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

2004

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Silver Lake Summary

Waterbody Name:	Silver Lake
County:	Palo Alto
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Upper Des Moines River Basin
Pollutant:	Phosphorus
Pollutant Sources:	Nonpoint, atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Medium
Watershed Area:	8,370 acres
Lake Area:	640 acres
Lake Volume:	3,090 acre-ft
Detention Time:	0.6 years
TSI Target(s):	Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65
Target Total Phosphorus Load:	See Table 2
Existing Total Phosphorus Load:	10,360 pounds per year
Load Reduction to Achieve Target:	See Table 2
Wasteload Allocation	0
Load Allocation	See Table 2

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. Silver Lake has been identified as impaired by algae and turbidity. The purpose of these TMDLs for Silver Lake is to calculate the maximum allowable nutrient loading for the lake associated with algae and turbidity levels that will meet water quality standards.

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

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

Section 5.0 of this TMDL includes a description of planned monitoring. The TMDL will have two phases. Phase 1 will consist of setting specific and quantifiable targets for total phosphorus, algal biomass and Secchi depth expressed as Carlson's Trophic State

Index (TSI). Phase 2 will consist of implementing the monitoring plan, evaluating collected data, and readjusting target values if needed.

Monitoring is essential to all TMDLs in order to:

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

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

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

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Silver Lake, S20, T95N, R34W, 2 miles west of Ayrshire, Palo Alto County.

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

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

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for Secchi depth, chlorophyll a and total phosphorus based on 2000 - 2003 sampling are 0.3 meters, 89 ug/L and 239 ug/L, respectively. A minimum in-lake increase in Secchi transparency of 133% and minimum in-lake reductions of 63% for chlorophyll a and 60% 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 Silver Lake is 10,360 pounds per year. The total phosphorus loading capacity for the lake based on lake response modeling is a function of the relative contribution of internal and external loads as shown in Table 2 and as described by the mathematical relationships given in Appendix E.

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 Silver Lake.

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Silver 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 is shown in Table 2. This includes 220 pounds per year attributable to atmospheric deposition.

Table 2. Silver Lake Total Phosphorus Loads

Total Phosphorus Load Allocation/Target Loads (lbs/year)			**Required Load Reduction (lbs/year)**
Internal	**External**	**Total**	
0	4,390	4,390	5,970
50	4,190	4,240	6,120
100	4,000	4,100	6,260
150	3,810	3,960	6,400
200	3,620	3,820	6,540
250	3,430	3,680	6,680
300	3,240	3,540	6,820
350	3,050	3,400	6,960
400	2,850	3,250	7,110
450	2,660	3,110	7,250
500	2,470	2,970	7,390
550	2,280	2,830	7,530
600	2,090	2,690	7,670
610	2,050	2,660	7,700

8. **A margin of safety:** The target total phosphorus loads are calculated using an in-lake concentration 10% below the desired endpoint to ensure that the required load reduction 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 Silver Lake watershed landuse are unlikely. Most of the watershed landuse is dedicated to agricultural production. The addition or deletion of animal feeding operations within the watershed could increase or decrease nutrient loading. Future increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and internal phosphorus loading. Such events cannot be predicted and at this time conditions are not expected to change, therefore, an allowance for their potential occurrence was not included in the TMDL.

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

2. Silver Lake, Description and History

2.1 The Lake

Silver Lake is a natural, glacial lake located in northwest Iowa, 2 miles west of Ayrshire. Public use for Silver Lake is estimated at 4,000 visitors per year. Users of the lake and adjacent park enjoy fishing, picnicking, hiking, boating, and snowmobiling.

Table 3. Silver Lake Features

Waterbody Name:	Silver Lake
Hydrologic Unit Code:	HUC10 0710000204
IDNR Waterbody ID:	IA 04-UDM-01020
Location:	Section 20 T95N R34W
Latitude:	43° 2’ N
Longitude:	94° 53’ W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	Drainage Ditch No. 6, Unnamed Creeks (3)
Receiving Waterbody:	Silver Creek
Lake Surface Area:	640 acres
Maximum Depth:	7 feet
Mean Depth:	4.8 feet
Volume:	3,090 acre-feet
Length of Shoreline:	32,200 feet
Watershed Area:	8,370 acres
Watershed/Lake Area Ratio:	13:1
Estimated Detention Time:	0.6 years

Morphometry

Silver Lake has a mean depth of 4.8 feet and a maximum depth of 7 feet. The lake has a surface area of 640 acres and a storage volume of approximately 3,090 acre-feet.

Temperature and dissolved oxygen sampling indicate that Silver Lake remains oxic and relatively well mixed throughout the growing season.

Hydrology

Silver Lake is fed by Drainage Ditch No. 6 and several unnamed tributaries. Silver Lake feeds into Silver Creek, a tributary to the Des Moines River. The estimated annual average detention time for Silver Lake is 0.6 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Silver Lake watershed has an area of approximately 8,370 acres and has a watershed to lake ratio of 13:1. The 2002 landuses and associated areas for the watershed were obtained from satellite imagery and are shown in Table 4. The 2002 landuse map is shown in Appendix D.

Table 4. 2002 Landuse in Silver Lake watershed.

