Total Maximum Daily Load
For Noxious Aquatic Plants
Upper Gar Lake
Dickinson County, Iowa

2004

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Upper Gar Lake Summary

Waterbody Name:	Upper Gar Lake
County:	Dickinson
Use Designation Class:	A1 (primary contact recreation) A2 (secondary contact recreation) B(LW) (aquatic life) HQ (high quality)
Major River Basin:	Little Sioux River Basin
Pollutant:	Phosphorus
Pollutant Sources:	Nonpoint, internal recycle, atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation) A2 (secondary contact recreation) B(LW) (aquatic life) HQ (high quality)
2002 303d Priority:	High
Watershed Area:	220 acres
Lake Area:	36 acres
Lake Volume:	122 acre-ft
Detention Time:	0.008 years
TSI Target(s):	Total Phosphorus less than 65; Chlorophyll a less than 60; Secchi Depth less than 60
Total Phosphorus Load Capacity (TMDL):	3,080 pounds per year
Existing Total Phosphorus Load:	6,080 pounds per year
Load Reduction to Achieve TMDL:	3,000 pounds per year
Margin of Safety	300 pounds per year
Wasteload Allocation	0
Load Allocation	2,780 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. Upper Gar Lake has been identified as impaired by noxious aquatic plants. Noxious aquatic plants are an expression of excess nutrients in the water column. The purpose of this TMDL for Upper Gar Lake is to calculate the maximum allowable nutrient loading for the lake associated with conditions that will meet water quality standards.

This document consists of a TMDL for noxious aquatic plants designed to provide Upper Gar 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 impairment.

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:** Upper Gar Lake, S29, T99N, R36W, east end of the City of Arnolds Park, Dickinson County.

2. **Identification of the pollutant and applicable water quality standards:** Noxious aquatic plants associated with excessive nutrient (phosphorus) loading are the cause of the impairment. Designated uses for Upper Gar Lake are Primary Contact Recreation (Class A1), Secondary Contact Recreation (Class A2), Aquatic Life (Class B(LW)) and High Quality (HQ). 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 65 for total phosphorus, and TSI values of less than 60 for both chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 68 and 20 ug/L, respectively, and a Secchi depth of 1.0 meters.

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for

Secchi depth, chlorophyll a and total phosphorus based on 2000 - 2003 CLAMP sampling are 0.7 meters, 45 ug/L and 130 ug/L, respectively. Based on these values, a minimum in-lake increase in Secchi transparency of 43% and minimum in-lake reductions of 56% for chlorophyll a and 48% 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 Upper Gar Lake is 6,080 pounds per year. The total phosphorus loading capacity for the lake is 3,080 pounds per year based on lake response modeling. An average annual load reduction of 3,000 pounds per year is required.

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

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Upper Gar Lake watershed. Therefore, the wasteload allocation will be set at zero.

7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus load allocation for the nonpoint sources and internal recycle is 2,780 pounds per year including 10 pounds per year attributable to atmospheric deposition.

8. **A margin of safety:** An explicit numerical MOS of 300 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 increased phosphorus loading was not included in this TMDL. Significant changes in the Upper Gar watershed landuse are unlikely except for some residential development. This potential landuse change could increase or decrease nutrient loading depending on the type and density of development. Future increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and internal phosphorus loading. Such events cannot be predicted and at this time conditions are not expected to change, therefore, an allowance for their potential occurrence was not included in the TMDL.

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

2. Upper Gar Lake, Description and History

2.1 The Lake

Upper Gar Lake is a natural, glacial lake located in northwest Iowa, at the east end of Arnolds Park. Public use for Upper Gar Lake is estimated at approximately 9,000 visitors per year. Users of the lake enjoy fishing, swimming, picnicking, hiking, boating, and snowmobiling.

Table 2. Upper Gar Lake Features

Waterbody Name:	Upper Gar Lake
Hydrologic Unit Code:	HUC10 1023000301
IDNR Waterbody ID:	IA 06-LSR-02830
Location:	Sec. 29, T99N R36W
Latitude:	43° 22’ N
Longitude:	95° 7’ W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Secondary Contact Recreation (A2) 3. Aquatic Life Support (B(LW)) 4. High Quality (HQ)
Tributaries:	East Okoboji Lake
Receiving Waterbody:	Minnewashta Lake
Lake Surface Area:	36 acres
Maximum Depth:	5 feet
Mean Depth:	3.4 feet
Volume:	122 acre-feet
Length of Shoreline:	6,500 feet
Watershed Area:	220 acres
Watershed/Lake Area Ratio:	6.1:1
Estimated Detention Time:	0.008 years

Morphometry

Upper Gar Lake has a mean depth of 3.4 feet and a maximum depth of 5 feet. The lake has a surface area of 36 acres and a storage volume of approximately 122 acre-feet. Temperature and dissolved oxygen sampling indicate that Upper Gar Lake remains oxic and relatively well mixed throughout the growing season.

Hydrology

Upper Gar Lake is fed by East Okoboji Lake (to which West Okoboji Lake is tributary), overland flow, direct precipitation, and groundwater. Upper Gar Lake feeds into Minnewashta Lake. The estimated annual average detention time is 0.008 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Upper Gar Lake watershed has an area of approximately 220 acres and has a watershed to lake ratio of 6.1:1. The 2002 landuses and associated areas for the watershed were determined from satellite imagery and are shown in Table 3. A map of watershed landuses is found in Appendix D.

