Total Maximum Daily Load
For Algae and Turbidity
Carter Lake,
Iowa and Nebraska

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TMDL INFORMATION SHEET

Total Maximum Daily Load for Carter Lake

Waterbody: Carter Lake
Parameters Addressed by TMDL: Algae/Algal Toxins, Chlorophyll *a*, Total Phosphorus and Total Nitrogen and pH

	Iowa	**Nebraska**
County	Pottawattamie	Douglas
Impaired Uses[1]	Primary Contact Recreation	Primary Contact Recreation
	Aquatic Life	Aquatic Life
	Aesthetics	Aesthetics
TMDL Parameter(s) of Concern	Algae	Algal toxins, chlorophyll *a*, nitrogen, phosphorus, pH
Water Quality Targets	TSI: Total P <70 TSI: Chlorophyll <65 TSI: Secchi <65	Total P = 133 μg/l Total N = 1460 μg/l Chl-*a* = 44 μg/l pH = 6.5-9.0 su Algal Toxins = 20 μg/l (measured as microcystin concentration)

[1] Impaired uses are based on Iowa's 2004 Integrated Report and Nebraska's 2006 Integrated Report

Summary of TMDL Results for Total Phosphorus

TMDL (lbs/yr)	**1,462**
WLA (lbs/yr)	**1,301**
LA (lbs/yr)	**15**
MOS (lbs/yr)	**146**
Existing Load (lbs/yr)	**3,166**
% Reduction	**53.8%**

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1. Introduction and Problem Identification

1.1 Waterbody Description

Carter Lake, an oxbow lake adjacent to the Missouri River near Omaha, Nebraska is unique in that the waterbody is wholly contained in the geographical State of Nebraska but is shared by the State of Iowa. This situation is a result of the channelization of the main stem Missouri River. Carter Lake is located in the metropolitan area of Omaha, Nebraska on the outer perimeter and by the City of Carter Lake, IA along the interior perimeter.

Carter Lake has been identified as impaired by excessive nutrients, algae blooms, PCBs and fecal coliform bacteria. Table 1 lists key features of Carter Lake.

Table 1: Carter Lake Features

Waterbody Name:	Carter Lake
Hydrologic Unit Code:	10230006
IDNR Waterbody ID:	IA 06-WEM-00265-L
NDEQ Waterbody ID:	MT1-L0090
Location:	Section 23 T75N R44W
Latitude:	41.29 N
Longitude:	95.92 W
Iowa Water Quality Standards Designated Uses:	Primary Contact Recreation Aquatic Life Support
Nebraska Water Quality Standards Designated Uses:	Primary Contact Recreation Aquatic Life-WWA Agriculture Water Supply Aesthetics
Tributaries:	None
Receiving Waterbody:	Missouri River
Lake Surface Area:	315 acres
Maximum Depth:	28 feet
Mean Depth:	8 feet
Volume:	2520 acre-feet
Length of Shoreline:	35,376 feet
Watershed Area:	2722 acres
Watershed/Lake Area Ratio:	8.6:1
Estimated Detention Time:	3.04 years

Samples collected from Carter Lake during the 2005 recreation season (May 1 – September 30) by the Nebraska Department of Environmental Quality were analyzed for *E. coli* bacteria and indicate full support of the primary contact recreation uses. Based on this data, Nebraska has removed the bacteria indicator parameter from the list of impairments in the 2006 Integrated Report. Iowa's assessment is also based on data collected by Nebraska, and therefore will result in removal of the bacteria impairment.

In 2004, Nebraska prepared a document supporting a category 4b listing for all waters with impairments due to PCBs in fish tissue with Iowa supporting this action for Carter Lake. The issue remains unresolved with EPA Region 7. At this time no TMDL will be prepared for PCBs

Therefore, contained in this document is a TMDL that targets excess phosphorus to address the remaining pollutant impairing the waterbody.

Morphometry

Carter Lake has a mean depth of 8 feet and a maximum depth of 28 feet. The lake surface area is 315 acres and the storage volume is 2,520 acre-feet.

Hydrology

Average rainfall in the area is 31.9 inches. The annual average detention time for Carter Lake is 3.04 year based on outflow. The methodology and calculations used to determine the detention times are shown in Appendix A.

1.2 Land Use

Carter Lake has a watershed area of 2,722 acres and has a watershed to lake ratio of 8.6 to 1. Land use data was obtained from aerial photos and a reconnaissance of the watershed. Land uses for Carter Lake are listed below in Table 2.

There are no continuously discharging point sources or confined animal feeding operation (CAFO) within the Carter Lake watershed.

There are storm sewer outlets that discharge to the lake. The City of Omaha, Nebraska and the City of Carter Lake, Iowa have been issued Municipal Separate Storm Sewer Systems (MS4) permits.

Figure 1 shows the location of Carter Lake. Figure 2 illustrates the land use in the watershed.

Table 2: Land Use in Carter Lake Watershed

Land Use	**Area (acres)**	**Percent**
Residential Curb and Gutter	532	19.5%
High Density Residential Overland	250	9.2%
Low Density Residential Overland	113	4.2%
Park	212	7.8%
Open Space	395	14.5%
Water	358	13.1%
Wetland	26	0.9%
Deciduous Forest	32	1.2%
Golf Course	122	4.5%
Commercial/Industrial	683	25.1%
TOTAL	2722	100%

