Lower Pine Lake

Hardin County, Iowa

Total Maximum Daily Load For:

Organic Enrichment

December 2002

Iowa Department of Natural Resources
Water Quality Bureau

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Executive Summary

Waterbody Name	Lower Pine Lake
IDNR Waterbody ID	IA 02-IOW-0330-L
Hydrologic Unit Code:	HUC 07080207
Location:	Sec. 4, T87N, R19W
Latitude:	42 Deg. 22 Min. N
Longitude:	93 Deg. 4 Min. W
Water Quality Standards Designated Uses	Primary Contact Recreation Aquatic Life Support
Watershed Area:	9,680 acres (1991)
Lake Area:	65.5 acres (1991)
Major River Basin:	Iowa River Basin
Tributaries:	Upper Pine Lake
Receiving Water Body	Iowa River
Pollutant, organic enrichment	Low dissolved oxygen, nutrient condition, total phosphorous
Pollutant Sources	Non-point
Impaired Use	Aquatic Life Support

The Federal Clean Water Act requires the development of a total maximum daily load (TMDL) for the pollutant(s) that causes a water body to be placed on the State of Iowa impaired waters list [303(d) list]. Lower Pine Lake is on the 1998 impaired waters list for organic enrichment that creates a condition only partially supporting aquatic life and primary recreation uses.

This document consists of a single TMDL for organic enrichment that will result in Lower Pine Lake water quality consistent with the Iowa Water Quality Standards requirements. The organic enrichment impairment is linked to low dissolved oxygen concentrations. In a highly productive and shallow lake such as Lower Pine organic enrichment is associated with algae blooms. These algae blooms are caused by excess nutrients, specifically phosphorous. Measuring chlorophyll concentration estimates algal biomass. Total phosphorous concentration predicts algal biomass in phosphorous limiting conditions. The 1998 assessment of the lake water quality stated that "nuisance blooms of algae and organic enrichment remain significant water quality problems.

A lot of effort has been focused on improving Upper and Lower Pine Lake water quality in the last decade. Much of this work was completed after the information used for the 1998 water quality assessment that found the Pine Lakes to be impaired was collected. Evaluation of the beneficial impacts of these efforts and a re-assessment of lake water quality will be among the objectives of the Lower Pine Lake TMDL process.

This is a phased TMDL. 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, waterbody load capacity, existing pollutant load over this capacity, pollutant sources, and load allocations to these sources are determined from available information. A monitoring plan will ascertain Phase 1 load reduction success as well as whether the calculated Phase 1 load capacity provides water quality adequate to support designated uses. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling. Section 5.0 includes a description of planned monitoring.

Phase 1 will consist of setting a specific and quantifiable target for chlorophyll and total phosphorous 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.

The Lower Pine Lake TMDL has been prepared in compliance with the current (November 2002) regulations for TMDL development 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:** Lower Pine Lake, Sec. 4, T87N, R19W; 2 miles NE of the City of Eldora, Hardin County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutants causing the water quality impairments are decaying algae and the high phosphorous concentrations that cause algal blooms and subsequent hyper-eutrophication. Designated uses for Lower Pine Lake are Primary Contact Recreation (Class A) and Aquatic Life (Class B(LW)). High nutrient inputs have created a hyper-eutrophic condition that impairs aesthetic and aquatic life water quality narrative criteria.

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 One target of this TMDL is a Carlson's Trophic State Index (TSI) of 70 for total phosphorous and 65 for chlorophyll and secchi depth. This correlates to a water column TP concentration of about 100 ug/l.

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 estimated annual total phosphorus load to Lower Pine Lake is 8,000 pounds per year. The Lower Pine Lake capacity for total phosphorous is 2,000 pounds per year based on lake response modeling results. To achieve and maintain lake water quality goals and protect for beneficial uses, a TP loading reduction of 6,000 pounds per year is required.

5. **Identification of pollution source category(s):** Nonpoint and internal sources of pollutants have been identified as the cause of impairment to Lower Pine Lake.

6. **Wasteload allocations for pollutants from point sources**: No significant point sources have been identified in the Lower Pine Lake watershed; therefore, the wasteload allocation will be set at zero.

7. **Load allocations for pollutants from nonpoint sources**: Load allocations designed to achieve compliance with the TMDL were developed for phosphorus sources in the Lower Pine Lake watershed and include TP estimates for Upper Pine Lake outflow, direct runoff and resuspended sediment. There was not a load allocation for “background” contributions because pollutant loads originated solely from non-point sources.

8. **A margin of safety**: The implicit margin of safety for this TMDL is the result of conservative assumptions and dual targets for defining the unimpaired condition.

- A significant part of water column total phosphorous is not available for algal growth as shown by the TSI values for TP and chlorophyll. It has been conservatively assumed that all TP will be expressed as algae. The TSI value for total phosphorous is 78 and for chlorophyll is 65. Every 10 TSI unit increase represents a doubling of algal biomass. The impairment is the result of algal productivity and therefore the MOS exceeds by more than 100% of the monitored chlorophyll.
- Additionally, there are dual targets for this TMDL that assure restoration of aquatic life uses regardless of the accuracy of the modeled total phosphorous load target of 2000 pounds per year. This TP load is the first target. The second target is the measurement of the aquatic life condition through bioassessment and fisheries studies. This assessment work will demonstrate whether the lake is still impaired.

9. **Consideration of seasonal variation**: This TMDL considered seasonal variation of algae induced impairment. High phosphorous occurs year-round although elevated TP concentrations and algal growth are more likely during the summer and early fall. Therefore an annual loading period was used to evaluate phosphorous impacts.

10. **Allowance for reasonably foreseeable increases in pollutant loads**: There are no allowances for increases in pollutant loads since it is unlikely that watershed landuse will change.

11. **Implementation plan**: Although not required by the current regulations, a brief water quality improvement plan has been included in this TMDL.

1. Introduction

The Federal Clean Water Act requires the development of a total maximum daily load (TMDL) for the pollutant(s) that causes a water body to be placed on the State of Iowa impaired waters list [303(d) list]. Lower Pine Lake is on the 1998 impaired waters list for organic enrichment resulting from elevated nutrient concentrations. High nutrient concentrations, specifically total phosphorous, are the start of the causal chain leading to depressed dissolved oxygen in the lake water column. This situation has created a water quality condition only partially supporting the lake's aquatic life designated use.

The TMDL for Lower Pine Lake will determine the maximum total phosphorous that the lake can receive and not cause water quality impairment, i.e., attain compliance with the requirements of the Iowa Water Quality Standards.

Specifically this organic enrichment TMDL for Lower Pine Lake will:

- Identify the adverse impact that nutrient induced organic enrichment is having on aquatic life use and link this to water quality criteria compliance.
- Identify an acceptable phosphorous load (load capacity) that ensures attainment of the lake's aquatic life use.
- Estimate how much the existing phosphorous load exceeds the load capacity.
- Identify phosphorous sources and estimate a load allocation for each source.
- Provide a brief implementation plan to guide the IDNR, other agencies, and stakeholders in efforts to reduce loads to acceptable levels.

This is a phased TMDL. 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, waterbody load capacity, existing pollutant load over this capacity, pollutant sources, and load allocations to these sources are determined from available information. A monitoring plan will ascertain Phase 1 load reduction success as well as whether the calculated Phase 1 load capacity provides water quality adequate to support designated uses. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling. Section 5.0 includes a description of planned monitoring.

Phase 1 will consist of setting a specific and quantifiable target for total phosphorous 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.

Upper and Lower Pine Lakes are located entirely within Pine Lake State Park in Hardin County two miles northeast of Eldora, Iowa. Pine Lake State Park is state owned and is managed by the IDNR. The 572 acre park and its two lakes provide facilities for boating, fishing, swimming, camping, picnicking, and hiking. There is a swimming beach on Lower Pine Lake but not on Upper Pine Lake. Estimated park usage is 500,000 visits per year.

2. Lower Pine Lake, Description and History

Pine Lake, now called Lower Pine Lake, was formed in 1922 when a dam was constructed just upstream from the confluence of Pine Creek and the Iowa River. Eleven years after it was created, one-third of Pine Lake's original volume had been lost to sediment. As a consequence, in 1934, a dam was constructed upstream from Pine Lake, creating a second basin to protect Pine Lake. This sediment detention basin has now become a valuable recreational resource in the region and is named Upper Pine Lake.

