Total Maximum Daily Load For Algae and Turbidity Five Island Lake, Palo Alto County, Iowa

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Iowa Department of Natural Resources
Watershed Improvement Section

Prepared by Parsons Corporation

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TMDL INFORMATION SHEET

Total Maximum Daily Load for Five Island Lake

Waterbody: Five Island Lake
Water Quality Impairment: Algae and Turbidity

County:	Palo Alto County, Iowa
Lake Area:	964 acres
Watershed Area:	8,689 acres
Designated Use that is Impaired:	A1 (primary contact recreation); B (LW) (aquatic life)
303(d) Listing:	Algae Growth / Chlorophyll-a and Turbidity
Trophic State Index Targets:	Total Phosphorus < 68 (98.5% of current level) Chlorophyll < 65 Secchi Depth < 65

Summary of TMDL Results for Total Phosphorous

TMDL (lbs/yr)	**4,065**
WLA (lbs/yr)	**0**
LA (lbs/yr)	**3,658**
MOS (lbs/yr)	**407**
Existing Load (lbs/yr)	**4,408**
% Reduction	**17.0%**

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1.1 Watershed Description

Five Island Lake is located on the north side of Emmetsburg, Iowa, in Palo Alto County. The lake is a glacial lake that is five miles long and a half mile wide, with a surface area of 964 acres. The Lake is widely used for boating, skiing, fishing, and swimming. In the winter, it is used for ice fishing, skating, cross country skiing, etc. Boat ramps are available around the lake. On the west side of the lake is Kearney State Park, which provides camping and picnicking facilities, and Emmetsburg Golf Club. To the south is a swimming beach, a beach house, and Soper Park which is extensively used in the summer for public events. Private homes dot the shoreline of the lake.

Five Island Lake has been identified as impaired by algae blooms in response to high nutrient loading. Table 1 lists key features of Five Island Lake.

Table 1: Five Island Lake Features

Waterbody Name:	Five Island Lake
Hydrologic Unit Code:	07100002
IDNR Waterbody ID:	IA 04-UDM-03850-L
Location:	S18, T96N, R32W
Latitude:	43° 7’ 56’’ N
Longitude:	94° 40’ 56’’ W
Water Quality Standards Designated Uses:	1. Aquatic Life Support 2. Primary Contact Recreation
Tributaries:	Unnamed intermittent creek
Receiving Waterbody:	Five Island Lake
Lake Surface Area:	964 acres
Maximum Depth:	20 feet
Mean Depth:	5 feet
Volume:	4,820 acre-feet
Length of Shoreline:	14.2 miles
Watershed Area:	8,689 acres
Watershed/Lake Area Ratio:	9.2 : 1
Estimated Detention Time:	0.92 year

Morphometry

Five Island Lake has a mean depth of 5 feet and a maximum depth of 20 feet. The lake surface area is 964 acres and the storage volume is 4,820 acre-feet. These figures are based on values available prior to the recent dredging project. As the project nears completion, new bathymetric maps will be completed, providing new depth and storage volume estimates.

Hydrology

Five Island Lake is fed by an unnamed intermittent tributary. Average rainfall in the area is 29.2 inches. The annual average detention time for Five Island Lake is 0.92 year based on inflow and direct precipitation. The methodology and calculations used to determine the detection times are shown in Appendix A.

Land Use

Five Island Lake has a watershed area of 8,689 acres and has a watershed to lake ratio of 9.2 to 1. Land uses for Five Island Lake watershed are listed in Table 2.

Table 2: Land Use in Five Island Lake Watershed

Land Use	Area (acres)	Percent
Cropland	6,565	75.5%
Water	982	11.3%
Permanent Grass	686	7.9%
Park	214	2.5%
Road	41	0.5%
Farmstead	104	1.2%
Pasture	98	1.1%
Total	8,689	100%

There are no point sources or confined animal feeding operations (CAFO) within the Five Island Lake watershed.

Figure 1 shows the location of Five Island Lake. Figure 2 illustrates the land use of the lake and its watershed.