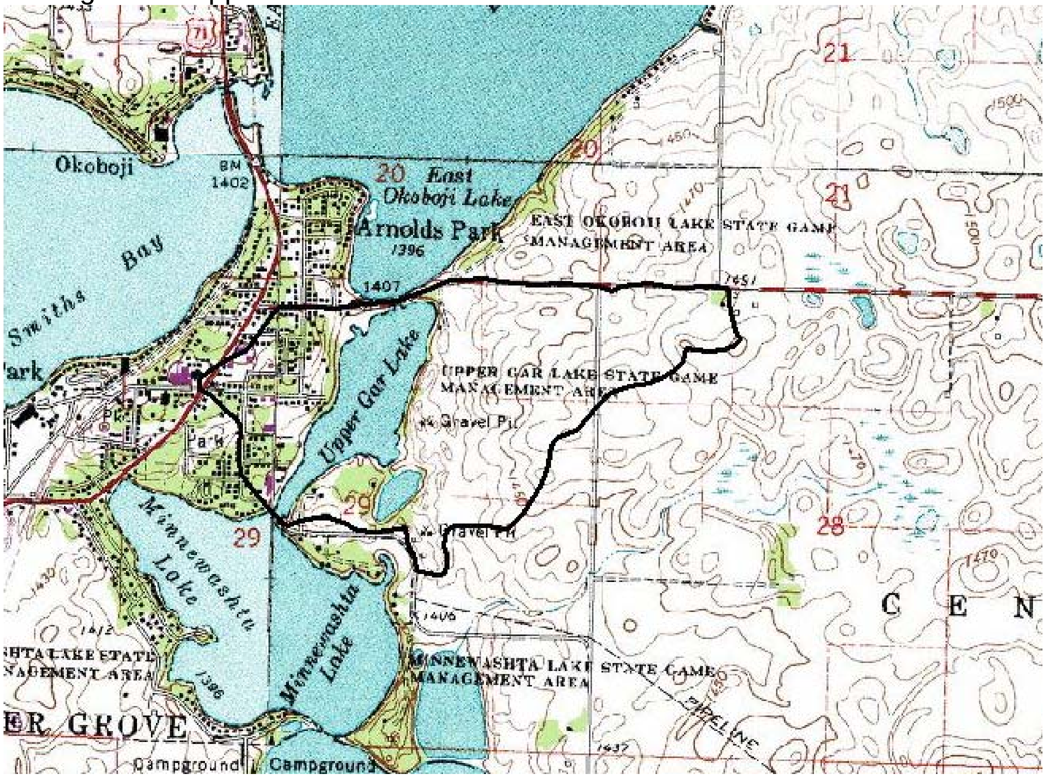
Table 3. 2002 Landuse in Upper Gar Lake watershed

Landuse	**Area in Acres**	**Percent of Total Area**
Grassland	130	59.1
Residential/Commercial	30	13.6
Forest	20	9.1
Row Crop	20	9.1
Water/Wetland	10	4.5
Other	10	4.5
Total	220	100

A field level survey of the watershed by IDNR has not been completed. There are no knownanimal feeding operations in the watershed. Medium density residential development is present on the west and south sides of the lake. The Upper Gar Lake State Game Management Area is located to the east of the lake.

The watershed is predominately level to moderately sloping (0-9%) prairie-derived soils. The most common soil types in the watershed are Clarion, Webster, Canisteo, and Nicollet with some Okoboji and Harps soils.

Figure 1. Upper Gar Lake Watershed



3. TMDL for Noxious Aquatic Plants

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (8) list the designated uses for Upper Gar Lake as Primary Contact (Class A1), Secondary Contact (Class A2), Aquatic Life (Class B(LW)) and High Quality (HQ). In 1999, Upper Gar Lake was included on the impaired water list due to the presence of noxious aquatic plants.

In 2002, the Class A designated use for Upper Gar Lake was assessed as "fully supporting/threatened." Since 1994, the Class B designated use has been assessed as "partially supporting." The 2002 assessment was based upon the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries bureau.

Impairments to the Class A (primary contact) use is through the presence of aesthetically objectionable blooms of algae. The eutrophic conditions at this lake, along with information from the IDNR Fisheries Bureau, suggest that the Class B(LW) aquatic life uses are "partially supported" due to excessive nutrient loading to the water column, nuisance blooms of algae, and re-suspension of sediment.

Data Sources

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

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

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

The second data source is the Bovbjerg Water Chemistry Laboratory of the Iowa Lakeside Lab. Upper Gar Lake data has been collected and analyzed since 1999 as part of the Cooperative Lakes Area Monitoring Project (CLAMP), which is coordinated by the Iowa Lakeside Lab and the Friends of Lakeside Lab, Inc. The CLAMP program is supported by local lake organizations, the Dickinson County Water Quality Commissions, and ISU.

The CLAMP sampling data focuses on phosphorus, nitrogen, chlorophyll a, and water clarity. For each year during 1999 to 2003, eight to ten samples have been taken in Upper Gar Lake. The CLAMP data represents a much larger sample set than the ISU data (n=44 vs. n=12 for total phosphorus). The CLAMP yearly sampling period also extends over a greater portion of the growing season and gives higher mean and median TSI values for total phosphorus, chlorophyll and Secchi depth. Therefore, this data was used for lake response modeling.

Interpreting Upper Gar Lake Water Quality Data

Based on mean values from CLAMP sampling during 1999 - 2003, the ratio of total nitrogen to total phosphorus for this lake is approximately 14:1. The ISU sampling from 2000 - 2003 gives a mean total nitrogen to total phosphorus ratio of 11:1. Data on inorganic suspended solids from the ISU survey indicate that this lake is subject to moderately 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 Upper Gar Lake during the same time period was 10.5 mg/l.

Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for in-lake sampling indicate that a non-phosphorus limitation to algal growth is present (see Figures 2 & 3 and Appendix C). This non-phosphorus limitation may be attributable to the moderately high levels of inorganic suspended solids that tend to limit algal growth by limiting light penetration to the water column. The relatively low nitrogen to phosphorus ratio may also impose a nitrogen limitation on algal growth during some periods.

TSI values for 1999 - 2003 CLAMP and 2000 - 2003 ISU monitoring data are shown in Tables 4 and 5. TSI values for all historical monitoring data and an explanation of Carlson's Trophic State Index are given in Appendix C.