2.1. The Lake

Lower Pine Lake water quality has been of significant regional interest and great effort and resources have been focused on improving it over the last seven decades. Siltation has been a serious problem in Lower Pine Lake since the dam that created it was built. In a 1991 ISU Diagnostic/Feasibility Study it was estimated that the volume loss to sediment in Lower Pine Lake was 48% of its original 1922 volume The consequent shallowness aggravates the impact of excess nutrients encouraging rapid eutrophication. The Lower Pine Lake physical features below are as described in the 1991 study.

Physical Features

Waterbody Name:	**Lower Pine Lake**
Hydrologic Unit Code:	HUC07 08207080
IDNR Waterbody ID	IA 02-IOW-00335-L
Location:	Sec. 24, T87N, R19W
Latitude:	42 Deg. 22 Min. N
Longitude:	93 Deg. 4 Min. W
Water Quality Standards Designated Uses	1. Primary Contact Recreation 2. Aquatic Life Support
Tributary	Upper Pine Lake
Receiving Waterbody	Pine Creek/Iowa River
Lake Surface Area	65.5 acres (1991)
Maximum Depth	10.0 feet (1991) 14 feet, (1997, post dredging)
Mean Depth	5.4 feet (1991) 6.8 feet (1997, post dredging)
Volume (1991) Volume (1997) post dredging	355 acre-feet (1991) 442 acre feet (1997)
Length of Shoreline	8,016 feet (1991)
Watershed Area (Upper and Lower)	9,680 acres
Watershed/Lake Area Ratio	148

There have been some important changes to the lake since the 1991 ISU study was completed. Among the recommendations from the study were plans to dredge both lakes and to build a dike across the upstream end of Upper Pine Lake to retain sediment. In 1997, both lakes were dredged and a 400-foot long sediment retention dike was constructed across Upper Pine Lake. A total of 140,000 cubic yards was removed from Lower Pine Lake and 40,000 cubic yards of material was dredged from Upper Pine Lake. Lower Pine Lake volume was increased by 87 acre-feet and the mean depth was increased 1.35 feet, from 5.4 to 6.75 feet.

Morphometry

Marshes and wetlands have formed in the upper reaches of the two lakes and have become ecologically valuable. The basins themselves are simple. Pine Creek is the only tributary to Upper Pine Lake and Upper Pine Lake is the only significant tributary to Lower Pine Lake. The lakes follow the contours of the original Pine Creek streambed and there are not any other significant tributaries forming branches. The deepest water in both lakes is towards the dam.

Bathymetry for Lower Pine Lake is available for the years 1922, 1932, 1950, and 1990. The 1991 ISU Study used the changes in volume between map years to evaluate lake volume loss and estimate average sedimentation rates. The map below shows the locations of the 1997 dredge cut. The 1991 ISU Study recommended removing 67 acre-feet of sediment over an area of 12 acres to a depth of 15 feet. The actual 1997 dredging work removed 87 acre-feet of material from the deeper west end of the lake to a depth of 14 or 15 feet.

Figure 1. 1997 Dredge cut and sediment dike locations, Lower Pine Lake

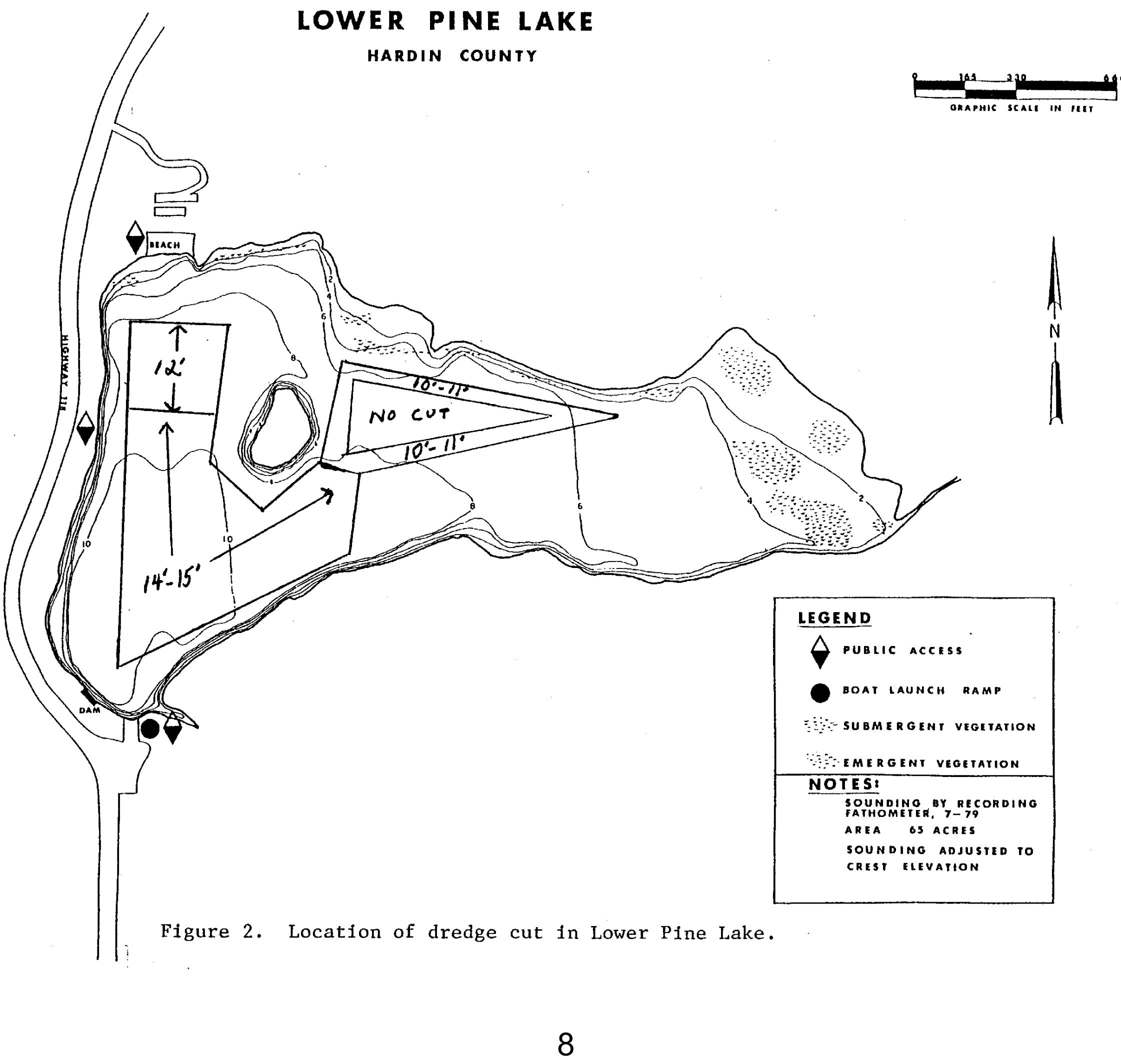


Figure 2. Location of dredge cut in Lower Pine Lake.

Hydrology
A hydraulic budget for both of the Pine Lakes was prepared for the 1991 ISU Study. This budget used the measured change in lake storage calculated from USGS lake stage records, watershed surface runoff calculations , precipitation and evaporation data from the National Weather Service stations in Eldora and Ames, and outflows over the spillways of the two dams from stage data and stage discharge curves. Groundwater inflow is the only unknown in the system equation. Flows into the lake are from surface runoff, groundwater, and direct precipitation. It was estimated that groundwater accounts for 88% of the inflow into Upper Pine Lake and 91% of the total watershed inflow to both lakes. The ISU Study comments on the groundwater contribution:

> This is …reasonable since … the majority of upland soils are loess over glacial till and the loess infiltration capacity is very high. … the groundwater moves through the loess over impermeable glacial till into the alluvial prism that provides the final route for groundwater into the lake.

The average flow from Upper Pine Lake to Lower Pine Lake was 9600 acre-feet per year and the average outflow from Lower Pine was 16,000 acre-feet per year.

