Total Maximum Daily Load
For Algae and Turbidity
Tuttle Lake
Emmet County, Iowa

2004

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Tuttle Lake Summary

Waterbody Name:	Tuttle Lake (a.k.a. Okamanpedan Lake)
County:	Emmet
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life) HQR (High Quality Resource)
Major River Basin:	East Fork Des Moines River Basin
Pollutant:	Phosphorus
Pollutant Sources:	Nonpoint, internal recycle, point (municipal WWTPs), atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Medium
Watershed Area:	122,800 acres
Lake Area:	2,270 acres
Lake Volume:	8,510 acre-ft
Detention Time:	0.1 years
TSI Target(s):	Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65
Total Phosphorus Load Capacity (TMDL):	33,580 pounds per year
Existing Total Phosphorus Load:	91,100 pounds per year
Load Reduction to Achieve TMDL:	57,520 pounds per year
Margin of Safety:	3,350 pounds per year
Wasteload Allocation:	0
Load Allocation:	30,230 pounds per year

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

This document consists of TMDLs for algae and turbidity designed to provide Tuttle Lake water quality that fully supports its designated uses. Phosphorus, which is related through the Trophic State Index (TSI) to chlorophyll and Secchi depth, is targeted to address the algae and turbidity impairments.

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

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

Monitoring is essential to all TMDLs in order to:

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

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

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

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Tuttle Lake, S11, T100N, R32W, 2 miles northeast of Dolliver, Emmet County.

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

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

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for Secchi depth, chlorophyll a and total phosphorus based on 2000 - 2003 sampling are 0.3 meters, 74 ug/L and 222 ug/L, respectively. A minimum in-lake increase in Secchi transparency of 133% and minimum in-lake reductions of 55% for chlorophyll a and 57% for total phosphorus are required to achieve

and maintain lake water quality goals and protect for beneficial uses. The estimated existing annual total phosphorus load to Tuttle Lake is 91,100 pounds per year. The total phosphorus loading capacity for the lake is 33,580 pounds per year based on lake response modeling. An average annual load reduction of 57,520 pounds per year is required.

5. **Identification of pollution source categories:** Nonpoint, point, atmospheric deposition (background) sources and internal recycling of phosphorus from lake bottom sediments are identified as the cause of impairments to Tuttle Lake.

6. **Wasteload allocations for pollutants from point sources:** Two point sources have been identified in the Tuttle Lake watershed. However, these sources are located in Minnesota and outside the Iowa Department of Natural Resources' authority to establish wasteload allocations. The loads from these sources are treated as a generalized loads from outside the state and the wasteload allocation for Iowa sources for this TMDL is set to zero.

7. **Load allocations for pollutants from nonpoint sources and generalized loads:** The total phosphorus load allocation for the nonpoint sources, internal recycling and generalized loads is 30,230 pounds per year including 730 pounds per year attributable to atmospheric deposition.

8. **A margin of safety:** An explicit numerical MOS of 3,350 pounds per year (10% of the calculated allowable phosphorus load) has been included to ensure that the load allocation will result in attainment of water quality targets.

9. **Consideration of seasonal variation:** This TMDL was developed based on the annual phosphorus loading that will result in attainment of TSI targets for the growing season (May through September).

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for increases in pollutant loads has not been included in this TMDL. Most of the watershed landuse is in agricultural production. The addition or deletion of animal feeding operations within the watershed could increase or decrease nutrient loading. Future increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and internal phosphorus loading. Changes in the populations of the watershed's small residential communities or their wastewater treatment methods may also affect nutrient loads. Such events cannot be predicted and at this time conditions are not expected to change, therefore, an allowance for their potential occurrence was not included in the TMDL.

11. **Implementation plan:** Although not required by the current regulations, an implementation plan is outlined in the report.

2. Tuttle Lake, Description and History

2.1 The Lake

Tuttle Lake is a natural lake located in northwest Iowa, 2 miles northeast of Dolliver. Public use for Tuttle Lake is estimated at 37,000 visitors in 2002. Users of the lake and of Tuttle Lake County Park enjoy fishing, swimming, picnicking, hiking, and boating.

Table 2. Tuttle Lake Features

Waterbody Name:	Tuttle Lake
Hydrologic Unit Code:	HUC10 0710000301
IDNR Waterbody ID:	IA 04-EDM-00290
Location:	Section 11 T100N R32W
Latitude:	43° 30' N
Longitude:	94° 35' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW)) 3. HQR (High Quality Resource)
Tributaries:	East Fork Des Moines River (to Little Tuttle Lake & The Inlet), Clayton Lake, Dutton Slough, unnamed creek
Receiving Waterbody:	unnamed creek to East Fork Des Moines River
Lake Surface Area:	2,270 acres
Maximum Depth:	6 feet
Mean Depth:	3.8 feet
Volume:	8,510 acre-feet
Length of Shoreline:	63,700 feet
Watershed Area:	122,800 acres
Watershed/Lake Area Ratio:	54:1
Estimated Detention Time:	0.1 years

Morphometry

Tuttle Lake has a mean depth of 3.8 feet and a maximum depth of 6 feet. The lake has a surface area of 2,270 acres and a storage volume of approximately 8,510 acre-feet. Temperature and dissolved oxygen sampling indicate that Tuttle Lake remains oxic throughout the growing season and is well mixed for most of the growing season.

Hydrology

Tuttle Lake is fed by the East Fork Des Moines River in Minnesota (via Little Tuttle Lake and The Inlet), Dutton Slough, Clayton Lake and an unnamed tributary. Tuttle Lake feeds into an unnamed tributary of the East Fork Des Moines River in Iowa. The estimated annual average detention time for Tuttle Lake is 0.1 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Tuttle Lake watershed has an area of approximately 122,800 acres and has a watershed to lake ratio of 54:1. The 2002 landuses and associated areas for the watershed were obtained from satellite imagery and are shown in Table 3. A map of the land uses in the Tuttle Lake watershed may be found in Appendix D.