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/2000	63	63	81
7/13/2000	70	53	79
8/4/2000	77	67	90
5/16/2001	49		66
6/13/2001	50	51	69
7/18/2001	56	48	62
5/22/2002	70	64	69
6/19/2002	63	62	64
7/24/2002	65	68	64
5/21/2003	59	51	61
6/18/2003	49	37	53
7/23/2003	56	64	68

Table 5. CLAMP TSI Values (21)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/17/1999	55	52	74
7/14/1999	67	--	79
7/28/1999	59	63	81
8/11/1999	65	58	81
8/24/1999	64	--	--
8/25/1999	--	--	74
9/8/1999	64	72	75
9/22/1999	64	67	73
10/6/1999	68	69	75
10/20/1999	70	66	76
5/20/2000	65	59	76
6/2/2000	65	67	75
6/16/2000	65	69	72
6/30/2000	65	67	74
7/14/2000	72	70	79
7/28/2000	70	73	82
8/11/2000	74	76	82
8/25/2000	70	66	80
9/9/2000	74	69	81
9/26/2000	64	65	77
6/8/2001	56	58	62
6/22/2001	59	56	70
7/3/2001	63	63	70
7/19/2001	60	65	70
8/3/2001	69	73	75
8/22/2001	69	73	73
9/1/2001	72	73	74
9/21/2001	69	69	69
6/5/2002	59	57	65
6/17/2002	66	65	67
7/2/2002	65	63	68
7/16/2002	74	71	74
8/2/2002	70	72	71
8/12/2002	68	67	68
8/28/2002	66	69	68
9/6/2002	67	67	67
9/27/2002	65	69	68
6/12/2003	52	43	59
6/28/2003	59	52	66
7/15/2003	54	68	68
7/30/2003	67	76	77
8/14/2003	75	74	77
8/30/2003	72	71	77
9/6/2003	72	66	75
9/13/2003	73	72	82

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

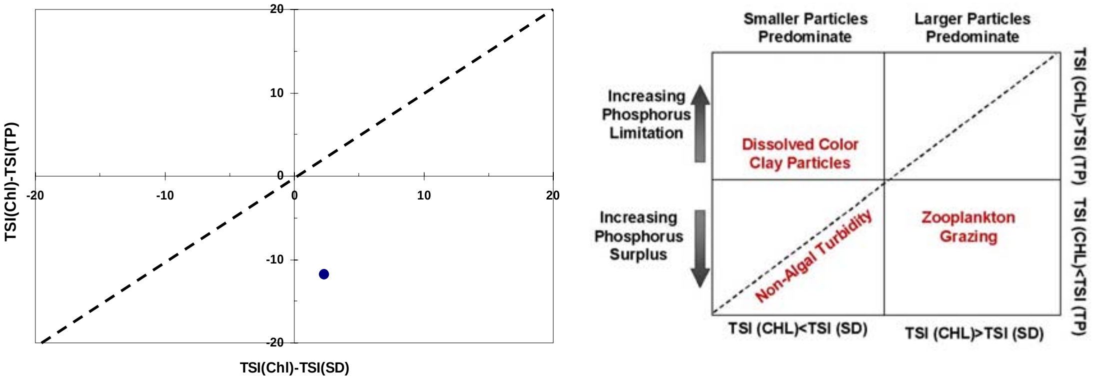
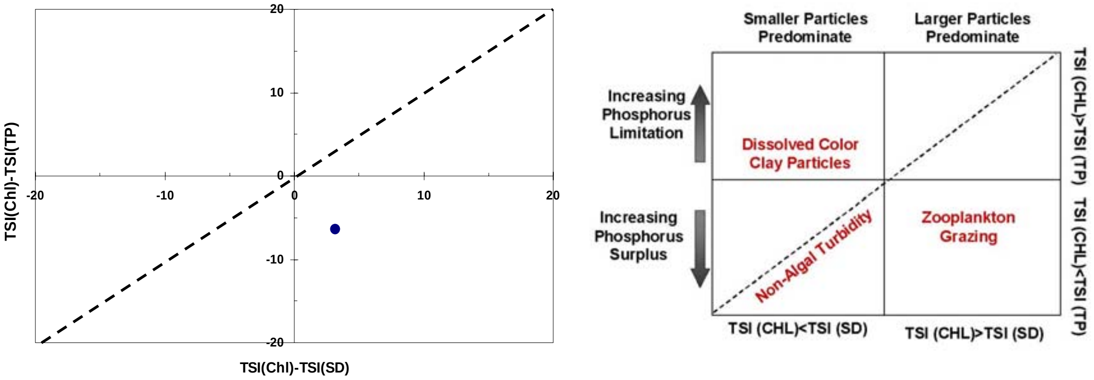


Figure 3. 2000 - 2003 CLAMP Sampling Mean TSI Multivariate Comparison Plot (22)



Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) can at times comprise a significant portion of the summertime phytoplankton community of Upper Gar Lake. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. Sampling in 2000 indicates a high level of bluegreen mass relative to other Iowa lakes. The 2000 average summer wet mass (30 mg/l) was the 33rd highest of 131 lakes sampled. The 2001 summer average wet mass decreased to 1.3 mg/L, although bluegreens comprised approximately 80% of the phytoplankton community. Sampling for cyanobacterial toxins has not been conducted at Upper Gar Lake. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

Potential Pollution Sources

Water quality in Upper Gar Lake is influenced only by nonpoint sources and internal recycling of pollutants from bottom sediments. Nonpoint source categories identified in this TMDL include inflow from East Okoboji Lake combined with internal recycle, atmospheric deposition and watershed loads in the immediate Upper Gar watershed. There are no point source discharges in the watershed.

Natural Background Conditions

For the phosphorus load attributable to atmospheric deposition directly on the lake surface, the annual average concentration of phosphorus in precipitation was assumed to be 0.05 mg/L based on a review of available literature (11,17,18,19) and the default values used in the EUTROMOD and WILMS modeling programs. Contributions of phosphorus attributable to dry atmospheric deposition were not separated from the direct precipitation load. 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 are mean TSI values of less than 65 for total phosphorus, and mean TSI values of less than 60 for both chlorophyll and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 68 and 20 ug/L, respectively, and a Secchi depth of 1.0 meters.