2.2. The Watershed

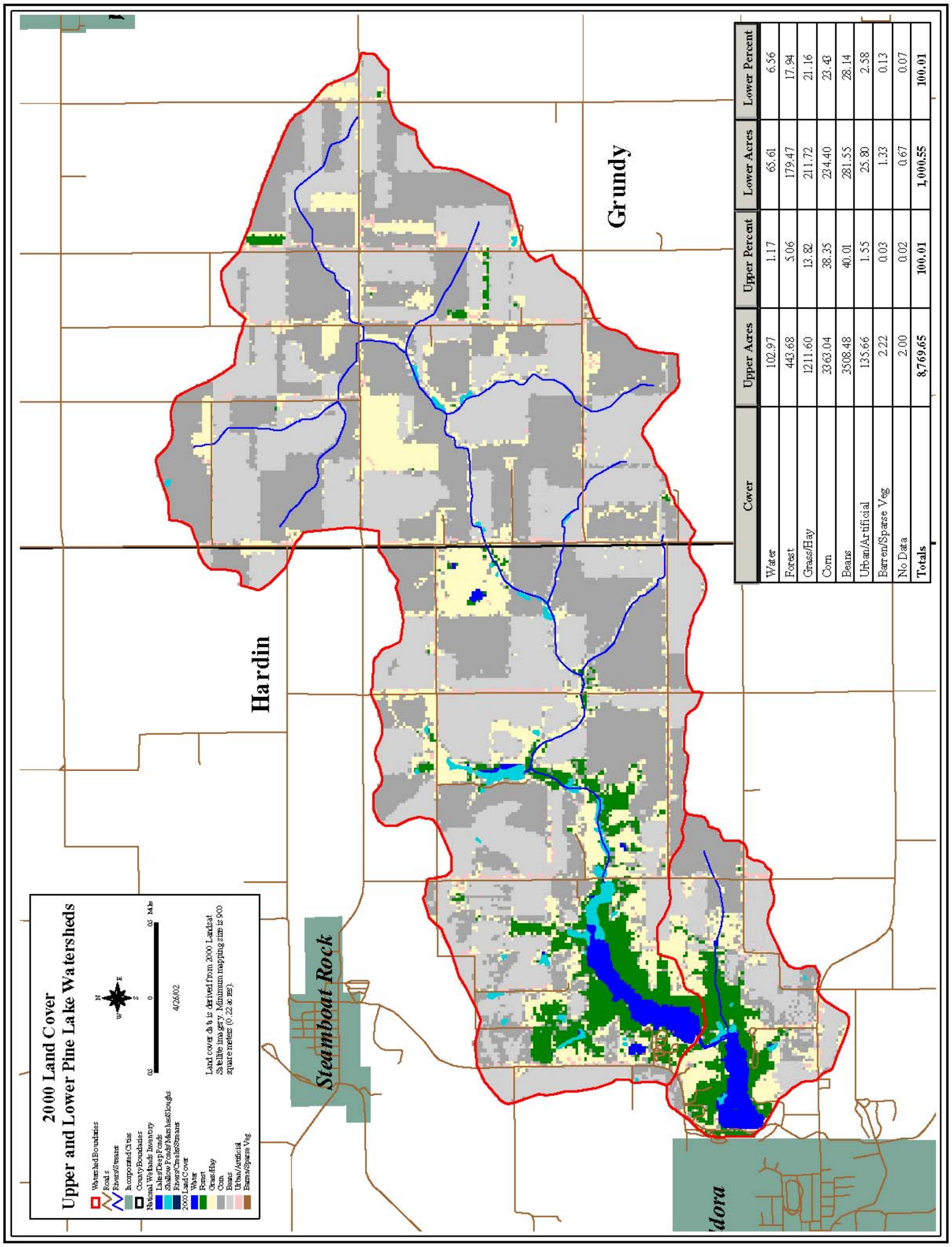
The Upper and Lower Pine Lake watershed area is about 9,680 acres of which 1,000 acres drains directly to Lower Pine Lake. The Lower Pine Lake watershed-to-lake ratio is 148:1 if the watershed that drains to Upper Pine Lake is included. An ideal ratio is 20:1. The consequence of a high ratio is that it does not require much from each watershed acre to overload the lake with nutrients and sediment. The watershed is 7 to 8 miles east to west and 2.5 to 3 miles north to south and drains east to west. There are not any urban areas within the watershed and the summerhouses and summer camps associated with Pine Lake State Park have received sewer service within the last few years. The collected wastewater is pumped to the City of Eldora's wastewater treatment plant.

Table 2, Watershed Characteristics

Upper and Lower Pine Lake Watershed Area	9,680 acres (1991)
Average Annual Precipitation	32 inches
Precipitation Highest Monthly Average	5.5 inches, June
Significant Sediment Point Sources	None
Stream Length, Pine Creek (doesn't include lakes)	6.9 miles

Topography and Soils:
In the watershed the upland terrain is gently rolling and leads to steeper slopes near Pine Creek. Closer to the lakes the land is moderately to strongly sloping. About 78% of the watershed is underlain by loess, 18% by alluvium, and 4% by sandstone, glacial till or sand. The soils that have developed over this all fall within the Group B hydrologic soil group. Group B soils have a moderate infiltration rate when thoroughly wet. They consist mainly of moderately deep or deep and moderately well-drained to well drained soils that have a moderately fine to moderately coarse texture and a moderate rate of water transmission.

Figure 2 Upper Pine Lake and its watershed



Cover	Upper Acres	Upper Percent	Lower Acres	Lower Percent
Water	102.97	1.17	65.61	6.56
Forest	443.68	5.06	179.47	17.94
Grass/Hay	1211.60	13.82	211.72	21.16
Corn	3363.04	38.35	234.40	23.43
Beans	3508.48	40.01	281.55	28.14
Urban/Artificial	135.66	1.55	25.80	2.58
Barren/Sparse Veg	2.22	0.03	1.33	0.13
No Data	2.00	0.02	0.67	0.07
Totals	**8,769.65**	**100.01**	**1,000.55**	**100.01**

Land Use

Table 3. 2000 Landuse in the Pine Lakes' Watershed

Landuse	Upper Pine watershed, acres	% of total	Lower Pine watershed, acres	% of Total
Water	103	1	66	7
Forest	444	5	179	18
Pasture & Hay	1212	14	212	21
Corn	3363	38	234	23
Soybeans	3508	40	282	28
Urban/Artificial	136	2	26	3
Barren or no data	4	<1	1	<1
Total	8770	100	1001	100

2.3. History and Background

The following table is a chronology of Lower and Upper Pine Lakes' and associated watershed activities.

Table 4. Lower and Upper Pine Lake Chronology

Year	Event
1922	Pine Lake created
1934	Dam built above Pine Lake to create Upper Pine Lake
1947	Hydrographic Survey of Upper Pine Lake
1961	Hydrographic Survey, lake drained, dam elevation raised 6 feet
1989-1990	Sept'89-Jun'90 Samples collected for Diagnostic Feasibility Study
1990	Hydrographic Surveys of Upper and Lower Pine Lakes Summer sampling for Classification of Iowa's Lakes for Restoration Study, Lower Pine Lake drained.
1991	May'91 ISU Study, Diagnostic Feasibility Report
1993-1998	Pine Lake Water Quality Project (3 yr study extended to 5 yr)
1997	DNR dredging at Upper and Lower Pine, sediment detention dike in Upper Pine
2000-2004	Summer sampling Iowa Lakes Survey
2005	Iowa Lakes Survey Report

There have been four recent projects or studies that have significant value for understanding the problems and potential solutions for Lower and Upper Pine Lake water quality problems.

1991 Upper and Lower Pine Lakes Restoration Diagnostic/Feasibility Study
The May 1991 Upper and Lower Pine Lakes Restoration Diagnostic/Feasibility Study (ISU Study) was a thorough review of the lake's past and existing condition. The study describes the origin of the sediment problem, quantifies it, and recommends steps to remedy it.

The Pine Creek Water Quality Project, 1993 to 1998
In 1993, the Hardin and Grundy County Soil and Water Conservation Districts began the Pine Creek Water Quality Project. The project implemented conservation practices as well as nutrient and best management strategies. These included:

- 60,888 feet of grassed waterways;
- 17,190 ft of terraces;
- 4 sediment and water control basins;
- numerous structures protecting 831 acres of drainage;
- critical area seeding;
- and streambank stabilization.

The project ended in 1998. Project staff used the Agricultural Non Point Source watershed model (AGNPS) to estimate the impact of erosion management and control on sediment delivery from watershed uplands. Implemented erosion control practices reduced sediment delivery an estimated 66%. These practices included 10,200 feet of 99-foot wide filter strips along Pine Creek

Clean Lakes Program, Phase II Project, Final Report
In 1997, both lakes were dredged. Forty thousand cubic yards were removed from Upper Pine Lake and 140,000 cubic yards were removed from Lower Pine. In addition, a 400-foot dike was constructed at the upper end of Upper Pine Lake to retain sediment and sediment adsorbed nutrients. In-lake and tributary monitoring collected data for water quality evaluations.

The Iowa State University Lake Study
The Iowa State University Lake Study began in 2000 and is scheduled to run five years. This study by the university Limnology Laboratory approximates a sampling scheme used by Roger Bachman in earlier Iowa lake studies. Samples are collected three times during the early, middle and late summer. Among the variables measured are secchi disk depth, phosphorous series, nitrogen series, TSS, and VSS. Data from 2000, 2001 and 2002 have been used to evaluate the lake's trophic state.

