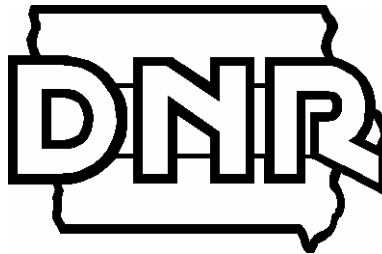


Total Maximum Daily Load  
For Algae and Turbidity  
Little Wall Lake  
Hamilton County, Iowa

2005

Iowa Department of Natural Resources  
Watershed Improvement Section



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## 1. Executive Summary

Table 1. Little Wall Lake Summary

Waterbody Name:	Little Wall Lake
County:	Hamilton
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Skunk River Basin
Pollutant:	Algae and Turbidity
Pollutant Sources:	Nonpoint (including water pumped from outside the watershed), internal recycle, atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Medium
Watershed Area:	185 acres
Lake Area:	248 acres
Lake Volume:	1,668 acre-ft (post-dredge)
Detention Time:	16 years (direct drainage area water inputs)
TSI Target(s):	Total Phosphorus less than 65; Chlorophyll a less than 65; Secchi Depth less than 65
Target Total Phosphorus Load:	See Table 2
Existing Total Phosphorus Load:	300 pounds (2003); 1,020 pounds (2004)
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 Wall Lake has been identified as impaired by algae and turbidity. As later explained in Section 3 of this document, the algae and turbidity impairments are symptomatic of excessive phosphorus and suspended solids loading to the lake. Phosphorus, which is related through the Trophic State Index (TSI) to chlorophyll and Secchi depth (a measurement of water clarity), is targeted to address the algae and turbidity impairments. Suspended solids, which are composed of both organic and inorganic particulate matter, are the primary transport mechanism for phosphorus. Load and wasteload allocations for suspended solids are not included in this TMDL. However, reductions in phosphorus loading should produce corresponding reductions in the suspended solids load. The purpose of the TMDL included herein is to determine the maximum allowable phosphorus load that the lake can receive and still meet water quality standards.

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 Wall Lake, S10, T86N, R24W, 2 miles south of Jewell, Hamilton 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 Wall 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 targets of this TMDL are Carlson's Trophic State Index (TSI) values of less than 65 for total phosphorus, chlorophyll a and Secchi depth. These values 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 2003 and 2004 combined UHL and ISU sampling are 0.4 meters, 48 ug/L and 109 ug/L, respectively. A minimum in-lake increase in Secchi transparency of 75% and minimum in-lake reductions of 31% for chlorophyll a and 38% 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 for Little Wall Lake in 2003 was 300 pounds while in 2004, when a significant volume of water from outside the watershed was pumped to the lake, the estimated load was 1,020 pounds. The total phosphorus loading capacity for the lake based on lake response modeling is a function of the volume of water pumped to the lake as shown in Table 2.
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 Wall Lake.
6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Little Wall Lake watershed. Therefore, the wasteload allocation will be set at zero.
7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus load allocation is shown in Table 2.

Table 2. Little Wall Lake Load Allocation

<b>Pumped Flow (acre-feet per year)</b>	<b>Load Allocation</b>
0	150
100	230
200	290
300	350
400	410
500	460
600	520
700	570

8. **A margin of safety:** The target total phosphorus loads are calculated using an explicit 10% margin of safety 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 the Little Wall Lake watershed landuse are unlikely. The watershed is very small and while half the watershed is used for agricultural production, approximately 35% of the watershed is owned by the Hamilton County Conservation Boards and the DNR or in grass. 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 body of the report.

## 2. Little Wall Lake, Description and History

### 2.1 The Lake

Little Wall Lake is located 2 miles south of Jewell in north central Iowa. Little Wall Lake is one of Iowa's 34 natural, glacial lakes and was formed by the scouring actions of glaciers and filled when the great ice sheets melted. Little Wall Lake has a surface area of 248 acres and is managed for water-based recreation and fishing.

The recorded history of Little Wall Lake dates back to 1892 and 1894 when the lake was reported to have gone dry. The lake went dry again in 1904-05 and 1936-41. The State Highway Commission realized few lakes existed in central Iowa and Little Wall Lake was denied permanent drainage in 1913. In 1953, approximately 65 acres were dredged by the State Conservation Commission. In 1960, the Iowa Conservation Commission passed the operation and maintenance of the lake and park to the Hamilton County Conservation Board.

The park presently consists of camping sites, a nature trail, and area for trap shooting. Bachmann (2) reported lake use at approximately 190,000 visits. Use is 53% camping, picnicking and other passive uses, 35% fishing, 5% pleasure boating, 3% swimming, and 4% other uses. Little Wall Lake is currently managed by the Hamilton County Conservation Board.

Table 3. Little Wall Lake Features

Waterbody Name:	Little Wall Lake
Hydrologic Unit Code:	HUC10 0708010504
IDNR Waterbody ID:	IA 03-SSK-00360-L
Location:	Section 10 T86N R24W
Latitude:	42° 16' N
Longitude:	93° 38' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	none
Receiving Waterbody:	Drainage Ditch No. 114
Lake Surface Area:	248 acres
Maximum Depth:	12 feet (approximate post-dredge)
Mean Depth:	6.7 feet (post-dredge)
Volume:	1,668 acre-feet (post-dredge)
Length of Shoreline:	43,885 feet
Watershed Area:	185 acres
Watershed/Lake Area Ratio:	1:1
Estimated Detention Time:	16 years (direct drainage area water inputs)

### Morphometry

Prior to dredging in 2002, the lake had a maximum depth of 8 ft. and an average depth of 5.3 ft. The volume of the lake was 1,247 ac-ft at crest. The water level of the lake was down approximately 2 feet prior to dredging in 2002, and was approximately 3 feet low in 2003.

In 2002, 679,558 cubic yards were dredged from Little Wall Lake. The dredge areas included the north and south boat ramp areas, and a large section in the middle of the lake. Original plans to dredge along the west shore were abandoned due to low water levels and the inability to get the hydraulic dredge close to shore. The volume of Little Wall Lake was increased by approximately 421 acre-feet to 1,668 acre-feet. The mean depth was increased from 5.3 feet to 6.7 feet, and the max depth was increased from 8 ft. to approximately 12 ft.

## **Hydrology**

Little Wall Lake has no distinct tributaries. In 1960, the state constructed facilities for pumping water from the Pray Glaman Drainage Ditch No. 114 to the lake. The county soon realized water from Drainage Ditch No. 114 was not sufficient to maintain the desired lake level during periods of low rainfall. In 1972, the operation was relocated to the Mud Lake Drainage Ditch No. 71 northeast of the lake. The operation has been used since 1972 during periods of low water level. However, the pumping system has not been the remedy of low lake levels during the past 20 years due to the time and cost involved in the operation and maintenance of the system. In 2004, pumping of water from DD No. 71 resumed in response to extremely low water levels following the hydraulic dredging of Little Wall Lake. This pumping continued through the spring of 2005. The Hamilton County Conservation Board is again investigating the feasibility of pumping water into Little Wall Lake as a long term solution to low water levels.

A 20 inch diameter concrete culvert is located at the northwest end of Little Wall Lake and drains the lake at an elevation of 1041 feet MSL to the north into Drainage Ditch No. 114. A natural outlet was located on the south side of the lake where flow continued in a southeast direction to the Skunk River. An earth embankment approximately 5 feet above the lake level prevents the use of the natural outlet. The estimated annual average detention time for Little Wall Lake is 16 years based on outflow considering only natural watershed flow inputs. However, the actual detention time has historically been significantly reduced during periods when water has been pumped to the lake. The methodology and calculations used to determine the detention time are shown in Appendix A.