Table 3. 2002 Landuse in Tuttle Lake watershed.

Landuse	Area in Acres	Percent of Total Area
Row Crop	102,810	83.7
Grassland	13,030	10.6
Water/Wetland	3,620	2.9
Forest	1,830	1.3
Other	1,510	1.5
Total	122,800	100

Approximately 95% of the watershed is located in Martin and Jackson counties of Minnesota. One open feedlot with a capacity of 175 beef animal units is located within the Iowa portion of the watershed. A field level survey of the entire watershed has not been completed. It is known that there are numerous Confined Animal Feeding Operations (CAFOs) located in the Minnesota portion of the watershed, however, the exact number has not been determined by IDNR.

Open feedlots are unroofed or partially roofed animal feeding operations in which no crop, vegetation, or forage growth or residue cover is maintained during the period that animals are confined in the operation. Runoff from open feedlots can deliver substantial quantities of nutrients to a waterbody dependent upon factors such as proximity to a water surface, number and type of livestock and manure controls. CAFOs are animal feeding operations in which animals are confined to areas which are totally roofed. CAFOs typically utilize earthen or concrete structures to contain and store manure prior to land application. Nutrients from CAFOs are delivered via runoff from land applied manure or from leaking/failing storage structures.

Several small communities are located within the watershed including Dolliver (IA), Sherburn (MN), Alpha (MN), and Ceylon (MN).

The watershed is predominately gently sloping (0-9%) prairie-derived soils. Three soil associations encompass the watershed. The Clarion-Nicollet-Webster soil association dominates the watershed with the Clarion-Stordon-Lester and Nicollet-Canisteo-Webster associations covering the rest of the land.

3. TMDL for Algae and Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (8) list the designated uses for Tuttle Lake as Primary Contact Recreational Use (Class A1), Aquatic Life (Class B(LW)) and High Quality Resource (HQR). In 2002, Tuttle Lake was included on the impaired waters list due to algae and turbidity impairments. At that time, Class A and B uses were assessed as "partially supported." The Iowa Water Quality Standards (8) do not include numeric criteria for algae or turbidity but they do include narrative standards that are applicable to Mariposa Lake stating that "such waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor, or other aesthetically objectionable conditions" (8). Therefore, the impaired water quality assessment was made based on measured chlorophyll and transparency values indicating algae and turbidity conditions that are producing objectionable color, odor, or other aesthetically objectionable conditions

The impairment to the Class A (primary contact) designated use was based on the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries bureau. Data from these sources suggest impairments to the Class A (primary contact) uses through presence of aesthetically objectionable blooms of algae and presence of nuisance algal species (e.g., bluegreen algae). However, non-algal turbidity may also be impairing primary contact uses.

The Class B (aquatic life) designated use has been assessed as partially supporting due to turbidity impacts caused both by suspended algae and by re-suspended sediment. Other contributing factors to this assessment are excessive nutrient loading, organic enrichment, and nuisance algal blooms.

Data Sources

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

Iowa State University Lake Study data from 2000 to 2003 were evaluated for this TMDL. This study is scheduled to run through 2004 and approximates a sampling scheme used by Roger Bachman in earlier Iowa lake studies. Samples are collected three times during the early, middle and late summer. A number of water quality parameters are measured including Secchi disk depth, phosphorus series, nitrogen series, TSS, and VSS.

Interpreting Tuttle Lake Water Quality Data

Based on mean values from ISU sampling during 2000 - 2003, the ratio of total nitrogen to total phosphorus for this lake is 16:1. Data on inorganic suspended solids from the ISU sampling suggest that this lake may be subject to high levels of non-algal turbidity. The median level of inorganic suspended solids in the 130 lakes sampled for the ISU lake survey in 2000 and 2001 was 5.27 mg/L. The median level of inorganic suspended solids at Tuttle Lake during the same time period was 17.1 mg/l, the twentieth highest of the 130 lakes.

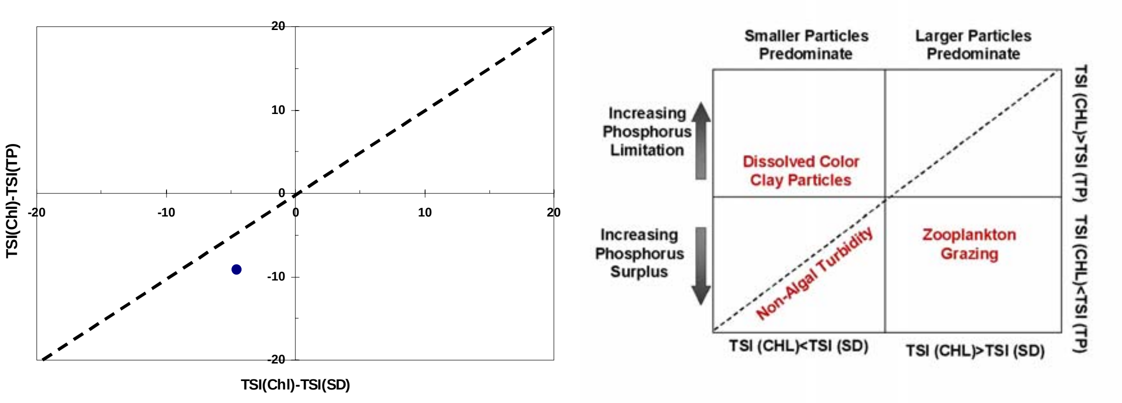
Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for 2000 - 2003 in-lake sampling indicate possible limitation of algal growth attributable to light attenuation by elevated levels of inorganic suspended solids (see Figure 1 and Appendix C).

TSI values for 2000 - 2003 monitoring data are shown in Table 4. TSI values for all historical monitoring data and an explanation of Carlson's Trophic State Index are given in Appendix C.

