Total Maximum Daily Load
For Turbidity and Nutrients
Williamson Pond
Lucas County, Iowa

2005

Iowa Department of Natural Resources
Watershed Improvement Section

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1. Executive Summary

Table 1. Williamson Pond Summary

Waterbody Name:	Williamson Pond
County:	Lucas
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Des Moines River Basin
Pollutant:	Turbidity
Pollutant Sources:	Nonpoint
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Low
Watershed Area:	1,474 acres
Lake Area:	26 acres
Lake Volume:	237 acre-ft
Detention Time:	0.2 years
Transparency Target:	Secchi Depth of more than 0.7 meters for turbidity
Existing Total Suspended Solids Load:	1,765 tons of sediment per year
Load Capacity	388 tons of sediment per year
Load Reduction to Achieve TMDL:	1,377 tons of sediment per year
Load Allocation:	349 tons of sediment per year
Wasteload Allocation:	0
Margin of Safety	39 tons of sediment per year
Total Phosphorous Target:	TSI of 70 = 804 pounds per year
Existing Phosphorous Load:	2,282 pounds per year
Load Capacity:	804 pounds per year
Load Reduction to achieve TMDL:	1,478 pounds per year (65% reduction)
Load Allocation:	724 pounds per year
Wasteload Allocation:	0
Margin of Safety:	80 pounds per year

The Federal Clean Water Act requires the Iowa Department of Natural Resources (IDNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's 303(d) list as impaired by a pollutant. Williamson Pond has been identified as impaired by turbidity. The purpose of this TMDL for Williamson Pond is to calculate the maximum allowable suspended sediment loading for the lake associated with turbidity levels that will meet water quality standards. In addition, a phosphorous target has been developed to minimize algal blooms as water transparency increases.

This document consists of a TMDL for turbidity designed to provide Williamson Pond with water quality that fully supports its designated uses. Suspended sediment and phosphorous, which are related through the Trophic State Index (TSI) to Secchi depth, is targeted to address the turbidity impairment.

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

Section 5.0 of this TMDL includes a description of planned monitoring. The TMDL will have two phases. Phase 1 will consist of setting specific and quantifiable targets for suspended sediment, phosphorous 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:** Williamson Pond, S25, T73N, R21W, 2 miles east of Williamson, Lucas County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutant causing the water quality impairment is turbidity. Designated uses for Williamson Pond are Primary Contact Recreation (Class A1) and Aquatic Life (Class B(LW)). Excess turbidity has impaired aesthetic and aquatic life water quality standards (8) 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 Secchi depth of 0.7 m, equivalent to 388 tons of total suspended solids. A second target for total phosphorous has been set at a TSI of 70, which is equivalent to a load of 804 pounds per year.

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 value for Secchi depth based on 2000-2004 sampling in 0.5 meters. The existing sediment load is 1,765 tons per year. In order to increase Secchi depth (transparency) to the target 0.7 meters, the sediment load must be decreased by 1,377 tons per year. The existing mean total phosphorous concentration in Williamson Pond is 241 ug/L. To achieve the total phosphorous target, a reduction of 1,478 pounds per year (65%) is needed.

5. **Identification of pollution source categories:** Sediment and nutrients (phosphorous) from nonpoint sources and internal recycling has been identified as causing the turbidity impairment.

6. **Wasteload allocations for pollutants from point sources:** No point sources have been identified in the Williamson Pond watershed. Therefore, the wasteload allocation for sediment and phosphorous are set at zero.

7. **Load allocations for pollutants from nonpoint sources:** Transparency as measured by Secchi depth is a function of non-algal and algal components. The load allocation for sediment is set at 349 tons to meet the transparency target of 0.7 meters Secchi depth. The phosphorous load allocation for Williamson Pond is set at 724 lbs/year.

8. **A margin of safety:** The Margin of Safety (MOS) for this TMDL is an explicit numerical MOS of 39 tons of sediment per year (10% of the calculated allowable sediment load) and has been included to ensure that the required load reduction will result in attainment of water quality targets. In addition, an explicit MOS has been calculated for the phosphorous load at 80 pounds per year (10% of the calculated allowable phosphorous load).

9. **Consideration of seasonal variation:** This TMDL was developed based on transparency that will result in attainment of targets on an average annual basis.

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for increased sediment and nutrient loading was not included in this TMDL. Significant changes in the Williamson Pond watershed landuse are unlikely. Future increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and nutrients. Because such events cannot be predicted or quantified at this time, a future 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. Williamson Pond, Description and History

2.1 The Lake

Williamson Pond is located 2 miles east of Williamson pond in south central Iowa. Williamson Pond was constructed in 1913 by the Chicago, Rock Island and Pacific Railroad as a source of water for steam locomotives. The pond was used as a source of water for the stream locomotives until diesel locomotives were present in the 1950's. At this time, the State of Iowa assumed the lake and managed it until the early 1990's. Williamson Pond has a surface area of 20 acres and is managed for water-based recreation and fishing.

Williamson Park is now managed by the Lucas County Conservation Board. Bachmann (2) reported annual lake and park use at approximately 3000 visits. Visitor use is focused on fishing, boating, hunting, and picnicking or other passive uses. Although the lake is designated for contact recreation, there is no beach or swimming facilities and no reported swimming use at Williamson Pond.