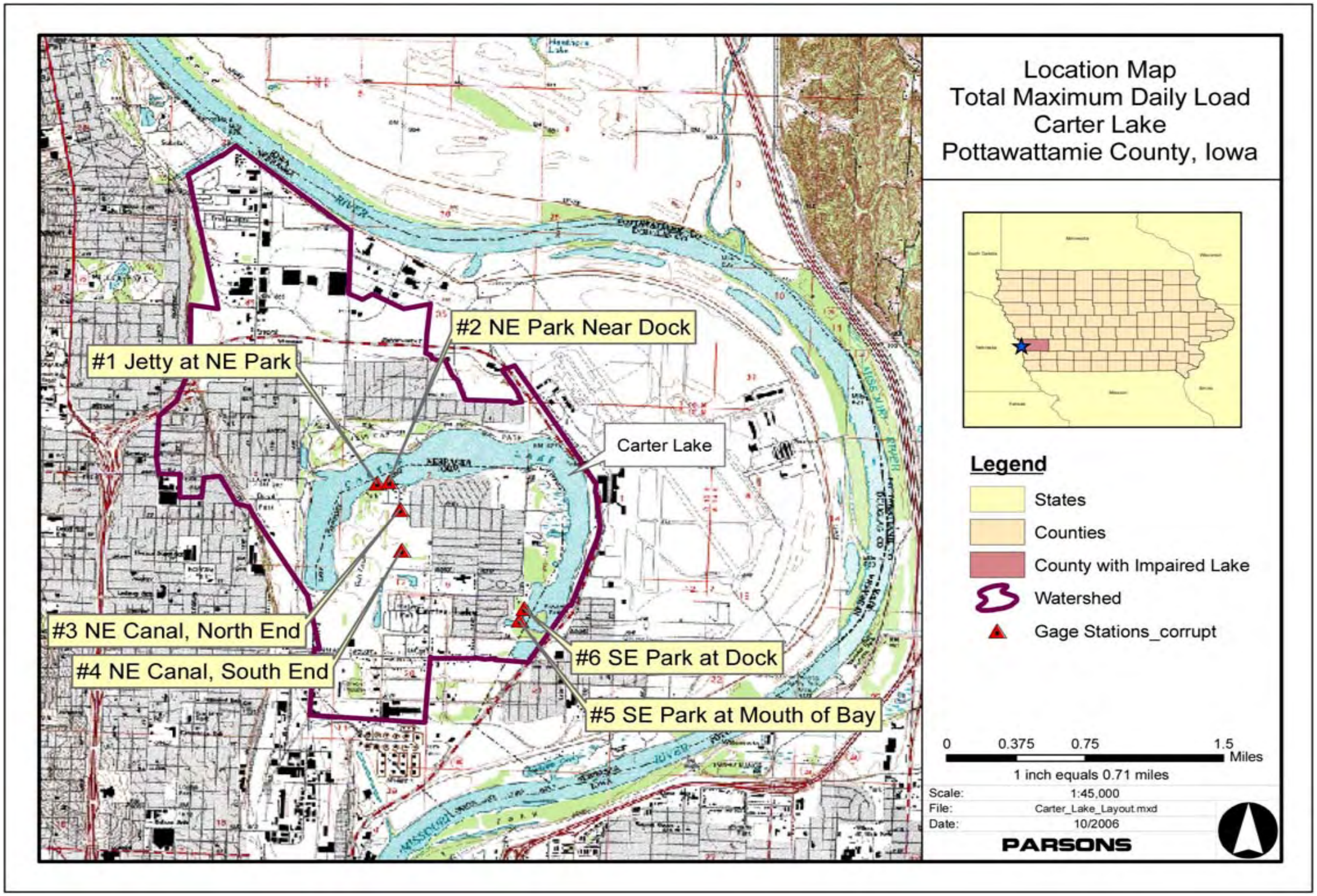

Figure 1: Location Map for Carter Lake

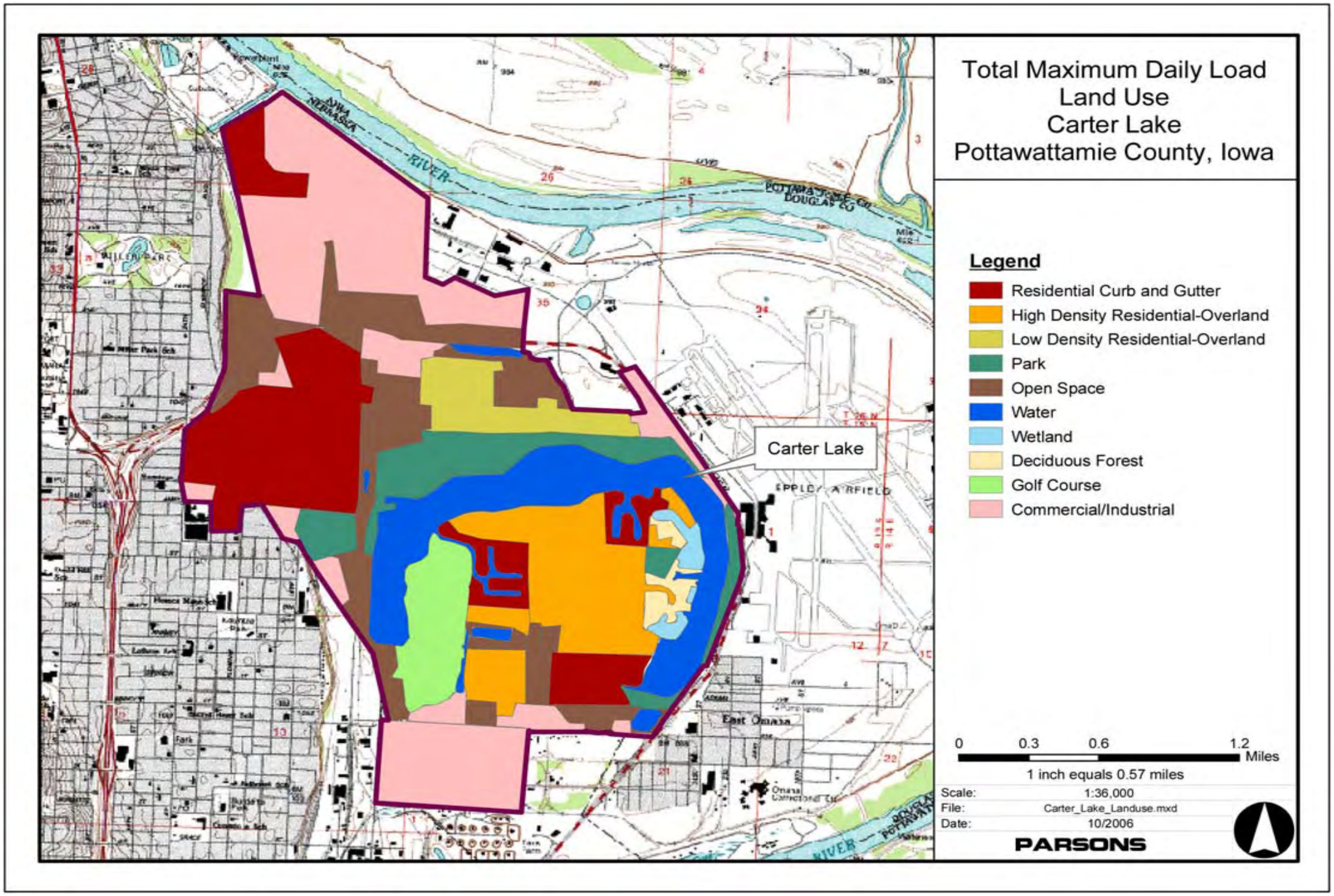

Figure 2: Land Use Map for Carter Lake

1.3 Problem Identification and Current Conditions

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

The Iowa Water Quality Standards (IAC 567-61) list the designated uses for Carter Lake as Primary Contact Recreational Use (Class A) and Aquatic Life (Class B(LW)). Carter Lake was included on the impaired waters list due to algae and turbidity impairments. The Class A (primary contact recreation) uses are assessed (monitored) as "partially supported" due to elevated levels of algal and non-algal turbidity at Carter Lake. The Class B(LW) aquatic life uses are assessed (evaluated) as "fully supporting / threatened" due to algae and non-algal turbidity (IDNR, 2004).

The 2006 Nebraska Surface Water Quality Report included Carter Lake on Part 5 (Section 303(d) List) for algal toxins, total phosphorus, total nitrogen, chlorophyll a, and pH (NDEQ, 2006). Excessive algal toxins have been assessed under the primary contact recreation beneficial use using a numeric water quality goal. pH criteria are included in the aquatic life beneficial use.

While several parameters are included, in the listing all can be categorized and addressed through the development of nutrient loading (e.g. total phosphorus). For example, algal toxins produced by blue green algae have been shown to be correlated to phosphorus, measures of transparency and overall chlorophyll concentrations. In addition, high concentrations of algae can lead to high pH in surface waters. During photosynthesis, the phytoplankton uptake carbon dioxide and give off oxygen. In this reaction, water molecules are cleaved. The organism takes up the hydrogen cation, and the remaining hydroxyl anion remains in solution. The pH value increases with the decrease in available hydrogen cations. Peaks in pH should occur in the afternoon, when the greatest amount of radiant energy reaches the river.

Data Sources

The sources of data for Carter Lake 305(b) assessment include: (1) results of Iowa State University (ISU) lake surveys in starting from 2000, (2) surveys by IDNR Fisheries Bureau, (3) ISU report on lake plankton communities in summer 2000 (Downing et al., 2003) and (4) the listing of fish consumption advisories for the state of Nebraska.

The primary data used to assess Carter Lake water quality and develop this TMDL are from Iowa State University Lake Study begun in 2000 and data from NDEQ. The study data were collected from 2000 to 2005 and during sampling visits in summer growing seasons. The samples were analyzed for variables including chlorophyll, secchi depth, the important forms of phosphorus and nitrogen, and suspended solids. Please refer to Appendix B for data summary.

<u>Carter Lake Water Quality Assessment</u>

Carlson’s trophic state index (TSI) has been used to relate TP, algae (as measured by chlorophyll) and transparency (as measured by secchi depth) to set water quality targets. TSI values for monitoring data are shown in Table 3. Using the median values from this survey from 2000 through 2005, Carlson's TSI values for TP, chlorophyll-a, and secchi depth are 75, 71, and 77, respectively. A detailed explanation on the TSI can be found in Appendix C.

