Total Maximum Daily Load
For Non-Algal Turbidity
Pierce Creek Lake
Page County, Iowa

2005

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Pierce Creek Lake Summary

Waterbody Name:	Pierce Creek Lake
County:	Page
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Nishnabotna River Basin
Pollutant:	Non-algal turbidity
Pollutant Sources:	Nonpoint
Impaired Use(s):	A1 (primary contact recreation) B(LW) (aquatic life)
2002 303d Priority:	Medium
Watershed Area:	2,800 acres
Lake Area:	33 acres
Lake Volume:	199 acre-ft
Detention Time:	0.12 years
Transparency Target:	Secchi Depth of more than 0.7 meters for non-algal turbidity
Load Capacity	370 tons of sediment per year
Existing Total Suspended Solids Load:	680 tons of sediment per year
Load Reduction to Achieve TMDL:	310 tons of sediment per year
Margin of Safety	40 tons of sediment per year
Wasteload Allocation:	0
Load Allocation:	330 tons of sediment 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. Pierce Creek Lake has been identified as impaired by non-algal turbidity. The purpose of the TMDL for Pierce Creek Lake is to calculate the maximum allowable non-algal turbidity loading that will meet water quality standards and fully supports its designated uses. The water quality impairment will be addressed by using transparency as measured by Secchi depth measurements as the target.

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. The TMDL will have two phases. 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. Phase 2 will consist of implementing the monitoring plan, evaluating collected data, and readjusting target values if needed.

Phase 1 will consist of setting specific and quantifiable targets for transparency as measured by Secchi depth. The existing condition is not phosphorus limited, attenuates light, and limits algal production. Reducing the quantity of non-algal turbidity may increase algal production, resulting in an algal turbidity impairment. However, this TMDL is restricted to the non-algal turbidity impairment.

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.

Monitoring is essential to 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 are effective in addressing the identified water quality impairment(s). The data and information can also be used to determine if the TMDL has 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:** Pierce Creek Lake, sec. 29, T70N, R39W, 4 miles north of Shenandoah, Page County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutant causing the water quality impairment is non-algal turbidity. Designated uses for Pierce Creek Lake 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 0.7 m Secchi depth. This is equivalent to 370 tons of total suspended solids.

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 2000-2003 sampling in 0.4 meters. The existing sediment load is 680 tons per year. In order to increase Secchi depth (transparency) to the target 0.7 meters, the sediment load must be decreased by 310 tons per year.

5. **Identification of pollution source categories:** Sediment from nonpoint sources and internal recycling has been identified as causing the non-algal turbidity impairment.

6. **Wasteload allocations for pollutants from point sources:** No point sources have been identified in the Pierce Creek Lake watershed. Therefore, the wasteload allocation will be 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. In Pierce Creek Lake, 80% of the load is attributed to non-algal turbidity and 20% is attributed to algal turbidity. Sediment will need to be decreased 310 tons to meet the transparency target of 0.7 meters Secchi depth.

8. **A margin of safety:** The Margin of Safety (MOS) for this TMDL is an explicit numerical MOS of 40 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.

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 loading was not included in this TMDL. Significant changes in the Pierce Creek Lake 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. 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. Pierce Creek Lake, Description and History

2.1 The Lake

Pierce Creek Lake is located in southwest Iowa, 4 miles north of Shenandoah. Public use for Pierce Creek Lake is estimated at 9,000 visitors per year. Users of the lake and of Pierce Creek Recreation Area enjoy fishing, picnicking, hiking, bicycling, bird watching, boating, and ice skating. Table 2 summarizes selected features of Pierce Creek Lake.

Table 2. Pierce Creek Lake Features

Waterbody Name:	Pierce Creek Lake
Hydrologic Unit Code:	HUC10 1024000307
IDNR Waterbody ID:	IA 05-NSH-00220-L
Location:	Section 29 T70N R39W
Latitude:	40° 50’ N
Longitude:	95° 21’ W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	None
Receiving Waterbody:	Unnamed tributary of the East Nishnabotna River
Lake Surface Area:	33 acres
Maximum Depth:	16 feet
Mean Depth:	6 feet
Volume:	199 acre-feet
Length of Shoreline:	10,000 feet
Watershed Area:	2,800 acres
Watershed/Lake Area Ratio:	84:1
Estimated Detention Time:	0.12 years

Morphometry

The lake has a mean depth of 6 feet and a maximum depth of 16 feet. It has a surface area of 33 acres and a storage volume of approximately 199 acre-feet. Temperature and dissolved oxygen sampling indicate that Pierce Creek Lake stratifies weakly in the deepest parts of the lake for much of the growing season, allowing periodic anoxia in the lower depths. However, due to shallow mean depth, the majority of the lake is likely well mixed and oxic.

Hydrology

Pierce Creek Lake is fed by an unnamed stream. A dam at the south end of Pierce Creek Lake discharges into the unnamed tributary of East Nishnabotna River. The estimated annual average detention time for Pierce Creek Lake is 0.12 years (45 days) based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix F. Average rainfall in the area is 32.5 inches/year.

2.2 The Watershed

The Pierce Creek Lake watershed has an area of approximately 2,800 acres and has a watershed to lake ratio of 84:1. Landuse data for the watershed based on 2002 satellite imagery is shown in Table 3.

