Total Maximum Daily Load
For Nutrients and Siltation
Lake Macbride
Johnson County, Iowa

2005

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Lake Macbride Summary

Waterbody Name:	Lake Macbride
County:	Johnson
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Iowa River Basin
Pollutants:	Phosphorus, Sediment
Pollutant Sources:	Nonpoint, point, internal recycle, atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation) B(LW) (aquatic life)
2002 303d Priority:	Low
Watershed Area:	16,220 acres
Lake Area:	812 acres
Lake Volume:	13,548 acre-ft
Detention Time:	0.8 years
TSI (nutrient) Targets:	Total Phosphorus less than 62 (existing); Chlorophyll a less than 60; Secchi Depth less than 60
Total Phosphorus Load Capacity (TMDL):	19,520 pounds per year
Existing Total Phosphorus Load:	19,520 pounds per year
Total Phosphorus Load Reduction to Achieve TMDL:	N/A
Total Phosphorus Margin of Safety:	Implicit
Total Phosphorus Wasteload Allocation:	2,750 pounds per year
Total Phosphorus Load Allocation:	16,770 pounds per year
Sediment Load Capacity (TMDL):	34,500 tons per year
Existing Sediment Load:	34,500 tons per year
Sediment Load Reduction to Achieve TMDL:	N/A
Sediment Margin of Safety:	3,400 tons per year
Sediment Wasteload Allocation:	0
Sediment Load Allocation:	31,100 tons per year

The Federal Clean Water Act requires the Iowa Department of Natural Resources (IDNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's 303(d) list as impaired by a pollutant. Lake Macbride has been identified as impaired by nutrients and siltation. The purpose of these TMDLs for Lake Macbride is to calculate the maximum allowable nutrient and sediment loads that the lake can receive and still meet water quality standards.

This document consists of TMDLs for nutrients and siltation designed to provide Lake Macbride 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 nutrient impairment. Sediment delivery is targeted to address the siltation impairment.

Phasing TMDLs is an iterative approach to managing water quality that becomes necessary when the origin, nature and sources of water quality impairments are not well understood. The TMDL will have two phases. In Phase 1, the waterbody load capacity, existing pollutant load in excess of this capacity, and the source load allocations are estimated based on the limited information available. Phase 2 will consist of implementing the monitoring plan, evaluating collected data, and readjusting target values if needed.

Phase 1 will consist of setting specific and quantifiable targets for total phosphorus, algal biomass, Secchi depth, and sediment delivery. The targets for total phosphorus, algal biomass, and Secchi depth will be related to the lake's trophic state through Carlson's Trophic State Index (TSI).

A monitoring plan will be used to determine if prescribed load reductions result in attainment of water quality standards and whether or not the target values are sufficient to meet designated uses. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling.

Monitoring is essential to all TMDLs in order to:

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

The additional data collected will be used to determine if the implemented TMDL and watershed management plan have been or are effective in addressing the identified water quality impairments. The data and information can also be used to determine if the TMDLs have accurately identified the required components (i.e. loading/assimilative capacity, load allocations, in-lake response to pollutant loads, etc.) and if revisions are appropriate.

This TMDL has been prepared in compliance with the current regulations for TMDL development that were promulgated in 1992 as 40 CFR Part 130.7. These regulations and consequent TMDL development are summarized below:

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Lake Macbride, S29, T81N, R6W, 2 miles west of Solon, Johnson County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutants causing the water quality impairments are phosphorus and sediment loading associated with excessive nutrients and siltation. Designated uses for Lake Macbride are Primary Contact Recreation (Class A1) and Aquatic Life (Class B(LW)). Excess nutrient and sediment loading have 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 nutrient targets are Carlson's Trophic State Index (TSI) values of less than 62 (existing) for total phosphorus, and TSI values of less than 60 for both

chlorophyll-a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 55 and 20 ug/L, respectively, and a Secchi depth of 1.0 meter. The initial sediment target was a delivery rate that would result in the loss of less than one third of the original lake volume within a 100-year design life, or 72,200 tons per year (51 acre-feet per year at 65 pounds per cubic foot). However, the existing estimate for annual average siltation is currently below this target. Therefore, the Phase 1 sediment-loading target is set at the estimated existing sediment delivery rate of 34,500 tons per year (24 acre-feet per year).

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for Secchi depth, chlorophyll-a and total phosphorus based on 2000 - 2003 sampling are 1.5 meters, 17 ug/L, and 55 ug/L, respectively. Based on these values, all of the nutrient targets have been achieved. Since the nutrient targets are currently being met, the total phosphorus loading capacity has been set at the existing load of 19,520 pounds per year.

   The estimated existing sediment load is 34,500 tons per year. Based on this value, the sediment load target has been achieved. The sediment load capacity has been set at the existing load.

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

6. **Wasteload allocations for pollutants from point sources:** Two point source dischargers that contribute phosphorus to the lake have been identified. The City of Solon owns and operates a municipal wastewater treatment facility (IA NPDES Permit # 5282001) consisting of a mechanical activated sludge treatment plant. This facility discharges treated effluent to Mill Creek approximately 1.2 miles upstream of where the creek enters the lake. The Macbride Sanitary Sewer District (IA NPDES Permit # 5200906) municipal wastewater treatment facility discharges treated effluent from a 3-cell aerated lagoon system to a 3.5 acre pond which in turn discharges to an unnamed creek approximately 1,400 feet upstream of where the creek enters the lake.

   Neither facility is currently required to monitor for phosphorus. The existing total phosphorus load from the facilities and the wasteload allocation for total phosphorus is estimated to be 2,750 pounds per year. No significant point source contributors of sediment to the lake have been identified. Therefore, the wasteload allocation for siltation will be set at zero.

7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus load allocation for the nonpoint sources and internal recycle is

16,770 pounds per year including 320 pounds per year attributable to atmospheric deposition. The sediment load allocation for nonpoint sources is 31,100 tons per year.

8. **A margin of safety:** The nutrient targets for Lake Macbride have already been achieved. An implicit MOS is present in that existing average TSI values for chlorophyll and Secchi depth are currently below their targets. An additional implicit MOS is present in that the lake response model used to estimate the allowable loading results in a value that is 38% less than the watershed loading predicted by the Loading Function Model, which uses recent landuse assessment information to estimate watershed phosphorus delivery.

   For sediment delivery, an explicit numerical MOS of 3,400 tons per year (a 10% reduction of the load capacity) has been included to ensure that the load allocation will result in attainment of water quality standards.

9. **Consideration of seasonal variation:** The nutrient TMDL was developed based on the annual phosphorus loading that will result in attainment of TSI targets for the growing season (May through September). An annual loading period was used to define Lake Macbride's sediment loading capacity. Sediment loads are actually the result of periodic precipitation events and the non-point source controls are targeted at times when high loading occurs.

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for significant new sources of phosphorus or sediment loading was not included in the TMDLs. Changes in the Lake Macbride watershed landuses are likely to include significant development in and around the City of Solon.

    Construction activities related to urban development could increase sediment loads. However, these contributions are expected to be minimized through erosion control measures as required by stormwater NPDES permits for all construction activities that disturb one or more acres.

    The addition or deletion of grazing or livestock operations within the watershed could increase or decrease nutrient and sediment loading. Future increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and internal phosphorus loading. Such events cannot be predicted and at this time conditions are not expected to change, therefore, an allowance for their potential occurrence was not included in the TMDLs.

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

2. Lake Macbride, Description and History

2.1 The Lake

Lake Macbride is located in Johnson County in eastern Iowa, 2 miles west of Solon. Lake Macbride is used for water-based recreation and fishing. Lake Macbride State Park has 120 camping sites in two campgrounds, 15 miles of nature trails, seven open shelters, playgrounds, a beach, picnic areas, seven boat ramps, several fishing piers, and a disc golf course. Adjacent to the beach, there is a boat rental area where pontoons, motorboats, paddleboats, and canoes may be rented. About 118,000 visitors enjoy the 2,180-acre park each year.

Lake Macbride State Park, one of the largest state parks in Iowa, opened to the public in June of 1937 with the 178 acre Lake Macbride as its focal point. When Coralville Reservoir was built in 1955, the dam was raised 28 feet and Lake Macbride was enlarged to 812 acres to keep the lake separate from the new reservoir.

In September of 2000, the lake was drawn down for improvements: riprap was added to 12 miles of shoreline to prevent erosion, a 930-foot silt retention dam was added to the north arm of Lake Macbride, and fish habitat structures were installed. Lake levels returned to normal in June of 2002.

Table 2. Lake Macbride Features

Waterbody Name:	Lake Macbride
Hydrologic Unit Code:	HUC10 0708020810
IDNR Waterbody ID:	IA 02-IOW-00390-L
Location:	Section 29 T81N R6W
Latitude:	41° 48’ N
Longitude:	91° 34’ W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	Mill Creek, Jordan Creek
Receiving Waterbody:	Coralville Reservoir
Lake Surface Area:	812 acres
Maximum Depth:	47 feet
Mean Depth:	16.7 feet
Volume:	13,500 acre-feet
Length of Shoreline:	103,800 feet
Watershed Area:	16,220 acres
Watershed/Lake Area Ratio:	20:1
Estimated Detention Time:	0.8 years

Morphometry

Lake Macbride has a surface area of 812 acres. The storage volume is approximately 13,500 acre-feet. The lake has a maximum depth of 47 feet and an average depth of 16.7 feet. Temperature and dissolved oxygen sampling indicate that the lake strongly stratifies and exhibits hypolimnetic anoxia during the growing season.

Hydrology

The lake has two arms of nearly equal size. The north arm of Lake Macbride is fed primarily by Mill Creek. Jordan Creek feeds into the southern arm. Lake Macbride empties directly into the Coralville Reservoir. The estimated annual average detention time is 0.8 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Lake Macbride watershed has an area of approximately 16,220 acres and has a watershed to lake ratio of 20:1. The 2002 landuses and associated areas for the watershed were obtained from satellite imagery and are shown in Table 3. 2002 and 2003 landuse maps are shown in Appendix D. Figure 1 shows the topographic relief map of the Lake Macbride watershed.

Table 3. 2002 Landuse in Lake Macbride watershed.

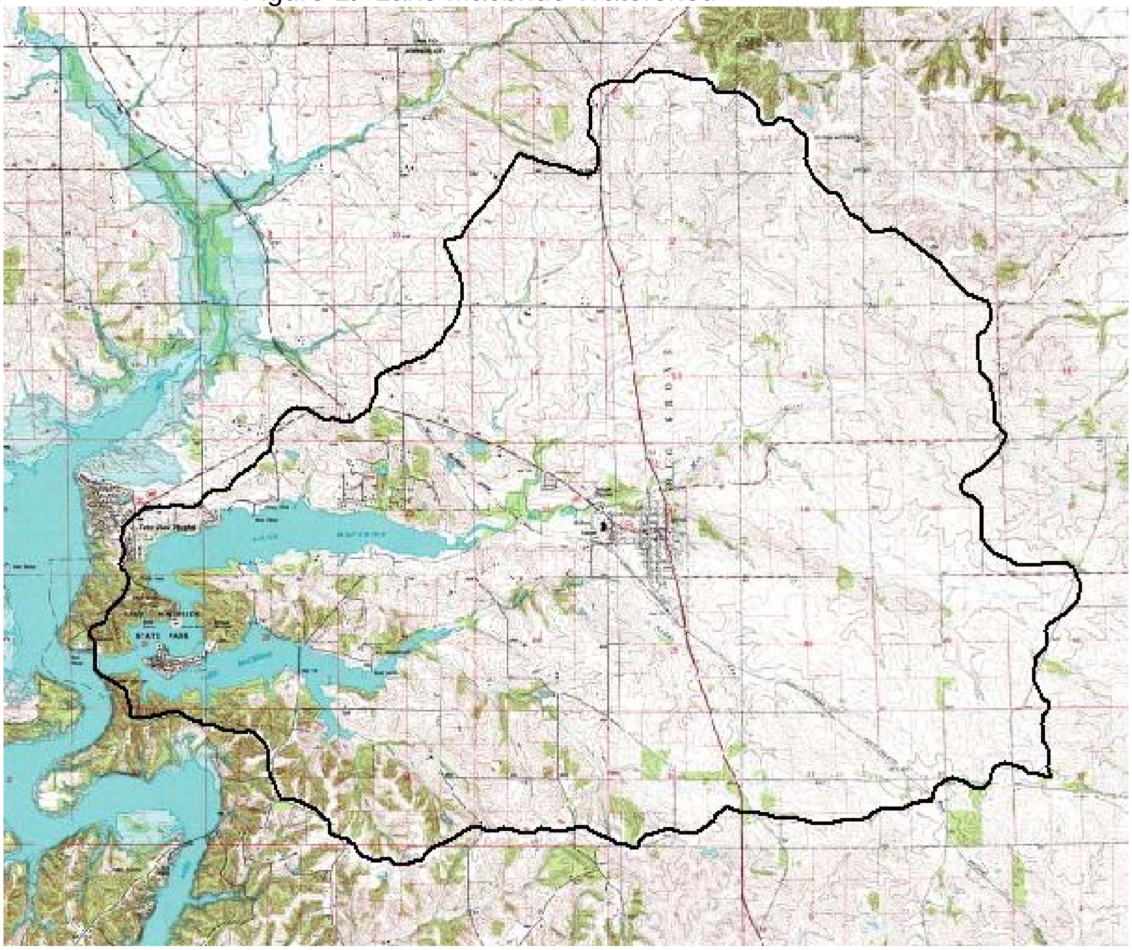
Landuse	Area in Acres	Percent of Total Area
Row Crop	8,770	54.1
Grassland	4,110	25.3
Forest	2,170	13.4
Roads	320	2.0
Alfalfa	320	2.0
Residential/Commercial	250	1.5
Water/Wetland	180	1.1
Other	100	0.6
Total	16,220	100

A more recent field-level watershed assessment was completed in 2003 to determine current landuses and associated cropping practice (CP) factors for use in calculating soil loss and delivery. The 2003 assessment also shows that the major landuse in the watershed is row crop (60%). Other major landuses in the 2003 watershed assessment include urban/homestead (9%), pasture/hay/grass (9%), timber (8%), state park (8%), CRP (3%), road (1%) and golf course (1%).

