Total Maximum Daily Load
For Algae and Turbidity
Littlefield Lake
Audubon County, Iowa

2006

Iowa Department of Natural Resources
Watershed Improvement Section

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1. Introduction

Table 1. Littlefield Lake Summary

Waterbody Name:	Littlefield Lake
County:	Audubon
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Nishnabotna River
Pollutant:	Phosphorous
Pollutant Sources:	Nonpoint, atmospheric (background)
Impaired Use(s):	Narrative criteria A1 (primary contact recreation)
2002 303d Priority:	Low
Watershed Area:	2,442 acres
Lake Area:	58 acres
Lake Volume:	437 acre-feet
Detention Time:	0.3 years
TSI Target(s):	Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65
Phosphrous TMDL:	
Target Total Phosphorus Load	925 lbs/year
Existing Total Phosphorus Load	2,157 lbs/year
Load Reduction to Achieve Target	1,232 lbs/year (57%)
Wasteload Allocation	0
Load Allocation	835 lbs/year
Margin of Safety	90 lbs/year
Sediment TMDL:	
Target Sediment Load	171 tons/year
Existing SedimentLoad	1,070 tons/year
Load Reduction to Achieve Target	899 tons/year (86%)
Wasteload Allocation	0
Load Allocation	154 tons/year
Margin of Safety	17 tons/year

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

This document consists of a TMDL for algae and turbidity designed to provide Littlefield Lake with water quality that fully supports its designated uses. Phosphorus, which is related through the Trophic State Index (TSI) to chlorophyll, and Secchi depth, are targeted to address these 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 phosphorus, algae, 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:** Littlefield Lake, S17, T78N, R34W, 5 miles southeast of Exira, Audubon 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) and sediment loading. Designated uses for Littlefield Lake are Primary Contact Recreation (Class A1) and Aquatic Life (Class B(LW)). Excessive nutrient and sediment 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. A sediment delivery target of 171 tons/year and a phosphorus delivery target of 925 lbs/year have also been established.

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 median values for Secchi depth, chlorophyll a and total phosphorus based on 2000 - 2005 sampling are 0.55 meters, 31.3 ug/L and 129 ug/L, respectively. A minimum in-lake increase in Secchi transparency of 27% and minimum in-lake reduction of 26% for total phosphorus is required to achieve and maintain lake water quality goals and protect for beneficial uses. Algae levels need to be maintained or reduced from current levels. The estimated existing annual total phosphorus load to Littlefield Lake is 2,157 pounds per year. The total phosphorus loading capacity for the lake is based on lake response modeling shown in Table 6. The estimated existing sediment delivery to the lake is 1,070 tons/yr. A reduction of 86% is needed to achieve the sediment delivery target of 171 tons/yr.

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

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Littlefield Lake watershed. Therefore, the wasteload allocation for sediment and phosphorous is set at zero.

7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus load allocation for the nonpoint sources is 835 lbs/year. This includes 21 pounds per year attributable to atmospheric deposition. The load allocation for sediment is 154 tons/year.

8. **A margin of safety:** An explicit margin of safety has been set for non-algal turbidity at 10% of the load capacity, or 17 tons of sediment per year (171 tons x 10%) and also for phosphorous at 10% of the load capacity, or 90 lbs of phosphorous per year (925 lbs. x 10%).

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 Littlefield Lake watershed landuse are unlikely. 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 and sediment 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. Littlefield Lake, Description and History

2.1 The Lake

Littlefield Lake is located 4 miles southeast of Exira in western Iowa. Littlefield Lake was constructed in 1977 by the Natural Resources Conservation Service under the Troublesome Creek Watershed Multiple Purpose Dam Project for recreation and flood prevention. The dam was constructed under the authority of PL-566. Littlefield Lake has a surface area of 58 acres and is managed for water-based recreation and fishing.

Littlefield Park is managed by the Audubon County Conservation Board, and includes 444 acres with camping, trails, swimming, and other water based recreation available. Excluding the lake, approximately 221 acres of the park are within the Littlefield Lake watershed. Bachmann et al. (1994) reported annual lake and park use at approximately 10,000 visits. Visitor use is focused on fishing, picnicking, and camping.

Table 2. Littlefield Lake Features

Waterbody Name:	Littlefield Lake
Hydrologic Unit Code:	HUC10 1024000302
IDNR Waterbody ID:	IA 0-NSH-00675-L
Location:	Section 17 T78N R34W
Latitude:	41° 32' N
Longitude:	94° 47' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	Two unnamed tributaries
Receiving Waterbody:	Unnamed tributary to Troublesome Creek
Lake Surface Area:	58 acres
Maximum Depth:	20 feet
Mean Depth:	8 feet
Volume:	437 acre-feet
Length of Shoreline:	12,452 feet
Watershed Area:	2,442 acres
Watershed/Lake Area Ratio:	42:1
Estimated Detention Time:	0.3 years

Morphometry

Littlefield Lake has a mean depth of 8 feet and a maximum depth of 20 feet. The main part of Littlefield Lake has a surface area of 54 acres, while the area to the east of the road includes an additional 4 acres. Littlefield Lake has a storage volume of approximately 437 acre-feet.

Hydrology

Littlefield Lake is fed by two unnamed tributaries, and feeds into an unnamed tributary of Troublesome Creek, a tributary of the East Nishnabotna River. The estimated annual average detention time for Littlefield Lake is 0.3 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The watershed of Littlefield Lake has an area of 2,442 acres, which results in a large watershed to lake area ratio of approximately 42:1. The 2005 landuses and associated areas for the watershed were obtained from a field level assessment by the IDNR in cooperation with the Audubon SWCD and are shown in Table 3. A landuse map is shown in Appendix D.

Table 3. 2005 Landuse in the Littlefield Lake Watershed.