Table 3. Williamson Pond Features

Waterbody Name:	Williamson Pond
Hydrologic Unit Code:	HUC10 0710000901
IDNR Waterbody ID:	IA 04-LDM-01995-L
Location:	Section 25 T73N R21W
Latitude:	41° 5' N
Longitude:	93° 13' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	English Creek
Receiving Waterbody:	English Creek
Lake Surface Area:	26 acres
Maximum Depth:	18 feet
Mean Depth:	8 feet
Volume:	237 acre-feet
Length of Shoreline:	8,189 feet
Watershed Area:	1,474 acres
Watershed/Lake Area Ratio:	57:1
Estimated Detention Time:	0.2 years

Morphometry

Williamson Pond has a mean depth of 8 feet and a maximum depth of 18 feet. The lake has a surface area of 26 acres and a storage volume of approximately 237 acre-feet. Temperature and dissolved oxygen sampling indicate that temperature and oxygen levels in Williamson Pond decrease with increased depth through much of the growing season.

Hydrology

Williamson Pond is fed by the headwaters of English Creek, and discharges into English Creek, a tributary of the Des Moines River. The estimated annual average detention time for Williamson Pond is 0.2 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

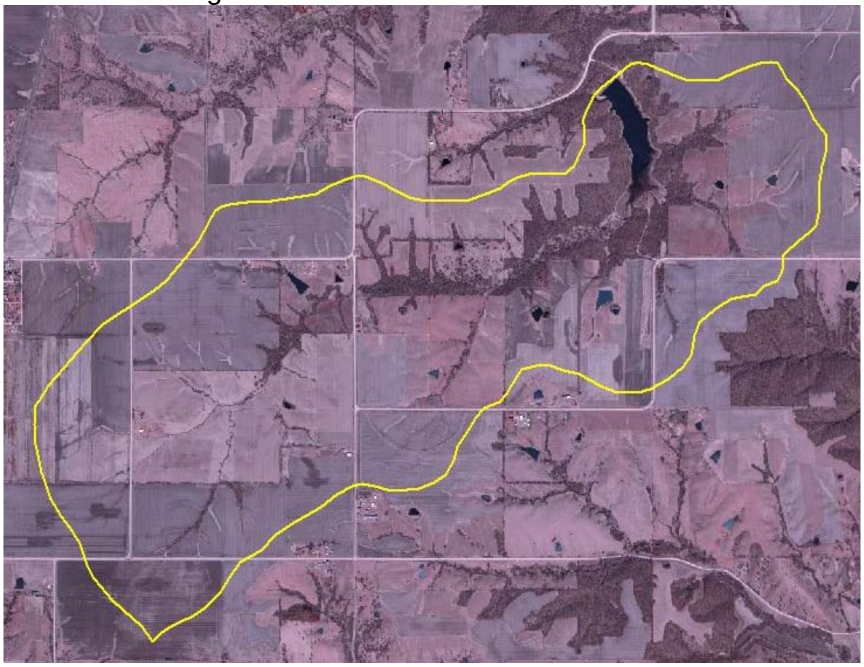
The watershed of Williamson Pond has an area of 1,474 acres, which results in a large watershed to lake area ratio of approximately 57:1. The 2005 landuses and associated areas for the watershed were obtained from a field level assessment and are shown in Table 4.

Table 4. 2005 Landuse in Williamson Pond watershed.

Landuse	**Area in Acres**	**Percent of Total Area**
Row Crop	630	43
Pasture,Grass, CRP	645	44
Forest	165	11
Residential, Roads,Other	34	2
Total	1,473	100

The watershed is predominately nearly level to strongly sloping (0-14%) with some moderately steep (2-18%) areas. Soils are developed from loess, pre-Wisconsin till, or pre-Wisconsin till-derived paleosols. Native vegetation was typically prairie grasses with some forested areas. Typical soils include Grundy, Haig, Shelby, and Adair.

Figure 1. Williamson Pond Watershed



3. TMDL for Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (8) list the designated uses for Williamson Pond as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). In 1998, Williamson Pond was included on the impaired water list due to turbidity and organic enrichment. In 2002, the organic enrichment listing was removed, but the turbidity impairment remained on the list.

The State of Iowa does not have numeric water quality criteria for turbidity that apply to Williamson Pond. Williamson Pond was assessed for the 2000 and 2002 305(b) report as partially supporting due to poor water clarity impairing the primary contact uses. This is a violation of the narrative water quality standards stating that waters shall be free from aesthetically objectionable conditions (8). The aesthetically objectionable conditions present at Williamson Pond are impairing the Class A use for primary contact recreation.

Impairments at Williamson Pond to the Class A1 (primary contact) use is due to reductions in water clarity caused primarily by moderately high levels of inorganic turbidity caused by suspended solids. 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 Williamson Pond in 1979, 1990, 2000, and 2002-04 (1, 2, 3, 4, 5, 6). Data from these surveys is available in Appendix B.

Iowa State University Lake Study data from 2000 to 2004 were evaluated for this TMDL. This study approximates a sampling scheme used by Roger Bachman in earlier Iowa lake studies. Samples were 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.

In addition to these more recent water quality surveys, studies were also conducted on Williamson Pond in 1979 and 1990, (1; 2).

Data collected in 1979 as part of Iowa’s lake classification survey identified Williamson Pond as a eutrophic lake. The mean total phosphorous concentration was 55.5 µg/L (n=8), mean total Kjeldahl nitrogen was 0.6 mg/L (n=2), and mean Secchi disk depth was 0.8 m (n=5).

From the Classification of Iowa’s Lakes for Restoration in 1994, data collected in 1990 indicated that Williamson Pond was still a eutrophic lake. The mean total phosphorous concentration was 386 µg/L (n=9), mean total nitrogen was 3.7 mg/L (n=9) and mean Secchi disk depth was 0.1 m (n=3).

Interpreting Williamson Pond Water Quality Data

Based on mean values from ISU sampling during 2000 - 2004, the inorganic suspended solids is 11.3 mg/L, the phosphorus level is 241 ug/L, the chlorophyll level is 33 ug/L, and the Secchi disk depth is 0.5 meters. Data on inorganic suspended solids from the ISU sampling suggest that this lake may be subject to high levels of non-algal turbidity.

Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for 2000 - 2004 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 - 2004 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. Williamson Pond TSI Values (3,4,5,6)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/29/2000	78	39	93
7/26/2000	67	61	93
8/24/2000	66	45	89
6/5/2002	72	47	78
7/10/2002	67	70	74
8/7/2002	69	61	79
6/4/2003	43	41	67
7/9/2003	74		84
8/7/2003	73	65	85
6/2/2004	79	61	80
6/30/2004	61	69	70
8/4/2004	67	63	79

Figure 2. Williamson Pond 2000 - 2004 Mean TSI Multivariate Comparison Plot (7).

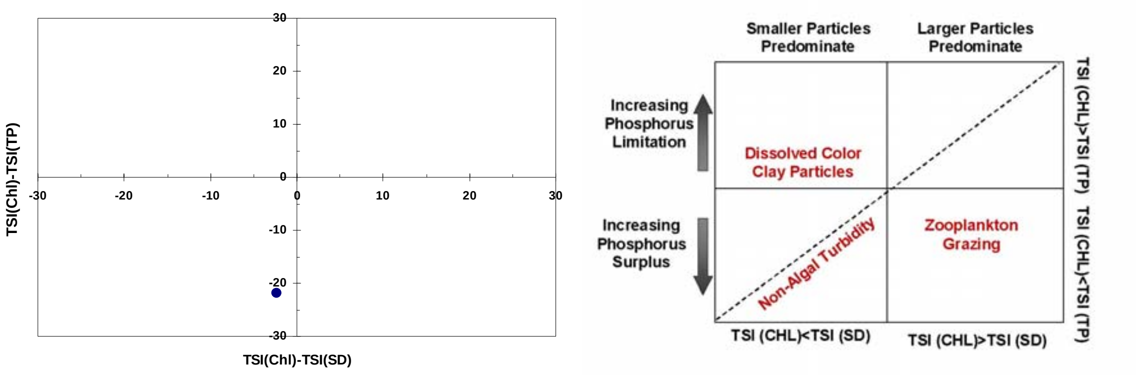


Figure 2 is a multivariate plot of mean TSI values. The blue dot on the left-hand graphic shows the relationship between TSI (SD), TSI (CHL), and TSI (TP) for Williamson Pond on the graph area. The lower left-hand quadrant on the graph area indicates that the water column is dominated by smaller particles and is not limiting in phosphorus. Also, being below the diagonal line from the lower left to the upper right indicates the water body is impaired by non-algal turbidity based on TSI values. A more complete discussion of this multivariate comparison plot and TSI interpretation can be found in Appendix C.

Data on the zooplankton community (13, 14) show that the zooplankton community at Williamson Pond has a large population of species known as algal grazers, thus reducing algal levels at this lake. Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) dominate the summertime phytoplankton community of Williamson Pond. 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 (62.7 mg/l) was in the upper quartile of 131 lakes sampled.

Potential Pollution Sources

There are no point sources of pollution in the Williamson Pond watershed. Turbidity is caused by the addition of sediment from the watershed and resuspension of sediment from the lake bottom. These sediments also contain attached phosphorus which contribute to the high phosphorus levels in the water and resulting algal production.

Natural Background Conditions

Background levels of sediment and nutrients were not separated from nonpoint sources.

3.2 TMDL Target

The Phase 1 target for this TMDL is an average water transparency level measured by Secchi depth greater than 0.7 meters. This target is equivalent to a TSI value of 65 which is the minimum depth considered to be fully supporting/threatened for the Section 305(b) use support category. In addition, a TSI target of 70 will be established for total phosphorous. This will help reduce algal impacts that may occur as light penetration is increased.

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for turbidity. Sediment and nutrients delivered from the watershed or resuspended from within the lake are causing increased turbidity, and may cause increased algal blooms. The transparency objective is defined by a mean Secchi depth of 0.7 meters, and the total phosphorous objective is a TSI of 70.