Table 6. Upper Gar Lake Existing vs. Target TSI Values

Parameter	ISU 2000-2003 TSI	ISU 2000-2003 Value	CLAMP 1999-2003 TSI	CLAMP 1999-2003 Value	Target TSI	Target Value
Chlorophyll	61	21 ug/L	68	45 ug/L	<60	<20 ug/L
Secchi Depth	58	1.1 meters	65	0.7 meters	<60	>1.0 meters
Total Phosphorus	72	113 ug/L	74	130 ug/L	<65	<68 ug/L

Table 7. In-Lake Increase or Reduction Required

Parameter	Minimum Increase or Reduction Required based on ISU Sampling	Minimum Increase or Reduction Required based on CLAMP Sampling
Chlorophyll	5% Decrease	56% Reduction
Secchi Depth	NA	43% Increase in transparency
Total Phosphorus	40% Decrease	48% 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 Upper Gar 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 nutrients. The noxious aquatic plant impairment is due to algal blooms caused by excessive nutrient loading to the lake. The nutrient-loading objective is defined by a mean total phosphorus TSI of less than 65, which is related through the Trophic State Index to chlorophyll a and Secchi depth. The TSI is not a standard, but is used as a guideline to relate phosphorus loading to the impairment for TMDL development purposes and to describe water quality that will meet Iowa’s narrative water quality standards.

Selection of Environmental Conditions

The critical condition for which the TMDL TSI target values apply is the growing season (May through September). It is during this period that nuisance algal blooms are prevalent. However, the existing and target total phosphorus loadings to the lake are expressed as annual averages. 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.

Table 8. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = ANN TP = 130 ug/L, SPO TP = 89 ug/L	Comments
Loading Function	5,260	Reckhow (10)
EPA Export	5,340	EPA/5-80-011
WILMS Export	5,250	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	7,080	GSM model
Canfield-Bachmann 1981 Natural Lake	6,080	GSM model
Canfield-Bachmann 1981 Artificial Lake	7,220	GSM model
Reckhow 1977 Anoxic Lake	6,170	GSM Model
Reckhow 1979 Natural Lake	7,030	GSM Model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	6,710	GSM model. P out of range
Nurnberg 1984 Oxic Lake	5,260 (internal load = 730)	Annual model. P out of range
Walker 1977 General Lake	4,060	SPO model.
Vollenweider 1982 Combined OECD	10,130	Annual model.
Vollenweider 1982 Shallow Lake	11,280	Annual model.

For the Loading Function and export watershed delivery estimates, the phosphorus contribution of East Okoboji Lake was calculated using the 1999 - 2003 average total phosphorus value for the southernmost CLAMP sampling point (Site # 57) and estimated average annual flow from East Okoboji Lake as follows:

Load from E. Okoboji = 124 ug/L x 15,310 acre-ft/yr x 2.72E-3 = 5,160 lbs/yr

The Canfield-Bachmann Natural Lake Model resulted in the value closest to the Loading Function and export estimates while remaining within the parameter ranges used to derive it when applied to Upper Gar Lake. Therefore, the Canfield-Bachmann Natural Lake relationship was selected as the 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 Upper Gar Lake are as follows:

$$P = 130(\mu g / L) = \frac{18{,}710(mg/m^2)}{1.02(m)\left[0.162\left(18{,}710(mg/m^2)\big/1.02(m)\right)^{0.458} + 126(yr^{-1})\right]}$$

The calculations for the total phosphorus load capacity are:

$$P = 68(\mu g / L) = \frac{9{,}490(mg/m^2)}{1.02(m)\left[0.162\left(9{,}490(mg/m^2)\big/1.02(m)\right)^{0.458} + 126(yr^{-1})\right]}$$

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 Upper Gar Lake can receive and meet its designated uses. Based on the selected lake response model and a target TSI (TP) value of less than 65, the Phase 1 total phosphorus loading capacity for the lake is 3,080 pounds per year.

3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Upper Gar Lake in this TMDL. The first is the phosphorus load attributable to inflow from East Okoboji Lake and phosphorus recycled from lake sediments within Upper Gar Lake. The second source is the watershed area that drains directly into the lake. The third source is atmospheric deposition directly onto the lake. 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 Upper Gar Lake is estimated to be 6,080 pounds per year based on the selected lake response model. Of this, 5,980 pounds per year is attributable to inflow from East Okoboji Lake and internal recycle within Upper Gar Lake. The remaining 100 pounds per year is divided into inputs from the immediate Upper Gar watershed (90 pounds per year) and atmospheric deposition (10 pounds per year). Due to the sensitivity of the load calculation for East Okoboji Lake to estimated flow (see *Section 3.2, Modeling Approach*), the influent load from East Okoboji Lake was not separated from the Upper Gar internal recycle load.

Departure from Load Capacity

The Phase 1 targeted total phosphorus load capacity for Upper Gar Lake is 3,080 pounds per year. The estimated existing load is 6,080 pounds per year. Therefore, to achieve and maintain Phase 1 water quality goals and protect the designated uses, a source load reduction of 3,000 pounds per year is required.

Identification of Pollutant Sources

There are no significant point source discharges in the Upper Gar Lake watershed. The primary sources of phosphorus are East Okoboji Lake and internal recycle within Upper Gar Lake. The combined phosphorus load from these sources was estimated by subtracting the Loading Function phosphorus inputs for the immediate Upper Gar watershed (90 lbs/yr) and atmospheric deposition (10 lbs/yr) from the in-lake response model total load (6,080 lbs/yr).

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Upper Gar Lake originates entirely from nonpoint sources (including East Okoboji Lake) and internal recycling. To meet the TMDL endpoint, the annual nonpoint source contribution to Upper Gar Lake needs to be reduced by 3,000 pounds per year.

3.4 Pollutant Allocation

Wasteload Allocation

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

Load Allocation

The Load Allocation (LA) for this TMDL is 2,780 pounds per year of total phosphorus distributed as follows:

- 2,770 pounds per year allocated to influent from East Okoboji Lake, internal recycling of phosphorus from lake bottom sediments, and the immediate Upper Gar Lake watershed.
- 10 pounds per year allocated to atmospheric deposition.