Landuse	Area in Acres	Percent of Total Area
Row Crop	1360	55
CRP, grass	530	22
Pasture (good condition)	54	2
Pasture (poor condition)	234	10
Audubon CCB	221	9
Farmsteads, other	43	2
Total	2,442	100

Significant landuse changes have occurred since a watershed analysis was completed in 1991 by the Division of Soil Conservation (IDALS, 1991). In 1991, row crop comprised 66% of the watershed, CRP and grass 14%, and pasture 8%. Since 1991, land has been moved out of row crop production and into CRP or permanent cover, and also into pasture.

The watershed is predominately gently sloping to moderately steep (2-18%). Soils are prairie derived and developed from loess, pre-Wisconsin till, or pre-Wisconsin till-derived paleosols. Typical soils include Marshall, Shelby, Sharpsburg, and Adair.

Figure 1. Littlefield Lake Watershed

3. TMDLs for Algae and Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (IAC, 2004) list the designated uses for Littlefield Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). Littlefield Lake was included on the 1998 impaired waters list due to high sediment delivery rates and poor water clarity. In 2004 the siltation impairment was changed to turbidity to better reflect the water quality impairment and algae was added as an impairment.

The State of Iowa does not have numeric water quality criteria for turbidity or algae that apply to Littlefield Lake. Littlefield Lake was assessed for the 2000, 2002, and 2004 305(b) reports as partially supporting due to poor water clarity and 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) (IAC, 2004). The aesthetically objectionable conditions and nuisance aquatic life present at Littlefield Lake are impairing the primary contact recreation uses. 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.

Data Sources

Water quality surveys have been conducted on Littlefield Lake in 1992 and 2000-05 (Bachmann, et al., 1994; Downing and Ramstack, 2001; Downing and Ramstack, 2002a;

Downing et al., 2003; Downing and Antoniou, 2004a; Downing and Antoniou, 2004d; Downing and Antoniou, 2005a). Additional water quality data was collected by the University of Iowa Hygenics Laboratory (UHL) under contract from the IDNR TMDL program from June through September of 2004 and 2005. Data from the 1992, and 2000 - 2005 surveys is available in Appendix B and also at http://limnology.eeob.iastate.edu/lakereport/chemical_report.aspx. UHL sampling data from 2004 and 2005 can be accessed at http://wqm.igsb.uiowa.edu/iastoret/.

Iowa State University Lake Study data from 2000 to 2005 were evaluated for this TMDL. This study approximates a sampling scheme used by Roger Bachmann in earlier Iowa lake studies (Bachmann et al., 1994). 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, and total suspended solids (TSS). The UHL monitoring includes samples taken six times during the growing season at each of three lake locations (shallow, mean and maximum depth) with measured water quality parameters similar to the ISU Lake Study.

From the Classification of Iowa's Lakes for Restoration in 1994 (Bachmann et al., 1994), data collected in 1992 indicated that Littlefield Lake was a eutrophic lake. The mean total phosphorous concentration for samples collected at the surface was 70 µg/L (n=3), mean total nitrogen was 2.6 mg/L (n=3) and mean Secchi disk depth was 0.6 m (n=3). Data from 2000-2005 (Downing and Ramstack, 2001; Downing and Ramstack, 2002a; Downing et al., 2003; Downing and Antoniou, 2004a; Downing and Antoniou, 2004d; Downing and Antoniou, 2005a) also indicate that Littlefield Lake is a eutrophic lake, with a median total phosphorous level of 129 ug/L, median chlorophyll-a concentration of 31.3 ug/L, and a median Secchi disk depth of 0.55 m. Based on median values from ISU sampling during 2000 – 2005, the ratio of total nitrogen to total phosphorus for this lake is 13.2:1. Littlefield Lake also had a median level of total suspended solids of 23 mg/L. That portion attributed to inorganic suspended solids had a median value of 10 mg/L. These levels are nearly twice the median of the 132 lakes sampled statewide.

Interpreting Littlefield Lake Water Quality Data

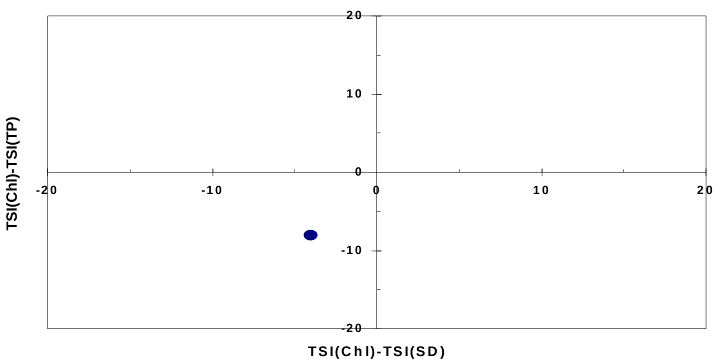
Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for 2000 - 2005 in-lake sampling indicate possible limitation of algal growth attributable to light attenuation by elevated levels of inorganic suspended solids (see Figure 2 and Appendix C). In addition, phytoplankton data (Downing et al., 2002b; Downing et al., 2004b; Downing et al., 2004c; Downing et al., 2004e; Downing et al., 2004f; Downing et al., 2005b) show relatively large populations of zooplankton species which graze on algae. This relatively large population of zooplankton grazers may also limit algal production in Littlefield Lake.

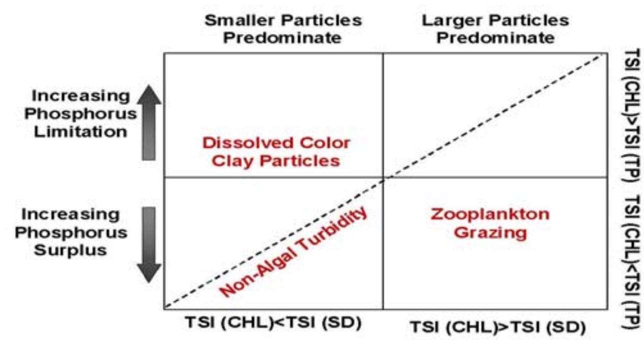
TSI values for 2000 - 2005 monitoring data are shown in Table 4. TSI values for all historical monitoring data and an explanation of Carlson's Trophic State Index are given in Appendix C.

