Total Maximum Daily Load
For Algae and Turbidity
Swan Lake
Carroll County, Iowa

2004

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Swan Lake Summary

Waterbody Name:	Swan Lake
County:	Carroll
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Raccoon River Basin
Pollutants:	Phosphorus
Pollutant Sources:	Nonpoint external, atmospheric (background), and nonpoint internal (sediment re-suspension and nutrient recycling)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Medium
Watershed Area:	770 acres
Lake Area:	120 acres
Lake Volume:	643 acre-ft
Detention Time:	1.5 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:	1,990 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. Swan Lake has been identified as impaired by algae and turbidity. The purpose of these TMDLs for Swan 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 Swan 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 stable;
- 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:** Swan Lake, S31, T84N, R34W, 3 miles southeast of the City of Carroll, Carroll 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 Swan 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 0.2 meters, 188 ug/L and 476 ug/L, respectively. A minimum in-lake increase in Secchi transparency of 250% and minimum in-lake

reductions of 82% for chlorophyll a and 80% 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 Swan Lake is 1,990 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 have been identified as the cause of impairment to Swan Lake.

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Swan 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 40 pounds per year attributable to atmospheric deposition.

Table 2. Swan Lake Total Phosphorus Loads

Total Phosphorus Load Allocation/Target Loads (lbs/year)			**Required Load Reduction (lbs/year)**
Internal	**External**	**Total**	
0	480	480	1,510
10	430	440	1,550
20	390	410	1,580
30	340	370	1,620
40	290	330	1,660
50	250	300	1,690
60	200	260	1,730
70	150	220	1,770
80	110	190	1,800
90	60	150	1,840

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. Although situated close to the City of Carroll, the current watershed landuses in are predominantly agricultural. Any future residential development within the watershed would likely be sewered due to the proximity of the lake to the City's existing corporate limits. 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 report.

2. Swan Lake, Description and History

2.1 The Lake

Swan Lake was constructed in 1934 and is located in west central Iowa, 3 miles southeast of Carroll. Public use for Swan Lake is estimated at 75,000 visitors per year. Users of the lake and of Swan Lake State Park enjoy fishing, swimming, picnicking, camping, hiking, and ice skating.

Prior to 1983, the lakes maximum depth was 6 feet with a mean depth of 3 feet. A restoration project in 1983-85 increased the lake depth and added 10 fishing jetties and an enclosed fishing shelter. Common carp were introduced into Swan Lake during a flood in 1990.

According to the IDNR Fisheries Bureau, two new wetlands have been constructed in the upper end of the lake and are expected to improve water quality. In addition, Swan Lake is currently undergoing renovation that includes elimination of the existing fish population, restocking of the lake, and installation of a fish barrier at the lake outlet to prevent common carp from entering the lake (as has happened during high-flow periods in the past).

Table 3. Swan Lake Features

Waterbody Name:	Swan Lake
Hydrologic Unit Code:	HUC10 0710000701
IDNR Waterbody ID:	IA 04-RAC-02370-L
Location:	Section 31 T84N R34W
Latitude:	42° 2' N
Longitude:	94° 51' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	Unnamed (2)
Receiving Waterbody:	Unnamed tributary to the Middle Raccoon River
Lake Surface Area:	120 acres
Maximum Depth:	14 feet
Mean Depth:	5.3 feet
Volume:	643 acre-feet
Length of Shoreline:	14,000 feet
Watershed Area:	770 acres
Watershed/Lake Area Ratio:	6.3:1
Estimated Detention Time:	1.5 years

Morphometry

Swan Lake has a mean depth of 5.3 feet and a maximum depth of 14 feet. The lake surface area is 120 acres and the storage volume is approximately 643 acre-feet. Temperature and dissolved oxygen sampling indicate that Swan Lake remains oxic and relatively well mixed throughout the growing season.

Hydrology

Swan Lake has two unnamed tributaries and discharges to an unnamed tributary of the Middle Raccoon River. The estimated annual average detention time is 1.5 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Swan Lake watershed has an area of approximately 770 acres and has a watershed to lake ratio of 6.3:1. The 2002 landuses and associated areas for the watershed were determined from satellite imagery and are shown in Table 4.

Table 4. 2002 Landuse in Swan Lake watershed

Landuse	Area in Acres	Percent of Total Area
Row Crop	370	47.9
Grassland	250	33.1
Forest	70	9.7
Alfalfa	40	4.7
Other	40	4.7
Total	770	100

A more recent field level watershed assessment completed in May 2004 by the IDNR determined current landuses and associated cropping practice factors for use in calculating soil loss and delivery. The 2004 assessment shows that the major landuse in the watershed is row crop (404 acres). Other landuses in the 2004 assessment include grass (186 acres), forest (122 acres), roads (23 acres), two Confinement Animal Feeding Operations (15 acres) and farmsteads (14 acres). One of the Confinement Animal Feeding Operations (CAFOs) has ceased operations. The estimated number of animal units associated with the remaining CAFO is 260 swine animal units.