Table 4. Tuttle Lake TSI Values (3,4,5,20)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/2000	83	75	85
7/13/2000	77	70	80
8/4/2000	83	79	87
5/16/2001	67	--	66
6/13/2001	73	62	80
7/18/2001	83	71	91
5/22/2002	83	71	83
6/19/2002	83	74	85
7/24/2002	83	83	91
5/21/2003	83	64	72
6/18/2003	70	63	69
7/23/2003	73	60	69

Figure 1. Tuttle Lake 2000 - 2003 Mean TSI Multivariate Comparison Plot (22)



Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) tend to dominate the summertime phytoplankton community of Tuttle Lake. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. However, the sampling does indicate a high level of bluegreen mass relative to other Iowa lakes. The 2000 average summer wet mass of bluegreen algae at this lake (90 mg/l) was the 11th highest of 131 lakes sampled. The 2001 average summer wet mass of bluegreen algae declined to 32 mg/L but still comprised over 70% of the total phytoplankton community. Sampling for cyanobacterial toxins has not been conducted at Tuttle Lake. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

Potential Pollution Sources

Water quality in Tuttle Lake is influenced by point sources, watershed nonpoint sources and internal recycling of pollutants from bottom sediments. Identified point sources include municipal domestic Wastewater Treatment Plants (WWTPs) located at Ceylon and Sherburn, Minnesota.

Natural Background Conditions

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

3.2 TMDL Target

The Phase 1 targets for this TMDL is a mean TSI value of less than 70 for total phosphorus, and mean TSI values of less than 65 for both chlorophyll and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

Table 5. Tuttle Lake Existing vs. Target TSI Values

Parameter	**2000-2003 Mean TSI**	**2000-2003 Mean Value**	**Target TSI**	**Target Value**	**Minimum In-Lake Increase or Reduction Required**
Chlorophyll	73	74 ug/L	<65	<33 ug/L	55% Reduction
Secchi Depth	77	0.3 meters	<65	>0.7 meters	133% Increase in transparency
Total Phosphorus	82	222 ug/L	<70	<96 ug/L	57% Reduction

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

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for algae or turbidity. The algae and turbidity impairments are due to algal blooms caused by excessive nutrient loading to the lake and inorganic suspended solids due to re-suspension of sediment. The nutrient-loading objective is defined by a mean total phosphorus TSI of less than 70, which is related through the Trophic State Index to chlorophyll a and Secchi depth. The TSI is not a standard, but is used as a guideline to relate phosphorus loading to the algal impairment for TMDL development purposes and to describe water quality that will meet Iowa’s narrative water quality standards.

Selection of Environmental Conditions

The critical condition for which the TMDL TSI target values apply is the growing season (May through September). It is during this period that nuisance algal blooms are prevalent. The existing and target total phosphorus loadings to the lake are expressed as annual averages. The model selected for estimating phosphorus loading to the lake utilizes growing season mean (GSM) in-lake total phosphorus concentrations to calculate an annual average total phosphorus loading.

Modeling Approach

A number of different empirical models that predict annual phosphorus load based on measured in-lake phosphorus concentrations were evaluated. In addition, watershed phosphorus delivery using both export coefficients and an annual loading function model as outlined in Reckhow's EUTROMOD User's Manual (10) was calculated. The results from both approaches were compared to select the best-fit empirical model.

Of the empirical models evaluated, the Canfield-Bachmann Natural Lake and Vollenweider models resulted in values closest to the Loading Function and export estimates while remaining within the parameter ranges used to derive them. Although the Vollenweider models give results near the watershed delivery estimates, these are annual models that should ideally be used in combination with annual average in-lake phosphorus estimates. The available in-lake phosphorus monitoring data for Tuttle Lake corresponds with the growing season.

Table 6. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = ANN TP = 222 ug/L, SPO TP = 140 ug/L	Comments
Loading Function	111,070	Reckhow (10)
EPA Export	142,900	EPA/5-80-011
WILMS Export	97,950	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	337,340	GSM model
Canfield-Bachmann 1981 Natural Lake	91,100	GSM model
Canfield-Bachmann 1981 Artificial Lake	162,020	GSM model
Reckhow 1977 Anoxic Lake	62,110	GSM model
Reckhow 1979 Natural Lake	117,180	GSM model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	74,060	GSM model. P out of range
Nurnberg 1984 Oxic Lake	108,190 (internal load = 0)	Annual model. P out of range
Walker 1977 General Lake	43,810	SPO model.
Vollenweider 1982 Combined OECD	136,010	Annual model.
Vollenweider 1982 Shallow Lake	144,800	Annual model.

The Nurnberg Oxic Lake and Reckhow Natural Lake models predict phosphorus loadings within the range of the watershed delivery estimates from the Loading Function and export methods. However, both models must be extrapolated beyond the limits of the data used to derive them for application to Tuttle Lake, whereas the Canfield-Bachmann relationship is within parameter ranges and gives a reasonable result when compared to the Loading Function and export estimates. Therefore, the Canfield-Bachmann Natural Lake relationship was selected as best-fit empirical model.

The equation for the Canfield-Bachmann Natural Lake Model is:

$$P = \frac{L}{z\left[0.162\left(L/z\right)^{0.458} + p\right]}$$

where

$P =$ predicted in-lake total phosphorus concentration (ug/L)
$L =$ areal total phosphorus load (mg/m^2 of lake area per year)
$z =$ lake mean depth (meters)
$p =$ lake flushing rate (yr^{-1})

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

$$P = 222(\mu g/L) = \frac{4{,}502(mg/m^2)}{1.14(m)\left[0.162\left(\dfrac{4{,}502(mg/m^2)}{1.14(m)}\right)^{0.458} + 10.54(yr^{-1})\right]}$$

The calculations for the total phosphorus load capacity are:

$$P = 96(\mu g/L) = \frac{1{,}660(mg/m^2)}{1.14(m)\left[0.162\left(\dfrac{1{,}660(mg/m^2)}{1.14(m)}\right)^{0.458} + 10.54(yr^{-1})\right]}$$

The annual total phosphorus load is obtained by multiplying the areal load (L) by the lake area in square meters and converting the resulting value from milligrams to pounds.

