Total Maximum Daily Load
For Algae and Turbidity
Trumbull Lake
Clay County, Iowa

2006

Iowa Department of Natural Resources
Watershed Improvement Section

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1. Summary

Table 1.1. Trumbull Lake Summary

Waterbody Name:	Trumbull Lake
County:	Clay
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	East Fork Des Moines River Basin
Pollutant:	Total Phosphorus
Pollutant Sources:	Watershed non-point and point, internal recycle, atmospheric deposition
Impaired Use(s):	A1 (primary contact recreation) B(LW) (aquatic life)
2002 303d Priority:	Medium
Watershed Area:	50,747 acres
Lake Area:	1,076 acres
Lake Volume:	3,575 acre-ft
Detention Time (outlet):	0.11 years
Trophic State Index (TSI) Targets:	Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65
Total Phosphorus Load Capacity (TMDL):	External = 7,760 lbs/year [1] Internal = 4,750 lbs/year [2]
Existing Total Phosphorus Load:	External = 21,800 lbs/ year [1] Internal = 13,200 lbs/year [2]
Load Reduction to Achieve TMDL:	External = 14,040 lbs/year [1] Internal = 8,450 lbs/year [2]
Margin of Safety	External = 750 lbs/year [1] Internal = 480 lbs/year [2]
Wasteload Allocation, City of Terrill	External = 250 pounds per year [1]
Load Allocation	External = 6,760 lbs/year [1] Internal = 4,270 lbs/year [2]

1. The model used to evaluate total phosphorous (TP) loads to the lake separates delivered watershed loads (external) from those that are the result of recycling of phosphorous in resuspended sediment.
2. The internal loads estimated by the model are not the equivalent of external loads on a mass basis. Therefore, they have been treated separately for this report.

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. Trumbull Lake has been identified as impaired by algae and turbidity. The purpose of these TMDL's for Trumbull Lake is to calculate the maximum allowable phosphorous, chlorophyll, and turbidity loading for the lake associated with algae and turbidity levels that will meet water quality standards.

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

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

Section 5.0 of this TMDL includes a description of planned monitoring. The TMDL will have two phases. Phase 1 will consist of setting specific and quantifiable targets for total phosphorus, algal biomass and Secchi depth expressed as Carlson's Trophic State Index and taking measures to achieve these targets as resources allow. Phase 2 will consist of implementing the monitoring plan, evaluating collected data, and readjusting target values if needed.

Monitoring is essential to all TMDLs in order to:

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

The additional data collected will be used to determine if the implemented TMDL and watershed management plan have been or are effective in addressing the identified water quality impairments. The data and information can also be used to determine if the 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:** Trumbull Lake, Sec. 27, T97N, R35W, four miles northwest of the City of Ruthven.

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

3. **Quantification of the pollutant load that may be present in the waterbody and still allow attainment and maintenance of water quality standards:** The Phase 1 target of this TMDL is a Carlson's Trophic State Index (TSI) of less than

70 for total phosphorus, and TSI values of less than 65 for both chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for Secchi depth, chlorophyll a and total phosphorus based on 2000 to 2005 sampling are 0.2 meters, 129 ug/L and 269 ug/L, respectively. A minimum in-lake increase in Secchi transparency of 250% and minimum in-lake reductions of 74% for chlorophyll a and 64% for total phosphorus are required to achieve and maintain lake water quality goals and protect for beneficial uses. The estimated existing annual total phosphorus load to Trumbull Lake from the watershed, the external load, is 21,800 pounds per year. The estimated existing annual total phosphorus load to Trumbull Lake from internal recycling of phosphorous from bottom sediments, the internal load, is 13,200 pounds per year. Based on lake response modeling the external loading capacity for the lake is 7,760 pounds per year and the internal loading capacity is 4,750 pounds per year. The required load reduction is 64% for both watershed and recycled pollutant sources.

5. **Identification of pollution source categories:** Nonpoint, point, and atmospheric deposition (background) watershed sources and internal recycling of phosphorus from the lake bottom sediments are identified as the cause of impairments to Trumbull Lake.

6. **Wasteload allocations for pollutants from point sources:** One point source has been identified in the Trumbull Lake watershed, the City of Terrill wastewater treatment plant (WWTP). The total phosphorous wasteload allocation for this point source is 250 pounds per year.

7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus allocation for the watershed, the external loads is 6,760 pounds per year including 350 pounds attributable to atmospheric deposition. The allocation for the recycled total phosphorous, the internal load, is 4,270 pounds per year.

8. **A margin of safety:** An explicit numerical margin of safety (MOS) that is 10% of the calculated allowable phosphorus load has been included to ensure that the load allocations will result in attainment of water quality targets. The MOS for external loads is 750 pounds per year and for internal loads is 480 pounds per year.

9. **Consideration of seasonal variation:** This TMDL was developed based on the annual phosphorus loading that will result in attainment of TSI targets for the growing season (May through September).

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for increased phosphorus loading was not included in this TMDL. Significant changes in the Trumbull Lake watershed landuses are unlikely. The Iowa Department of Natural Resources (IDNR) maintains the entire shoreline around the lake. Most of the watershed landuse is in agricultural production with row crops predominating. The addition of animal feeding operations could increase loading. Increases in the rough fish population or activities that add to lake turbulence could re-suspend sediment and increase internal phosphorus loading. These conditions are not expected to change so an allowance future pollutant increases was not included in the TMDL.

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

2. Trumbull Lake, Description and History

2.1 The Lake

Trumbull Lake is located in northwest Iowa, four miles northwest of Ruthven. Public use of the lake is averages 20,000-day trips per year. Users of the lake and the adjoining Smith Slough and Trumbull Lake Wildlife Management Areas enjoy fishing, boating, and hunting. Trumbull Lake is classified as a Significant Publicly Owned Lake. Other lake information is in Table 2.1. The Figure 1 map shows the lake and its watershed.

Table 2.1. Trumbull Lake

Waterbody Name:	**Trumbull Lake**
Hydrologic Unit Code:	HUC10 1023000307
IDNR Waterbody ID:	IA 06-LSR-02450-L
Location:	Section 27 T97N R35W
Latitude:	43° 11’ N
Longitude:	94° 57’ W
Water Quality Standard Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	Two unnamed tributaries
Receiving Waterbody:	Headwaters of Pickerel Run
Lake Surface Area:	1,076 acres
Maximum Depth:	4 feet
Mean Depth:	3.3 feet
Volume:	3,575 acre-feet
Length of Shoreline:	38,000 feet
Watershed Area:	50,747 acres
Watershed/Lake Area Ratio:	46.2
Lake Detention Time (outlet):	0.11 years

Morphometry

Trumbull Lake has a mean depth of 3.3 feet and a maximum depth of 4.0 feet. The lake surface area is 1,076 acres and the storage volume is 3,575 acre-feet. Temperature and dissolved oxygen sampling indicate that Trumbull Lake does not stratify and remains mixed and oxic the entire year.

Hydrology

Trumbull Lake has two major surface tributaries. An unnamed drainage ditch from Drainage District 61 enters the northwest end of Trumbull Lake. A second tributary is a marsh causeway on the southeast corner of the Lake. This causeway drains from Mud Lake and drains the eastern portion of the watershed. The Trumbull Lake outlet is the headwaters for Pickerel Run drainage ditch that is a tributary to Lost Island Lake Outlet. The annual average detention time for Trumbull Lake is 0.11 years (40 days) based on outflow. The methodology and calculations used to determine the detention times are shown in Appendix A. Average rainfall in the area is 28.5 inches/year.

2.2 The Watershed

The Trumbull Lake watershed has a drainage area of 49,671 acres and has a watershed to lake ratio of 46:1. Landuses and associated areas for the watershed are listed in Table 2.2. The 2002 landuse map is shown in Appendix D. The Iowa Department of Natural Resources (IDNR) owns or maintains the entire shoreline around the lake.

Table 2.2 Landuse in Trumbull Lake Watershed

Landuse	Area in Acres [1]	Percent of Total Area
Row Crop	40,600	82
Grassland/pasture/CRP	7,900	16
Forest	500	1
Other (roads, farmsteads)	500	1
Total	49,500	100

1. Areas rounded to nearest hundreds.

The City of Terrill, population 404, is located within the Trumbull Lake watershed. The city has a wastewater treatment facility that consists of a two-cell controlled discharge facultative lagoon. It discharges to Drainage District 61's main ditch seven miles upstream of Trumbull Lake. The remaining watershed population uses onsite septic tank systems for wastewater treatment. Based on a survey done by the Clay County sanitarian, many of these onsite systems consist of a septic tank discharging directly to a ditch or tile.