There are five open feedlots present in the watershed used to hold beef cows over the winter months. The estimated numbers of animal units associated with feedlots is 330 beef animal units. 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 body, number and type of livestock, and manure controls.

One incorporated municipality, the City of Solon, is located within the watershed. The 2000 Census population of Solon was 1,177 (24). Low to medium density unincorporated residential development is present to the north and south of the north arm of the lake. The majority of this unincorporated development is included within the Macbride Sanitary Sewer District.

Figure 1. Lake Macbride Watershed



Three soil associations are included in the watershed. Nearly 45% of the watershed has prairie and forest-derived loess soils with 2-14% slope. One third of the watershed has forest-derived soils formed in loess or glacial till with 2-25% slopes. The remaining soils are prairie-derived soils developed in loess over glacial till or glacial till on the Iowa Erosion Surface with 0-9% slopes.

The need for conservation practices has been recognized in the Lake Macbride watershed since 1970. At that time, soil conservation efforts were recommended by the State Conservation Commission in order to reduce the total sediment delivered to the lake. The Johnson County Soil Conservation District completed a watershed assessment of soil loss in 1973 with the assistance of the USDA Soil Conservation Service.

An extensive watershed improvement project in the Lake Macbride watershed began in 2001 and will continue through the end of 2005. The Lake Macbride Watershed Project is financed by EPA Section 319 funds, the Watershed Protection Program Fund, and the Water Protection Fund. Project goals include the installation of 20 acres of conservation buffers, seven acres of grassed waterways, three water and sediment control basins, five acres of windbreaks, two acres of erosion control matting, 50 acres of pasture management or rotational grazing, 667 feet of stream bank stabilization, 500 feet of terraces, and 20 acres of tree and shrub plantings. The project is also working to develop four wetlands, install several demonstration plots, and add riparian buffers to 25% of all stream segments. Cost-share and financial incentives are available to landowners.

An ecological plan is currently under development for Lake Macbride State Park.

3. TMDLs for Nutrients and Siltation

3.1 TMDL for Nutrients

3.1.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (8) list the designated uses for Lake Macbride as Primary Contact Recreation (Class A1) and Aquatic Life (Class B(LW)). The primary contact (Class A1) use of Lake Macbride was assessed for the 2002 305(b) report as fully supporting/threatened due to moderately high phosphorus levels. The aquatic life (Class B) use of Lake Macbride has been assessed since the 1998 305(b) report as fully supporting/threatened due to nutrient loading to the water column, siltation in the lake, and the presence of exotic species. A waterbody is considered fully supporting but threatened for a particular designated use when it fully supports that use now but may not in the future unless pollution prevention or control action is taken because of anticipated sources or adverse pollution trends.

The Iowa Water Quality Standards (8) do not include numeric criteria for nutrients but they do include narrative standards that are applicable to Lake Macbride, stating that "such waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor, or other aesthetically objectionable conditions."

Data Sources

Water quality surveys have been conducted on Lake Macbride in 1979, 1986, 1990, and 2000-03 (1,2,3,4,5,20,26). Additional water quality data was collected by the University of Iowa Hygienic Laboratory (UHL) from July through September of 2003. Data from the 1979, 1990, and 2000 - 2003 surveys is available in Appendix B. UHL sampling data from 2003 can be accessed at http://wqm.igsb.uiowa.edu/iastoret/.

Iowa State University Lake Study data from 2000 to 2003 and UHL monitoring data from 2003 were evaluated for this TMDL. The ISU study is scheduled to run through 2004 and approximates a sampling scheme used by Roger Bachmann in earlier Iowa lake studies. Samples are collected at one location (maximum depth) three times during the early, middle, and late summer. A number of water quality parameters are measured including Secchi disk depth, phosphorus series, nitrogen series, TSS, and VSS. The UHL monitoring includes samples taken six times during the growing season at each of three lake locations (shallow, mean, and maximum depth) with measured water quality parameters similar to the ISU Lake Study.

One observed in-lake phosphorus value from the ISU Study data (372 ug/L sampled on 6/12/2003) was excluded from analyses as an outlier based on the unusually low resulting nitrogen to phosphorus ratio it returned (1.5:1).

Interpreting Lake Macbride Water Quality Data

Based on mean values from ISU sampling during 2000 - 2003, the ratio of total nitrogen to total phosphorus for this lake is 39:1. Data on inorganic suspended solids from the ISU sampling indicate relatively low levels of non-algal turbidity. The median level of inorganic suspended solids in the 131 lakes sampled for the ISU lake survey from 2000 through 2002 was 4.8 mg/L. The median level of inorganic suspended solids at Lake Macbride during the same time period was 3.8 mg/l.

Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for 2000 - 2003 in-lake sampling indicate a slight limitation of algal growth potentially attributable to a combination of zooplankton grazing and non-algal turbidity (see Figure 2 and Appendix C).

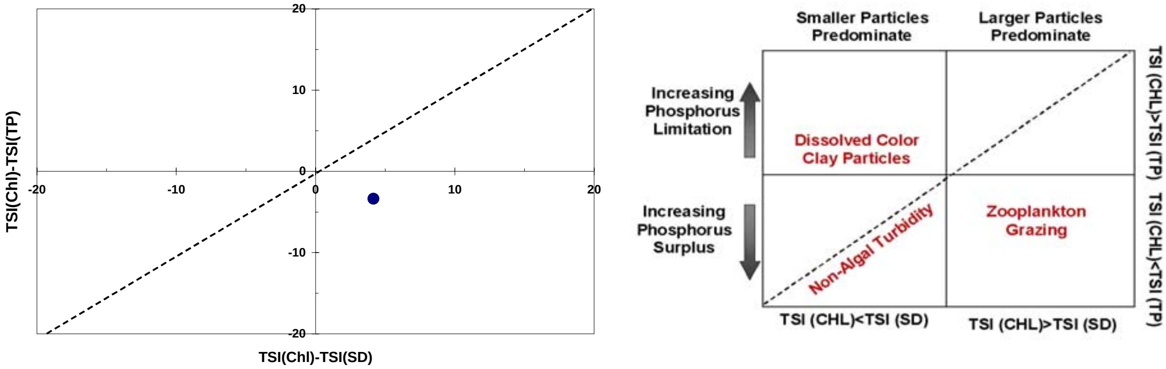
TSI values for 2000 - 2003 ISU and UHL maximum depth monitoring data are shown in Table 4. TSI values for all historical monitoring data and an explanation of Carlson's Trophic State Index are given in Appendix C.

Table 4. Lake Macbride TSI Values (3,4,5,20)

Sample Date	Source	TSI (SD)	TSI (CHL)	TSI (TP)
7/7/2000	ISU	60	60	75
8/2/2000	ISU	63	67	69
8/31/2000	ISU	62	46	60
6/7/2001	ISU	62	52	68
7/12/2001	ISU	48	41	53
8/8/2001	ISU	59	56	55
6/13/2002	ISU	44	46	49
7/18/2002	ISU	50	55	50
8/14/2002	ISU	63	55	63
6/12/2003	ISU	46	55	90*
7/8/2003	UHL	58	67	57
7/17/2003	ISU	59	65	61
7/23/2003	UHL	62	68	65
8/6/2003	UHL	62	68	57
8/14/2003	ISU	65	61	60
8/20/2003	UHL	65	69	61
9/17/2003	UHL	46	48	61
9/29/2003	UHL	47	48	61

*excluded from analysis as outlier

Figure 2. Lake Macbride 2000 - 2003 Mean TSI Multivariate Comparison Plot (22)



Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) comprise a relatively large portion of the summertime phytoplankton community. The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. The 2000 average summer wet mass of bluegreen algae at this lake (13.7 mg/l) was the 51st highest of 131 lakes sampled with bluegreens consisting of approximately 85% of the phytoplankton community. The 2001 average summer wet mass of bluegreen algae increased to 17.4 mg/L with bluegreens comprising approximately 80% of the phytoplankton community. Sampling for cyanobacterial toxins was not conducted at Lake Macbride for the 2000 - 2003 sampling period. 2000 and 2001 phytoplankton sampling results are given in Table B-8 of Appendix B.

Potential Pollution Sources

The potential nutrient sources for Lake Macbride are watershed nonpoint sources, point sources, internal recycling of phosphorus from bottom sediments, and contributions from atmospheric deposition. The identified point sources are municipal wastewater treatment facilities that serve the City of Solon and the Macbride Sanitary Sewer District.

Natural Background Conditions

For the phosphorus load attributable to atmospheric deposition directly on the lake surface, the annual average concentration of phosphorus in precipitation was assumed to be 0.05 mg/L based on a review of available literature (11,17,18,19) and the default values used in the EUTROMOD and WILMS modeling programs. Contributions of phosphorus attributable to dry atmospheric deposition were not separated from the direct precipitation load. Potential phosphorus contributions from groundwater influx were not separated from the total nonpoint source load.

3.1.2 TMDL Target

The Phase 1 targets for this TMDL are mean TSI values of less than 62 (existing) for total phosphorus, and TSI values of less than 60 for both chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 55 and 20 ug/L, respectively, and a Secchi depth of 1.0 meter. Observed 2000 - 2003 average chlorophyll and Secchi depth values for Lake Macbride are currently below targeted levels. Therefore, the target for total phosphorus is set at the concentration.

Table 5. Lake Macbride Existing vs. Target TSI Values

Parameter	2000-2003 Mean TSI	2000-2003 Mean Value	Target TSI	Target Value	Minimum In-Lake Increase or Reduction Required
Chlorophyll	59	17 ug/L	<60	<20 ug/L	N/A
Secchi Depth	54	1.5 meters	<60	>1.0 meter	N/A
Total Phosphorus	62	55 ug/L	<62 (existing)	<55 ug/L	N/A

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for nutrients. The nutrient-loading objective is defined by a mean total phosphorus TSI of less than 62 (existing), which is related through the Trophic State Index to chlorophyll-a and Secchi depth. The TSI is not a standard, but is used as a guideline to relate phosphorus loading to chlorophyll and Secchi depth for TMDL development purposes and to describe water quality that will meet Iowa's narrative water quality standards.

Selection of Environmental Conditions

The critical condition for which the TMDL TSI target values apply is the growing season (May through September). It is during this period that nuisance algal blooms are prevalent. The existing and target total phosphorus loadings to the lake are expressed as annual averages. 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 Approach

A number of different empirical models that predict annual phosphorus load based on measured in-lake phosphorus concentrations were evaluated. In addition, watershed phosphorus delivery using both export coefficients and an annual loading function model as outlined in Reckhow's EUTROMOD User's Manual (10) was calculated. Finally, the lake was segmented and Walker's BATHTUB (23) program was used with the Walker Reservoir Model to account for spatial variations in water quality with respect to sampling location. The results from all approaches were compared to select the best-fit empirical model.

All of the empirical models evaluated gave results that were significantly below the watershed load estimates. Lake Macbride is elongated with a shoreline development ratio of approximately 4.9 and strongly stratifies. Also, the sampling location for the majority of available sampling data (maximum depth) is at the end of the lake opposite the main tributary channels at the point where the two arms of the lake join. Therefore, it was concluded that the empirical models alone did not adequately account for spatial variations in water quality. The BATHTUB program, which uses empirical eutrophication models but also accounts for advective and diffusive transport in a segmented network, was used to address this issue.

Table 6. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = ANN TP = 55 ug/L, SPO TP = 81 ug/L	Comments
Loading Function	26,890	Reckhow (10)
EPA Export	18,040	EPA/5-80-011
WILMS Export	12,870	“most likely” export coefficients
Reckhow 1991 EUTROMOD Equation	8,160	GSM model
Canfield-Bachmann 1981 Natural Lake	5,760	GSM model
Canfield-Bachmann 1981 Artificial Lake	7,900	GSM model
Reckhow 1977 Anoxic Lake	3,090	GSM model
Reckhow 1979 Natural Lake	7,550	GSM model.
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	5,170	GSM model.
Nurnberg 1984 Oxic Lake	6,450 (internal load = 0)	Annual model.
Walker 1977 General Lake	6,280	SPO model
Vollenweider 1982 Combined OECD	6,580	Annual model
Vollenweider 1982 Shallow Lake	7,860	Annual model
Walker Reservoir	9,640	GSM model
Walker Reservoir (BATHTUB)	19,520	GSM model. Segmented.

For the BATHTUB program, the lake was divided into seven segments (Mill Upper, Mill Mid, Mill Lower, Jordan Upper, Jordan Mid, Jordan Lower and Dam Area). The total influent load was then adjusted to match the predicted in-lake concentration with observed sampling data at the maximum depth (Dam Area) location. Because only one year of shallow and mean depth sampling was available (versus four years of maximum depth sampling), the model was not calibrated to the observed area-weighted mean concentration. In addition, nutrient partitioning was not modeled due to lack of site-specific data for tributary ortho phosphorus concentrations. The selected model used in the BATHTUB program was the Walker Reservoir Model.

The equation for the Walker Reservoir Model is:

$$P = \frac{-1 + (1 + 4A_1 P_i T)^{0.5}}{2A_1 T}$$

where

$$A_1 = {0.17Q_s} \Big/ {(Q_s + 13.3)}$$

Q_s = surface overflow rate (meters/year)
P = predicted in-lake total phosphorus concentration (ug/L)
P_i = inflow total phosphorus concentration (ug/L)
T = hydraulic residence time (years)

The predicted load from the BATHTUB program using the Walker Reservoir Model is within the range of watershed load estimates. Input and output from the BATHTUB program is shown in Appendix E.