Waterbody Pollutant Loading Capacity

The chlorophyll a and Secchi depth objectives are related through the Trophic State Index to total phosphorus. The load capacity for this TMDL is the annual amount of phosphorus Tuttle 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 33,580 pounds per year.

3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Tuttle Lake in this TMDL. The first is the phosphorus load from the watershed areas that drain directly into the lake and the phosphorus recycled from lake sediments. The second source is atmospheric deposition. The third source is the contribution of municipal wastewater treatment plants within the watershed. An additional potential source is groundwater influx. Note that load contributions from groundwater influx have not been separated from the total nonpoint source loads.

Existing Load

The annual total phosphorus load to Tuttle Lake is estimated to be 91,100 pounds per year based on the selected lake response model. This estimate includes 89,440 pounds per year from a combination of nonpoint sources in the watershed and the internal phosphorus load recycled from the lake bottom sediment, 930 pounds per year from point sources and 730 pounds per year from atmospheric deposition.

Departure from Load Capacity

The Phase 1 targeted total phosphorus load capacity for Tuttle Lake is 33,580 pounds per year or 0.3 pounds per year per acre of watershed area. The estimated existing load is 91,100 pounds per year or 0.7 pounds per year per acre of watershed if all loads were attributed to the watershed without any internal recycling of phosphorus.

Identification of Pollutant Sources

The majority of phosphorus delivered to the lake is from a combination of watershed nonpoint sources and internal recycle. However, there are two point source discharges in the Tuttle Lake watershed. The City of Ceylon Wastewater Treatment Facility (NPDES ID MNG580006) discharges treated effluent to Dutton Slough approximately 1 ½ miles upstream of where it enters Tuttle Lake. The City of Ceylon's treatment facility consists of a waste stabilization lagoon system that discharges only during certain periods of the year.

The City of Sherburn Wastewater Treatment Plant (NPDES ID MN0024872) discharges treated effluent to an unnamed tributary of the East Fork Des Moines River approximately 13 miles upstream of Little Tuttle Lake, which is tributary to Tuttle Lake. The City of Sherburn's treatment facility is a mechanical activated sludge treatment plant.

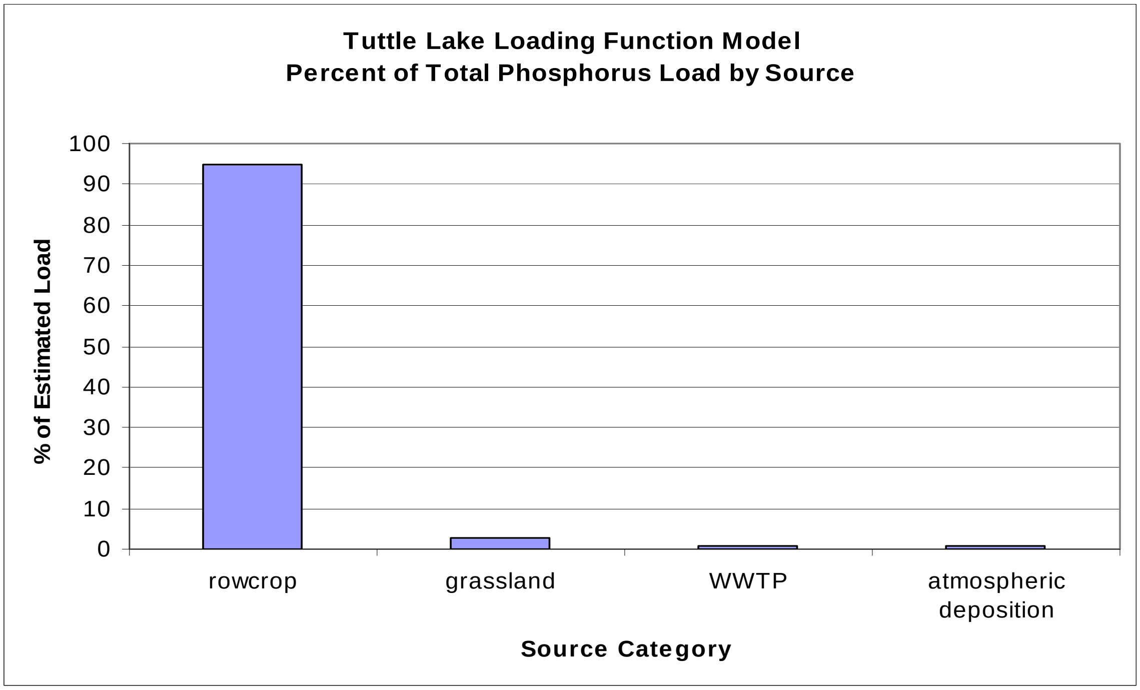
Both municipal facilities have NPDES discharge permits. Neither facility currently employs phosphorus removal technologies, although some phosphorus removal is indicated by plant monitoring data. The estimated existing loads from these treatment facilities were obtained through monitoring reports provided by the Minnesota Pollution Control Agency (MPCA) and are shown in Table 7.

Table 7. Existing Point Source Loads

Facility	Monitoring Period Evaluated	Existing Average Effluent Flow (MGD)	Existing Average Total Phosphorus Concentration (mg/L)	Estimated Load (lbs/year)
Ceylon WWTF	5/00 - 5/04	0.043	1.76	230
Sherburn WWTP	12/00 - 7/04	0.086	2.69	700

From the Loading Function Model, the most nonpoint source phosphorus delivered to the lake is from row crop landuse as shown in Figure 2. It should be noted that while the Loading Function Model provides estimates of the primary potential pollutant sources, it was used only for comparison purposes to select an empirical lake response model in the development of existing and target total phosphorus loads identified in this TMDL. Existing and target loads were calculated from measured and target in-lake total phosphorus concentrations using the selected lake response model as shown in *Section 3.2, Modeling Approach*. Also, the Loading Function Model estimates only external watershed phosphorus inputs and does not account for internal loading.