3. TMDL for Organic Enrichment

3.1 Problem Identification

Lower Pine Lake was put on the 1998 impaired water list for organic enrichment that causes low water column dissolved oxygen concentrations. In Lower Pine Lake the dissolved oxygen impairment is the result of algal decay oxygen demand. The direct organic enrichment indicator is chlorophyll. Chlorophyll estimates the algal biomass. Nuisance algal blooms are the consequence of excess nutrients, specifically phosphorous. Chlorophyll concentration is a gage of algal mass and total phosphorous concentration measures the availability of the limiting nutrient for algal growth.

Data collected in 1990, 1992, and more recently in 2000 and 2001 show intermittent drops in DO in the lower depths of the lake. Recent and historical measurements of in-lake conditions indicate that accelerated eutrophication caused by high phosphorous loading is the cause of Lower Pine Lake water quality impairments. The connection between hyper-eutrophic conditions and water quality impairment is well documented and recognized by the scientific community. These conditions promote heavy algal blooms through the summer and fall leading to the predominance of blue-green algae, limited clarity, floating algal scum, and the prevalence of rough fish.

The prevailing nutrient problem in Iowa lakes is excess phosphorous. Phosphorous is the limiting nutrient and controlling it means controlling the rate of eutrophication and the subsequent use impairments. The Lower Pine Lake hyper-eutrophic condition has led to the selection of total phosphorous as the indicator for the total maximum pollutant load to the lake.

Impaired Beneficial Uses and Applicable Water Quality Standards
The Iowa Water Quality Standards list the designated uses for Lower Pine Lake as:

- Class “A”. Primary Contact Recreation. Waters in which recreational or other uses may result in prolonged and direct contact with the water with the risk of ingesting water such as swimming, water skiing, and canoeing.

- Class “B (LW)”. Aquatic Life. Water in which a significant and viable aquatic community is maintained year round. Class B waters are to be protected for wildlife, fish, aquatic and semi-aquatic life, and secondary contact uses.

The “partially supported” assessment for aquatic life uses was made by IDNR staff based on information collected in the late 1980’s and early 1990’s for the 1991 ISU Diagnostic/Feasibilty Study and follow up monitoring and evaluation.

The following assessments are from relevant 305(b) Reports:

- *1994 Report based primarily on data from the 1991 ISU Study*. Fishable uses (aquatic life) were assessed as partially supported due to high total phosphorous concentrations, estimated summer fish kill frequency of 10 years, and excessive blue-green algae blooms in July and August. Organic enrichment leads to summer kills and excessive algae impairing primary contact recreation and aquatic life.
- *1996 Report based on 1994 assessment*. Assessed Partial Support of primary contact recreation and aquatic life uses. Reviewed 1992 and 1993 data and noted that data does not suggest problem with “chemical” water quality.
- *1998 Report based on 1996 assessment*. There was concurrence of IDNR Fisheries staff with the evaluation for Lower Pine Lake and that “nuisance blooms of algae and organic enrichment remained significant water quality

problems". Placed on the 1998 impaired waters list on the IDNR Fisheries Bureau recommendation.

- *2000 Report based on 1998 assessment and change in assessment methodology*. Primary contact recreation use is "not assessed" because of a lack of data on pathogen indicators and of recent data on algal conditions. Aquatic life use remains assessed as impaired. The IDNR Fisheries Bureau concurred with the aquatic life assessment.

The 1994 evaluation of partially supporting aquatic life use carried over into the 1996 and 1998 assessments resulting in the placement of Lower Pine Lake on the 1998 impaired waters list. The organic enrichment impairment is the consequence of high phosphorous concentrations leading to nuisance algal blooms. The algae blooms cause dissolved oxygen problems in two ways. Decaying algal biomass creates an oxygen demand in the lower part of the water column. There is frequent complete mixing of the water column from wind and waves because the lake is shallow so the oxygen demanding material is distributed bottom to top. The second DO problem caused by high algal biomass is the large diurnal swing in oxygen demand caused by darkness. As long as there is sunlight, the algae produce oxygen. At night the algae use DO to metabolize and DO problems are exacerbated. The shallowness of the lake also aggravates the problem in another way, sediment and adsorbed phosphorous are re-suspended by wind and wave energy.

Iowa has numeric water quality standards for water column dissolved oxygen but not for phosphorous. The DO criteria apply to the mixed upper layer of the water column. For a shallow frequently mixed lake this would include the entire water column. Data collected in the three most recent studies indicate that there are low dissolved oxygen concentrations in the lake. This data is included in Appendix B.

Data Sources
There are four sources of lake data that have been incorporated into this TMDL. These four sources collected data at different times in the life of the various watershed and waterbody improvement projects and are described in the watershed history section. The data sources are:

- May 1991 ISU Diagnostic/Feasibility Study.
- Final Report for the Pine Creek Water Quality Project, 1993-1998
- Clean Lakes Program Phase II Project Final Report, May, 1998
- ISU Iowa Lake Study, 2000 to 2005

Original dissolved oxygen, transparency, chlorophyll a, total phosphorous, and total nitrogen data from these sources can be found in Appendix B.

Interpreting Lower Pine Lake Water Quality Data
Since Iowa does not have numeric water quality criteria for nutrients or the associated organic enrichment, Carlson's Trophic State Index (TSI) can provide a framework for water quality data evaluation and interpretation. The equations

that generate the total phosphorous (TP), chlorophyll a (chlor a), and secchi depth (SD) index values are in Appendix B. The calculated TSI's for these three variables locate the lake in a continuum of trophic state from oligotrophic to hyper-eutrophic. TSI values can also indicate if a lake is phosphorous or light limited for algal growth. If the lake is phosphorous limited then the calculated TSI values for TP, chlor a, and SD are about the same. A lake is becoming more than just eutrophic at TSI's of 60 to 70. A TSI over 70 indicates a hypereutrophic condition.

Water Quality Conditions:
The TSI equations have been applied to the data collected in the years 2000, 2001, and 2002 for the 2000 ISU Iowa Lakes Study. The data for the ISU Lakes Study were collected in June, July and August. These are the months when algal productivity peaks because of longer daylight hours, higher temperatures, and higher nutrient inputs. The median values for total phosphorous, secchi, and chlorophyll data for these years have been determined from the annual averages and TSI's calculated in the following table.

	2000	**2001**	**2002**	**median**	**TSI**
Total P, ug/l	239	104	172	172	78.4
Chlor a, ug/l	13	32	113	32	64.6
Secchi D, m	0.5	1.0	0.5	0.5	69.7

These TSI values show that chlorophyll *a* does not respond to phosphorous concentration as predicted by the assumption of phosphorous availability as the limiting condition for algae productivity. This may be because:

- Chlorophyll *a* is not a good indicator of algal biomass in the lake.
- Macrophytes may be using a large fraction of the available phosphorous.
- An unusually large fraction of total phosphorous is not available for algal metabolism. TP strongly adsorbed on particulates.
- Light limits algal productivity, non-algal turbidity.
- Zooplankton grazing on algae.
- Insufficient, unrepresentative, and/or misleading data.

The variability in the calculated TSI values indicates that phosphorous may not always be the controlling factor for the lake's trophic state. It may also indicate that a greater fraction of measured TP than expected is not available for algal metabolism.

In 2001 Lower Pine Lake was described by IDNR Fisheries Bureau staff as follows: *The lake is prone to nuisance algal blooms, including blue-greens. The resulting turbidity is impacting reproduction of bass and bluegill. The size distribution for these species is skewed with poor recruitment for younger ages. The main problem is excess nutrients from the watershed promoting algal growth. There has been no record of winter fish kills but there have been some uninvestigated summer fishkills. The lake is not aerated. There is a large gizzard shad population. Gizzard shad are in direct competition with the bluegill* *and tolerate the variable water conditions better than the bluegill. There are also a substantial number of bottom feeding carp that contribute to turbidity problems.*

Potential Pollution Sources

Point Sources: No significant phosphorous point sources exist in the Lower Pine Lake watershed.

Non-point Sources**:** There are three non-point phosphorous sources to Lower Pine Lake. These are inflow from Upper Pine Lake, runoff from the directly draining 1,000 acre watershed, and the turbulent recycling of previously settled material.

Natural Background Conditions

Natural background contributions of phosphorous were not separated from the total non-point source load.