Table 3. 2002 Landuse in Pierce Creek Lake watershed.

Landuse	Area in Acres	Percent of Total Area
Row Crop	1,264	45
CRP / Grass / Hay	993	35
Pasture	297	11
Timber	129	5
Other (water, roads, residential)	118	4
Total	2,800	100

A field assessment of the watershed was completed in June 2004 by the Iowa DNR to determine current landuse and cropping and management conditions. This information was used for calculating soil erosion rates using the Revised Universal Soil Loss Equation (RUSLE) (9, 12). The field assessment showed similar land use as in 2002. However, one major difference noted was a parcel of Conservation Reserve Land (CRP) returning to row crop production. The 2004 land use assessment map is in Appendix B. A map showing the distribution of soil erosion using the RUSLE model is in Appendix C. An explanation of the RUSLE model is in Appendix E.

There are no confined animal feeding operations or open feedlots existing in the watershed. Four large ponds in the watershed trap sediment from approximately 620 acres. The largest pond, located about three miles upstream of Pierce Creek Lake on the main channel, controls the drainage from approximately 290 acres. Much of the sloping cropland in the watershed has tile outlet contour terraces installed.

The watershed is gently to strongly sloping (2-14%) prairie-derived Marshall soil developed from loess and Adair and Shelby soils developed in glacial till.

3. TMDL for Non-Algal Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (8) list the designated uses for Pierce Creek Lake as Primary Contact (Class A1) and Aquatic Life (Class B(LW)). In 1998, Pierce Creek Lake was included on the impaired waters list as recommended by the DNR Fisheries Bureau due to siltation and elevated levels of nutrients. The nutrient impairment was removed in 2002, but the lake remains on the 303(d) list due to a non-algal turbidity impairment.

In 2002, the Class A (primary contact recreation) uses are assessed (monitored) as "partially supporting" due to presence of aesthetically objectionable blooms of algae and high levels of non-algal turbidity. The Class B(LW) aquatic life uses remain assessed (evaluated) as "partially supporting." Fish consumption uses are "not assessed." The sources of data for this assessment include 1.) results of the statewide survey of Iowa lakes conducted in 2000 and 2001 by Iowa State University (ISU), 2.) information from the IDNR Fisheries Bureau, and 3.) information on phytoplankton communities at Iowa lakes in 2000 from Downing et al. (3).

The lake has experienced severe siltation in the main lake upper reaches and also the coves. Extensive shallow areas around the lake impair shoreline fishing and make small boat access difficult. Nutrient enrichment from the watershed is significant and favors the common carp population in the lake.

Data Sources

Water quality surveys have been conducted on Pierce Creek Lake in 1979, 1990, and 2000-2003. Data from these surveys is available in Appendix A.

The ISU Lake Study data from 2000 to 2003 were evaluated for this TMDL. This study was continued through 2004 and approximates a sampling scheme used by Roger Bachman in earlier Iowa lake studies. Samples are collected three times per year in the early, middle, and late summer. A number of water quality parameters are measured including Secchi disk depth, phosphorus series, nitrogen series, total suspended solids (TSS), inorganic suspended solids (ISS), and volatile suspended solids (VSS).

Interpreting Pierce Creek Lake Water Quality Data

Based on the mean values from the ISU lake study 2000-2003, the inorganic suspended solids is 24.8 mg/L, the phosphorus level is 146 ug/L, the chlorophyll level is 27 ug/L, and the Secchi disk depth is 0.4 meters. The median level of inorganic suspended solids in the 131 lakes sampled for the ISU lake study for 2000-2002 was 4.8 mg/L. Of the 131 lakes sampled, Pierce Creek Pond had the fifth highest median of inorganic suspended solids (25.3 mg/L) for the same time period.

Comparisons of the Trophic State Index (TSI) values (7) for chlorophyll, Secchi depth, and total phosphorus for in-lake sampling from 2000-2003 indicate possible non-algal turbidity limits the production of algae through light attenuation and contributes to impairments of both primary contact recreation and aquatic life uses. Table 4 summarizes the TSI values.

Table 4. Pierce Creek Lake TSI Values

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/21/2000	73	63	85
7/20/2000	67	53	77
8/9/2000	70	55	75
5/22/2001	70	--	75
6/20/2001	77	62	81
7/24/2001	70	71	73
5/29/2002	63	55	58
6/25/2002	73	87*	72
7/30/2002	77	69	78
5/28/2003	67	62	65
6/24/2003	83	57	78
7/29/2003	83	66	78