Figure 2. Loading Function Model Source Contributions



Other sources of phosphorus capable of being delivered to the water body exist. These sources include septic systems and toilet pits from campsites, individual residences, and seasonal-use businesses and housing units. Manure and waste from wildlife, pets, fish cleaning stations, etc. also contribute to the phosphorus loading. Unfortunately, the potential phosphorus being contributed from these sources is difficult to quantify. These potential sources have been considered, but are deemed smaller contributors or have less impact than the sources previously identified. However, these sources will be evaluated and quantified as required in Phase II of this TMDL.

Linkage of Sources to Target

The average annual phosphorus load to Tuttle Lake originates primarily from nonpoint sources and internal recycling with minor point source contributions. To meet the TMDL endpoint, the annual point and nonpoint source and internal recycling contributions to Tuttle Lake need to be reduced by 57,520 pounds per year.

3.4 Pollutant Allocation

Wasteload Allocation

This section includes information on two point sources located within the Minnesota portion of the watershed. This information is presented for informational purposes only as the allocation of wasteloads for Minnesota is not within the authority of the Iowa Department of Natural Resources. Proposed loads from these sources are discussed. However, the wasteload allocation for Iowa sources is set to zero for the purposes of this TMDL and the loads from Minnesota point sources will be considered as generalized loads from the Minnesota portion of the watershed.

Under the MPCA's Phosphorus Management Strategy (23), all point sources discharging directly to or affecting a lake or reservoir are required to remove phosphorus to 1 mg/L or less. The point source dischargers within the Tuttle Lake watershed are currently considered *de minimus* facilities by Minnesota in that they discharge less than 1,800 lbs/year of total phosphorus. *De minimus* facilities are considered to be small dischargers that do not have a measurable impact on the environment. These facilities are not required to remove phosphorus provided that they do not discharge directly to or have a demonstrated impact on a lake or reservoir.

The MPCA Phosphorus Management Strategy also states the following:

> *For water quality segments that are impaired or threatened for phosphorus or phosphorus-related conditions as listed on the 303(d) list, the MPCA shall use its authority to limit point-source discharges, including existing discharges, by including phosphorus limits where appropriate in NPDES permits as part of a TMDL allocation of point and/or nonpoint discharges.*

Per a discussion with MPCA staff, Tuttle Lake has not yet been added to Minnesota's 303(d) list because available lake sampling has not met minimum data requirements. However, it is likely to be included when additional sampling data becomes available. Table 8 shows proposed loads for Minnesota point sources based on facility design flows and implementation of a 1.0 mg/L total phosphorus limit.

Table 8. Proposed Point Source Contributions

Facility	Design Flow (MGD)	Average Total Phosphorus Concentration (mg/L)	WLA (lbs/year)
Ceylon WWTF	0.061	1.0	190
Sherburn WWTP	0.21	1.0	640

Load Allocation

The Load Allocation (LA) for this TMDL is 30,230 pounds per year of total phosphorus distributed as follows:

- 29,500 pounds per year allocated to the nonpoint sources within the Tuttle Lake watershed, internal recycling of phosphorus from the lake bottom sediments, and generalized loads.

- 730 pounds per year allocated to atmospheric deposition.

Margin of Safety

An explicit numerical MOS of 3,350 pounds per year (10% of the calculated allowable phosphorus load) has been included to ensure that the load allocation will result in attainment of water quality targets.

4. Implementation Plan

The following implementation plan is not a required component of a Total Maximum Daily Load but can provide department staff, partners, and watershed stakeholders with a strategy for improving Tuttle Lake water quality. Any projects designed to improve water quality in the lake should include communication with and cooperation from stakeholders in Martin County, Minnesota. Without a cooperative effort, it will not be possible to substantially improve the condition of the lake.

If the entire phosphorus load were attributed to watershed sources, the estimated loading from watershed sources would need to be reduced from 0.7 pounds/acre/year to 0.3 pounds/acre/year to meet the TMDL target. However, this does not account for the internally recycled load, which could be significant.

Among the mechanisms of resuspension are bottom feeding rough fish such as carp, wind-driven waves and currents, and boat propellers. Methods are needed to evaluate the magnitude of the phosphorus load from internal recycling, preferably by direct measurement of resuspension and recycling from lake bottom sediments. The department is investigating methods of measuring sediment phosphorus flux by evaluating lake sediment cores. This work is being done at Iowa State University and is supported by an EPA grant.

Because of the uncertainty as to how much of the phosphorus load originates in the watershed and how much is recycled from lake bottom sediment, an adaptive management approach is recommended. In this approach management practices to reduce both watershed loads and recycled loads are incrementally applied and the results monitored to determine if water quality goals have been achieved. Also, the reductions in watershed loads will require land management changes that take time to implement. For these reasons, the following timetable is suggested for watershed improvements:

- Reduce watershed and recycle loading from 91,000 pounds per year to 70,000 pounds per year by 2010.
- Reduce watershed and recycle loading from 70,000 pounds per year to 50,000 pounds per year by 2015.
- Reduce watershed and recycle loading from 50,000 pounds per year to 30,000 pounds per year by 2020.

Best management practices to reduce nutrient delivery, particularly phosphorus, should be emphasized in the Tuttle Lake watershed. These practices include the following:

- Nutrient management on production agriculture ground to achieve the optimum soil test range. This soil test range is the most profitable for producers to sustain in the long term.
- Open feedlots in the watershed need to be assessed for water quality impacts on the lake and the level of needed pollutant controls determined.
- Incorporate or subsurface apply phosphorus (manure and commercial fertilizer) while controlling soil erosion. Incorporation will physically separate the phosphorus from surface runoff.

