Total Maximum Daily Loads
For Nutrients and Siltation
Easter Lake
Polk County, Iowa

2004

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Easter Lake Summary

Waterbody Name:	Easter Lake
County:	Polk
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life)
Major River Basin:	Des Moines River Basin
Pollutants:	Phosphorus, Sediment
Pollutant Sources:	Nonpoint, point (regulated storm water), internal recycle, atmospheric (background)
Impaired Use(s):	A1 (primary contact recreation) B(LW) (aquatic life)
2002 303d Priority:	Medium
Watershed Area:	6,380 acres
Lake Area:	178 acres
Lake Volume:	1,466 acre-ft
Detention Time:	0.28 years
TSI (nutrient) Targets:	Total Phosphorus less than 65; Chlorophyll a less than 65; Secchi Depth less than 65
Total Phosphorus Load Capacity (TMDL):	2,540 pounds per year
Existing Total Phosphorus Load:	4,250 pounds per year
Total Phosphorus Load Reduction to Achieve TMDL:	1,710 pounds per year
Total Phosphorus Margin of Safety:	250 pounds per year
Total Phosphorus Wasteload Allocation:	2,200 pounds per year
Total Phosphorus Load Allocation:	90 pounds per year
Sediment Load Capacity (TMDL):	5,400 tons per year
Existing Sediment Load:	7,000 tons per year
Sediment Load Reduction to Achieve TMDL:	1,600 tons per year
Sediment Margin of Safety:	540 tons per year
Sediment Wasteload Allocation:	2,100 tons per year
Sediment Load Allocation:	2,760 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. Easter Lake has been identified as impaired by nutrients and siltation. The purpose of these TMDLs for Easter Lake 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 Easter Lake water quality that fully supports its designated uses. Phosphorus, which is related through the Trophic State Index (TSI) to chlorophyll and Secchi depth, is targeted to address the 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:** Easter Lake, S19, T78N, R23W, in the southeast portion of Des Moines, Polk 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 Easter Lake are Primary Contact Recreation (Class A1) and Aquatic Life Support (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 65 for total phosphorus, chlorophyll a, and Secchi depth. TSI values of 65 are equivalent to total phosphorus and chlorophyll concentrations of 68 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters. The Phase 1 sediment target is a sediment delivery rate that will result in the loss of less than one third of the original lake volume within a 100-year design life.

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 0.8 meters, 42 ug/L, and 90 ug/L, respectively. Based on these values, the Secchi depth target has been met. Minimum in-lake reductions of 21% for chlorophyll a and 24% for total phosphorus are required to achieve and maintain lake water quality goals and protect for beneficial uses. The estimated existing annual total phosphorus load to Easter Lake is 4,250 pounds per year. The total phosphorus loading capacity for the lake is 2,540 pounds per year based on lake response modeling. An average annual load reduction of 1,710 pounds per year is required.

   The estimated existing sediment load is 7,000 tons per year. The sediment load associated with the targeted volume loss is 5,400 tons per year. A sediment load reduction of 1,600 tons per year is required.

5. **Identification of pollution source categories:** Point (regulated storm water), nonpoint, atmospheric deposition (background), and internal recycling of phosphorus from the lake bottom sediments are identified as the sources of phosphorus loading to Easter Lake. Regulated storm water and nonpoint sources are identified as the sources of sediment loading to the lake.

6. **Wasteload allocations for pollutants from point sources:** Two regulated storm water discharges are located within the watershed. The lake and most of the lake watershed is located within the corporate limits of the City of Des Moines. The City of Des Moines is authorized to discharge from a Municipal Separate Storm Sewer System (MS4) under Iowa NPDES Permit #77-27-0-07. The Des Moines International Airport also discharges storm water within the watershed under Iowa NPDES Permit #77-27-0-08. The airport storm water is primarily associated with industrial activity from vehicle maintenance, equipment cleaning, deicing, etc. but also includes surface water drainage from precipitation events.

   The existing annual average total phosphorus load from the regulated storm water sources is estimated to be 4,130 pounds per year. The total phosphorus wasteload allocation for these sources is 2,200 pounds per year.