CAFOs are animal feeding operations in which animals are confined to areas that 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.

The watershed is predominately gently to strongly sloping (0-14%) prairie-derived soils. About two thirds of the watershed is Marshall soils developed from loess. A third of the watershed is Clarion, Canisteo, Nicollet, Webster, and Storden soils developed from Wisconsin till. Average rainfall in the area is 31.6 inches/year.

Land use maps for both 2002 and 2004 are shown in Appendix D.

Figure 1. Swan 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 Swan Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). In 1998, Swan Lake was included on the impaired waters list as recommended by the DNR Fisheries and Water Quality bureaus due to pathogen impairments. At that time, Class A and B uses were assessed as “partially supported.” The pathogen impairment was removed in 2002, but the lake remains on the 303(d) list due to elevated levels of nutrients and turbidity.

In 2002, the Class A designated use was assessed as “not supporting” and Class B use remained “partially supported” for Swan Lake. This assessment was based upon the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau.

Swan Lake has a history of problems with algal blooms. This condition indicates impairments to the Class A1 use through presence of aesthetically objectionable blooms of algae and presence of nuisance algal species (e.g., bluegreen algae). ISU sampling in 2000 and 2001 show that bluegreen algae comprise nearly 100% of the wet mass of the phytoplankton community throughout the growing season.

Data Sources

Water quality surveys have been conducted on Swan Lake in 1979, 1990, and 2000-03 (1,2,3,4,5,22). 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 began in 2000 and 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 Swan 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 5:1. Data on inorganic suspended solids from the ISU survey indicate that this lake is 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 Swan Lake during the same time period was 46.9 mg/l, the highest of the 130 lakes, thus suggesting that non-algal turbidity limits the production of algae as well as impairs beneficial uses. Much of the suspended inorganic material in the water column of Swan Lake is believed due to a large population of common carp that re-suspend sediments and nutrients during feeding and spawning activities.

Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) completely dominate the summertime phytoplankton community of Swan Lake. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. However, the sampling does indicate an extremely high level of bluegreen mass relative to other Iowa lakes. The 2000 average summer wet mass of bluegreen algae at this lake (2,200 mg/l) was the highest of 131 lakes sampled. The 2001 summer average wet mass declined to 410 mg/L but still indicates that almost the entire phytoplankton community is made up of bluegreen algae throughout the growing season. Sampling for cyanobacterial toxins has not been conducted at Swan Lake. 2000 and 2001 phytoplankton sampling results are given in Appendix B.

Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for in-lake sampling reaffirm that despite very high chlorophyll levels, a non-phosphorus limitation to algal growth is present (see Figure 2 and Appendix C). This non-phosphorus limitation is attributable to light attenuation by elevated levels of inorganic suspended solids. Since the phytoplankton community at Swan Lake is comprised primarily of bluegreen algae, it is less likely that the low nitrogen to phosphorus ratio is currently limiting algal growth.

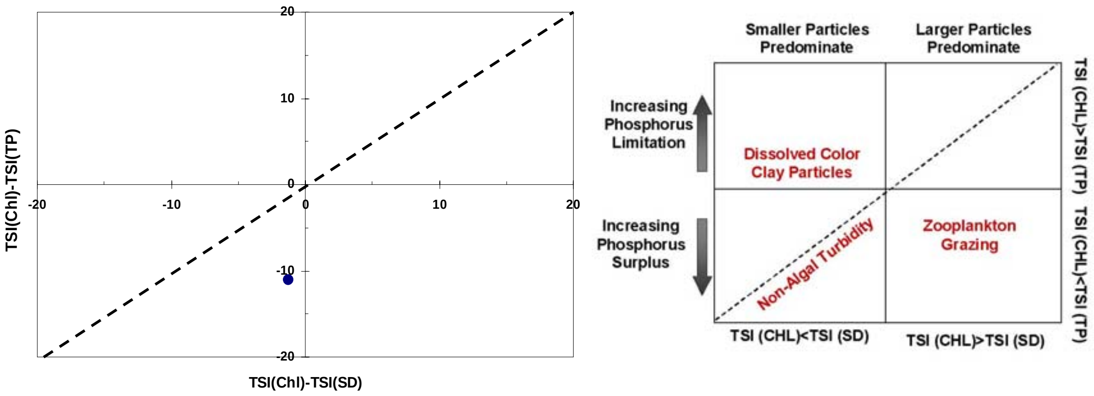
Based on the nitrogen to phosphorus ratio, nitrogen is currently the limiting nutrient at Swan Lake, presumably due to the overabundance of phosphorus. However, a reduction in nitrogen levels is unlikely to significantly curtail nuisance blooms of bluegreen algae due to their ability to fix atmospheric nitrogen. Therefore, phosphorus is the targeted nutrient in this TMDL.