Waterbody Pollutant Loading Capacity

The chlorophyll-a and Secchi depth objectives are related through the Trophic State Index to total phosphorus. The load capacity for this TMDL is the annual amount of phosphorus Lake Macbride can receive and meet its designated uses. Based on the selected lake response model and a target TSI (TP) value of less than 62 (existing), the Phase 1 total phosphorus loading capacity for the lake is 19,520 pounds per year.

3.1.3 Pollution Source Assessment

There are three quantified phosphorus sources for Lake Macbride in this TMDL. The first is the phosphorus load from the watershed areas that drain into the lake and the phosphorus recycled from lake sediments. The second source is atmospheric deposition. The third source is the contribution of municipal wastewater treatment plants within the watershed. Note that load contributions from groundwater influx have not been separated from the total nonpoint source loads.

Existing Load

The annual total phosphorus load to Lake Macbride is estimated to be 19,520 pounds per year based on the selected lake response model. This estimate includes 16,450 pounds per year from a combination of nonpoint sources in the watershed and the internal phosphorus load recycled from the lake bottom sediment, 2,750 pounds per year from point sources and 320 pounds per year from atmospheric deposition.

Departure from Load Capacity

Observed 2000 - 2003 average chlorophyll and Secchi depth values for Lake Macbride are currently below targeted values. Therefore, the targeted load capacity for total phosphorus is set at the existing load. The Phase 1 targeted load capacity and estimated existing load for Lake Macbride is 19,520 pounds per year or 1.2 pounds per year per acre of watershed area.

Identification of Pollutant Sources

There are two identified point sources of phosphorus in the Lake Macbride watershed. The City of Solon owns and operates a municipal wastewater treatment facility (IA NPDES Permit # 5282001) consisting of a mechanical activated sludge treatment plant. This facility discharges treated effluent to Mill Creek approximately 1.2 miles upstream of where the creek enters the lake. The Macbride Sanitary Sewer District (IA NPDES Permit # 5200906) municipal wastewater treatment facility discharges treated effluent from a 3-cell aerated lagoon system to a 3.5 acre pond which in turn discharges to an unnamed creek approximately 1,400 feet upstream of where the creek enters Lake Macbride.

Neither facility is currently required to monitor for phosphorus or employ phosphorus removal technologies, although some phosphorus removal is expected to result from biological uptake and solids separation/removal in the treatment processes.

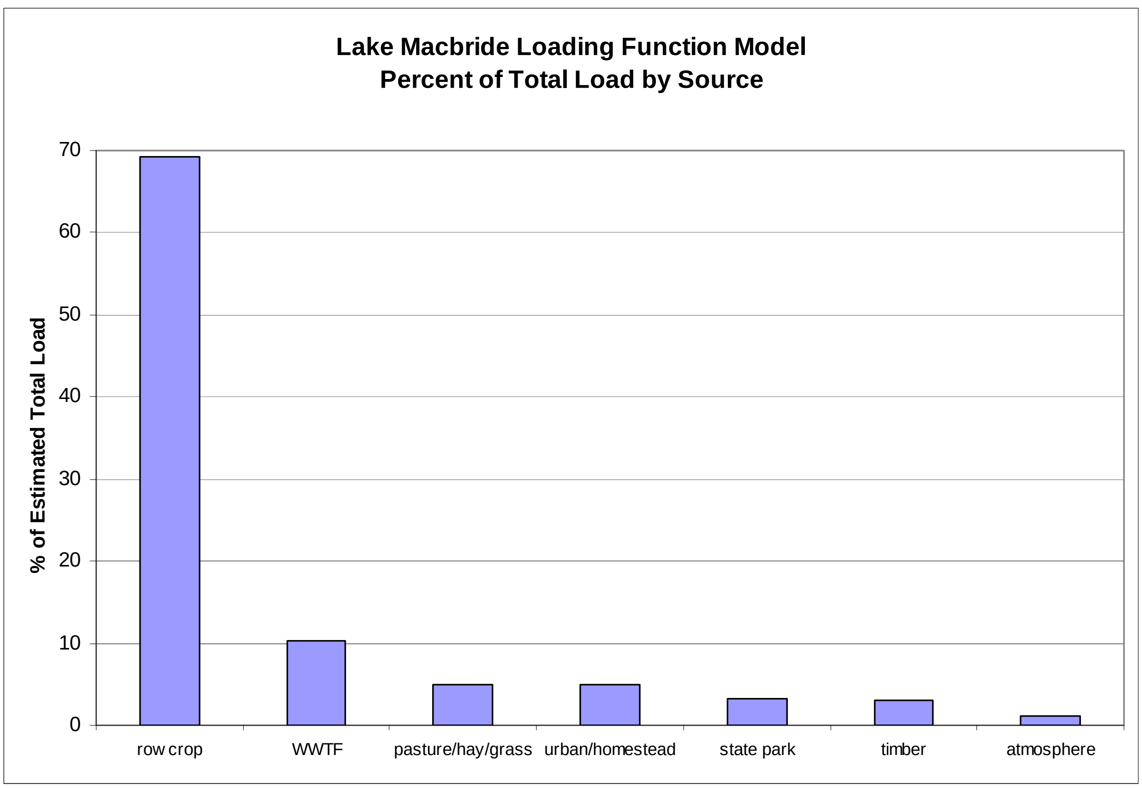
The existing loads from these treatment facilities were estimated by using observed average flow from NPDES monitoring reports and expected effluent concentrations based on the type of treatment provided (25). The estimated existing loads are shown in Table 7.

Table 7. Existing Point Source Loads

Facility	Treatment Type	Monitoring Period Evaluated	Existing Average Effluent Flow (MGD)	Expected Effluent Total Phosphorus Concentration (mg/L)	Estimated Load (lbs/year)
Solon WWTF	Activated Sludge	5/01 - 9/04	0.1805	3.5	1,920
Macbride S.S.D. WWTF	Aerated Lagoon	4/01 - 9/04	0.0548	5.0	830

From the Loading Function Model, the most nonpoint source phosphorus delivered to the lake is from row crop landuse as shown in Figure 3. It should be noted that while the Loading Function Model provides estimates of the primary potential pollutant sources, it was used only for comparison purposes to aid in selecting an empirical lake response model in the development of the target total phosphorus load identified in this TMDL. The target load was calculated from measured in-lake total phosphorus concentrations using the selected lake response model as described in *Section 3.2, Modeling Approach*.

Figure 3. Loading Function Model Source Contributions



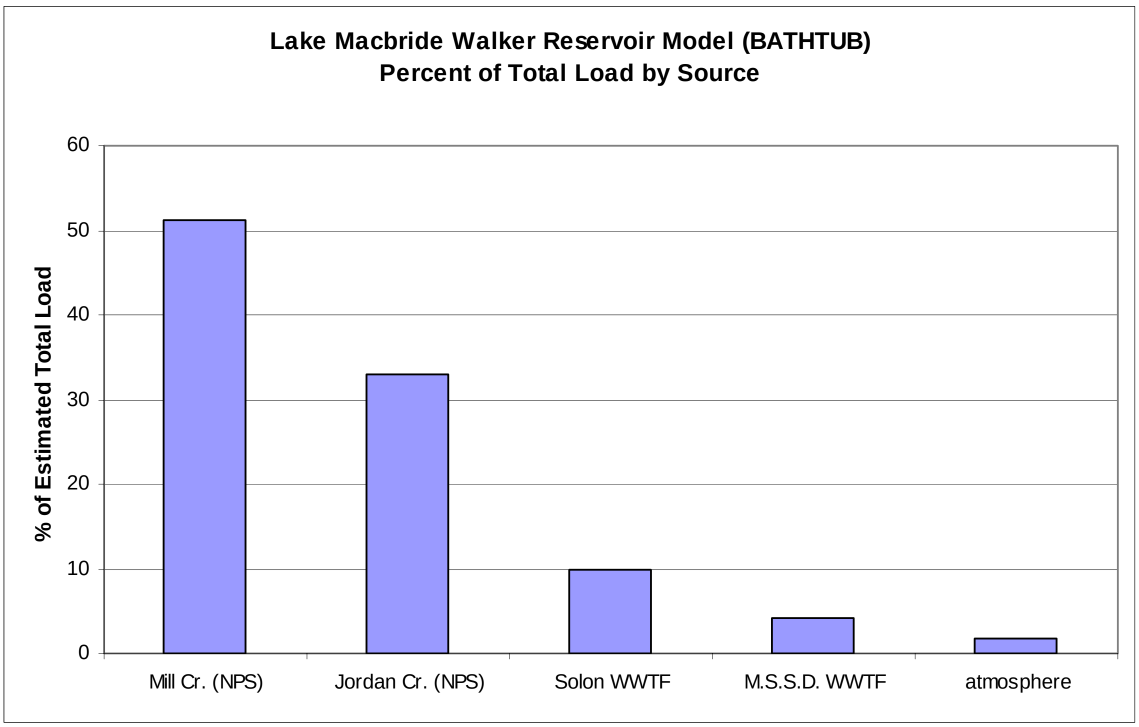
The Walker Reservoir/BATHTUB lake response model indicates a total loading significantly lower than the Loading Function Model, and consequently allocates a greater percentage of the total load to point sources. Figure 4 shows the percent load by source for the lake response modeling. For the estimated nonpoint source contributions from the Mill Creek and Jordan Creek watersheds, the loads were split in proportion to those indicated by the Loading Function Model.

Other sources of phosphorus capable of being delivered to the water body exist. These sources include septic systems and toilet pits from campsites and individual residences. Manure and waste from wildlife, pets, etc. also contribute to the phosphorus loading. Unfortunately, the potential phosphorus being contributed from these sources is difficult to quantify. These potential sources have been considered, but are deemed smaller contributors or have less impact than the sources previously identified. However, these sources will be evaluated and quantified as required in Phase 2 of this TMDL.

Linkage of Sources to Target

To meet the TMDL, the annual point source, nonpoint source, and internal recycling total phosphorus contributions to Lake Macbride need to be limited to less than 19,520 pounds per year.

Figure 4. Walker Reservoir Model (BATHTUB) Source Contributions



3.1.4 Pollutant Allocation

Wasteload Allocation

The Wasteload Allocations (WLAs) for the two point source dischargers are shown in Table 8. Since nutrient targets for the lake are currently being met, the WLAs are set at estimated existing loads. Total phosphorus monitoring data for the point sources is currently unavailable. Therefore, the estimated existing loads are based on monitored plant flows and typical effluent phosphorus concentrations for the type of treatment provided. It should be noted that the actual existing effluent concentrations could vary substantially from those estimated due to site-specific wastewater characteristics.

Effluent monitoring as described in *Section 5* will be necessary to more accurately establish the existing point source loads and their impact on the lake.

Table 8. Point Source Contributions

Facility	Existing Flow (MGD)	Expected Effluent Total Phosphorus Concentration (mg/L)	Total Phosphorus WLA (lbs/year)	Design Flow (MGD)	Allowable Effluent Concentration at Design Flow (mg/L)
Solon WWTF	0.1805	3.5	1,920	0.2684[1]	2.3
Macbride S.S.D. WWTF	0.0548	5.0	830	0.0548[2]	5.0[2]

Load Allocation

The Load Allocation (LA) for this TMDL is 16,770 pounds per year of total phosphorus distributed as follows:

- 16,450 pounds per year allocated to the Lake Macbride watershed and internal recycling of phosphorus from the lake bottom sediments.
- 320 pounds per year allocated to atmospheric deposition.

Margin of Safety

The nutrient targets for Lake Macbride have already been achieved. An implicit MOS is present in that existing TSI values for chlorophyll and Secchi depth are currently below their targets. An additional implicit MOS is present in that the lake response model used to estimate the allowable loading results in a value that is 38% less than the watershed loading predicted by the Loading Function Model, which uses recent landuse assessment information to estimate watershed phosphorus delivery.

3.1.5 Nutrient TMDL Summary

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

TMDL = Load Capacity (19,520 lbs/year) = WLA (2,750 lbs/year) + LA (16,770 lbs/year) + MOS (implicit)

[1] Estimated average yearly flow based on projected population equivalent from plant design data.
[2] The average flow currently exceeds the original design flow of 0.051 MGD. The projected design flow is unknown. The allowable effluent concentration will decrease for future flows greater than existing.

3.2 TMDL for Siltation

3.2.1 Problem Identification

In 1998 and again in 2002, siltation in Lake Macbride was reported as a significant threat to the continued support of the lake's beneficial uses by IDNR Fisheries staff. Excessive sediment deposition harms normal aquatic life in many ways:

- The impact from reduction of volume and depth is greatest in shallow areas that are critical for feeding and reproduction of aquatic life. Some of the most critical areas are in the upstream areas of tributary arms where most sediment settles as stream velocities rapidly decrease.
- As lakes lose depth, they become more susceptible to summer algal blooms and winter fish kills. The reduced volume of water under the winter ice provides less dissolved oxygen.
- Shallow water favors an increase in rough fish such as bullheads and carp. Experience with temporarily drained Iowa lakes shows that populations of these species explode as more shallow water predominates. These species also overgraze on macrophytes and stir up bottom sediments, causing turbidity and nutrient recycling.

One of the biggest obstacles to assessing the nature and extent of a siltation problem is knowing how much silt has accumulated and how much of a lake's volume has been lost. IDNR and US Geological Survey cooperated to develop a method to map lake bottom and sediment volume using specialized sonar equipment.