## **2.2 The Watershed**

The watershed of Little Wall Lake has an area of 185 acres, which results in an extremely small watershed to lake area ratio of approximately 1:1. The watershed has no one well defined channel, and half of the watershed area is used for agricultural purposes, with the other half of the watershed occupied by Little Wall County Park, residences, or permanent grass cover. The 2003 landuses and associated areas for the watershed were obtained from a field level assessment and are shown in Table 4.



Table 4. 2003 Landuse in Little Wall Lake watershed.

<b>Landuse</b>	<b>Area in Acres</b>	<b>Percent of Total Area</b>
Row Crop	69	37
Pasture, Grass, Alfalfa	12	6
CCB and DNR	64	35
Residential, Roads	40	22
<b>Total</b>	<b>185</b>	<b>100</b>

The watershed is predominately nearly level to gently sloping (0-5%) with some strongly sloping (9-14%) areas. Soils are poorly drained to well drained and formed in calcareous silty and clayey lacustrine sediments over glacial till and loamy glacial till. Native vegetation was prairie grasses. Typical soils include Brownton, Canisteo, Bode, and Clarion.

Figure 1. Little Wall 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 Wall Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). In 1999, Little Wall Lake was included on the impaired waters list due to noxious aquatic plants. In 2002, this impairment was changed to algae and turbidity, which are more descriptive of the problems identified at Little Wall Lake.

The most recent assessment of Little Wall Lake was in 2004, during which the Class A1 (primary contact) and Class B(LW) designated uses were assessed as “partially supporting”. These assessments were based upon the 2000-02 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau.

Impairments in Little Wall Lake to the Class A1 (primary contact) use is through the presence of aesthetically objectionable blooms of algae and of nuisance algal species (e.g., bluegreen algae). Class B(LW) aquatic life uses are evaluated as partially supported due to hyper-eutrophic conditions at this lake, along with recommendations from the IDNR Fisheries Bureau.

The State of Iowa does not have numeric water quality criteria for algae that apply to Little Wall Lake. Little Wall Lake has been assessed as partially supporting its designated uses since 2000 due to heavy blooms of bluegreen algae impairing the primary contact uses. This is a violation of the narrative water quality standards stating that waters shall be free from aesthetically objectionable conditions and also free from nuisance or undesirable aquatic life (cyanobacteria) (8). The aesthetically objectionable conditions and nuisance aquatic life present at Little Wall Lake are impairing the Class A1 use for primary contact recreation.

Bachmann reported on the vegetation at Little Wall Lake in 1992, and at that time the lake was 80-90% covered with submergent vegetation (23). Little Wall Lake was assessed as partially supporting due to excess macrophyte growth (submergent and emergent) for all 305(b) reports prior to 2000. The lake has shifted from a clear water phase with macrophyte growth, into a turbid, algae covered lake with no macrophyte growth.

##### **Data Sources**

Water quality surveys have been conducted on Little Wall Lake in 1979, 1990, 1990-91, and 2000-04 (1, 2, 23, 3, 4, 5, 20, 21). Monitoring of Little Wall Lake was also conducted in 2003 and 2005 in preparation of TMDL development.

Data collected in 1979 as part of Iowa's lake classification survey (1) identified Little Wall Lake as a eutrophic lake. The mean total phosphorous concentration was 171.9 µg/L (n=9), mean total Kjeldahl nitrogen was 1.8 mg/L (n=2), and mean Secchi disk depth was 1.0 m (n=5).

Little Wall Lake was monitored from September 1990 to September 1991 as part of the Diagnostic and Feasibility Study for Little Wall Lake (23). Because of the simple morphometry of the lake, one sample station was established at the deepest area of the lake. This sample station was considered to represent conditions of the entire lake. There is no channelized flow into Little Wall Lake, therefore no tributary sampling was completed. A summary of results from the Diagnostic and Feasibility Study are included in Appendix B.

From the Classification of Iowa's Lakes for Restoration in 1994 (2), data collected in 1990 indicated that Little Wall Lake was still a eutrophic lake. The mean total phosphorous concentration was 181 µg/L (n=9), mean total nitrogen was 3.7 mg/L (n=9) and mean Secchi disk depth was 1.5 m (n=3).

Iowa State University Lake Study data from 2000 to 2004 (3, 4, 5, 20, 21) were evaluated for this TMDL. This study approximates a sampling scheme used by Roger Bachman in earlier Iowa lake studies. Samples were 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. This data is summarized in Appendix B.

### **Interpreting Little Wall Lake Water Quality Data**

Data from the Iowa Lakes Survey should be analyzed by separating pre- and post-dredge data. Data from 2000-01 represents pre-dredge water quality conditions, while data collected from 2003-04 are more representative of the current water quality at Little Wall Lake (post-dredge). Based on mean values from ISU sampling during 2000 - 2004, the ratio of total nitrogen to total phosphorus for this lake is pre-dredge is 6.7:1, while the post dredge ratio is 22.7:1. Data on inorganic suspended solids from the ISU sampling suggest that this lake may be subject to high levels of non-algal turbidity. The mean level of inorganic suspended solids in the 130 lakes sampled for the ISU lake survey in 2000-04 was 5.3 mg/L. The mean level of inorganic suspended solids at Little Wall Lake pre-dredge was 29.2 mg/l, while the post-dredge mean dropped to 14.3 mg/L.

Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for 2000 - 2004 in-lake sampling indicate possible limitation of algal growth attributable to light attenuation by elevated levels of inorganic suspended solids (see Figures 2 & 3 and Appendix C).

TSI values for 2000 - 2004 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. Little Wall Lake TSI Values (3, 4, 5, 20, 21)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/10/2000	77	73	86
7/31/2000	77	69	84
8/29/2000	70	51	76
6/4/2001	83	72	83
7/9/2001	83	79	88
8/6/2001	83	79	81
7/15/2002	83	66	69
8/12/2002	65	61	66
6/9/2003	77	67	68
7/14/2003	73	24*	70
8/11/2003	73	62	72
6/7/2004	73	63	72
7/12/2004	83	72	72
8/9/2004	70	72	69

\*Excluded from analysis based on comparison with UHL data

Table 6. Little Wall Lake 2003 TSI Values (UHL data)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/10/2003	71	70	74
7/23/2003	72	68	73
8/5/2003	71	69	73
8/21/2003	77	69	69
9/9/2003	74	68	69
9/24/2003	77	72	77
10/8/2003	77	68	73