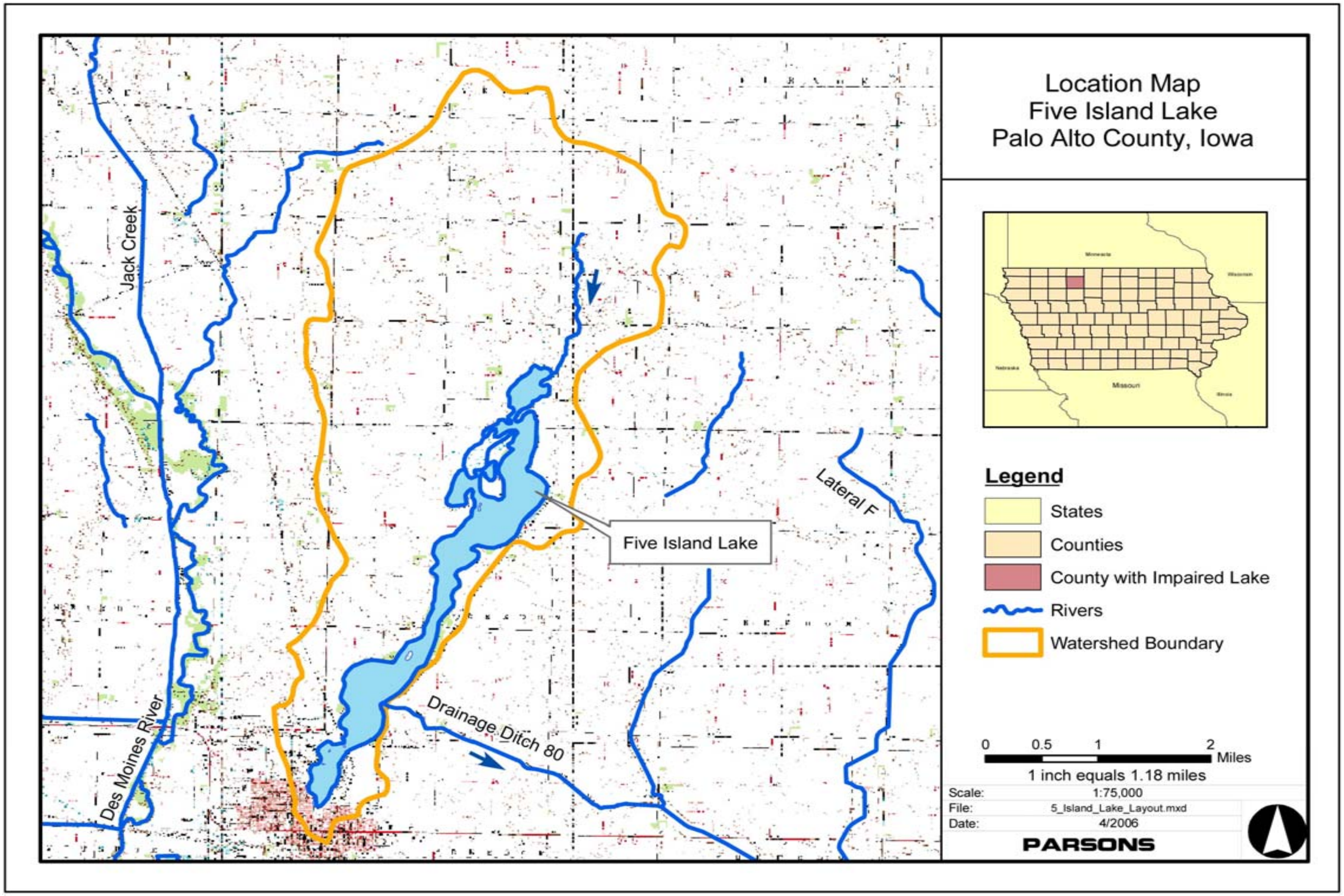

Figure 1: Location Map for Five Island Lake

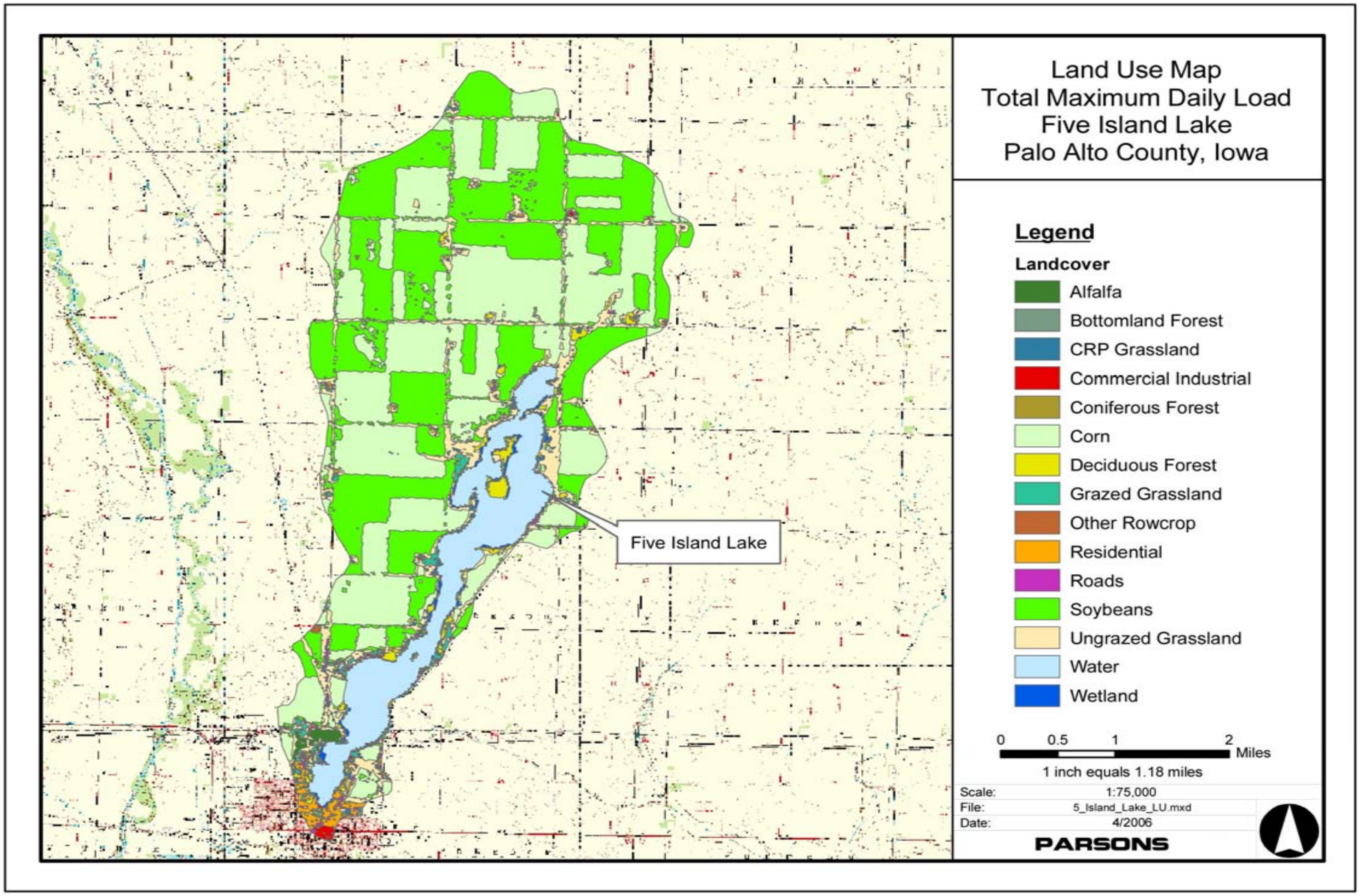

Figure 2: Land Use Map for Five Island Lake

1.2 Problem Identification and Current Conditions

Section 303(d) of the Clean Water Act and the USEPA Water Quality Planning and Management Regulation (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies not meeting applicable water quality standards or designated uses under technology-based controls. TMDLs identify the maximum amount of a pollutant that a waterbody can assimilate and still meet water quality standards.

The Iowa Water Quality Standards (IAC 567-61) list the designated uses for Five Island Lake as Primary Contact Recreational Use (Class A) and Aquatic Life (Class B(LW)).

Five Island Lake was included on the impaired waters list due to algae and turbidity impairments. The Class A (primary contact recreation) uses are assessed (monitored) as "partially supported" due to slightly elevated levels of algal and non-algal turbidity at Five Island Lake. The Class B(LW) aquatic life uses are assessed (evaluated) as "fully supporting / threatened" due to algae and non-algal turbidity (IDNR, 2004).

<u>Data Sources</u>

The primary data used to assess the water quality of Five Island Lake and to develop this TMDL are from an Iowa State University Lake Study that began in 2000. Data for this study were collected from 2000 to 2005 on three occasions during the summer growing seasons. The samples were analyzed for variables including chlorophyll, secchi depth, total phosphorus and total nitrogen series, and suspended solids. A summary of this data is provided in Appendix B.

<u>Five Island Lake Water Quality Assessment</u>

Carlson's trophic state index (TSI) has been used to relate TP, algae (as measured by chlorophyll) and transparency (as measured by secchi depth) to set water quality targets. TSI values for monitoring data are shown in Table 3. Using the median values from this survey from 2000 through 2005, Carlson's TSI values for secchi depth, chlorophyll-a, and total phosphrous are 65, 66, and 69, respectively. A detailed explanation on the TSI can be found in Appendix C.

Table 3: Five Island Lake TSI Values Based on Iowa Lake Survey Data

Sample Data				TSI Values		
DATE: Jul. 2000 – Aug. 2005	**Secchi Depth (m)**	**Chlorophyll (µg/L)**	**Total Phosphorus (µg/L)**	**Secchi Depth**	**Chlorophyll**	**Total Phosphorus**
average	0.75	42	92	64	67	69
median	**0.7**	**36**	**88**	**65**	**66**	**69**
TARGETS	**> 0.7**	**< 33**	**< 96**	**< 65**	**< 65**	**< 70**

These index values suggest (1) marginally high levels of chlorophyll-a in the water column, (2) marginally low levels of total phosphorus, and (3) marginally high transparency as secchi depth.

Comparison of TSI values for TP, chlorophyll and secchi depth for Five Island Lake shows the occurrence of a higher TSI value for TP with relatively lower values for chlorophyll-a and secchi depth. This typically indicates that algae dominate light attenuation but some factor (e.g. nitrogen limitation, zooplankton grazing or some other factor) other than phosphorus limits algal biomass.

Plots that compare the three TSI variables are shown in Figures 3 and 4.

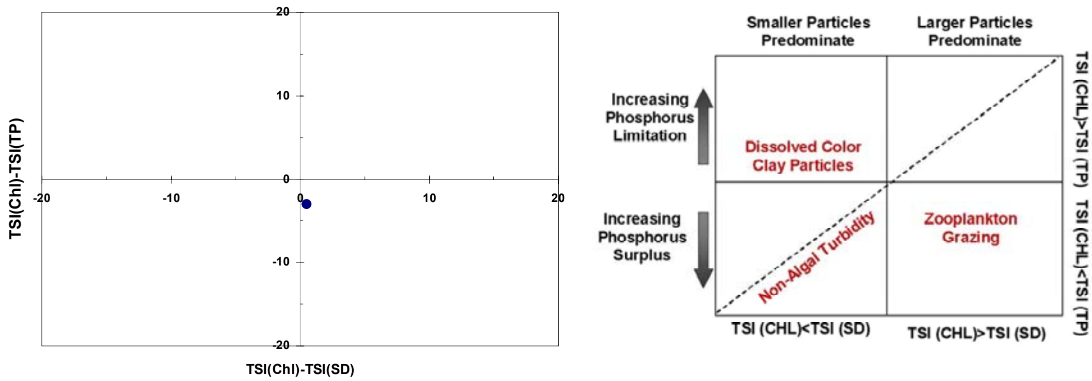

Figure 3: Five Island Lake Median TSI Multivariate Comparison Plot
(Plotted Point: 0.5, -3.1)