The Lake Macbride field mapping and sediment volume analysis was done in the summer of 2003 by USGS. This was two years after the lake was drawn down 15 feet for improvements including shoreline riprap, a 900 foot silt dam, fish habitat including "humps and trenches", and six fishing jetties. Temporary lake bottom roads were also built to facilitate construction. Because of this disturbance to the bottom, the siltation estimate includes only those parts of the lake bottom below a depth of 20 feet at normal pool. The "below 20 foot" silt estimate shows that the lake has lost significant volume in the deeper areas and some surface area near the inlet. The siltation study is able to estimate the amount of sediment accumulated over the life of the lake but not when the sediment was deposited. Table 9 summarizes Lake Macbride sediment accumulation between 1960 and 2003 but includes only the silt volume >20 foot water depth.

Table 9. Lake Macbride sediment accumulation

"Original" total water volume	15,400 acre-feet
Current total water volume	13,500 acre-feet
Original water volume > 20 foot depth	4,300 acre-feet
Current water volume >20 foot depth	2,500 acre-feet
Sediment volume > 20 foot depth	1,800 acre-feet

The Lake Macbride watershed to lake area ratio is 20:1. This is generally considered a desirable ratio. The watershed falls on two different landform regions, the Southern Iowa Drift Plain and the Iowan Surface and the watershed surface area is 25 square miles. Using the NRCS method based on landform region and watershed area, the sediment delivery ratio (SDR) is estimated to be 0.24 since this represents the larger landform area of the watershed and the region at the outlets to the lake.

Data Sources

A bathymetric survey was conducted by the USGS under a cooperative agreement with the DNR in the summer of 2003. This data provides the current and historic lake bottom and an estimate of the amount of sediment accumulated in the lake. Data from this survey show the current water volume in the lake and the sediment volume below a depth of 20 feet. The USGS mapping and sediment estimating procedure are outlined in Appendix G.

An estimate of the sediment volume in the upstream part of the two lake arms was made using lake and watershed maps. A description of Lake Macbride in 1960 when it was raised 28 feet estimates water surface area to be 950 acres. In a 1979 evaluation it was noted that the water surface area was 812 acres and that in 1986 it was 825 acres. The area lost between 1960 and 1986, about 100 acres, was in the upstream reaches of the lake.

The evaluation of soil loss from the watershed was performed using adjusted RUSLE erosion modeling within the IDNR geographical information system. A brief explanation of this method can be found in Appendix F.

Interpreting Lake Macbride Water Quality Data

The information that most directly addresses the sedimentation impairment is the bathymetric mapping that was done in 2003. For the 2003 USGS bathymetry and siltation estimate, the lake bottom mapping was performed separately from the siltation estimate. The volume between the existing lake bottom and the original bottom derived by USGS was calculated and this is the estimate for the siltation volume.

The data for the current and original lake bottom provides an estimate of the amount of sediment accumulated in the lake. Data from this survey show that the current water volume in the lake is 13,500 acre-feet and the sediment volume below a water depth of 20 feet is 1,800 acre-feet. Given that the existing water volume below the 20-foot depth is 2,500 acre-feet, this represents a 42% loss in volume in the deepest locations since the lake was created. The mass of the accumulated sediment at 65 pounds per cubic foot is shown in Table 10.

The upstream sediment in the two arms of the lake that resulted in the loss of lake area has been estimated by examining photographs and contour maps of these areas.

North arm: Two upstream sections were evaluated.

Section 1: 2,000 feet by 700 feet
Section 2: 2,200 feet by 400 feet
Total area = 52 acres, slope ~ 0.0011 ft/ft, 4.8 feet of drop, avg. = 2.4 feet
(52 acres)(2.4 feet) = 125 acre-feet

South arm: Two sections were evaluated:

Section 1: 4,000 feet by 350 feet
Section 2: 1,000 feet by 200 feet
Total area = 37 acres, slope ~ 0.002 ft/ft, 4.5 feet of drop, avg. = 2.25 feet
(37 acres)(2.25 feet) = 83 acre-feet

Total upstream silt = 125 + 83 = 208 acre-feet

At 65 pounds per cubic foot the sediment mass is 294,000 tons.
Over the 45 years since 1960 the upstream siltation rate is 6,500 tons per year.

The silt volume including the upstream estimate and the > 20 foot depth volume is:
208 acre-feet + 1,807 acre-feet = 2,015 acre-feet

The average annual rate since 1960 is:
(2,015 acre-feet) / (45 years) = 45 acre-feet per year

Table 10. Estimated existing silt in Lake Macbride after completion of improvements

	Sediment volume	Sediment mass at 65 lb/cf	Annual siltation rate over 45 years
Silt at > 20 ft depth	1,807 acre-feet	2,550,000 tons	56,700 tons per year
Silt at < 20 ft depth	unknown	unknown	unknown
Silt in upstream arms	208 acre-feet	294,000 tons	6,500 tons per year
Total	2,015 acre-feet	2,844,000 tons	63,200 tons per year

Note that the existing sediment delivery estimate of 34,500 tons per year is less than the historic average annual sedimentation rate of 63,200 tons per year.

Potential Pollution Sources

No significant sediment point sources exist in the Lake Macbride watershed. Three important non-point sediment sources exist in the Lake Macbride watershed:

- Upland sheet and rill erosion in farmed fields.
- Ephemeral gully erosion, and
- Streambank and gully erosion

Other less significant sources are wind resuspension of lake sediment, construction and development activities, grasslands, and forest.

Natural Background Conditions

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

3.2.2 TMDL Target

The water quality target for this siltation TMDL is the volume of sediment that can be delivered to the lake annually and not cause an impairment of the lake's designated uses and also does not allow for the degradation of the existing lake condition.

The design life of Lake Macbride does not appear to have been explicitly determined when it was constructed. A design life of 100 years has been selected for this TMDL because it is frequently used by the U.S. Army Corps of Engineers for reservoir projects. It is usually considered an economic parameter and not a physical limitation. The original lake volume in 1960 was estimated at 15,400 acre-feet (see Table 9) and one third of this is 5,100 acre-feet.

Assuming that a one-third loss of the original volume over 100 years causes an impairment of recreational and aquatic life use, then the total volume loss of 5,100 acre-feet spread over 100 years yields an average annual volume loss of 51 acre-feet per year. If this were used as the criterion for the Lake Macbride siltation rate, the estimated allowable annual volume loss would be 51 acre-feet per year based on a 100-year design life and a one-third loss of volume over the design life.

However, the existing estimate (See Section 3.2.3, *Pollution Source Assessment and Existing Sediment Load*) of annual average siltation is 24 acre-feet per year. Therefore, to prevent degradation of existing uses, the Phase 1 target for this TMDL is the existing siltation volume loss of 24 acre-feet per year and the associated sediment delivery of 34,500 tons per year at a specific weight of 65 pounds per cubic foot. This is less than the historic average annual volume loss over the 45 years since the lake was created in its current form. The average annual volume loss since 1960 was 45 acre-feet per year.

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criterion for siltation (i.e. loss of volume, area, or depth). Siltation is a loss of lake volume, area, and depth that can be measured. An allowable average annual rate of sediment delivery and associated volume loss is the measure that is used to determine attainment of water quality standards.

Selection of Environmental Conditions

The critical condition for which this sediment TMDL applies is the entire year. An annual loading period was used to define Lake Macbride's sediment loading capacity. Sediment loads are actually the result of periodic precipitation events and the non-point source controls are targeted at times when high loading occurs.

Waterbody Pollutant Loading Capacity

The load capacity for this siltation TMDL is the amount of deposited sediment Lake Macbride can receive annually and not exceed a rate based on the lake design life or the existing sedimentation rate, whichever is less. The allowable annual volume loss rate for the design life estimate is 51 acre-feet per year for a sediment loading capacity of 74,000 tons per year. This exceeds the estimated existing sediment delivery of 34,500-tons per year and loss of 24 acre-feet of lake volume. To prevent degradation of the lake uses this existing annual sediment delivery will be used as the pollutant loading capacity.

3.2.3 Pollution Source Assessment and Existing Sediment Load

The watershed sheet and rill erosion was estimated using an approach that adjusted the RUSLE 1 model results to more closely match those calculated using RUSLE 2 and the original USLE models. This adjustment increased the erosion from tilled fields by a factor of three based on NRCS evaluations of the three models applied to Iowa conditions.

The resulting estimate for gross sheet and rill erosion for the Macbride watershed is 82,400 tons/year. The estimated ephemeral gully erosion based on a literature value is 31% of the gross sheet and rill erosion, or 25,500 tons/year, for a total gross erosion of 107,900 tons/year. Applying the 24% SDR to the total gives a delivered sediment value of 25,900 tons/year. Based on literature values it is estimated that streambank and bed erosion is 25% of the total erosion, or 8,600 tons per year. The current estimate for total sediment delivery to Lake Macbride is 34,500 tons per year.

Table 11. Current gross and delivered sediment based on SDR = 0.24

	Gross erosion	Delivered sediment
Sheet and rill	82,400 tons per year	19,800 tons per year
Ephemeral gully	25,500 tons per year	6,100 tons per year
Streambank and lake shoreline	NA	8,600 tons per year
Total		34,500 tons per year

The gross sheet and rill erosion was estimated using a 2003 IDNR watershed assessment and GIS coverage data in an adjusted RUSLE model (see Appendix F).

Existing Load

The estimated existing Lake Macbride average annual sediment load is 34,500 tons per year delivered by two streams that form two separate arms of the lake and shoreline erosion. Sediment discharged from the lake is not considered in the siltation loading but trap efficiency for this type of reservoir is typically 90 to 95%.

Departure from Load Capacity

The Phase 1 targeted total sediment loading capacity for Lake Macbride is 34,500 tons per year. The estimated existing load to the lake is the same.

Identification of Pollutant Sources

There are no significant point source sediment discharges in the Lake Macbride watershed. Non-point source identification and sediment quantification were established with data and modeling done for watershed projects and through the application of an IDNR model based on the RUSLE and IDNR GIS data.

Linkage of Sources to Target

The target and existing average annual sediment load of 34,500 tons per year to Lake Macbride originates entirely from non-point sources. The sediment load from non-point sources must be maintained at or below the existing load to meet the TMDL target.

3.2.4 Pollutant Allocation

Wasteload Allocation

There are no significant sediment point source contributors in the Lake Macbride watershed. Therefore, the sediment Wasteload Allocation (WLA) is zero tons per year.

Load Allocation

The Load Allocation (LA) for this siltation TMDL is 31,100 tons per year of and is distributed among the identified non-point sources. In the absence of detailed source information, the load is divided between sheet and rill, ephemeral gully, and streambank and shoreline erosion.

Margin of Safety

The explicit margin of safety for this TMDL is a 10% reduction of the load capacity. The calculated MOS is 3,400 tons per year.

3.2.5 Sediment TMDL Summary

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

TMDL = Load Capacity (34,500 tons/year) = WLA (0 tons/year) + LA (31,100 tons/year) + MOS (3,400 tons/year)

4. Implementation Plan

The following implementation plan is not a required component of a Total Maximum Daily Load but can provide department staff, partners, and watershed stakeholders with a strategy for improving Lake Macbride water quality. Many of the recommended lake and watershed improvements have already been constructed or implemented through the recently completed 2001 - 2002 Lake Renovation Project and the ongoing watershed improvement projects as described in Sections 2.1 and 2.2 of this report, respectively. These improvements will reduce both nutrient and sediment delivery from nonpoint sources to the lake. It is expected that water quality in the lake will improve as a result of these projects.

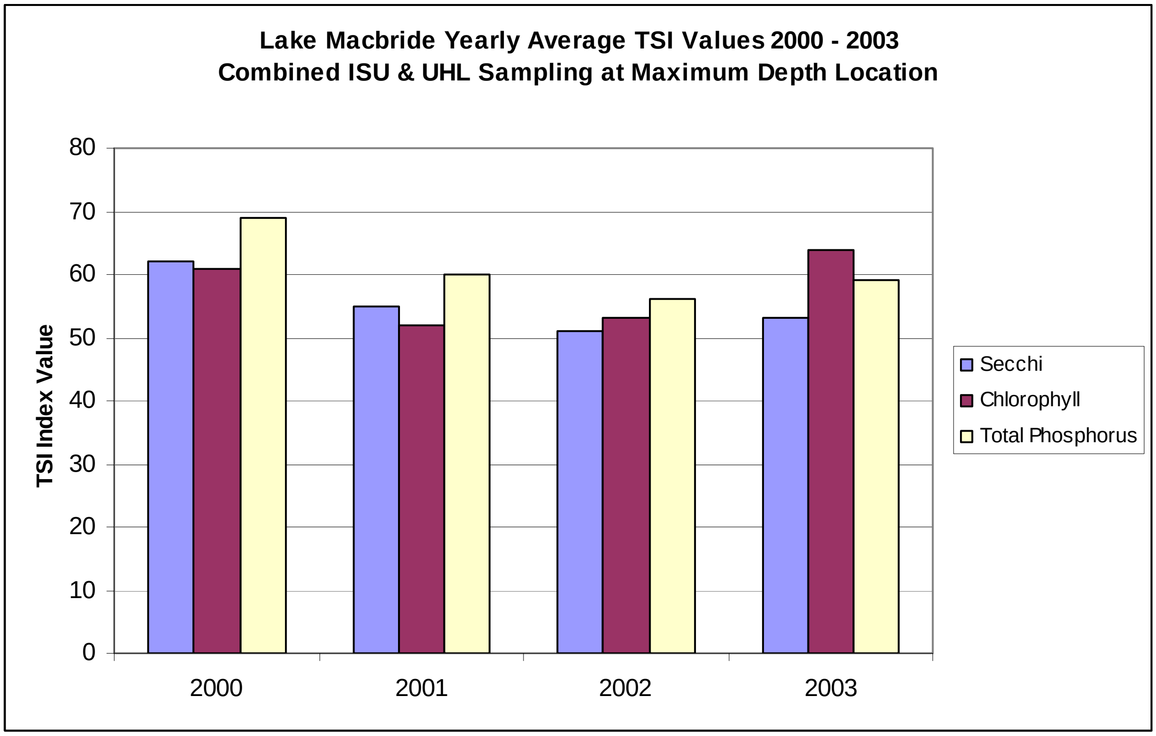
4.1 Nutrients

Based on 2000 - 2003 monitoring data for chlorophyll and Secchi depth, the existing average annual nutrient loading to Lake Macbride is below that which would cause impairment due to algal turbidity. The observed TSI values for these parameters do not show any obvious increasing or decreasing trend during the monitoring period as shown in Figure 6. However, this does not imply that continuation of existing and implementation of new management practices that will prevent degradation of water quality is not necessary.