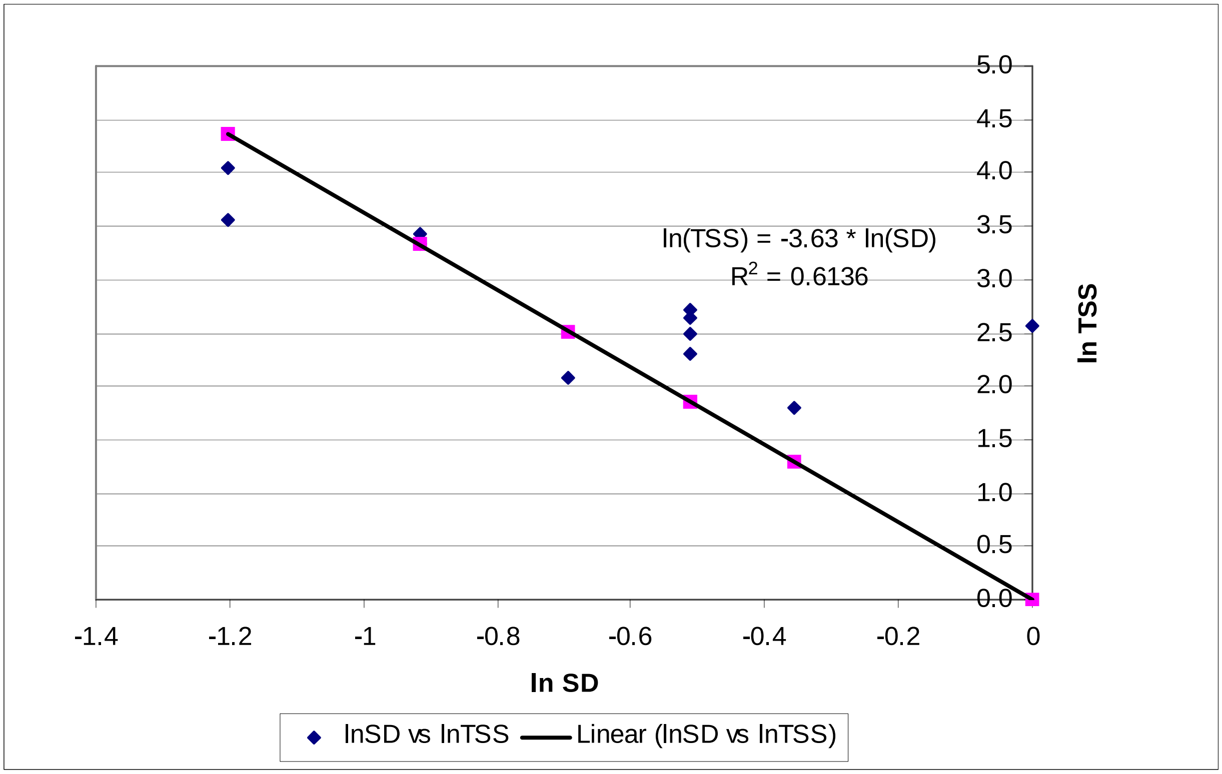
Selection of Environmental Conditions

The critical condition for the TMDL target transparency applies to the annual average transparency value. The existing and target values of Secchi depth are expressed as annual averages. Growing season mean (GSM) in-lake total phosphorus concentrations are used to calculate an annual average total phosphorus loading.

Waterbody Pollutant Loading Capacity

Excessive levels of total suspended solids (TSS) is causing high levels of turbidity. The loading capacity of the lake is determined by a Secchi depth TSI of 65, equivalent to a Secchi depth of 0.7 meters. The relationship between total suspended solids and transparency is shown in Figure 3.

Figure 3. Natural log transformed relationship between total suspended solids (TSS) and Secchi depth (SD).



Using the relationship between Secchi depth and TSS from Figure 3, the target total suspended solids (TSS) concentration is calculated as:

ln(TSS) = -3.63*ln(SD)
ln(TSS) = -3.63*ln(0.7)
ln(TSS) = 1.295
TSS = 3.6 mg/L

To achieve the desired secchi depth target of 0.7 meters, the in-lake total suspended solids value should be 3.6 mg/L. The current mean total suspended solids value is 16.6 mg/L. This is equivalent to a 78% reduction.

Sediment delivery to Williamson Pond was calculated using RUSLE and land uses derived from the 2002 CIR photography. Gross sheet and rill erosion in the Williamson Pond watershed is estimated at 6,930 tons/year. From this, the estimated current sediment delivery to Williamson Pond is 1,765 tons/year.

Assuming a direct relationship between the TSS concentration in Williamson Pond and sediment delivery to the lake, a 78% reduction is needed in sediment delivery to the lake. This results in a sediment loading capacity of 388 tons/year.

To achieve a lake phosphorous TSI of 70, the phosphorous loading capacity of Williamson Pond was determined to be 804 lbs/year based on the Vollenweider 1982 Shallow Lake and Reservoir model (Appendix F).

3.3 Pollution Source Assessment

Existing Load

Turbidity levels in Williamson Pond are created by a current estimated sediment load of 1,765 tons/year delivered to or resuspended in the lake. This current sediment delivery was determined using RUSLE and 2002 landuses (Appendix E).

The current phosphorous load was determined using the Vollenweider 1982 Shallow Lake and Reservoir model. This model estimated current phosphorous delivery at 2,282 lbs./yr.

Departure from Load Capacity

The non-algal turbidity load capacity is 388 tons of sediment. The existing non-algal turbidity load is 1,765 tons resulting in a departure from load capacity of 1377 tons of sediment. The phosphorous loading capacity is 804 lbs./yr. The current phosphorous load is 2,282 lbs/yr, resulting in a departure from the loading capacity of 1,478 lbs.

Identification of Pollutant Sources

There are no point sources of pollution in Williamson Pond watershed. Therefore, all the non-algal turbidity is attributed to non-point sources.

Linkage of Sources to Target

The load capacity of Williamson Pond is 388 tons of sediment per year. The current sediment load is 1,765 tons per year. The total phosphorous load capacity is 804 lbs. per year. These loads originate from nonpoint sources in the watershed and internal lake resuspension.

3.4 Pollutant Allocation

Wasteload Allocation

There are no known point sources of pollution in the watershed. Therefore, the wasteload allocations for sediment and phosphorous are set at zero.

Load Allocation

The load allocation for turbidity is 349 tons of sediment in the lake allocated to nonpoint sources, and lake resuspension. A load allocation for phosphorous is set at 724 lbs. per year.

Margin of Safety

An explicit margin of safety for non-algal turbidity is set at 10% of the load capacity, or 39 tons sediment (388 tons x 10%) and 80 lbs. of phosphorous (804 lbs. x 10%).

TMDL Summary

Sediment:
TMDL = WLA + LA + MOS
= 0 + 349 tons/yr + 39 tons/yr
= 388 tons/yr
Phosphorous:
TMDL = WLA + LA + MOS
= 0 + 724 lbs/yr + 80 lbs/yr
= 804 lbs/yr

4. Implementation Plan

The Iowa Department of Natural Resources recognizes that an implementation plan is not a required component of a Total Maximum Daily Load. However, the IDNR offers the following implementation strategy to DNR staff, partners, and watershed stakeholders as a guide to improving water quality at Williamson Pond. Comments received at the public meeting to discuss the draft TMDL identified that there were areas of significant gully erosion within the watershed. To address these concerns and to better understand the current sources within the Williamson Pond watershed two assessments will be completed. The first is a detailed field level watershed assessment to identify current needs and potential sites for best management practice implementation. This assessment should include an analysis of the trapping efficiencies of the numerous existing ponds and grade stabilization structures located in the watershed.