Margin of Safety

An explicit numerical MOS of 300 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 Upper Gar Lake water quality.

Due to the small size of the immediate Upper Gar Lake watershed relative to the watersheds of the lake system that feeds it, the major phosphorus loads to the lake are influent from East Okoboji Lake (to which West Okoboji Lake is a tributary) and internal recycling. Because the load calculation for East Okoboji Lake is very sensitive to the accuracy of the estimated flow, the influent load from East Okoboji Lake was not separated from the Upper Gar 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 sediment. 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 is attributable to influent from East Okoboji and how much is recycled from lake bottom sediment, an adaptive management approach is recommended. In this approach management practices to reduce upstream 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 6,100 pounds per year to 5,000 pounds per year by 2010.
- Reduce watershed and recycle loading from 5,000 pounds per year to 3,900 pounds per year by 2015.
- Reduce watershed and recycle loading from 3,900 pounds per year to 2,800 pounds per year by 2020.

Best management practices to reduce nutrient delivery, particularly phosphorus, should be emphasized in both the immediate Upper Gar Lake watershed and in the upstream Iowa Great Lakes watersheds. 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.
- 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 watersheds to control erosion and reduce delivery of sediment and phosphorus to the lake.

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

In addition to the external nutrient loading from watershed sources to Upper Gar 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 Upper Gar 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. Upper Gar 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. It is anticipated that CLAMP monitoring will continue for the foreseeable future.

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 Upper Gar. 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

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

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

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

There are approximately 127 public lakes in Iowa. The contributing watersheds for these lakes range in area from 0.028 mi^2 to 195 mi^2 with mean and median values of 10 mi^2 and 3.5 mi^2, respectively. Few, if any, of these lakes have gauging data available to determine flow statistics for the tributaries that feed into them. A select few have some type of stage information that may be useful in determining historical discharge from the lake itself.

With the large number of lakes on the State's 303(d) list and the requirement for rapid development of TMDLs for these lakes, it was realized that a method to quickly estimate flow statistics for required lake response model inputs would be desirable. In an attempt to achieve this goal, flow data and watershed characteristics for a number of USGS gauging stations with small contributing watershed areas were compiled and evaluated via both simple and multiple linear regressions. The primary focus of this evaluation was estimation of the average annual flow statistic for input to empirical lake response models. However, regression equations for monthly average and calendar year flow statistics were also developed that may be of additional use.

It should be noted that attempts were made to develop regression equations for low-flow streamflow statistics (1Q10, 7Q10, 30Q10, 30Q5 and harmonic mean) but the relationships derived were for the most part considered too weak (R^2 adj.< 70%) to be of practical use. One exception to this is the 30Q5 statistic, which gave an R^2 adj. of 85%. In addition, regression equations were developed for monthly flow prediction models for two months (January and May). Once again, the relationships did not exhibit a high level of correlation and due to the large amount of data required to develop these models, development of equations for additional months was not attempted.

Data

Flow data and watershed characteristics from 26 USGS gauging stations were used to derive the regression equations. The ranges of basin characteristics used to develop the regression equations are shown in Table A-1.

Drainage areas were taken directly from USGS gauge information available at http://water.usgs.gov/waterwatch/ . Precipitation values were obtained through the Iowa Environmental Mesonet IEM Climodat Interface at http://mesonet.agron.iastate.edu/climodat/index.phtml . Where weather and gauging stations were not located in the same town, precipitation information was obtained from the weather station located in the town with the shortest straight-line distance from the gauging station.

Average basin slope and land cover percentages were determined using Arc View and statewide coverages clipped within HUC-12 sub-watersheds. It should be noted that the smallest basin coverages used in determining land cover percentages and average basin slopes were single HUC-12 units (i.e. no attempt was made to subdivide HUC-12 basins into smaller units where the drainage area was less than the area of the HUC-12 basin). Therefore, the regression models assume that for very small watersheds the land cover percentages of the HUC-12 basin are representative of the watershed located within the basin.

The Hydrologic Region for each station was determined from Figure 1 of USGS Water-Resources Investigation Report 87-4132, Method for Estimating the Magnitude and Frequency of Floods at Ungaged Sites on Unregulated Rural Streams in Iowa. None of the stations included in the analyses were located in Regions 1 or 5. This is reflected in the regression equations developed that utilize the hydrologic region as a variable.

Table A-1. Ranges of Basin Characteristics Used to Develop the Regression Equations

Basin Characteristic	Name in equations	Minimum	Mean	Maximum
Drainage Area (mi^2)	DA	2.94	80.7	204
Mean Annual Precip (inches)	$\overline{P}_A$	26.0	34.0	36.2
Average Basin Slope (%)	S	1.53	4.89	10.9
Landcover - % Water	W	0.020	0.336	2.80
Landcover - % Forest	F	2.45	10.3	29.9
Landcover - % Grass/Hay	G	9.91	31.3	58.7
Landcover - % Corn	C	6.71	31.9	52.3
Landcover - % Beans	B	6.01	23.1	37.0
Landcover - % Urban/Artificial	U	0	2.29	7.26
Landcover - % Barren/Sparse	B'	0	0.322	2.67
Hydrologic Region	H	Regions 1 - 5 used for delineation but data for USGS stations in Regions 2, 3 & 4 only.		