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

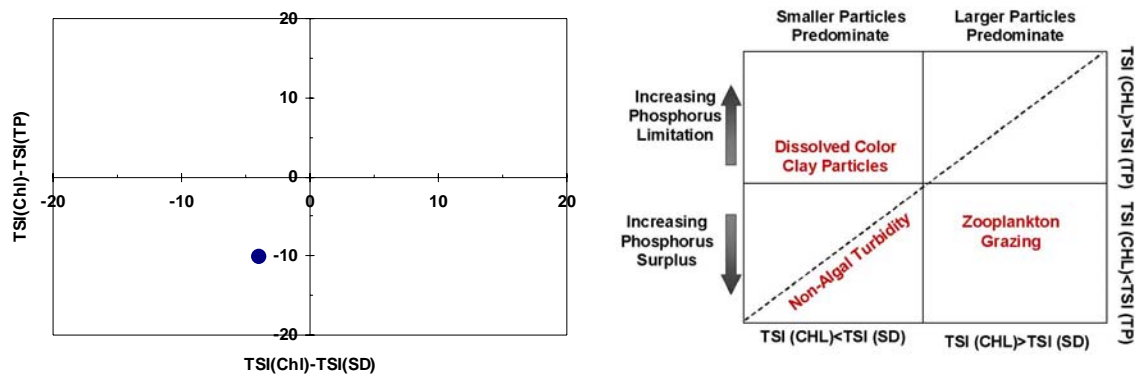
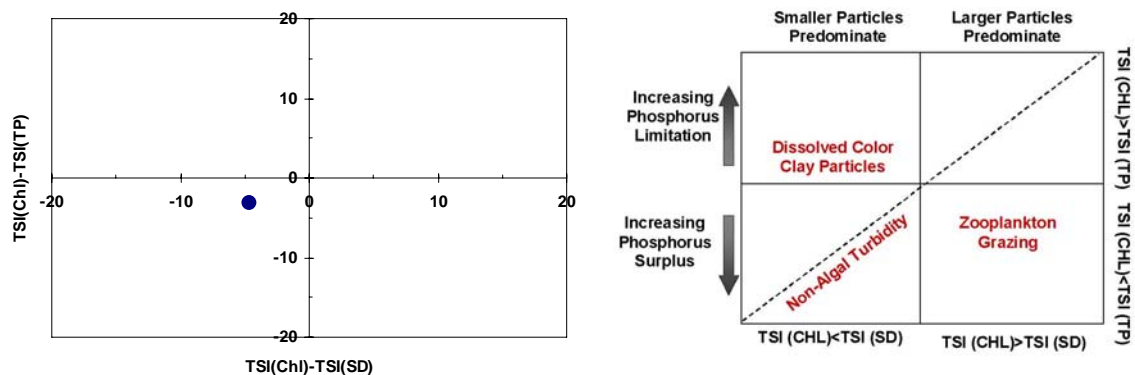


Figure 3. Little Wall Lake 2003 - 2004 Mean TSI Multivariate Comparison Plot (22)



Data from ISU phytoplankton sampling in 2000 and 2001 (30, 31) indicate that bluegreen algae (Cyanophyta) tend to dominate the summertime phytoplankton community of Little Wall 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 (33.3 mg/l) was in the upper quartile of the 131 lakes sampled. While the average summer wet mass of bluegreen algae decreased in 2001 and 2002 to 20.1 mg/L and 26.9 mg/L, respectively, the 2003 and 2004 averages were significantly higher at 156.6 mg/L and 108 mg/L. Phytoplankton sampling results from 2000- 2004 are given in Appendix B.

### Potential Pollution Sources

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

### Natural Background Conditions

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

### 3.2 TMDL Target

The Phase 1 targets of this TMDL are TSI values of less than 65 for total phosphorus, chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 68 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

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

Parameter	2003-2004 Mean TSI	2003-2004 Mean Value	Target TSI	Target Value	In-Lake Increase or Reduction Required
Chlorophyll	69	48 ug/L	<65	<33 ug/L	31% reduction
Secchi Depth	73	0.4 meters	<65	>0.7 meters	75% Increase in transparency
Total Phosphorus	72	109 ug/L	<65	<68 ug/L	38% reduction

The State of Iowa does not have numeric water quality criteria for algae or turbidity applicable to Little Wall Lake. Therefore, acceptable targets need to be identified.

Trophic State Indices (TSI) are an attempt to provide a single quantitative index for the purpose of classifying and ranking lakes, most often from the standpoint of assessing water quality. The Carlson Index is a measure of the trophic status of a body of water using several measures of water quality including: transparency or turbidity (Secchi disk

depth), chlorophyll-a concentrations (algal biomass), and total phosphorous levels (usually the limiting nutrient in algal growth).

The Carlson TSI ranges along a scale from 0-100 that is based upon relationships between secchi depth and surface water concentrations of algal chlorophyll, and total phosphorous for a set of reference lakes. A TSI value above 70 indicates a very productive water body with hypereutrophic characteristics; low clarity, high chlorophyll and phosphorous concentrations, and noxious surface scums of algae.

Without numeric water quality standards to base a target on, the Carlson TSI will be used to determine the Phase I target for algae, turbidity and phosphorus. The Phase I target is to reduce the trophic state of Little Wall Lake to target TSI values for all parameters to 65 or below.

### **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 inorganic suspended solids loading. 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 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. Inorganic suspended solids (i.e. non-algal turbidity) also contribute to lake turbidity. Since load reductions from phosphorus sources are expected to coincide with reductions in suspended solids loads the Phase I targeted pollutant is phosphorus. Future monitoring will determine if the targeted phosphorus reductions and corresponding reduction in suspended solids loading results in achievement of the TSI targets for chlorophyll and Secchi depth.

The inclusion of Little Wall Lake on the impaired waters list is based on violations of narrative criteria. Little Wall Lake has been assessed as "partially supported" since 1994. The 1998 Iowa 305(b) report assessed the Class A uses as "partially supported" due to excessive plant growth. Little Wall Lake was assessed in 2000 and 2002 as partially supported due to heavy algal blooms. Stocking of grass carp had reduced the macrophyte plant growth, and resulted in excess nutrients available and thus resulting in algal blooms which are aesthetically objectionable and produce nuisance aquatic life. These are violations of the narrative water quality standards which are applicable to all of Iowa's waterbodies.

There are no numeric criteria for algae applicable to Little Wall Lake or its sources in Chapter 61 of the Iowa Water Quality Standards (8). The targets for Little Wall Lake need to include a measure of algae (chlorophyll-a) in the water column, and a corresponding nutrient load. This is a phased TMDL where Phase I includes a target for nutrient delivery to the lake and algae production in the lake. Monitoring the water quality of the lake will be included in both Phase I and Phase II.

### **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. Growing season mean (GSM) in-lake total phosphorus concentrations are used to calculate an annual average total phosphorus loading.

## Modeling Approach

During the 2000 - 2004 sampling period the lake experienced significantly varying hydrologic conditions. In 2000 and 2001, the pre-dredge lake volume at crest was 1,247 acre-feet and no water was pumped to the lake. In addition, the lake was approximately 2 feet below crest prior to dredging. In 2002, the lake was dredged, removing approximately 421 acre-feet of sediment. Following the dredging project, the lake was approximately 3 feet below crest in 2003, and approximately 690 acre-feet of water was pumped to the lake in 2004.

The varying lake conditions throughout the sampling period make a long-term steady-state analysis of existing loading conditions difficult. Post-dredge conditions more truly represent the “existing” condition and a number of different empirical models that predict annual phosphorus load based on measured in-lake phosphorus concentrations were evaluated for the 2003 and 2004 monitoring data. Since the lake level and flow conditions (i.e. pumping in 2004) for these years were drastically different, the models were run separately for each year’s monitoring data. 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 for the 2003 and 2004 data. The results from both approaches were compared to select the best-fit empirical model. For pumped flow to the lake, a total phosphorus concentration in the pumped water of 0.31 mg/L was used for the Loading Function and export models based on monitored average total phosphorus reported in Iowa’s Nutrient Budget (24) for the South Skunk River upstream of Ames.

Table 8. Model Results for 2003 Data

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = 112 = ANN TP	Comments
Loading Function	250	Reckhow (10)
EPA Export	330	EPA/5-80-011
WILMS Export	210	“most likely” export coefficients
Reckhow 1991 EUTROMOD Equation	77,190	GSM model
Canfield-Bachmann 1981 Natural Lake	630	GSM model
Canfield-Bachmann 1981 Artificial Lake	1,390	GSM model
Walker Reservoir	720	GSM model. HRT out of range
Reckhow 1977 Anoxic Lake	100	GSM model
Reckhow 1979 Natural Lake	2,500	GSM model. P out of range
Reckhow 1977 Oxidic Lake ( $z/T_w < 50$ m/yr)	510	GSM model. P out of range
Nurnberg 1984 Oxidic Lake	240 (internal load = 3)	Annual model. P out of range
Vollenweider 1982 Combined OECD	270	Annual model.
Vollenweider 1982 Shallow Lake	300	Annual model.