There is one confined animal feeding operation and one open feedlot within the watershed. Open feedlots are unroofed or partially roofed animal feeding operations in which no crop, vegetation, or forage growth or residue cover is maintained during the period that animals are confined in the operation. Runoff from open feedlots can deliver substantial quantities of nutrients to a waterbody dependent upon factors such as proximity to a water surface, number and type of livestock and manure controls.

Soils

Topography in the watershed is level to strongly sloping (0-14%). Soils are well drained to very poorly drained and developed in loamy or silty Wisconsin till and associated loamy or silty sediments on uplands. Native vegetation was tall prairie grasses.

Predominate soils include the Clarion, Nicollet, Canisteo, Webster, and Okoboji series. Minor soils include the Storden and Salida.

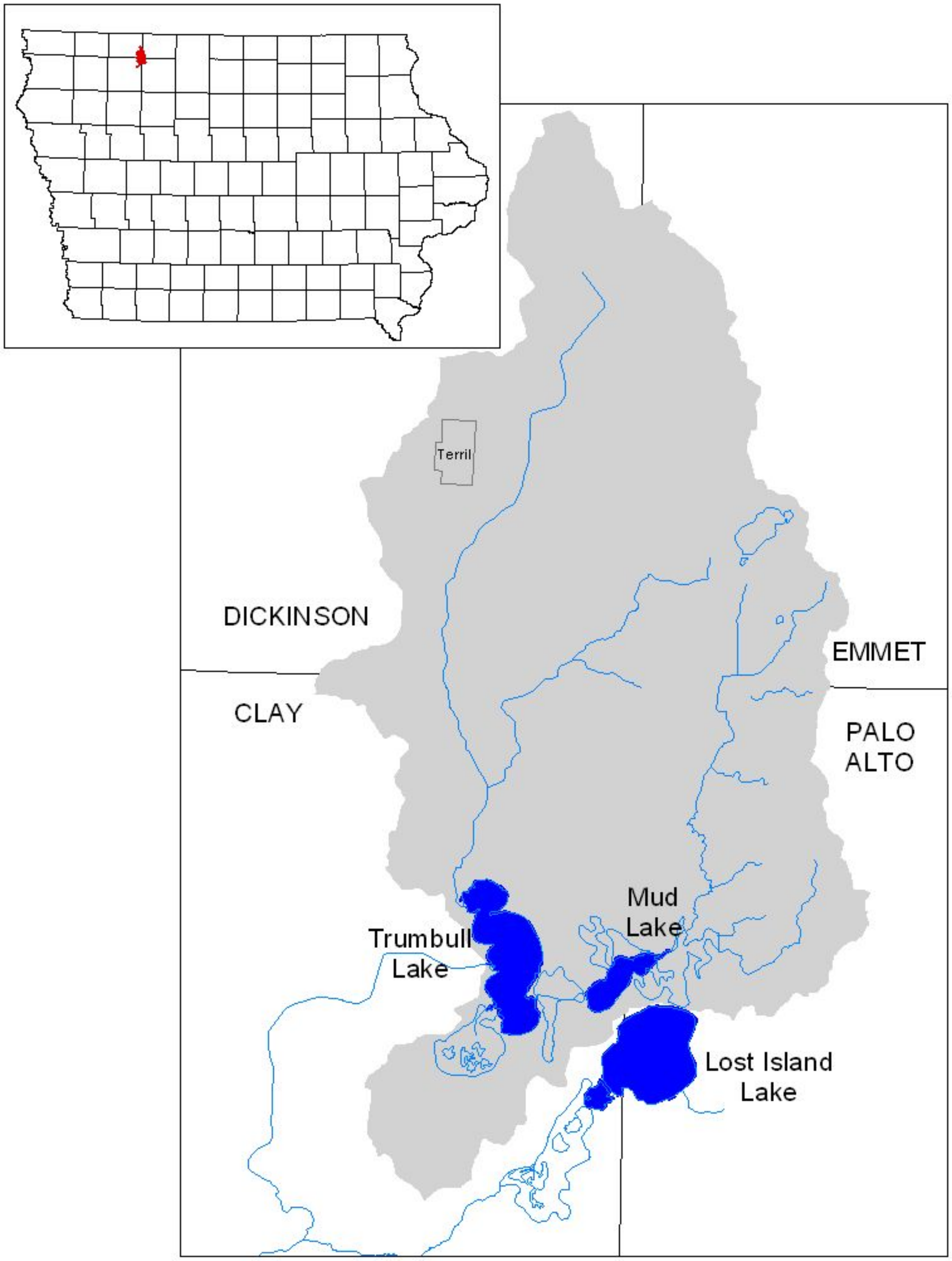


Figure 1. Trumbull Lake Watershed

3. TMDL for Algae and Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (IAC 567-61) list the designated uses for Trumbull Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). Trumbull Lake was listed originally in 1998 for low dissolved oxygen. The impairment was changed in the 2002 impaired waters list to algae and turbidity impairments with the Class A use assessed (monitored) as “not supporting” and the Class B use assessed (evaluated) as “partially supporting”. The difference between a “monitored” and an “evaluated” assessment is that a monitored assessment is based on recent water quality data and an evaluated assessment is based on the best professional judgment of IDNR staff. A monitored assessment is considered more reliable and a monitored “not supporting” or “partially supporting” evaluation will usually result in a listing as an impaired water.

The Class A Primary Contact Recreation Use was assessed as “not supporting” due to extremely large populations of suspended algae and high turbidity caused by algal blooms and sediment resuspension. These conditions have produced aesthetically objectionable conditions that violate the narrative criteria in the Iowa water quality standards. This impaired condition is aggravated by the composition of the suspended algae. The average blue-green algae fraction of the ISU lake study (3) is 73%. Blue-green algae are associated with objectionable odors; dense floating algal mats, and can produce toxins such as microcystin.

The Class B use was assessed as “partially supporting” due to the excessive water column nutrient loading, nuisance algal blooms, and re-suspension of sediment. The 2004 assessment was similar to the 2002 assessment.

Data Sources

The primary data used to assess Trumbull Lake water quality and to develop this TMDL are from the Iowa State University Lake Study (3) begun in 2000. The study data were collected from 2000 and 2005 and are summarized in Appendix B. This data was collected during three summer growing season sampling visits. The samples were analyzed for variables including total and volatile suspended solids, secchi depth, chlorophyll, and the important forms of phosphorous and nitrogen for water quality evaluation. Samples were also examined for phytoplankton and zooplankton composition.

Targeted TMDL monitoring was done in 2005. The averaged in-lake concentration samples were very similar to those from the six years of ISU data. The six-year average ISU total phosphorous concentration was 269 ug/l and for the 2005 targeted in-lake TMDL sampling was 268 ug/l. The TMDL monitoring included nine in-lake samples taken between April and October 2005 and is summarized in Appendix B.

Interpreting Trumbull Lake Water Quality Data

Based on mean values from ISU sampling during 2000 to 2005, the ratio of total nitrogen to total phosphorus for this lake is 16.7. This ratio indicates that nitrogen is not the limiting nutrient in Trumbull Lake.

Review of inorganic suspended solids data from the 2000 to 2005 ISU sampling suggest that this lake may be subject to episodes of high non-algal turbidity. For the 2004 305b water quality assessment, data from 2000, 2001 and 2002 was used to rank the 131 study lakes by median inorganic suspended solids. 2002 was the cutoff for data used in the 2004 305b assessment report. The median level of inorganic suspended solids in the 131 lakes sampled for the ISU lake survey in 2000, 2001, and 2002 was 5.27 mg/L. The median level of inorganic suspended solids at Trumbull Lake during the same time period was 41 mg/l, ranking it the second highest inorganic suspended solids concentration of the 131 lakes evaluated.

Carlson's trophic state index (TSI) has been used in this report to relate algae, as measured by chlorophyll, transparency, as measured by secchi depth, and total phosphorous to one another and to set water quality improvement targets. TSI values for monitoring data are shown in Table 3.1 and a detailed explanation of the TSI can be found in Appendix C.