Methods

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

Equation Variables

Table A-2. Regression Equation Variables

Annual Average Flow (cfs)	$\overline{Q}_A$
Monthly Average Flow (cfs)	$\overline{Q}_{MONTH}$
Annual Flow – calendar year (cfs)	Q_{YEAR}
Drainage Area (mi^2)	DA
Mean Annual Precip (inches)	$\overline{P}_A$
Mean Monthly Precip (inches)	$\overline{P}_{MONTH}$
Antecedent Mean Monthly Precip (inches)	$\overline{A}_{MONTH}$
Annual Precip – calendar year (inches)	P_{YEAR}
Antecedent Precip – calendar year (inches)	A_{YEAR}
Average Basin Slope (%)	S
Landcover - % Water	W
Landcover - % Forest	F
Landcover - % Grass/Hay	G
Landcover - % Corn	C
Landcover - % Beans	B
Landcover - % Urban/Artificial	U
Landcover - % Barren/Sparse	B'
Hydrologic Region	H

Equations

Table A-3. Drainage Area Only Equations

Equation	R^2 adjusted (%)	PRESS (log transform)
$\overline{Q}_A = 0.832 DA^{0.955}$	96.1	0.207290
$\overline{Q}_{JAN} = 0.312 DA^{0.950}$	85.0	0.968253
$\overline{Q}_{FEB} = 1.32 DA^{0.838}$	90.7	0.419138
$\overline{Q}_{MAR} = 0.907 DA^{1.03}$	96.6	0.220384
$\overline{Q}_{APR} = 0.983 DA^{1.02}$	93.1	0.463554
$\overline{Q}_{MAY} = 1.97 DA^{0.906}$	89.0	0.603766
$\overline{Q}_{JUN} = 2.01 DA^{0.878}$	88.9	0.572863
$\overline{Q}_{JUL} = 0.822 DA^{0.977}$	87.2	0.803808
$\overline{Q}_{AUG} = 0.537 DA^{0.914}$	74.0	1.69929
$\overline{Q}_{SEP} = 0.123 DA^{1.21}$	78.7	2.64993
$\overline{Q}_{OCT} = 0.284 DA^{1.04}$	90.2	0.713257
$\overline{Q}_{NOV} = 0.340 DA^{0.999}$	89.8	0.697353
$\overline{Q}_{DEC} = 0.271 DA^{1.00}$	86.3	1.02455

Table A-4. Multiple Regression Equations

Equation	**R^2 adjusted (%)**	**PRESS (log transform)**
$\overline{Q}_{A} = 1.17 \times 10^{-3} DA^{0.998} \overline{P}_{A}^{1.54} S^{-0.261} (1+F)^{0.249} C^{0.230}$	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 Upper Gar Lake – Calculations

Table A-5. Upper Gar Lake Hydrology Calculations

Lake	Upper Gar	
Type	Natural	
Inlet(s)	E. Okoboji Lake	
Outlet(s)	Minnewashta Lake	
Volume	122	(acre-ft)
Lake Area	36	(acres)
Mean Depth	3.36	(ft)
Drainage Area (immediate U. Gar watershed)	222	(acres)
Mean Annual Precip	28.3	(inches)
Average Basin Slope	3.99	(%)
%Water	0	
%Forest	36.15450799	
%Grass/Hay	51.76380021	
%Corn	1.308698999	
%Beans	9.464293801	
%Urban/Artificial	0.303400806	
%Barren/Sparse	1.005298193	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	48.00	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow (U. Gar watershed)	94.25	(acre-ft)
Direct Lake Precip	85.92	(acre-ft/yr)
West Okoboji		
Lake Area	3883.00	(acres)
Drainage Area	15066.00	(acres)
Mean Annual Precip	28.30	(inches)
Average Basin Slope	2.83	(%)
%Water	2.926931525	
%Forest	13.43700517	
%Grass/Hay	40.45563067	
%Corn	21.39621307	
%Beans	20.5494	
%Urban/Artificial	0.4957	
%Barren/Sparse	0.716972846	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	48	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow	10409.85	(acre-ft)
Direct Lake Precip	9160.64	(acre-ft/yr)
East Okoboji		
Lake Area	1843.00	(acres)
Drainage Area	11764.00	(acres)
Mean Annual Precip	28.30	(inches)
Average Basin Slope	2.91	(%)
%Water	0.438150067	
%Forest	13.36073081	
%Grass/Hay	29.22308865	
%Corn	24.73742432	
%Beans	30.8783	
%Urban/Artificial	0.4440	
%Barren/Sparse	0.901279021	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	48	(inches)
Mean Annual Lake Evap	35.52	(inches)
Est. Annual Average Inflow	8336.62	(acre-ft)
Direct Lake Precip	4347.94	(acre-ft/yr)
East Okoboji-->Upper Gar	15306	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.0079	(yr)
Est. Annual Average Det. Time (outflow)	0.0080	(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	0.6	0.7
Chlorophyll (ug/L)	--	--	--
NO_3+NO_2-N (mg/L)	--	--	0.62
Total Phosphorus (ug/l as P)	133	137	122
Alkalinity (mg/L)	197	198	197

Data above is averaged over the upper 6 feet.

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

Parameter	**5/26/1990**	**6/30/1990**	**7/28/1990**
Secchi Depth (m)	1.5	0.6	1.2
Chlorophyll (ug/L)	196.9	83.7	74.5
Total Nitrogen (mg/L as N)	1.7	2.2	3.4
Total Phosphorus (ug/l as P)	224.8	147.5	217.2
Total Suspended Solids (mg/L)	22.8	26.9	20.0
Inorganic Suspended Solids (mg/L)	6.9	3.0	9.9

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)	0.8	0.5	0.3
Chlorophyll (ug/L)	27	10	40
NH_3+NH_4^+ -N (ug/L)	514	711	1178
NH_3 –N (un-ionized) (ug/L)	30	106	147
NO_3+NO_2-N (mg/L)	0.19	0.20	0.17
Total Nitrogen (mg/L as N)	1.08	1.39	1.69
Total Phosphorus (ug/l as P)	156	150	377
Silica (mg/L as SiO_2)	23	36	100
pH	8.2	8.4	8.4
Alkalinity (mg/L)	198	198	191
Total Suspended Solids (mg/L)	14.3	32.1	63.0
Inorganic Suspended Solids (mg/L)	9.1	25.2	49.5
Volatile Suspended Solids (mg/L)	5.2	6.9	13.5