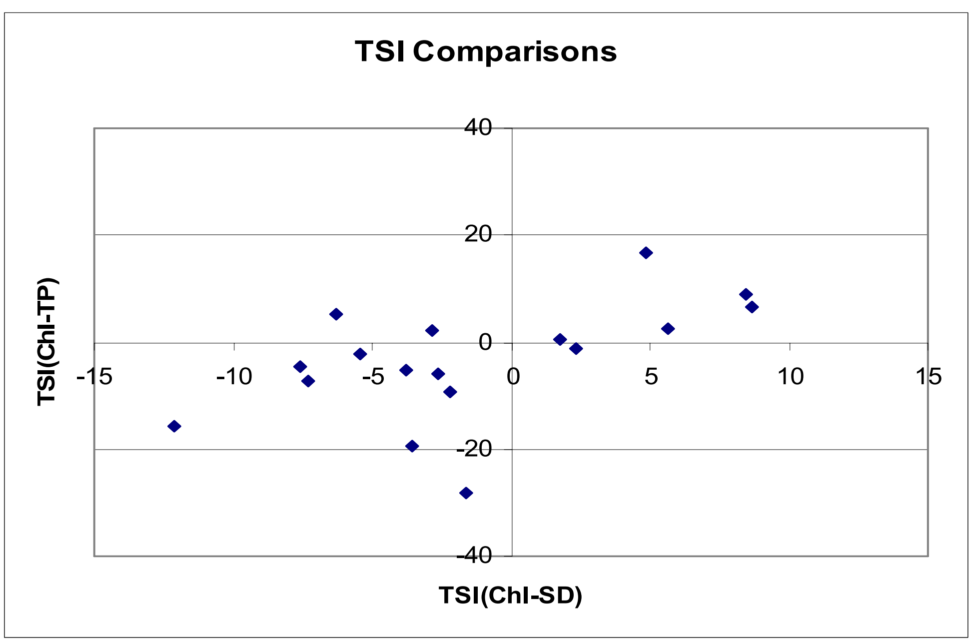

Figure 4: Five Island Lake TSI Comparison Plot

Downing et al. (2003) shows a moderately large population of zooplankton species at Five Island Lake that graze on algae. Sampling in 2000 showed that Cladoceran taxa (e.g., Daphnia) comprised approximately 15% of the dry mass of the zooplankton community in the mid-July sample and 30% of the early August sample. The summer 2000 average mass of Cladocerans (19 mg/L) was only the 64th highest of the 131 lakes sampled. Thus, zooplankton grazers likely have a limited influence on limiting algal production (IDNR, 2004).

Based on median values from ISU sampling from 2000 through 2005, the ratio of total nitrogen to total phosphorus for Five Island Lake is 32, which indicates phosphorus is the limiting nutrient for algal production at this lake.

The TSI value for TP is slightly higher than TSI for chlorophyll. This implies there could be limitations to algae growth besides phosphorus (e.g. non-algal particulates). Based on results of the ISU monitoring from 2000-2005, the primary non-phosphorus limitation to algal production appears to be inorganic suspended solids. In Figure 4, the data points for TSI (Chl-SD) and TSI (Chl-TP) are scattered along both axis. The median TSI (Chl-TP) and TSI (Chl-SD) are (0.5, -3.1), which suggests although non-algal turbidity is a component of algae problem, its impact is not quite strong.

The levels of inorganic suspended solids at this lake are relatively high and likely contribute to in-lake turbidity and suppression of algal production. The median level of inorganic suspended solids in the 131 lakes sampled for the ISU lake survey from 2000 through 2002 was 4.8 mg/L. The median level of inorganic suspended solids at Five Island Lake from 2000 through 2005 was 12.0 mg/L. This suggests that non-algal turbidity likely limits the production of algae as well as contribute to in-lake turbidity that threatens full support of designated uses at this lake. Thus, the slightly elevated TSI value for chlorophyll-a suggests potential impairments of the Class A (primary contact) uses through presence of reduced water transparencies caused by algae and by inorganic suspended solids.

The levels of bluegreen algae at this lake are low and neither threaten nor impair the designated uses. Sampling in 2000 showed the percent wet mass of bluegreens ranged from approximately 45% in the mid-June sampling, to approximately 55% in the late July sampling, and approximately 40% in the late August sampling. The summer 2000 average wet mass of bluegreen algae at this lake (6.7 mg/L) was the 49th lowest of the 131 lakes and thus does not suggest a significant problem (Downing et. al., 2003).

Overall, Five Island Lake has consistently shown improvement over time. The water quality improvements at Five Island Lake reflect results of the lake dredging project.

1.3 TMDL Endpoint

The ultimate goal of this TMDL is to reduce the excessive algae and turbidity in Five Island Lake. A TMDL target has been established to link water chemistry, particularly nutrients, to the characteristic of an ecosystem (e.g. lake) that may be affected by exposure, or in this case cause observed algae bloom and lake transparency problems. Water quality targets are quantifiable measures that are protective of water use attainment similar to water quality standards.

Iowa does not have numeric water quality criteria for algae or turbidity. The cause of Five Island Lake algae and turbidity impairments is algal blooms caused by excessive nutrient loading to the lake and potentially inorganic suspended solids due to re-suspension of sediment. The TSI is used as a guideline to relate phosphorus loading to the algal and turbidity impairment for TMDL development. It describes and explains nutrient conditions that will allow a waterbody to meet Iowa's narrative water quality standards.

Typically, a total phosphorus TSI of less than 70, which is related through the trophic state index to chlorophyll a and secchi depth, defines the nutrient-loading target. Thus the Phase I targets for lake TMDL in Iowa are normally a median TSI value of less than 70 for TP, median TSI value of less than 65 for both chlorophyll and secchi depth. These values are equivalent to TP and chlorophyll concentrations of 96 and 33 µg/L, respectively, and a secchi depth of 0.7 meters.

Because chlorophyll is in non-compliance for Five Island Lake (i.e. TSI value of 66 for median water quality data greater than target TSI of 65), the objective of this TMDL is to improve the chlorophyll by (66-65)/66 = 1.5%. Assuming a 1:1 response between TSI (Chl-a) and TSI (TP), the target TSI for total phosphorus is set at 98.5% of its current TSI level, which corresponds (69*0.985) = 68. TSI of 68 for TP corresponds to in-lake TP target 82 µg/L. Table 4 describes TMDL existing and target values for TSI and concentrations in Five Island Lake.

Table 4: Five Island Lake Existing versus Target Values

Parameter	2000-2005 Median TSI	2000-2005 Median Value	Target TSI	Target Value	Water quality improvements needed, as defined by TSI
Total Phosphorus	69	88 µg/l	<68	<82 µg/L	1.5% Reduction
Chlorophyll a	66	36 µg/l	<65	<33 µg/L	1.5% Reduction
Secchi Depth	65	0.7 m	<65	>0.7 meters	0% Increase

Because the ambient water quality improvement through BMP implementations to reduce phosphorus load would also translate to a commensurate reduction in chlorophyll, the levels of algae would thereby decrease and chlorophyll levels would be expected to drop below impairment thresholds. However, future monitoring will be needed to determine if phosphorus loading reduction will result in full compliance of the TSI target for chlorophyll-a.

2. Calculation of Total Maximum Daily Load

The following equation was used to calculate the TMDL.

TMDL = WLA + LA + MOS (Eq. 1)

where:

TMDL: Total Maximum Daily Load
WLA: Waste Load Allocation (for point sources)
LA: Load Allocation (for non-point sources)
MOS: Margin of Safety (to account for uncertainties in TMDL development)

2.1 TMDL Calculation

TMDL is defined as the maximum pollutant load that a waterbody can assimilate and still attain water quality standards. The TMDL for Five Island Lake calculates the maximum allowable phosphorus loading that will meet narrative standards for nuisance algal blooms and turbidity, thus provide water quality fully supporting the lake's designated uses. The relationship of total phosphorus to chlorophyll a (algae indicator) and secchi depth (turbidity indicator) is made by using Carlson's Trophic State Index.

The Lake Phosphorus Worksheet developed by Iowa Department of Natural Resources was used as the modeling tool for this TMDL analysis.