- Continue encouraging the adoption of reduced tillage systems, specifically no till and strip tillage.
- Initiate a fall-seeded cover crop incentive program. Target low residue producing crops (e.g. soybeans) or low residue crops after harvest (e.g. corn silage fields). This practice increases residue cover on the soil surface and improves water infiltration.
- Through incentives, add landscape diversity to reduce runoff volume and/or velocity through the strategic location of contour grass buffer strips, filter strips, and grass waterways, etc.
- Install terraces, ponds, or other erosion and water control structures at appropriate locations within the watershed to control erosion and reduce delivery of sediment and phosphorus to the lake.

Although the municipal wastewater treatment plants make up only a small portion of the total phosphorus load to Tuttle Lake, both chemical and biological wastewater treatment methods are available that can substantially increase their phosphorus removal efficiency. Chemical addition of metal salts (e.g. alum) can be added to lagoons or at strategic points in mechanical treatment processes to precipitate phosphorus from the treatment stream. Biological removal typically employs alternating anaerobic and aerobic treatment stages to force biological uptake of phosphorus by activated sludge microorganisms to above normal levels. For both chemical and biological treatment methods, the accumulated excess phosphorus is ultimately removed from the treatment system through the wasting of sludge. Stabilized waste sludge from domestic wastewater treatment facilities is typically land applied as a fertilizer to non-food crops.

In addition to the external nutrient loading from watershed sources to Tuttle Lake, it is believed there may be a significant internal loading component due to rough fish and wind and wave action on the lake. This internal component can be controlled through fish management to control rough fish (i.e., carp), rip rap along the shoreline to reduce shoreline erosion, and dredging to remove nutrients from the lake system.

5. Monitoring

Further monitoring is needed at Tuttle Lake to follow-up on the implementation of the TMDL. This monitoring will, at a minimum, meet the minimum data requirements established by Iowa's 305(b) guidelines for a complete water quality assessment (3 lake samples per year over 3 years, 10 lake samples over 2 years, etc.). This data will be collected by 2010. Tuttle Lake has been included in the five-year lake study conducted by Iowa State University under contract with the IDNR. Although this lake monitoring program concluded in 2004, it may be extended under a new lake monitoring strategy. The TMDL program is committed to monitoring waters where TMDLs have been completed, and in the absence of a statewide lake monitoring program, follow-up monitoring will be conducted through the TMDL program.

As noted in *Section 4, Implementation*, the phosphorus load due to internal recycling needs to be measured and evaluated. The department is working with Iowa State University to develop a method for quantifying phosphorus sediment flux that will clarify its impact on lakes such as Tuttle. When a protocol for measuring phosphorus flux becomes available, coring will be done for this lake and the recycling load component estimated.

6. Public Participation

A presentation was given to the Emmet County Conservation Board (CCB) on July 1, 2004 regarding the TMDL process for Tuttle Lake. The draft TMDL was presented at a public meeting in Estherville, Iowa on November 22, 2004. The meeting was attended by representatives from the Emmet CCB, IDNR Fisheries Bureau, the NRCS, and the Okamanpedan Lake Association. Comments received were reviewed and given consideration and, where appropriate, incorporated into the 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)**
$\overline{Q}_A = 0.832DA^{0.955}$	96.1	0.207290
$\overline{Q}_{JAN} = 0.312DA^{0.950}$	85.0	0.968253
$\overline{Q}_{FEB} = 1.32DA^{0.838}$	90.7	0.419138
$\overline{Q}_{MAR} = 0.907DA^{1.03}$	96.6	0.220384
$\overline{Q}_{APR} = 0.983DA^{1.02}$	93.1	0.463554
$\overline{Q}_{MAY} = 1.97DA^{0.906}$	89.0	0.603766
$\overline{Q}_{JUN} = 2.01DA^{0.878}$	88.9	0.572863
$\overline{Q}_{JUL} = 0.822DA^{0.977}$	87.2	0.803808
$\overline{Q}_{AUG} = 0.537DA^{0.914}$	74.0	1.69929
$\overline{Q}_{SEP} = 0.123DA^{1.21}$	78.7	2.64993
$\overline{Q}_{OCT} = 0.284DA^{1.04}$	90.2	0.713257
$\overline{Q}_{NOV} = 0.340DA^{0.999}$	89.8	0.697353
$\overline{Q}_{DEC} = 0.271DA^{1.00}$	86.3	1.02455