Table 4. Littlefield Lake TSI Values collected by ISU from 2000-05 (Appendix B).

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/22/2000	65	64	75
7/18/2000	65	55	88
8/9/2000	65	52	73
5/23/2001	67		69
6/19/2001	70	79	73
7/24/2001	70	73	87
5/29/2002	65	61	68
6/25/2002	83	77	82
7/30/2002	73	77	78
5/29/2003	46	55	94
6/25/2003	73	66	60
7/30/2003	70	65	70
5/26/2004	93	46	61
6/21/2004	56	57	80
7/28/2004	73	75	90
6/1/2005	64	70	69
6/28/2005	83	84	75
7/28/2005	69	76	73

Figure 2. Littlefield Lake 2000 - 2005 Median TSI Multivariate Comparison Plot (Carlson and Simpson, 1996)





Data from ISU phytoplankton sampling in 2000 - 2005 indicate that bluegreen algae (Cyanophyta) comprise a significant portion of the summertime phytoplankton community, but dominate this community in mid and late summer. 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. Phytoplankton sampling results are provided in Appendix B.

Potential Pollution Sources

Water quality in Littlefield Lake is influenced only by nonpoint sources and internal recycling of pollutants from bottom sediments. While a lagoon system is present in the watershed for treatment of wastewater from the camping areas, the discharge from this lagoon is downstream of the Littlefield Lake dam. There are no point source discharges in the watershed.

The high levels of algae and poor water clarity at Littlefield Lake are a result of nonpoint sources of sediment and phosphorous located within the Littlefield Lake watershed. These primary sources include row crop and pastures. In addition, internal resuspension of sediment and nutrients from within the lake are contributing to the elevated phosphorous levels and resulting algal production as well as the poor water clarity. Other sources of sediment and phosphorus capable of being delivered to the water body exist, including septic systems, manure and waste from wildlife or pets. Unfortunately, the potential phosphorus being contributed from these sources is difficult to quantify. These potential sources have been considered, but are deemed minor contributors of phosphorous to the lake.

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 (Novotny and Chesters, 1981; USGS, 1999; Walker, 1998; Brock et al.) and also based on the default values used in the EUTROMOD and WILMS modeling programs. Contributions of phosphorus attributable to dry atmospheric deposition and groundwater influx were not separated from the direct precipitation load. Background levels of sediment was not separated from nonpoint sources.

3.2 TMDL Target

The Phase 1 target for this TMDL is an average water transparency level measured by Secchi depth greater than 0.7 meters. This target is equivalent to a TSI value of 65 which is the minimum depth considered to be fully supporting/threatened for the Section 305(b) use support category. In addition, a TSI target of 70 will be established for total phosphorous and a TSI target of 65 will be established for chlorophyll-a. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, and will help reduce algal impacts that may occur as light penetration is increased.

Table 5. Littlefield Lake Existing vs. Target TSI Values

Parameter	2000-2005 Median TSI	2000-2005 Median Value	Target TSI	Target Value	In-Lake Increase or Reduction Required
Chlorophyll	64	31.3 ug/L	<65	<33 ug/L	Maintain or reduce chlorophyll-a levels
Secchi Depth	69	0.55 meters	<65	>0.7 meters	27% Increase in transparency
Total Phosphorus	74	129 ug/L	<70	<96 ug/L	26% Reduction

As discussed in section 3.1.1, the State of Iowa does not have numeric water quality criteria for algae applicable to Littlefield Lake. Therefore, an acceptable algae target needs 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 North American 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 and nutrients. The Phase I target is to reduce the trophic state of Littlefield Lake to below hypereutrophic. This would be reflected in a TSI of 70 or below. The current mean TSI values for Littlefield Lake are shown in Table 5.

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for turbidity. Sediment and nutrients delivered from the watershed or resuspended from within the lake are causing increased turbidity, and may cause increased algal blooms. The transparency objective is defined by a mean Secchi depth of 0.7 meters, and the total phosphorous objective is a TSI of less than 70. The TSI is not a standard, but is used as a guideline to relate phosphorus loading to chlorophyll and Secchi depth for TMDL development purposes and to describe water quality that will meet Iowa's narrative water quality standards.

Selection of Environmental Conditions

The critical condition for which the TMDL TSI target values apply is the growing season (May through September). It is during this period that nuisance algal blooms are prevalent. The existing and target total phosphorus loadings to the lake are expressed as annual averages. 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 (Reckhow, 1990) was calculated. The results from all approaches were compared to select the best-fit empirical model.

Table 6. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = 193 ug/L	Comments
Loading Function	11984	Reckhow (1990); 90% pond trap efficiency
EPA Export	2066	EPA/5-80-011
WILMS Export	1442	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	16919	GSM model
Canfield-Bachmann 1981 Natural Lake	1810	GSM model
Canfield-Bachmann 1981 Artificial Lake	3748	GSM model
Reckhow 1977 Anoxic Lake	882	GSM model
Reckhow 1979 Natural Lake	2049	GSM model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	1193	GSM model. P out of range
Nurnberg 1984 Oxic Lake	1812	Annual model. P out of range
Vollenweider 1982 Combined OECD	2157	Annual model
Vollenweider 1982 Shallow Lake	2323	Annual model
Walker Reservoir	3926	GSM model

With the exception of Reckhow's Eutromod equation, all of the empirical models evaluated produced results that were significantly lower than the watershed load estimate derived from the Loading function. Both the EPA export and WILMS export models estimated loading similar to the empirical models. The Canfield Bachmann Artificial Lake, Walker Reservoir, Vollenweider models produced the closest estimates to the export models. Of these, the Vollenweider 1982 Combined OECD model was selected based on the data set used to develop the model.