*Data point excluded from analysis

Figure 1. Pierce Creek Lake 2000-2003 Mean TSI Multivariate Comparison Plot

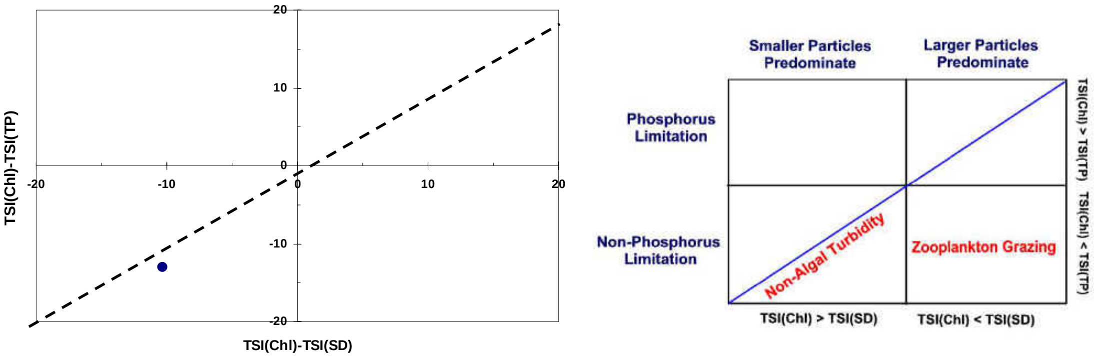

Figure 1 is a multivariate plot of mean TSI values. The blue dot on the left-hand graphic shows the relationship between TSI (SD), TSI (CHL), and TSI (TP) for Pierce Creek Lake on the graph area. The lower left-hand quadrant on the graph area indicates that the water column is dominated by smaller particles 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 D.

Table 5 lists selected parameters and their relationship to transparency.

Table 5. Water Quality Parameters Related to Transparency

Parameter	Physical Meaning
Turbidity	Properties of the water column that cause light to be scattered and absorbed, primarily caused by algal and inorganic TSS.
Secchi Depth (SD, m)	Measures water column transparency and used as a translator for turbidity.
Total Suspended Solids (TSS, mg/L)	Solids residue captured on an 0.45 um filter and dried at 105 C.
Inorganic Suspended Solids (ISS, mg/L)	Solids residue remaining after heating at 550 C.
Volatile Suspended Solids (VSS, mg/L)	Weight lost after heating, VSS is the difference between TSS and ISS. This is the organic fraction found in the water.
Chlorophyll (CHL, ug/L)	Chlorophyll is a measure of the algae concentration in the water column. Usually chlorophyll will be correlated with VSS.
Total Phosphorous (TP, ug/L)	Total phosphorous is often the limiting factor in algal productivity. In the absence of light limitation TP would likely control the extent of algae blooms in lakes. It can be related to chlorophyll and Secchi depth with the trophic state index in the absence of other limiting conditions.

As described in the Pierce Creek Lake water quality assessment, the main cause of the lake's turbid condition is non-algal turbidity, e.g., total suspended solids. An evaluation of the ISU Iowa Lake Study data shows a strong correlation between TSS and Secchi depth and no correlation between chlorophyll and Secchi depth. ISS and VSS are also significant. Figures 2 through 5 show the relationships between TSS, ISS, VSS, and chlorophyll to Secchi depth.