Table A-4. Multiple Regression Equations

Equation	R^2 adjusted (%)	PRESS (log transform)
$\overline{Q}_A = 1.17 \times 10^{-3} DA^{0.998} \overline{P}_A^{1.54} S^{-0.261} (1+F)^{0.249} C^{0.230}$	98.7	0.177268 (n=26)
$\overline{Q}_{JAN} = 0.213 DA^{0.997} \overline{A}_{JAN}^{0.949}$	89.0	0.729610 (n=26;same for all $\overline{Q}_{MONTH}$)
$\overline{Q}_{FEB} = 2.98 DA^{0.955} \overline{A}_{FEB}^{0.648} G^{-0.594} (1+F)^{0.324}$	97.0	0.07089
$\overline{Q}_{MAR} = 6.19 DA^{1.10} B^{-0.386} G^{-0.296}$	97.8	0.07276
$\overline{Q}_{APR} = 1.24 DA^{1.09} \overline{A}_{APR}^{1.64} S^{-0.311} B^{-0.443}$	97.1	0.257064
$\overline{Q}_{MAY} = 10^{(-3.03+0.114H)} DA^{0.846} \overline{P}_A^{2.05}$ Hydrologic Regions 2, 3 & 4 Only	92.1	0.958859
$\overline{Q}_{MAY} = 1.86 \times 10^{-3} DA^{0.903} \overline{P}_A^{1.98}$	90.5	1.07231
$\overline{Q}_{JUN} = 10^{(-1.47+0.0729H)} DA^{0.891} C^{0.404} \overline{P}_{JUN}^{1.84} (1+F)^{0.326} G^{-0.387}$ Hydrologic Regions 2, 3 & 4 Only	97.0	0.193715
$\overline{Q}_{JUN} = 8.13 \times 10^{-3} DA^{0.828} C^{0.478} \overline{P}_{JUN}^{2.70}$	95.9	0.256941
$\overline{Q}_{JUL} = 1.78 \times 10^{-3} DA^{0.923} \overline{A}_{JUL}^{4.19}$	91.7	0.542940
$\overline{Q}_{AUG} = 4.17 \times 10^{7} DA^{0.981} (1+B')^{-1.64} (1+U)^{0.692} \overline{P}_A^{-7.2} \overline{A}_{AUG}^{4.59}$	90.4	1.11413
$\overline{Q}_{SEP} = 1.63 DA^{1.39} B^{-1.08}$	86.9	1.53072
$\overline{Q}_{OCT} = 5.98 DA^{1.14} B^{-0.755} S^{-0.688} (1+B')^{-0.481}$	95.7	0.375296
$\overline{Q}_{NOV} = 5.79 DA^{1.17} B^{-0.701} G^{-0.463} (1+U)^{0.267} (1+B')^{-0.397}$	95.1	0.492686
$\overline{Q}_{DEC} = 0.785 DA^{1.18} B^{-0.654} (1+U)^{0.331} (1+B')^{-0.490}$	92.4	0.590576
$Q_{YEAR} = 3.164 \times 10^{-4} DA^{0.942} P_{YEAR}^{2.39} A_{YEAR}^{1.02} S^{-0.206} \overline{P}_A^{1.27} C^{0.121} (1+U)^{0.0966}$	83.9	32.6357 (n=716)

General Application

In general, the regression equations developed using multiple watershed characteristics will be better predictors than those using drainage area as the sole explanatory variable. The single exception to this appears to be for the May Average Flow worksheet where the PRESS statistic values indicate that use of drainage area alone results in the least error in the prediction of future observations.

Although 2002 land cover grids for the state are now available with 19 different classifications, the older 2000 land cover grids with 9 different classifications were used in developing the regression equations. The 2000 land cover grids should be used in development of flow estimates using the equations.

The equations were developed from stream gauge data for watersheds with relatively minor open water surface percentages relative to other types of land cover (see Table A-1). For application to lake watersheds, particularly those with small watershed/lake area ratios, the basin slope and land cover percentages taken from HUC-12 basins may need to be adjusted so that the hydraulic budget components of surface inflow and direct precipitation on the lake itself can be treated separately. One method of accomplishing this is by subtraction of lake water surface acreage from the total land cover and slope (lakes will have 0% slope) acreages and recalculation of the % coverages. The watershed (drainage) area used in the equations should not include the area of the lake surface.

Application to Tuttle Lake - Calculations

Table A-5. Tuttle Lake Hydrology Calculations

Lake	Tuttle Lake	
Type	Natural	
Inlet(s)	E. Fork DM R., Clayton Lake, Dutton Sough, unnamed creek	
Outlet(s)	E. Fork DM River	
Volume	8507	(acre-ft)
Lake Area	2268	(acres)
Mean Depth	3.75	(ft)
Drainage Area	122815	(acres)
Mean Annual Precip	28.2	(inches)
Average Basin Slope	--	(%)
%Water	--	
%Forest	--	
%Grass/Hay	--	
%Corn	--	
%Beans	--	
%Urban/Artificial	--	
%Barren/Sparse	--	
Hydrologic Region	--	
Mean Annual Class A Pan Evap	48	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow	91084.21	(acre-ft)
Direct Lake Precip	5331.69	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.0882	(yr)
Est. Annual Average Det. Time (outflow)	0.0948	(yr)

9. Appendix B - Sampling Data

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

Parameter	7/11/1979	8/14/1979	9/18/1979
Secchi Depth (m)	0.3	0.5	0.5
Chlorophyll (ug/L)	--	--	--
NO_3+NO_2-N (mg/L)	--	--	0.1
Total Phosphorus (ug/l as P)	265	216	126
Alkalinity (mg/L)	194	165	186

Data above is averaged over the upper 6 feet.

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

Parameter	5/27/1990	6/28/1990	7/26/1990
Secchi Depth (m)	0.2	0.4	0.2
Chlorophyll (ug/L)	172.1	126.7	166.9
Total Nitrogen (mg/L as N)	4.0	7.2	3.8
Total Phosphorus (ug/l as P)	190.5	122.2	186.8
Total Suspended Solids (mg/L)	64.6	33.7	73.3
Inorganic Suspended Solids (mg/L)	31.7	6.8	42.3

Data above is for surface depth.

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

Parameter	6/14/2000	7/13/2000	8/04/2000
Secchi Depth (m)	0.2	0.3	0.2
Chlorophyll (ug/L)	89	56	142
NH_3+NH_4^+ -N (ug/L)	1078	1074	1788
NH_3 –N (un-ionized) (ug/L)	51	151	555
NO_3+NO_2-N (mg/L)	1.26	0.92	0.22
Total Nitrogen (mg/L as N)	2.47	2.38	2.32
Total Phosphorus (ug/l as P)	278	186	319
Silica (mg/L as SiO_2)	35	40	117
pH	8.1	8.4	8.9
Alkalinity (mg/L)	136	158	125
Total Suspended Solids (mg/L)	43.9	33.3	34.1
Inorganic Suspended Solids (mg/L)	33.2	20.0	14.1
Volatile Suspended Solids (mg/L)	10.7	13.3	20.0