Landuse	Area in Acres	Percent of Total Area
Row Crop	6,610	79.0
Grassland	1,380	16.5
Forest	150	1.8
Alfalfa	110	1.3
Other	120	1.4
Total	8,370	100

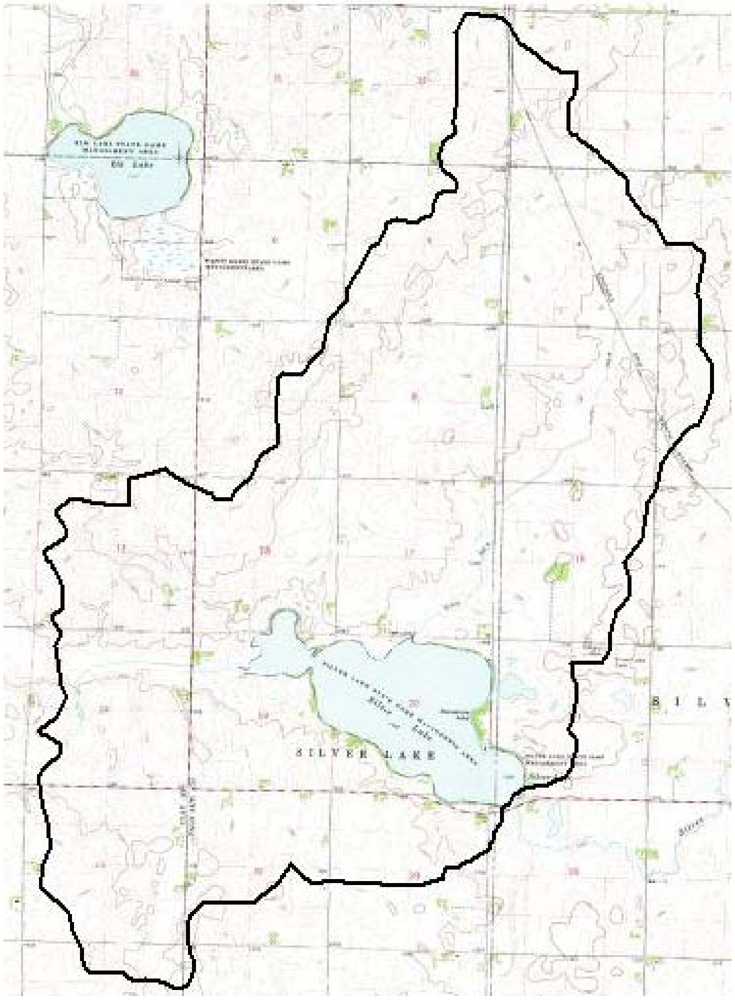
A more recent field-level landuse assessment was completed in Summer 2004 by the IDNR. The 2004 assessment also shows that the major landuse is row crop and noted the presence of five Confinement Animal Feeding Operations (CAFOs) and a single open feedlot within the watershed. The estimated numbers of animal units associated with CAFOs and feedlots within the watershed are 3300 swine animal units and 225 beef animal units.

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

Limited residential development is present on the north shore of the lake. A wildlife management area and county conservation board park are located on the east and northwest shorelines, respectively.

The watershed is predominately level to moderately sloping (0-9%) prairie-derived soils developed from Wisconsin till. The most common soil types in the watershed are Clarion, Webster, Canisteo, Storden, and Nicollet.

Figure 1. Silver Lake Watershed



3. TMDL for Algae and Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (8) list the designated uses for Silver Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). In 1999, Silver Lake was included on the impaired water list due to organic enrichment. In 2002, the organic enrichment listing was removed, but impairments due to algae and turbidity were added to the list.

In 2002, the Class A designated use was assessed as “partially supporting”; prior to this assessment, this use was not assessed. This assessment was based upon the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau. Class B use has been listed as “partially supporting” for Silver Lake since 1994.

Impairments in Silver Lake to the Class A1 (primary contact) use is through the presence of aesthetically objectionable blooms of algae and of nuisance algal species (e.g., bluegreen algae). Class B(LW) aquatic life uses are evaluated as partially supported due to hyper-eutrophic conditions at this lake, along with recommendations from the IDNR Fisheries Bureau.

Data Sources

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

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

Interpreting Silver Lake Water Quality Data

Based on mean values from ISU sampling during 2000 - 2003, the ratio of total nitrogen to total phosphorus for this lake is 12:1. Data on inorganic suspended solids from the ISU sampling suggest that this lake may be subject to high levels of non-algal turbidity. The median level of inorganic suspended solids in the 130 lakes sampled for the ISU lake survey in 2000 and 2001 was 5.27 mg/L. The median level of inorganic suspended solids at Silver Lake during the same time period was 21.4 mg/l, the 7th highest of the 130 lakes.

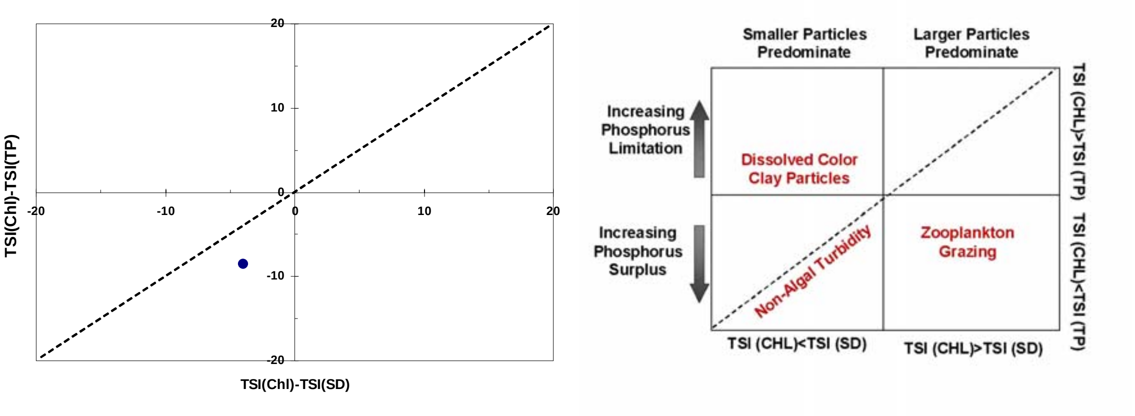
Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for 2000 - 2003 in-lake sampling indicate possible limitation of algal growth attributable to light attenuation by elevated levels of inorganic suspended solids (see Figure 2 and Appendix C).