Table 9. Model Results for 2004 Data

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP =105 = ANN TP	Comments
Loading Function	830	Reckhow (10)
EPA Export	880	EPA/5-80-011
WILMS Export	780	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	19,860	GSM model
Canfield-Bachmann 1981 Natural Lake	1,230	GSM model
Canfield-Bachmann 1981 Artificial Lake	2,420	GSM model
Walker Reservoir	1,590	GSM model. HRT out of range
Reckhow 1977 Anoxic Lake	340	GSM model
Reckhow 1979 Natural Lake	2,960	GSM model. P out of range
Reckhow 1977 Oxidic Lake (z/Tw < 50 m/yr)	950	GSM model. P out of range
Nurnberg 1984 Oxidic Lake	820 (internal load = 54)	Annual model. P out of range
Vollenweider 1982 Combined OECD	900	Annual model.
Vollenweider 1982 Shallow Lake	1,020	Annual model.

The Vollenweider and Nurnberg models resulted in values closest to the Loading Function and export estimates. Of these, only the Vollenweider models are within the parameter ranges used to derive them when applied to Little Wall Lake. The Nurnberg model indicates little internal loading for 2003 data with a larger internal load value for 2004. However, there is greater uncertainty associated with the Loading Function and export estimates for 2004 due to the large volume of water pumped to the lake and the estimate of the pumped water total phosphorus concentration. Generally, the modeling results from pre-dredge conditions (not shown) indicate much higher internal phosphorus loading than post-dredge data from 2003 and 2004.

The Vollenweider 1982 Shallow Lake Model was selected for the total phosphorus TMDL loads determined in this report. The results of this model for post-dredge data compare well with the Loading Function and export estimates, it is within all parameter ranges, and it is derived from analysis of shallow lakes comparable to Little Wall Lake. It is an annual model that should ideally be used in combination with annual average in-lake phosphorus measurements. The available in-lake phosphorus monitoring data for Little Wall Lake corresponds with the growing season, but temperature and dissolved oxygen profiles for the lake indicate that it is polymictic. For polymictic lakes the annual average phosphorus concentration can be approximated by the epilimnetic growing season concentration.

The equation for the Vollenweider 1982 Shallow Lake Model is:

$$P = 1.02 \left[ \frac{\left( \frac{LT_w}{z} \right)^{0.88}}{1 + \sqrt{T_w}} \right]$$

where:

$P$  = predicted in-lake total phosphorus concentration (ug/L)

$L$  = areal total phosphorus load (mg/m<sup>2</sup> of lake area per year)



$T_w$  = lake hydraulic detention time (years)

$z$  = lake mean depth (meters)

Example calculations for the existing total phosphorus load to Little Wall Lake for 2004 are as follows:

$$P = 105(ug / L) = 1.02 \left[ \frac{\left( \frac{462(mg / m^2)2.10(yr)}{2.04(m)} \right)}{1 + \sqrt{2.10(yr)}} \right]^{0.88}$$

The total phosphorus load capacity is dependent upon the hydraulic retention time, which is in turn largely dependent upon the volume of water pumped to the lake due to the small lake watershed. For the volume pumped in 2004 (690 acre-feet) the calculations for the total phosphorus load capacity are:

$$P = 68(ug / L) = 1.02 \left[ \frac{\left( \frac{282(mg / m^2)2.10(yr)}{2.04(m)} \right)}{1 + \sqrt{2.10(yr)}} \right]^{0.88}$$

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.

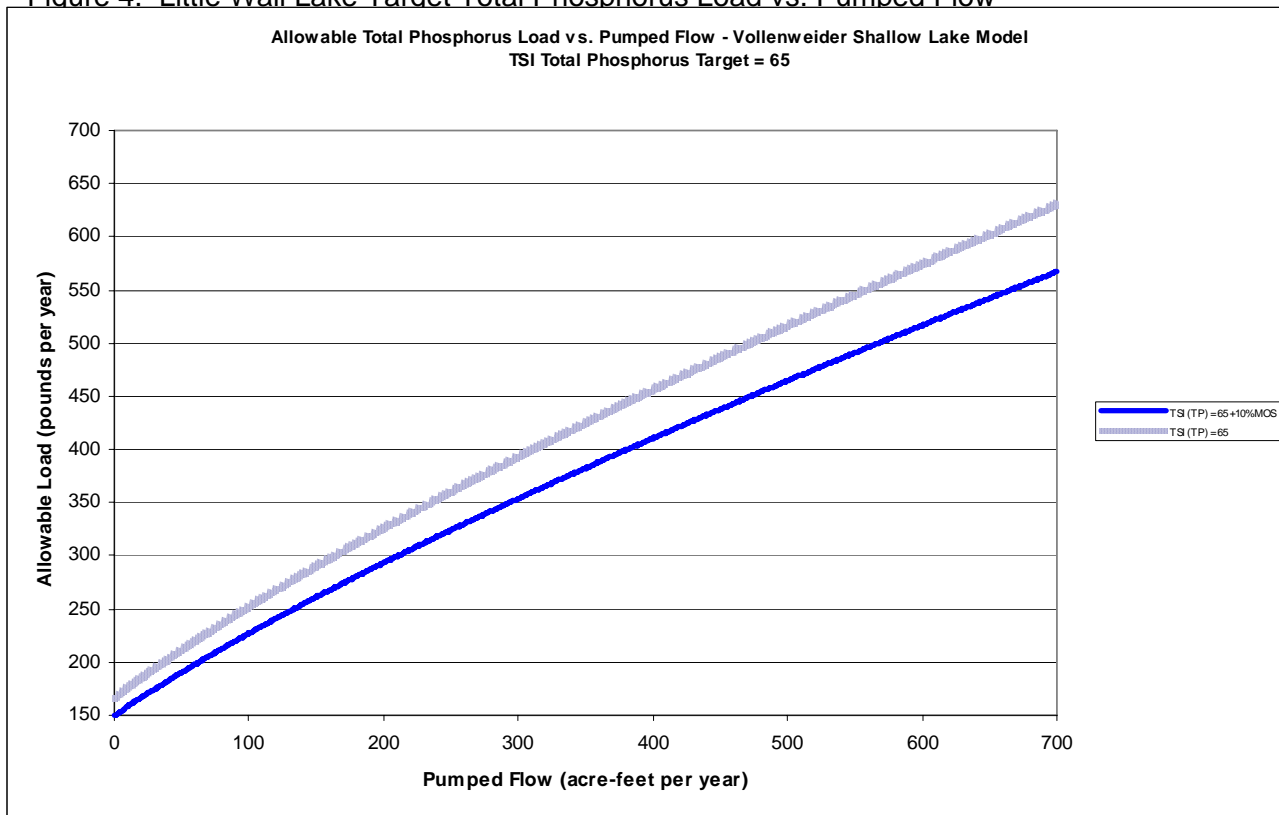
### Waterbody Pollutant Loading Capacity

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 Little Wall Lake can receive and meet its designated uses. The Phase 1 target TSI (TP) value is less than 65, corresponding to an in-lake total phosphorus concentration of less than 68 ug/L. For the selected lake response model, the target total load is a function of the water volume pumped to the lake as shown in Table 10 and Figure 4.