Figure 2. Total Suspended Solids vs Transparency

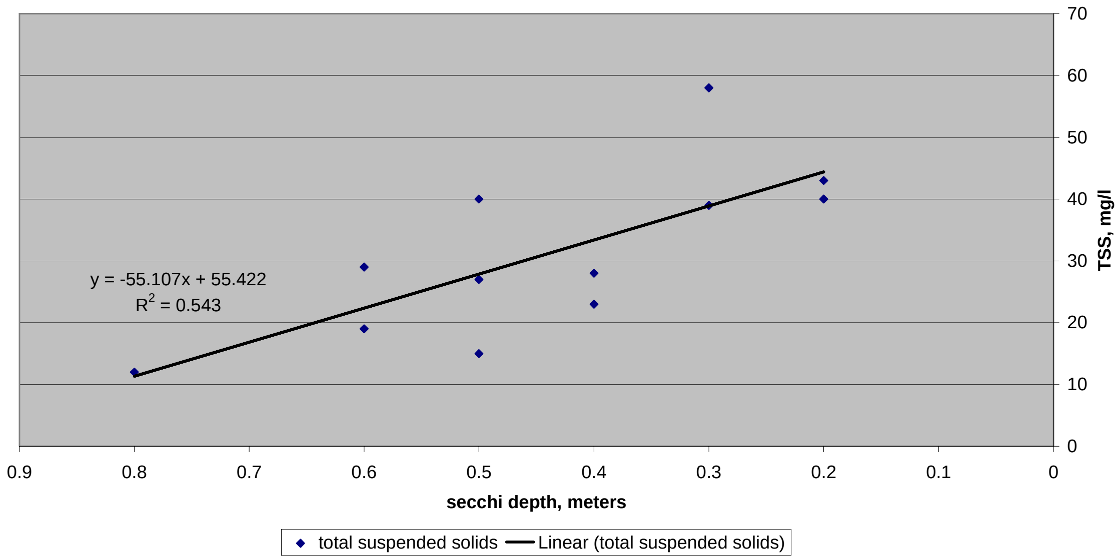

Figure 3. Inorganic Suspended Solids vs Transparency

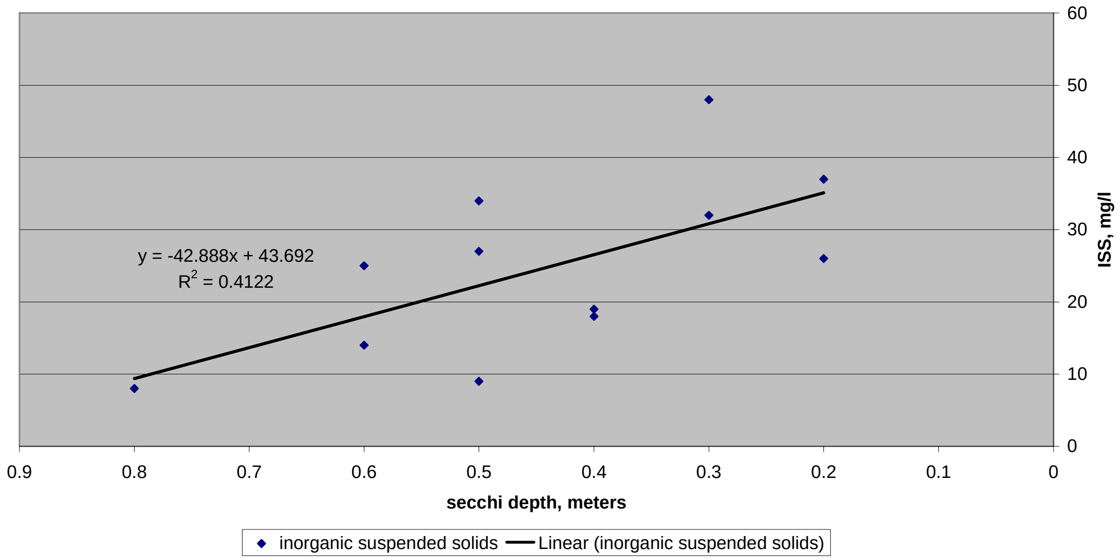

Figure 4. Volatile Suspended Solids vs Transparency

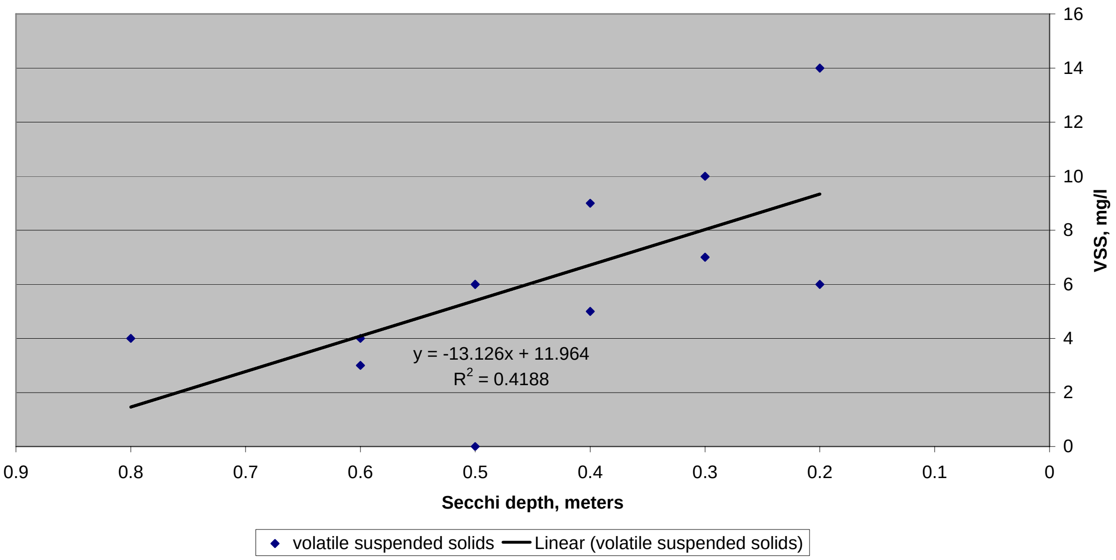

Figure 5. Chlorophyll vs Transparency

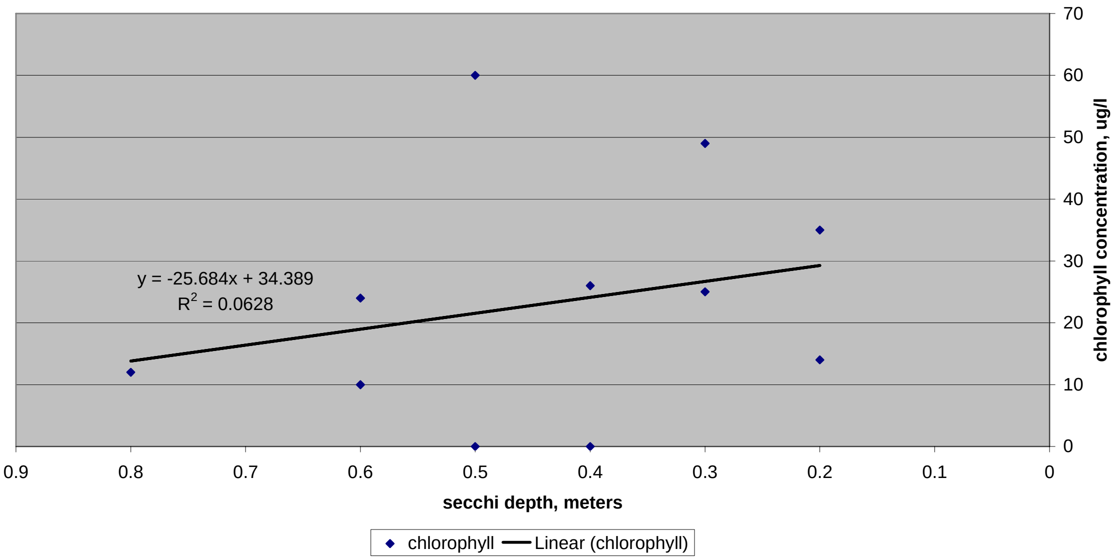

Table 6. Statistics for linear regressions of Secchi depth vs.TSS, ISS, VSS, and chlorophyll

	r squared	r=correlation coefficient	p=probability of null hypothesis, n=12
Log TSS	0.54	0.73	0.01
Log ISS	0.41	0.64	0.05
Log VSS	0.42	0.65	0.05
Log Chl	0.06	0.24	Not Significant, >0.05