Waterbody Pollutant Loading Capacity

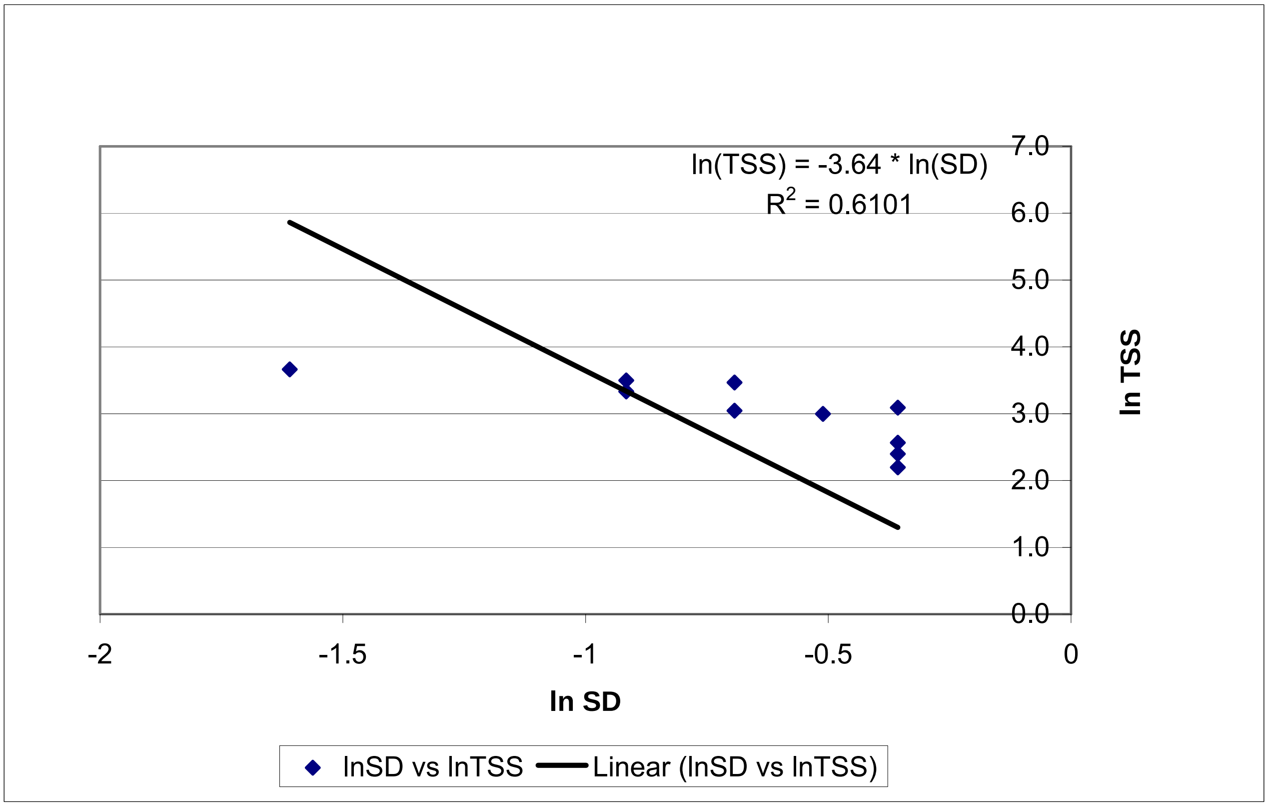
The chlorophyll-a and Secchi depth objectives are related through the Trophic State Index to total phosphorus. The load capacity for this TMDL is the annual amount of phosphorus Littlefield Lake can receive and meet its designated uses. Based on the selected lake response model and a target TSI (TP) value of less than 70, the Phase 1 total phosphorus loading capacity for the lake is 925 lbs/year.

The State of Iowa does not have numeric water quality criteria for nutrients or algae that apply to Littlefield 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). While Littlefield Lake does have lower than expected chlorophyll-a levels, this is likely due to high inorganic suspended solids levels in the water column. If the water clarity improves, it is possible for the high phosphorous levels to be expressed through higher algae levels.

The Phase I nutrient target for Littlefield Lake is to achieve a Carlson TSI for chlorophyll-a of 65 and for total phosphorous of 70. This initial target will bring the lake below hypereutrophy and result in an initial step towards restoring the narrative criteria. The Phase I total phosphorous target with a TSI value of 70 results in a loading capacity of 925 lbs/year of phosphorous. 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.

Excessive levels of total suspended solids (TSS) are causing high levels of turbidity. The loading capacity of the lake is determined by a Secchi depth TSI of 65, equivalent to a Secchi depth of 0.7 meters. The relationship between total suspended solids and transparency is shown in Figure 3.

Figure 3. Natural log transformed relationship between total suspended solids (TSS) and Secchi depth (SD).



Using the relationship between Secchi depth and TSS from Figure 3, the target total suspended solids (TSS) concentration is calculated as:

$$\ln(TSS) = -3.64 \cdot \ln(SD)$$
$$\ln(TSS) = -3.64 \cdot \ln(0.7)$$
$$\ln(TSS) = 1.298$$
$$TSS = 3.7 \text{ mg/L}$$

To achieve the desired secchi depth target of 0.7 meters, the in-lake total suspended solids value should be 3.7 mg/L. The current (2000-05) median total suspended solids value is 23 mg/L. This is equivalent to an 84% reduction.

Sediment delivery to Littlefield Lake was calculated using RUSLE and land uses derived from a field assessment completed by the IDNR in conjunction with the Audubon County SWCD in May 2005. Gross sheet and rill erosion in the Littlefield Lake watershed is estimated at 4,480 tons/year. From this, the estimated current sediment delivery to Littlefield Lake is 1,070 tons/year.

Assuming a direct relationship between the TSS concentration in Littlefield Lake and sediment delivery to the lake, an 84% reduction is needed in sediment delivery to the lake. This results in a sediment loading capacity of 171 tons/year.