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. Swan Lake TSI Values (1,2,3,4,5,22)

Sample Date	**TSI (SD)**	**TSI (CHL)**	**TSI (TP)**
6/22/2000	93	92	103
7/19/2000	93	84	99
8/9/2000	93	65	95
5/24/2001	93	81	91
6/20/2001	83	95	99
7/25/2001	77	84	92
5/30/2002	83	73	85
6/26/2002	83	73	88
7/31/2002	83	75	89
5/30/2003	77	61	82
6/26/2003	83	62	91
7/31/2003	73	64	83

Figure 2. Swan Lake 2000 - 2003 Mean TSI Multivariate Comparison Plot (23)



Potential Pollution Sources

Water quality in Swan Lake is influenced only by watershed nonpoint sources and internal recycling of pollutants from bottom sediments. There are no point source discharges in the watershed.

As stated previously, it is suspected that a large rough fish population has contributed significantly to re-suspension of lake sediments and internal recycling of nutrients. In addition, poor manure management practices have been previously reported within the watershed (20,21). The watershed includes two CAFOs, each with a manure storage structure.

A large winter goose population has been cited by stakeholders as potentially contributing nutrient loads to the lake. Other potential sources cited by stakeholders are on-site septic systems that serve the lake's camping facilities and visitors, captive animals that the Swan Lake Park maintains, and spoils from previous dredging that were deposited in the northwest portion of the lake.

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. Swan Lake Existing vs. Target TSI Values

Parameter	**2000-2003 Mean TSI**	**2000-2003 Mean Value**	**Target TSI**	**Target Value**	**Minimum In-Lake Increase or Reduction Required**
Chlorophyll	82	188 ug/L	<65	<33 ug/L	82% Reduction
Secchi Depth	83	0.2 meters	<65	>0.7 meters	250% Increase in transparency
Total Phosphorus	93	476 ug/L	<70	<96 ug/L	80% 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 Swan 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 = 476 ug/L, SPO TP = 304 ug/L	Comments
Loading Function	1,810	Reckhow (10)
EPA Export	1,200	EPA/5-80-011
WILMS Export	780	“most likely” export coefficients
Reckhow 1991 EUTROMOD Equation	22,703,740	GSM model
Canfield-Bachmann 1981 Natural Lake	6,310	GSM model
Canfield-Bachmann 1981 Artificial Lake	30,420	GSM model
Reckhow 1977 Anoxic Lake	780	GSM Model
Reckhow 1979 Natural Lake	6,620	GSM Model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	1,890	GSM model. P/Pin out of range
Nurnberg 1984 Oxic Lake	1,810 (internal load = 180)	Annual model. P out of range
Walker 1977 General Lake	720	SPO model.
Vollenweider 1982 Combined OECD	2,850	Annual model. Pin out of range
Vollenweider 1982 Shallow Lake	2,840	Annual model. Pin out of range

The Reckhow Anoxic, Reckhow Oxic, Walker, Nurnberg and Vollenweider models resulted in values closest to the Loading Function and export estimates. Of these, only the Reckhow Anoxic and Walker models are within the parameter ranges used to derive them when applied to Swan Lake with its extremely high in-lake phosphorus levels. Swan Lake is an oxic lake, making application of the Reckhow Anoxic Model questionable. The Walker Model is a Spring Overturn (SPO) model. The available in-lake phosphorus monitoring for Swan Lake corresponds with the growing season, requiring late spring or early summer sampling values to be used as a surrogate for the early spring phosphorus values used to derive the Walker Model.

The Reckhow Oxic and Vollenweider models return values that are above, but reasonably close to, the range predicted by the Loading Function and export estimates. However, the high phosphorus and inorganic suspended solids levels at Swan 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 of lake area per year)
$L_{Int} =$ internal areal total phosphorus load (mg/m^2 of lake area per year)
$q_s =$ 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:

$$P = 476(\mu g / L) = \frac{1{,}684(mg/m^2)}{1.11(m/yr)}(1 - \frac{15}{18 + 1.11(m/yr)}) + \frac{166(mg/m^2)}{1.11(m/yr)}$$

An example of a load calculation for target internal and external loads of 30 and 340 pounds, respectively, is:

$$P = 87(\mu g / L) = \frac{316(mg/m^2)}{1.11(m/yr)}(1 - \frac{15}{18 + 1.11(m/yr)}) + \frac{27.9(mg/m^2)}{1.11(m/yr)}$$

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 Swan Lake can receive and meet its designated uses. The Phase 1 target TSI (TP) value is less than 70, corresponding with 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. Swan Lake Total Phosphorus Target

Total Phosphorus Target Loads (lbs/year)		
Internal	**External**	**Total**
0	480	480
10	430	440
20	390	410
30	340	370
40	290	330
50	250	300
60	200	260
70	150	220
80	110	190
90	60	150