Table 6 summarizes the analysis comparing Secchi depth to measured water quality parameters. The r-squared term is an indication of how much of the variability in Secchi depth is explained by the regression of TSS, ISS, VSS and chlorophyll with 1 being perfect correlation. The r term is the linear correlation coefficient and measures the linear association between the two variables. The p-value term is the likelihood that the variability is random. For TSS, the likelihood that the relationship with Secchi depth is random is 1 in 100. For ISS and VSS, the likelihood that the relationship with Secchi depth is random is 5 in 100. A p-value less than or equal to 0.05 is considered significant for this document.

These statistics indicate that the Pierce Creek Lake non-algal turbidity impairment is caused by total suspended solids and that there is little correlation between algae and turbidity as measured by chlorophyll and Secchi depth transparency. Total suspended solids are dominated (80%) by inorganic suspended solids.

Potential Pollution Sources

There are no point sources of pollution in the Pierce Creek Lake watershed. The non-algal 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 were not separated from nonpoint sources of sediment.

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.

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 Pierce Creek Lake has fully supporting aquatic life uses as determined by assessments 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 non-algal turbidity. Sediments delivered from the watershed or resuspended from the lake bottom by common carp foraging activity and wave action are causing the non-algal turbidity. The transparency objective is defined by a mean Secchi depth of 0.7 meters.

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.

Waterbody Pollutant Loading Capacity

Total suspended solids (TSS) causes turbidity. The loading capacity of the lake is determined by a Secchi depth TSI of 65, equivalent to a Secchi depth of 0.7 meter. Using the relationship between Secchi depth and TSS from Figure 2, the load capacity is calculated as:

$$\begin{aligned} \text{TSS (mg/L)} &= -55.107(\text{SD}) + 55.422 \\ &= -55.107(0.7) + 55.422 \\ &= 17 \text{ mg/L} \end{aligned}$$

Based upon lake retention time, TSS concentration, and dam trapping efficiency this is equivalent to:

(199 ac-ft lake volume)(17 mg TSS/L)(365 days/45 day retention)(1,233,482 L/ac-ft)(2.204 lbs/10^6mg)(1 ton/2000 lbs) = 37 tons sediment exiting the lake annually.

Assuming a 90% trap efficiency of the lake, this is (0.1x = 37 tons) => 370 tons of sediment per year load capacity of the lake.

3.3 Pollution Source Assessment

Existing Load

The existing load of non-algal turbidity is 680 tons of sediment delivered to or resuspended in the lake. This is calculated using lake hydrology, measured TSS and dam trapping efficiency. The calculations are:

(199 ac-ft lake volume)(31 mg TSS/L)(365 days/45 day retention)(1,233,482 L/ac-ft)(2.204 lbs/10^6mg)(1 ton/2000 lbs) = 68 tons sediment exiting the lake.

Assuming a 90% trap efficiency of the lake, this is (0.1x = 68 tons) => 680 tons of existing sediment load to the lake.

Departure from Load Capacity

The non-algal turbidity load capacity is 370 tons of sediment. The existing non-algal turbidity load is 680 tons resulting in a departure from load capacity of 310 tons of sediment.

Identification of Pollutant Sources

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

Linkage of Sources to Target

The non-algal turbidity load capacity of Pierce Creek Lake is 370 tons of sediment per year. The current sediment load is 680 tons per year. This load originates 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 allocation for this TMDL is set at zero.

Load Allocation

The load allocation for non-algal turbidity is 330 tons of sediment in the lake allocated to nonpoint sources, and lake resuspension.

Margin of Safety

An explicit margin of safety for non-algal turbidity is set at 10% of the load capacity, or 40 tons sediment (370 tons x 10%).

TMDL Summary

$$\begin{aligned} TMDL &= WLA + LA + MOS \\ &= 0 + 330 \text{ tons/yr} + 40 \text{ tons/yr} \\ &= 370 \text{ tons/yr} \end{aligned}$$

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 Pierce Creek Lake.

If the entire sediment load were attributed to watershed sources, the estimated loading from watershed sources would need to be reduced from 0.24 tons/acre/year to about 0.13 tons/acre/year to meet the TMDL target. 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, wind-driven waves and currents, and boat propellers.

Because of the uncertainty as to how much of the sediment load originates in the watershed and how much is resuspended from 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:

- Reduce watershed and resuspension loading from 680 tons per year to 560 pounds per year by 2010.
- Reduce watershed and resuspension loading from 560 tons per year to 440 pounds per year by 2015.
- Reduce watershed and resuspension loading from 440 pounds per year to 350 pounds per year by 2020.

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 Pierce Creek Lake.
- 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 Pierce Creek 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. Pierce Creek 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.