The second assessment includes development of a forestry management plan for the public lands in the Williamson Pond watershed by the IDNR Forestry Bureau. This plan will identify management objectives for the forestry resource and also identify currently contributing areas of sediment and phosphorous within the forested portion of the watershed.

If the entire sediment load were attributed to watershed sources, the estimated loading from watershed sources would need to be reduced from 1.2 tons/acre/year to about 0.24 tons/acre/year to meet the TMDL target. Similarly, if the entire phosphorous load is attributed to the watershed, the estimated watershed loading would need to be reduced from 1.5 lbs/acre/year to 0.5 lbs/acre/year. However, this does not account for the in-lake resuspension or shoreline erosion.

Among the mechanisms of resuspension are bottom feeding rough fish such as carp, and wind-driven waves and currents.

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

- By 2010, reduce watershed and resuspension loading:
    1. for sediment from 1,765 tons per year to 1,400 tons per year.
    2. for phosphorous from 2282 pounds per year to 1500 pounds per year.
- By 2015, reduce watershed and resuspension loading:
    1. for sediment from 1,400 tons per year to 900 tons per year.
    2. for phosphorous from 1500 pounds per year to 1000 pounds per year.
- By 2020, reduce watershed and resuspension loading:
    1. for sediment from 900 tons per year to 349 tons per year.
    2. for phosphorous from 1000 pounds per year to 724 pounds per year.

To reduce the amount of non-algal turbidity from being delivered to, or being resuspended in the lake, the following management suggestions are presented:

- Remove the common carp from the lake.
- Install additional buffer strips and filterstrips along the streams and channels in the watershed to filter runoff and reduce the amount of sediment delivered to Williamson Pond.
- Construct ponds, terraces and erosion control structures in the watershed to reduce soil erosion, trap sediment, and lower peak runoff rates.
- Adopt continuous no till to increase the amount of infiltration, reducing runoff and erosion.
- Outlet terrace underground outlets into artificial wetlands or detention basins to reduce the amount of fine sediments being delivered directly into the streams.

Water quality monitoring indicates a high concentration of phosphorus in the water column. Most of this phosphorus may be attached to suspended sediment particles. However, if significant dissolved phosphorus remains in the water column after water transparency improves, this may result in a rapid increase in algal production. To reduce the amount of total phosphorus from being delivered to, or being re-suspended in the lake, all of the suggestions listed above apply. In addition, specific phosphorus management suggestions include:

- Practice nutrient best management practices. Specifically, manage for the optimum soil test category for phosphorus and inject or incorporate phosphorus fertilizers and manure.
- Dredge the lake to remove phosphorus-containing sediments.
- Increase the average depth of the lake so that it more completely stratifies. A deep lake that stratifies will "turn over" only twice per year resulting in a well-mixed conditions. Shallow lakes are continually well-mixed leading to higher phosphorus amounts in the water column.

5. Monitoring

Further monitoring is needed at Williamson Pond 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. Williamson Pond 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, the Department is continuing a lake monitoring program.

Current measurements of gully, shoreline, streambed, and stream bank erosion need to be obtained. The IDNR will work with local NRCS and DSC staff to collect this data to verify and improve the implementation of this TMDL. A forestry management plan will be completed by the IDNR Forestry Bureau in cooperation with the Lucas County Conservation Board. This plan will not only identify forestry management priorities, but identify currently eroding areas within the forested portion of the watershed, such as active gully erosion. In addition, lake water chemistry and sediment particle size analyses should be completed to better understand why the sediments remain suspended and determine how these suspended particles can flocculate and settle.

6. Public Participation

A public meeting was held at the Pin Oak Nature Center on May 16, 2005 to discuss the water quality at Williamson Pond and the TMDL process. A second public meeting was held on October 27, 2005 at the Pin Oak Nature Center in Chariton to present and discuss the draft TMDL. Comments received were reviewed and given consideration and, where appropriate, incorporated into the development of the TMDL.

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

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

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

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

Data

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

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

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

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

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

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

Methods

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

Equation Variables

Table A-2. Regression Equation Variables

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

Equations

Table A-3. Drainage Area Only Equations

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

Table A-4. Multiple Regression Equations

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

General Application

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

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

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

Application to Williamson Pond – Calculations

Table A-5. Williamson Pond Hydrology Calculations

Lake	Williamson Pond	
Type	Impoundment	
Inlet(s)	English Creek	
Outlet(s)	English Creek	
Volume	237	acre-feet
Surface Area	26	acres
Drainage Area	1474	acres
Mean Annual Precipitation	35.4	inches
Average Basin Slope	4.1	%
% Forest (2000 Land Cover)	12.8	
% Corn (2000 Land Cover)	24.8	
% Rowcrop (2002 Land Cover)	42.8	
Mean Annual Class A Pan Evaporation	50	inches
Mean Annual Class A Pan Evaporation	50	inches
Mean Annual Lake Evaporation	6067.2	inches
Annual Average Inflow	4395349	acre-feet/year
Direct Precipitation on Lake Surface	9085	acre-feet/year
Est. Annual Det. Time (Inflow + Precip)	23.29	year
Est. Annual Det. Time (Outflow)	0.13	year

9. Appendix B - Sampling Data

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

Parameter	**7/19/1979**	**8/21/1979**	**9/27/1979**
Secchi Depth (m)	0.7	1.2	0.6
Total Kjeldahl Nitrogen (mg/L as N)	-	-	0.63
NO_3+NO_2-N (mg/L)	-	-	0.1
Total Phosphate (mg/l as PO4)	0.375	0.16	0.17
Alkalinity (mg/L)	90	102	106

Data above is averaged over the upper 6 feet.