2.1.1 Modeling Procedures and Results

The procedures used to estimate TP loads to Five Island Lake consist of:

1. Estimates of the delivered loads from the point and non-point sources in the watershed using three different methods. They are the Loading Function Model component of EUTROMOD, EPA export coefficients, and WILMS export coefficients.
2. Estimates of the annual TP load to Five Island Lake using measured in-lake phosphorous concentrations, estimated hydraulic detention time, and mean depth as inputs for eleven different empirical models.
3. Comparison of the estimated TP loads based on watershed sources and the empirical models to select the best-fit empirical model for existing loads.
4. Estimates of the allowable TP loads at the target concentration (TP = 82 µg/L) for the lake, using the selected empirical model.

Table 5 lists the watershed and lake response models used to evaluate the existing and targeted Five Island Lake water quality conditions.

Watershed Load Estimates

The three watershed load estimates are different because the procedures and assumptions about loads from different land uses and the way that these are accounted for are different.

The loading function procedure is based on the Annual Loading Function Model in within the EUTROMOD Watershed and Lake Model by Reckhow (1990) to evaluate nutrient load delivered to lakes. It incorporates approximations of both soluble phosphorous in the runoff to Five Island Lake and the sediment attached phosphorus derived from erosion modeling and an estimated delivery ratio that considers watershed size and ecoregion. Export coefficients in EPA and WILMS methods are unit area annual averages for phosphorous loads associated with a particular land use.

Lake Response Load Estimates

In-lake monitoring data is used in conjunction with empirical mass balance models to estimate total phosphorus loads delivered to the lake that would cause the observed concentrations. These loads include the watershed nonpoint and point source loads, phosphorus recycled by re-suspension of sediment, and phosphorous from direct rainfall and dry deposition.

The estimated annual average TP load by Loading Function Method, EPA Export Coefficient Method and WILMS Export Coefficient Model is 14,250 lbs/year, 8,143 lbs/year and 5,614 lbs/year.

The marginally low total phosphorus (88 µg/L) and inorganic suspended solids (12.0 mg/L) at Five Island Lake indicate a minor internal loading. Given lack of site-specific data for lake sediment, the internal load for Five Island Lake is assumed as insignificant in the TMDL calculation.

Table 5: Model Results for Five Island Lake

Watershed Load Estimates	Predicted Existing Annual TP Load (lbs/yr)[1]	Comments
Loading Function Method	14,250	Reckhow (Eutromod)
EPA Export Coefficient Methid	8,143	EPA 440-5-80-011
WILMS Export Coefficient Model	5,614	"most likely" export coefficients[3]
In-lake response load estimates		
1. Canfield-Bachmann 1981 Natural Lake	3,736	Growing Season Mean (GSM) model
2. Canfield-Bachmann 1981 Artificial Lake	6,192	GSM model
3. Reckhow Natural Lake	10,277	GSM model
4. Reckhow Anoxic Lake	1,607	GSM model
5. Reckhow Oxic Lake (Z/Tw < 50 m/year)	3,138	GSM model
6. Vollenweider 1982 Combined OECD	3,833	Annual Model[2]
7. Vollenweider 1982 Shallow Lake and Reservoir	4,408	Annual Model[2]
8. Walker Reservoir	4,912	Annual Model[2]
9. Simple First Order (Walker)	1,945	Annual Model[2]
10. First Order Settling	1,945	Annual Model[2]
11. Nurnberg 1984 Oxic Lake - Lake response external load when internal load = zero	5,275	Annual Model[2]
Nurnberg external load from Loading Function Method	2,898	
Nurnberg internal load, calculated based on external load	563	

(1) For in-lake GSM concentration TP = ANN TP = 88 µg/l (which is lower than target TP 96 µg/l). This is the average of the ISU Lake Study TP values, from 2000 to 2005.
(2) Note that P annual = P growing season for polymictic lakes.
(3) There are three values estimates for the WILMS export coefficients, low, most likely, and high.

After verifying whether all model parameters are in range, the applicable in-lake response models whose parameters are within the range in Table 5 are:

- Canfield-Bachmann 1981 Natural Lake, 3,736 lbs/year
- Vollenweider 1982 Combine OECD, 3,833 lbs/year
- Vollenweider 1982 Shallow Lake and Reservoir, 4,408 lbs/year

Vollenweider Shallow Lake and Reservoir model is preferred, because it is closest to the range of estimate by three watershed loading methods (Loading Function method, EPA and WILMS Export Coefficient methods). In addition, it is derived from analysis of shallow lakes comparable to Five Island Lake (mean depth is 5 feet). For a polymictic lake, the annual average phosphorus concentration can be approximated by the growing season concentration.

The equation for Vollenweider 1982 Shallow Lake and Reservoir model is:

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

where,

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

L = areal total phosphorus load (mg/m^2 of lake area per year)

T_w = lake hydraulic detention time (years)

z = lake mean depth (meters)

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

$$P(88ug / L) = 1.02[\frac{(513*0.92 / 1.52)}{1+\sqrt{0.92}}]^{0.88}$$

The calculations for the loading capacity of total phosphorus for Five Island Lake are as follows:

$$P(82ug / L) = 1.02[\frac{(473*0.92 / 1.52)}{1+\sqrt{0.92}}]^{0.88}$$

The annual total phosphorus is obtained by multiplying the areal load (L in mg/m^2) by the lake area (in square meters) and converting the resulting value to pounds. The loading capacity of total phosphorus for Five Island Lake is 4,065 lbs/year. This TMDL has established annual loads rather than daily loads because the lake response is a result of the loading for an extended time period prior to any given measurement. There is little, if any benefit, in modeling the lake on a daily basis nor to establish targets on a daily basis. While localized turbidity and, to some degree, algae may be tracked as responding to short-term rainfall, targets set on a yearly basis or on a daily basis would not change the implementation practices necessary for this non-point source only TMDL.

The chlorophyll a and secchi depth objectives are related through the Trophic State Index to total phosphorus. The loading capacity for this TMDL is the annual amount of total phosphorus that Five Island Lake can receive but still meet its designated uses.

Based on selected lake response model and a target TSI (TP) value of less than 68 (corresponding to an in-lake average TP concentration of 82 µg/L), the TMDL for total phosphorus is 4,065 lbs/year.

2.1.2 Estimate of Existing Loads:

There are two quantified phosphorus sources for Five Island Lake in this TMDL. The first is the phosphorus load from the watershed areas that drain directly into the lake and the phosphorus recycled from lake sediments (internal load). The second source is atmospheric deposition.

<u>Existing Load</u>

The existing annual total phosphorus load to Five Island Lake is estimated to be 4,408 lbs/year, based on the selected lake response model.

<u>Departure from Loading Capacity</u>

The loading capacity of total phosphorus for Five Island Lake is 4,065 lbs/year. The existing watershed load is estimated as 4,408 lbs/year. Therefore, a load reduction of 343 lbs/year is needed in order to achieve water quality goals and protect the designated uses.

Identification of Pollutant Sources

There are no significant point source discharges in the Five Island Lake watershed. Most phosphorous is delivered to the lake from nonpoint sources. Figure 5 shows the TP loads for the external watershed sources estimated by the Loading Function Model. As can be seen, most nonpoint source phosphorus delivered to the lake is from cropland.

Linkage of Pollution Sources to TMDL Target

The pollutant sources of TP from the watershed have been linked to the water quality impairment through the use of Loading Function model, EPA and WILMS export coefficient models, along with selected in-lake response model in Lake Phosphorus Worksheet by IDNR.