If the entire phosphorus load were attributed to watershed sources, the estimated loading from watershed sources would need to be maintained below 1.2 pounds/year/acre to meet the TMDL target. However, this does not account for the internal recycled load, which could be significant.

Among the potential mechanisms of internal loading are resuspension of bottom sediments from bottom feeding rough fish such as carp, wind-driven waves and currents, and boat propellers. Significant internal loading may also occur during turnover events when accumulated phosphorus-laden sediment is disturbed. Methods 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.

Figure 6. Yearly Average TSI Values



Best management practices to reduce nutrient delivery, particularly phosphorus, should be emphasized in the Lake Macbride 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.
- The open feedlots in the watershed need to be assessed for water quality impacts on the lake and the level of pollutant control required needs to be determined.
- 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 contour grass buffer strips, 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.

In addition to the recommended best management practices on agricultural land, there are practices that can be implemented in the residential areas that contribute stormwater flows to the lake. These include use of low or no-phosphorous fertilizers on lawns and use of appropriate erosion controls on construction sites.

Internal loading can be controlled through fish management to control rough fish (i.e., carp), rip rap along the shoreline to reduce shoreline erosion, and dredging to remove nutrients from the lake system.

The two municipal wastewater treatment plants that discharge treated effluent within the watershed are estimated to contribute a significant portion of the total phosphorus load to the lake. Chemical and biological wastewater treatment methods are available that can substantially increase wastewater treatment phosphorus removal efficiency. Chemical addition of metal salts (e.g. alum) can be added to lagoons or at strategic points in mechanical treatment processes to precipitate phosphorus from the treatment stream. Biological removal typically employs alternating anaerobic and aerobic treatment stages to force biological uptake of phosphorus by activated sludge microorganisms to above normal levels. For both chemical and biological treatment methods, the accumulated excess phosphorus is ultimately removed from the treatment system through the wasting of sludge. Stabilized waste sludge from domestic wastewater treatment facilities is typically land applied as a fertilizer to non-food crops.

In lieu of treatment alternatives, the facilities could pump treated effluent outside of the lake watershed. However, this option may not be practical depending on factors such as the available discharge point(s) and receiving stream considerations, the distance the effluent would need to be pumped, and the additional construction and operating expenses that would be required.

Due to the lack of historical effluent monitoring for total phosphorus at both of the treatment facilities, the loading from each facility can only be estimated based on typical expected effluent concentrations at this time. The IDNR will include monitoring requirements for total phosphorus in both of the facilities' NPDES permits to more accurately establish the existing loads. Following a one year monitoring period, the NPDES permits will be amended to include effluent limits for total phosphorus.

4.2 Siltation

This siltation TMDL implementation plan provides guidance for agencies and stakeholders working to improve Lake Macbride water quality. The emphasis is on non-point source reduction activities targeting sediment. These include:

Gully and streambed and bank erosion: Significant stream and gully sediment contributions should be identified and stream bank restoration work done. Identify problem locations and target restoration activities at eroding stream banks contributing significant sediment. 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 sediment contributors. 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.

4.3 Reasonable Assurance

To maintain existing water quality in Lake Macbride, both wasteload and load allocations were determined for phosphorous. The allocations in this TMDL are set at existing levels, not requiring reductions at this time. However, the Lake Macbride water quality project was initiated in 2001, and is funded with CWA Section 319 non-point source grant funds from EPA. The Lake Macbride water quality project was initiated by the Johnson County Soil and Water Conservation District. The objectives of this project include providing educational opportunities and develop public relations encouraging voluntary participation, promote and install conservation practices that reduce erosion and improve water quality, and working with municipal and county government to improve policies impacting water quality (such as erosion on urban developments).

To date, this project has received $435,000 in funding through Section 319, and additional funding from the Iowa Department of Agriculture and Land Stewardship – Division of Soil Conservation. This project will reduce non point source phosphorous contributions, therefore providing reasonable assurance that overall phosphorous loading will be maintained or reduced.

5. Monitoring

Further monitoring is needed at Lake Macbride to follow-up on the implementation of the TMDLs. 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. Lake Macbride has been included in the five-year lake study conducted by Iowa State University under contract with the IDNR. Although this lake monitoring program concluded in 2004, it may be extended under a new lake monitoring strategy. The TMDL program is committed to monitoring waters where TMDLs have been completed, and in the absence of a statewide lake monitoring program, follow-up monitoring will be conducted through the TMDL program.

As noted in *Section 4, Implementation*, the existing contribution from point sources needs to be more accurately quantified and 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 becomes available, coring will be done for this lake and the recycling load component estimated.

The IDNR will include monitoring requirements for total phosphorus in both of the wastewater treatment facilities' NPDES permits to more accurately establish the existing loads. Following a one-year monitoring period, the NPDES permits will be amended to include effluent limits for total phosphorus.

6. Public Participation

A public meeting was held in Solon regarding the proposed TMDL for Lake Macbride on July 13, 2004, with representatives of the Lake Macbride Watershed Advisory Board. A second public meeting will be held in Solon on January 20, 2005 to present the draft TMDL for public comment. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

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

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

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

Data

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

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

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

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

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

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

Methods

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

Equation Variables

Table A-2. Regression Equation Variables

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

Equations

Table A-3. Drainage Area Only Equations

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

Table A-4. Multiple Regression Equations

Equation	**R^2 adjusted (%)**	**PRESS (log transform)**
$\overline{Q}_A = 1.17\times10^{-3} DA^{0.998}\overline{P}_A^{1.54} S^{-0.261}(1+F)^{0.249} C^{0.230}$	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
$\overline{Q}_{MAY} = 1.86\times10^{-3} DA^{0.903}\overline{P}_A^{1.98}$	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
$\overline{Q}_{JUN} = 8.13\times10^{-3} DA^{0.828} C^{0.478}\overline{P}_{JUN}^{2.70}$	95.9	0.256941
$\overline{Q}_{JUL} = 1.78\times10^{-3} DA^{0.923}\overline{A}_{JUL}^{4.19}$	91.7	0.542940
$\overline{Q}_{AUG} = 4.17\times10^{7} DA^{0.981}(1+B')^{-1.64}(1+U)^{0.692}\overline{P}_A^{-7.2}\overline{A}_{AUG}^{4.59}$	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
$Q_{YEAR} = 3.164\times10^{-4} DA^{0.942} P_{YEAR}^{2.39} A_{YEAR}^{1.02} S^{-0.206}\overline{P}_A^{1.27} C^{0.121}(1+U)^{0.0966}$	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 Lake Macbride - Calculations

Table A-5. Lake Macbride Hydrology Calculations

Lake	Lake Macbride	
Type	Impoundment	
Inlet(s)	Mill Creek, Jordan Creek	
Outlet(s)	Coralville Reservoir	
Volume	13548	(acre-ft)
Lake Area	812	(acres)
Mean Depth	16.68	(ft)
Drainage Area	16220	(acres)
Mean Annual Precip	35.3	(inches)
Average Basin Slope	4.9	(%)
%Water	1.48	
%Forest	16.79	
%Grass/Hay	24.47	
%Corn	35.98	
%Beans	20.07	
%Urban/Artificial	1.18	
%Barren/Sparse	0.03	
Hydrologic Region	2	
Mean Annual Class A Pan Evap	47.00	(inches)
Mean Annual Lake Evap	34.78	(inches)
Est. Annual Average Inflow	16176.89	(acre-ft)
Direct Lake Precip	2386.60	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.7298	(yr)
Est. Annual Average Det. Time (outflow)	0.8358	(yr)

9. Appendix B - Sampling Data

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

Parameter	6/26/1979	7/30/1979	8/29/1979
Secchi Depth (m)	0.8	0.8	0.5
Chlorophyll (ug/L)	40.4	27.7	37.8
NO_3+NO_2-N (mg/L)	--	--	0.2
Total Phosphorus (ug/l as P)	44	74	55
Alkalinity (mg/L)	115	88	94

Data above is averaged over the upper 6 feet.

Table B-2. Data collected in 1986 by the University Hygienic Laboratory (26)

Parameter	6/18/1986			7/30/1986			9/09/1986		
Depth (ft)	0	11	38	0	11	40	0	24	42
Secchi Depth (m)	2.2	--	--	1.7	--	--	0.9	--	--
Temperature (C)	24	21.5	9.7	28	27	10.4	20	17	11
Dissolved Oxygen (mg/l)	7.0	4.0	1.0	10.2	5.4	0.2	6.6	0.4	0.4
pH	8.5	8.5	7.7	9.0	9.0	7.7	9.0	8.3	7.5
NH_4^+ -N (mg/L)	0.16	0.15	0.27	0.04	0.10	3.0	0.15	0.46	4.7
NO_3+NO_2-N (mg/L)	4.2	4.2	0.5	3.8	4.0	0.2	2.1	1.9	1.9
Suspended Solids (mg/l)	9	10	43	11	10	160	10	9	200
Total Phosphorus (mg/l as P)	0.07	0.12	0.18	0.04	0.04	0.13	0.10	0.10	1.2
Chlorophyll (ug/L)	3	3	3	15	10	19	23	17	64

Table B-3. Data collected in 1990 by Iowa State University (2)

Parameter	5/20/1990	6/20/1990	7/20/1990
Secchi Depth (m)	1.0	0.2	1.0
Chlorophyll (ug/L)	46.4	9.9	37.8
Total Nitrogen (mg/L as N)	1.7	3.4	4.6
Total Phosphorus (ug/l as P)	88.4	185.1	65
Total Suspended Solids (mg/L)	7.6	62.2	9.5
Inorganic Suspended Solids (mg/L)	--	15.9	3.5

Data above is for surface depth.

Table B-4. Data collected in 2000 by Iowa State University (3)

Parameter	7/07/2000	8/02/2000	8/31/2000
Secchi Depth (m)	1.0	0.8	0.9
Chlorophyll (ug/L)	20	41	5
NH_3+NH_4^+ -N (ug/L)	617	545	476
NH_3 –N (un-ionized) (ug/L)	<1	15	8
NO_3+NO_2-N (mg/L)	0.4	0.14	
Total Nitrogen (mg/L as N)	1.33	1.09	0.92
Total Phosphorus (ug/l as P)	137	90	47
Silica (mg/L as SiO_2)	13	11	14
pH	6	7.7	7.5
Alkalinity (mg/L)	120	101	97
Total Suspended Solids (mg/L)	12.9	7.9	1.8
Inorganic Suspended Solids (mg/L)	5.1	3.0	0.7
Volatile Suspended Solids (mg/L)	7.7	4.8	1.1

Table B-5. Data collected in 2001 by Iowa State University (4)

Parameter	**6/07/2001**	**7/12/2001**	**8/08/2001**
Secchi Depth (m)	0.9	2.3	1.1
Chlorophyll (ug/L)	9	3	14
NH_3+NH_4^+ -N (ug/L)	1137	304	230
NH_3 –N (un-ionized) (ug/L)	13	79	120
NO_3+NO_2-N (mg/L)	4.74	4.79	2.45
Total Nitrogen (mg/L as N)	6.30	5.88	3.89
Total Phosphorus (ug/l as P)	83	29	35
Silica (mg/L as SiO_2)	9	9	8
pH	7.6	8.7	9.1
Alkalinity (mg/L)	118	260	58
Total Suspended Solids (mg/L)	9.7	5.9	10.0
Inorganic Suspended Solids (mg/L)	7.0	3.8	4.4
Volatile Suspended Solids (mg/L)	2.7	2.1	5.6

Table B-6. Data collected in 2002 by Iowa State University (4)

Parameter	**6/13/2002**	**7/18/2002**	**8/14/2002**
Secchi Depth (m)	3.0	2.0	0.8
Chlorophyll (ug/L)	5	12	12
NH_3+NH_4^+ -N (ug/L)	99	115	454
NH_3 –N (un-ionized) (ug/L)	13	39	29
NO_3+NO_2-N (mg/L)	1.89	1.17	0.18
Total Nitrogen (mg/L as N)	2.07	1.53	1.20
Total Phosphorus (ug/l as P)	23	24	59
Silica (mg/L as SiO_2)	1	1	3
pH	8.4	8.9	8.1
Alkalinity (mg/L)	138	98	104
Total Suspended Solids (mg/L)	6.7	5.5	10.8
Inorganic Suspended Solids (mg/L)	4.7	2.0	2.4
Volatile Suspended Solids (mg/L)	2.0	3.5	8.4

Table B-7. Data collected in 2003 by Iowa State University (20)

Parameter	**6/12/2003**	**7/17/2003**	**8/14/2003**
Secchi Depth (m)	2.6	1.1	0.7
Chlorophyll (ug/L)	12.5	34.1	21.6
NH_3+NH_4^+ -N (ug/L)	271	100	107
NH_3 –N (un-ionized) (ug/L)	--	9	28
NO_3+NO_2-N (mg/L)	0.26	<0.07	0.13
Total Nitrogen (mg/L as N)	2.56	0.95	1.04
Total Phosphorus (ug/l as P)	372	50	48
Silica (mg/L as SiO_2)	3.5	1.0	1.8
pH	--	8.2	8.8
Alkalinity (mg/L)	--	80	70
Total Suspended Solids (mg/L)	4	12	8
Inorganic Suspended Solids (mg/L)	1	4	2
Volatile Suspended Solids (mg/L)	3	8	6

Table B-8. 2000 and 2001 Phytoplankton Data (3,4)

	2000	**2001**
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	1.743	0.201
Chlorophyta	0.686	0.652
Chrysophyta	0	0
Cryptophyta	1.469	0.914
Cyanobacteria	17.43	13.575
Dinophyta Wet	0.477	0.345
Euglenophyta	0	0.267
Total	21.806	15.954

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

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:

$$TSI\ (TP) = 14.42\ \ln(TP) + 4.15$$

$$TSI\ (CHL) = 9.81\ \ln(CHL) + 30.6$$

$$TSI\ (SD) = 60 - 14.41\ \ln(SD)$$

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.