3.2 TMDL Endpoint

There a dual water quality targets for this TMDL. The first water quality target is based on a Phase 1 total phosphorous (TP) TSI target of 70 which is equivalent to a TP concentration of 100 ug/l. The difference between this target and the existing load is the load reduction needed to attain beneficial uses. The second target is the attainment of aquatic life uses as measured by biological assessment and fishery evaluation. Both of these targets will need to be met before the lake will be considered unimpaired

Criteria for Assessing Water Quality Standards Attainment

Numeric Water Quality Standards Criteria**:** There is not a numeric water quality criterion for chlorophyll or total phosphorous.

Quantification of Water Quality Standards Criteria: As previously illustrated, organic enrichment is a critical decrease in dissolved oxygen caused by the decay of large quantities of algae. In turn, large algal blooms are caused by excess phosphorous, which is the nutrient that limits algae production. Chlorophyll is an indicator of algal biomass and is related to the impairment through trophic state concepts that indicate support or non-support of the aquatic life uses.

Selection of Environmental Conditions

The "critical condition" for which this organic enrichment TMDL applies is the entire year. An annual loading period defines the phosphorous loading capacity of Lower Pine Lake. Some phosphorous loads are the result of periodic events such as rainfall and others are the result of sediment resuspension and nutrient recycling. Non-point source controls are targeted at times of high loading.

Waterbody Pollutant Loading Capacity

The load capacity for this organic enrichment TMDL is the annual amount of total phosphorous Lower Pine Lake can receive without causing water quality impairment. Based on lake response modeling, the targeted Phase 1 total phosphorus loading capacity is 2,000 pounds per year. The model predicts that at a load of 2,000 pounds per year, the Phase 1 TSI (TP) water quality target will be achieved

The Lower Pine Lake Phase 1 annual load capacity is **2000 pounds of total phosphorous per year.**

3.3. Pollution Source Assessment

There are three Lower Pine Lake phosphorous sources. The first is the discharge from Upper Pine Lake. The second is from the watershed areas that drain directly into the lake. The third source is from resuspension of sediment and entrained phosphorous. The loads from these sources will be evaluated as follows:

- The estimated load from Upper Pine Lake will be the average Upper Pine Lake phosphorous concentration times the annual Upper Pine Lake discharge.
- The load from direct drainage will be estimated using watershed modeling.
- The load from recycling of re-suspended phosphorous will be what is left after the other two sources have been subtracted from the total load estimate.

Existing Phosphorus Load
The estimated annual TP load to Lower Pine Lake is 8,000 pounds per year all of which is from non-point sources.

Departure from Phosphorous Load Capacity
The targeted total phosphorus load for Lower Pine Lake is 2,000 pounds per year based on in-lake response modeling results. To achieve and maintain water quality goals and protect for designated uses, a loading reduction is required. The estimated existing load to the lake is 8,000 pounds per year. This is 6,000 pounds per year over the TP load capacity.

Identification of Pollutant Sources
There are no significant phosphorous point sources in the Lower Pine Lake watershed.

Nonpoint source identification and quantification for phosphorus were established with data and modeling done for other projects and studies and through the application of lake response and watershed models. The estimated annual NPS TP load to Lower Pine Lake is 8,000 pounds per year. Of this,

- 4,000 pounds per year is delivered directly to Lower Pine Lake from Pine Creek and Upper Pine Lake,
- 2,700 pounds per year is from the watershed that drains directly to Lower Pine Lake, and
- 1,300 pounds per year is from re-suspension and recycling of previously settled phosphorous.

Linkage of Sources to Endpoint

The Lower Pine Lake average annual phosphorus load of 8,000 pounds originates entirely from nonpoint sources. To meet this TMDL's desired endpoint, the annual nonpoint source phosphorus contribution of 8,000 pounds needs to be reduced by 6,000 pounds per year.

3.4 Pollutant Allocation

Waste Load Allocation

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

Load Allocations

The Load Allocation (LA) for this TMDL is 2,000 pounds per year of total phosphorus and is distributed evenly among the identified nonpoint source categories.

- 1,000 pounds per year allocated to Pine Creek and Upper Pine Lake,
- 700 pounds per year allocated to the watershed that drains directly to Lower Pine Lake, and
- 300 pounds per year allocated to re-suspension and recycling of previously settled phosphorous.

Margin of Safety

The implicit margin of safety for this TMDL is the result of a conservative assumption.

- A significant part of water column total phosphorous is not available for algal growth as shown by the TSI values for TP and chlorophyll. It has been conservatively assumed that all TP will be expressed as algae. The TSI value for total phosphorous is 78 and for chlorophyll is 65. Every 10 TSI unit increase represents a doubling of algal biomass. The impairment is the result of algal productivity and therefore the MOS is more than 100% of the estimated chlorophyll.
- Additionally, there are dual targets for this TMDL that assure restoration of aquatic life uses regardless of the accuracy of the modeled total phosphorous load target of 2000 pounds per year. This TP load is the first target. The second target is the measurement of the aquatic life condition through bioassessment and fisheries studies. This assessment work will demonstrate whether the lake is still impaired.

3.5 Phosphorus TMDL Summary

WLA (0 pounds/year) + LA (2,000 pounds/year) / MOS (Implicit) = LC (2,000 pounds/year).

4. Implementation Plan

This TMDL implementation plan provides guidance for agencies and stakeholders working to improve Lower Pine Lake water quality. The emphasis is on non-point source reduction activities that target the non-point source categories of phosphorous. These include:

Discharge from Upper Pine Lake and the directly draining watershed:
Half of the phosphorous load to Lower Pine Lake flows out of Upper Pine Lake. An inventory should be made of watershed phosphorous applications. Since much of the phosphorous from the watershed is associated with sediment, controls that reduce erosion in the Upper and Lower Pine Lakes' watershed will reduce water column TP in both lakes.

Gully and stream bed and bank erosion: IDNR Fisheries and the NRCS have identified bed and bank erosion as the significant sediment source now that so many upland erosion controls have been initiated. Many significant stream and gully sediment contributions were identified in the 1998 Pine Creek Project Final Report and some stream bank restoration work was done. Additional problem locations should be identified. Restoration activities should be targeted at areas that are the largest contributors of sediment from eroding stream banks. Suggested controls are:

- Install check dams on smaller tributaries to reduce peak flows during runoff events.
- Install stream bank protection using vegetation and graded rock.
- Stabilize stream banks by shaping and removing overhangs.

Overland sheet and rill erosion: Erosion control activities, including the maintenance of installed structures, need to continue in the watershed. The watershed should be periodically evaluated and erosion control activities focused on identified large contributors of lake sediment. Emphasis should be on row crop fields close to the lake or stream and having steeper slopes without effective management practices in place. Suggested controls are:

- Management practices that will increase crop residue such as no-till farming,
- Construct terraces and grassed waterways.
- Install buffer strips along stream corridors.
- Construct grade stabilization structures to reduce head cutting and gully expansion.

Sediment resuspension and phosphorous recycling.
Up to a quarter of the phosphorous in the Lower Pine Lake water column results from recycling of phosphorous that previously settled to the bottom. This sediment entrained phosphorous is disturbed by wind action and large numbers of bottom feeding and dwelling fish. Suggested controls are:

- Reduce the numbers of bottom feeding fish.

- Minimize wind impacts with tree lines.

Phosphorous Reduction Goal
In addition to correction of the water quality impairment in Lower Pine Lake, the phosphorous reductions identified in this TMDL are necessary to protect the public investment in the Pine Lakes and Pine Lake State Park. If future evaluations of the lake condition indicate that the phosphorous delivery goal is inadequate to prevent impairment, the TMDL will be revised and new phosphorous allocations will be made.

5. Monitoring and Evaluation Plan

Monitor Lower Pine Lake to assess the lake's trophic state and compare it to the TP, chlorophyll, and secchi TSI objectives outlined in the TMDL. The monitoring and evaluation plan for Lower Pine Lake should consist of the following:

1. The most important information for evaluation is the measurement of total phosphorous, chlorophyll a, and secchi depth for the calculation of tropic state. This is being done for the 2000 ISU Iowa Lake Study until 2005.
2. Make a biological assessment to determine the current state of aquatic life uses.
3. Perform additional watershed modeling to improve knowledge of the origin of watershed phosphorous and to assess the effectiveness of implemented management practices.
4. Carry out continuous flow measurement of Upper Pine Lake discharge.

6. Public Participation

Public meetings regarding the procedure and timetable for developing the Lower Pine Lake TMDL were held on January 14, 2002, in Des Moines, Iowa; and on February 4, 2002 in Eldora, Iowa. The public notice period was from December 3, 2002 through December 14, 2002. The draft TMDL was available to the public on the IDNR Internet site and copies of the draft TMDL were be electronically distributed to stakeholders.