The existing sediment load from the point sources is estimated to be 3,030 tons per year. The sediment wasteload allocation is 2,100 tons per year.

7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus load allocation for nonpoint sources is 90 pounds per year including 60 pounds per year attributable to atmospheric deposition. The sediment load allocation for nonpoint sources is 2,760 tons per year.

8. **A margin of safety:** For the nutrient TMDL, an explicit numerical MOS of 250 pounds per year (10% of the calculated allowable phosphorus load) has been included to ensure that the wasteload and load allocations will result in attainment of water quality targets.

   For sediment delivery, an explicit MOS of 540 tons per year (a 10% reduction of the allowable load capacity) has been included to ensure that the wasteload and load allocations will result in attainment of water quality targets.

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 Easter Lake’s sediment loading capacity.

   Sediment loads are actually the result of periodic intensive and/or high volume precipitation events. Non-point source controls are typically designed for average annual long-term conditions. The sediment TMDL is expressed as an annual average loading. However, the sediment load for any given year may exceed the annual average target load provided that the overall average for the duration of the remaining lake design life (64 years) does not exceed the target value.

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. Most of the Easter Lake watershed is within the corporate limits of the City of Des Moines. The western portion of the watershed is urban. The eastern portion of the watershed is in the process of transition from agricultural to urban use. The City of Des Moines has recently constructed a number of storm water control facilities (including 6 retention basins) in the eastern portion of the watershed as development has occurred in accordance with the Southeast Annex Area Comprehensive Storm Water Study and Master Plan (26). There are plans for a total of 10 retention basins, one of which is currently under design.

    Significant residential and commercial development will increase urban storm water contributions in the watershed. Also, construction activities related to urban development have the potential to increase sediment loading to the lake.

However, implemented storm water controls are expected to significantly reduce both temporary construction-related erosion and long-term future sediment and phosphorus delivery to the lake.

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. Easter Lake, Description and History

2.1 The Lake

Easter Lake was constructed in 1967 and is located in central Iowa, in the southeast part of Des Moines. Public use for Easter Lake is estimated at approximately 350,000 visitors per year. Users of the lake and of Ewing and Easter Lake Parks enjoy fishing, swimming, picnicking, hiking, and boating.

Table 2. Easter Lake Features

Waterbody Name:	Easter Lake
Hydrologic Unit Code:	HUC10 0710000815
IDNR Waterbody ID:	IA 04-LDM-00490-L
Location:	Section 19 T78N R23W
Latitude:	41° 33' N
Longitude:	93° 33' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW))
Tributaries:	Yeader Creek, Unnamed Creeks (2)
Receiving Waterbody:	Yeader Creek
Lake Surface Area:	178 acres
Maximum Depth:	21 feet
Mean Depth:	8.2 feet
Volume:	1,466 acre-feet
Length of Shoreline:	35,300 feet
Watershed Area:	6,380 acres
Watershed/Lake Area Ratio:	36:1
Estimated Detention Time:	0.28 years

Morphometry

Easter Lake has a mean depth of 8.2 feet and a maximum depth of 21 feet. The lake has a surface area of 178 acres and a volume of approximately 1,466 acre-feet. Temperature and dissolved oxygen sampling indicate that the lake stratifies during the growing season.

Hydrology

Easter Lake is fed by Yeader Creek from the west and unnamed creeks from the south and southwest. Easter Lake discharges from a dam at the northeast end to Yeader Creek. The estimated annual average detention time for Easter Lake is 0.28 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