3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Swan Lake in this TMDL. The first is the phosphorus load from the watershed that drains 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 Swan Lake is estimated to be 1,990 pounds per year based on the Loading Function and Nurnberg Oxic Lake models. This estimate includes 1,770 pounds per year from external nonpoint sources in the watershed, 180 pounds per year attributable to internal loading, and 40 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. Swan Lake Load Reductions to Meet Phase 1 Goals

Total Phosphorus Loads (lbs/year)		Required Load Reduction (lbs/year)
Internal	External	
0	480	1,510
10	430	1,550
20	390	1,580
30	340	1,620
40	290	1,660
50	250	1,690
60	200	1,730
70	150	1,770
80	110	1,800
90	60	1,840

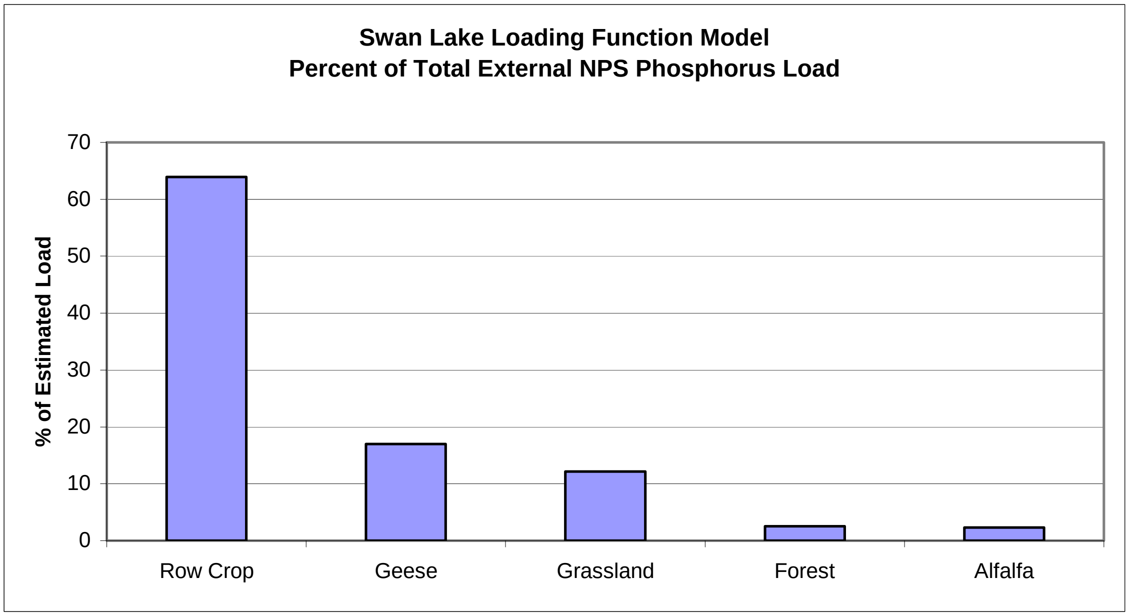
Identification of Pollutant Sources

There are no significant point source discharges in the Swan 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. 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.

Canada geese have been considered as contributing phosphorus through direct manure deposition to the lake. This manure phosphorus is an external nonpoint source load. Christmas bird counts and additional information provided by the Carroll County Conservation Board director (24) were used to estimate 280,000 Canada geese-days at the lake annually. This population was then used to calculate goose manure phosphorus production and deposition (25).

The Nurnberg Model indicates that internal loading makes up approximately 9% 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 4.6 pounds of external loading. In terms of lake response, the internal load is estimated to comprise approximately 31% of the total load. The dredge spoils mentioned in *Section 3.1, Potential Pollution Sources,* may constitute a portion of the internal load.

Figure 3. Loading Function Model External Nonpoint Source Contributions



Other sources of phosphorus capable of being delivered to the water body exist. These sources include septic systems and toilet pits from campsites, individual residences, and seasonal-use businesses and housing units. Manure and waste from wildlife, pets, fish cleaning stations, 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.

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Swan Lake originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source and internal recycling contributions to Swan 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 Swan 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 include 40 pounds per year from atmospheric deposition.

Table 10. Swan Lake Load Allocation

Total Phosphorus Load Allocation (lbs/year)		
Internal	**External**	**Total**
0	480	480
10	430	440
20	390	410
30	340	370
40	290	330
50	250	300
60	200	260
70	150	220
80	110	190
90	60	150

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 Swan Lake water quality.

Swan Lake receives nutrient loading from the watershed and through internal recycling. The internal component is due in large part to a large rough fish population that entered the lake during high flow events in 1990. Once established, common 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. Other mechanisms of resuspension are wind-driven waves and currents, and boat propellers.

During the summer and fall of 2004, the IDNR Fisheries Bureau is renovating the fishery of Swan Lake and making improvements to the spillway. In August 2004, the water level at Swan Lake was drawn down so that the fish population, largely rough fish, could be renovated and so that work could be completed on the spillway. The new spillway will have a barrier so that fish cannot move into the lake during high water events. Following completion of the lake renovation, the IDNR Fisheries Bureau will carefully monitor the fishery of Swan Lake and the overall water quality.