Public comment was received by email from one person regarding both Upper and Lower Pine Lakes. The comment suggested that tributary and lake shore erosion be addressed. This TMDL incorporated these comments as appropriate.

Commentators: Carl A. Carlson, 22587 V Avenue, Eldora, Iowa

7. References

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Appendix A: Model inputs

Short spreadsheet version of Eutromod Lake Response Component

Calibration of phosphorous load to in-lake data

Lower Pine Lake	Input data in green cells
Surface Acres (acres)	66
Lake Volume (ac-ft)	442
Inflow (ac-ft/year)	16000
Inflow (cfs)	
Annual Precipitation	32.0
Watershed P Loading (lbs)	**8000**
Detention Time (years)	*0.11*
Lake Volume (10^6 m^3)	*0.545*
Volumetric Water Load (10^6 m^3/yr)	*4.957*
Mean Depth (ft)	*6.70*
Mean Depth (m)	*2.041*
Watershed P Loading (kg)	3629
Precip P Load (kg)	*10.9*
Septic P Load (kg)	0
WWTF P Load (kg)	0
Total P Loading (kg)	*3640*
Total P Loading (lbs)	*8023.9*
Expected Total P-in	*0.734*

	Phosphorus (mg/l)	Chlorophyll a	Secchi Depth	Secchi Depth (inches)
Monitored In-lake Value	0.1720	32	0.51	20
Predicted	0.1718	18.80	0.227	8.9
% Similar	1.00	0.59	0.45	

	TSI - phosphorus	TSI - chlorophyll *a*	TSI - secchi	
Monitored In-lake Value	78.4	64.6	69.7	
Predicted	78.4	59.4	81.4	
% Similar	1.00	0.92	0.86	

Watershed load to meet in-lake p concentration (lbs)	Watershed load to meet in-lake Chlorophyll *a* (lbs)	Watershed load to meet in-lake secchi (lbs)

Load Summary	
Minimum	0
Mean	#DIV/0!
Median	#NUM!
Maximum	0

Estimated phosphorous load reduction required

Lower Pine Lake	Input data in green cells		Phosphorus (mg/l)	Chlorophyll a	Secchi Depth	Secchi Depth (inches)
Reduction %	75	Predicted	0.0912	13.61	0.343	13.5
Lake Volume (ac-ft)	442	Water Quality Goals	0.1000	20.00	0.76	30
Surface Acres (acres)	66	% Similar	0.91	0.68	0.45	
Detention Time (years)	0.11					
Watershed P Loading (lbs)	8000		TSI - phosphorus	TSI - chlorophyll *a*	TSI - secchi	MEAN TSI
Reduced Watershed Load (lbs)	*2000*	Predicted	69.2	56.2	75.4	66.9
Volumetric Water Load (10^6 m^3/yr)	*4.957*	Water Quality Goals	70.6	60.0	64.0	64.9
Lake Volume (10^6 m^3)	*0.545*	% Similar	0.98	0.94	0.85	0.97
Mean Depth (ft)	*6.70*					
Mean Depth (m)	*2.041*		Phosphorus load Reduction to meet p concentration water quality goal (lbs)	Phosphorus load reduction to meet Chlorophyll *a* water quality goal (lbs)	Phosphorus load reduction to meet secchi measurement goal (lbs)	
Watershed P Loading (kg)	3629		6000			
Precip P Load (kg)	10.9		Reduction Summary			
Septic P Load (kg)	*0*		Minimum	6000		
WWTF P Load (kg)	*0*		Mean	6000.00		
Total Reduced P Loading (kg)	*909.9*		Median	6000		
Total Reduced P Loading (lbs)	*2006.0*		Maximum	6000		
Expected Total P-in	*0.184*					

EUTROMOD is a water quality model that has two components. The first is the lake response model used in this TMDL. The second is a watershed nutrient loading model that has not been used here. The spreadsheet version used here was developed by the Nebraska Department of Environmental Quality. The NDEQ documentation for this version follows.

Instructions for Using the Lake Response Model
Simulation models facilitate the water quality planning process. One model is a spreadsheet-based program called EUTROMOD developed by Kenneth Reckhow of Duke University in 1992. The EUTROMOD model predicts watershed (nutrient) loading and in-lake conditions (water

transparency, chlorophyll *a,* and total phosphorus concentration) based on land use, waterbody physical characteristics and other factors.

The accuracy of a model depends on the quality of data and information inputs. Model outputs are expressed as "average annual conditions". Although simple compared to some other water quality models like AGNPS and SWAT, the watershed loading part of EUTROMOD requires information on land use, soil erodibility, cropping factors, sediment-attached nutrient concentrations, trapping efficiencies, etc. The data and information must represent "average" conditions that can be difficult to define.

Several variables can contribute to or influence the water quality response to nutrient inputs and, while models can predict waterbody conditions, it is difficult to dispute water quality data and information collected directly from the waterbody in question. The Nebraska Department of Environmental Quality has been monitoring lakes and reservoirs for several years and has developed a process whereby average annual conditions are described. What is lacking for several waterbodies is a measurement or an estimation of the annual nutrient "load" delivered to the lake.

The lake response model part of EUTROMOD requires minimal input to predict lake trophic conditions and average annual nutrient load. The Lake Response Model spreadsheet was developed using minimum inputs and calculations needed for the lake response part of the EUTROMOD water quality model.

In-Lake Calibration Worksheet

The following information is needed to complete the in-lake calibration worksheet. The cells that require inputs have been shaded green as shown in the calibration spreadsheet above.

Input	Units
Lake Surface Area	Acres
Lake Volume	Acre-Feet
Tributary/Watershed Inflow	Acre-feet/year or cubic feet/second
Annual Precipitation	Inches/Year
Observed In-lake Total Phosphorus	mg/l
Observed Chlorophyll *a*	mg/m^3
Observed In-lake transparency (secchi depth)	inches

Once the data has been entered, the phosphorus load (lbs/year) cell, shaded orange can be manipulated until the predicted conditions match the selected observed conditions. Input the value determined to best match the parameter (total p, chlorophyll a or secchi depth) into the appropriate cell.

Typically, the phosphorus load arrived at and used in waterbody planning (i.e. watershed management plans, TMDLs) will be based upon a calibration of the in-lake total phosphorus concentration. Regardless of which load is used, the in-lake response worksheet must be completed and remain completed before moving on, as the cells are linked.

On all worksheets, trophic state indices as defined by Carlson (1977, 1996) will be calculated for both the manually input and predicted water quality conditions.

Total Phosphorus and Watershed Load Reduction Worksheets

Water quality planning may include managing waterbody to meet water quality targets, goals or criteria (goals) for in-lake phosphorus, chlorophyll *a* or water transparency. Meeting these goals may require a reduction in the phosphorus load. To determine the load necessary to meet these goals, two worksheets have been developed. The Total Phosphorus Load Reduction Worksheet considers a reduction in the total load. That is, all source (watershed, precipitation, septic tanks and wastewater treatment facilities) loads are reduced equally. To complete this spreadsheet, the water quality goals for in-lake phosphorus, chlorophyll *a* or water transparency should be entered into the green cells. The orange reduction cell can then be varied until the predicted value(s) is/are equivalent to the water quality goals. The reduction should be a percentage reduction and input as a whole number (50, 80, etc.) not a decimal.

References

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Carlson, R.E. and J. Simpson. 1996 A coordinator's guide to volunteer monitoring methods. North American Lake Management Society and the Educational Foundation of North America.

Reckhow, K.H. 1992 EUTROMOD Nutrient Loading and Lake Eutrophication Model. Duke University School of the Environment. Durham, North Carolina.