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)	2.2	2.0	1.3
Chlorophyll (ug/L)		8	6
NH_3+NH_4^+ -N (ug/L)	466	256	275
NH_3 –N (un-ionized) (ug/L)	16	15	31
NO_3+NO_2-N (mg/L)	0.56	0.71	0.12
Total Nitrogen (mg/L as N)	1.28	1.05	1.10
Total Phosphorus (ug/l as P)	69	89	63
Silica (mg/L as SiO_2)	12	3	5
pH	8.0	8.2	8.3
Alkalinity (mg/L)	85	170	168
Total Suspended Solids (mg/L)	2.4	16.8	2.5
Inorganic Suspended Solids (mg/L)	1.2	11.9	0.0
Volatile Suspended Solids (mg/L)	1.2	4.9	2.5

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

Parameter	**5/22/2002**	**6/19/2002**	**7/24/2002**
Secchi Depth (m)	0.5	0.8	0.7
Chlorophyll (ug/L)	29	26	47
NH_3+NH_4^+ -N (ug/L)	368	202	185
NH_3 –N (un-ionized) (ug/L)	25	19	21
NO_3+NO_2-N (mg/L)	0.16	0.17	0.17
Total Nitrogen (mg/L as N)	1.23	0.97	1.37
Total Phosphorus (ug/l as P)	87	65	65
Silica (mg/L as SiO_2)	1	4	5
pH	8.4	8.4	8.3
Alkalinity (mg/L)	191	198	187
Total Suspended Solids (mg/L)	41.3	17.7	14.2
Inorganic Suspended Solids (mg/L)	30.0	8.7	7.5
Volatile Suspended Solids (mg/L)	11.3	9.0	6.8

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

Parameter	**5/21/2003**	**6/18/2003**	**7/23/2003**
Secchi Depth (m)	1.1	2.2	1.7
Chlorophyll (ug/L)	7.9	1.9	29.1
NH_3+NH_4^+ -N (ug/L)	196	184	194
NH_3 –N (un-ionized) (ug/L)	12	34	27
NO_3+NO_2-N (mg/L)	0.14	0.14	<0.07
Total Nitrogen (mg/L as N)	1.10	0.99	1.36
Total Phosphorus (ug/l as P)	52	30	86
Silica (mg/L as SiO_2)	3.12	4.16	10.00
pH	8.4	8.6	8.5
Alkalinity (mg/L)	191	131	134
Total Suspended Solids (mg/L)	13	5	8
Inorganic Suspended Solids (mg/L)	9	2	3
Volatile Suspended Solids (mg/L)	4	3	4

Table B-7. CLAMP Data (Iowa Lakeside Laboratory)

Date	Total Phosphorous (mg/L)	Total P (ug/L)	P-TSI	Secchi Disc Depth (m)	S-TSI	chlorophyll a (mg/m3)	C-TSI	Total Nitrogen (mg/L)	Nitrate (mg/L)
6/17/1999	0.124	124.335	74	1.4	55	9.19	52	4.28	0.82
7/14/1999	0.185	185.225	79	0.6	67			2.32	0.11
7/28/1999	0.208	208.2	81	1.1	59	26.77	63	2.05	0.08
8/11/1999	0.200	199.775	81	0.7	65	15.79	58	2.22	0.09
8/24/1999				0.7	64				
8/25/1999	0.126	125.8	74					1.81	0.10
9/8/1999	0.137	137.42	75	0.8	64	65.04	72	1.69	0.11
9/22/1999	0.115	115.4	73	0.8	64	39.91	67	1.54	0.13
10/6/1999	0.139	139.435	75	0.6	68	50.49	69	2.15	0.10
10/20/1999	0.150	150.2	76	0.5	70	35.11	66	1.71	0.24
5/20/2000	0.151	150.925	76	0.7	65	17.94	59	2.96	0.17
6/2/2000	0.139	139.335	75	0.7	65	40.00	67	2.23	0.18
6/16/2000	0.112	111.52	72	0.7	65	52.13	69	2.19	0.07
6/30/2000	0.126	126.12	74	0.7	65	41.10	67	2.07	0.10
7/14/2000	0.180	180.085	79	0.5	72	53.00	70	1.82	0.07
7/28/2000	0.221	220.805	82	0.5	70	76.63	73	2.37	0.08
8/11/2000	0.216	216.165	82	0.4	74	101.98	76	2.35	0.12
8/25/2000	0.193	193.15	80	0.5	70	36.40	66	2.01	0.07
9/9/2000	0.206	205.735	81	0.4	74	50.27	69	2.24	0.09
9/26/2000	0.162	161.655	77	0.8	64	34.49	65	1.93	0.11
6/8/2001	0.056	55.5365	62	1.3	56	15.62	58	2.02	0.79
6/22/2001	0.098	98.416	70	1.1	59	12.97	56	1.93	0.80
7/3/2001	0.095	95.4	70	0.8	63	27.05	63	1.51	0.51
7/19/2001	0.097	96.7245	70	1.0	60	32.06	65	1.10	0.11
8/3/2001	0.140	139.72	75	0.6	69	73.08	73	1.36	0.08
8/22/2001	0.121	121.355	73	0.5	69	72.51	73	1.46	0.13
9/1/2001	0.124	123.525	74	0.5	72	79.01	73	1.61	0.12
9/21/2001	0.093	92.696	69	0.6	69	48.34	69	1.42	0.11
6/5/2002	0.069	68.72	65	1.1	59	15.19	57	1.10	0.12
6/17/2002	0.076	75.928	67	0.7	66	32.05	65	1.07	0.07
7/2/2002	0.081	81.104	68	0.7	65	26.46	63	0.96	0.10
7/16/2002	0.129	129.225	74	0.4	74	64.15	71	1.44	0.12
8/2/2002	0.100	100.403	71	0.5	70	67.73	72	1.33	0.11
8/12/2002	0.083	82.7495	68	0.6	68	42.79	67	1.25	0.11
8/28/2002	0.084	83.6865	68	0.7	66	48.00	69	1.50	0.09
9/6/2002	0.077	77.344	67	0.6	67	39.99	67	1.24	0.14
9/27/2002	0.087	86.6605	68	0.7	65	51.08	69	1.40	0.12
6/12/2003	0.046	46.0265	59	1.7	52	3.57	43	1.13	0.06
6/28/2003	0.074	73.555	66	1.1	59	8.97	52	1.59	0.15
7/15/2003	0.085	85.1385	68	1.5	54	44.17	68	1.66	0.07
7/30/2003	0.159	158.67	77	0.6	67	106.10	76	2.49	0.11
8/14/2003	0.161	161.325	77	0.4	75	80.97	74	2.15	0.08
8/30/2003	0.157	156.57	77	0.5	72	58.48	71	1.81	0.11
9/6/2003	0.138	137.945	75	0.5	72	35.99	66	1.65	0.06
9/13/2003	0.215	215.375	82	0.4	73	69.48	72	2.25	0.09