The estimated existing phosphorus loading from watershed sources is approximately 2.3 pounds/year/acre. Depending on the internal recycle load reduction achieved, the watershed loading would need to be reduced to a maximum of 0.6 pounds/year/acre. Because reductions in watershed loads will require land management practices that take time to implement, the following timetable is suggested for watershed improvements:

- Reduce watershed and recycle loading from 2,000 pounds per year to 1,400 pounds per year by 2010.
- Reduce watershed and recycle loading from 1,400 pounds per year to 900 pounds per year by 2015.
- Reduce watershed and recycle loading from 900 pounds per year to 400 pounds per year by 2020.

The final target of 400 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 Swan Lake watershed has undergone several improvements in the last five years, all reducing the nutrient inputs from the watershed. Two new wetlands have recently been constructed within Swan Lake Park to receive runoff from the watershed prior to discharging to the lake. An animal feeding operation directly above the lake has eliminated livestock from the facility, therefore reducing potential nutrient delivery to the lake.

Although gross soil erosion in the Swan Lake watershed is being controlled, it is believed that phosphorus dissolved in surface runoff and/or attached to fine sediment entering tile through terrace inlets is contributing to the phosphorus loading. The following recommendations are listed, in order of impact, to reduce the nonpoint source delivery of phosphorus to Swan Lake. These practices should be applied even though gross soil erosion is calculated to be less than the tolerable soil loss level "T".

- Nutrient management on production agriculture ground to achieve the optimum soil test range. This soil test range is the most profitable for producers to sustain in the long term.
- Incorporate or subsurface apply phosphorus (manure and commercial fertilizer) while controlling soil erosion. Incorporation will physically separate the phosphorus from surface runoff.
- Continue encouraging the adoption of reduced tillage systems, specifically no till.
- 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.

5. Monitoring

Further monitoring is needed at Swan 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. Swan 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

Presentations were given to the Carroll County Conservation Board on June 9, 2004 and the Carroll County Soil and Water Conservation District on June 23, 2004. The draft TMDL was presented at a public meeting in Carroll, Iowa on October 12, 2004. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

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

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

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

Data

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

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

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

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

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

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

Methods

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

Equation Variables

Table A-2. Regression Equation Variables

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

Equations

Table A-3. Drainage Area Only Equations

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

Table A-4. Multiple Regression Equations

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

Table A-5. Swan Lake Hydrology Calculations

Lake	Swan Lake	
Type	Artificial	
Inlet(s)	Unnamed Creek	
Outlet(s)	Unnamed Creek	
Volume	642.8	(acre-ft)
Lake Area	120.44	(acres)
Mean Depth	5.33709731	(ft)
Drainage Area	764.56	(acres)
Mean Annual Precip	31.6	(inches)
Average Basin Slope	5.59	(%)
%Water	0	
%Forest	14.66130288	
%Grass/Hay	35.15182974	
%Corn	17.54736569	
%Beans	31.08227355	
%Urban/Artificial	0.778614067	
%Barren/Sparse	0.778614067	
Hydrologic Region	4	
Mean Annual Class A Pan Evap	53	(inches)
Mean Annual Lake Evap	39.22	(inches)
Est. Annual Average Inflow	514.5413213	(acre-ft)
Direct Lake Precip	317.1586667	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.772874846	(yr)
Est. Annual Average Det. Time (outflow)	1.467372462	(yr)

9. Appendix B - Sampling Data

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

Parameter	7/11/1979	8/02/1979	8/30/1979
Secchi Depth (m)	0.5	0.5	0.5
Chlorophyll (ug/L)	40.5	65.1	
NO_3+NO_2-N (mg/L)			0.08
Total Phosphorus (ug/l as P)	170	194	263
Alkalinity (mg/L)	150	148	155

Data above is averaged over the upper 6 feet.

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

Parameter	6/04/1990	7/09/1990	8/07/1990
Secchi Depth (m)	1.4	0.3	0.4
Chlorophyll (ug/L)	38.7	231.9	86.2
Total Nitrogen (mg/L as N)	2.5	3.0	2.3
Total Phosphorus (ug/l as P)	185.3	451	470.6
Total Suspended Solids (mg/L)	12.2	80.9	37.4
Inorganic Suspended Solids (mg/L)	9.9	7.0	16.7

Data above is for surface depth.