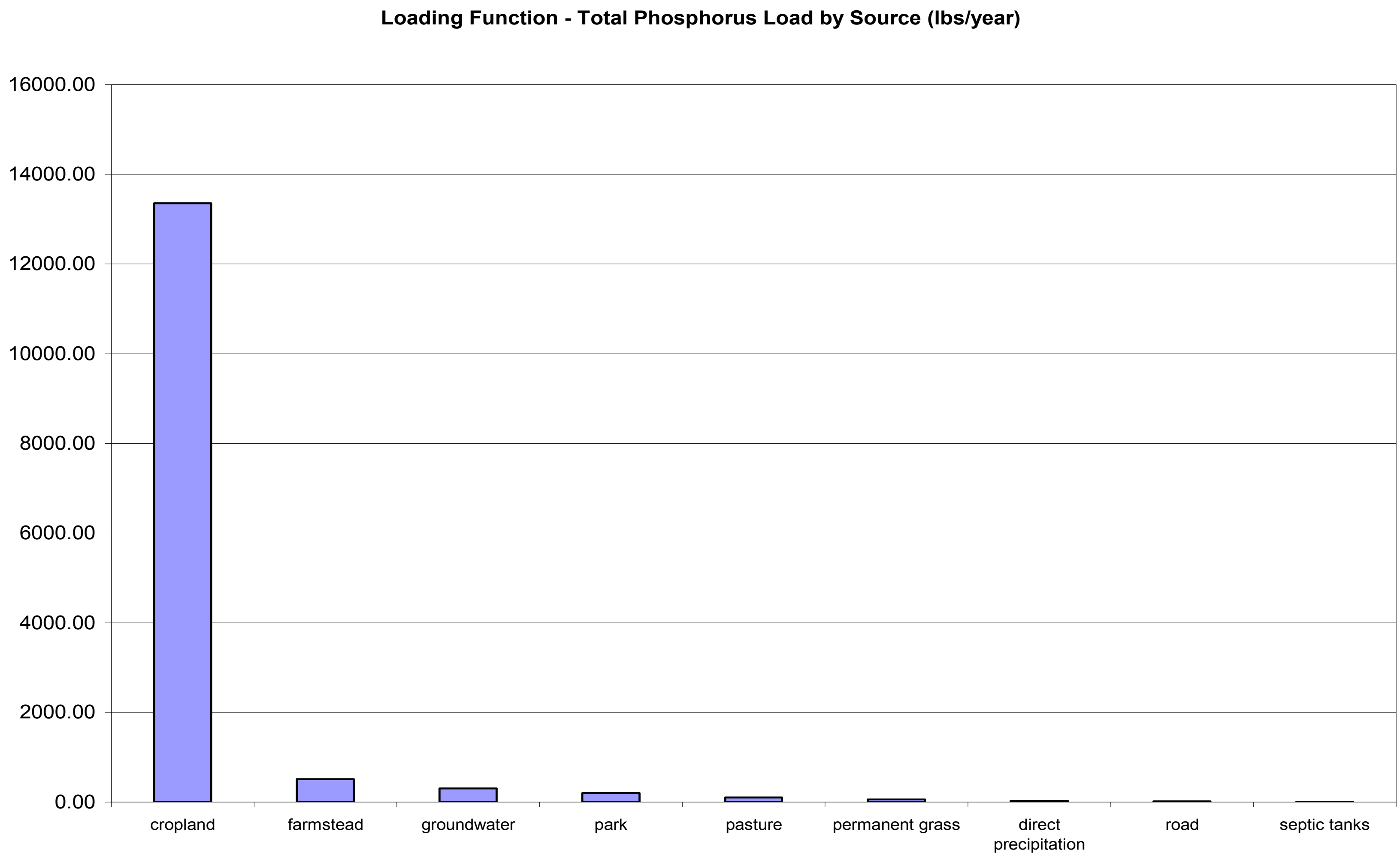

Figure 5: Loading Function Model - Total Phosphorus Load by Source (lbs/year)

2.2 Consideration of Critical Condition and Seasonal Variations

(1) Critical Condition

The Clean Water Act [40 CFR 130.7(c)(1)] and USEPA'S TMDL regulations require that in developing TMDLs, one must "*take into account the critical conditions for stream flow, loading, and water quality parameters*". The "critical condition" is generally defined as the condition when the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or characteristic water uses. The intent of this requirement is to ensure that the water quality of the receiving water body is protected during times when it is most vulnerable.

The critical condition for this TMDL study is during the growing season (May through September) when nuisance algal blooms and low transparency in the lake are most likely to occur. During this critical flow period, impacts from wet weather sources are limited since storm runoff is minimal under dry weather condition.

The existing and target total phosphorus loadings to the lake are expressed as annual averages. The model selected for estimating phosphorus loading to the lake utilizes annual in-lake total phosphorus concentrations to calculate an annual average total phosphorus loading. For polymictic lake, the annual average phosphorus concentration can be approximated by the growing season concentration.

(2) Considerations of Seasonal Variations

The TMDL target was derived using May through September data when nuisance algal blooms and low transparency in Five Island Lake were most likely to occur. By using data from this most problematic period instead of the entire year, the target is meant to prevent nuisance algal bloom and low transparency occurrences year-round. If a phosphorus limit were instituted for the growing season only, it would ignore the effects of nutrient re-suspension in the water column within Five Island Lake.

2.3 Margin of Safety

The Margin of Safety (MOS) is included to account for uncertainties associated with TMDL development including WLA, to protect water quality in the event that the "true" TMDL (or WLA) is underestimated, and to assure that the watershed is adequately protected. EPA's TMDL guideline (USEPA, 1999) suggests using an implicit or explicit approach to estimate the MOS. The implicit approach is to incorporate MOS using conservative model assumptions to develop allocations while the explicit approach is to reserve a portion of the total TMDL for MOS.

Based on data availability for this TMDL study and guidance from EPA and IDNR, an explicit margin of safety 10% (407 lbs/year) of loading capacity is reserved for MOS.

2.4 Waste Load Allocation:

The Waste Load Allocation (WLA) is the maximum allowable amount of the pollutant that can be assigned to point sources. There are no point sources or CAFOs in the Five Island Lake watershed. Therefore, the WLA for this TMDL is set at zero pounds per year.

2.5 Load Allocation:

Load Allocation (LA) can be calculated from (Eq. 1) by subtracting WLA and MOS from TMDL.

TMDL = WLA + LA + MOS

LA = TMDL – MOS – WLA (Eq. 2)
= 4,065 – 10%*4,065 – 0 = 3,658 lbs/yr

LA for this TMDL is further divided into watershed non-point sources and atmospheric deposition. Assuming atmospheric deposition consists of 10% of total LA, the watershed nonpoint source load is:

3,658 lbs/yr – 10%*3,658 lbs/yr = 3,292 lbs/yr

2.6 Percentage of Reduction:

Estimating required percentage of reduction is given as follows:

Determination of Required Load Reduction
% TP Reduction = (Existing Load – LA) / Existing Loading (Eq. 3)
= (4,408 – 3,658) / 4,408 = 17.0%

A TP load reduction of 17.0% is needed in order to achieve water quality goals and protect the designated uses.

Table 6: Summary of TMDL Results for Five Island Lake

TMDL (lbs/yr)	**4,065**
WLA (lbs/yr)	**0**
LA (lbs/yr)	**3,658**
MOS (lbs/yr)	**407**
Existing Load (lbs/yr)	**4,408**
% of Reduction	**17.0%**

3. Reasonable Assurance

Reasonable assurance of the TMDL established for Five Island Lake will require a comprehensive approach that addresses:

- non-point source pollution (since there are no point sources in the watershed),
- existing and potential future sources,
- regulatory and voluntary approaches.

There is reasonable assurance that the goals of the TMDL for Five Island Lake can be met with proper watershed planning, implementation of BMPs, and strong financial mechanisms. As can be seen in the development of the TMDL, there are two major components to the phosphorous inputs for Five Island Lake, the external watershed load and the internal recycled load. Because of the uncertainty as to how much of the phosphorus load originates in the watershed and how much is recycled from lake bottom sediment, an adaptive management approach to phosphorous reduction is recommended. In this approach management practices to reduce both watershed loads and recycled loads are incrementally applied and the results monitored to determine if water quality goals have been achieved.

Reaching the reduction goals established by these TMDLs will only occur through changes in current land use practices, including the incorporation of best management practices (BMPs). BMPs that would be helpful in lowering the amount of nutrients and sediments reaching Five Island Lake include riparian buffer strips, strip cropping, contour plowing, and conservation crop rotation, among many others. The Natural Resources Conservation Service maintains a National Handbook of Conservation Practices (NHCP), which provides information on a variety of BMPs (USDA, 2005). The NHCP is available online at (http://www.nrcs.usda.gov/technical/standards/nhcp.html). Many of the practices described in the handbook could be used on agricultural lands in the Five Island Lake watershed to help limit impairments due to algae growth and turbidity.