Appendix B. Data and Data Evaluation

Lower Pine Lake - data used to develop TSI evaluation of nutrient condition
Data from three different studies:
1. Phase 1, 1991 Diagnostic/Feasibility Study
2. Phase 2, 1998 Project Final Report
3. ISU 2000 Iowa Lakes Study

Phase 1, 1991 Project Final Report Data, TSI development data
Top Layer, 0.5 m

date	SD	TP	Chlor a	TN
9/18/1989	1.2	111	1.8	1.43
10/2/1989	0.9	280	92.8	2.73
10/25/1989	0.6	128	9.5	2.73
12/20/1989	2.5	76	2.19	2.72
1/20/1990	2.4	45	1.58	2.86
2/24/1990	1.5	39	12.9	2.47
3/31/1990	0.7	126	67.7	3.95
4/27/1990	2.5	76	4.1	3.22
5/11/1990	1.0	80	27.7	4.27
5/30/1990	1.6	109	5.66	11.25
6/12/1990	0.6	61	3.12	11.52

TSI summer values, July and August data not available

date	SD	TP	Chlor a	TN
9/18/1989	1.2	111	1.8	1.43
5/30/1990	1.6	109	5.66	11.25
6/12/1990	0.6	61	3.12	11.52
average	**1.1**	**93.7**	**3.5**	**8.1**
stddev	**0.5**	**28.3**	**2.0**	**5.7**
TSI 0.5m	**58.2**	**69.6**	**43.0**	**84.6**

Phase 1, 1991 Project Final Report Data, TSI development data
Middle Layer, 1.5 m

date	SD	TP	Chlor a	TN
9/18/1989	1.2	123	7.2	1.52
10/2/1989	0.9	253	126.1	2.51
10/25/1989	0.6	126	12.6	2.47
12/20/1989	2.5	74	2.49	2.71
1/20/1990	2.4	47	3.78	2.95
2/24/1990	1.5	111	7.66	2.8
3/31/1990	0.7	90	23.1	3.4
4/27/1990	2.5	249	2.24	3.29
5/11/1990	1.0	121	5.43	4.25
5/30/1990	1.6	107	3.67	11.58
6/12/1990	0.6	128	6.24	11.7

TSI summer values, July and August data not available

date	SD	TP	Chlor a	TN
9/18/1989	1.2	123	7.2	1.52
5/30/1990	1.6	107	3.67	11.58
6/12/1990	0.6	128	6.24	11.7
average	**1.1**	**119.3**	**5.7**	**8.3**
stddev	**0.5**	**11.0**	**1.8**	**5.8**
TSI 0.5m	**58.2**	**73.1**	**47.7**	**84.9**

Lower Pine Lake - data used to develop TSI evaluation of nutrient condition
Data from three different studies:
1. Phase 1, 1991
Diagnostic/Feasibility Study
2. Phase 2, 1998 Project Final Report
3. ISU 2000 Iowa
Lakes Study

TSI development data from Phase 2, 1998 Project Final Report Data
Top Layer,
0.5 m

date	SD	TP	Chlor a	TN
5/6/1992	2.2	34	6.16	8.28
5/28/1992	4.0	39	0	5.48
6/4/1992	3.3	42	13.58	6.2
6/26/1992	1.4	71	18.17	4.22
7/10/1992	0.8	87	52.81	4.05
7/23/1992	0.7	99	45.59	3.56
8/12/1992	0.6	79	47.63	5.32
8/25/1992	0.7	82	?6.61	2.95
9/17/1992	0.7	78	46.59	1.74
9/29/1992	0.6	139	67.06	1.9
10/20/1992	0.7	117	5.11	1.31
11/4/1992	1.7	108	21.13	1.5
12/2/1992	1.0	71	31.42	4.18
1/21/1993	1.9	36	22.64	6.15
2/24/1993	1.6	42	10.48	7.96
3/18/1993	0.4	514	14.42	4.71
4/22/1993	1.0	121	0	8.02

TSI summer values

date	SD	TP	Chlor a	TN
6/4/1992	3.3	42	13.58	6.2
6/26/1992	1.4	71	18.17	4.22
7/10/1992	0.8	87	52.81	4.05
7/23/1992	0.7	99	45.59	3.56
8/12/1992	0.6	79	47.63	5.32
8/25/1992	0.7	82	6.61	2.95
average	**1.3**	**76.7**	**30.7**	**4.4**
stddev	**1.0**	**19.4**	**20.1**	**1.2**
TSI 0.5m	**56.8**	**66.7**	**64.2**	**75.8**

TSI development data from Phase 2, 1998 Project Final Report Data
Middle Layer, 2.0 m

date	SD	TP	Chlor a	TN
5/6/1992	2.2	60	16.73	8.42
5/28/1992	4.0	42	2.15	6.14
6/4/1992	3.3	33	3.85	6.4
6/26/1992	1.4	---	---	---
7/10/1992	0.8	---	---	---
7/23/1992	0.7	---	---	---
8/12/1992	0.6	---	---	---
8/25/1992	0.7	129	5.67	3.55
9/17/1992	0.7	85	37.52	1.95
9/29/1992	0.6	158	46.48	1.76
10/20/1992	0.7	131	5.42	1.34
11/4/1992	1.7	128	25.57	1.44
12/2/1992	1.0	71	29.7	5.63
1/21/1993	1.9	20	22.64	5.84
2/24/1993	1.6	32	7.26	5.9
3/18/1993	0.4	349	1.92	11.01
4/22/1993	1.0	10	8.7	7.84

TSI summer values

date	SD	TP	Chlor a	TN
5/28/1992	4.0	42	2.15	6.14
6/4/1992	3.3	33	3.85	6.4
6/26/1992	1.4	---	---	---
7/10/1992	0.8	---	---	---
7/23/1992	0.7	---	---	---
8/12/1992	0.6	---	---	---
8/25/1992	0.7	129	5.67	3.55
9/17/1992	0.7	85	37.52	1.95
average	**1.3**	**81.0**	**4.8**	**5.0**
stddev	**1.0**	**67.9**	**1.3**	**2.0**
TSI 0.5m	**56.8**	**67.5**	**45.9**	**77.6**

Lower Pine Lake - data used to develop TSI evaluation of nutrient condition
Data from three different studies:
1. Phase 1, 1991 Diagnostic/Feasibility Study
2. Phase 2, 1998 Project Final Report
3. ISU 2000 Iowa Lakes Study

date	SD	TP	Chlor a	TN
7/10/2000	0.3	406	20	6.02
7/31/2000	0.5	117	14	5.17
8/28/2000	0.7	194	4	2.86
6/4/2001	1.1	78	18	
7/9/2001	1.1	103	43	
8/6/2001	0.8	131	34	
2002, all 3	0.5	172	113	
average	**0.8**	**171.5**	**22.2**	**4.7**
stddev	**0.3**	**121.3**	**14.1**	**1.6**
TSI 0.5m	**64.1**	**78.3**	**61.0**	**76.7**

Data from summer 2000

date	SD	TP	Chlor a	TN
7/10/2000	0.3	406	20	6.02
7/31/2000	0.5	117	14	5.17
8/28/2000	0.7	194	4	2.86
average	**0.5**	**239.0**	**12.7**	**4.7**
stddev	**0.2**	**149.7**	**8.1**	**1.6**
TSI 0.5m	**70.0**	**83.1**	**55.5**	**76.7**

Data from summer 2001

date	SD	TP	Chlor a
6/4/2001	1.1	78	18
7/9/2001	1.1	103	43
8/6/2001	0.8	131	34
average	**1.0**	**104.0**	**31.7**
stddev	**0.2**	**26.5**	**12.7**
TSI 0.5m	**60.0**	**71.1**	**64.5**

Data from summer 2002

date	SD	TP	Chlor a
all 3	0.5	172	113

Carlson's TSI Equations:

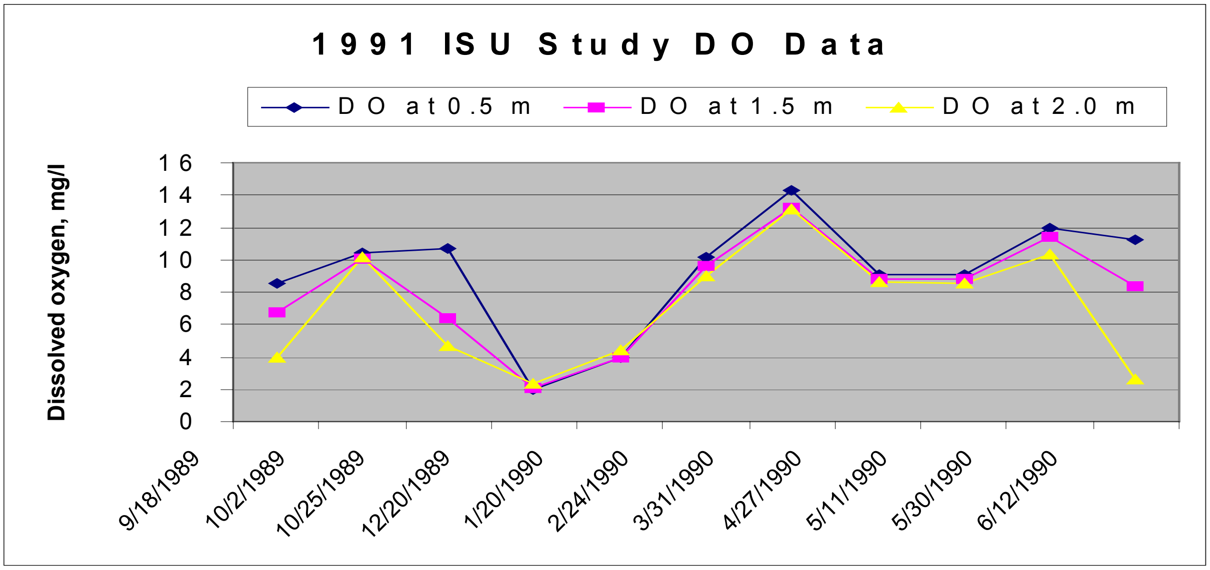
TSI (SD) = 60 – 14.41 (ln SD)
TSI CHL) = 9.81 (ln CHL) + 30.6
TSI (TP) = 14.42 (ln TP) + 4.15