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

Parameter	**6/8/1990**	**7/7/1990**	**8/5/1990**
Secchi Depth (m)	.01	0.05	0.05
Chlorophyll (ug/L)	2.2	2.7	4.1
Total Nitrogen (mg/L as N)	4.6	4.0	2.5
Total Phosphorus (ug/l as P)	283.7	494	381
Total Suspended Solids (mg/L)	158.3	180.1	133.3
Inorganic Suspended Solids (mg/L)	154.5	120.1	106.9

Data above is for surface depth.

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

Parameter	**6/29/2000**	**7/26/2000**	**8/24/2000**
Secchi Depth (m)	0.3	0.6	0.7
Chlorophyll (ug/L)	2.5	22.9	4.2
NO_3+NO_2-N (mg/L)	0.44	0.14	0.18
Total Nitrogen (mg/L as N)	3.72	1.45	1.61
Total Phosphorus (ug/l as P)	474	491	366
Silica (mg/L as SiO_2)			
pH	6.8	7.8	7.2
Alkalinity (mg/L)	121	173	87
Total Suspended Solids (mg/L)	35	10	6
Inorganic Suspended Solids (mg/L)	30	5	3
Volatile Suspended Solids (mg/L)	4	5	3

Table B-4. Data collected in 2002 by Iowa State University (4)

Parameter	**6/5/2002**	**7/10/2002**	**8/7/2002**
Secchi Depth (m)	0.5	0.6	0.6
Chlorophyll (ug/L)	5.2	56.4	23.4
NO_3+NO_2-N (mg/L)	3.51	0.13	0.11
Total Nitrogen (mg/L as N)	4.33	1.01	1.37
Total Phosphorus (ug/l as P)	175	125	186
Silica (mg/L as SiO_2)	7.65	2.82	5.20
pH	7.7	8.9	8.3
Alkalinity (mg/L)	99	88	95
Total Suspended Solids (mg/L)	8	12	14
Inorganic Suspended Solids (mg/L)	4	2	5
Volatile Suspended Solids (mg/L)	4	11	9

Table B-5. Data collected in 2003 by Iowa State University (5)

Parameter	**6/4/2003**	**7/9/2003**	**8/7/2003**
Secchi Depth (m)	3.3	0.4	0.4
Chlorophyll (ug/L)	3.0	-	33.6
NH_3+NH_4^+ -N (ug/L)	566	267	315
NH_3 –N (un-ionized) (ug/L)	20	96	23
NO_3+NO_2-N (mg/L)	0.66	0.14	0.11
Total Nitrogen (mg/L as N)	1.94	1.76	1.88
Total Phosphorus (ug/l as P)	80	251	274
Silica (mg/L as SiO_2)	3.38	5.12	8.50
pH	8.0	8.9	8.1
Alkalinity (mg/L)	86	67	83
Total Suspended Solids (mg/L)	7	31	28
Inorganic Suspended Solids (mg/L)	5	6	16
Volatile Suspended Solids (mg/L)	3	24	12

Table B-6. Data collected in 2004 by Iowa State University (6)

Parameter	**6/2/2004**	**6/30/2004**	**8/4/2004**
Secchi Depth (m)	0.3	1.0	0.6
Chlorophyll (ug/L)	22.8	48.9	28.6
NH_3+NH_4^+ -N (ug/L)	229	79	306
NH_3 –N (un-ionized) (ug/L)	10	33	16
NO_3+NO_2-N (mg/L)	4.16	1.02	0.11
Total Nitrogen (mg/L as N)	5.66	2.42	1.69
Total Phosphorus (ug/l as P)	198	97	175
Silica (mg/L as SiO_2)	15.58	5.76	3.02
pH	8.1	9.1	7.9
Alkalinity (mg/L)	85	105	104
Total Suspended Solids (mg/L)	57	13	15
Inorganic Suspended Solids (mg/L)	46	6	8
Volatile Suspended Solids (mg/L)	11	7	7

Table B-7. 2000-2004 Phytoplankton Data (3)

	2000	2001	2002	2003	2004
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	0.220	-	0.385	0.003	2.961
Chlorophyta	1.261	-	3.999	0.015	0.438
Cryptophyta	0.315	-	1.296	0.095	1.763
Cyanophyta	58.882	-	247.235	278.614	70.461
Dinophyta	2.016	-	3.526	0.039	0.000
Euglenophyta	0.038	-	0.177	0.017	0.076
Total	**62.732**	**-**	**256.618**	**278.783**	**75.700**

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 (7, 11).

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.

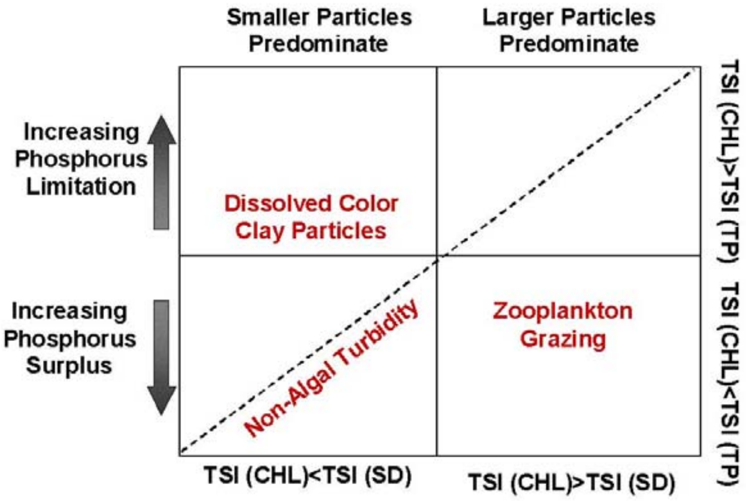
Level of Support	**TSI value**	**Chlorophyll-a (ug/l)**	**Secchi Depth (m)**
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 → 65	*12 → 33*	*1.4 → 0.7*
partially supported (evaluated: in need of further investigation)	65 → 70	*33 → 55*	*0.7 → 0.5*
partially supported (monitored: candidates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