3.3 Pollution Source Assessment

Water quality in Littlefield Lake is influenced only by nonpoint sources. There are no point source discharges in the watershed.

There are no permitted livestock facilities in the watershed.

Existing Load

The existing annual total phosphorus load to Littlefield Lake is estimated to be 2,157 lbs/year based on the selected lake response model (Vollenweider 1982 Combined OECD). This estimate includes a combination of nonpoint sources in the watershed and the internal phosphorus load recycled from the lake bottom sediment as well as an estimated load of 21 lbs/year from atmospheric deposition.

Turbidity levels in Littlefield Lake are created by a current estimated sediment load of 1,070 tons/year delivered to or resuspended in the lake. This current sediment delivery was determined using RUSLE and 2005 landuses (Appendix D).

Departure from Load Capacity

The non-algal turbidity load capacity is 171 tons of sediment. The existing non-algal turbidity load is 1,070 tons resulting in a departure from load capacity of 899 tons of sediment. The phosphorous loading capacity is 925 lbs/yr, or .38 lbs/year per acre of watershed area. The current phosphorous load is 2,157 lbs/yr, resulting in a departure from the loading capacity of 1,232 lbs/yr.

Identification of Pollutant Sources

There are no point sources of pollution in the Littlefield Lake watershed. Turbidity is caused by the addition of sediment from the watershed and resuspension of sediment from the lake bottom. These sediments also contain attached phosphorus which contribute to the high phosphorus levels in the water and resulting algal production. While a lagoon system is present in the watershed for treatment of wastewater from the camping areas, the discharge from this lagoon is downstream of the Littlefield Lake dam.

Linkage of Sources to Target

Excluding background sources, the sediment and total phosphorus loads to Littlefield Lake originate entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the nonpoint source contributions of sediment to Littlefield Lake must be reduced by 86%, while nonpoint source contributions of phosphorous must be reduced by 61%.

3.4 Pollutant Allocation

Wasteload Allocation

Since there are no point source contributors in the Littlefield Lake watershed, the Waste Load Allocation (WLA) for phosphorous is zero lbs/year.

There are no point source contributors of sediment in the Littlefield Lake watershed, therefore the Waste Load Allocation (WLA) for sediment is zero tons/year.

Load Allocation

The Load Allocation (LA) of total phosphorous for this TMDL is 835 lbs/year distributed as follows:

- 814 lbs/year allocated to the nonpoint sources in the Littlefield Lake watershed and internal recycling of phosphorus from the lake bottom sediments.

- 21 pounds per year allocated to atmospheric deposition.

Nonpoint sources in the Littlefield Lake watershed include agricultural production land, pasture, precipitation, and groundwater. To meet the desired in-lake water quality of 96 ug/L of total phosphorous, a 61% reduction from current loads would be required. This results in an annual total phosphorous loading of 835 lbs/year. This reduction in total phosphorous loading will also reduce chlorophyll-a concentrations.

The Load Allocation to nonpoint sources for turbidity is 154 tons of sediment delivered or resuspended in the lake. Nonpoint sources in the Littlefield Lake watershed include agricultural production land, pasture, precipitation, and groundwater. To meet the desired water clarity in the lake of 0.7m, an 86% reduction from current sediment loads is required. This results in an annual sediment loading of 154 tons/year.

Margin of Safety

An explicit margin of safety has been set for non-algal turbidity at 10% of the load capacity, or 17 tons of sediment per year (171 tons x 10%) and also for phosphorous at 10% of the load capacity, or 90 lbs of phosphorous per year (925 lbs. x 10%).

3.5 TMDL Summary

The equation for the total maximum daily loads shows the lake total phosphorus load capacity.

Phosphorous:

TMDL = Load Capacity 925 lbs/yr = WLA (0 lbs/yr) + LA 835 lbs/yr + MOS 90 lbs/yr

Sediment:

TMDL = Load Capacity 171 tons/yr = WLA (0 lbs/yr) + LA 154 tons/year + MOS 17 tons/yr

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 Littlefield Lake water quality.

A watershed analysis completed in 1990 by the Iowa Department of Agriculture and Land Stewardship - Division of Soil Conservation identified 1,690 acres in the Littlefield Lake watershed that exceeded tolerable soil loss limits "T". The analysis completed by the IDNR based on 2005 landuse and management practices indicates that approximately 200 acres still exceed "T".

To reduce soil erosion and sediment delivery to Littlefield Lake, additional best management practices are still needed in the watershed. These include terraces, reduced tillage, and contour cropping. This is especially true in the south tributaries, where local have noted that the water often flows very turbid from these areas.

In addition, improved pasture management may be needed on 230 acres of pasture identified as in poor condition.

The road riser structure on the east end of the lake does not function effectively as a sediment trap. It is estimated that the structure only has a trap efficiency of 25%. If this structure functioned more effectively as a sediment trap it would help to protect Littlefield Lake from sediment and nutrient delivery from the east. Additional investigation is needed to determine feasible alternatives to improve the functionality of this structure site.

Erosion control activities, including the maintenance of installed structures, need to continue in the watershed. The watershed should be periodically evaluated and erosion control activities focused on identified sediment contributors. Emphasis should be on row crop fields close to the lake or stream and having steeper slopes without effective management practices in place. The following best management practices would be beneficial for reducing sediment and nutrient (phosphorous) delivery to Littlefield Lake.

- Installation of buffer strips along stream corridors, and conversion of highly erodable row crop ground to the conservation reserve program.

- Construction and maintenance of terraces and grassed waterways.
- Manage agricultural soils for the optimum soil test range. This soil test range is the most profitable for producers to sustain in the long term.
- Continue encouraging the adoption of reduced tillage systems, specifically no till or 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.