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. 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 informational meeting was held June 23, 2004 with the Page County Conservation Board. The draft Pierce Creek Lake TMDL was reviewed at a public meeting January 20, 2005. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

7. References

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8. Appendix A - Sampling Data

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

Parameter	**7/16/1979**	**8/07/1979**	**9/04/1979**
Secchi Depth (m)	0.5	0.4	0.2
Chlorophyll (ug/L)	44.7	56.9	23.2
NO_3+NO_2-N (mg/L)			0.5
Total Phosphorus (ug/L as P)	104	85	199
Alkalinity (mg/L)	128	117	109

Data above is averaged over the upper 6 feet.

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

Parameter	**6/06/1990**	**7/07/1990**	**8/05/1990**
Secchi Depth (m)	0.7	0.1	0.05
Chlorophyll (ug/L)	34.3	9.9	54.1
Total Nitrogen (mg/L as N)	1.4	3.4	2.5
Total Phosphorus (ug/L as P)	85.2	188.5	317.1
Total Suspended Solids (mg/L)	62.3	103.4	192
Inorganic Suspended Solids (mg/L)	55.6	63.8	154.6

Data above is for surface depth.

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

Parameter	**6/21/2000**	**7/20/2000**	**8/09/2000**
Secchi Depth (m)	0.4	0.6	0.5
Chlorophyll (ug/L)	26	10	12
NH_3+NH_4^+ -N (ug/L)	976	1285	964
NH_3 –N (un-ionized) (ug/L)	23	28	21
NO_3+NO_2-N (mg/L)	0.17	0.14	0.12
Total Nitrogen (mg/L as N)	1.42	1.78	1.45
Total Phosphorus (ug/L as P)	280	158	130
Silica (mg/L as SiO_2)	48		11
pH	7.7	7.6	7.5
Alkalinity (mg/L)	169	151	124
Total Suspended Solids (mg/L)	22.6	28.7	26.9
Inorganic Suspended Solids (mg/L)	17.7	25.3	26.9
Volatile Suspended Solids (mg/L)	4.9	3.3	0.0

Table A-4. Data collected in 2001 by Iowa State University (4)

Parameter	**5/22/2001**	**6/20/2001**	**7/24/2001**
Secchi Depth (m)	0.5	0.3	0.5
Chlorophyll (ug/L)		25	60
NH_3+NH_4^+ -N (ug/L)	1150	1550	629
NH_3 –N (un-ionized) (ug/L)	12	55	59
NO_3+NO_2-N (mg/L)	2.32	3.80	0.61

Total Nitrogen (mg/L as N)	2.86	4.17	1.55
Total Phosphorus (ug/L as P)	139	205	121
Silica (mg/L as SiO_2)	16	26	8
pH	7.5	7.9	8.1
Alkalinity (mg/L)	149	150	124
Total Suspended Solids (mg/L)	40.3	57.8	14.9
Inorganic Suspended Solids (mg/L)	34.4	47.8	9.3
Volatile Suspended Solids (mg/L)	5.9	10.0	5.6