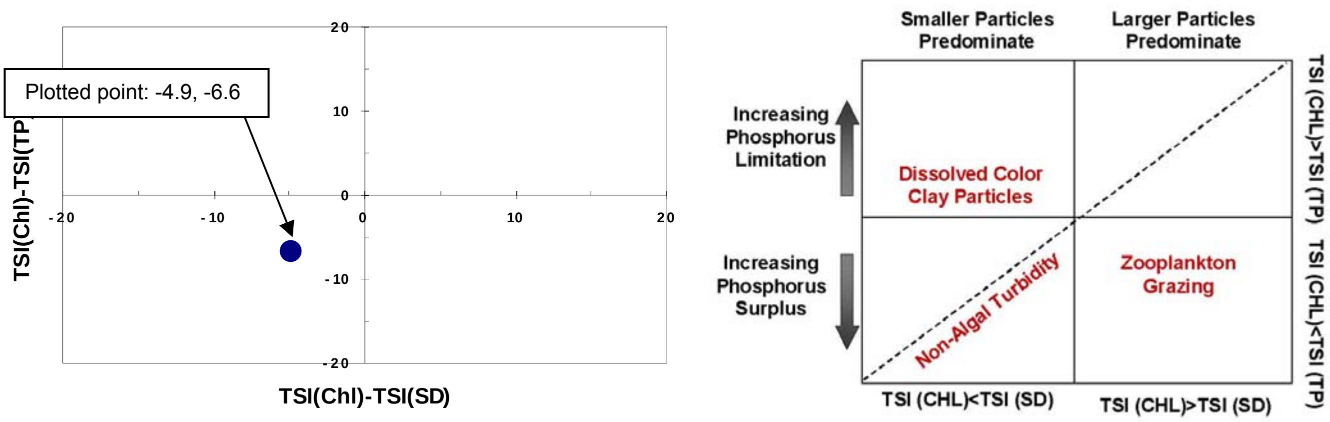
TSI values for the 2000 to 2005 monitoring data are shown in Table 3.1. If the TSI values for the three variables are the same, this shows that the relationship between TP and algae and transparency are strong. If the TP TSI values are higher than the chlorophyll values this means that there are limitations to algae growth besides phosphorous. Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for Trumbull Lake 2000 to 2005 in-lake sampling indicate some limitation of algal growth attributable to light attenuation by elevated suspended solids.

A plot that compares the three TSI variables and interprets the differences in the TSI variables is shown in Figure 2. This comparison shows that the Trumbull lake system plots in the lower left hand quadrant. The interpretive plot on the right side of the figure shows that a point in this location indicates that there is surplus phosphorous, i.e., not all available TP is expressed as algae. The other piece of information that this plot provides is that the system is on the line where suspended solids create light limitation, i.e., non-algal turbidity is a factor.

Table 3.1. Trumbull Lake TSI Values based on ISU Lake Study data (3)

Sample Date	TSI (TP)	TSI (CHL)	TSI (SD)
06/15/2000	89	77	83
07/14/2000	90	80	93
08/07/2000	93	87	83
05/16/2001	70	67	67
06/14/2001	89	NA	83
07/19/2001	90	83	77
05/22/2002	94	80	93
06/19/2002	91	81	93
07/25/2002	92	84	93
05/22/2003	77	64	83
06/19/2003	80	63	83
07/23/2003	69	58	73
05/20/2004	80	74	77
06/17/2004	72	72	77
07/22/2004	78	78	83
5/26/2005	77	68	93
6/22/2005	70	64	83
7/25/2005	86	89	93

Figure 2. Trumbull Lake Mean TSI Multivariate Comparison Plot



Phytoplankton (algae) composition is an indicator of the extent of the algae problem. Blue-green algae cause taste and odor problems, form dense mats on the water surface, and can produce toxins such as microcystin. Data from the 2000 to 2005 ISU Lake Study (3) sampling shows that, on average, blue-green algae are 73% of the total summertime phytoplankton community in Trumbull Lake. This is one of the highest blue-green algae fractions of the 131 lakes sampled in the ISU Iowa Lakes study. In fact, the 2000 average summer mass of blue-green algae was the highest of all of the lakes sampled. Summarized phytoplankton monitoring results are in Appendix B.

Potential Pollution Sources

Point sources, watershed nonpoint sources and internal recycling of pollutants from bottom sediments adversely affect water quality in Trumbull Lake. The only permitted point source in the watershed is the City of Terrill controlled discharge wastewater lagoon. The potential non-point sources are agricultural activities, inadequate on-site septic tank treatment systems, wildlife, runoff from built-up areas, atmospheric deposition, and internal recycling loads.

Natural Background Conditions

There are two natural background conditions, atmospheric deposition directly to the lake and groundwater. For the phosphorus load attributable to atmospheric deposition directly on the lake surface, the annual average concentration of phosphorus in precipitation was assumed to be 0.05 mg/L based on a review of available literature and the default values used in the EUTROMOD and WILMS watershed modeling programs. Contributions of phosphorus attributable to dry atmospheric deposition were not separated from the direct precipitation load. Potential phosphorus contributions from groundwater influx were not separated from the total nonpoint source load.

3.2 TMDL Target

The Phase 1 targets for this TMDL are a mean TSI value of less than 70 for total phosphorus, and mean TSI values of less than 65 for both chlorophyll and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L respectively, and a Secchi depth of 0.7 meters. The existing and target values for concentration and TSI are shown in Table 3.2.

Table 3.2. Trumbull Lake Existing vs. Target TSI Values

Parameter	2000-2005 Mean TSI	2000-2005 Mean Value	Target TSI	Target Value	Water quality improvements needed
Chlorophyll a	78	129 ug/l	<65	<33 ug/L	74% Reduction
Secchi Depth	81	0.2 m	<65	>0.7 meters	250% Increase
Total Phosphorus	86	269 ug/l	<70	<96 ug/L	64% Reduction

Criteria for Assessing Water Quality Standards Attainment

Iowa does not have numeric water quality criteria for algae or turbidity. The cause of Trumbull Lake algae and turbidity impairments is algal blooms caused by excessive nutrient loading to the lake and inorganic suspended solids due to re-suspension of sediment. A total phosphorus TSI of less than 70, which is related through the Trophic State Index to chlorophyll a and Secchi depth, defines the nutrient-loading target. The TSI is used as a guideline to relate phosphorus loading to the algal and turbidity impairment for TMDL development. It describes and explains nutrient conditions that will allow a waterbody to meet Iowa’s narrative water quality standards.

Inorganic suspended solids (i.e. non-algal turbidity) also contribute to lake turbidity. Since load reductions from phosphorus sources are expected to coincide with reductions in suspended solids loads the Phase 1 targeted pollutant is phosphorus. Future monitoring will determine if the targeted phosphorus reductions and corresponding reduction in suspended solids loading results in achievement of the TSI targets for chlorophyll and Secchi depth.

Selection of Environmental Conditions

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

Modeling Procedures and Results

The procedures used to estimate TP loads to Trumbull Lake consist of:

1. Estimates of the delivered loads from the point and non-point sources in the watershed using three different methods, EPA export coefficients; WILMS export coefficients, and the Loading Function Model component of EUTROMOD.
2. Estimates of the annual TP load to Trumbull Lake using measured in-lake phosphorous concentrations, estimated hydraulic detention time, and mean depth as inputs for nine different empirical models.
3. Comparison of the estimated TP loads based on watershed sources and the empirical models to select the best-fit empirical model for existing loads.
4. Estimates of the allowable TP loads at the target concentration (TP=96 ug/l) for the lake, using the selected empirical model.

Table 3.3 lists the watershed and lake response models used to evaluate the existing and targeted Trumbull Lake water quality conditions. The models and the modeling procedures are included in the spreadsheet *Trumbull Lake Phosphorous Loading.xls*. This spreadsheet also includes worksheets containing the hydrological calculations and the TSI calculator.

Table 3.3. Model Results

Watershed load estimates	**Predicted Existing Annual TP Load, lbs/yr[1]**	**Comments**
Loading Function Method	**21,800**	Reckhow (Eutromod)
EPA Export Coefficient Method	63,400	EPA 440-5-80-011
WILMS Export Coefficient Method	42,700	“most likely” export coefficients[3]
In-lake response load estimates		
1. Canfield-Bachmann 1981 Natural Lake	46,100	GSM model
2. Canfield-Bachmann 1981 Artificial Lake	95,600	GSM model
3. Reckhow Natural Lake	61,000	GSM model
4. Reckhow Anoxic Lake	28,000	GSM model
5. Reckhow Oxic Lake (z/Tw < 50 m/year)	32,900	GSM model
6. Vollenweider 1982 Combined OECD	66,000	Annual Model. [2]
7. Vollenweider 1982 Shallow Lake and Reservoir	68,800	Annual Model. [2]
8. Simple First Order (Walker)	28,100	Annual Model. [2]
9. Nurnberg 1984 Oxic Lake – Lake response external load when internal load = zero	51,800	Annual Model. [2]
Nurnberg external load from watershed loading function	**21,800**	
Nurnberg internal load, calculated based on external load	13,200	

1. For in-lake GSM concentration TP = ANN TP = 269 ug/L. This is the average of the ISU Lake Study TP values, 2000 to 2005.
2. Note that P annual = P growing season for polymictic lakes.
3. There are three values estimates for the WILMS export coefficients, low, most likely, and high.