Table 3: Carter Lake TSI Values Based on Lake Survey Data

		Sample Data			TSI Values		
DATE	**SOURCE**	**Secchi Depth (m)**	**Chlorophyll (µg/l)**	**Total Phosphorus (µg/l)**	**Secchi Depth**	**Chlorophyll**	**Total Phosphorus**
average		0.5	97	168	71	75	78
median		**0.4**	**59**	**153**	**75**	**71**	**77**
TARGETS		**> 0.7**	**< 33**	**< 96**	**< 65**	**< 65**	**< 70**

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

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

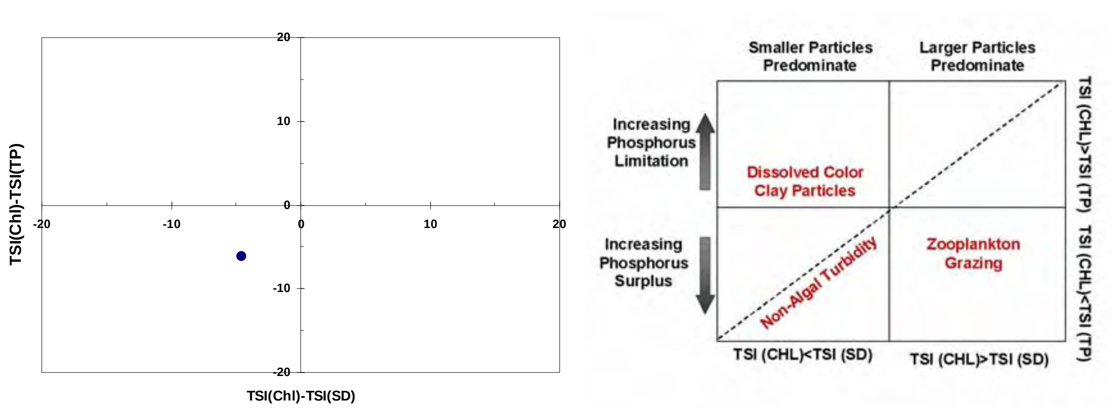

Figure 3: Carter Lake Median TSI Multivariate Comparison Plot
(Plotted Point: -4.6, -6.0)

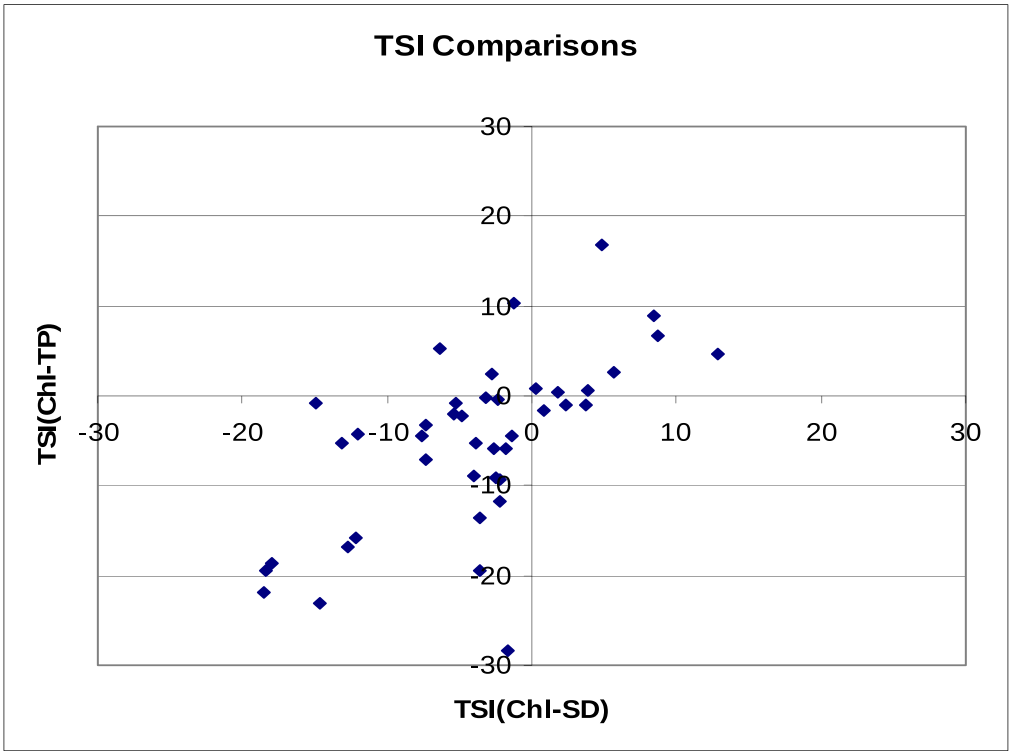

Figure 4: Carter Lake TSI Comparison Plot

Although results of ISU plankton monitoring in 2000 show a moderately large zooplankton population at Carter Lake (Downing et al., 2003), a relatively small percentage of the zooplankton are grazers on algae. The 2000 average summer mass of Cladocerans (6.9 mg/l) was the 41st lowest of the 131 lakes sampled (IDNR, 2004).

Based on median values from ISU sampling from 2000 through 2005, the ratio of total nitrogen to total phosphorus for Carter Lake is 16, which suggests the possibility that algal production at this lake is limited by nitrogen availability.

The TSI value for TP is higher than TSI for chlorophyll, which implies there could be limitations to algae growth besides phosphorus (e.g. non-algal particulates). Based on results of the ISU monitoring from 2000-2005, the primary non-phosphorus limitation to algal production appears to be inorganic suspended solids. In Figure 4, the data points for TSI (Chl-SD) and TSI (Chl-TP) are scattered along both axis. The median TSI (Chl-TP) and TSI (Chl-SD) are (-4.6, -6.0).

Data from the ISU survey suggest that this lake has marginally high levels of inorganic suspended solids and thus has potential problems with high levels of non-algal turbidity. The median level of inorganic suspended solids in the 131 lakes sampled for the ISU lake survey from 2000 through 2002 was 4.8 mg/l. The median level of inorganic suspended solids at Carter Lake was 6.4 mg/l, thus suggesting that non-algal turbidity may present some light-limitation to the production of suspended algae and may contribute to the poor water transparency at this lake.

Bluegreen algae (Cyanophyta) dominate the phytoplankton community of Carter Lake. Sampling in summer 2000 showed that greater than 95% of the wet mass of phytoplankton in the three summer samples from this lake was in bluegreen algae. The 2000 average summer mass of bluegreen algae at this lake (51.3 mg/l) was the 19th highest of the 131 lakes sampled. The presence of this very large population of bluegreen algae suggests an impairment of designated uses of this lake due to violation of Iowa's narrative water quality standard protecting against presence of nuisance aquatic life (Downing et. al., 2003).

Overall, Carter Lake is in the range of hyper-eutrophic lakes and suggests extremely high levels of phosphorus in the water column, extremely high levels of chlorophyll-a, and poor water transparency.

1.4 TMDL Endpoint

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

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

Typically, a total phosphorus TSI of less than 70, which is related through the trophic state index to chlorophyll a and secchi depth, defines the nutrient-loading target. Thus the targets for lake TMDLs in Iowa are normally a median TSI value of less than 70 for TP, median TSI value of less than 65 for both chlorophyll and secchi depth. These values are equivalent to TP and chlorophyll concentrations of 96 and 33 μg/L, respectively, and a secchi depth of 0.7 meters. Table 4 describes TMDL existing and target values for TSI and concentrations in Carter Lake.

Table 4: Carter Lake Existing versus Target Values

Parameter	2000-2005 Median TSI	2000-2005 Median Value	Target TSI	Target Value	Water quality improvements needed, as defined by TSI
Total Phosphorus	77	153 μg/l	<70	<96 μg/L	37% Reduction
Chlorophyll a	71	59 μg/l	<65	<33 μg/L	44% Reduction
Secchi Depth	75	0.4 m	<65	>0.7 meters	75% Increase

Nebraska does not have numeric water quality criteria for lakes that include total phosphorus, total nitrogen and chlorophyll *a* however, values submitted to EPA Region 7 for a review and approval/disapproval will be used to assess the aesthetics water quality criteria. The values applied to Carter Lake being, 133 μg/l, 1460 μg/l and 44 μg/l, respectively. These correspond to TSI values of 74.7 and 67.7 for total phosphorus and chlorophyll a, respectively. As shown in table 4, the target values for total phosphorus (96 μg/l) and chlorophyll *a* (33 μg/l) will meet the Nebraska targets.

Reductions in phosphorous loading through BMP implementations will also result in reductions in chlorophyll and nitrogen and an increase in Secchi depth, thereby achieving the TMDL targets. Blue green alga, which produce algal toxins, has also been shown to be correlated to phosphorus, measures of transparency and overall chlorophyll concentrations. Blue-green algae blooms are most commonly associated with the production of microcystin (algal toxins). Reductions in blue green algae would be expected as phosphorus levels are decreased. However, future monitoring will be needed to determine if phosphorus loading reductions will result in full compliance of the TSI target for chlorophyll-a and Secchi depth as well as the applicable Nebraska water quality criteria for Carter Lake.

2. Calculation of Total Maximum Daily Load

The following equation was used to calculate the TMDL.

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

where:

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

2.1 TMDL Calculation

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

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

2.1.1 Modeling Procedures and Results

The procedures used to estimate TP loads to Carter Lake consist of:

1. Estimates of the delivered loads from the point and non-point sources in the watershed using three different methods. They are the Loading Function Model component of EUTROMOD, EPA export coefficients, and WILMS export coefficients.
2. Estimates of the annual TP load to Carter Lake using measured in-lake phosphorous concentrations, estimated hydraulic detention time, and mean depth as inputs for eleven different empirical models.
3. Comparison of the estimated TP loads based on watershed sources and the empirical models to select the best-fit empirical model for existing loads.
4. Estimates of the allowable TP loads at the target concentration (TP = 96 µg/L) for the lake, using the selected empirical model.