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

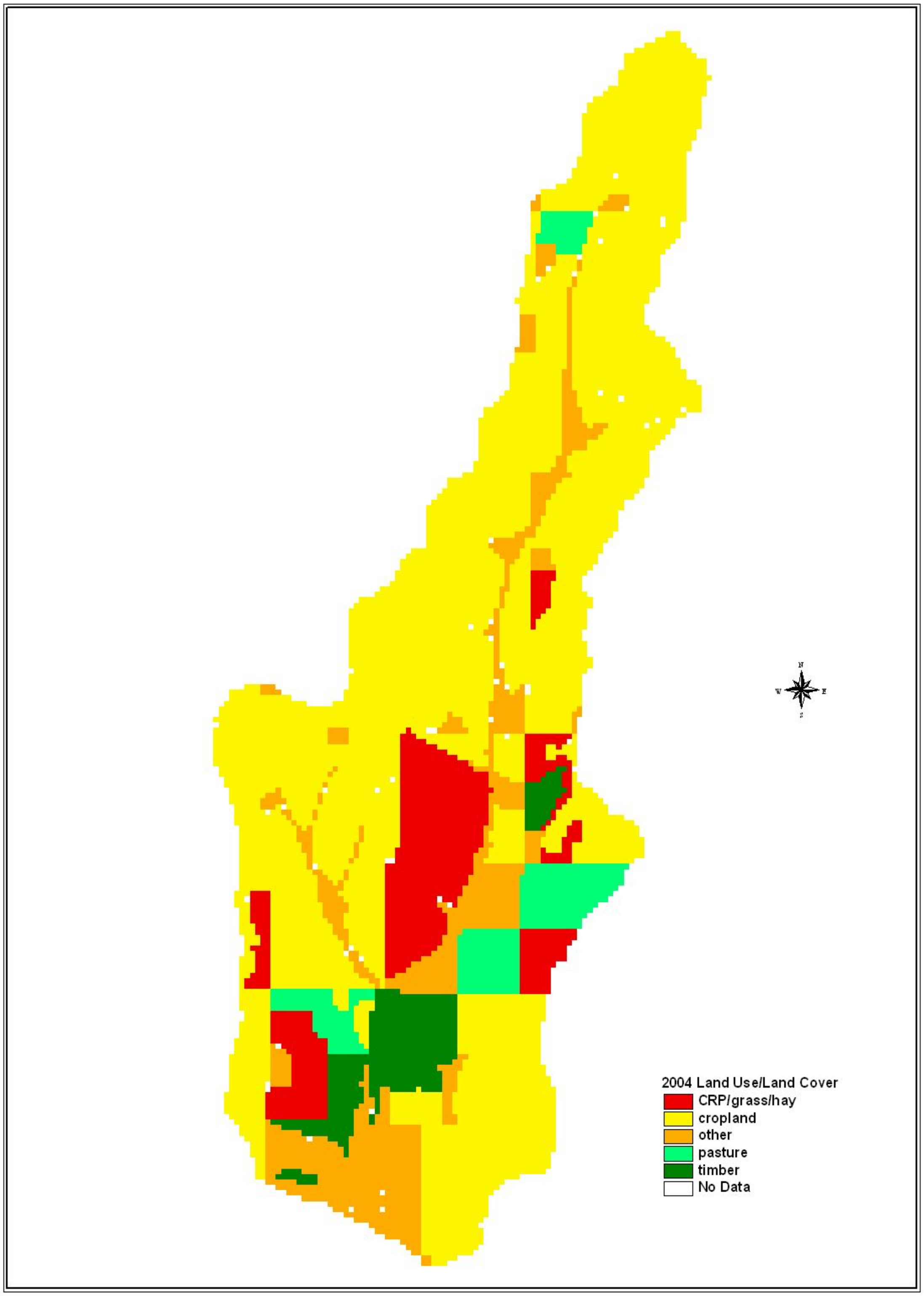
Parameter	**5/29/2002**	**6/25/2002**	**7/30/2002**
Secchi Depth (m)	0.8	0.4	0.3
Chlorophyll (ug/L)	12	321	49
NH_3+NH_4^+ -N (ug/L)	215	463	629
NH_3 –N (un-ionized) (ug/L)	21	52	45
NO_3+NO_2-N (mg/L)	0.76	0.09	0.19
Total Nitrogen (mg/L as N)	1.41	1.07	1.09
Total Phosphorus (ug/L as P)	41	113	168
Silica (mg/L as SiO_2)	1	5	4
pH	8.4	8.3	8.1
Alkalinity (mg/L)	151	161	111
Total Suspended Solids (mg/L)	12.3	27.6	39.4
Inorganic Suspended Solids (mg/L)	8.3	18.5	32.2
Volatile Suspended Solids (mg/L)	4.0	9.1	7.2

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

Parameter	**5/28/2003**	**6/24/2003**	**7/29/2003**
Secchi Depth (m)	0.6	0.2	0.2
Chlorophyll (ug/L)	24.3	13.8	34.5
NH_3+NH_4^+ -N (ug/L)	422	994	442
NH_3 –N (un-ionized) (ug/L)	53	59	87
NO_3+NO_2-N (mg/L)	0.71	0.55	0.13
Total Nitrogen (mg/L as N)	1.56	1.81	1.44
Total Phosphorus (ug/L as P)	68	163	167
Silica (mg/L as SiO_2)	2.16	5.76	5.28
pH	8.5	8.0	8.5
Alkalinity (mg/L)	122	105	97
Total Suspended Solids (mg/L)	19	43	40
Inorganic Suspended Solids (mg/L)	14	37	26
Volatile Suspended Solids (mg/L)	4	6	14