Determining the most appropriate BMPs, where they should be installed, and actually putting them into practice, will require the development and implementation of a comprehensive watershed restoration plan. Development of any watershed restoration plan will involve the gathering of site-specific information regarding current land uses and existing conservation practices. Successful implementation of the activities necessary to address current use impairment in Five Island Lake watershed will require local citizen’s active interest in the watershed and cooperation of other relevant entities. By developing nutrient TMDL for Five Island Lake, the stage has been set for local citizens to design and implement restoration plans to correct current use impairments. For example, the citizens of Emmetsburg have invested over $1.5 million in the dredging and improvement of the lake. The long-term project has resulted in reaching their goal – to improve the water quality and depth (IDNR, 2006a).

4. Implementation Plan

An 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 Five Island Lake water quality. This plan will continue to be developed in cooperation with local partners through the public participation process.

During the public meeting held in Emmetsburg, local stakeholders presented several needs for improving Five Island Lake. Needs were identified in both the watershed and within Five Island Lake.

To address the needs in the watershed, the Palo Alto Soil and Water Conservation District was awarded a Development Grant in 2006 for use in completing a more thorough assessment of the watershed and in preparation for grant applications for funds through the CWA Section 319 program administered by the Iowa DNR and also for grant funds administered by the Iowa Department of Agriculture and Land Stewardship – Division of Soil Conservation.

Other watershed needs include addressing illegal or failing septic systems within the watershed. The Palo Alto Soil and Water Conservation District has submitted a grant application to the Watershed Improvement Review Board to address septics in the Five Island Lake watershed.

Stakeholders at the public meeting felt it is important to investigate alternatives to field tile surface intakes. It was generally felt that these allowed sediment to enter the tile system and therefore the lake. Creating a way that allows the water to infiltrate to the tile would reduce the sediment transport. Adopting systems similar to those used in Waseca, MN was discussed, where a rock bed is created and covered with soil. These are a new technology and do not yet have an approved NRCS design standard, but continued research should be conducted as to their applicability and effectiveness.

Several needs exist within Five Island Lake. The Five Island Lake Restoration Board has been dredging Five Island Lake since 1989. This project has deepened the lake, as well as removed sediment and nutrients from the system, thereby improving water quality. The IDNR continues to support this project, contributing $100,000 towards operational costs of dredging in FY2007.

Managing the rough fish population, particularly carp in Five Island Lake may also improve water quality in the lake. Removing carp should also result in the reestablishment of aquatic plants which will bind sediments of the lake bottom and utilize available nutrients.

5. Monitoring

Further monitoring is needed at Five Island 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 Five Island Lake, with a minimum of three samples collected per growing season.

6. Public Participation

A public meeting was held in Emmetsburg on July 26, 2006 to discuss the Five Island Lake TMDL and begin development of the implementation strategy. The meeting was attended by representatives of the Palo Alto County Conservation Board, Palo Alto Soil and Water Conservation District, and the Five Island Lake Restoration Board. Public comments received regarding an implementation plan were incorporated in the implementation section of this TMDL.

References

Alexander, R. B., Smith, R. A., and Schwarz, G. E. (2004). Estimates of Diffuse Phosphorus Sources in Surface Wastes of the United States using a spatially referenced watershed model, *Water Sciences and Technology*, 49(3): 1-10

Bachmann, R.W., M.R. Johnson, M.V. Moore, and T.A. Noonan (1980). Clean lakes classification study of Iowa's lakes for restoration. Iowa Cooperative Fisheries Research Unit and Department of Animal Ecology, Iowa State University, Ames, Iowa. 715 p.

Bachmann, R.W., T.A. Hoyman, L.K. Hatch, and B.P. Hutchins (1994). A classification of Iowa's lakes for restoration. Iowa State University, Ames, Iowa. 517 p.

Canfield, D. E. Jr., and R. W. Bachmann (1981). Prediction of total phosphorus concentrations, chlorophyll a, and secchi depths in natural and artificial lakes. Can. J. Fish. Aquat. Sci. 38: 414-423

Carlson, R. E. (1977). A trophic state index for lakes. Limnology and Oceanography 25:378-382.

Carlson, R.E. and J. Simpson (1996). A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society, 96p. http://dipin.kent.edu/tsi.htm

Downing, J. A., Ramstack, J. M., Haapa-aho, K., and Lee, K. (2003). Iowa Lakes Survey, Department of Ecology, Evolution, and Organismal Biology, Iowa State University

Iowa General Assembly (2004). Iowa Administrative Code, Chapter 567-61: Water Quality Standards, http://www.legis.state.ia.us/IAC.html

Iowa Department of Natural Resources (IDNR) (2004). Iowa Section 303(d) Impaired Waters Listings, http://wqm.igsb.uiowa.edu/WQA/303d.html

Iowa Department of Natural Resources (IDNR) (2005). Iowa State University Statewide Lake Study, http://limnology.eeob.iastate.edu/lakereport/

Iowa Department of Natural Resources (IDNR) (2006). Water Quality Improvement Plans – Publications and Report, http://www.iowadnr.com/water/watershed/pubs.html

Iowa Department of Natural Resources (IDNR) (2006a). Lake Restoration Report and Plan 2006, http://www.legis.state.ia.us/lsadocs/Docs_Filed/2006/DFJYD152.PDF

Iowa State University (2005). Center for Agricultural Research and Rural Development (CARD) Resource and Environmental Policy Division. Iowa Lakes Valuation Project. Available at http://www.card.iastate.edu/lakes/

Organisation for Economic Co-operation and Development (OECD) (1982). Eutrophication of waters: monitoring, assessment and control, by Vollenweider, R.A., and Kerekes, J., Paris, France, 154p

Reckhow, K. H. (1990). EUTROMOD Watershed and Lake Modeling Software Tech. Transfer. North American Lake Management Society.

Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder (1997). Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703. 404 pp.

Toy, T. J. and Foster, G. R. (1998). Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands, Western Regional Coordinating Center, Office of Surface Mining, Denver, Colorado..

U.S. Army Corps of Engineers (2004). Review of Published Export Coefficient and Event Mean Concentration (EMC) Data, Report ERDC TN-WRAP-04-3

U. S. Department of Agriculture (USDA) (2000). Predicting Rainfall Erosion Losses, the Revised Universal Soil Loss Equation (RUSLE), Natural Resources Conservation Service - Field Office Technical Guide.

U. S. Department of Agriculture (USDA) (2005). National Handbook of Conservation Practices (NHCP), http://www.nrcs.usda.gov/technical/standards/nhcp.html

USEPA (1980). Modeling Phosphorus Loading and Lake Response under Uncertainty: A Manual and Compilation of Export Coefficients, EPA Report 440-5-80-011

USEPA (1998). Lake and Reservoir Bioassessment and Biocriteria, EPA Report 841-B-98-007

USEPA (1999). Protocol for Developing Nutrient TMDLs (First Edition), EPA Report 841-B-99-007

USEPA (1999a). Draft Guidance for Water Quality-based Decisions: The TMDL Process (Second Edition), EPA Report 841-D-99-001

Vollenweider, R. A. (1976). Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33:53-83

Vollenweider R. A., Kerekes J. J. (1980). Background and summary results of the OECD cooperative program on eutrophication. In: Proceedings of an International Symposium on Inland Waters and Lake Restoration, EPA Report 440/5-81-01, p26-36

Walker, W.W. (2004). BATHTUB - Version 6.1. Simplified Techniques for Eutrophication Assessment & Prediction. USACE Waterways Experiment Station, Vicksburg, MS.

Wisconsin Department of Natural Resources (2003). Wisconsin Lake Modeling Suite Program Documentation and User’s Manual. 2003 PUBL-WR-363-94.