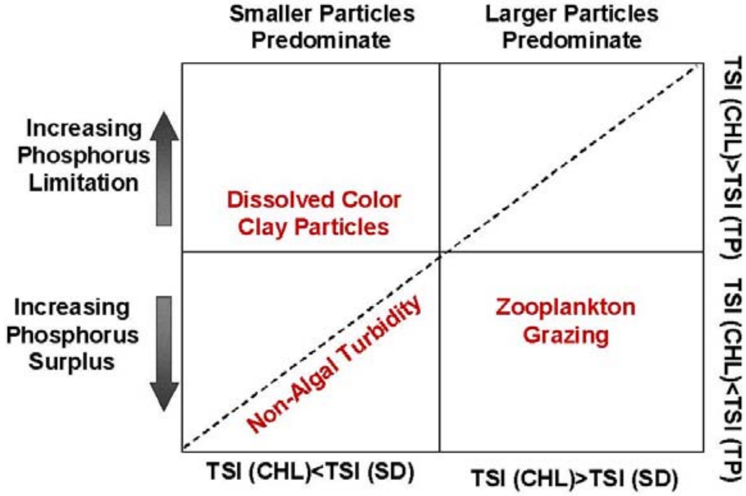
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 → 65	*12 → 33*	*1.4 → 0.7*
partially supported (evaluated: in need of further investigation)	65 → 70	*33 → 55*	*0.7 → 0.5*
partially supported (monitored: candidates for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



Lake Macbride TSI Values

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/26/1979	63	67	59
7/30/1979	63	63	66
8/29/1979	70	66	62

Table C-5. 1990 Lake Macbride TSI Values (Bachmann)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
5/20/1990	60	68	69
6/20/1990	83	53	79
7/20/1990	60	66	64

Table C-6. 2000 - 2003 Lake Macbride TSI Values (Downing et al.)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/7/2000	60	60	75
8/2/2000	63	67	69
8/31/2000	62	46	60
6/7/2001	62	52	68
7/12/2001	48	41	53
8/8/2001	59	56	55
6/13/2002	44	46	49
7/18/2002	50	55	50
8/14/2002	63	55	63
6/12/2003	46	55	90
7/17/2003	59	65	61
8/14/2003	65	61	60

Table C-7. 2003 Lake Macbride TSI Values (UHL maximum depth)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/8/2003	58	67	57
7/23/2003	62	68	65
8/6/2003	62	68	57
8/20/2003	65	69	61
9/17/2003	46	48	61
9/29/2003	47	48	61

11. Appendix D - Land Use Maps

Figure D-1. Lake Macbride Watershed 2002 Landuse

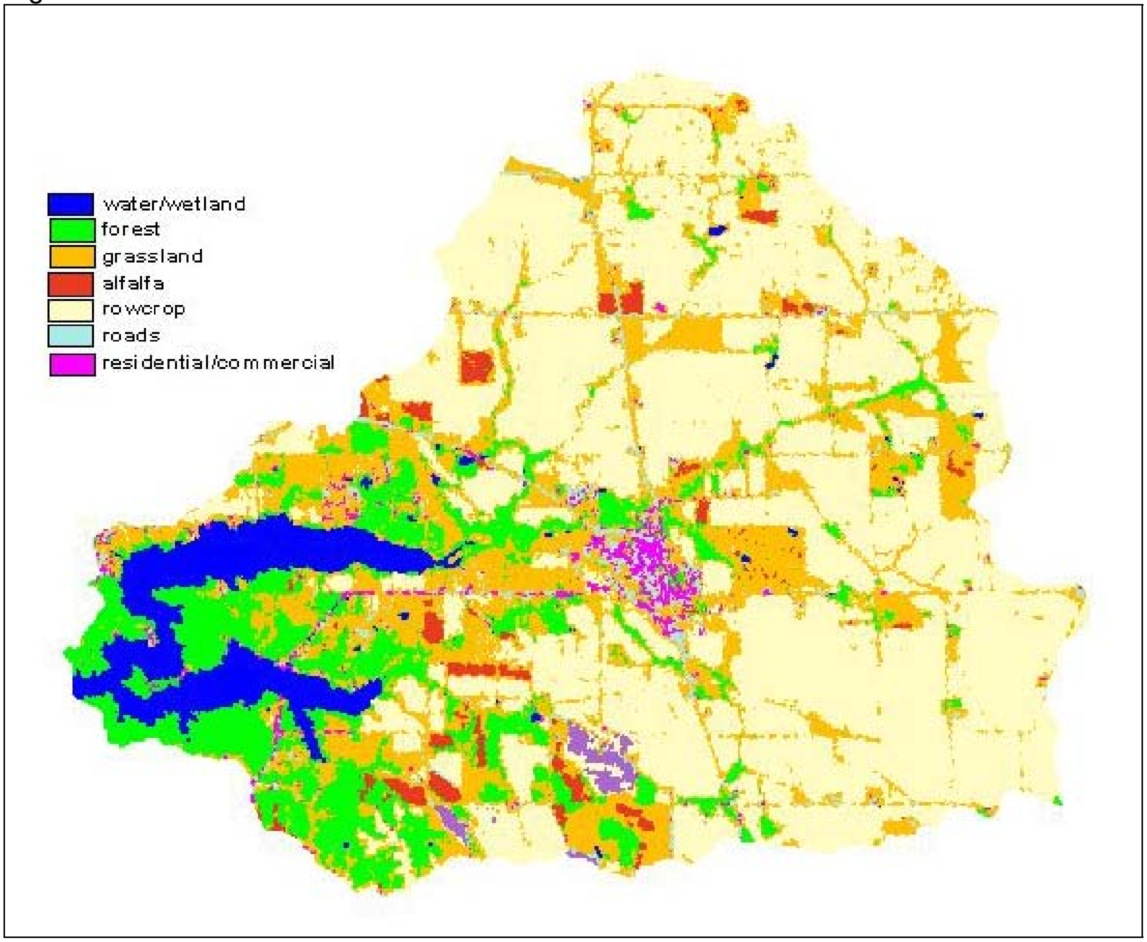
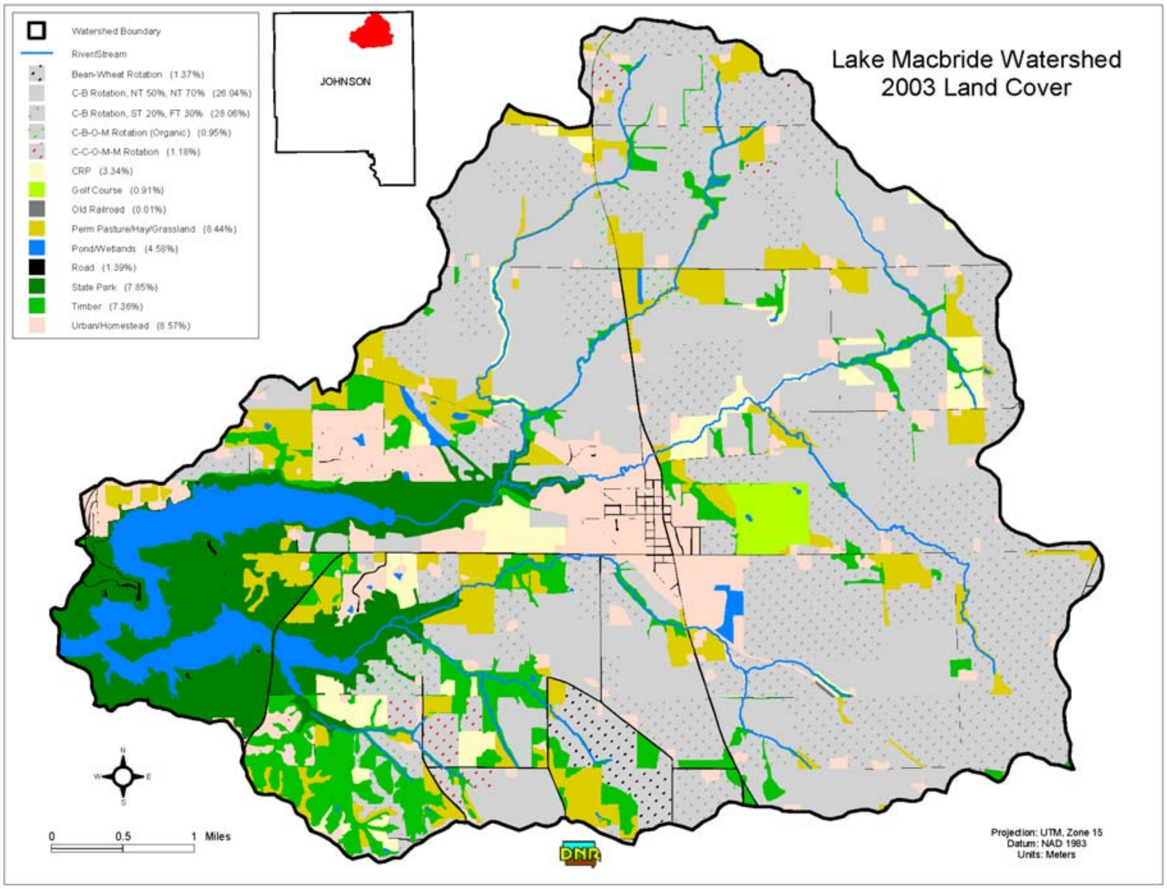


Figure D-2. Lake Macbride Watershed 2003 Site Assessment



12. Appendix E - Bathtub Program Input/Output

Lake Macbride
File: C:\Bathtubexe2\macbridefinal.btb
Description:
7 segments, 2 tributaries, 2 point sources; suggested default values for model options & model coefficients; phosphorus budgets based upon total P only; availability factors ignored

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.896	0.0
Evaporation (m)	0.883	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	45	0.50
Total N	0	0.00
Ortho P	0	0.00
Inorganic N	0	0.00

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	1	2ND ORDER, AVAIL P
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	MILL UPPER	2	1	0.82	3.25	2	3.25	0.12	0	0	0.93	0.25	0	0	0	0	0	0
2	MILL MID	3	1	0.62	5.45	2	4.9	0	0	0	0.08	0.2	0	0	0	0	0	0
3	MILL LOWER	7	1	0.62	6.97	2	5.7	0	0	0	0.08	0.2	0	0	0	0	0	0
4	JORDAN UPPER	5	1	0.51	2.84	1.2	2.8	0.12	0	0	0.08	0.2	0	0	0	0	0	0
5	JORDAN MID	6	1	0.31	5.45	1.2	4.9	0	0	0	0.08	6.13	0	0	0	0	0	0
6	JORDAN LOWER	7	1	0.31	6.97	1.2	5.7	0	0	0	0.08	0.2	0	0	0	0	0	0
7	DAM AREA	0	1	0.086	12.19	0.4	7.3	0.12	0	0	0.26	0.63	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	80	0.17	0	0	37	0.18	0.54	0.09	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	57	0.07	0	0	59	0.32	0.75	0.1	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	55	0.22	0	0	17	0.29	1.47	0.15	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
3	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
4	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
5	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
6	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
7	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	MILL INFLOW	1	1	44.33	13.47	0.1	0	0	337	0.2	0	0	0	0	0	0
2	JORDAN INFLOW	4	1	21.31	6.48	0.1	0	0	450	0.2	0	0	0	0	0	0
3	SOLON WWTP	1	3	0	0.249	0	0	0	3500	0	0	0	3500	0	0	0
4	MSD WWTF	2	3	0	0.0757	0	0	0	5000	0	0	0	5000	0	0	0

Tributary Non-Point Source Drainage Areas (km^2)

		Land Use Category--->							
Trib	Trib Name	1	2	3	4	5	6	7	8
1	MILL INFLOW	44.6	0	0	0	0	0	0	0
2	JORDAN INFLOW	0	21.44	0	0	0	0	0	0
3	SOLON WWTP	0	0	0	0	0	0	0	0
4	MSD WWTF	0	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	4.000	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Lake Macbride
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Segment & Tributary Network

--------Segment:	1	MILL UPPER	
Outflow Segment:	2	MILL MID	
Tributary:	1	MILL INFLOW	Type: Monitored Inflow
Tributary:	3	SOLON WWTP	Type: Point Source
--------Segment:	2	MILL MID	
Outflow Segment:	3	MILL LOWER	
Tributary:	4	MSD WWTF	Type: Point Source
--------Segment:	3	MILL LOWER	
Outflow Segment:	7	DAM AREA	
--------Segment:	4	JORDAN UPPER	
Outflow Segment:	5	JORDAN MID	
Tributary:	2	JORDAN INFLOW	Type: Monitored Inflow
--------Segment:	5	JORDAN MID	
Outflow Segment:	6	JORDAN LOWER	
--------Segment:	6	JORDAN LOWER	
Outflow Segment:	7	DAM AREA	
--------Segment:	7	DAM AREA	
Outflow Segment:	0	Out of Reservoir	