Table 5 lists the watershed and lake response models used to evaluate the existing and targeted Carter Lake water quality conditions. The models and the modeling procedures are included in the spreadsheet "*Carter Lake Phosphorus Worksheet.xls*". This spreadsheet also includes individual worksheets containing the hydrological calculation and the TSI calculator.

Watershed Load Estimates

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

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

The estimated annual average TP load by Loading Function Method, EPA Export Coefficient Method and WILMS Export Coefficient Model is 4,320 lbs/year, 1,647 lbs/year and 2,100 lbs/year.

Lake Response Load Estimates

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

The high total phosphorus (153 µg/L) and marginally high inorganic suspended solids (6.4 mg/L) at Carter Lake are indications of potential internal loading. Given lack of site-specific data for lake sediment, the internal load for Carter Lake was not separated from the total point and nonpoint loads in the TMDL calculation.

Table 5: Model Results for Carter Lake

Watershed Load Estimates	Predicted Existing Annual TP Load (lbs/yr)[1]	Comments	All Parameters In Range
Loading Function Method	4,320	Reckhow (Eutromod)	
EPA Export Coefficient Method	1,647	EPA 440-5-80-011	
WILMS Export Coefficient Model	2,100	"most likely" export coefficients[3]	
In-lake response load estimates			
1. Canfield-Bachmann 1981 Natural Lake	3,166	Growing Season Mean (GSM) model	YES
2. Canfield-Bachmann 1981 Artificial Lake	8,004	GSM model	YES
3. Reckhow Natural Lake	5,401	GSM model	NO
4. Reckhow Anoxic Lake	568	GSM model	YES
5. Reckhow Oxic Lake (Z/Tw < 50 m/year)	1,883	GSM model	NO
6. Vollenweider 1982 Combined OECD	1,672	Annual Model[2]	YES
7. Vollenweider 1982 Shallow Lake and Reservoir	1,836	Annual Model[2]	YES
8. Walker Reservoir	4,472	Annual Model[2]	NO
9. Simple First Order (Walker)	814	Annual Model[2]	
10. First Order Settling	814	Annual Model[2]	
11. Nurnberg 1984 Oxic Lake - Lake response external load when internal load = zero	1,705	Annual Model[2]	NO

(1) For in-lake GSM concentration TP = ANN TP = 153 µg/L (median).

(2) Note that P annual = P growing season for polymictic lakes.

(3) There are three values estimates for the WILMS export coefficients, low, most likely, and high.

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

• Canfield-Bachmann 1981 Natural Lake, 3,166 lbs/year

• Vollenweider 1982 Combine OECD, 1,672 lbs/year

• Vollenweider 1982 Shallow Lake and Reservoir, 1,836 lbs/year

Canfield-Bachmann Natural Lake model is preferred because it is closet to the estimate by Loading Function Method, which is the primary methodology for watershed load estimates. It is also within the general range of estimates by all three watershed loading methods. In addition, it is a growing season mean (GSM) model, which is suitable to address requirement of "critical condition" in the TMDL development. In comparison, EPA Export Coefficient Method is based on Nationwide Urban Runoff Program (NURP) in early 1980s. WILMS Export Coefficient Model is based on Wisconsin Lake Modeling Suite. The ranges of estimates by these two methods are used as general reference.

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

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

where,

P = predicted in-lake total phosphorus concentration (µg/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 Carter Lake are as follows:

$$P(153ug/L) = \frac{1127}{2.44[0.162(1127/2.44)^{0.458} + 0.329]}$$

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

$$P(96.2ug/L) = \frac{520}{2.44[0.162(520/2.44)^{0.458} + 0.329]}$$

The annual total phosphorus is obtained by multiplying the areal load (L in mg/m^2) by the lake area (in square meters) and converting the resulting value to pounds. The loading capacity of total phosphorus for Carter Lake is 1,462 lbs/year.

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

Based on selected lake response model and a target TSI (TP) value of less than 70 (corresponding to an in-lake average TP concentration of 96 µg/L), the TMDL for total phosphorus is 1,462 lbs/year.

2.1.2 Estimate of Existing Loads:

There are three quantified phosphorus sources for Carter Lake in this TMDL. The first is the phosphorus load from regulated storm water discharges within MS4 areas (the corporate limits of the City of Omaha, NE and City of Carter Lake, IA). The second source is nonpoint source phosphorus load from the watershed areas outside of the corporate limits of the City of Omaha. The third source is atmospheric deposition. Potential load contributions from phosphorus recycled from lake sediments (internal load) was not separated from total point and nonpoint source loads.

<u>Existing Load</u>

The existing annual total phosphorus load to Carter Lake is estimated to be 3,166 lbs/year, based on the selected lake response model.

<u>Departure from Loading Capacity</u>

The loading capacity of total phosphorus for Carter Lake is 1,462 lbs/year. The existing watershed load is estimated as 3,166 lbs/year. Therefore, a load reduction of 1,704 lbs/year is needed in order to achieve water quality goals and protect the designated uses.

Identification of Pollutant Sources

There is no continuously discharging point source in the Carter Lake watershed. Most phosphorous is delivered to the lake from stormwater discharges or nonpoint sources. The Loading Function Model estimates 63% of the load to originate from urban and industrial land uses.

Linkage of Pollution Sources to TMDL Target

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

2.2 Consideration of Critical Condition and Seasonal Variations

(1) Critical Condition

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

The critical condition for this TMDL study is during the growing season (May through September) when nuisance algal blooms and low transparency in the lake are most likely to occur. As well, Nebraska's nutrient criteria for lakes and impounded waters are based on seasonal average from April 1 through September 30.

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.

(2) Considerations of Seasonal Variations

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

2.3 Margin of Safety

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

Based on data availability for this TMDL study and guidance from EPA and IDNR, an explicit margin of safety of 10% of the loading capacity is reserved for a MOS.

2.4 Waste Load Allocation:

The Waste Load Allocation (WLA) is the maximum allowable amount of the pollutant that can be assigned to point sources. There is no continuously discharging point source in the Carter Lake watershed.

EPA's stormwater permitting regulations require municipalities to obtain permit coverage for all stormwater discharges from an urban municipal separate storm sewer system. For the City of Omaha, NE and the City of Carter Lake, IA, the areas within the corporate limits (98.9% of the total watershed area) are covered under the MS4 NPDES permit and make up the WLA. The areas outside of the corporate limits (1.1% of total area) are included in the Load Allocation described below.

WLA = 98.9% * (TMDL – MOS) = 98.9% * (1,462 – 10%*1,462) = 1,301 lbs/yr

Based on relative land use size between the City of Omaha, NE and the City of Carter Lake, IA, the individual WLA for the City of Omaha and the City of Cater Lake is 904 lbs/yr and 397 lbs/yr, respectively.

2.5 Load Allocation:

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

TMDL = WLA + LA + MOS

LA = TMDL – MOS – WLA (Eq. 2)
= 1,462 – 10%*1,462 – 1,301 = 15 lbs/yr

The LA for this TMDL is further divided into watershed non-point sources and atmospheric deposition. TP loading from atmospheric deposition is estimated as 5.6 lb/yr, based on wet deposition value of 0.02 Kg/ha/yr in Zaimes and Schultz (2002) and lake surface area. Because 98.9% of Carter Lake watershed is in the MS4 area, atmospheric deposition composes 37% of LA, which is larger than watershed without MS4. Therefore, the watershed nonpoint source load is:

15 lbs/yr –5.6 lbs/yr = 9.4 lbs/yr

2.6 Conversion to Daily Loads

The TMDL has established an annual average phosphorus load that if achieves should meet the water quality targets. A recent court decision often referred to as Anacostia decision have dictated that TMDL include a "daily" load (*Friends of the Earth, Inc. v. EPA, et al.)*

Expressing this TMDL in daily time steps could mislead the reader by implying a daily response to a daily load. It is important to recognize that the growing season mean is affected by many factors such as the following: internal lake nutrient loading, water residence time, wind action and the interaction between light penetration, nutrients, sediment load and algal response.