Watershed load estimates: The three watershed load estimates are different because the procedures and assumptions about loads from different landuses and the way that these are accounted for are different. The two export coefficient methods have produced higher loads because they do not account for some of the important factors that affect TP delivery in the Trumbull Lake watershed. They do not consider that the Trumbull Lake watershed is relatively large, that it is in the Des Moines lobe region where the sediment delivery ratios are low, or that tile drainage is a significant delivery mechanism of water and soluble phosphorous. Export coefficients are unit area annual averages for phosphorous loads associated with a particular landuse.

The loading function procedure is based on the Annual Loading Function Model in within the Eutromod Watershed and Lake Model developed by Kenneth Reckhow (4) to evaluate nutrient load delivered to lakes. It incorporates approximations of both soluble phosphorous in the runoff to Trumbull Lake and the sediment attached phosphorous derived from erosion modeling and an estimated delivery ratio that considers watershed size and ecoregion.

<u>Lake response load estimates</u>: In-lake monitoring data is used in conjunction with empirical mass balance models to estimate total phosphorous loads delivered to the lake that would cause the observed concentrations. These loads include the watershed non-point and point source loads, phosphorous recycled by resuspension of sediment, and phosphorous from direct rainfall and dry deposition. As a relatively large and shallow lake with considerable numbers of rough fish, Trumbull Lake has a large recycled TP component.

The loading function model has been selected as the best approximation of the total phosphorous load from the watershed point and non-point sources. The Loading Function model estimates an annual average TP load of 21,800 pounds per year. The applicable in-lake response models that are closest to this value are:

- Canfield-Bachman Natural Lake, 42,500 lbs/year,
- Reckhow Natural Lake, 57,400 lbs/year
- Reckhow Oxic Lake (z/Tw<50m/year), 31,000 lbs/year
- Nurnberg Oxic Lake, eternal load = 51,800 lbs/year when internal load = zero
- Simple first order (Walker) = 28,100 lbs/year

The other models in Table 3.3 were not considered for various reasons. The Canfield-Bachman artificial lake model predicted a much higher TP load than the watershed loading estimates and is based on assumptions that are not applicable to Trumbull Lake. The Reckhow Anoxic lake model assumes stratification and the presence of a thermo-cline. Trumbull Lake does not stratify at all and there is no thermo-cline because it is shallow everywhere. The two Vollenweider models, the Combined OECD and the Shallow Lake and Reservoir, predict higher TP loads than the load predicted by the watershed Loading Function.

None of the models except the Nurnberg Oxic Lake model separate an internal recycled total phosphorous load from the load delivered from the watershed sources. The Reckhow Oxic, Vollenweider, and Nurnberg (external load based on lake response only with no internal load) models return values that are above, but reasonably close to, the range predicted by the Loading Function and export coefficient estimates. The models within the total phosphorous ranges used to derive them are the Canfield-Bachman Natural Lake, Reckhow Anoxic Lake, and the Vollenweider Combined OECD and Shallow Lake and Reservoir. The others are extrapolated when applied to Trumbull Lake because of its extremely high in-lake phosphorus levels.

The high phosphorus and inorganic suspended solids levels at Trumbull Lake indicate a significant internal loading. The load predicted by the Nurnberg Model is similar to the loads estimated by the in-range models and existing load predicted by the Nurnberg Model also indicates a significant internal load. Therefore, the Loading Function estimate was used with the Nurnberg Oxic Lake Model as the basis for determining the existing external and internal loads. The Nurnberg Model was also used to determine load targets as a function of the relative contribution from internal and external sources.

The equation for the Nurnberg Oxic Lake Model is:

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

where

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

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

The Nurnberg Model represents a continuum of external and internal loads for a given in-lake total phosphorus concentration. The Loading Function Model external load estimate (21,800 lbs/year) was used as the external load with the Nurnberg Model to predict the existing external (21,800 lbs/year) and internal (13,200 lbs/year) load conditions for the average in-lake TP concentration of 269 ug/l. The model uses areal units (square meters) for the lake TP and hydraulic loadings based on a water surface of 1,076 acres.

$$P = 269(\mu g/L) = \frac{2271(mg/m^2/yr)}{8.8(m/yr)}(1 - \frac{15}{18 + 8.8(m/yr)}) + \frac{1378(mg/m^2/yr)}{8.8(m/yr)}$$

The target load calculation for the in-lake target TP concentration of 96.4 ug/l for the external and internal loads of 7760 and 4750 pounds, respectively, is:

$$P = 96.4(\mu g/L) = \frac{808(mg/m^2/yr)}{8.8(m/yr)}(1 - \frac{15}{18 + 8.8(m/yr)}) + \frac{495(mg/m^2/yr)}{8.8(m/yr)}$$

Multiplying the areal loads (L_{Ext}, L_{Int}, q_s) by the lake area in square meters and converting the resulting values from milligrams to pounds gives the annual external and internal loads. The target loads were based on the assumption that the same ratio of the modeled values for existing internal and external loads should be maintained for the internal and external target loads.

For any internal target load, the corresponding external target load can be determined from the chart in Figure 3 that was generated by the Nurnberg equation.

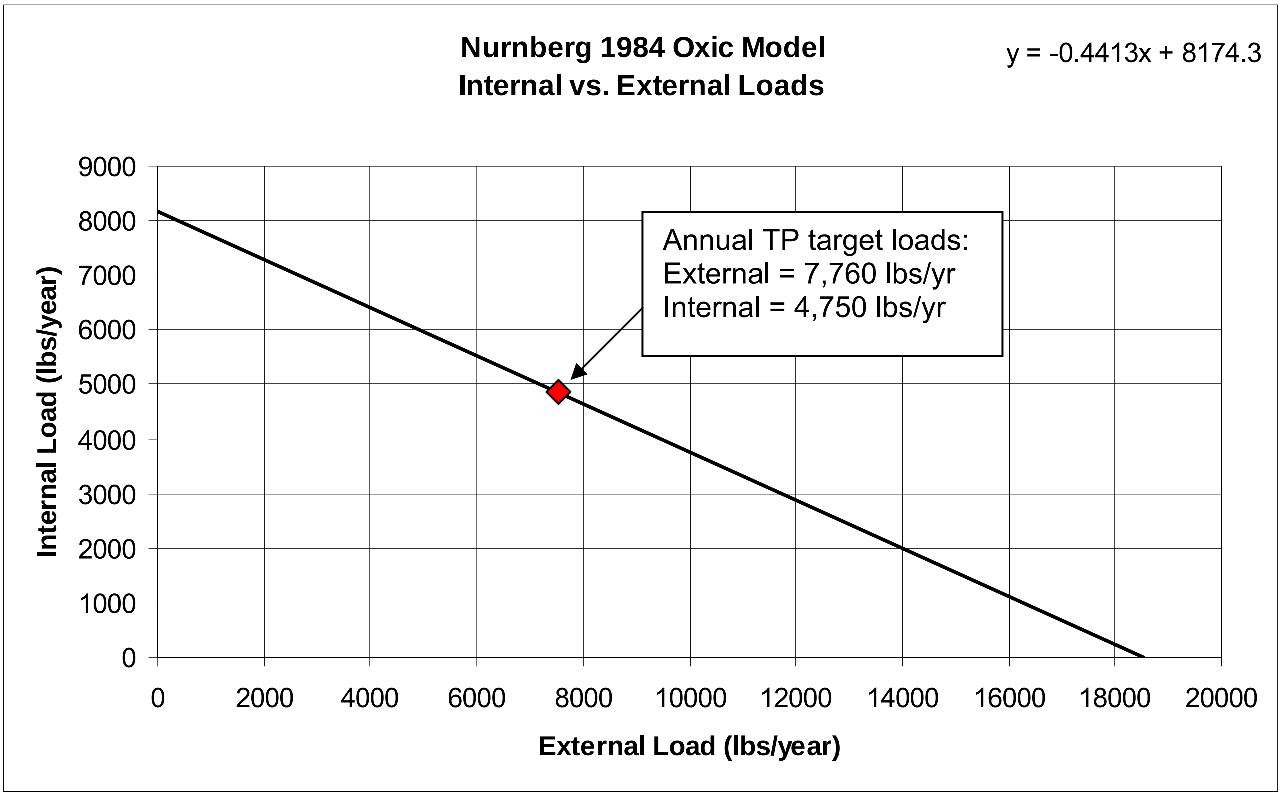


Figure 3 Total phosphorous, internal loads for a given external load

Waterbody Pollutant Loading Capacity

The chlorophyll a and Secchi depth objectives are related through the Trophic State Index to total phosphorus. The load capacity for this TMDL is the annual amount of phosphorus Trumbull Lake can receive and meet its designated uses. Based on the selected lake response model and a target TSI (TP) value of less than 70 (corresponding to an in-lake average TP concentration of 96 ug/l), the total phosphorus loading capacity is divided between the internal and external loads in the same ratio as for the estimated existing loads and requires a reduction of 64% of each load component.