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

Parameter	6/22/2000	7/19/2000	8/09/2000
Secchi Depth (m)	0.1	0.1	0.1
Chlorophyll (ug/L)	544	241	35
NH_3+NH_4^+ -N (ug/L)	4	3388	2784
NH_3 –N (un-ionized) (ug/L)	1	846	811
NO_3+NO_2-N (mg/L)	0.05	0.36	0.08
Total Nitrogen (mg/L as N)	1.98	2.66	2.30
Total Phosphorus (ug/l as P)	975	721	558
Silica (mg/L as SiO_2)	166	97	74
pH	8.7	8.8	8.8
Alkalinity (mg/L)	137	114	116
Total Suspended Solids (mg/L)	87.1	36.7	111.3
Inorganic Suspended Solids (mg/L)	24.3	10.0	81.2
Volatile Suspended Solids (mg/L)	62.9	26.7	30.0

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

Parameter	5/24/2001	6/20/2001	7/25/2001
Secchi Depth (m)	0.1	0.2	0.3
Chlorophyll (ug/L)	177	696	242
NH_3+NH_4^+ -N (ug/L)	2152	4895	1593
NH_3 –N (un-ionized) (ug/L)	416	1371	1037
NO_3+NO_2-N (mg/L)	0.64	0.76	0.23
Total Nitrogen (mg/L as N)	3.63	3.52	2.41
Total Phosphorus (ug/l as P)	414	736	456
Silica (mg/L as SiO_2)	33	39	26
pH	9.0	8.9	9.5
Alkalinity (mg/L)	110	110	98
Total Suspended Solids (mg/L)	135.2	268.0	25.4
Inorganic Suspended Solids (mg/L)	69.5	180.0	17.7
Volatile Suspended Solids (mg/L)	65.7	88.0	7.7

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

Parameter	**5/30/2002**	**6/26/2002**	**7/31/2002**
Secchi Depth (m)	0.2	0.2	0.2
Chlorophyll (ug/L)	76	72	97
$NH_3+NH_4^+$ -N (ug/L)	398	496	315
NH_3 –N (un-ionized) (ug/L)	248	379	208
NO_3+NO_2-N (mg/L)	0.14	0.11	0.12
Total Nitrogen (mg/L as N)	2.08	1.19	1.78
Total Phosphorus (ug/l as P)	276	343	363
Silica (mg/L as SiO_2)	3	8	7
pH	9.6	9.7	9.4
Alkalinity (mg/L)	102	98	111
Total Suspended Solids (mg/L)	96.0	77.4	96.0
Inorganic Suspended Solids (mg/L)	49.0	21.7	50.7
Volatile Suspended Solids (mg/L)	47.0	55.7	45.3

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

Parameter	**5/30/2003**	**6/26/2003**	**7/31/2003**
Secchi Depth (m)	0.3	0.2	0.4
Chlorophyll (ug/L)	22.1	24.9	29.7
$NH_3+NH_4^+$ -N (ug/L)	275	733	212
NH_3 –N (un-ionized) (ug/L)	177	279	159
NO_3+NO_2-N (mg/L)	0.34	<0.07	0.13
Total Nitrogen (mg/L as N)	2.17	2.28	1.86
Total Phosphorus (ug/l as P)	223	418	232
Silica (mg/L as SiO_2)	3.66	6.98	5.49
pH	9.7	9.1	9.7
Alkalinity (mg/L)	76	61	70
Total Suspended Solids (mg/L)	68	104	42
Inorganic Suspended Solids (mg/L)	15	70	18
Volatile Suspended Solids (mg/L)	52	34	24

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

	6/22/2000	7/19/2000	8/9/2000
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Cyanophyta	6.1E+03	3.0E+02	2.9E+02
Cryptophyta	0.0E+00	0.0E+00	0.0E+00
Chlorophyta	0.0E+00	0.0E+00	0.0E+00
Dinophyta	0.0E+00	0.0E+00	0.0E+00
Chrysophyta	0.0E+00	0.0E+00	2.3E-01
Euglenophyta	0.0E+00	0.0E+00	0.0E+00
Total	**6.1E+03**	**3.0E+02**	**2.9E+02**

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

	5/24/2001	6/20/2001	7/25/2001
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Chlorophyta	3.90E-02	1.60E-02	0.00E+00
Chrysophyta	5.16E+00	1.43E+00	0.00E+00
Cryptophyta	0.00E+00	0.00E+00	0.00E+00
Cyanobacteria	5.67E+02	1.99E+02	4.59E+02
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Total	5.72E+02	2.00E+02	4.59E+02

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:

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

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

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

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

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

SD = lake Secchi depth, meters

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

Table C-1. Changes in temperate lake attributes according to trophic state (modified from 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.