Table 10. Little Wall Lake Total Phosphorus Target

Pumped Flow (acre-feet per year)	Allowable Load (pounds/year)	Load Allocation (Allowable Load - 10% MOS - pounds/year)
0	170	150
100	250	230
200	330	290
300	390	350
400	460	410
500	520	460
600	570	520
700	630	570

Figure 4. Little Wall Lake Target Total Phosphorus Load vs. Pumped Flow



The State of Iowa does not have numeric water quality criteria for nutrients or algae that apply to Little Wall Lake. Impairment of the primary contact use is caused by excess nutrients and resulting algal blooms which are a violation of the narrative water quality standards stating that waters shall be free from aesthetically objectionable conditions and also free from nuisance or undesirable aquatic life (cyanobacteria).

The Phase I nutrient target for Little Wall Lake is to achieve Carlson TSI values of 65 or less for both chlorophyll-a and total phosphorus. This initial target will bring the lake below hypereutrophy and result in an initial step towards restoring the primary contact uses. Since algae is a response to excess nutrients, a decrease in chlorophyll-a concentrations is expected to follow a reduction of the total phosphorous load to the lake.

### 3.3 Pollution Source Assessment

Water quality in Little Wall Lake is influenced only by nonpoint sources. There are no point source discharges in the watershed. Phosphorus sources for Little Wall Lake include pumped flow from drainage areas outside the watershed, watershed areas that drain directly into the lake, groundwater and direct precipitation on the lake surface.

The Little Wall Lake natural drainage area is very small at 185 acres, therefore the lake is substantially affected by pumped flow and direct precipitation.

While there are no point source discharges in the watershed, there is stormwater runoff that flows from the residential areas to the lake. In addition, residential areas in the watershed can deliver nutrients via septic system leach fields. If a septic system is determined to not be in compliance, there are county and federal low-interest loan programs to assist in updating or replacing septic systems.

There are no permitted livestock facilities in the watershed.

### **Existing Load**

The existing annual total phosphorus load to Little Wall Lake is dependent upon how much water is pumped to the lake. In 2003, when no water was pumped to the lake, the total phosphorus load was estimated to be 300 pounds based on the selected lake response model. For 2004, when a significant volume of water was pumped, the total phosphorus load was estimated to be 1,020 pounds.

From modeling using the Revised Universal Soil Loss Equation (RUSLE), the existing sediment loading from the watershed is estimated to be 54 tons per year. In addition, the suspended solids contribution (including both inorganic and organic suspended solids) of the pumped water was estimated to be 18 tons in 2004 based on the average monitored concentration of TSS present in the Skunk River upstream of Ames.

### **Departure from Load Capacity**

Due to the varying lake conditions during the sampling period establishment of a long-term existing load estimate is difficult. Based on the selected lake response model the estimated 2003 load, when no water was pumped to the lake, was 300 pounds while the target load would be 150 pounds. For 2004, the existing load was 1,020 pounds while the target load for the same pumped volume (690 acre-feet) is 560 pounds. These target loads include a 10% margin of safety.

### **Identification of Pollutant Sources**

There are no significant point source discharges in the Little Wall Lake watershed. As shown previously, the Vollenweider model uses lake characteristics and hydrology to determine a response loading from the measured in-lake total phosphorus concentration. Thus, this model gives only a total load and does not differentiate between loading sources.

The Loading Function Model estimates external total phosphorus inputs from various sources. For this model, the estimated existing loads for 2003 were 80 pounds from direct precipitation, 10 pounds from groundwater, and 160 pounds from watershed sources including runoff from various land cover types and estimated septic tank contributions. In 2004, the estimated loads were 580 pounds from pumped water, 90 pounds from direct precipitation, 10 pounds from groundwater and 150 pounds from watershed sources. Figures 5 and 6 show the Loading Function Model estimates for different source categories. For loading attributable to groundwater inputs, a mean groundwater concentration of 0.1 mg/L was used (25). For the septic tank load estimates, all septic systems were assumed to be properly functioning, with a soil retention coefficient of 0.9 and a unit output of 1.1 pounds per capita-year (9) for an equivalent of 54 permanent residents served by septic systems in the watershed.

It should be noted that while the Loading Function Model provides estimates of the primary potential pollutant sources, the existing and target total loads identified in this TMDL are independent of the Loading Function Model. The Loading Function Model was used only for comparison purposes to select an empirical lake response model. 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 any internal loading that may be present.

Other sources of phosphorus capable of being delivered to the water body exist. These sources include manure and waste from wildlife, pets, fish cleaning stations, etc. The potential phosphorus being contributed from these sources is difficult to quantify. These potential sources have been considered, but are deemed smaller contributors or have less impact than the sources previously identified. However, these sources will be evaluated and quantified as required in Phase II of this TMDL.

Figure 5. Loading Function Model Nonpoint Source Contributions - 2003

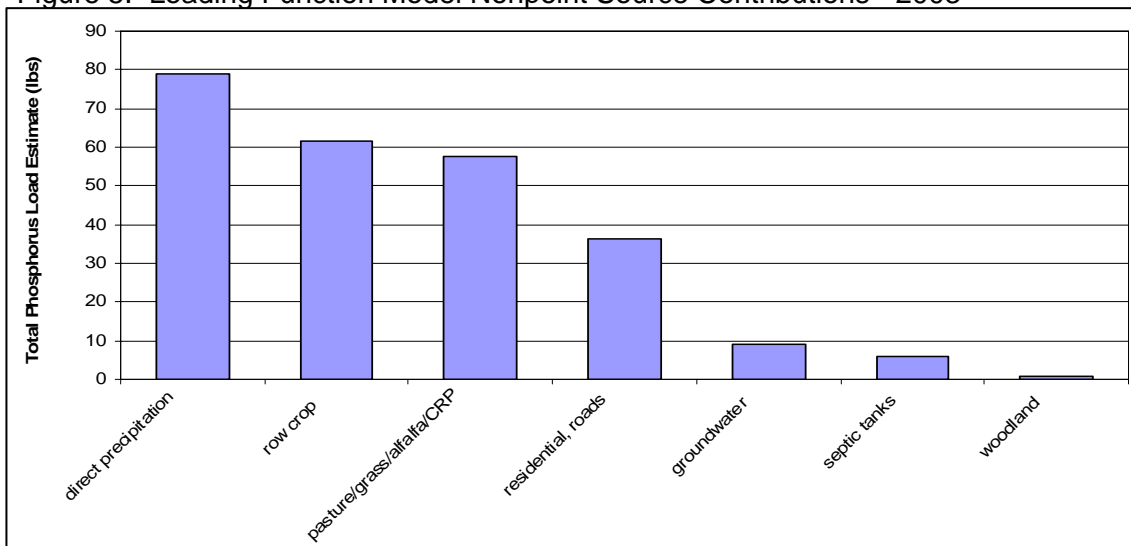
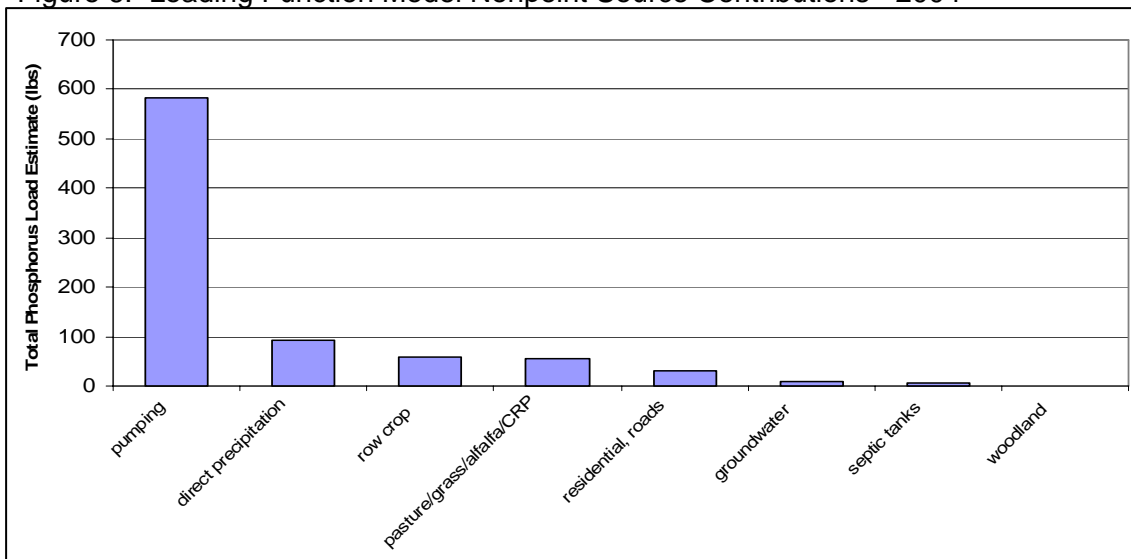