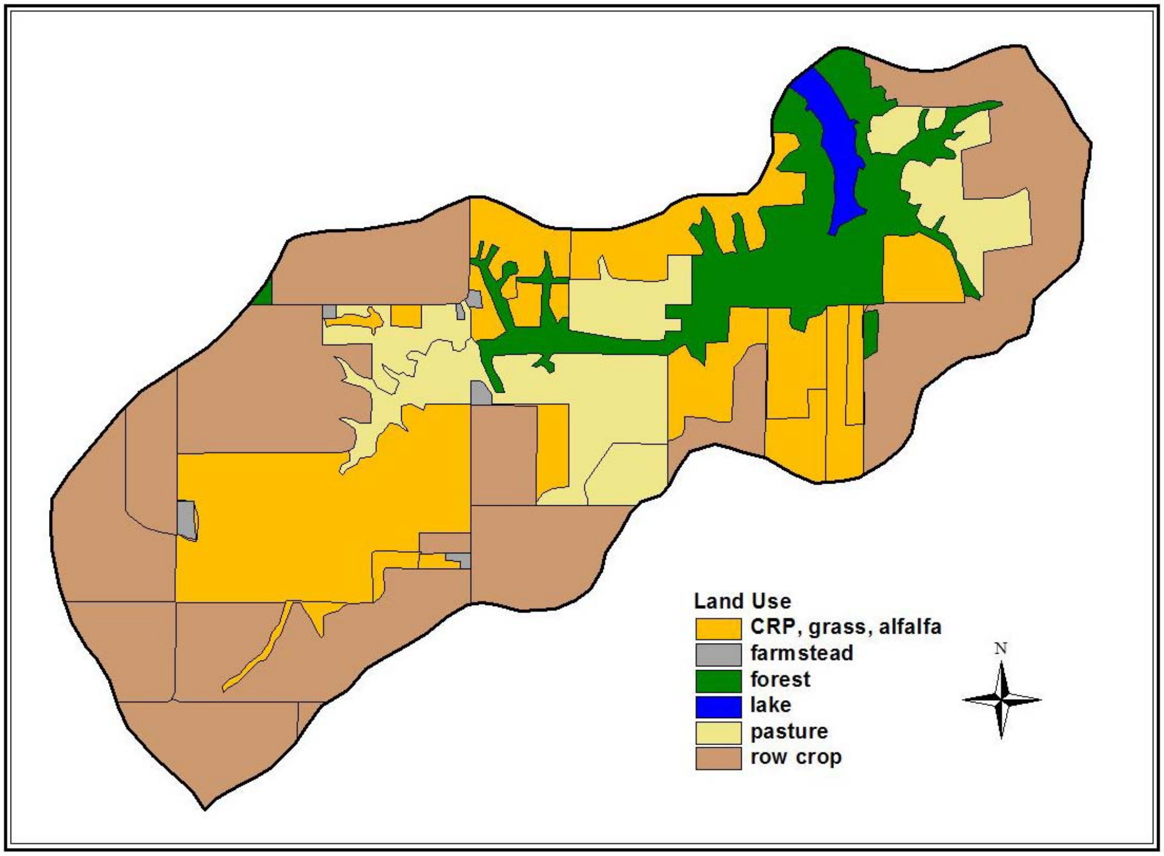
The relationship between TSI variables can be used to identify potential causal relationships. For example, TSI values for chlorophyll that are consistently well below those for total phosphorus suggest that something other than phosphorus limits algal growth. The TSI values can be plotted to show potential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

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



11. Appendix D – Williamson Pond Land Use Map

Figure B-1. Watershed land uses for Williamson Pond



12. Appendix E - Erosion Model and Model inputs

The Revised Universal Soil Loss Equation (RUSLE) (12) is an erosion model designed to predict the longtime annual average soil loss (A) carried by runoff from specific field slopes in specified cropping and management systems. The equation used by RUSLE is:

A=(R)x(K)x(L)x(S)x(C)x(P)