The loading capacity for external loads from the watershed and direct deposition is 7,760 lbs/year and for internal loads caused by resuspension and recycling is 4,750 lbs/year.

3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Trumbull Lake in this TMDL. The first is the phosphorus load from the watershed areas that drain directly into the lake and the phosphorus recycled from lake sediments. The second is the phosphorus contributions from the City of Terrill wastewater treatment lagoon. The third source is atmospheric deposition. Load contributions from groundwater influx have not been separated from the total nonpoint source loads.

Existing Load

The annual total phosphorus load to Trumbull Lake consists of external watershed loads and internal recycled loads. The existing watershed load based on the loading function model is 21,800 lbs/year. The existing internal recycled load is 13,200 lbs/year. These loads cannot be added together to get a total load since they are related only through the Nurnberg model equation. If the load were all from external watershed sources and was calculated using the Nurnberg lake response model, it would be 51,800 lbs/year. The external loads include 250 pounds per year from the Terrill wwtp, and an estimated atmospheric deposition of 350 pounds per year.

Departure from Load Capacity

The targeted total phosphorous load capacity for Trumbull Lake is split between watershed and recycled loads. The existing watershed loads are estimated to be 21,800 lbs/year and the target is 7760 lbs/year for a difference of 14,040 lbs/year. This is a reduction of 64% and is 0.28 pounds per year per acre of watershed area. The estimated existing recycled load is 13,200 lbs/ and the target is 4750 lbs/year or 8.8 pounds per year per acre of lake surface. If all loads were attributed to the watershed without any internal recycling of phosphorus the model load would be 51,800 lbs/year. If the target loads were all attributed to the watershed they would be 18,500 lbs/year. The difference would be 33,500 lbs/year or 0.67 lbs/ year per acre.

Identification of Pollutant Sources

Point Sources: There is one point source, the City of Terrill wastewater treatment facility. The facility is a facultative controlled discharge stabilization lagoon treating waste from 404 people. Controlled discharge lagoons are designed to discharge about twice a year for two to three weeks during high stream flow. Discharges are in the spring and fall. It has been assumed that the entire annual total phosphorous load from this facility is delivered to Trumbull Lake.

Non-point Sources: Most phosphorous is delivered to the lake from watershed non-point sources and internal recycle. Figure 4 shows the total phosphorous loads for the external watershed sources estimated by the Loading Function Model. As can be seen, most external nonpoint source phosphorus delivered to the lake is from row crop landuses. Besides row crop uses and other agriculturally related TP sources there are septic tank systems, and wildlife and pet feces. These are relatively small contributors with less impact than agricultural and internal recycled loads.

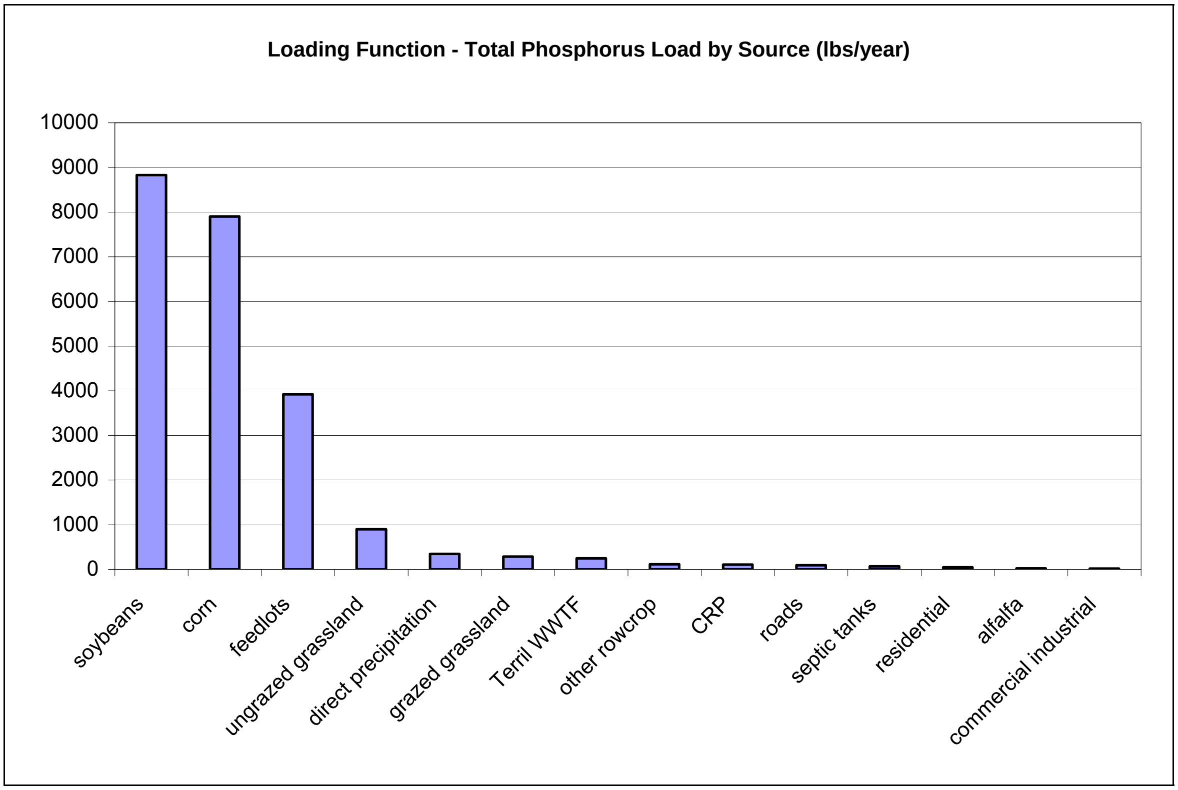


Figure 4. Loading Function Model Watershed Contributions (external), TP load, lbs/yr

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Trumbull Lake originates entirely from watershed nonpoint sources, internal recycling, and the Terrill wastewater treatment facility discharge. The watershed TP sources, including the Terrill WWTP, have been linked to the water quality impairment through the use of the Loading Function model that estimates annual average delivery. The recycled TP load has been estimated using the Nurnberg model in conjunction with watershed load estimate generated by the Loading Function model.

3.4 Pollutant Allocations

The total phosphorous allocations separate the external loads that include watershed non-point and point sources from internal recycle loads because a pound of TP from an external source is not the equivalent of a pound of internal TP as estimated by the Nurnberg model. The wasteload allocation for the Terrill WWTP is an external load as is the atmospheric deposition load. These loads are included in the Loading Function model results that is the external load in the calculation for the internal recycle load.

Wasteload Allocation

The Wasteload Allocations (WLA) for the point source discharger is shown in Table 3.4. The WLA is set at the estimated existing load because this load is less than one percent of the total existing TP load and reducing it would have no discernable impact on the lake nutrient impairment. Total phosphorus monitoring data for the point sources is currently unavailable and the existing load has been estimated based on a literature value on a per capita basis. The loads based on estimated plant effluent flow and literature phosphorus concentrations for facultative lagoon treatment were also considered. Existing effluent concentrations may vary from those estimated and total phosphorous monitoring would be needed to confirm the point source load.

Table 3.4. City of Terrill Total Phosphorous Wasteload Allocation

Facility	Existing PE [1]	Total Phos. WLA, lbs/year [2]	Design Flow, gal/day [3]	WLA, Conc. at Design Flow, mg/L [4]
Terrill WWTP	404	250	41,000	2

1. Population equivalent. The estimated per capita total phosphorous load is 0.08 lb/day.
2. Wasteload allocation based on design flow.
3. Design flow based on plant monitoring records from 2000 to 2005.
4. Wasteload allocation concentration based on treated stabilization lagoon effluent of 2 mg/l.

Load Allocations

The Load Allocation (LA) for this TMDL is consists of two parts, the external load that includes watershed non-point sources and atmospheric deposition, and the corresponding internal recycle load. The total phosphorous load allocation less the margin of safety is distributed as follows:

- 6,410 pounds per year allocated to the Trumbull Lake watershed.
- 350 pounds per year allocated to atmospheric deposition.
- 4,270 pounds per year allocated to internal recycling of phosphorus from the lake bottom sediments.