Figure 6. Loading Function Model Nonpoint Source Contributions - 2004



## Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Little Wall Lake originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source contributions to Little Wall Lake must be reduced to the levels shown in Table 10 and Figure 4 (above).

### 3.4 Pollutant Allocation

#### Wasteload Allocation

There are no significant phosphorus point source contributors in the Little Wall Lake watershed. The Waste Load Allocation (WLA) is zero pounds per year.

#### Load Allocation

Table 10 and Figure 4 (above) show the Load Allocation (LA) for this TMDL as a function of the volume of water pumped to the lake.

#### Margin of Safety

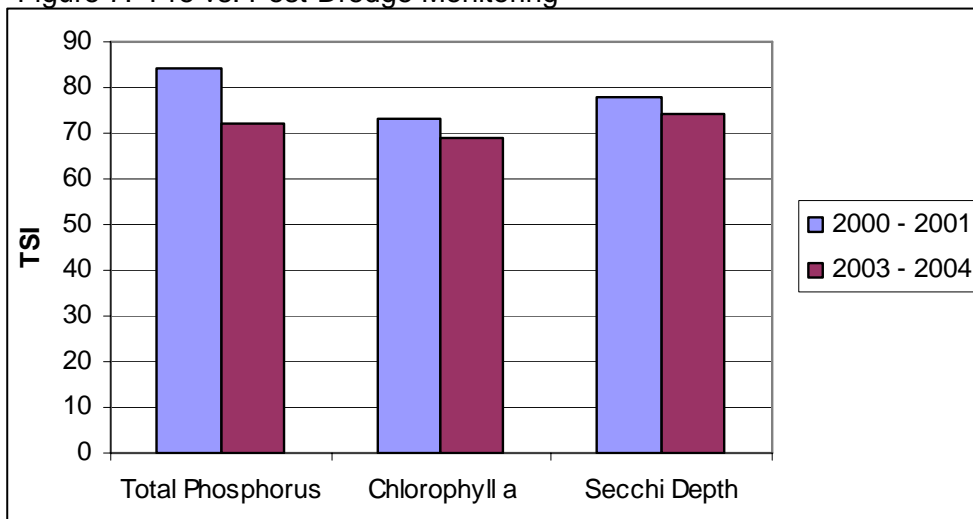
The load allocation values are calculated by applying an explicit 10% safety factor to the calculated allowable loading for the TSI target of 65 to ensure that the required load reduction will result in attainment of water quality targets.

## 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 Wall Lake water quality.

As shown in Figure 7, a comparison of the pre and post-dredge water quality monitoring data for Little Wall Lake indicates that the 2002 dredging project has improved water quality. The primary reason for this improvement is most likely that deepening the lake has reduced resuspension of sediment and associated internal phosphorus loading. This is also indicated by the drop in average inorganic suspended levels and modeling results for pre vs. post-dredge monitoring data.

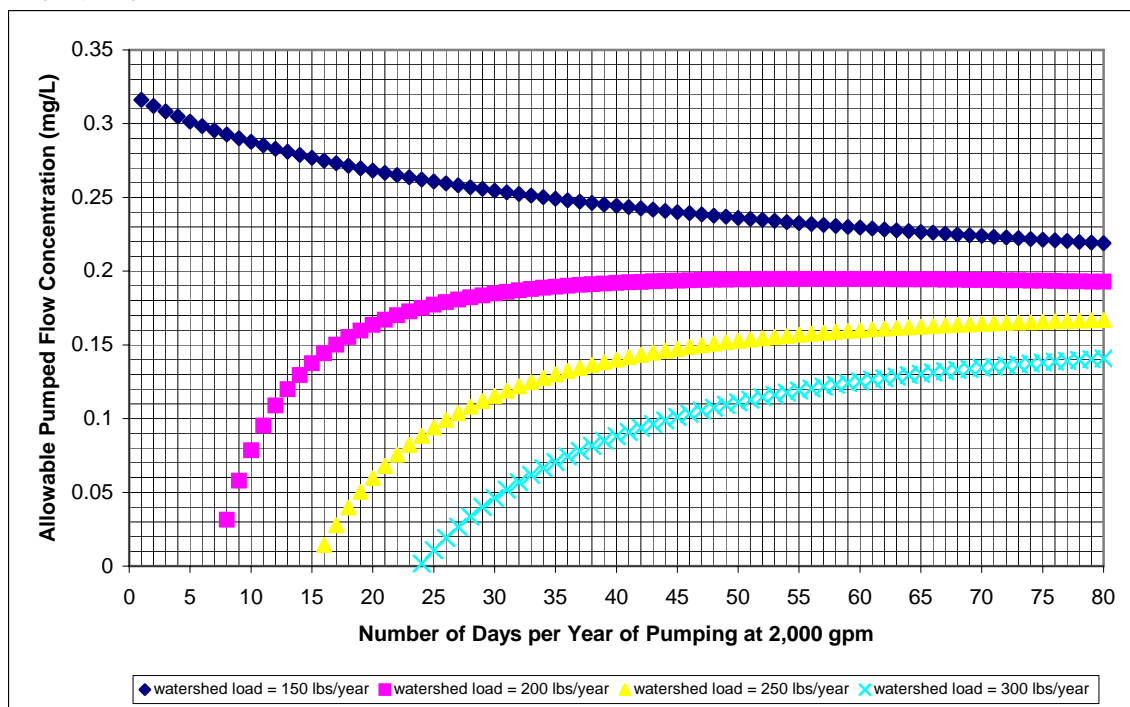
Figure 7. Pre vs. Post-Dredge Monitoring



Given the very small watershed to lake ratio, the recent dredging project, and anticipated lake management practices (i.e., pumping from outside the watershed to maintain the lake level), efforts should be focused not only on watershed practices but also on ways to reduce the nutrient load from the water that is pumped to the lake. The pumped water can make up a large portion of the hydraulic budget for the lake, and therefore becomes a primary source of nutrient delivery.

Figure 8 shows the relationship between total phosphorous concentration of the return water and the number of days that water is pumped. This relationship is shown for four different watershed loading rates. For total phosphorous loads from the watershed greater than 200 lbs per year, a minimum number of pumping days is identified. In both 2003 and 2004, the combined estimated phosphorous loading from precipitation, groundwater, and the watershed was 250 lbs. per year. This would result in a minimum of 16 days of pumping to maintain the desired phosphorous levels in Little Wall Lake.

Figure 8. Relationship between Phosphorous Concentration and Number of Pumping days per year.