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

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/15/2000	70	67	77
7/13/2000	83	81	94
8/7/2000	93	79	87
5/17/2001	73	73	81
6/14/2001	83	71	80
7/19/2001	83	71	89
5/23/2002	77	69	76
6/20/2002	77	79	78
7/25/2002	93	85	94
5/22/2003	77	63	73
6/19/2003	77	63	72
7/23/2003	73	64	69

Figure 2. Silver Lake 2000 - 2003 Mean TSI Multivariate Comparison Plot (22)



Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) comprise a significant portion of the summertime phytoplankton community of Silver Lake. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. However, the sampling does indicate a high level of bluegreen mass relative to other Iowa lakes. The 2000 average summer wet mass of bluegreen algae at this lake (30.2 mg/l) was the 32nd highest of 131 lakes sampled. The 2001 summer average wet mass of bluegreen algae declined to 11.4 mg/L but shows one sample (August) where bluegreens comprised over 80% of the phytoplankton community. Sampling for cyanobacterial toxins has not been conducted at Silver Lake. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

Potential Pollution Sources

Water quality in Silver Lake is influenced only by nonpoint sources and internal recycling of pollutants from bottom sediments. 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 target of this TMDL is a TSI of less than 70 for total phosphorus, and TSI values of less than 65 for both chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

Table 6. Silver Lake Existing vs. Target TSI Values

Parameter	2000-2003 Mean TSI	2000-2003 Mean Value	Target TSI	Target Value	In-Lake Increase or Reduction Required
Chlorophyll	75	89 ug/L	<65	<33 ug/L	63% Reduction
Secchi Depth	79	0.3 meters	<65	>0.7 meters	133% Increase in transparency
Total Phosphorus	83	239 ug/L	<70	<96 ug/L	60% 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 Silver Lake is determined to be fully supporting the aquatic life uses. This determination will be accomplished through an assessment conducted by the IDNR Fisheries Bureau.

Criteria for Assessing Water Quality Standards Attainment

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

Selection of Environmental Conditions

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

Modeling Approach

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

Table 7. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = = ANN TP = 239 ug/L, SPO TP = 157 ug/L	Comments
Loading Function	9,750	Reckhow (10)
EPA Export	10,230	EPA/5-80-011
WILMS Export	6,990	“most likely” export coefficients
Reckhow 1991 EUTROMOD Equation	776,400	GSM model
Canfield-Bachmann 1981 Natural Lake	12,320	GSM model
Canfield-Bachmann 1981 Artificial Lake	33,210	GSM model
Reckhow 1977 Anoxic Lake	3,910	GSM model
Reckhow 1979 Natural Lake	19,710	GSM model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	6,560	GSM model. P out of range
Nurnberg 1984 Oxic Lake	9,750 (internal load = 610)	Annual model. P out of range
Walker 1977 General Lake	3,470	SPO model.
Vollenweider 1982 Combined OECD	11,060	Annual model.
Vollenweider 1982 Shallow Lake	11,710	Annual model.

The Canfield-Bachmann Natural Lake, Nurnberg and Vollenweider models resulted in values closest to the Loading Function and export estimates. Of these, the Canfield-Bachman and Vollenweider models are within the parameter ranges used to derive them when applied to Silver Lake. The Nurnberg and Vollenweider models are annual models that should ideally be used in combination with annual average in-lake phosphorus measurements. However, for a polymictic lake the annual average phosphorus concentration can be approximated by the epilimnetic growing season concentration. The available in-lake phosphorus monitoring data for Silver Lake corresponds with the growing season.

The high phosphorus and inorganic suspended solids levels at Silver Lake indicate the likelihood of a significant internal loading. The existing load predicted by the Nurnberg Model also indicates a significant internal load. Therefore, use of the Loading Function estimate with the Nurnberg Oxic Lake Model was selected as the basis for determining the existing load. The Nurnberg Model was also used to determine load targets as a function of the relative contribution from internal and external sources.

The equation for the Nurnberg Oxic Lake Model is:

$$P = \frac{L_{Ext}}{q_s}(1 - R) + \frac{L_{Int}}{q_s}$$

where

$$R = \frac{15}{18 + q_s}$$

$P =$ predicted in-lake total phosphorus concentration (ug/L)
$L_{Ext} =$ external areal total phosphorus load (mg/m^2)
$L_{Int} =$ internal areal total phosphorus load (mg/m^2)
$q_s =$ areal water loading (m/yr)

The Nurnberg Model represents a possible continuum of internal and external loads for a given in-lake total phosphorus concentration. The Loading Function Model external load estimate was used in combination with the Nurnberg Model to determine the existing loads as follows:

$$P = 239(\mu g/L) = \frac{1{,}697(mg/m^2)}{2.3(m/yr)}(1 - \frac{15}{18 + 2.3(m/yr)}) + \frac{106(mg/m^2)}{2.3(m/yr)}$$

An example of a target load calculation for target internal and external loads of 200 and 3,620 lbs, respectively, is:

$$P = 87(\mu g/L) = \frac{630(mg/m^2)}{2.3(m/yr)}(1 - \frac{15}{18 + 2.3(m/yr)}) + \frac{35(mg/m^2)}{2.3(m/yr)}$$

The above calculation includes a margin of safety by using an in-lake concentration 10% below the desired endpoint (P < 96 ug/L) to calculate the target loads. The annual total phosphorus loads are obtained by multiplying the areal loads (L_{Ext} , L_{Int}) by the lake area in square meters and converting the resulting values from milligrams to pounds.