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

Parameter	5/16/2001	6/13/2001	7/18/2001
Secchi Depth (m)	0.6	0.4	0.2
Chlorophyll (ug/L)		24	63
NH_3+NH_4^+ -N (ug/L)	602	1084	925
NH_3 –N (un-ionized) (ug/L)	47	35	96
NO_3+NO_2-N (mg/L)	6.5	5.76	0.15
Total Nitrogen (mg/L as N)	7.72	6.71	0.24
Total Phosphorus (ug/l as P)	73	190	406
Silica (mg/L as SiO_2)	25	16	44
pH	8.3	7.9	8.2
Alkalinity (mg/L)	110	171	170
Total Suspended Solids (mg/L)	19.0	42.8	25.1
Inorganic Suspended Solids (mg/L)	7.0	30.8	1.5
Volatile Suspended Solids (mg/L)	12.0	12.0	23.6

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

Parameter	5/22/2002	6/19/2002	7/24/2002
Secchi Depth (m)	0.2	0.2	0.2
Chlorophyll (ug/L)	64	87	214
NH_3+NH_4^+ -N (ug/L)	404	343	465
NH_3 –N (un-ionized) (ug/L)	37	20	101
NO_3+NO_2-N (mg/L)	0.14	0.77	0.19
Total Nitrogen (mg/L as N)	1.68	2.75	2.95
Total Phosphorus (ug/l as P)	240	266	426
Silica (mg/L as SiO_2)	6	14	23
pH	8.4	8.2	8.7
Alkalinity (mg/L)	161	144	126
Total Suspended Solids (mg/L)	118.0	82.6	74.4
Inorganic Suspended Solids (mg/L)	93.3	0.9	31.2
Volatile Suspended Solids (mg/L)	24.7	81.7	43.2

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

Parameter	5/21/2003	6/18/2003	7/23/2003
Secchi Depth (m)	0.2	0.5	0.4
Chlorophyll (ug/L)	30.0	27.5	20.1
NH_3+NH_4^+ -N (ug/L)	274	183	242
NH_3 –N (un-ionized) (ug/L)	17	34	101
NO_3+NO_2-N (mg/L)	2.97	2.51	1.41
Total Nitrogen (mg/L as N)	4.68	4.23	3.29
Total Phosphorus (ug/l as P)	107	88	87
Silica (mg/L as SiO_2)	3.41	3.46	3.58
pH	8.4	8.6	9.2
Alkalinity (mg/L)	168	104	79
Total Suspended Solids (mg/L)	44	26	31
Inorganic Suspended Solids (mg/L)	26	12	12
Volatile Suspended Solids (mg/L)	18	14	19

Table B-7. 2000 Phytoplankton Data (3)

	6/14/2000	**7/13/2000**	**8/4/2000**
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Cyanophyta	1.6E+02	2.2E+01	8.7E+01
Cryptophyta	0.0E+00	9.4E-02	0.0E+00
Chlorophyta	1.0E+01	7.8E-02	1.6E-01
Dinophyta	0.0E+00	3.3E-01	1.5E+00
Chrysophyta	1.4E+01	1.3E+01	9.4E+00
Euglenophyta	0.0E+00	0.0E+00	0.0E+00
Total	**1.9E+02**	**3.5E+01**	**9.8E+01**

Table B-8. 2001 Phytoplankton Data (4)

	5/16/2001	6/13/2001	7/18/2001
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Chlorophyta	4.55E-01	5.10E+00	2.09E-01
Chrysophyta	1.87E+01	1.08E+00	0.00E+00
Cryptophyta	4.44E-01	1.27E+00	0.00E+00
Cyanobacteria	1.50E+01	9.20E-02	5.49E+01
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	9.20E-02	0.00E+00
Total	3.45E+01	7.63E+00	5.51E+01

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

10. Appendix C - Trophic State Index

Carlson's Trophic State Index

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

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

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

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

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

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

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

SD = lake Secchi depth, meters

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

Table C-1. Changes in temperate lake attributes according to trophic state (modified from 22,24,25).

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.

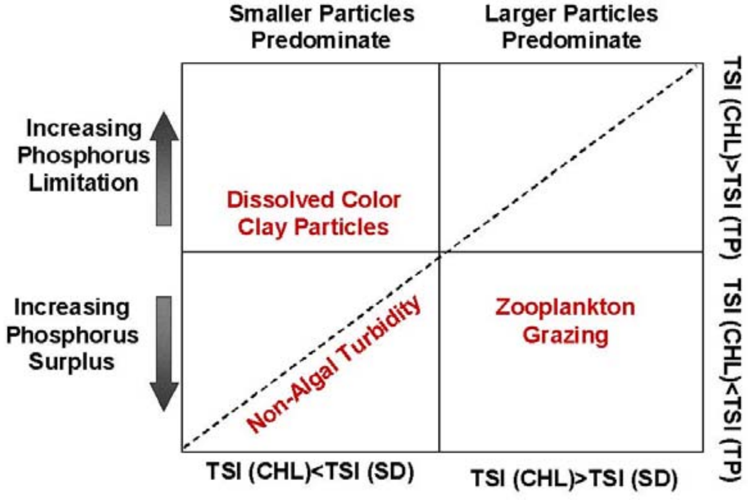
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for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



Tuttle Lake TSI Values

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/11/1979	77		85
8/14/1979	70		82
9/18/1979	70		74

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
5/27/1990	83	80	81
6/28/1990	73	78	74
7/26/1990	83	81	78

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/2000	83	75	85
7/13/2000	77	70	80
8/4/2000	83	79	87
5/16/2001	67	--	66
6/13/2001	73	62	80
7/18/2001	83	71	91
5/22/2002	83	71	83
6/19/2002	83	74	85
7/24/2002	83	83	91
5/21/2003	83	64	72
6/18/2003	70	63	69
7/23/2003	73	60	69

11. Appendix D - Land Use Map

Figure D-1. Tuttle Lake Watershed - 2002 Landuse