As stated, the TMDL does set a total phosphorus allocation of 1,462 lbs/year. To translate the long term average to maximum daily values EPA Region 7 has suggested the approach described in the Technical Support Document for Water Quality Based Toxics Control (EPA/505/2-90-001) (TSD). The maximum daily load (MDL) equals the long term average (LTA) * exp(z*sigma-0.5*sigma^2). The data used in the TMDL has a coefficient of variation (CV) of 0.5. From the TSD, the 99th percentile occurrence probability for a CV of 0.5 is 2.68. Using these assumptions, the MDL = LTA*2.68. Therefore, the total phosphorus would be:

1,462 lbs/year ÷365 days/year * 2.68 = 10.7 lbs/day.

2.7 Percentage of Reduction:

Estimating required percentage of reduction is given as follows:

Determination of Required Load Reduction

% TP Reduction = (Existing Load – LA) / Existing Loading (Eq. 3)

= (3,166 – 1,462) / 3,166 = 53.8%

A TP load reduction of 53.8% is needed in order to achieve water quality goals and protect the designated uses.

Table 6: Summary of TMDL Results for Total Phosphorus

TMDL (lbs/yr)	**1,462**
WLA (lbs/yr)	**1,301**
LA (lbs/yr)	**15**
MOS (lbs/yr)	**146**
Existing Load (lbs/yr)	**3,166**
% of Reduction	**53.8%**

3. Reasonable Assurance

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

- regulated stormwater discharges under MS4 NPDES permit
- non-point source pollution outside MS4 area
- existing and potential future sources
- regulatory and voluntary approaches

There is reasonable assurance that the goals of the TMDL for Carter Lake can be met with proper watershed planning, implementation of BMPs, and strong financial mechanisms. As can be seen in the development of the TMDL, there are three major components to the phosphorous inputs for Carter Lake: the regulated stormwater discharges, nonpoint source loading from the watershed areas outside the corporate limits of the City of Omaha, NE and City of Carter Lake, IA, and the load from atmospheric deposition.

Carter Lake and most of the lake watershed is located within the corporate limits of the City of Omaha. The city of Omaha is authorized to discharge from a Municipal Separate Storm Sewer System (MS4) under NPDES permit. This MS4 permit requires development of a Stormwater Pollution Prevention & Management Program (SWMP). The SWMP includes requirements for implementation of BMPs including controls to reduce pollutants in discharges from municipal application of fertilizers and operation of a public environmental information and education program to inform the public about the proper use of fertilizes.

Reaching the reduction goals for nonpoint source loads established by this TMDL will only occur through changes in current land use practices, including the incorporation of best management practices (BMPs). BMPs would be helpful in lowering the amount of nutrients and sediments reaching Carter Lake. Determining the most appropriate BMPs, where they should be installed, and actually putting them into practice will require the development and implementation of a comprehensive watershed restoration plan. Development of any watershed restoration plan will involve the gathering of site-specific information regarding current land uses and existing conservation practices. Successful implementation of the activities necessary to address current use impairment in the Carter Lake watershed will require local citizens' active interest in the watershed and cooperation of other relevant entities. By developing a nutrient TMDL for Carter Lake, the stage has been set for local citizens to design and implement restoration plans to correct current use impairments.

Because of the uncertainty as to how much of the phosphorus load originates in the watershed and how much is recycled from lake bottom sediment, an adaptive management approach to phosphorous reduction is recommended. In this approach management practices to reduce both watershed loads and recycled loads are incrementally applied and the results monitored to determine if water quality goals have been achieved. Practical methods are needed to evaluate the magnitude of the phosphorus load from internal recycling, preferably by direct measurement of re-suspension and recycling from lake bottom sediment. Based on the Lake Restoration Report and Plan by IDNR (IDNR, 2006a) and NDEQ, feasibility studies prior to lake restoration (e.g. dredging) will be underway at Carter Lake in the near future.

4.0 Monitoring Plan

Since the response in water quality to in-lake and watershed treatments are only speculative, a long term monitoring program will be required to evaluate the progress in meeting the water quality goals and objectives identified in this plan. It should be noted that it may take several years after project completion before the biological communities and chemical constituents reach stability.

Information provided through the monitoring activities will be distributed to the project stakeholders. The monitoring results will be used, as appropriate, to revise the monitoring strategies, implementation strategies, and/or the project goals and objectives.

Since water quality goals and objectives pertain to in-lake conditions, monitoring activities will be focused in the lake. Monitoring activities will encompass a combination of physical, chemical, and biological elements. Specific monitoring approaches will be designed annually through a coordinated effort among several agencies. All monitoring activities will follow existing protocols established by the respective agencies and will be documented in an annual monitoring plan. Proposed monitoring parameters, collection frequency and responsibilities are provided in Table 7.

5.0 Public Participation

The availability of the TMDL in draft form was published in the Omaha World Herald by NDEQ with the public comment period running from May 14, 2007 to June 18, 2007. These TMDLs were also made available to the public on the IDNR and NDEQ’s Internet sites and interested stakeholders were informed via email of the availability of the draft TMDL. No public comments were received by NDEQ or IDNR on the Draft Carter Lake TMDL.

Table 7. Proposed Monitoring At Carter Lake

Parameter	**Frequency**	**Responsible Party (a)**
Lake Water Levels	??????	CLPS
User Surveys	Annually	CLPS
Water Clarity	Monthly During Growing Season	NDEQ
Total Suspended Solids	Monthly During Growing Season	NDEQ
Total Phosphorus	Monthly During Growing Season	NDEQ
Kjeldahl Nitrogen	Monthly During Growing Season	NDEQ
Nitrate/Nitrite Nitrogen	Monthly During Growing Season	NDEQ
Chlorophyll	Monthly During Growing Season	NDEQ
Atrazine	Monthly During Growing Season	NDEQ
Alachlor	Monthly During Growing Season	NDEQ
Metolachlor	Monthly During Growing Season	NDEQ
Dissolved Oxygen	Monthly During Growing Season	NDEQ
Temperature	Monthly During Growing Season	NDEQ
pH	Monthly During Growing Season	NDEQ
Conductivity	Monthly During Growing Season	NDEQ
Algae Toxins	Weekly During Recreation Season	NDEQ
e.coli bacteria	Weekly During Recreation Season	NDEQ
Dissolved Copper	Annually	NDEQ
Dissolved Zinc	Annually	NDEQ
Dissolved Lead	Annually	NDEQ
Dissolved Mercury	Annually	NDEQ
Dissolved Iron	Annually	NDEQ
Dissolved Manganese	Annually	NDEQ
Total Selenium	Annually	NDEQ
Fish Tissue	1 Time Every Five Years	NDEQ
Fish Communities	??????????	IDNR/NGPC

(a) CLPS = Carter Lake Preservation Society, NDEQ = Nebraska Department of Environmental Quality, IDNR = Iowa Department of Natural Resources, NGPC = Nebraska Game and Parks Commission

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Appendices

Appendix A – Carter Lake Hydrologic Calculations

Appendix B – Sampling Data

Appendix C – Trophic State Index

Appendix A – Carter Lake Hydrologic Calculations

Lake	Carter	
Type	Impoundment	
Inlet(s)	None	
Outlet(s)	None	
Volume	2520	acre-feet
Surface Area	315	acres
Watershed Area	2713	acres
Mean Annual Precipitation	31.9	inches
Average Basin Slope	1.2	%
% Forest (2000 Land Cover)		
% Corn (2000 Land Cover)		
% Rowcrop (2002 Land Cover)	2.0	
Basin Soils Average % Sand	20.0	
Soil Permeability	0.1	inches/hour
Mean Annual Class A Pan Evaporation	58	inches
Evaporation Coefficient	0.74	
Optional User Input Inflow Estimate		acre-feet/year
Optional User Input Runoff Component		acre-feet/year
Optional User Input Baseflow Component		acre-feet/year
Mean Depth	8.0	feet
Drainage Area	2398	acres
Drainage Area	3.7	square miles
Drainage Area/Lake Area	7.6	
Mean Annual Lake Evaporation	42.9	inches
Mean Annual Lake Evaporation	1127	acre-feet/year
Annual Average Inflow	1.5	cfs
Annual Average Inflow	1118	acre-feet/year
Runoff Component	1446	acre-feet/year
Baseflow Component	-328	acre-feet/year
Direct Precipitation on Lake Surface	837	acre-feet/year
Inflow + Direct Precipitation	1955	acre-feet/year
% Inflow	57.2	
% Direct Precipitation	42.8	
Outflow	828	acre-feet/year
HRT Based on Inflow + Direct Precipitation	1.29	year
HRT Based on Outflow	3.04	year

Appendix B – Sampling Data

Table B-1. Data collected in 1980 Bachmann Report.