For the in-lake total phosphorus target and any selected target internal load, the corresponding target external load, target total load or target load reduction can be calculated from the relationships shown in Figures E-1 through E-3 in Appendix E.

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 Silver Lake can receive and meet its designated uses. The Phase 1 target TSI (TP) value is less than 70, corresponding to an in-lake total phosphorus concentration of less than 96 ug/L. For the selected lake response model, the target total load is a function of the relative internal and external load contributions as shown in Table 8.

Table 8. Silver Lake Total Phosphorus Target

Total Phosphorus Target Loads (lbs/year)		
Internal	**External**	**Total**
0	4,390	4,390
50	4,190	4,240
100	4,000	4,100
150	3,810	3,960
200	3,620	3,820
250	3,430	3,680
300	3,240	3,540
350	3,050	3,400
400	2,850	3,250
450	2,660	3,110
500	2,470	2,970
550	2,280	2,830
600	2,090	2,690
610	2,050	2,660

3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Silver Lake in this TMDL. The first is the phosphorus load from the watershed areas that drain directly into the lake. The second source is internal phosphorus loading from re-suspended sediments. The third source is atmospheric deposition. 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 Silver Lake is estimated to be 10,360 pounds per year based on the Loading Function and Nurnberg Oxic Lake models. This estimate includes 9,530 pounds per year from external nonpoint sources in the watershed, 610 pounds per year attributable to internal loading, and 220 pounds per year from atmospheric deposition.

Departure from Load Capacity

Table 9 shows the load reductions necessary to achieve and maintain Phase 1 water quality goals.

Table 9. Silver Lake Load Reductions to Meet Phase 1 Goals

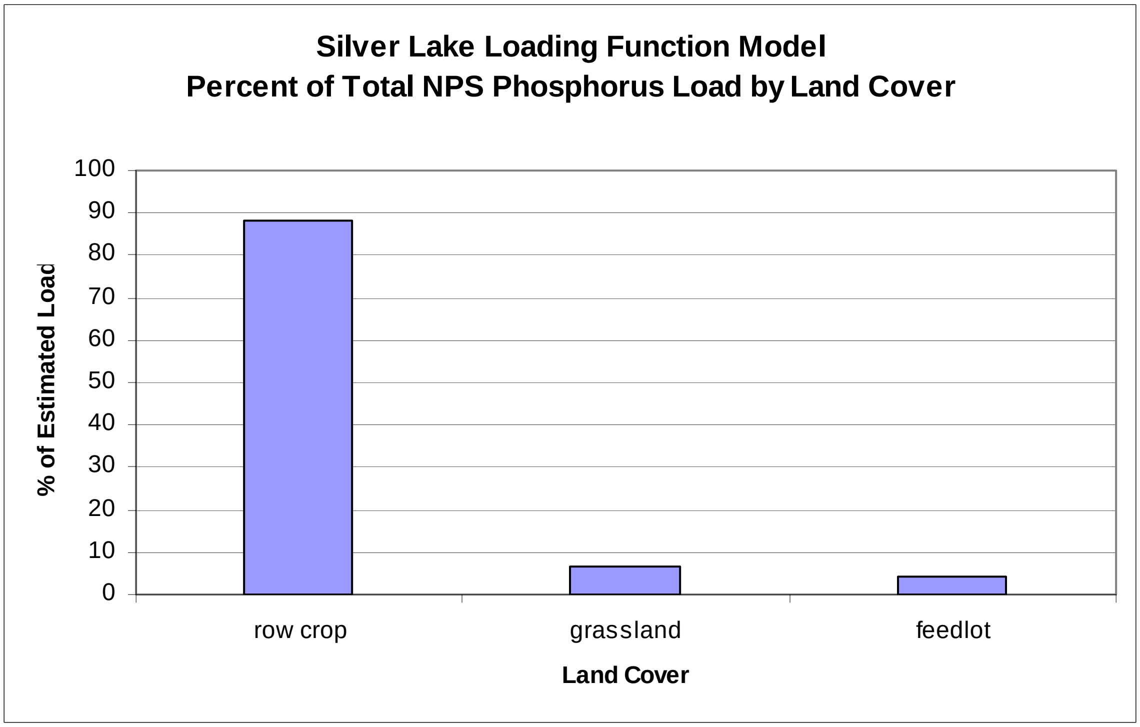
Total Phosphorus Loads (lbs/year)		**Required Load Reduction (lbs/year)**
Internal	**External**	
0	4,390	5,970
50	4,190	6,120
100	4,000	6,260
150	3,810	6,400
200	3,620	6,540
250	3,430	6,680
300	3,240	6,820
350	3,050	6,960
400	2,850	7,110
450	2,660	7,250
500	2,470	7,390
550	2,280	7,530
600	2,090	7,670
610	2,050	7,700

Identification of Pollutant Sources

There are no significant point source discharges in the Silver Lake watershed. From the Loading Function Model, the most external nonpoint source phosphorus delivered to the lake is from row crop landuse as shown in Figure 3. Loading from the feedlot was estimated based on an export coefficient of 200 lbs/acre/year (21). Actual loading from the feedlot may vary substantially from this estimate depending on the number of animals, extent of use, runoff controls and other factors. It should be noted that while the Loading Function Model provides estimates of the primary potential pollutant sources and a means of estimating existing internal versus external loads, the existing and target total loads identified in this TMDL are independent of the Loading Function Model. The Loading Function Model was used only for comparison purposes to select an empirical lake response model and to separate the existing total load predicted by the lake response model into internal and external components. Existing and target loads were calculated from measured and target in-lake total phosphorus concentrations using the selected lake response model as shown in *Section 3.2, Modeling Approach*. Also, the Loading Function Model estimates only external watershed phosphorus inputs and does not account for internal loading.