Margin of Safety

The explicit numeric margin of safety for this TMDL has two components. One is the external TP load MOS and one is for the internal recycle TP load MOS. The external load MOS does not include the 250 lbs/year WLA for the Terrill wastewater treatment plant. The explicit MOS is a 10% reduction in the load allocations for each of these components. The external load MOS is (7760 – 250)*(0.10) = 750 lbs/year giving a load allocation of 6,760 lbs/year (includes atmospheric deposition). The internal load MOS is 4750*(0.10) = 480 lbs/year giving a load allocation of 4270 lbs/year.

Nutrient TMDL Summary

The equation for the total maximum daily load shows the lake total phosphorus load capacity.

TMDL = Load Capacity (7760 lbs/year external + 4750 lbs/year internal) = WLA (250 lbs/year external) + LA (6760 lbs/year external + 4270 lbs/year internal) + MOS (750 lbs/year external + 480 lbs/year internal)

4. Implementation Plan

The Trumbull Lake implementation plan is not a required component of a Total Maximum Daily Load but can provide department staff, partners, and watershed stakeholders with a strategy for improving Trumbull Lake water quality. It is recommended that a two-part approach be used to improve Trumbull Lake water quality. The first part of this strategy is to reduce nutrient inputs from the watershed (external loads) and recycling from lake bottom sediments, specifically total phosphorous. The second part is to manage the hydrology, macrophyte growth and fish populations as a way of restoring water clarity by shifting away from a turbid algae dominated waterbody. The first of these is discussed in the following section on reducing total phosphorous from the water column. The second is based on a method of changing the lake's hydrology and turbid conditions being developed by IDNR fisheries staff and others.

Lake Improvement Strategy Part 1: Total Phosphorous Reduction
As can be seen in the development of the TMDL, there are two major components to the Trumbull Lake phosphorous inputs, the external watershed load and the internal recycled load. Because of the uncertainty as to how much of the phosphorus load originates in the watershed and how much is recycled from lake bottom sediment, an adaptive management approach to phosphorous reduction is recommended.

In this approach management practices to reduce both watershed loads and recycled 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 external loading from 21,800 lbs/year to 16,000 lbs/year and recycle internal loading from 13,200 lbs/year to 10,500 lbs/year by 2010.
- Reduce watershed external loading from 16,000 lbs/year to 12,000 lbs/year and recycle internal loading from 10,500 lbs/year to 7,000 lbs/year by 2015.
- Reduce watershed external loading from 12,000 lbs/year to 7,760 lbs/year and recycle internal loading from 7,000 lbs/year to 4,750 lbs/year by 2020.

Best management practices to reduce external nutrient delivery, particularly phosphorus, should be emphasized in the Trumbull Lake watershed. These practices include the following:

- Nutrient management on production agriculture ground to achieve the optimum soil test category. This soil test category is the most profitable for producers to sustain in the long term.
- Incorporate or subsurface apply phosphorus (manure and commercial fertilizer) while controlling soil erosion. Incorporation will physically separate the phosphorus from surface runoff.
- Continue encouraging the adoption of reduced tillage systems, specifically no till and strip tillage.
- Initiate a fall-seeded cover crop incentive program. Target low residue producing crops (e.g. soybeans) or low residue crops after harvest (e.g. corn silage fields). This practice increases residue cover on the soil surface and improves water infiltration.
- Through incentives, add landscape diversity to reduce runoff volume and/or velocity through the strategic location of filter strips and grass waterways, etc.
- Install terraces, ponds, or other erosion and water control structures at appropriate locations within the watershed to control erosion and reduce delivery of sediment and phosphorus to the lake.
- Encourage the reduction in the number of open vertical intakes that are connected to tile lines both in cropland and road ditches or convert them into filtered systems. Vertical intakes are a direct route for soil particles and attached

phosphorous to get to Trumbull Lake. Perhaps a demonstration of these systems that shows local farmers the benefits of these filter systems would convince them to convert the intakes in their fields and also avoid farming around the vertical intakes.

Internal loading can be controlled through management of rough fish (i.e., carp) and shoreline erosion. Among the mechanisms of resuspension are bottom feeding rough fish such as carp, wind-driven waves and currents, and boat propellers. Historically, rough fish have been a problem at Trumbull Lake. It is suspected that a significant portion of the internal loading at this lake is due to the large rough fish population. However, some internal loading may remain due to resuspension of accumulated sediments by wind and wave action on the lake. Internal loads can be decreased by:

- Significantly reducing the numbers of bottom feeding fish.
- Minimizing the factors that contribute to turbulence in shallow areas.
- Encouraging the growth of rooted aquatic plants to stabilize bottom sediments thereby reducing resuspension.

Procedures are needed to evaluate the magnitude of the phosphorus load from internal recycling, preferably by direct measurement of resuspension and recycling from lake bottom sediment. The department is investigating methods of measuring sediment phosphorus flux by evaluating lake sediment cores. This work is being done at Iowa State University and is supported by an EPA grant.

Lake Improvement Strategy Part 2: Managing Watershed Hydrology and Lake Level

Over the past decade IDNR has gained valuable insight into the mechanisms that drive the water and fisheries quality of Iowa shallow natural lakes such as Trumbull Lake. IDNR is developing new management strategies for these systems by investigating the management of water levels as a water quality tool that can change these lakes into clear water macrophyte dominated systems.

Lake restorations have historically focused on reducing nutrient inputs by repairing the watershed, or removing phosphorus-laden sediments from the lake. While these methods have worked well in deeper lakes, this approach has not been as successful in shallow lakes. Shallow lakes differ substantially from deeper lakes in many respects. Shallow lakes usually exist in either of two alternative stable trophic states with or without any change in the nutrient budget of the lake. These lakes can exist as a very turbid, algae-dominated system with little to no vegetation, or as clear water, macrophyte dominated systems.

In shallow lakes, the bottom-feeding and plankton-feeding fishes along with wind and wave action and in some cases heavy boating traffic can perpetuate the algae dominated system. By controlling or removing the factors perpetuating the algae dominated turbid system it is possible to “flip” the system into a clear water macrophyte dominated system.

The positive impacts of emergent and submergent vegetation on water quality are due to several factors. Rooted vegetation prevents re-suspension of sediments into the water column by solidifying bottom sediments and suppressing wind and wave action. Rooted plants provide habitat for periphyton and zooplankton and fish species commonly found in clear water lakes. Rooted vegetation also ties up nutrients such as phosphorous making them unavailable for algae. Some macrophytes also release chemical substances that inhibit the growth of nearby plants including algae. Many of these mechanisms are difficult to assess and vary among water bodies, however their combined effect stabilizes the clear water trophic state.

Both the clear water macrophyte state and the algae dominated state are stable, and it takes a major disturbance to move from one state to another. Three methods that show great promise to cause the shift from the turbid to the clear water state are bottom-feeding fish control, heavy fish-feeding stockings (to control both bottom-feeding and plankton-feeding fishes), and water level draw downs.

In addition, many shallow natural lake watersheds have been drastically altered from systems filled with wetlands and intermittent streams to pipe drained systems. These altered systems decrease the storage and retention of water in the watershed. Rain that falls in the watershed is transported to the lake rapidly and water levels fluctuate quickly during both drought and wet cycles. Rapidly fluctuating water levels in shallow lakes are detrimental to emergent and submergent vegetation.

Conclusions

Sediment and phosphorous inputs from the watershed are important considerations, but in shallow lakes loss of aquatic vegetation, and alterations to the watershed's drainage hydrology are also important factors allowing these systems to remain in an algae dominated turbid water state. In-lake improvements should be targeted at remediation of the conditions preventing the establishment of aquatic plant communities. Watershed improvements in shallow natural lake watersheds need to include actions that increase the capacity of the watershed to retain water through targeted wetland construction.

Stakeholders should be aware of in-lake management options for shallow lakes and the paradigm shift to not only managing the quality of water coming from the watershed, but also the **water quantity and the speed** at which it gets to the lake.

Dredging is often considered as a method to remediate water quality problems in shallow lakes. However, recent evaluations by Iowa State University researchers indicate that for dredging alone to have an impact on water quality requires an average lake depth of ten feet. The existing average depth of Trumbull Lake is three feet. For Trumbull Lake, the dredging cost is estimated conservatively at $40 million. For practical and economic reasons, dredging is not considered a primary restoration tool for Trumbull Lake, although limited dredging might be useful in conjunction with other management activities.

Shallow natural lakes have some special needs when considering restoration and management actions. The State's shallow natural lakes have some exciting potential and IDNR is in the process of developing effective tools for management. An important factor in this effort will be for the public to decide that this type of management is the right choice for lakes with certain characteristics.

5. Monitoring

Further monitoring is needed at Trumbull 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. Trumbull Lake continues to be monitored by the IDNR as part of an ongoing lake monitoring program.