Lake Macbride
File: C:\Bathtubexe2\macbridefinal.btb

Hydraulic & Dispersion Parameters

			Net	Resid	Overflow		Dispersion-------->		
		Outflow	Inflow	Time	Rate	Velocity	Estimated	Numeric	Exchange
Seg	Name	Seg	hm^3/yr	years	m/yr	km/yr	km^2/yr	km^2/yr	hm^3/yr
1	MILL UPPER	2	13.7	0.1941	16.7	10.3	64.4	10.3	36.0
2	MILL MID	3	13.8	0.2446	22.3	8.2	18.9	8.2	9.1
3	MILL LOWER	7	13.8	0.3127	22.3	6.4	12.0	6.4	6.1
4	JORDAN UPPER	5	6.5	0.2233	12.7	5.4	40.4	3.2	37.4
5	JORDAN MID	6	6.5	0.2603	20.9	4.6	7.4	2.8	5.4
6	JORDAN LOWER	7	6.5	0.3327	21.0	3.6	4.7	2.2	3.8
7	DAM AREA	0	20.3	0.0516	236.2	7.8	4.4	1.6	0.0

Morphometry

		Area	Zmean	Zmix	Length	Volume	Width	L/W
Seg	Name	km^2	m	m	km	hm^3	km	-
1	MILL UPPER	0.8	3.3	3.3	2.0	2.7	0.4	4.9
2	MILL MID	0.6	5.4	4.9	2.0	3.4	0.3	6.5
3	MILL LOWER	0.6	7.0	5.7	2.0	4.3	0.3	6.5
4	JORDAN UPPER	0.5	2.8	2.8	1.2	1.4	0.4	2.8
5	JORDAN MID	0.3	5.4	4.9	1.2	1.7	0.3	4.6
6	JORDAN LOWER	0.3	7.0	5.7	1.2	2.2	0.3	4.6
7	DAM AREA	0.1	12.2	7.3	0.4	1.0	0.2	1.9
Totals		3.3	5.1			16.7		

Lake Macbride
File: C:\Bathtubexe2\macbridefinal.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance $(hm3/yr)^2$	CV -	Runoff m/yr
1	1	1	MILL INFLOW	44.3	13.5	1.81E+00	0.10	0.30
2	1	4	JORDAN INFLOW	21.3	6.5	4.20E-01	0.10	0.30
3	3	1	SOLON WWTP		0.2	0.00E+00	0.00	
4	3	2	MSD WWTF		0.1	0.00E+00	0.00	
PRECIPITATION				3.3	2.9	7.75E-03	0.03	0.90
TRIBUTARY INFLOW				65.6	20.0	2.23E+00	0.07	0.30
POINT-SOURCE INFLOW					0.3	0.00E+00	0.00	
***TOTAL INFLOW				68.9	23.2	2.24E+00	0.06	0.34
ADVECTIVE OUTFLOW				68.9	20.3	3.00E+00	0.09	0.29
***TOTAL OUTFLOW				68.9	20.3	3.00E+00	0.09	0.29
***EVAPORATION					2.9	7.53E-01	0.30	

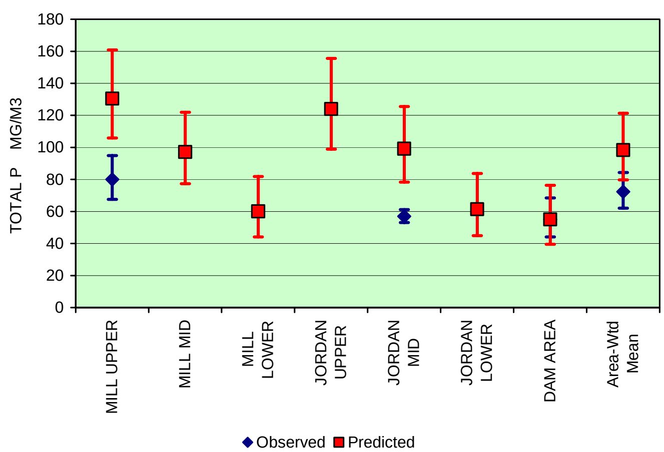
Overall Mass Balance Based Upon Component: **Predicted TOTAL P** — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	MILL INFLOW	4539.4	51.3%	1.03E+06	70.5%	0.22	337.0	102.4
2	1	4	JORDAN INFLOW	2916.0	32.9%	4.25E+05	29.1%	0.22	450.0	136.8
3	3	1	SOLON WWTP	871.5	9.8%	0.00E+00		0.00	3500.0	
4	3	2	MSD WWTF	378.5	4.3%	0.00E+00		0.00	5000.0	
PRECIPITATION				147.4	1.7%	5.43E+03	0.4%	0.50	50.2	45.0
TRIBUTARY INFLOW				7455.4	84.2%	1.46E+06	99.6%	0.16	373.7	113.6
POINT-SOURCE INFLOW				1250.0	14.1%	0.00E+00		0.00	3849.7	
***TOTAL INFLOW				8852.8	100.0%	1.46E+06	100.0%	0.14	381.4	128.5
ADVECTIVE OUTFLOW				1117.3	12.6%	1.44E+05		0.34	55.0	16.2
***TOTAL OUTFLOW				1117.3	12.6%	1.44E+05		0.34	55.0	16.2
***RETENTION				7735.5	87.4%	1.41E+06		0.15		

Overflow Rate (m/yr)	6.2	Nutrient Resid. Time (yrs)	0.1857
Hydraulic Resid. Time (yrs)	0.8226	Turnover Ratio	5.4
Reservoir Conc (mg/m3)	98	Retention Coef.	0.874

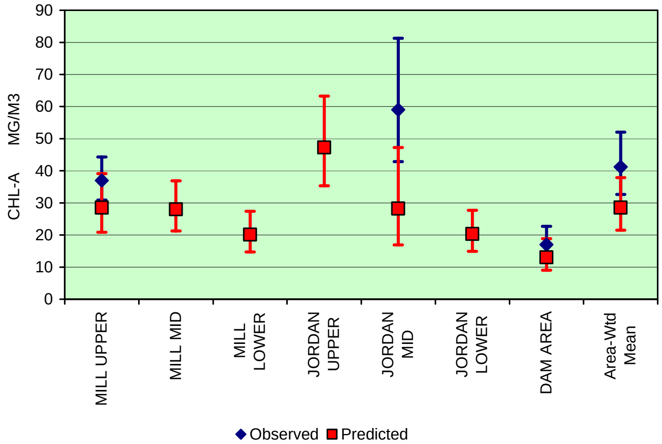
Lake Macbride
File: **C:\Bathtubexe2\macbridefinal.btb**
Variable: **TOTAL P MG/M3**

Segment	Predicted Mean	CV	Observed Mean	CV
MILL UPPER	130.5	0.21	80.0	0.17
MILL MID	97.1	0.23		
MILL LOWER	60.1	0.31		
JORDAN UPPER	124.0	0.23		
JORDAN MID	99.2	0.24	57.0	0.07
JORDAN LOWER	61.4	0.31		
DAM AREA	55.0	0.33	55.0	0.22
Area-Wtd Mean	98.4	0.21	72.4	0.15



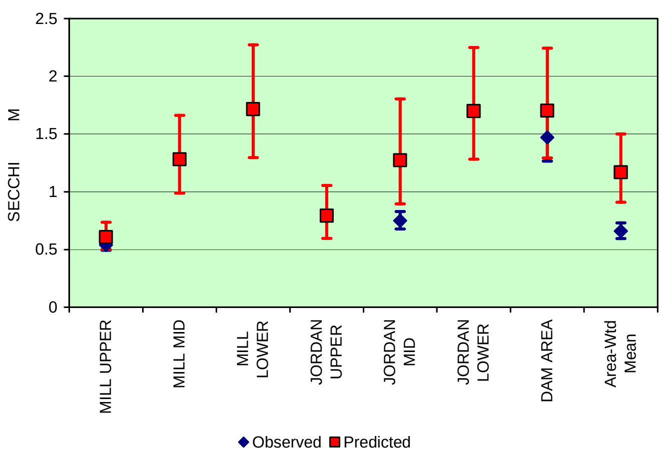
Lake Macbride
File: **C:\Bathtubexe2\macbridefinal.btb**
Variable: **CHL-A MG/M3**

Segment	Predicted Mean	CV	Observed Mean	CV
MILL UPPER	28.6	0.31	37.0	0.18
MILL MID	28.0	0.27		
MILL LOWER	20.1	0.31		
JORDAN UPPER	47.3	0.29		
JORDAN MID	28.3	0.51	59.0	0.32
JORDAN LOWER	20.3	0.31		
DAM AREA	13.1	0.37	17.0	0.29
Area-Wtd Mean	28.6	0.28	41.2	0.23



Lake Macbride
File: **C:\Bathtubexe2\macbridefinal.btb**
Variable: **SECCHI M**

Segment	Predicted Mean	CV	Observed Mean	CV
MILL UPPER	0.6	0.19	0.5	0.09
MILL MID	1.3	0.26		
MILL LOWER	1.7	0.28		
JORDAN UPPER	0.8	0.29		
JORDAN MID	1.3	0.35	0.8	0.10
JORDAN LOWER	1.7	0.28		
DAM AREA	1.7	0.28	1.5	0.15
Area-Wtd Mean	1.2	0.25	0.7	0.10



13. Appendix F - Erosion Model and Model inputs

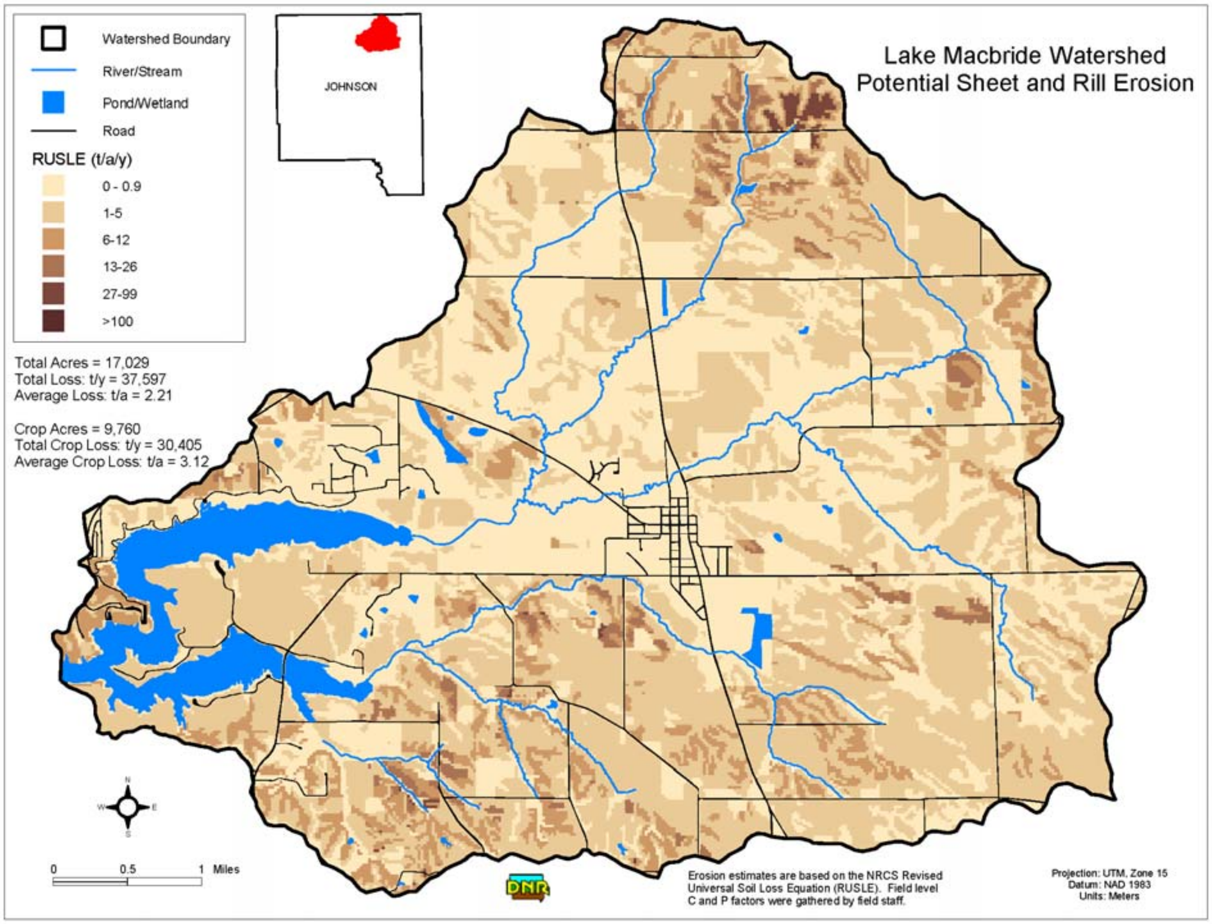
The Revised Universal Soil Loss Equation (RUSLE) is an erosion model designed to predict the longtime annual average soil loss (A) carried by runoff from specific field slopes in specified cropping and management systems. The equation used by RUSLE is:

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

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

Data from IDNR soil, landuse and other GIS coverages have been used as input to the RUSLE equation. The IDNR RUSLE erosion model uses a grid of 30 by 30 meter cells to estimate gross sheet and rill erosion. Sediment yield is the quantity of gross erosion that is delivered to a specific location such as a water body. Sediment yield was calculated using the NRCS Sediment Delivery Procedure (14).