## 5. Monitoring

Further monitoring is needed at Little Wall 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 Wall 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, a lake monitoring program will continue in Iowa.

## 6. Public Participation

DNR staff met with the Hamilton County Conservation Board on May 3, 2005 to discuss the TMDL process. A second public meeting was held at Little Wall Lake on October 26, 2005 to present and discuss the draft TMDL. The draft TMDL was available at the meeting and on the IDNR website. Comments received were reviewed and given consideration and, where appropriate, incorporated into the final TMDL.

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## 8. Appendix A - Lake Hydrology

### General Methodology

#### Purpose

There are approximately 127 public lakes in Iowa. The contributing watersheds for these lakes range in area from 0.028 mi<sup>2</sup> to 195 mi<sup>2</sup> with mean and median values of 10 mi<sup>2</sup> and 3.5 mi<sup>2</sup>, 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 <sup>2</sup> )	DA	2.94	80.7	204
Mean Annual Precip (inches)	$\bar{P}_A$	26.0	34.0	36.2
Average Basin Slope (%)	S	1.53	4.89	10.9
Landcover - % Water	W	0.020	0.336	2.80
Landcover - % Forest	F	2.45	10.3	29.9
Landcover - % Grass/Hay	G	9.91	31.3	58.7
Landcover - % Corn	C	6.71	31.9	52.3
Landcover - % Beans	B	6.01	23.1	37.0
Landcover - % Urban/Artificial	U	0	2.29	7.26
Landcover - % Barren/Sparse	B'	0	0.322	2.67
Hydrologic Region	H	Regions 1 - 5 used for delineation but data for USGS stations in Regions 2, 3 & 4 only.		

## Methods

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

## Equation Variables

Table A-2. Regression Equation Variables

Annual Average Flow (cfs)	$\bar{Q}_A$
Monthly Average Flow (cfs)	$\bar{Q}_{MONTH}$
Annual Flow – calendar year (cfs)	$Q_{YEAR}$
Drainage Area (mi <sup>2</sup> )	DA
Mean Annual Precip (inches)	$\bar{P}_A$
Mean Monthly Precip (inches)	$\bar{P}_{MONTH}$
Antecedent Mean Monthly Precip (inches)	$\bar{A}_{MONTH}$
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 <sup>2</sup> adjusted (%)	PRESS (log transform)
$\bar{Q}_A = 0.832DA^{0.955}$	96.1	0.207290
$\bar{Q}_{JAN} = 0.312DA^{0.950}$	85.0	0.968253
$\bar{Q}_{FEB} = 1.32DA^{0.838}$	90.7	0.419138
$\bar{Q}_{MAR} = 0.907DA^{1.03}$	96.6	0.220384
$\bar{Q}_{APR} = 0.983DA^{1.02}$	93.1	0.463554
$\bar{Q}_{MAY} = 1.97DA^{0.906}$	89.0	0.603766
$\bar{Q}_{JUN} = 2.01DA^{0.878}$	88.9	0.572863
$\bar{Q}_{JUL} = 0.822DA^{0.977}$	87.2	0.803808
$\bar{Q}_{AUG} = 0.537DA^{0.914}$	74.0	1.69929
$\bar{Q}_{SEP} = 0.123DA^{1.21}$	78.7	2.64993
$\bar{Q}_{OCT} = 0.284DA^{1.04}$	90.2	0.713257
$\bar{Q}_{NOV} = 0.340DA^{0.999}$	89.8	0.697353
$\bar{Q}_{DEC} = 0.271DA^{1.00}$	86.3	1.02455

Table A-4. Multiple Regression Equations

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

Table A-5. Little Wall Lake Hydrology Calculations

Flow Estimate Method	2	
Lake	Little Wall Lake	
Type	natural	
Inlet(s)	none	
Outlet(s)	none	
Volume	1668	acre-feet
Surface Area	248	acres
Watershed Area	433	acres
Mean Annual Precipitation	33.0	inches
Average Basin Slope	1.3	%
% Forest (2000 Land Cover)	9.0	
% Corn (2000 Land Cover)	9.6	
% Rowcrop (2002 Land Cover)	27.3	
Basin Soils Average % Sand	11.0	
Soil Permeability	1.0	inches/hour
Mean Annual Class A Pan Evaporation	50	inches
Evaporation Coefficient	0.74	
Optional User Input Inflow Estimate		acre-feet/year
Optional User Input Runoff Component	155	acre-feet/year
Optional User Input Baseflow Component	30	acre-feet/year
Mean Depth	6.7	feet
Drainage Area	185	acres
Drainage Area	0.3	square miles
Drainage Area/Lake Area	0.7	
Mean Annual Lake Evaporation	37.0	inches
Mean Annual Lake Evaporation	763	acre-feet/year
Annual Average Inflow	0.3	cfs
Annual Average Inflow	185	acre-feet/year
Runoff Component	155	acre-feet/year
Baseflow Component	30	acre-feet/year
Direct Precipitation on Lake Surface	681	acre-feet/year
Inflow + Direct Precipitation	865	acre-feet/year
% Inflow	21.3	
% Direct Precipitation	78.7	
Outflow	102	acre-feet/year
HRT Based on Inflow + Direct Precipitation	1.93	year
HRT Based on Outflow	16.34	year

Flow Estimate Methods		user inputs
1	Schilling & Wolter Regression	spreadsheet calculations
2	LWB Regression (SLR)	fixed text or identifiers
3	LWB Regression (MLR)	
	User Input	

## 9. Appendix B - Sampling Data

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

Parameter	6/22/1979	8/23/1979	9/25/1979
Secchi Depth (m)	0.3	1.5	1.65
Chlorophyll (ug/L)	104	37	5.9
NO <sub>3</sub> +NO <sub>2</sub> -N (mg/L)			0.1
Total Phosphate (mg/L as P <sub>04</sub> )	0.44	0.73	0.12
Alkalinity (mg/L)	202	186	189

Data above is averaged over the upper 6 feet.

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

Parameter	5/26/1990	6/30/1990	7/28/1990
Secchi Depth (m)	0.4	0.3	0.3
Chlorophyll (ug/L)	53.2	73.9	60.9
Total Nitrogen (mg/L as N)	3.6	3.8	2.7
Total Phosphorus (ug/l as P)	165.3	139.4	118.9
Total Suspended Solids (mg/L)	61.2	63.4	43.0
Inorganic Suspended Solids (mg/L)	8.6	13.4	29.6

Data above is for surface depth.

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

Parameter	7/10/2000	7/31/2000	8/29/2000
Secchi Depth (m)	0.3	0.3	0.5
Chlorophyll (ug/L)	72.1	51.9	8.2
NO <sub>3</sub> +NO <sub>2</sub> -N (mg/L)	0.25	0.3	0.38
Total Nitrogen (mg/L as N)	2.67	2.74	2.54
Total Phosphorus (ug/l as P)	302	262	142
pH	7.0	8.8	8.2
Alkalinity (mg/L)	201	192	172
Total Suspended Solids (mg/L)	48	57	26
Inorganic Suspended Solids (mg/L)	21	35	4
Volatile Suspended Solids (mg/L)	27	22	22

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

Parameter	6/4/2001	7/9/2001	8/6/2001
Secchi Depth (m)	0.2	0.2	0.2
Chlorophyll (ug/L)	67.4	135.5	138.7
NO <sub>3</sub> +NO <sub>2</sub> -N (mg/L)	0.27	0.23	0.37
Total Nitrogen (mg/L as N)	0.95	0.28	0.78
Total Phosphorus (ug/l as P)	239	337	204
pH	8.6	8.8	8.6
Alkalinity (mg/L)	168	168	160
Total Suspended Solids (mg/L)	84	197	140
Inorganic Suspended Solids (mg/L)	21	74	20
Volatile Suspended Solids (mg/L)	63	123	120

