internal & External Loads