Appendices

Appendix A – Five Island Lake Hydrologic Calculations

Appendix B – Sampling Data

Appendix C – Trophic State Index

Appendix A – Five Island Lake Hydrologic Calculations

Lake	Five Island	
Type	Impoundment	
Inlet(s)	Intermittent Stream	
Outlet(s)	Drainage Ditch 80	
Volume	4820	acre-feet
Surface Area	964	acres
Watershed Area	8851	acres
Mean Annual Precipitation	29.2	inches
Average Basin Slope	0.7	%
% Forest (2000 Land Cover)		
% Corn (2000 Land Cover)		
% Rowcrop (2002 Land Cover)	85.6	
Basin Soils Average % Sand	30.0	
Soil Permeability	4.0	inches/hour
Mean Annual Class A Pan Evaporation	49	inches
Evaporation Coefficient	0.74	
Optional User Input Inflow Estimate		acre-feet/year
Optional User Input Runoff Component		acre-feet/year
Optional User Input Baseflow Component		acre-feet/year
Mean Depth	5.0	feet
Drainage Area	7887	acres
Drainage Area	12.3	square miles
Drainage Area/Lake Area	8.2	
Mean Annual Lake Evaporation	36.3	inches
Mean Annual Lake Evaporation	2913	acre-feet/year
Annual Average Inflow	8.0	cfs
Annual Average Inflow	5783	acre-feet/year
Runoff Component	3509	acre-feet/year
Baseflow Component	2274	acre-feet/year
Direct Precipitation on Lake Surface	2346	acre-feet/year
Inflow + Direct Precipitation	8129	acre-feet/year
% Inflow	71.1	
% Direct Precipitation	28.9	
Outflow	5216	acre-feet/year
HRT Based on Inflow + Direct Precipitation	0.59	year
HRT Based on Outflow	0.92	year

Appendix B – Sampling Data

Table B-1: Data collected in 1980 Bachmann Report

Lake Survey Year	1979
Secchi Disk Depth (m)	2.4
Chlorophyll a (µg/l)	2.7
TOT Phosphorus (µ/l)	147.3
Kjeldahl Nitrogen (mg/l)	1.1
Ammonia Nitrogen (mg/l)	0.2
Nitrate + Nitrite Nitrogen (mg/l)	0.1
Seston Dry Weight (mg/l)	2.7
Turbidity (NTU)	1.6
TOT Hardness (mg/l) as $CaCO_3$	192
Calcium Hardness (mg/l) as $CaCO_3$	113.2
TOT Alkalinity (mg/l) as $CaCO_3$	147.4
Dissolved Oxygen (mg/l)	5.6
Specific Conductance (microhmes/cm) at 25°C	391.4
Sulfate (mg/l)	16.2
Chloride (mg/l)	33.5
Sodium (mg/l)	8
Potassium (mg/l)	3.5

Table B-2: Data collected in 1994 Bachmann Report

Lake Survey Year	1990
Secchi Disk Depth (m)	0.1
Chlorophyll a (µg/l)	255
TOT Phosphorus (µg/l)	282
TOT Nitrogen (mg/l)	5.4
Inorganic Suspended Solids (mg/l)	68.7
TOT Suspended Solids (mg/l)	130.4

Table B-3: Data collected in 2000 by Iowa State University

Parameter	6/15/2000	7/13/2000	8/7/2000
Lake Depth (m)	5.5	5.2	5.5
Thermocline Depth (m)	NIL	4	NIL
Secchi Disk Depth (m)	0.8	0.9	0.7
Temperature(^{o}C)	20.3	28.0	26.0
Dissolved Oxygen (mg/L)	8.4	7.7	9.0
Dissolved Oxygen Saturation (%)	93	98	111
Specific Conductivity (µS/cm)	437.5	-	400.0
Turbidity (NTU)	6	17	21
Chlorophyll a (µg/L)	19.4	-	27.1
Total Phosphorus as P (µg/L)	182	124	113
Total Nitrogen as N (mg/L)	1.63	1.55	1.57
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.36	0.25	0.17
TN:TP ratio	9	13	14
pH	8.0	8.2	8.3
Alkalinity as $CaCO_3$ (mg/L)	181	186	172
Inorganic Suspended Solids (mg/L)	10	12	14
Volatile Suspended Solids (mg/L)	10	2	12
Total Suspended Solids (mg/L)	20	14	26

Table B-4: Data collected in 2001 by Iowa State University

Parameter	5/17/2001	6/14/2001	7/19/2001
Lake Depth (m)	6.2	5.5	6.1
Thermocline Depth (m)	3.0	3.8	2.7
Secchi Disk Depth (m)	2.1	0.9	1.1
Temperature(^{o}C)	20.3	21.7	27.7
Dissolved Oxygen (mg/L)	8.9	8.1	9.4
Dissolved Oxygen Saturation (%)	99	92	120
Specific Conductivity (µS/cm)	370.7	371.0	591.3
Turbidity (NTU)	61.2	24.4	20.2
Chlorophyll a (µg/L)	5.7	17.9	28.5
Total Phosphorus as P (µg/L)	146	67	19
Total Nitrogen as N (mg/L)	2.37	3.29	2.32
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	1.37	2.18	0.96
TN:TP ratio	16	49	121
pH	7.8	8.0	8.8
Alkalinity as $CaCO_3$ (mg/L)	138	144	124
Inorganic Suspended Solids (mg/L)	15	12	2
Volatile Suspended Solids (mg/L)	4	8	9
Total Suspended Solids (mg/L)	19	20	10

Table B-5: Data collected in 2002 by Iowa State University

Parameter	5/23/2002	6/20/2002	7/25/2002
Lake Depth (m)	5.8	4.3	5.5
Thermocline Depth (m)	2.8	NIL	NIL
Secchi Disk Depth (m)	0.7	0.4	0.6
Temperature(^oC)	21.9	22.4	25.7
Dissolved Oxygen (mg/L)	9.1	7.8	8.0
Dissolved Oxygen Saturation (%)	104	89	97
Specific Conductivity (µS/cm)	424.6	547.8	457.2
Turbidity (NTU)	8.0	51.2	31.3
Chlorophyll a (µg/L)	9.8	35.6	50.8
Total Phosphorus as P (µg/L)	88	97	88
Total Nitrogen as N (mg/L)	1.74	2.18	1.44
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.46	0.83	0.20
TN:TP ratio	20	23	17
pH	8.4	8.2	8.4
Alkalinity as $CaCO_3$ (mg/L)	151	172	167
Inorganic Suspended Solids (mg/L)	11	26	13
Volatile Suspended Solids (mg/L)	6	7	13
Total Suspended Solids (mg/L)	17	34	27
SRP as P (µg/L)	3	6	2
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	337	389	300
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	34	29	40
Silica as Si (mg/L)	1.52	2.09	6.15
Dissolved Organic Carbon (mg/L)	-	-	14.12

Table B-6: Data collected in 2003 by Iowa State University

Parameter	5/22/2003	6/19/2003	7/23/2003
Lake Depth (m)	6.5	6.4	5.2
Thermocline Depth (m)	NIL	5.0	1.3
Secchi Disk Depth (m)	0.6	0.5	0.4
Temperature(^oC)	15.7	22.8	27.1
Dissolved Oxygen (mg/L)	8.5	7.6	12.6
Dissolved Oxygen Saturation (%)	86	89	158
Specific Conductivity (µS/cm)	521.9	472.7	417.6
Turbidity (NTU)	42.1	26.7	20.3
Chlorophyll a (µg/L)	20.1	31.9	40.5
Total Phosphorus as P (µg/L)	79	76	54
Total Nitrogen as N (mg/L)	3.14	3.80	1.63
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	2.64	2.10	0.13
TN:TP ratio	40	50	30
pH	8.3	8.3	9.0
Alkalinity as $CaCO_3$ (mg/L)	150	128	100
Inorganic Suspended Solids (mg/L)	19	21	4
Volatile Suspended Solids (mg/L)	6	9	14
Total Suspended Solids (mg/L)	25	30	18
SRP as P (µg/L)	4	4	1
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	620	579	298
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	31	47	112
Silica as Si (mg/L)	2.20	1.80	3.04
Dissolved Organic Carbon (mg/L)	13.71	11.96	10.98