Lake Survey Year	1979
Secchi Disk Depth (m)	0.6
Chlorophyll a (µg/l)	39.4
TOT Phosphorus (µ/l)	86.3
Kjeldahl Nitrogen (mg/l)	0.9
Ammonia Nitrogen (mg/l)	0.2
Nitrate + Nitrite Nitrogen (mg/l)	0.1
Seston Dry Weight (mg/l)	11.9
Turbidity (NTU)	9.8
TOT Hardness (mg/l) as $CaCO_3$	219
Calcium Hardness (mg/l) as $CaCO_3$	107.3
TOT Alkalinity (mg/l) as $CaCO_3$	218.4
Dissolved Oxygen (mg/l)	7.5
Specific Conductance (microhmes/cm) at 25°C	541.1
Sulfate (mg/l)	60.2
Chloride (mg/l)	24.8
Sodium (mg/l)	45
Potassium (mg/l)	8.5

Table B-2. Data collected in 1994 Bachmann Report.

Lake Survey Year	1992
Secchi Disk Depth (m)	0.05
Chlorophyll a (µg/l)	43.8
TOT Phosphorus (µg/l)	89
TOT Nitrogen (mg/l)	1.19
Ammonia Nitrogen (mg/l)	0.011
Nitrate + Nitrite Nitrogen (mg/l)	0.04
TOT Alkalinity (mg/l) as $CaCO_3$	196
Organic Suspended Solids (mg/l)	4.18
TOT Hardness (mg/l) as $CaCO_3$	227
Inorganic Suspended Solids (mg/l)	7.28
TOT Suspended Solids (mg/l)	11.46

Table B-3. Data collected in 2000 by Iowa State University and Iowa Department of Natural Resources.

Parameter	6/15/2000	6/21/2000	7/13/2000	7/19/2000	8/7/2000	8/9/2000
Lake Depth (m)	5.5	7.0	5.2	7.3	5.5	7.0
Thermocline Depth (m)	NIL	NIL	4	NIL	NIL	5
Secchi Disk Depth (m)	0.8	0.4	0.9	0.3	0.7	0.2
Temperature(^oC)	20.3	23.4	28	25.8	26	28.3
Dissolved Oxygen (mg/L)	8.4	7.7	7.7	5.9	9	9.1
Dissolved Oxygen Saturation (%)	93	90	98	73	111	117
Specific Conductivity (µS/cm)	437.5	755	-	665.8	400	658.7
Turbidity (NTU)	6	47.6	17	60.1	21	61.5
Chlorophyll a (µg/L)	19.4	53.5	-	120.2	27.1	167.6
Total Phosphorus as P (µg/L)	182	240	124	153	113	209
Total Nitrogen as N (mg/L)	1.63	1.61	1.55	2.52	1.57	2.62
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.36	0.15	0.25	0.11	0.17	0.17
TN:TP ratio	9	7	13	17	14	13
pH	8	8.2	8.2	8.2	8.3	8.5
Alkalinity as $CaCO_3$ (mg/L)	181	249	186	207	172	193
Inorganic Suspended Solids (mg/L)	10	7	12	6	14	2
Volatile Suspended Solids (mg/L)	10	6	2	11	12	8
Total Suspended Solids (mg/L)	20	13	14	18	26	10
Carlson Trophic State Index (Secchi)*	63		62		66	
Carlson Trophic State Index (Chl a)*	60		-		63	
Carlson Trophic State Index (TP)*	79		74		72	

Table B-4. Data collected in 2001 by Iowa State University and Iowa Department of Natural Resources.

Parameter	5/17/2001	5/22/2001	6/14/2001	6/20/2001	7/19/2001	7/24/2001
Lake Depth (m)	6.2	7.9	5.5	7.9	6.1	7.8
Thermocline Depth (m)	3	6.5	3.8	4.9	2.7	2.3
Secchi Disk Depth (m)	2.1	0.6	0.9	0.4	1.1	0.3
Temperature(^{o}C)	20.3	18.7	21.7	23.5	27.7	30.2
Dissolved Oxygen (mg/L)	8.9	10.7	8.1	5.8	9.4	8.5
Dissolved Oxygen Saturation (%)	99	114	92	69	120	113
Specific Conductivity (µS/cm)	370.7	581.7	371	596.3	591.3	639.2
Turbidity (NTU)	61.2	50	24.4	59.6	20.2	69.4
Chlorophyll a (µg/L)	5.7	157.1	17.9	60	28.5	78.4
Total Phosphorus as P (µg/L)	146	141	67	191	19	227
Total Nitrogen as N (mg/L)	2.37	2	3.29	1.74	2.32	2.14
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	1.37	0.21	2.18	0.09	0.96	0.28
TN:TP ratio	16	14	49	9	121	9
pH	7.8	8.7	8	7.9	8.8	9.1
Alkalinity as $CaCO_3$ (mg/L)	138	196	144	195	124	203
Inorganic Suspended Solids (mg/L)	15	8	12	8	2	1
Volatile Suspended Solids (mg/L)	4	17	8	12	9	19
Total Suspended Solids (mg/L)	19	24	20	20	10	20
Carlson Trophic State Index (Secchi)*	49		62		59	
Carlson Trophic State Index (Chl a)*	48		59		63	
Carlson Trophic State Index (TP)*	76		65		47	

Table B-5. Data collected in 2002 by Iowa State University and Iowa Department of Natural Resources.

Parameter	5/23/2002	5/29/2002	6/20/2002	6/25/2002	7/25/2002	7/30/2002
Lake Depth (m)	5.8	7.3	4.3	7.1	5.5	6.7
Thermocline Depth (m)	2.8	1.7	NIL	1	NIL	1.7
Secchi Disk Depth (m)	0.7	0.3	0.4	0.2	0.6	0.2
Temperature(^{o}C)	21.9	22.6	22.4	27.8	25.7	28.3
Dissolved Oxygen (mg/L)	9.1	8.4	7.8	9.4	8	9
Dissolved Oxygen Saturation (%)	104	97	89	119	97	116
Specific Conductivity (µS/cm)	424.6	667.9	547.8	686.8	457.2	595.9
Turbidity (NTU)	8	6.2	51.2	68.9	31.3	107.5
Chlorophyll a (µg/L)	9.8	84.3	35.6	125.4	50.8	309.9
Total Phosphorus as P (µg/L)	88	130	97	177	88	332
Total Nitrogen as N (mg/L)	1.74	0.15	2.18	1.66	1.44	3.16
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.46	0.12	0.83	0.1	0.2	0.11
TN:TP ratio	20	1	23	9	17	10
pH	8.4	7.9	8.2	9	8.4	8.9
Alkalinity as $CaCO_3$ (mg/L)	151	192	172	208	167	182
Inorganic Suspended Solids (mg/L)	11	1	26	2	13	13
Volatile Suspended Solids (mg/L)	6	15	7	25	13	25
Total Suspended Solids (mg/L)	17	16	34	26	27	38
Carlson Trophic State Index (Secchi)*	65		75		67	
Carlson Trophic State Index (Chl a)*	53		66		69	
Carlson Trophic State Index (TP)*	69		70		69	
SRP as P (µg/L)	3	3	6	2	2	7
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	337		389		300	
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	34		29		40	
Silica as Si (mg/L)	1.52	3.22	2.09	8.77	6.15	15.49
Dissolved Organic Carbon (mg/L)	-		-		14.12	10.03

Table B-6a. Data collected in May and June, 2003 by Iowa State University, Iowa Department of Natural Resources, and Nebraska Department of Environmental Quality.