As noted in *Section 4, Implementation*, the phosphorus load due to internal recycling needs to be measured and evaluated. The department is working with Iowa State University to develop a method for quantifying phosphorus sediment flux that will clarify its impact on lakes. When a protocol for measuring phosphorus flux and the resources to do the work become available, coring may be done for this lake and the recycling load component estimated.

6. Public Participation

There have been two opportunities for the public and stakeholders to get information and to provide input and comments on the Trumbull Lake TMDL. The first of these was at the regular monthly meeting of the Clay County Soil and Water Conservation District Board on April 20, 2005. IDNR staff presented general information on the nature of TMDL reports, the development of the Trumbull Lake TMDL, and solicited input and comments.

The draft TMDL report was posted on the IDNR Watershed Improvement website and notice sent to the statewide TMDL stakeholders on April 3, 2006. A notice was included in the IDNR Environmental Services Division weekly news release on April 6 and April 13, 2006 with information about the location, date and time of the public meeting and on how to get a copy of the draft Trumbull Lake TMDL. The IDNR public meeting was held at 6 PM on April 20, 2006 at the Oneota Lodge in the City of Spencer, Iowa. The 30-day comment period ended May 5, 2006. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL report.

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

There are 127 public lakes in Iowa. The watersheds for these lakes range in area from 0.028 to 195 square miles with mean and median values of 10 and 3.5 square miles, respectively. Few of these lakes have gauging data available to determine flow statistics for the lake tributaries. Only a few lakes have stage information that can be used to estimate discharge.

The requirement for rapid lake TMDL development established the need for a method to quickly estimate flow statistics for lake response modeling inputs. To accomplish this, flow and watershed characteristics for several USGS gauging stations with small contributing watershed areas was compiled and evaluated using both simple and multiple linear regressions. The evaluation focus was estimates for the average annual flow. The average annual flow is a key input for the empirical lake response models used in TMDL development. Useful regression equations for monthly average and calendar year flow were also developed.

Data

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

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

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

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

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

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

Methods

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

Equation Variables

Table A-2. Regression Equation Variables

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

Equations

Table A-3. Drainage Area Only Equations

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

Table A-4. Multiple Regression Equations

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

General Application

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

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

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

Application to Trumbull Lake Calculations

Table A-5. Trumbull Lake Hydrology Calculations

Characteristic or calculated variable	
Lake Name	Trumbull
Type	Natural
Inlet(s)	DD61, Mud Lake outlet
Outlet(s)	Pickerel Run
Volume	3575 acre-feet
Surface Area	1076 acres
Watershed Area	50747 acres
Mean Annual Precipitation	28.5 inches
Mean Annual Class A Pan Evaporation	48 inches
Evaporation Coefficient	0.74
Optional User Input Inflow Estimate	31874 acre-feet/year
Optional User Input Runoff Component	19768 acre-feet/year
Optional User Input Baseflow Component	12106 acre-feet/year
Mean Depth	3.3 feet
Drainage Area	49671 acres
Drainage Area	77.6 square miles
Drainage Area/Lake Area	46.2
Mean Annual Lake Evaporation	35.5 inches
Mean Annual Lake Evaporation	3185 acre-feet per year
Annual Average Inflow	44.0 cfs
Annual Average Inflow	31874 acre-feet/year
Runoff Component	19768 acre-feet/year
Baseflow Component	12106 acre-feet/year
Direct Precipitation on Lake Surface	2554 acre-feet/year
Inflow + Direct Precipitation	34428 acre-feet/year
% Inflow	92.6 %
% Direct Precipitation	7.4 %
Outflow	31243 acre-feet/year
HRT Based on Inflow + Direct Precipitation	0.10 1/year
HRT Based on Outflow	0.11 1/year

9. Appendix B - Sampling Data

Table B-1. Data collected in 1990 by Iowa State University (6)

Parameter	**Value**
Lake Survey Date	1990
Secchi Disc Depth, Mean, m	0.2
Chlorophyll A, Mean, ug/l	189.2
Total Phosphorus, Mean, ug/l	267
Total Nitrogen, Mean, mg/l	3.3
Ammonia, Mean, ug/l	0
Nitrate, Mean, ug/l	0
Inorganic Suspended Solids, Mean, mg/l	76.3
Total Suspended Solids, Mean, mg/l	141.6

Table B-2. Data collected in 2000 by Iowa State University (3, 2001)

Parameter	6/15/2000	7/14/2000	8/7/2000	2000
Lake Depth (m)	1.2	1.2	1.2	1.2
Thermocline Depth (m)	NIL	NIL	NIL	N/A
Secchi Disk Depth (m)	0.2	0.1	0.2	0.2
Temperature(^oC)	18	26.7	25.9	23.5
Dissolved Oxygen (mg/L)	9.6	5.9	12	9.2
Dissolved Oxygen Saturation (%)	101	73	148	107.5
Specific Conductivity (µS/cm)	409	-	357	383
Turbidity (NTU)	145.7	164.1	2332.7	880.8
Chlorophyll a (µg/L)	115.9	151.8	320.4	196
Total Phosphorus as P (µg/L)	362	376	475	404
Total Nitrogen as N (mg/L)	3.65	2.97	3.78	3.47
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.91	0.81	0.22	0.65
TN:TP ratio	10	8	8	9
pH	8.3	8.5	8.3	8.4
Alkalinity as $CaCO_3$ (mg/L)	167	142	129	146
Inorganic Suspended Solids (mg/L)	41	40	88	56
Volatile Suspended Solids (mg/L)	33	12	36	27
Total Suspended Solids (mg/L)	74	52	124	83

Table B-3. Data collected in 2001 by Iowa State University (3, 2002)

Parameter	5/16/2001	6/14/2001	7/19/2001	2001
Lake Depth (m)	1.2	1.2	1.2	1.2
Thermocline Depth (m)	NIL	NIL	NIL	N/A
Secchi Disk Depth (m)	0.6	0.2	0.3	0.3
Temperature(^{o}C)	24.5	-	27.3	25.9
Dissolved Oxygen (mg/L)	18.8	-	8.4	13.6
Dissolved Oxygen Saturation (%)	225	-	106	165.6
Specific Conductivity (µS/cm)	419.7	-	487.9	453.8
Turbidity (NTU)	45.1	-	230	137.6
Chlorophyll a (µg/L)	39.3	-	204	121.7
Total Phosphorus as P (µg/L)	96	350	372	273
Total Nitrogen as N (mg/L)	6.69	8.37	3.38	6.15
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	5.92	6.74	0.13	4.26
TN:TP ratio	70	24	9	34
pH	7.9	8.2	9.3	8.5
Alkalinity as $CaCO_3$ (mg/L)	185	240	102	176
Inorganic Suspended Solids (mg/L)	27	191	9	76
Volatile Suspended Solids (mg/L)	8	37	34	26
Total Suspended Solids (mg/L)	35	228	42	102

Table B-4. Data collected in 2002 by Iowa State University (3, 2003)

Parameter	5/22/2002	6/19/2002	7/25/2002	2002
Lake Depth (m)	1.1	1.2	1.2	1.2
Thermocline Depth (m)	NIL	NIL	NIL	N/A
Secchi Disk Depth (m)	0.1	0.1	0.1	0.1
Temperature(^{o}C)	13.9	21.7	23	19.5
Dissolved Oxygen (mg/L)	9.6	8.7	6.1	8.1
Dissolved Oxygen Saturation (%)	93	99	71	87.5
Specific Conductivity (µS/cm)	483.9	443.7	476.4	468
Turbidity (NTU)	1139.8	1336.6	325.2	933.9
Chlorophyll a (µg/L)	151.1	169.4	228.2	182.9
Total Phosphorus as P (µg/L)	519	401	438	453
SRP as P (µg/L)	62	6	13	27
Total Nitrogen as N (mg/L)	3.43	8.65	3.09	5.06
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	959	588	867	805
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	48	56	63	55
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	1.71	5.55	0.15	2.47
TN:TP ratio	7	22	7	12
pH	8.3	8.4	8.2	8.3
Alkalinity as $CaCO_3$ (mg/L)	241	240	175	219
Silica as Si (mg/L)	11.81	15.11	22	16.31
Dissolved Organic Carbon (mg/L)	-	-	15.25	15.25
Inorganic Suspended Solids (mg/L)	340	148	44	178
Volatile Suspended Solids (mg/L)	65	37	21	41
Total Suspended Solids (mg/L)	405	185	65	218

Table B-5. Data collected in 2003 by Iowa State University (3, 2004)