Figure F-1. Lake Macbride RUSLE modeling results, sheet & rill erosion estimates



14. Appendix G - Lake Bed and Sediment Mapping

Summarized Excerpts from:
Lake Bed and Sediment Mapping Standard Operation Procedures
On Iowa Lakes, and Reservoirs
Version 1.0, February 23, 2004
By Jason C. McVay, S. Mike Linhart, Jon F. Nania
U.S. Department of the Interior, U.S. Geological Survey

Introduction
The Iowa District of the United States Geological Survey (USGS) began a lake bathymetric mapping program in June 2001 on Lake Delhi in east central Iowa resulting in a published bathymetric map and report. Since the work at Lake Delhi other opportunities for lake bathymetric and sediment mapping have arisen. This manual outlines office preparation, field data collection, and data editing for bathymetric and sedimentation mapping used by the Iowa district on Iowa lakes and reservoirs. A brief discussion of water quality sampling methods is included.

Bathymetric Mapping
Bathymetry mapping can provide useful information for water quality managers to address sedimentation issues on Iowa's Lakes and Reservoirs. In order to have a consistent method for comparing historic data to present day data it was determined that the water depths should be converted into National Geodetic Vertical Datum (NGVD) of 1929. The map production steps are office preparation, field data collection, and office post-processing of the data and construction of the maps.

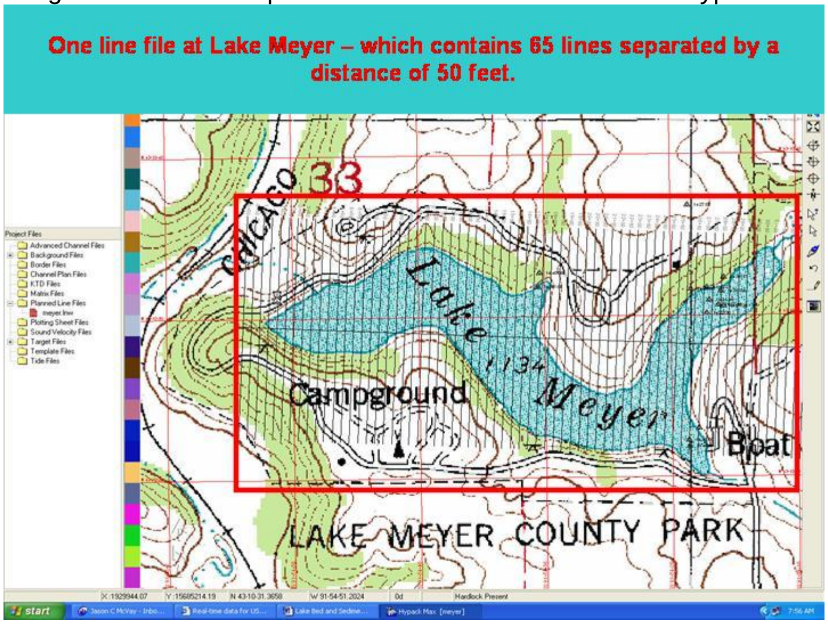
Computer Setup
Preparation includes computer setup and identifying the location of established benchmarks. Computer preparation work involves loading background maps (digital raster USGS topographic maps) in the file format. Background map files are used to help establish the lines that will be used for data collection. These map files are then converted to a local projection and datum to be used with the hydrographic data collection software. With the background maps in the correct projection and datum, the hydrographic mapping software can then be set up to collect the data in the correct projection and datum. The files are projected in UTM, Zone 15, north, and into NAD-83.

These background files are loaded into software where line files can be created. The line files are used to ensure that data are collected in an efficient and representative manner. Line files contain many individual lines that are placed a set distance apart from one another (figure 1).

The basis for determining the orientation and distance between the lines is affected by several factors. The first being the location of submerged original creek beds, where data must be collected perpendicular to the original creek beds, usually located in coves or inlets. Surveying along lines that are set parallel to the creek bed could miss the original profile of the creek. Fewer line files are needed if the lake is round in nature and devoid of any large coves. Conversely, if there are large coves in the lake, then several line files may need to be created.

The topography of a lake bed will also affect the number and location of lines needed. More closely spaced lines need to be located, in areas of the lake where there is greater variation in lake bed elevation, for example areas with submerged or exposed islands associated with steep drop offs. Other lakes may have relatively flat beds with little elevation change and would not require the lines to be as closely spaced. The location and spacing of these lines can vary greatly, even within the same lake.

Figure 1 - Screen capture of data collection lines within Hypack® Max



The above factors are used as a guide to determine the number, orientation, and spacing between lines. There is not a set formula to determine the distance between lines. The bathymetry work in Iowa, by the USGS, over the past few years has shown an average of about 125 feet between lines. Efficiency and cost of data collection should also be taken into consideration when setting up the data collection lines.

Location of Benchmarks

The next step in office preparation is to locate established benchmarks as close as possible to the lake, so that elevation data can be referenced to the National Geodetic Vertical Datum (NGVD) of 1929. Efforts to locate established benchmarks include contacting local and state agencies that work directly with the individual bodies of water, locating benchmarks using USGS 1:24,000 quadrangle maps, and accessing the National Geodetic Survey datasheet web page. Benchmarks that are found are generally first or second order and believed to be stable and viable.

Bathymetry Data Collection

GPS Accuracy

The accuracy of the differential Global Positioning System (GPS) location is recorded at the beginning of data collection. Horizontal data are collected using differential GPS that has an accuracy of less than one meter. Each lake survey must be assessed to determine the most accurate and available differential GPS acquisition method to be used. There are several ways of measuring the accuracy of the differential GPS before and during data collection, including standard deviation, position dilution of precision (PDOP), and signal to noise ratio. Accuracy increases as the signal strength increases. A value of six or more indicates a strong enough signal for differential position. These indicators of GPS accuracy are constantly monitored and any problems are noted on the field sheet.

Lake Surface Elevation

The lake surface elevation is obtained by measuring down from a reference point with a known elevation to the water surface. Measurements of the lake surface elevation are made at the beginning and end of each day. This technique involves measuring down from the reference point with a steel tape or an engineers rule and read to the nearest one hundredth of a foot.

The NGVD of the reference point can be determined using one of three different methods depending on the situation encountered at the field site: (1) the reference point can be an existing benchmark on the lake itself or; (2) elevations can be surveyed in from a known benchmark to a newly established reference point on the lake or; (3) GPS static data collection is used to establish a reference point elevation.

Shallow Water Limitations
Present limitations of the data collection equipment restrict data collection to depths greater than 3.3 feet. This limitation is a function of how deep the transducer is set in the water column (draft), and other acoustical properties. The acoustic constraints are basic sound travel properties that include side lobe interference and blanking distance.

For areas that are too shallow to profile or that are congested with debris, depths are collected using the target point method. The boat is driven into the shallow water where a depth is obtained using a top-set rod or some other manual measuring device. At each depth location, a horizontal GPS value is determined which will be manually incorporated into sounding data during processing. Determining the number and the location of target points is based on the amount of contour change in, and the size of, the shallow water areas.

Shore points
Shore points are collected to define the shoreline of the lake or reservoir. These points are collected by touching the bow of the boat to the shoreline. A GPS antenna is mounted at the bow and a laptop with the data acquisition software is logging these locations. A transducer is not used for this aspect of lake mapping. The depths at these points are considered to have a value of zero and will later be converted to the water surface elevation of the lake. Shore points are collected wherever there is a change of direction in the shoreline.

Perimeter
The purpose of the perimeter drive is to merge the data collected on the main body of the lake to the shore points. Perimeter data collection involves both transducer and GPS data. The boat is driven around the entire lake along the shore line at depths greater than the 3.3 foot threshold.

Bathymetry data editing
Bathymetry data are edited using special software. This involves removing data spikes, converting the depth data into NGVD, entering target point depth values, and exporting the data into an XYZ format. Theses methods can be found in the software operations manual.

Sediment Thickness Mapping
Recent advancements in hydro-acoustic technology and equipment have given rise to several new applications being developed. These advancements have given the Iowa District an opportunity to use a simple, compact, and effective system for the determination of sediment thickness in lakes and reservoirs. Present procedures for determining the sediment thickness are discussed in the following pages.

Sediment Thickness Data Collection
There are several quality assurance (QA) methods used in the bathymetric and sediment mapping work. The sediment mapping QA methods are similar to the bathymetric methods and include GPS accuracy, transducer draft, and depth calibration. Bathymetric and seismic data are collected at the same time using the same line spacing. The sediment thickness data are collected using a different software package (SDI Depth).

During data collection, SDI Depth interprets the signals from each of the five different transducers within the transducer array and displays them digitally on the computer screen. Depths are monitored closely. If the lake depth falls outside of the initial range set in SDI Depth, then incorrect values may be observed. In a lake where there is large variation in depth, the range setting may need to be changed several times during data collection. Since the bathymetry software and SDI depth are using the same transducers, this range setting will affect both sets of data.

Target and Calibration Cores

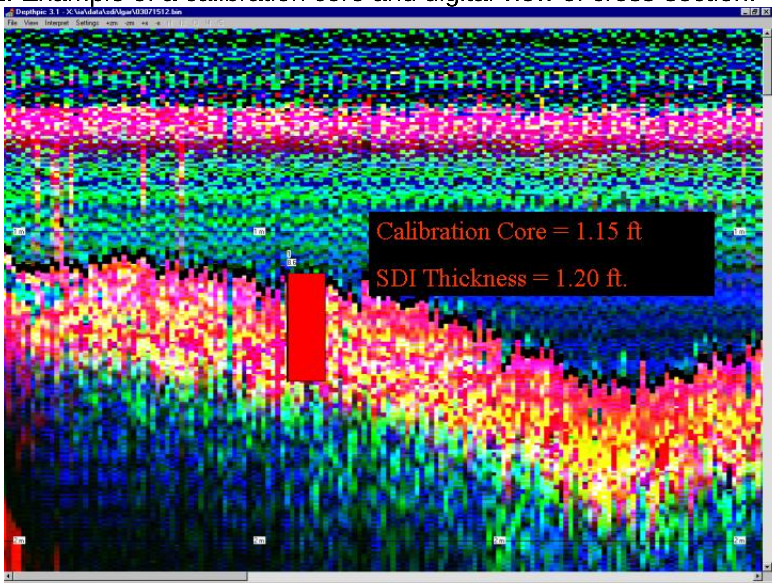
Sediment mapping has the same water depth limitations as the bathymetry. Collection of sediment cores is needed in lake areas where seismic data collection is not possible. Sediment cores are used to interpret sediment thickness during post-processing. Upon collection of the core samples, a visual determination of the original lake bottom is found and a physical measurement of the recent sedimentation is made. The original lake bottom may be determined by inspecting the core for a layer of grasses, twigs, color and/or hardness changes, and texture change set below a layer of sediment. The original lakebed is the same kind of material as the area surrounding the lake. Sediment thickness is recorded on the field form (along with the GPS locations) to be used during post processing. The equipment used for coring consists of a 6 to 12 ft., 2 5/8" diameter clear butyrate tube attached to a vibrating coring head.

Calibration cores are used to validate the digital data being collected by the seismic equipment. Calibration cores are collected in the same manor as the target cores. The selection of core locations is specific to each lake. Five cores is usually sufficient to validate digital data in a small lake without large coves or inlets. When anomalies are observed during seismic data collection the location is recorded for possible coring. At least five calibration cores are collected for each lake.

Sediment thickness data processing

The data editing process utilizes a software package that removes spikes and other false depth values. Digitization of the recent sediment deposition layer is also performed. A file containing the calibration core data is opened during editing and is viewed on the screen in the cross-section of the digital data (see below). After digitization, sediment thickness files are exported in XYZ format to be used in mapping software packages.

Figure 2. Example of a calibration core and digital view of cross-section.



GIS Work

Bathymetry and sediment thickness contour maps are produced using a GIS package. Calculations are also performed to produce lake and sediment thickness volumes. Files of processed data from software are converted into point coverages representing discrete point locations of bathymetry or sediment thickness and the appropriate projection and datum are applied (for Iowa: UTM, zone 15, datum NAD83). The point coverages are put into gridding or tin model applications within the GIS software to produce three-dimensional surfaces representing bathymetry or sediment thickness. The surfaces are then contoured and adjusted for any interpretive errors. Volumetric calculations are also performed within the grid or tin model applications. To ensure that consistent and viable surface modeling techniques are being used, quality assurance methods are currently being developed by the Iowa District. The various methods used to develop maps and calculate volumes are discussed within the individual software user manuals.

Water Quality

In addition to the bathymetry and sediment mapping, water-quality data are collected. Field parameters (specific conductance, pH, temperature, and dissolved oxygen) are collected at the same location as the core samples. If water depths are less than twelve feet, water column measurements are taken at one-foot intervals using a multi-parameter meter. When the water depth is twelve feet or greater ten equally spaced readings are made. The data are entered and stored in the USGS National Water Information System (NWIS) database.

Cores samples are analyzed for nutrients and particle size distribution. Two cores are collected at each location. One is sent to the cooperator (IDNR) and the other is processed by Iowa District USGS personnel. For samples processed by the Iowa District, the core barrels are split open. Two samples are taken from each, one from the upper portion of recent sedimentation and one just above the break between recent deposition and the original bed material. Sediment nutrient samples are sent to the NWQL for analysis. The bottom material size analysis is done at the Iowa District Sediment Laboratory. A whole water sample for suspended sediment is also collected and is analyzed for concentration by the Iowa District Sediment Laboratory

Summary

This procedure manual discusses the current techniques used by the Iowa District of the United States Geological Survey. Techniques and procedures for the collection and processing of bathymetric and sediment thickness data may change and develop over time as the need for improvements become apparent.