Table B-8. 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	4.2E+00	7.7E+00	7.7E+01
Cryptophyta	2.6E-01	3.7E-01	4.4E-02
Chlorophyta	6.1E-01	1.1E+00	1.6E-01
Dinophyta	0.0E+00	0.0E+00	1.4E-01
Chrysophyta	6.7E+01	6.1E+01	3.3E+01
Euglenophyta	2.7E-01	8.2E-01	8.4E-02
Total	**7.2E+01**	**7.1E+01**	**1.1E+02**

Table B-9. 2001 Phytoplankton Data (4)

	5/16/2001	6/13/2001	7/18/2001
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Chlorophyta	0.00E+00	0.00E+00	7.51E-01
Chrysophyta	0.00E+00	1.99E-01	3.60E-02
Cryptophyta	0.00E+00	0.00E+00	0.00E+00
Cyanobacteria	2.43E+00	1.12E+00	2.75E-01
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	0.00E+00	0.00E+00
Total	2.43E+00	1.32E+00	1.06E+00

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

10. Appendix C - Trophic State Index

Carlson's Trophic State Index

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

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

$$\text{TSI (TP)} = 14.42 \ln(\text{TP}) + 4.15$$

$$\text{TSI (CHL)} = 9.81 \ln(\text{CHL}) + 30.6$$

$$\text{TSI (SD)} = 60 - 14.41 \ln(\text{SD})$$

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

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

SD = lake Secchi depth, meters

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

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

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

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

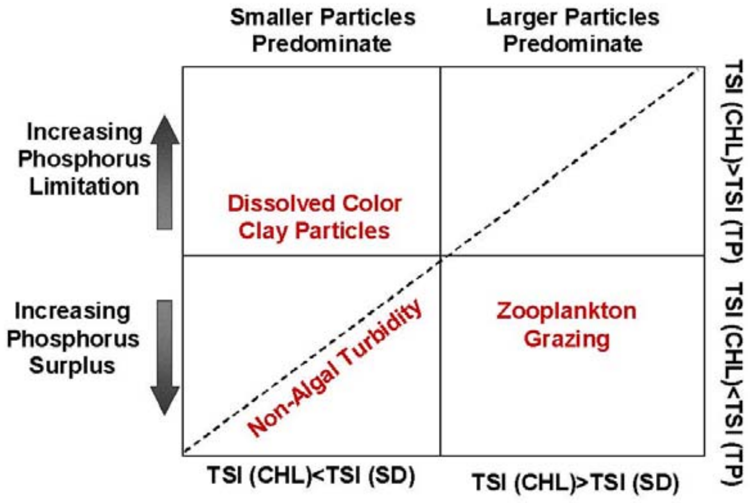
Level of Support	**TSI value**	**Chlorophyll-a (ug/l)**	**Secchi Depth (m)**
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates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

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

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

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

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



Upper Gar Lake TSI Values

Table C-4. 1979 Upper Gar TSI Values (1)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/11/1979	77	--	75
8/14/1979	67	--	75
9/18/1979	65	--	73

Table C-5. 1990 Upper Gar TSI Values (2)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
5/26/1990	73	70	78
6/30/1990	77	72	75
7/28/1990	77	71	72

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/2000	64	63	81
7/13/2000	71	53	79
8/4/2000	76	67	90
5/16/2001	49	--	66
6/13/2001	50	51	69
7/18/2001	56	48	62
5/22/2002	72	64	68
6/19/2002	63	62	64
7/24/2002	66	68	64
5/21/2003	59	51	61
6/18/2003	49	37	53
7/23/2003	57	64	68

Table C-7. CLAMP TSI Values (21)

Sample Date	**TSI (SD)**	**TSI (CHL)**	**TSI (TP)**
6/17/1999	55	52	74
7/14/1999	67	--	79
7/28/1999	59	63	81
8/11/1999	65	58	81
8/24/1999	64	--	--
8/25/1999	--	--	74
9/8/1999	64	72	75
9/22/1999	64	67	73
10/6/1999	68	69	75
10/20/1999	70	66	76
5/20/2000	65	59	76
6/2/2000	65	67	75
6/16/2000	65	69	72
6/30/2000	65	67	74
7/14/2000	72	70	79
7/28/2000	70	73	82
8/11/2000	74	76	82
8/25/2000	70	66	80
9/9/2000	74	69	81
9/26/2000	64	65	77
6/8/2001	56	58	62
6/22/2001	59	56	70
7/3/2001	63	63	70
7/19/2001	60	65	70
8/3/2001	69	73	75
8/22/2001	69	73	73
9/1/2001	72	73	74
9/21/2001	69	69	69
6/5/2002	59	57	65
6/17/2002	66	65	67
7/2/2002	65	63	68
7/16/2002	74	71	74
8/2/2002	70	72	71
8/12/2002	68	67	68
8/28/2002	66	69	68
9/6/2002	67	67	67
9/27/2002	65	69	68
6/12/2003	52	43	59
6/28/2003	59	52	66
7/15/2003	54	68	68
7/30/2003	67	76	77
8/14/2003	75	74	77
8/30/2003	72	71	77
9/6/2003	72	66	75
9/13/2003	73	72	82

11. Appendix D - Land Use Map

Figure D-1. Upper Gar Lake 2002 Landuse