Parameter	5/22/2003	5/28/2003	5/29/2003	6/19/2003	6/24/2003	6/25/2003
Lake Depth (m)	6.5	7.0		6.4	6.7	
Thermocline Depth (m)	NIL	3.1		5	1.8	
Secchi Disk Depth (m)	0.6	0.3	0.1	0.5	0.3	0.1
Temperature(^{o}C)	15.7	22.7	22.45	22.8	26.8	26.45
Dissolved Oxygen (mg/L)	8.5	8.7	5.55	7.6	9.8	6.5
Dissolved Oxygen Saturation (%)	86	101		89	123	
Specific Conductivity (µS/cm)	521.9	665.8	679	472.7	684.2	703.5
Turbidity (NTU)	42.1	67.2		26.7	63.7	
Chlorophyll a (µg/L)	20.1	18.1		31.9	32.1	128.53
Total Phosphorus as P (µg/L)	79	172	140	76	214	180
Total Nitrogen as N (mg/L)	3.14	1.62	2.14773	3.8	2.07	2.84145
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	2.64	0.01	0.05	2.1	0.02	0.05
TN:TP ratio	40	9	15.3409	50	10	15.78583
pH	8.3	8.9	8.2	8.3	8.7	8.475
Alkalinity as $CaCO_3$ (mg/L)	150	165		128	145	
Inorganic Suspended Solids (mg/L)	19	9		21	11	
Volatile Suspended Solids (mg/L)	6	20		9	24	
Total Suspended Solids (mg/L)	25	29		30	34	
Carlson Trophic State Index (Secchi)*	67			72		
Carlson Trophic State Index (Chl a)*	60			65		
Carlson Trophic State Index (TP)*	67			67		
SRP as P (µg/L)	4	2		4	2	
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	620			579		
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	31			47		
Silica as Si (mg/L)	2.2	6.46		1.8	9.9	
Dissolved Organic Carbon (mg/L)	13.71	11.83		11.96	11.05	

Table B-6b. Data collected in July, August, and September, 2003 by Iowa State University, Iowa Department of Natural Resources, and Nebraska Department of Environmental Quality.

Parameter	7/23/2003	7/30/2003	7/30/2003	8/28/2003	9/25/2003
Lake Depth (m)	5.2	7.1			
Thermocline Depth (m)	1.3	NIL			
Secchi Disk Depth (m)	0.4	0.2	0.3	0.1	0.3
Temperature(^{o}C)	27.1	26		28	19.225
Dissolved Oxygen (mg/L)	12.6			4.6	13.475
Dissolved Oxygen Saturation (%)	158				
Specific Conductivity (µS/cm)	417.6	693.6		676.33	692
Turbidity (NTU)	20.3	96.2			
Chlorophyll a (µg/L)	40.5	32.2	94.32	173.9	26.5
Total Phosphorus as P (µg/L)	54	303	310	280	290
Total Nitrogen as N (mg/L)	1.63	3.81	5.15012	4.67557	5.91957
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.13	0.01	0.05	0.05	0.05
TN:TP ratio	30	13	16.61327	16.69847	20.41232
pH	9	8.4		8.76667	9.15
Alkalinity as $CaCO_3$ (mg/L)	100	134			
Inorganic Suspended Solids (mg/L)	4	9			
Volatile Suspended Solids (mg/L)	14	37			
Total Suspended Solids (mg/L)	18	45			
Carlson Trophic State Index (Secchi)*	73				
Carlson Trophic State Index (Chl a)*	67				
Carlson Trophic State Index (TP)*	62				
SRP as P (µg/L)	1	2			
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	298				
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	112				
Silica as Si (mg/L)	3.04	13.98			
Dissolved Organic Carbon (mg/L)	10.98	11.27			

Table B-7. Data collected in 2004 by Iowa State University and Iowa Department of Natural Resources.

Parameter	5/20/2004	5/25/2004	6/17/2004	6/22/2004	7/21/2004	7/27/2004
Lake Depth (m)	6.2	7.3	6.0	7.3	6.6	7.5
Thermocline Depth (m)	5.6	5	NIL	0.8	0.7	NIL
Secchi Disk Depth (m)	1.0	0.3	0.7	0.4	0.4	0.3
Temperature(^{o}C)	17.3	20.9	21.6	25.7	29.1	24.9
Dissolved Oxygen (mg/L)	10.5	8.2	7.2	12.6	11.3	6.2
Dissolved Oxygen Saturation (%)	109	92	82	154	147	74
Specific Conductivity (µS/cm)	485.5	599.8	467.6	743	403	700.9
Turbidity (NTU)	16.9	54.7	53.9	29.5	26.5	71.1
Chlorophyll a (µg/L)	35.6	18.8	42.8	83.7	57.7	102.2
Total Phosphorus as P (µg/L)	59	168	87	142	84	199
Total Nitrogen as N (mg/L)	1.95	2.06	5.94	2.51	5.05	2.17
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.55	0.12	4.35	0.15	2.08	0.18
TN:TP ratio	33	12	68	18	60	11
pH	8.6	8.6	8.5	8.8	8.8	8.3
Alkalinity as $CaCO_3$ (mg/L)	127	170	160	209	132	208
Inorganic Suspended Solids (mg/L)	4	6	21	8	7	10
Volatile Suspended Solids (mg/L)	7	19	11	15	20	22
Total Suspended Solids (mg/L)	11	25	32	23	27	32
Carlson Trophic State Index (Secchi)*	61		66		73	
Carlson Trophic State Index (Chl a)*	66		67		70	
Carlson Trophic State Index (TP)*	63		69		68	
SRP as P (µg/L)	1	1	1	3	1	2
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	127	10.2	145	369.2	36	9.5
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	15	1.4	19	77.4	9	1
Silica as Si (mg/L)	2.02	7.44	3.33	7.86	4.35	11.97
Dissolved Organic Carbon (mg/L)	12.8	8.46	43.82		12.81	4.25
Microcystin (ng/L)	9.9	361.59	19.8	148.12	96	150.44

Table B-8a. Data collected in May and June, 2005 by Iowa State University, Iowa Department of Natural Resources, and Nebraska Department of Environmental Quality.

Parameter	5/2/2005	5/26/2005	6/1/2005	6/22/2005	6/28/2005
Lake Depth (m)		6.3	7.0	6.3	6.1
Thermocline Depth (m)		NIL	5.7	1.5	1.2
Secchi Disk Depth (m)		0.5	0.3	0.8	0.1
Temperature(^oC)		17.7	20.4	26.5	27.1
Dissolved Oxygen (mg/L)		7.5	6.7	10.5	6.9
Dissolved Oxygen Saturation (%)		78	75	131	87
Specific Conductivity (µS/cm)		515	731.6	496.2	705.9
Turbidity (NTU)		54.6	53.2	6.9	48.6
Chlorophyll a (µg/L)		37.6	97.6	67.3	521.1
Total Phosphorus as P (µg/L)	150	106	212	69	215
Total Nitrogen as N (mg/L)	2.72245	5.79	2.05	4.59	0.29
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	2.16	4.23	0.16	3.1	
TN:TP ratio	18.14965	56	10	66	1
pH		8.3	8.2	8.3	8.6
Alkalinity as $CaCO_3$ (mg/L)		209	200	194	193
Inorganic Suspended Solids (mg/L)		18	8	12	19
Volatile Suspended Solids (mg/L)		19	22	11	26
Total Suspended Solids (mg/L)		36	30	23	44
Carlson Trophic State Index (Secchi)*		70		64	
Carlson Trophic State Index (Chl a)*		66		72	
Carlson Trophic State Index (TP)*		71		65	
SRP as P (µg/L)		-	3	1	1
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)		14.7	25.2	247.6	
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)		0.8	1.2	27.1	
Silica as Si (mg/L)		1.93	8.45	4.04	12.5
Dissolved Organic Carbon (mg/L)		6.63	0.04	5.91	9.19
Microcystin (ng/L)		1.39	54.73	14.67	27.66

Table B-8b. Data collected in July, August, and October, 2005 by Iowa State University, Iowa Department of Natural Resources, and Nebraska Department of Environmental Quality.

Parameter	7/6/2005	7/25/2005	8/1/2005	8/18/2005	10/18/2005
Lake Depth (m)	6.9	6.0	6.8	6.9	6.8
Thermocline Depth (m)	0	2	NIL	0	1.9
Secchi Disk Depth (m)	0.1	0.4	0.2	0.1	0.2
Temperature(^oC)	26.9	29.5	25.1	24.4	18
Dissolved Oxygen (mg/L)	4.2	11.8	2.1	4	9.3
Dissolved Oxygen Saturation (%)		155	25		
Specific Conductivity (µS/cm)	691	423.4	784.5	694	710
Turbidity (NTU)	85	23.2	70.5	102	113
Chlorophyll a (µg/L)	155	181.8	316.2	280	130
Total Phosphorus as P (µg/L)	280	116	303	360	200
Total Nitrogen as N (mg/L)	4.8	2.19	4.45	6.6	4
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.05	0.57	0.12	0.05	0.05
TN:TP ratio		19	15		
pH	8.1	8.6	8.1	8.3	8.8
Alkalinity as $CaCO_3$ (mg/L)	180	147	186	180	180
Inorganic Suspended Solids (mg/L)		-	3		
Volatile Suspended Solids (mg/L)	33.5	-	45	38	44
Total Suspended Solids (mg/L)	39	-	48	43	54
Carlson Trophic State Index (Secchi)*		73			
Carlson Trophic State Index (Chl a)*		82			
Carlson Trophic State Index (TP)*		73			
SRP as P (µg/L)		1	1		
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	760	60.2	759.9	1600	50
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	70	14.4	117.2	190	10
Silica as Si (mg/L)	18	4.69	16.39	20	15
Dissolved Organic Carbon (mg/L)		7.55	0.05		
Microcystin (ng/L)		5.81	9.43		

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

Table B-9. 2000-2005 Phytoplankton Data.