Within Littlefield Lake, the promotion of aquatic vegetation within the lake may help to stabilize the lake bottom sediments and utilize existing phosphorous within the lake. The importance of aquatic plants can be noticed when standing on the road separating the wetland and Littlefield Lake. The wetland, with extensive plant growth, maintains clear water, even though it is very shallow. When looking at the water in the lake, it is very turbid, and there is very little plant growth. In addition, management of the existing grass carp population was discussed as a need to improve aquatic vegetation in the lake.

Local residents discussed the current lake level and size, and noted that the original plans for the lake made it four feet deeper. This discrepancy is being investigated with Natural Resources Conservation Service state office, as Littlefield Lake was built under the PL-566 program. Analysis of the lake shows that if four feet of water were added to the lake, it would not significantly change the shoreline, but would provide a significant increase in water volume and mean depth, reducing in-lake resuspension.

5. Monitoring

Further monitoring is needed at Littlefield 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.). Lake monitoring is currently ongoing at Littlefield Lake, with a minimum of three samples collected per growing season.

6. Public Participation

TMDL staff met with the Audubon County Conservation Board on July 5, 2005 and with the Audubon Soil and Water Conservation District office on May 11, 2005 to discuss the TMDL process and gather information regarding the lake and its watershed. The draft TMDL was discussed at a public meeting on July 18 at Littlefield Lake. Public comments received were 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^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)**
$\overline{Q}_A = 0.832 DA^{0.955}$	96.1	0.207290
$\overline{Q}_{JAN} = 0.312 DA^{0.950}$	85.0	0.968253
$\overline{Q}_{FEB} = 1.32 DA^{0.838}$	90.7	0.419138
$\overline{Q}_{MAR} = 0.907 DA^{1.03}$	96.6	0.220384
$\overline{Q}_{APR} = 0.983 DA^{1.02}$	93.1	0.463554
$\overline{Q}_{MAY} = 1.97 DA^{0.906}$	89.0	0.603766
$\overline{Q}_{JUN} = 2.01 DA^{0.878}$	88.9	0.572863
$\overline{Q}_{JUL} = 0.822 DA^{0.977}$	87.2	0.803808
$\overline{Q}_{AUG} = 0.537 DA^{0.914}$	74.0	1.69929
$\overline{Q}_{SEP} = 0.123 DA^{1.21}$	78.7	2.64993
$\overline{Q}_{OCT} = 0.284 DA^{1.04}$	90.2	0.713257
$\overline{Q}_{NOV} = 0.340 DA^{0.999}$	89.8	0.697353
$\overline{Q}_{DEC} = 0.271 DA^{1.00}$	86.3	1.02455

Table A-4. Multiple Regression Equations

Equation	**R^2 adjusted (%)**	**PRESS (log transform)**
$\overline{Q}_A = 1.17\times10^{-3} DA^{0.998} \overline{P}_A^{1.54} S^{-0.261} (1+F)^{0.249} C^{0.230}$	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
$\overline{Q}_{MAY} = 1.86\times10^{-3} DA^{0.903} \overline{P}_A^{1.98}$	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
$\overline{Q}_{JUN} = 8.13\times10^{-3} DA^{0.828} C^{0.478} \overline{P}_{JUN}^{2.70}$	95.9	0.256941
$\overline{Q}_{JUL} = 1.78\times10^{-3} DA^{0.923} \overline{A}_{JUL}^{4.19}$	91.7	0.542940
$\overline{Q}_{AUG} = 4.17\times10^{7} DA^{0.981} (1+B')^{-1.64} (1+U)^{0.692} \overline{P}_A^{-7.2} \overline{A}_{AUG}^{4.59}$	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
$Q_{YEAR} = 3.164\times10^{-4} DA^{0.942} P_{YEAR}^{2.39} A_{YEAR}^{1.02} S^{-0.206} \overline{P}_A^{1.27} C^{0.121} (1+U)^{0.0966}$	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 Littlefield Lake - Calculations

Table A-5. Littlefield Lake Hydrology Calculations

Lake	Littlefield Lake	
Type	Impoundment	
Inlet(s)	Unnamed Creek	
Outlet(s)	Troublesome Creek	
Volume	437	acre-feet
Surface Area	58	acres
Mean Depth	7.6	feet
Drainage Area	2442	acres
Mean Annual Precipitation	32.1	inches
Average Basin Slope	7.0	%
% Forest (2000 Land Cover)	2.6	
% Corn (2000 Land Cover)	21.2	
% Rowcrop (2002 Land Cover)	38.2	
Basin Soils Average % Sand	13.5	
Mean Annual Class A Pan Evaporation	55	inches
Evaporation Coefficient	0.74	
Mean Annual Lake Evaporation	40.7	inches
Annual Average Inflow	1467	acre-feet/year
Direct Precipitation on Lake Surface	155	acre-feet/year
Inflow + Direct Precipitation	1621	acre-feet/year
% Inflow	90.5	
% Direct Precipitation	9.5	
Outflow	14	acre-feet/year
HRT Based on Inflow + Direct Precipitation	0.27	year
HRT Based on Outflow	0.31	year

9. Appendix B - Sampling Data

Table B-1. Data collected in 1992 by Iowa State University (Bachmann et al., 1994)

Parameter	5/27/1992	6/24/1992	7/19/1992
Secchi Depth (m)	0.6	0.4	0.7
Chlorophyll (ug/L)	21.5	16.5	6.6
Total Nitrogen (mg/L as N)	3.18	3.01	1.53
Total Phosphorus (ug/l as P)	68	97	45
Total Suspended Solids (mg/L)	10.96	16.88	9.24
Inorganic Suspended Solids (mg/L)	9.34	13.48	6.92

Data above is for surface depth.