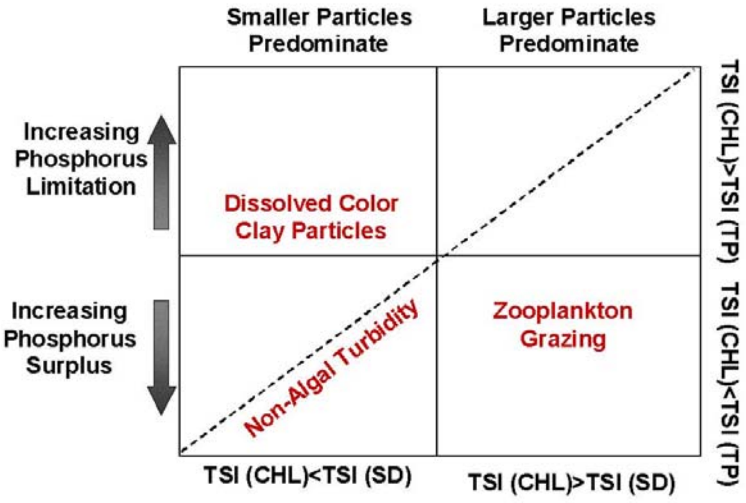
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 → 65	*12 → 33*	*1.4 → 0.7*
partially supported (evaluated: in need of further investigation)	65 → 70	*33 → 55*	*0.7 → 0.5*
partially supported (monitored: candidates for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



Swan Lake TSI Values

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/11/1979	70	67	78
8/2/1979	70	72	80
8/30/1979	70		85

Table C-5. 1990 Swan TSI Values (Bachmann)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/4/1990	55	66	80
7/9/1990	77	84	91
8/7/1990	73	75	93

Table C-6. 2000 - 2003 Swan TSI Values (Downing and Ramstack)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/22/2000	93	92	103
7/19/2000	93	84	99
8/9/2000	93	65	95
5/24/2001	93	81	91
6/20/2001	83	95	99
7/25/2001	77	84	92
5/30/2002	83	73	85
6/26/2002	83	73	88
7/31/2002	83	75	89
5/30/2003	77	61	82
6/26/2003	83	62	91
7/31/2003	73	64	83

11. Appendix D - Land Use Maps

Figure D-1. Swan Lake Watershed 2002 Landuse

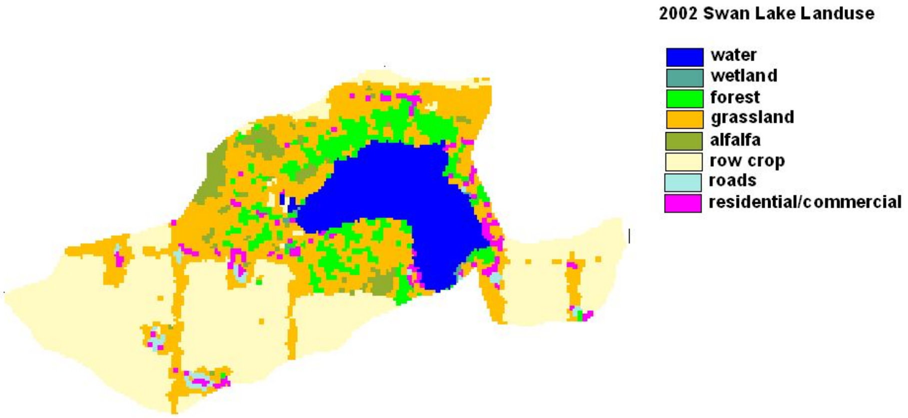
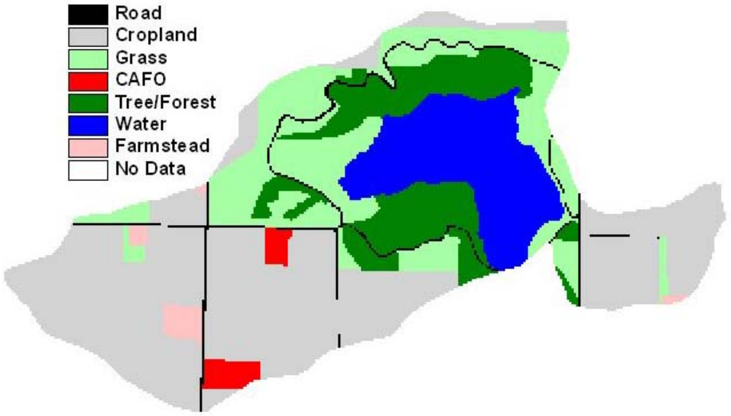