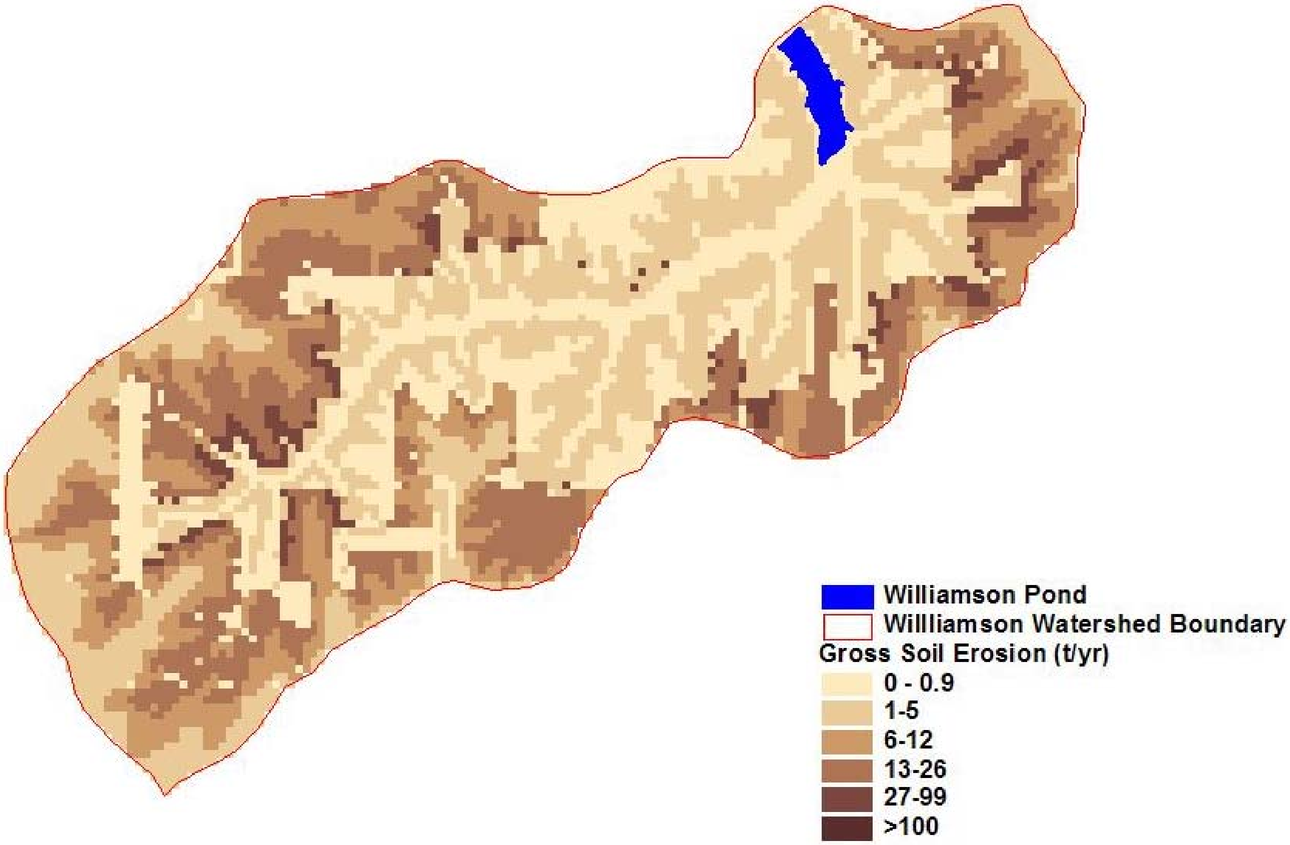
- A= computed spatial average soil loss and temporal average soil loss per unit of area expressed in the selected units for K and for the period selected for R. Typically, A is expressed as tons/acre/year.
- R= rainfall-runoff erosivity factor. The rainfall erosion index plus a factor for any significant runoff from snowmelt.
- K= soil erodibility factor. The soil loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6-ft length of uniform 9% slope in continuous clean-till fallow.
- L= slope length factor. The ratio of soil loss from the field slope length to soil loss from a standard plot length under identical conditions.
- S= slope steepness factor. The ratio of soil loss from the field slope gradient to soil loss from a standard plot gradient under identical conditions.
- C= cover management factor. The ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.
- P= support practice factor. The ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight row farming up and down the slope.

Data from IDNR soil, landuse and other GIS coverages have been used as input to the RUSLE equation. The IDNR RUSLE erosion model uses a grid of 30 by 30 meter cells to estimate sheet and rill erosion. Sediment yield is the quantity of gross erosion that is delivered to a specific location such as a water body.

Williamson Pond RUSLE Map

Figure E-1 identifies the potential gross sheet and rill erosion from the Williamson Pond watershed based on 2002 satellite imagery. The calculations do not take credit for installed best management practices, and is intended to identify priority areas within the watershed.

Figure E-1. Sheet and rill erosion in the watershed of Williamson Pond.



13. Appendix F – Lake Modeling Results

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 F-1. Model Results for existing conditions.

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = 241 ug/L	Comments
Loading Function	6235	Reckhow (10)
EPA Export	1438	EPA/5-80-011
WILMS Export	922	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	18825	GSM model
Canfield-Bachmann 1981 Natural Lake	1685	GSM model
Canfield-Bachmann 1981 Artificial Lake	3624	GSM model
Reckhow 1977 Anoxic Lake	886	GSM model
Reckhow 1979 Natural Lake	1552	GSM model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	1161	GSM model. P out of range
Nurnberg 1984 Oxic Lake	1439	Annual model. P out of range
Walker 1977 General Lake	4276	SPO model.
Vollenweider 1982 Combined OECD	2158	Annual model.
Vollenweider 1982 Shallow Lake	2282	Annual model.

The Loading Function appears to overestimate current total phosphorous loading to Williamson Pond. This is due in part to the location of Williamson Pond in the Southern Iowa Drift Plain and the lack of a current detailed field level assessment. The Vollenweider 1982 Shallow Lake model estimated loading more in line with the export coefficient estimates. This model is an annual model, not a growing season model, but may reasonably be used for well mixed lakes such as Williamson Pond. This model was selected over the Vollenweider OECD model because it was deloped based on a specific set of lakes (shallow reservoirs), while the OECD model is based on various lakes located throughout the world.

Table F-2. Model Results for target conditions.

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = 96 ug/L	Comments
Reckhow 1991 EUTROMOD Equation	864	GSM model
Canfield-Bachmann 1981 Natural Lake	519	GSM model
Canfield-Bachmann 1981 Artificial Lake	759	GSM model
Reckhow 1977 Anoxic Lake	354	GSM model
Reckhow 1979 Natural Lake	619	GSM model. P out of range
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	464	GSM model. P out of range
Nurnberg 1984 Oxic Lake	575	Annual model. P out of range
Walker 1977 General Lake	876	SPO model.
Vollenweider 1982 Combined OECD	704	Annual model.
Vollenweider 1982 Shallow Lake	804	Annual model.

Using the results of the Vollenweider 1982 Shallow Lake model, to achieve the desired TSI target of 70, the expected annual total phosphorous load is 804 lbs./year.