Table B-2. Data collected in 2000 by Iowa State University (Downing and Ramstack, 2001)

Parameter	6/22/2000	7/18/2000	8/9/2000
Secchi Depth (m)	0.7	0.7	0.7
Chlorophyll (ug/L)	46.2	15.5	22.2
NH_3+NH_4^+ -N (ug/L)			
NH_3 –N (un-ionized) (ug/L)			
NO_3+NO_2-N (mg/L)	0.16	0.79	0.13
Total Nitrogen (mg/L as N)	1.65	2.2	1.58
Total Phosphorus (ug/l as P)	140	333	116
Silica (mg/L as SiO_2)			
pH	8	7.8	7.6
Alkalinity (mg/L)	148	123	113
Total Suspended Solids (mg/L)	22	9	13
Inorganic Suspended Solids (mg/L)	11	5	6
Volatile Suspended Solids (mg/L)	11	5	7

Table B-3. Data collected in 2001 by Iowa State University (Downing and Ramstack, 2002a)

Parameter	5/23/2001	6/19/2001	7/24/2001
Secchi Depth (m)	0.6	0.5	0.5
Chlorophyll (ug/L)		136.6	71.4
NH_3+NH_4^+ -N (ug/L)			
NH_3 –N (un-ionized) (ug/L)			
NO_3+NO_2-N (mg/L)	0.29	2.19	0.26
Total Nitrogen (mg/L as N)	1.48	4.06	1.32
Total Phosphorus (ug/l as P)	89	119	318
Silica (mg/L as SiO_2)			
pH	8.7	8.5	9.4
Alkalinity (mg/L)	102	104	89
Total Suspended Solids (mg/L)	20	21	32
Inorganic Suspended Solids (mg/L)	9	8	12
Volatile Suspended Solids (mg/L)	11	14	19

Table B-4. Data collected in 2002 by Iowa State University (Downing et al., 2003)

Parameter	5/29/2002	6/25/2002	7/30/2002
Secchi Depth (m)	0.7	0.2	0.4
Chlorophyll (ug/L)	22.8	116.5	117.4
NH_3+NH_4^+ -N (ug/L)	309	302	242
NH_3 –N (un-ionized) (ug/L)	62	146	94
NO_3+NO_2-N (mg/L)	0.4	0.35	0.17
Total Nitrogen (mg/L as N)	0.9	1.86	1.53
Total Phosphorus (ug/l as P)	83	228	165
Silica (mg/L as SiO_2)	1.63	5.82	2.65
pH	8.7	9.2	8.9
Alkalinity (mg/L)	121	114	103
Total Suspended Solids (mg/L)	11	39	28
Inorganic Suspended Solids (mg/L)	3	7	14
Volatile Suspended Solids (mg/L)	7	31	14

Table B-5. Data collected in 2003 by Iowa State University (Downing and Antoniou, 2004a)

Parameter	5/29/2003	6/25/2003	7/30/2003
Secchi Depth (m)	2.7	0.4	0.5
Chlorophyll (ug/L)	11.4	37.6	32.7
NH_3+NH_4^+ -N (ug/L)	417	237	287
NH_3 –N (un-ionized) (ug/L)	46	53	110
NO_3+NO_2-N (mg/L)	3.57	0.73	0.11
Total Nitrogen (mg/L as N)	4.73	2.49	1.54
Total Phosphorus (ug/l as P)	53	186	390
Silica (mg/L as SiO_2)	2.17	5.03	6.02
PH	8.5	8.7	9
Alkalinity (mg/L)	101	87	73
Total Suspended Solids (mg/L)	8	33	32
Inorganic Suspended Solids (mg/L)	5	10	16
Volatile Suspended Solids (mg/L)	3	23	16

Table B-6. Data collected in 2004 by Iowa State University (Downing and Antoniou, 2004d)

Parameter	5/26/2004	6/21/2004	7/28/2004
Secchi Depth (m)	0.1	1.3	0.4
Chlorophyll (ug/L)	5	14.4	90.6
NH_3+NH_4^+ -N (ug/L)	184	213	36
NH_3 –N (un-ionized) (ug/L)	5	11	2
NO_3+NO_2-N (mg/L)	5.97	4.29	0.61
Total Nitrogen (mg/L as N)	4.56	4.92	1.87
Total Phosphorus (ug/l as P)	524	47	98
Silica (mg/L as SiO_2)	50.46	3.33	5.44
PH	7.9	8.1	8.6
Alkalinity (mg/L)	85	131	160
Total Suspended Solids (mg/L)	273		28
Inorganic Suspended Solids (mg/L)	230		12
Volatile Suspended Solids (mg/L)	42		16

Table B-7. Data collected in 2005 by Iowa State University (Downing and Antoniou, 2005a)

Parameter	6/1/2005	6/28/2005	7/28/2005
Secchi Depth (m)	0.8	0.2	0.6
Chlorophyll (ug/L)	56.9	241.9	100.2
NH_3+NH_4^+ -N (ug/L)	32.8	-	31.3
NH_3 –N (un-ionized) (ug/L)	1.8	-	2.4
NO_3+NO_2-N (mg/L)	3.32	0.6	0.16
Total Nitrogen (mg/L as N)	4.33	1	1.03
Total Phosphorus (ug/l as P)	90	136	121
Silica (mg/L as SiO_2)	4.38	7.08	5.3
PH	8.2	8.5	8.2
Alkalinity (mg/L)	138	113	128
Total Suspended Solids (mg/L)	23	38	17
Inorganic Suspended Solids (mg/L)	18	16	7
Volatile Suspended Solids (mg/L)	5	22	9

Table B-8. 2000 Phytoplankton Data (Downing et al., 2002b)

	6/22/2000	7/18/2000	8/09/2000
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	2.21E-01	0.00E+00	5.60E-02
Chlorophyta	0.00E+00	0.00E+00	1.80E-02
Cryptophyta	0.00E-00	6.50E-02	2.14E+00
Cyanobacteria	7.11E+00	1.21E+02	1.14E+02
Dinophyta	0.00E-00	0.00E+00	0.00E+00
Euglenophyta	0.00E-00	0.00E+00	0.00E+00
Total	7.33E+00	1.21E+02	1.16E+02