Figure D-2. Swan Lake Watershed 2004 Site Assessment



12. Appendix E - Swan Lake Loading Relationships

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

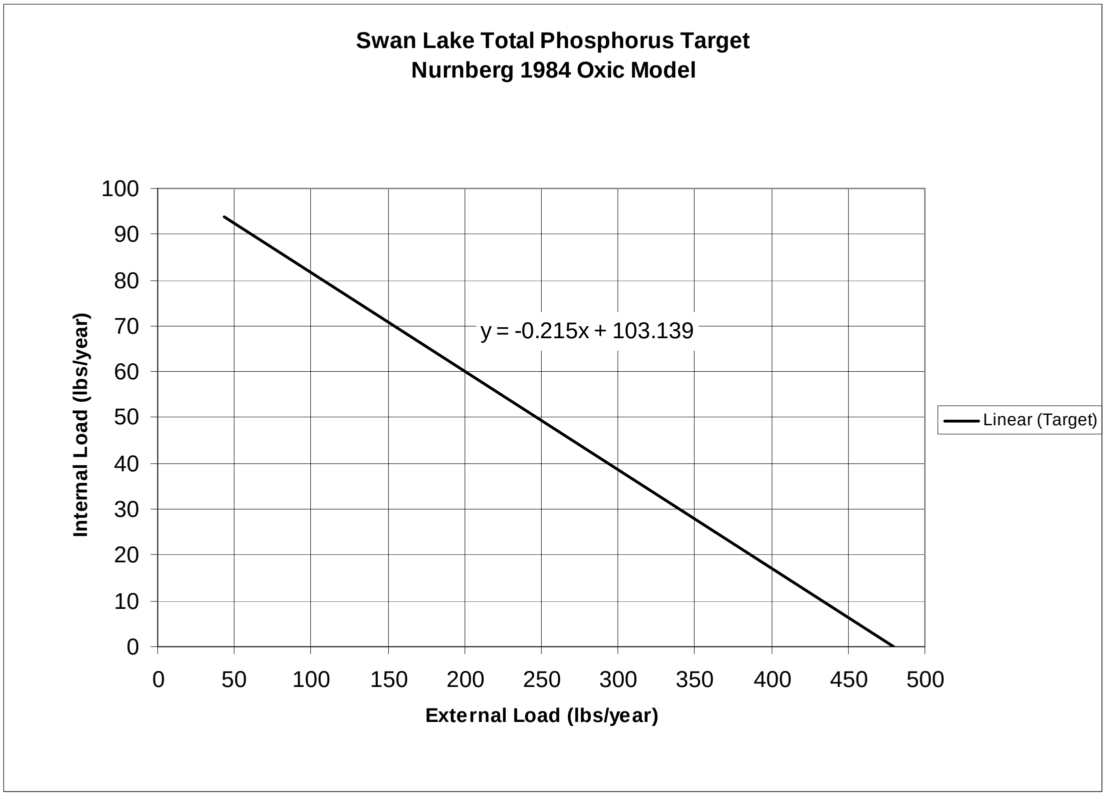


Figure E-2. Swan Lake Target Total Load vs. Internal & External Loads

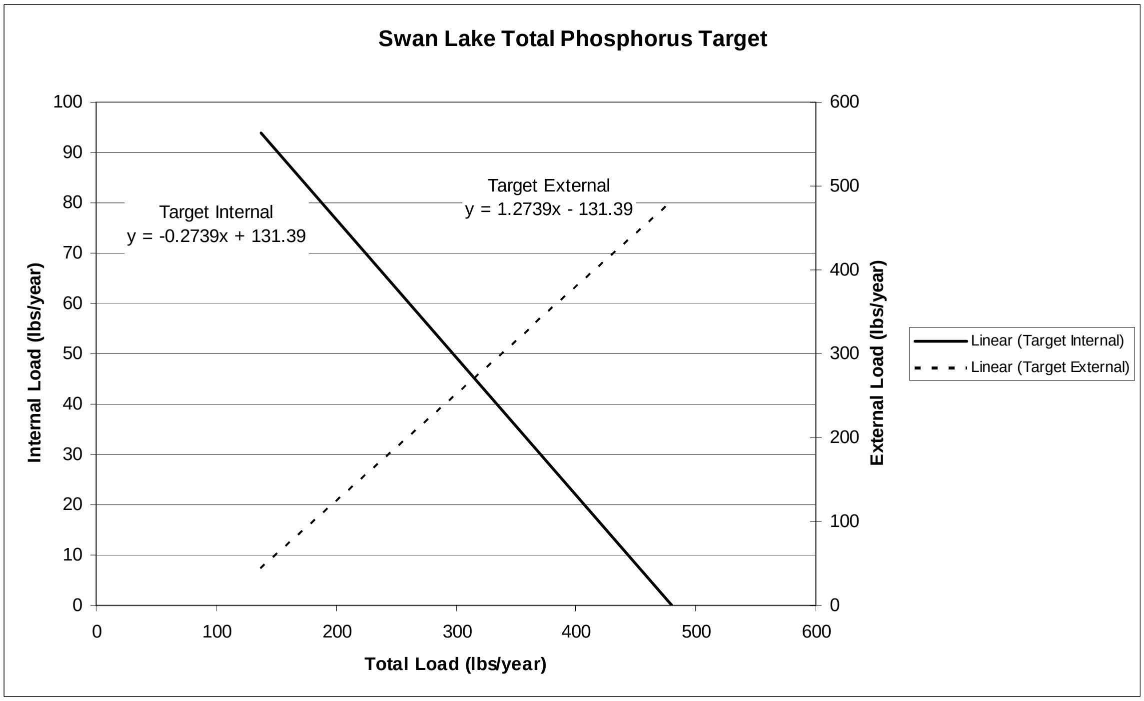


Figure E-3. Swan Lake Load Reduction vs. Internal & External Loads