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

<b>Parameter</b>	<b>7/15/2002</b>	<b>8/12/2002</b>
Secchi Depth (m)	0.2	0.7
Chlorophyll (ug/L)	35.3	21.6
NH <sub>3</sub> +NH <sub>4</sub> <sup>+</sup> -N (ug/L)	782	829
NH <sub>3</sub> -N (un-ionized) (ug/L)	212	95
NO <sub>3</sub> +NO <sub>2</sub> -N (mg/L)	1.71	1.64
Total Nitrogen (mg/L as N)	2.08	2.96
Total Phosphorus (ug/l as P)	91	71
Silica (mg/L as SiO <sub>2</sub> )	9.39	4.86
pH	8.8	8.4
Alkalinity (mg/L)	171	197
Total Suspended Solids (mg/L)	55	10
Inorganic Suspended Solids (mg/L)	32	4
Volatile Suspended Solids (mg/L)	23	6

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

<b>Parameter</b>	<b>6/9/2003</b>	<b>7/14/2003</b>	<b>8/11/2003</b>
Secchi Depth (m)	0.3	0.4	0.4
Chlorophyll (ug/L)	40.9	0.5	23.7
NH <sub>3</sub> +NH <sub>4</sub> <sup>+</sup> -N (ug/L)	523	542	616
NH <sub>3</sub> -N (un-ionized) (ug/L)	85	217	297
NO <sub>3</sub> +NO <sub>2</sub> -N (mg/L)	0.24	0.20	0.24
Total Nitrogen (mg/L as N)	2.32	2.25	2.50
Total Phosphorus (ug/l as P)	81	98	114
Silica (mg/L as SiO <sub>2</sub> )	3.78	6.79	8.30
pH	8.7	9.1	9.2
Alkalinity (mg/L)	146	119	130
Total Suspended Solids (mg/L)	19	49	51
Inorganic Suspended Solids (mg/L)	7	23	13
Volatile Suspended Solids (mg/L)	12	27	37

Table B-7. Data collected in 2004 by Iowa State University (21)

<b>Parameter</b>	<b>6/7/2004</b>	<b>7/12/2004</b>	<b>8/9/2004</b>
Secchi Depth (m)	0.4	0.2	0.5
Chlorophyll (ug/L)	28.2	65.0	66.2
NH <sub>3</sub> +NH <sub>4</sub> <sup>+</sup> -N (ug/L)	36	98	36
NH <sub>3</sub> -N (un-ionized) (ug/L)	9	48	6
NO <sub>3</sub> +NO <sub>2</sub> -N (mg/L)	0.20	0.56	1.21
Total Nitrogen (mg/L as N)	1.43	1.18	2.83
Total Phosphorus (ug/l as P)	114	113	89
Silica (mg/L as SiO <sub>2</sub> )	6.61	12.67	9.81
pH	8.9	9.3	9.1
Alkalinity (mg/L)	158	165	166
Total Suspended Solids (mg/L)	49	-	38
Inorganic Suspended Solids (mg/L)	15	-	6
Volatile Suspended Solids (mg/L)	34	-	32



Table B-8. 2000-2004 Phytoplankton Data ()

	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>
<b>Division</b>	<b>Wet Mass (mg/L)</b>	<b>Wet Mass (mg/L)</b>	<b>Wet Mass (mg/L)</b>	<b>Wet Mass (mg/L)</b>	<b>Wet Mass (mg/L)</b>
<b>Bacillariophyta</b>	0.374	2.743	0.822	0.243	0.364
<b>Chlorophyta</b>	0.749	5.811	0.516	0.813	0.902
<b>Cryptophyta</b>	0.935	0.253	0.012	0.045	0.182
<b>Cyanobacteria</b>	33.333	20.1	26.928	156.661	108.038
<b>Dinophyta</b>	1.142	1.28	0.403	0.329	0
<b>Euglenophyta</b>	0	0	0.025	0.012	0.005
<b>Total</b>	36.532	30.187	28.706	158.104	109.492

Additional lake sampling results and information can be viewed at:

<http://limnology.eeob.iastate.edu/>

Table B-9. Summary of Little Wall Lake data collected as part of the Diagnostic / Feasibility Study (23).

<b>Parameter</b>	<b>N</b>	<b>Mean</b>	<b>Standard Error</b>
Secchi Depth (m)	15	1.6	0.1
Temperature (C)	45	17.5	1.3
pH	30	8.9	0.2
Total Alkalinity (mg/L as CaCO <sub>3</sub> )	30	190	9
Dissolved Oxygen (mg/L)	30	9.4	0.4
Total Suspended Solids (mg/L)	30	9.68	3.51
Chlorophyll-a (mg/m <sup>3</sup> )	30	7.439	1.091
Ammonia-Nitrogen (mg/L)	30	0.10	0.03
Total Kjeldahl Nitrogen (mg/L)	30	1.69	0.18
Nitrate/Nitrite Nitrogen (mg/L)	30	0.11	0.19
Soluble Reactive Phosphorous (mg/L)	30	0.031	0.006
Total Phosphorous (mg/L)	30	0.114	0.011

## 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.

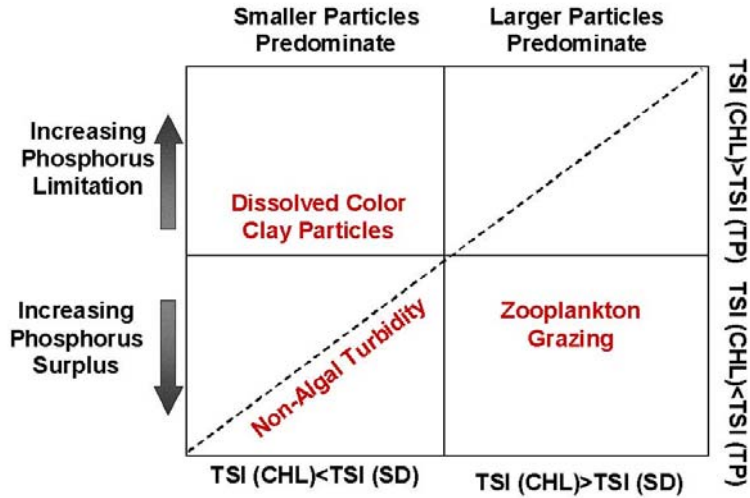
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
<b>fully supported</b>	<=55	<=12	>1.4
<b>fully supported / threatened</b>	55 → 65	12 → 33	1.4 → 0.7
<b>partially supported</b> (evaluated: in need of further investigation)	65 → 70	33 → 55	0.7 → 0.5
<b>partially supported</b> (monitored: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

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/22/1979	77	76	
8/23/1979	54	66	
9/25/1979	53	48	

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
5/26/1990	73	70	78
6/30/1990	77	73	75
7/28/1990	77	71	73

Table C-6. 2000 - 2004 Little Wall Lake TSI Values (3, 4, 5, 20, 21)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/10/2000	76	73	87
7/31/2000	76	69	84
8/29/2000	72	51	76
6/4/2001	87	72	83
7/9/2001	87	79	88
8/6/2001	83	79	81
7/15/2002	83	66	69
8/12/2002	65	61	66
6/9/2003	77	67	68
7/14/2003	74	24	70
8/11/2003	75	62	72
6/7/2004	75	63	72
7/12/2004	87	72	72
8/9/2004	72	72	69

## 11. Appendix D - Land Use Maps

Figure D-1. Little Wall Lake Watershed 2002 Landuse