Parameter	5/22/2003	6/19/2003	7/23/2003	2003
Lake Depth (m)	1.2	1.2	1.1	1.2
Thermocline Depth (m)	NIL	NIL	0.5	N/A
Secchi Disk Depth (m)	0.2	0.2	0.4	0.2
Temperature(^{o}C)	15.1	22.2	26.4	21.2
Dissolved Oxygen (mg/L)	12.9	8.3	16.3	12.5
Dissolved Oxygen Saturation (%)	128	95	202	141.5
Specific Conductivity (µS/cm)	437.9	496	449.5	461.1
Turbidity (NTU)	68.4	91.2	55.9	71.8
Chlorophyll a (µg/L)	28.9	27.7	16.7	24.4
Total Phosphorus as P (µg/L)	159	194	91	148
SRP as P (µg/L)	1	5	1	2
Total Nitrogen as N (mg/L)	2.4	7.09	5.29	4.92
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	158	390	221	256
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	26	24	63	38
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	1.96	5.4	3.61	3.66
TN:TP ratio	15	37	58	36
pH	8.9	8.1	8.8	8.6
Alkalinity as $CaCO_3$ (mg/L)	124	141	117	127
Silica as Si (mg/L)	3.02	11.8	4.35	6.39
Dissolved Organic Carbon (mg/L)	10.77	9.69	8.28	9.58
Inorganic Suspended Solids (mg/L)	27	42	27	32
Volatile Suspended Solids (mg/L)	17	17	16	16
Total Suspended Solids (mg/L)	44	59	43	49

Table B-6. Data collected in 2004 by Iowa State University (3, 2005)

Parameter	5/20/2004	6/17/2004	7/22/2004	2004
Lake Depth (m)	1.1	1.2	1.2	1.2
Thermocline Depth (m)	NIL	NIL	NIL	N/A
Secchi Disk Depth (m)	0.3	0.3	0.2	0.2
Temperature(^{o}C)	19.1	19.8	27.4	22.1
Dissolved Oxygen (mg/L)	10.7	8.3	8.9	9.3
Dissolved Oxygen Saturation (%)	116	90	112	106.1
Specific Conductivity (µS/cm)	481	446.3	385.1	437.5
Turbidity (NTU)	196.9	234.7	622.3	351.3
Chlorophyll a (µg/L)	80	69.6	128	92.5
Total Phosphorus as P (µg/L)	189	107	164	154
SRP as P (µg/L)	12	7	2	7
Total Nitrogen as N (mg/L)	2	3.36	3.36	2.91
Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	191	58	36	85
Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	33	8	2	14
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	0.59	2.07	1.44	1.37
TN:TP ratio	11	31	20	21
pH	8.8	8.6	8.8	8.7
Alkalinity as $CaCO_3$ (mg/L)	188	143	148	160
Silica as Si (mg/L)	2.84	2.31	4.24	3.13
Dissolved Organic Carbon (mg/L)	10.26	7.19	4.66	7.37
Inorganic Suspended Solids (mg/L)	49	40	43	44
Volatile Suspended Solids (mg/L)	28	13	18	20
Total Suspended Solids (mg/L)	77	53	61	63
Microcystin (ng/L)	1.4	7.2	33.1	13.9

Table B7. Data collected in 2005 by Iowa State University (3, 2005)

Parameter	04/18/2005	05/26/2005	06/22/2005	07/25/2005	2005
Lake Depth (m)	1.2	1.2	1.3	1	1.2
Thermocline Depth (m)	NIL	NIL	NIL	NIL	N/A
Secchi Disk Depth (m)	0.1	0.1	0.2	0.1	0.1
Temperature(^oC)	17.7	15.8	25.1	27.5	21.5
Dissolved Oxygen (mg/L)	10.8	9.4	8.5	7.6	9.1
Dissolved Oxygen Saturation (%)	114	95	103	96	101.7
Specific Conductivity (µS/cm)	562.8	527.1	463.4	441.2	498.6
Turbidity (NTU)	79.7	415.4	153.1	7.1	163.8
Chlorophyll a (µg/L)	116.9	46.9	28.9	386.2	144.7
Total Phosphorus as P (µg/L)	95	154	96	296	160
SRP as P (µg/L)	1	8	9	31	12
Total Nitrogen as N (mg/L)	3.74	7.17	3	2	3.98
(Phenate)Ammonia Nitrogen (NH_3 + NH_4^+) as N (µg/L)	22.2	18.4	57.6	39.1	34.3
(Phenate)Ammonia Nitrogen (NH_3) as N (un-ionized)(µg/L)	1.4	1.1	6	3.5	3
Nitrate + Nitrite (NO_3 + NO_2) as N (mg/L)	2.93	6.3	2.14	0.11	2.86
TN:TP ratio	40	47	31	7	31
pH	8.3	8.4	8.3	8.2	8.3
Alkalinity as $CaCO_3$ (mg/L)	272	233	199	205	227
Silica as Si (mg/L)	7.07	11.52	4.32	12.49	8.85
Dissolved Organic Carbon (mg/L)	-	5.68	5.37	7.71	6.25
Inorganic Suspended Solids (mg/L)	109	15	50	166	85
Volatile Suspended Solids (mg/L)	30	9	14	32	21
Total Suspended Solids (mg/L)	139	24	64	198	106
Microcystin (ng/L)	-	0.44	3.34	1.58	1.79

Table B-8. Phytoplankton Data (3)

Division	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
Bacillariophyta Wet Mass (mg/L)	13.67	12.77	0.468	2.579	0.286	0.53
Chlorophyta Wet Mass (mg/L)	21.12	0.90	0.111	2.104	0.562	0
Chrysophyta Wet Mass (mg/L)	0	0	0	0.379	0	0
Cryptophyta Wet Mass (mg/L)	0.46	0.572	0.014	0.263	0	0.292
Cyanobacteria Wet Mass (mg/L)	**0.15**	**55.24**	**20.304**	**531.063**	**0.249**	**60.357**
Euglenophyta Wet Mass (mg/L)	0.026	0.033	0.019	0	0	0.253
Total	35.43	69.53	20.915	536.388	1.097	61.432
Taxonomic Richness	14	12	10	6	7	5

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

Table B-9 Targeted TMDL in-lake monitoring data

Trumbull Lake, 2005 TMDL monitoring data, In-lake samples and TSI calculation									
							TSI	**TSI**	**TSI**
Date	**TP, ug/l**	**chl a, ug/l**	**SD, m**	**TN, mg/l**	**TN:TP**	**ISS, mg/l**	**TP**	**Chl a**	**SD**
05/11/2005	220	26	0.06	4.9	22.3	56	82	63	101
05/23/2005	120	50	0.21	10	83.3	45	73	69	82
06/08/2005	440	110	0.05	6.8	15.5	202	92	77	103
06/22/2005	130	35	0.24	3.5	26.9	48	74	65	81
07/12/2005	180	1	0.34	2.41	13.4	32	79	31	76
07/27/2005	220	110	0.09	2.35	10.7	64	82	77	95
08/24/2005	460	150	0.06	4.15	9.0	226	93	80	101
09/13/2005	310	160	0.18	3.25	10.5	66	87	80	85
09/27/2005	330	93	0.15	3.32	10.1	130	88	75	87
mean	267.78	81.67	0.15	4.52	22.40	96.56			
median	220.00	93.00	0.15	3.50	13.39	64.00			

10. Appendix C - Trophic State Index

Carlson's Trophic State Index

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

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

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

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

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

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

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

SD = lake Secchi depth, meters

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

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

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

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

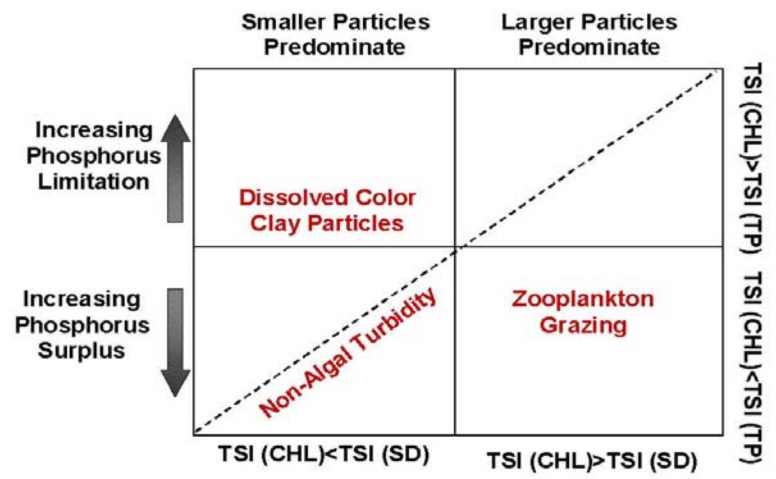
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for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

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

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

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

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



11. Appendix D - Land Use Map

Figure D1 Trumbull Lake Watershed Landuse