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

Figure 3. Loading Function Model Nonpoint Source Contributions



The Nurnberg Model indicates that internal loading makes up approximately 6% of the existing total phosphorus mass loading to the lake. However, the internal load has a much greater effect on in-lake total phosphorus concentrations on a pound for pound basis. The model relationship shows that one pound of internal loading is equivalent to 3.8 pounds of external loading. In terms of lake response, the internal load is estimated to comprise approximately 19% of the existing total load.

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Silver Lake originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source contributions to Silver Lake must be reduced as shown in Table 9 (above).

3.4 Pollutant Allocation

Wasteload Allocation

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

Load Allocation

Table 10 shows the Load Allocation (LA) for this TMDL based on varying internal and external load contributions. The external and total loads shown include 220 pounds per year from atmospheric deposition.

Table 10. Silver Lake Load Allocation

Total Phosphorus Load Allocation (lbs/year)		
Internal	**External**	**Total**
0	4,390	4,390
50	4,190	4,240
100	4,000	4,100
150	3,810	3,960
200	3,620	3,820
250	3,430	3,680
300	3,240	3,540
350	3,050	3,400
400	2,850	3,250
450	2,660	3,110
500	2,470	2,970
550	2,280	2,830
600	2,090	2,690
610	2,050	2,660

Margin of Safety

The target total phosphorus loads are calculated using an in-lake concentration 10% below the desired endpoint to ensure that the required load reduction 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 Silver Lake water quality.

The estimated existing phosphorus loading from watershed sources is approximately 1.1 pounds/year/acre. Depending on the internal recycle load reduction achieved, the watershed loading would need to be reduced to a maximum of 0.5 pounds/year/acre. Because reductions in internal recycling and watershed loading will require management practices that take time to implement, the following timetable is suggested for improvements:

- Reduce watershed and recycle loading from 10,400 pounds per year to 8,200 pounds per year by 2010.
- Reduce watershed and recycle loading from 8,200 pounds per year to 6,000 pounds per year by 2015.
- Reduce watershed and recycle loading from 6,000 pounds per year to 3,800 pounds per year by 2020.

The final target of 3,800 pounds per year assumes that reductions in internal and external loads will be roughly proportional. It should be noted that the final total target load may vary depending upon the internal and external load reductions achieved as shown in previous sections of this report.

The Loading Function Model (Figure 3) indicates that the majority of the phosphorous load to Silver Lake originates on row crop ground. With 79% of the watershed in row crop production, significant improvements need to be made to reduce the external loading to the lake. Although Silver Lake is located within the pothole region, many of these wetlands have been drained and are currently being farmed. The moderately sloping topography of the Silver Lake watershed causes concern regarding soil erosion on the row crop ground. There are many best management practices available to reduce soil loss and resulting sediment delivery to the lake. These include, terraces, filter strips, buffers, grassed waterways, and reduced tillage systems.

The following best management practices would be beneficial for reducing sediment and nutrient (phosphorous) delivery to Silver Lake.

- Manage agricultural soils for the optimum soil test range. This soil test range is the most profitable for producers to sustain in the long term.
- Incorporate or subsurface apply phosphorus while controlling soil erosion. Incorporation will physically separate the phosphorus from surface runoff.
- Continue encouraging the adoption of reduced tillage systems, specifically no till or strip tillage
- Remove surface tile inlets to force surface water to infiltrate and percolate through the soil.
- Identify key locations in the watershed and construct wetlands to settle out adsorbed and dissolved phosphorus in surface runoff and tile water.
- 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.

The internal nutrient component of Silver Lake is due in large part to wind and wave action continually mixing the lake. Silver Lake is a shallow natural lake and does not readily stratify. Minimizing the impact of wind and wave action on the lake could be accomplished through the installation of wind breaks to reduce wind fetch across the lake. Increasing the mean depth to at least 3 meters would allow the lake to stratify, reducing the internal mixing. This option may not be feasible due to limitations in the morphometry of the lake as well as cost limitations.

In addition to wind and wave action continually stirring the lake, a large rough fish population comprised of bullheads and carp degrade water quality by eliminating aquatic macrophytes that take up available nutrients and by stirring up bottom sediments aiding in sediment and nutrient resuspension. Commercial harvesting of the rough fish population would improve water quality by reducing the impact these fish have on mixing of the water column and macrophyte populations in the lake.

5. Monitoring

Further monitoring is needed at Silver 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. Silver 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.

The phosphorus load due to internal recycling is estimated by the selected lake response model but due to uncertainty inherent in the available data and model predictions further investigation is warranted. The department is working with Iowa State University to develop a method for quantifying phosphorus sediment flux that will clarify its impact on lakes. When a protocol for measuring phosphorus flux becomes available, coring will be done for this lake and the recycling load component estimate will be further refined.

6. Public Participation

TMDL staff met with the Palo Alto County Conservation Board on June 10, 2004 and with the Palo Alto Soil and Water Conservation District on June 29, 2004 to discuss the TMDL process. The draft TMDL was reviewed at a public meeting held September 20, 2004 and was available for public comment prior to submittal to EPA. Comments received were reviewed and given consideration and, where appropriate, incorporated into the final TMDL.