Table B-7: Data collected in 2004 by Iowa State University

Parameter	5/20/2004	6/17/2004	7/21/2004
Lake Depth (m)	6.2	6.0	6.6
Thermocline Depth (m)	5.6	NIL	0.7
Secchi Disk Depth (m)	1.0	0.7	0.4
Temperature(^{o}C)	17.3	21.6	29.1
Dissolved Oxygen (mg/L)	10.5	7.2	11.3
Dissolved Oxygen Saturation (%)	109	82	147
Specific Conductivity (µS/cm)	485.5	467.6	403.0
Turbidity (NTU)	16.9	53.9	26.5
Chlorophyll a (µg/L)	35.6	42.8	57.7
Total Phosphorus as P (µg/L)	59	87	84
Total Nitrogen as N (mg/L)	1.95	5.94	5.05
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.55	4.35	2.08
TN:TP ratio	33	68	60
pH	8.6	8.5	8.8
Alkalinity as $CaCO_3$ (mg/L)	127	160	132
Inorganic Suspended Solids (mg/L)	4	21	7
Volatile Suspended Solids (mg/L)	7	11	20
Total Suspended Solids (mg/L)	11	32	27
SRP as P (µg/L)	1	1	1
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	127	145	36
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	15	19	9
Silica as Si (mg/L)	2.02	3.33	4.35
Dissolved Organic Carbon (mg/L)	12.80	43.82	12.81
Microcystin (ng/L)	9.9	19.8	96.0

Table B-8: Data collected in 2005 by Iowa State University

Parameter	5/26/2005	6/22/2005	7/25/2005
Lake Depth (m)	6.3	6.3	6.0
Thermocline Depth (m)	NIL	1.5	2.0
Secchi Disk Depth (m)	0.5	0.8	0.4
Temperature(^oC)	17.7	26.5	29.5
Dissolved Oxygen (mg/L)	7.5	10.5	11.8
Dissolved Oxygen Saturation (%)	78	131	155
Specific Conductivity (µS/cm)	515.0	496.2	423.4
Turbidity (NTU)	54.6	6.9	23.2
Chlorophyll a (µg/L)	37.6	67.3	181.8
Total Phosphorus as P (µg/L)	106	69	116
Total Nitrogen as N (mg/L)	5.79	4.59	2.19
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	4.23	3.10	0.57
TN:TP ratio	56	66	19
pH	8.3	8.3	8.6
Alkalinity as $CaCO_3$ (mg/L)	209	194	147
Inorganic Suspended Solids (mg/L)	18	12	-
Volatile Suspended Solids (mg/L)	19	11	-
Total Suspended Solids (mg/L)	36	23	-
SRP as P (µg/L)	-	1	1
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	14.7	247.6	60.2
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	0.8	27.1	14.4
Silica as Si (mg/L)	1.93	4.04	4.69
Dissolved Organic Carbon (mg/L)	6.63	5.91	7.55
Microcystin (ng/L)	1.39	14.67	5.81

*Index values generally range between 0 and 100, with increasing values indicating more eutrophic conditions.

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

Table B-9: TSI values calculated from the Iowa Lake Survey data through 2005 and the mean and median values for the Secchi depth, chlorophyll, and total phosphorus

Sample Data					TSI Values		
DATE	**SOURCE**	**Secchi Depth (m)**	**Chlorophyll (µg/l)**	**Total Phosphorus (µg/l)**	**Secchi Depth**	**Chlorophyll**	**Total Phosphorus**
6/15/2000	IA St. Univ.	0.8	19.4	182	63	60	79
7/13/2000	IA St. Univ.	0.9	-	124	62	-	74
8/7/2000	IA St. Univ.	0.7	27.1	113	65	63	72
5/17/2001	IA St. Univ.	2.1	5.7	146	49	48	76
6/14/2001	IA St. Univ.	0.9	17.9	67	62	59	65
7/19/2001	IA St. Univ.	1.1	28.5	19	59	63	47
5/23/2002	IA St. Univ.	0.7	9.8	88	65	53	69
6/20/2002	IA St. Univ.	0.4	35.6	97	73	66	70
7/25/2002	IA St. Univ.	0.6	50.8	88	67	69	69
5/22/2003	IA St. Univ.	0.6	20.1	79	67	60	67
6/19/2003	IA St. Univ.	0.5	31.9	76	70	65	67
7/23/2003	IA St. Univ.	0.4	40.5	54	73	67	62
5/20/2004	IA St. Univ.	1.0	35.6	59	60	66	63
6/17/2004	IA St. Univ.	0.7	42.8	87	65	67	69
7/21/2004	IA St. Univ.	0.4	57.7	84	73	70	68
5/26/2005	IA St. Univ.	0.5	37.6	106	70	66	71
6/22/2005	IA St. Univ.	0.8	67.3	69	63	72	65
7/25/2005	IA St. Univ.	0.4	181.8	116	73	82	73
average		0.75	42	92	64	67	69
median		**0.7**	**36**	**88**	**65**	**66**	**69**
TARGET		**> 0.7**	**< 33**	**< 96**	**< 65**	**< 65**	**< 70**

Table B-10: Summary table of measurements made on all Five Island Lake sampling stations between July 2000 & July 2005.
All dates, depths & stations are combined.

Parameter	Units	Mean	Median	Standard Error	*n*
Total Phosphorus	µg/L as P	92	88	9	18
Total Nitrogen	mg/L as N	2.90	2.26	0.36	18
Nitrate-Nitrogen	mg/L as N	1.47	0.90	0.33	18
Ammonia-Nitrogen	mg/L as N	0.2628	0.2728	0.0576	12
Chlorophyll *a*	µg/L	41.8	35.6	9.6	17
Secchi depth	m	0.75	0.70	0.09	18
Alkalinity	mg/L as $CaCO_3$	155	151	7	18
Dissolved Oxygen	mg/L	9.1	8.7	0.4	18
Specific Conductance	µmhos/cm	459	457	15	17
Total Suspended Solids	mg/L	22.9	23.0	1.9	17
Volatile Suspended Solids	mg/L	9.9	9.0	1.2	17
Inorganic Suspended Solids	mg/L	13.0	12.0	1.6	17
pH	neg. log H^+ conc.	8.38	8.30	0.07	18
Turbidity	NTU	28.4	23.8	4.0	18

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, µg/L
CHL = in-lake chlorophyll-a concentration, µg/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 USEPA (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	weeds, 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 (µg/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.

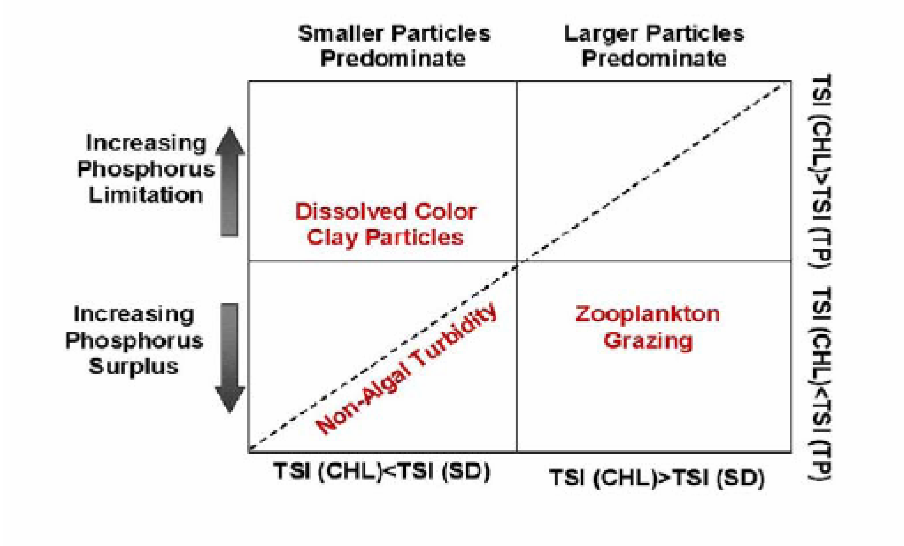

Figure C-1. Multivariate TSI Comparison Chart (Carlson)