Division	2000	2001	2002	2003	2004	2005
	Wet Mass (mg/l)	Wet Mass (mg/l)	Wet Mass (mg/l)	Wet Mass (mg/l)	Wet Mass (mg/l)	Wet Mass (mg/l)
Bacillariophyta	0.026	0.179	0.207	0.723	0.001	0.000
Chlorophyta	0.401	0.522	0.015	0.058	2.626	0.000
Cryptophyta	0.266	0.042	0.262	0.124	0.070	0.191
Cyanobacteria	102.4	69.8	68.6	857.7	52.8	39.9
Dinophyta	0.00	0.29	0.00	0.00	0.00	0.00
Euglenophyta	0.58	0.40	0.20	0.00	0.00	0.00
Total	103.7	71.2	69.3	858.6	55.5	40.1

Table B-10. 2000-2005 Carter Lake Trophic State Index* Values.

	Sample Data				TSI Values		
DATE	**SOURCE**	**Secchi Depth (m)**	**Chlorophyll (µg/l)**	**Total Phosphorus (µg/l)**	**Secchi Depth**	**Chlorophyll**	**Total Phosphorus**
6/15/2000	IA St. Univ.	0.8	19.4	182	63	60	79
6/21/2000	IA-DNR	0.4	53.5	240	73	70	83
7/13/2000	IA-DNR	0.9		124	62		74
7/19/2000	IA-DNR	0.3	120.2	153	77	78	77
8/7/2000	IA St. Univ.	0.7	27.1	113	66	63	72
8/9/2000	IA-DNR	0.2	167.6	209	83	81	81
5/17/2001	IA St. Univ.	2.1	5.7	146	49	48	76
5/22/2001	IA-DNR	0.6	157.1	141	67	80	76
6/14/2001	IA St. Univ.	0.9	17.9	67	62	59	65
6/20/2001	IA-DNR	0.4	60.0	191	73	71	80
7/19/2001	IA St. Univ.	1.1	28.5	19	59	63	47
7/24/2001	IA-DNR	0.3	78.4	227	77	73	82
5/23/2002	IA St. Univ.	0.7	9.8	88	65	53	69
5/29/2002	IA-DNR	0.3	84.3	130	77	74	74
6/20/2002	IA St. Univ.	0.4	35.6	97	75	66	70
6/25/2002	IA-DNR	0.2	125.4	177	83	78	79
7/25/2002	IA St. Univ.	0.6	50.8	88	67	69	69
7/30/2002	IA-DNR	0.2	309.9	332	83	87	88
5/22/2003	IA St. Univ.	0.6	20.1	79	67	60	67
5/28/2003	IA-DNR	0.3	18.1	172	77	59	78
5/29/2003	NE-DEQ	0.1		140	97		75
6/19/2003	IA St. Univ.	0.5	31.9	76	72	65	67
6/24/2003	IA-DNR	0.3	32.1	214	77	65	82
6/25/2003	NE-DEQ	0.1	128.5	180	97	78	79
7/23/2003	IA St. Univ.	0.4	40.5	54	73	67	62
7/30/2003	IA-DNR	0.2	32.2	303	83	65	87
7/30/2003	NE-DEQ	0.3	94.3	310	80	75	87
8/28/2003	NE-DEQ	0.1	173.9	280	90	81	85
9/25/2003	NE-DEQ	0.3	26.5	290	77	63	86
5/20/2004	IA St. Univ.	1.0	35.6	59	61	66	63
5/25/2004	IA-DNR	0.3	18.8	168	77	59	78
6/17/2004	IA St. Univ.	0.7	42.8	87	66	67	69
6/22/2004	IA-DNR	0.4	83.7	142	73	74	76
7/21/2004	IA St. Univ.	0.4	57.7	84	73	70	68
7/27/2004	IA-DNR	0.3	102.2	199	77	76	80
5/2/2005	NE-DEQ			150			76
5/26/2005	IA St. Univ.	0.5	37.6	106	70	66	71
6/1/2005	IA-DNR	0.3	97.6	212	77	76	81
6/22/2005	IA St. Univ.	0.8	67.3	69	64	72	65
6/28/2005	IA-DNR	0.1	521.1	215	93	92	82
7/6/2005	IA-DNR	0.1	155.0	280	93	80	85
7/25/2005	IA St. Univ.	0.4	181.8	116	73	82	73
8/1/2005	IA-DNR	0.2	316.2	303	83	87	87

	Sample Data			TSI Values			
DATE	**SOURCE**	**Secchi Depth (m)**	**Chlorophyll (µg/l)**	**Total Phosphorus (µg/l)**	**Secchi Depth**	**Chlorophyll**	**Total Phosphorus**
8/18/2005	IA-DNR	0.1	280.0	360	93	86	89
10/18/2005	IA-DNR	0.2	130.0	200	83	78	81
average		0.5	97	168	71	75	78
median		**0.4**	**59**	**153**	**75**	**71**	**77**
TARGETS		**> 0.7**	**< 33**	**< 96**	**< 65**	**< 65**	**< 70**

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

Table B-11. Summary of Carter Lake data.

Parameter	Units	*n*	Median	Mean	Standard Error
Secchi Depth	m	44	0.40	0.46	0.06
Temperature	degrees C	43	25.0	24.1	0.6
pH	neg. log H^+ conc.	43	8.44	8.46	0.05
Total Alkalinity	mg/L as $CaCO_3$	39	176	173	5
Dissolved Oxygen	mg/L	42	8.5	8.3	0.4
Total Suspended Solids	mg/L	38	26.0	26.8	1.8
Inorganic Suspended Solids	mg/L	35	9.0	10.1	1.1
Chlorophyll *a*	µg/L	42	58.9	97.1	15.9
Ammonia-Nitrogen	mg/L as N	20	0.27	0.34	0.09
Total Nitrogen	mg/L as N	45	2.44	2.88	0.23
Nitrate-Nitrogen	mg/L as N	44	0.16	0.71	0.17
Total Phosphorous	µg/L as P	45	152	168	13
Turbidity	NTU	39	53.6	48.6	4.6

Appendix C – Trophic State Index

Carlson's Trophic State Index

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

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

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

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

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

TP = in-lake total phosphorus concentration, µg/L
CHL = in-lake chlorophyll-a concentration, µg/L
SD = lake Secchi depth, meters.

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

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

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

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

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

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

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

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

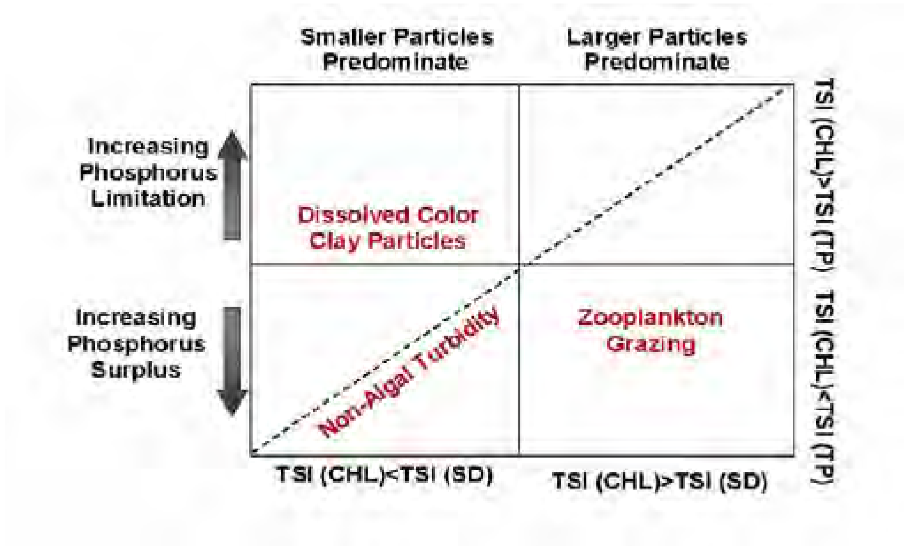

Figure C-1. Multivariate TSI Comparison Chart (Carlson)