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

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

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

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

Data

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

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

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

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

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

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

Methods

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

Equation Variables

Table A-2. Regression Equation Variables

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

Equations

Table A-3. Drainage Area Only Equations

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

Table A-4. Multiple Regression Equations

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

General Application

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

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

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

Application to Silver Lake - Calculations

Table A-5. Silver Lake Hydrology Calculations

Lake	Silver Lake	
Type	Natural	
Inlet(s)	Drainage Ditch No. 6, unnamed (3)	
Outlet(s)	Silver Creek	
Volume	3091	(acre-ft)
Lake Area	644	(acres)
Mean Depth	4.80	(ft)
Drainage Area	8365	(acres)
Mean Annual Precip	30.2	(inches)
Average Basin Slope	2.43	(%)
%Water	0.068138946	
%Forest	2.190607345	
%Grass/Hay	14.67784624	
%Corn	37.37110383	
%Beans	45.52482529	
%Urban/Artificial	0.039927032	
%Barren/Sparse	0.127551325	
Hydrologic Region	5	
Mean Annual Class A Pan Evap	49	(inches)
Mean Annual Lake Evap	36.26	(inches)
Est. Annual Average Inflow	5188.84	(acre-ft)
Direct Lake Precip	1621.64	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.4539	(yr)
Est. Annual Average Det. Time (outflow)	0.6356	(yr)

9. Appendix B - Sampling Data

Table B-1. Data collected in 1979 by Iowa State University (Bachmann, 1980)

Parameter	**7/12/1979**	**8/14/1979**	**9/18/1979**
Secchi Depth (m)	0.8	0.6	0.3
Chlorophyll (ug/L)	21.4	70.6	127.2
NO_3+NO_2-N (mg/L)			0.08
Total Phosphorus (ug/l as P)	142	218	293
Alkalinity (mg/L)	162	159	139

Data above is averaged over the upper 6 feet.

Table B-2. Data collected in 1990 by Iowa State University (Bachmann, 1994)

Parameter	**6/14/1990**	**7/15/1990**	**8/14/1990**
Secchi Depth (m)	0.2	0.2	0.2
Chlorophyll (ug/L)	117.2	166.1	156.6
Total Nitrogen (mg/L as N)	3.4	3.4	2.7
Total Phosphorus (ug/l as P)	287.3	180.5	188.3
Total Suspended Solids (mg/L)	75.4	42.6	63.8
Inorganic Suspended Solids (mg/L)	44.9	10.3	38.2

Data above is for surface depth.

Table B-3. Data collected in 2000 by Iowa State University (Downing and Ramstack, 2001)

Parameter	**6/21/2000**	**7/13/2000**	**8/07/2000**
Secchi Depth (m)	0.5	0.2	0.1
Chlorophyll (ug/L)	42	165	141
NH_3+NH_4^+ -N (ug/L)	659	1737	1770
NH_3 –N (un-ionized) (ug/L)	42	378	285
NO_3+NO_2-N (mg/L)	0.25	0.25	0.17
Total Nitrogen (mg/L as N)	1.17	3.05	2.24
Total Phosphorus (ug/l as P)	158	506	315
Silica (mg/L as SiO_2)	21	30	61
pH	8.3	8.6	8.5
Alkalinity (mg/L)	168	148	131
Total Suspended Solids (mg/L)	32.0	106.0	76.4
Inorganic Suspended Solids (mg/L)	4.8	83.3	52.1
Volatile Suspended Solids (mg/L)	27.2	22.7	24.3

Table B-4. Data collected in 2001 by Iowa State University (Downing and Ramstack, 2002)

Parameter	**5/17/2001**	**6/14/2001**	**7/19/2001**
Secchi Depth (m)	0.4	0.2	0.2
Chlorophyll (ug/L)	75	64	63
NH_3+NH_4^+ -N (ug/L)	182	1594	1672
NH_3 –N (un-ionized) (ug/L)	22	79	146
NO_3+NO_2-N (mg/L)	4.84	3.26	0.15
Total Nitrogen (mg/L as N)	6.24	4.87	2.37
Total Phosphorus (ug/l as P)	205	186	350
Silica (mg/L as SiO_2)	17	12	39
pH	8.5	8.1	8.2
Alkalinity (mg/L)	131	178	208
Total Suspended Solids (mg/L)	9.4	95.9	51.9
Inorganic Suspended Solids (mg/L)	0.0	75.3	41.0
Volatile Suspended Solids (mg/L)	9.4	20.6	11.0

Table B-5. Data collected in 2002 by Iowa State University (Downing et al., 2003)

Parameter	**5/23/2002**	**6/20/2002**	**7/25/2002**
Secchi Depth (m)	0.3	0.3	0.1
Chlorophyll (ug/L)	49	133	254
NH_3+NH_4^+ -N (ug/L)	364	326	918
NH_3 –N (un-ionized) (ug/L)	37	39	96
NO_3+NO_2-N (mg/L)	0.46	0.25	0.15
Total Nitrogen (mg/L as N)	1.56	1.73	3.04
Total Phosphorus (ug/l as P)	144	167	516
Silica (mg/L as SiO_2)	2	4	27
pH	8.4	8.5	8.3
Alkalinity (mg/L)	167	182	210
Total Suspended Solids (mg/L)	49.7	26.3	100.0
Inorganic Suspended Solids (mg/L)	34.7	10.0	64.3
Volatile Suspended Solids (mg/L)	15.0	16.3	35.7

Table B-6. Data collected in 2003 by Iowa State University (Downing et al., 2004)

Parameter	**5/22/2003**	**6/19/2003**	**7/23/2003**
Secchi Depth (m)	0.3	0.3	0.4
Chlorophyll (ug/L)	27.1	26.9	30.0
NH_3+NH_4^+ -N (ug/L)	531	517	196
NH_3 –N (un-ionized) (ug/L)	29	56	100
NO_3+NO_2-N (mg/L)	2.41	1.51	1.30
Total Nitrogen (mg/L as N)	2.84	2.83	3.21
Total Phosphorus (ug/l as P)	122	108	88
Silica (mg/L as SiO_2)	12.4	6.1	6.8
pH	8.3	8.4	9.3
Alkalinity (mg/L)	157	124	84
Total Suspended Solids (mg/L)	23	44	23
Inorganic Suspended Solids (mg/L)	18	30	7
Volatile Suspended Solids (mg/L)	4	15	16