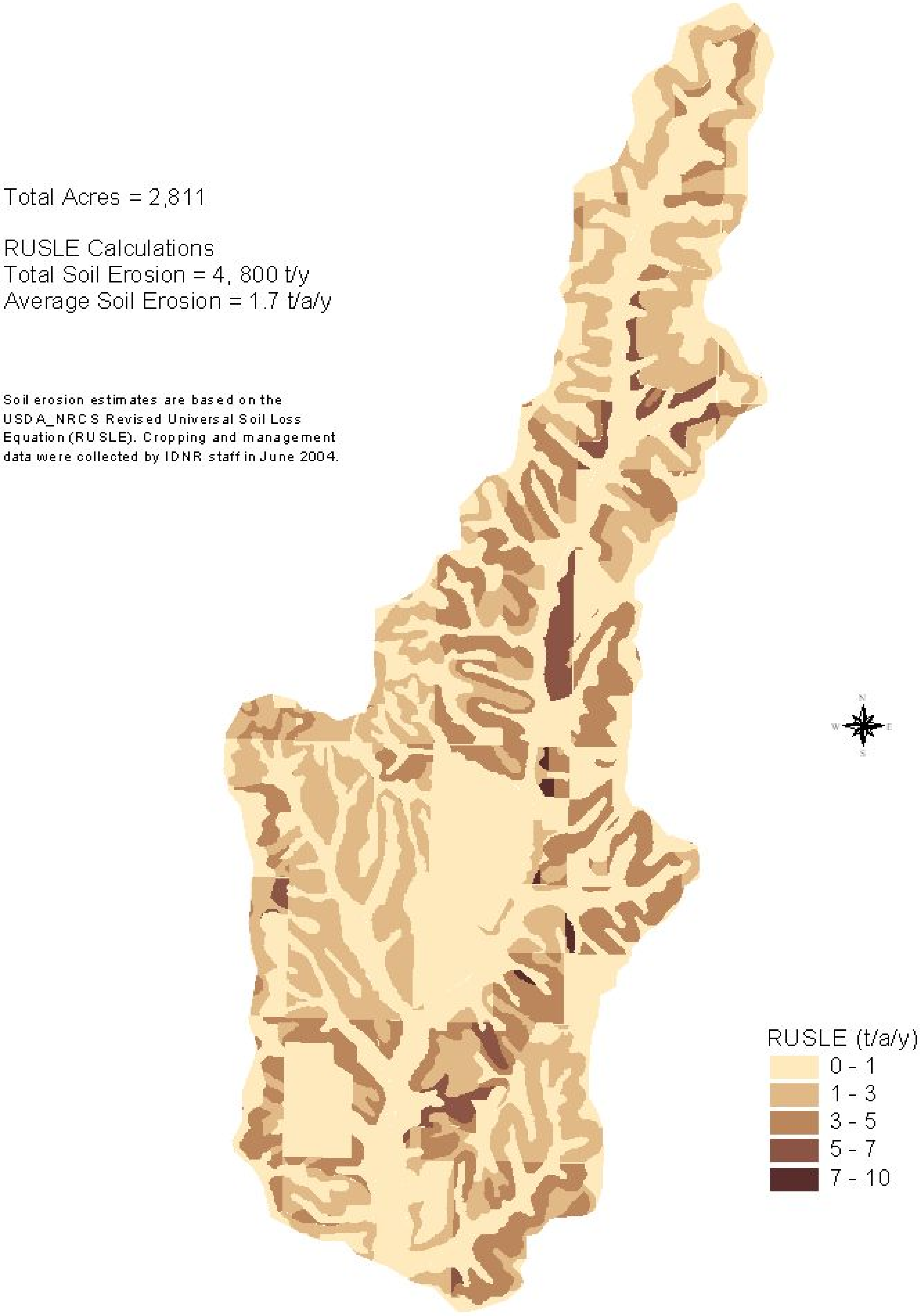
9. Appendix B - Pierce Creek Lake Land Use Map

Figure B-1. Watershed land uses for Pierce Creek Lake



10. Appendix C - Pierce Creek Lake RUSLE Map

Figure C-1. Sheet and rill erosion as in the watershed of Pierce Creek Lake.



Total Acres = 2,811

RUSLE Calculations
Total Soil Erosion = 4, 800 t/y
Average Soil Erosion = 1.7 t/a/y

Soil erosion estimates are based on the USDA_NRCS Revised Universal Soil Loss Equation (RUSLE). Cropping and management data were collected by IDNR staff in June 2004.

11. Appendix D - 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:

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

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

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

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 D-1. Changes in temperate lake attributes according to trophic state (10, 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 D-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.

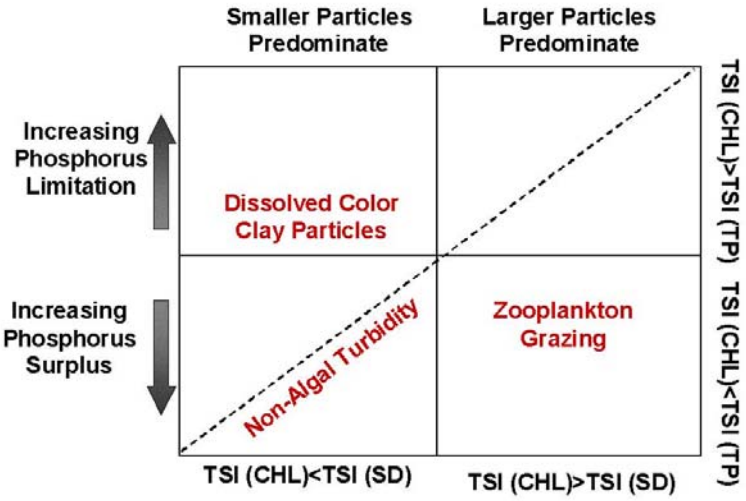
Level of Support	**TSI value**	**Chlorophyll-a (ug/l)**	**Secchi Depth (m)**
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates 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 D-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 D-1.

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



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.

13. Appendix F - 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 F-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 F-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 F-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 F-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 F-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 Pierce Creek Lake – Calculations

Table F-5. Pierce Creek Lake Hydrology Calculations

Lake	Pierce Creek Lake	
Type	Impoundment	
Inlet(s)	unnamed creek	
Outlet(s)	unnamed creek	
Volume	199	(acre-ft)
Lake Area	34	(acres)
Mean Depth	5.87	(ft)
Drainage Area	2767	(acres)
Mean Annual Precip	32.5	(inches)
Average Basin Slope	6.51	(%)
%Water	0.00	
%Forest	5.58	
%Grass/Hay	33.72	
%Corn	25.70	
%Beans	34.94	
%Urban/Artificial	0.06	
%Barren/Sparse	0.02	
Hydrologic Region	2	
Mean Annual Class A Pan Evap	57.00	(inches)
Mean Annual Lake Evap	42.18	(inches)
Est. Annual Average Inflow	1634.74	(acre-ft)
Direct Lake Precip	91.86	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.1154	(yr)
Est. Annual Average Det. Time (outflow)	0.1240	(yr)