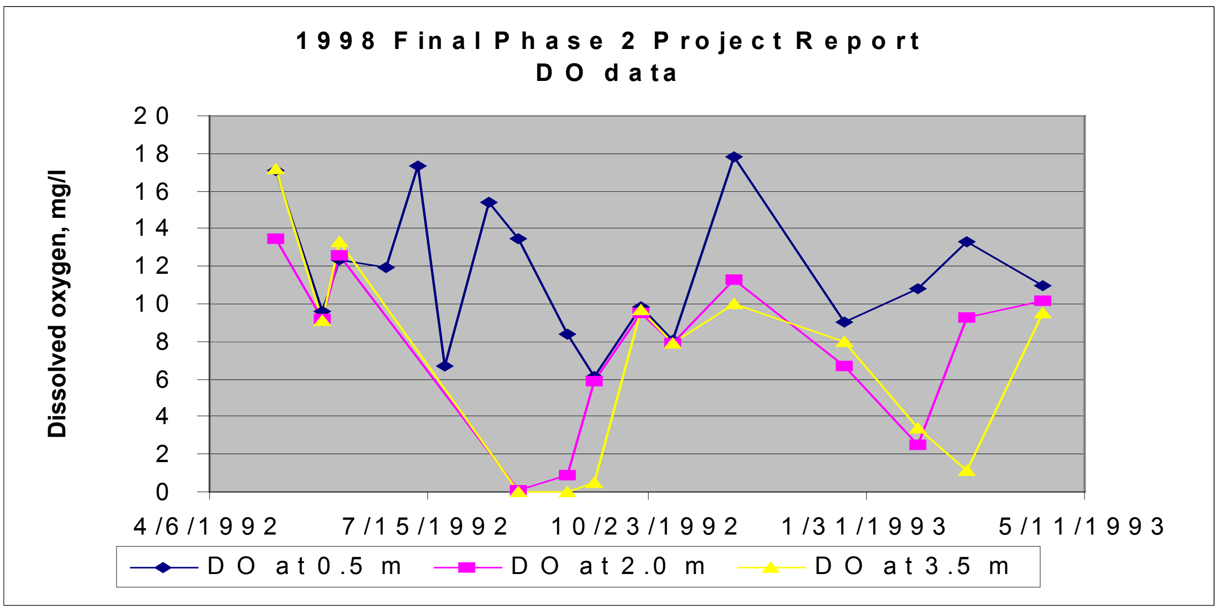
Lower Pine Lake - dissolved oxygen data for evaluation of nutrient condition
Data from three different studies:
1. Phase 1, 1991 Diagnostic/Feasibility Study
2. Phase 2, 1998 Project Final Report
3. ISU 2000 Iowa Lakes Study

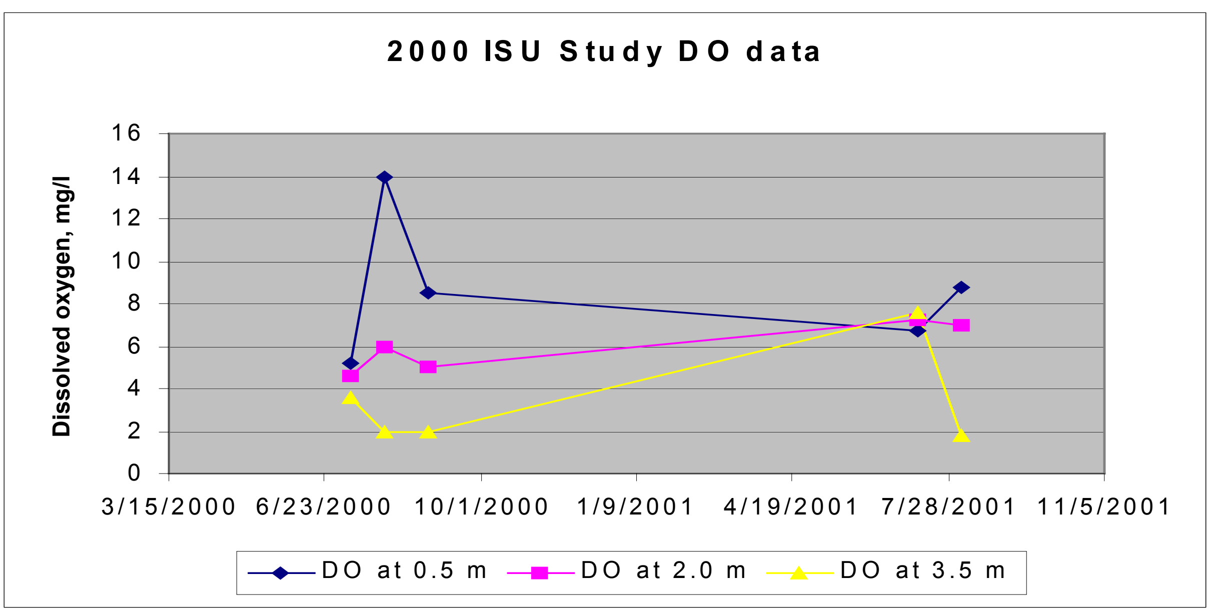
date	DO at 0.5 m	DO at 1.5 m	DO at 2.0 m
9/18/1989	8.5	6.7	4
10/2/1989	10.4	10.1	10.2
10/25/1989	10.7	6.4	4.7
12/20/1989	2	2.1	2.3
1/20/1990	4	4	4.4
2/24/1990	10.2	9.6	9
3/31/1990	14.3	13.2	13.1
4/27/1990	9.1	8.8	8.6
5/11/1990	9.1	8.8	8.5
5/30/1990	12	11.4	10.3
6/12/1990	11.2	8.4	2.6

date	DO at 0.5 m	DO at 2.0 m	DO at 3.5 m
5/6/1992	17.1	13.5	17.2
5/28/1992	9.6	9.2	9.1
6/4/1992	12.3	12.6	13.3
6/26/1992	11.9	#N/A	#N/A
7/10/1992	17.3	#N/A	#N/A
7/23/1992	6.7	#N/A	#N/A
8/12/1992	15.4	#N/A	#N/A
8/25/1992	13.5	0.1	0
9/17/1992	8.4	0.9	0
9/29/1992	6.1	5.9	0.5
10/20/1992	9.8	9.5	9.7
11/4/1992	8.1	7.9	7.9
12/2/1992	17.8	11.3	10
1/21/1993	9	6.7	8
2/24/1993	10.8	2.5	3.4
3/18/1993	13.3	9.3	1.1
4/22/1993	11	10.2	9.5

date	DO at 0.5 m	DO at 2.0 m	DO at 3.5 m
7/10/2000	5.2	4.6	3.6
7/31/2000	14	6	2
8/28/2000	8.5	5	2
6/4/2001	#N/A	#N/A	#N/A
7/9/2001	6.7	7.2	7.6
8/6/2001	8.8	7	1.8


1991 ISU Study DO Data
DO at 0.5 m
DO at 1.5 m
DO at 2.0 m
Dissolved oxygen, mg/l
16
14
12
10
8
6
4
2
0
9/18/1989
10/2/1989
10/25/1989
12/20/1989
1/20/1990
2/24/1990
3/31/1990
4/27/1990
5/11/1990
5/30/1990
6/12/1990


1998 Final Phase 2 Project Report
DO data
Dissolved oxygen, mg/l
20
18
16
14
12
10
8
6
4
2
0
4/6/1992
7/15/1992
10/23/1992
1/31/1993
5/11/1993
DO at 0.5 m
DO at 2.0 m
DO at 3.5 m


2000 ISU Study DO data
Dissolved oxygen, mg/l
16
14
12
10
8
6
4
2
0
3/15/2000
6/23/2000
10/1/2000
1/9/2001
4/19/2001
7/28/2001
11/5/2001
DO at 0.5 m
DO at 2.0 m
DO at 3.5 m