Table B-7. 2000 Phytoplankton Data (Downing and Ramstack, 2001)

	6/23/2000	7/20/2000	8/10/2000
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Cyanophyta	7.6E+01	2.5E+02	2.8E+02
Cryptophyta	0.0E+00	0.0E+00	0.0E+00
Chlorophyta	1.7E+00	0.0E+00	3.3E+00
Dinophyta	0.0E+00	0.0E+00	0.0E+00
Chrysophyta	4.6E+00	9.0E+00	0.0E+00
Euglenophyta	0.0E+00	0.0E+00	0.0E+00
Total	**8.3E+01**	**2.6E+02**	**2.8E+02**

Table B-8. 2001 Phytoplankton Data (Downing and Ramstack, 2002)

	5/16/2001	**6/13/2001**	**7/18/2001**
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Chlorophyta	6.90E-02	3.94E+00	0.00E+00
Chrysophyta	2.57E+01	3.82E+00	5.67E-01
Cryptophyta	2.89E+00	1.88E-01	0.00E+00
Cyanobacteria	7.12E-01	0.00E+00	3.36E+01
Dinophyta	0.00E+00	0.00E+00	6.47E+00
Total	2.93E+01	7.95E+00	4.07E+01

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

10. Appendix C - Trophic State Index

Carlson's Trophic State Index

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

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

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

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

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

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

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

SD = lake Secchi depth, meters

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

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

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

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

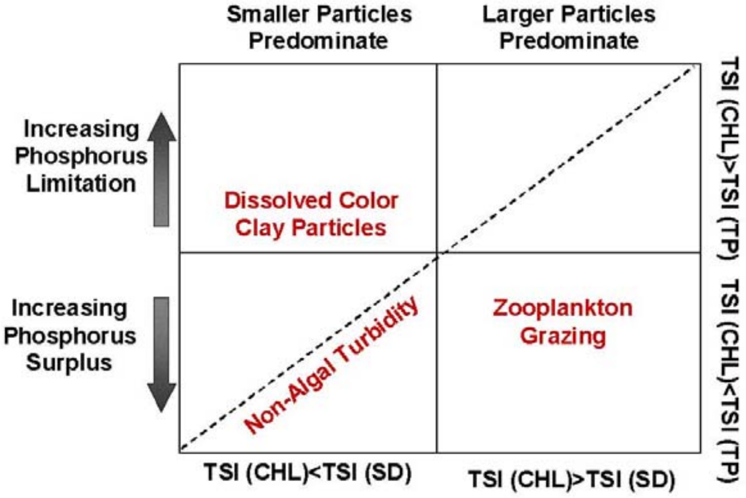
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for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

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

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

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

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



Silver Lake TSI Values

Table C-4. 1979 Silver Lake TSI Values (Bachmann)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/12/1979	63	61	76
8/14/1979	69	72	82
9/18/1979	77	78	86

Table C-5. 1990 Silver Lake TSI Values (Bachmann)

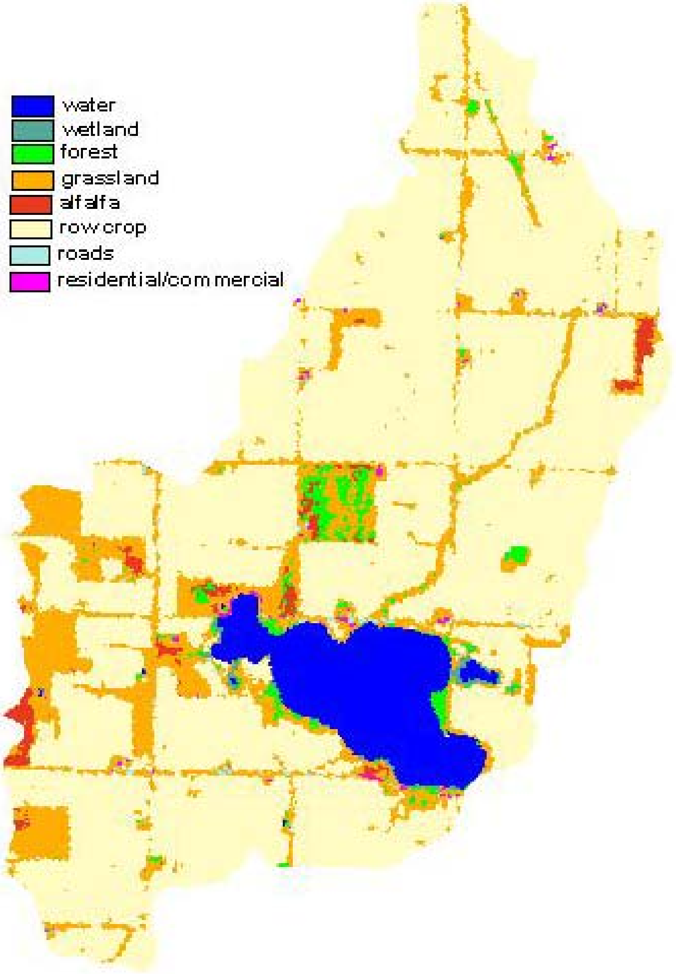
Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/14/1990	83	78	85
7/15/1990	83	80	79
8/13/1990	83	80	80