Table B-9. 2001 Phytoplankton Data (Downing et al., 2004b)

	5/23/2001	6/19/2001	7/24//2001
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	0.00E+00	9.00E-03	0.00E+00
Chlorophyta	5.51E+00	1.00E-00	0.00E+00
Cryptophyta	1.90E-01	0.00E+00	0.00E+00
Cyanobacteria	6.51E+02	2.20E-02	2.78E+02
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	0.00E+00	0.00E+00
Total	6.56E+02	1.03E+00	2.78E+02

Table B-10. 2002 Phytoplankton Data (Downing et al., 2004c)

	5/29/2002	6/25/2002	7/30/2002
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	1.83E+02	0.00E+00	5.98E+00
Chlorophyta	2.41E+00	0.00E+00	2.04E+01
Cryptophyta	0.00E+00	0.00E+00	1.73E-01
Cyanobacteria	2.30E+02	4.99E+03	5.42E+01
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	0.00E+00	0.00E+00
Total	4.15E+02	4.99E+03	6.05E+01

Table B-11. 2003 Phytoplankton Data (Downing et al., 2004e)

	5/29/2003	6/25/2003	7/30/2003
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	6.74E+00	1.07E-01	3.46E-01
Chlorophyta	1.88E-01	0.00E+00	2.92E-01
Cryptophyta	1.05E-01	0.00E+00	1.02E-01
Cyanobacteria	2.80E+01	5.94E+02	1.44E+02
Dinophyta	8.80E-02	0.00E+00	0.00E+00
Euglenophyta	2.10E-02	0.00E+00	0.00E+00
Total	3.51E+01	5.94E+02	1.45E+02

Table B-12. 2004 Phytoplankton Data (Downing et al., 2004f)

	5/26/2004	6/21/2004	7/28//2004
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	4.86E+00	1.81E+00	1.33E+00
Chlorophyta	0.00E+00	2.78E-01	0.00E+00
Cryptophyta	2.70E-01	2.40E-02	0.00E+00
Cyanobacteria	1.42E+02	1.53E+02	5.79E+02
Dinophyta	0.00E+00	0.00E+00	1.91E-01
Euglenophyta	0.00E+00	1.06E-01	0.00E+00
Total	1.48E+02	1.56E+02	5.81E+02

Table B-13. 2005 Phytoplankton Data (Downing et al., 2005b)

	6/01/2005	6/28/2005	7/28//2005
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	3.61E+01	1.77E+00	2.30E+01
Chlorophyta	1.03E+00	1.40E-02	5.57E-01
Cryptophyta	1.94E+00	4.37E-01	2.87E+00
Cyanobacteria	0.00E+00	2.89E+03	1.81E+01
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	5.46E-01	8.19E-01
Total	3.91E+01	2.89E+03	4.54E+01

Table B-14. Zooplankton data from 2000-05 (average dry mass in ug/L).

Suborder	2000	2001	2002	2003	2004	2005
Cladocera	57.757	109.22	159.69	265.42	175.21	40.45
Copepoda	20.123	37.934	209.40	105.81	163.80	49.69
Rotifera	0.170	2.847	32.02	5.48	2.49	7.16

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

10. Appendix C - Trophic State Index

Carlson's Trophic State Index

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

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

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

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

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

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

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

SD = lake Secchi depth, meters

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

Table C-1. Changes in temperate lake attributes according to trophic state (modified from U.S. EPA 2000, Carlson and Simpson 1995, and Oglesby et al. 1987).

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

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

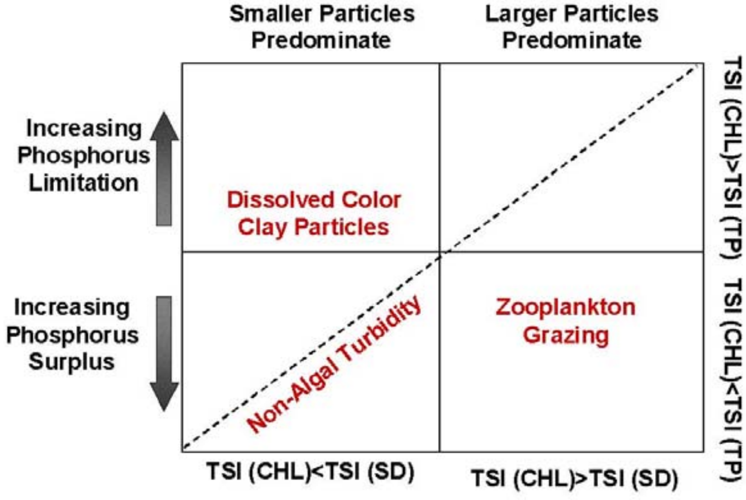
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 → 65	*12 → 33*	*1.4 → 0.7*
partially supported (evaluated: in need of further investigation)	65 → 70	*33 → 55*	*0.7 → 0.5*
partially supported (monitored: candidates for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

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

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

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

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



Littlefield Lake TSI Values

Table C-4. 1990 Littlefield Lake TSI Values

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
5/27/1992	67	61	65
6/24/1992	73	58	70
7/19/1992	65	49	59

Table C-5. 2000 - 2004 Littlefield Lake TSI Values

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/22/2000	65	64	75
7/18/2000	65	55	88
8/09/2000	65	52	73
5/23/2001	67		69
6/19/2001	70	79	73
7/24/2001	70	73	87
5/29/2002	65	61	68
6/25/2002	83	77	82
7/30/2002	73	77	78
5/29/2003	46	55	61
6/25/2003	73	66	80
7/30/2003	70	65	90
5/26/2004	93	46	94
6/21/2004	56	57	60
7/28/2004	73	75	70
6/01/2005	63	70	69
6/28/2005	83	84	75
7/28/2005	67	76	73

11. Appendix D - Land Use Maps

Figure D-1. Littlefield Lake Watershed 2005 Landuse