Table C-6. 2000 - 2003 Silver Lake TSI Values (Downing et al.)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/15/2000	70	67	77
7/13/2000	83	81	94
8/7/2000	93	79	87
5/17/2001	73	73	81
6/14/2001	83	71	80
7/19/2001	83	71	89
5/23/2002	77	69	76
6/20/2002	77	79	78
7/25/2002	93	85	94
5/22/2003	77	63	73
6/19/2003	77	63	72
7/23/2003	73	64	69

11. Appendix D - Land Use Maps

Figure D-1. Silver Lake Watershed 2002 Landuse



12. Appendix E – Silver Lake Loading Relationships

Figure E-1. Silver Lake Target Internal vs. External Load

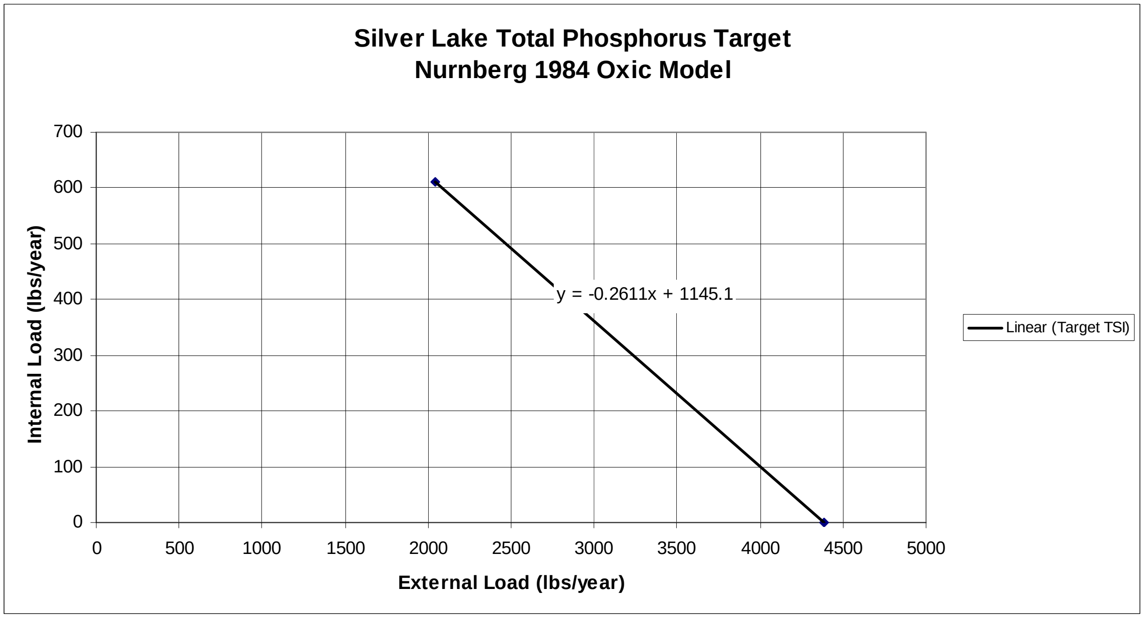


Figure E-2. Silver Lake Target Total Load vs. Internal & External Loads

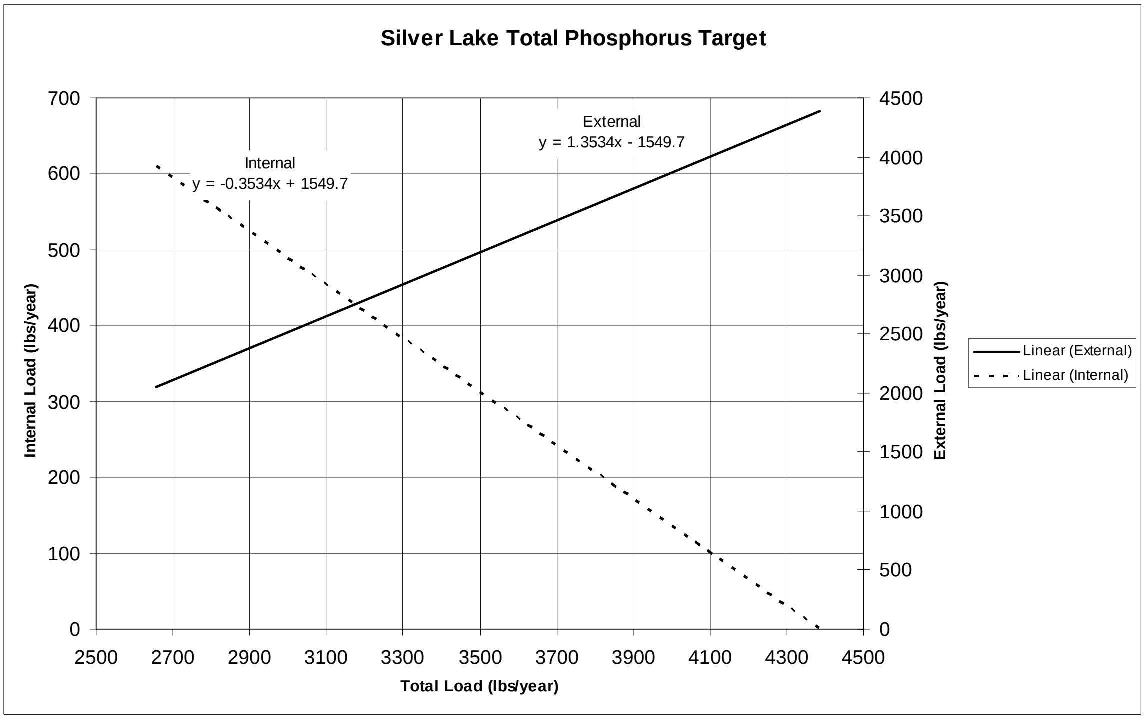


Figure E-3. Silver Lake Load Reduction vs. Internal & External Loads