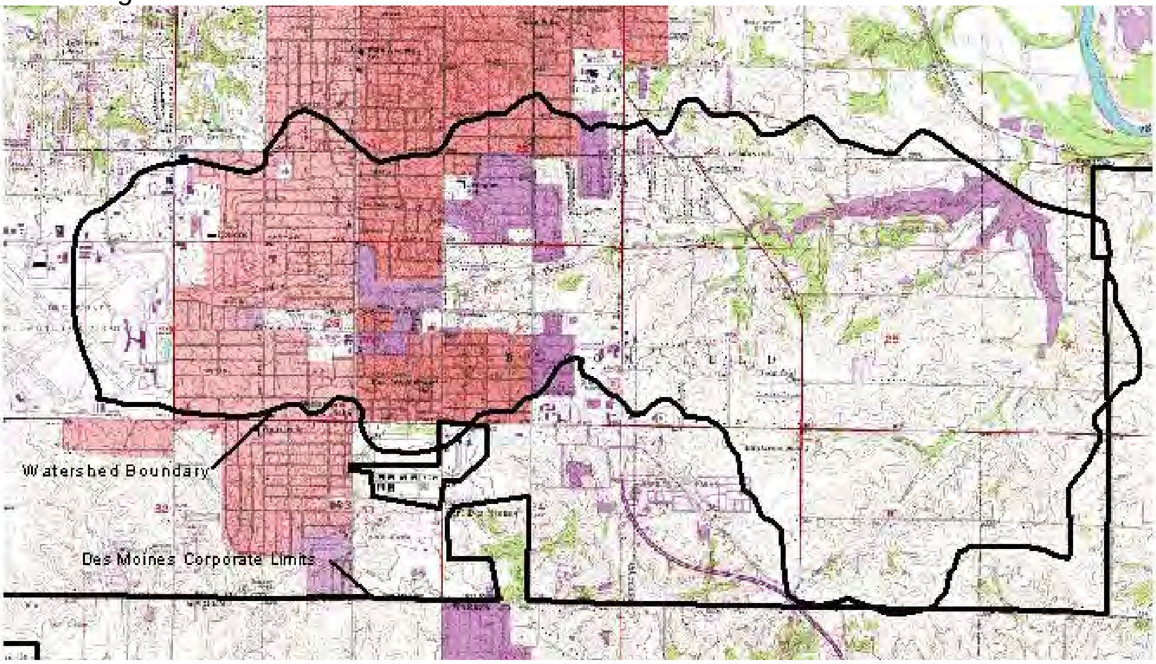
2.2 The Watershed

The Easter Lake watershed has an area of approximately 6,380 acres and has a watershed to lake ratio of 36:1. The 2002 landuses and associated areas for the watershed were obtained from satellite imagery and are shown in Table 3. The 2002 watershed landuse map is shown in Appendix D. Figure 1 shows the topographic relief map of the Easter Lake watershed.

Table 3. 2002 Landuse in Easter Lake watershed.

Landuse	Area in Acres	Percent of Total Area
Urban	2,890	45.3
Grassland	1,580	24.8
Forest	890	13.9
Cropland	860	13.4
Barren	80	1.3
Water/Wetland	80	1.3
Total	6,380	100

Figure 1. Easter Lake Watershed



The watershed is predominately gently to strongly sloping (2-14%) prairie-derived soils developed from loess and till. Three soil types encompass the watershed: Sharpsburg, Shelby, and Adair. Average rainfall in the area is 31 inches per year.

In 1994, the City of Des Moines adopted the Southeast Annex Area Comprehensive Storm Water Study and Master Plan (26). The plan includes various recommended measures to control storm water flows and erosion in the eastern portion of the watershed where urban development is occurring, including construction of ten storm water retention basins. Presently, six of the ten basins have been constructed with a seventh basin currently under design. The basins are expected to improve water quality in the lake by not only by reducing sediment delivery associated with temporary construction activities, but also by limiting future sediment and sediment-attached nutrient delivery after development occurs. The basins are also expected to reduce stream bank erosion by dampening high flows associated with storm events.

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 Easter Lake as Primary Contact Recreational Use (Class A1) and Aquatic Life (Class B(LW)). In 1998, Easter Lake was included on the impaired water list as recommended by the DNR Fisheries and Water Quality bureaus due to elevated levels of silt and nutrients. At that time, Class A and B uses were assessed as "partially supported."

In 2002, the Class A designated use was re-assessed as "fully supporting/threatened" for Easter Lake. This assessment was based upon the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries bureau. More recent monitoring data suggests that the Class A designated use will be assessed as "partially supported" for the 2004 assessment cycle.

The primary threat to Class A recreational uses is the presence of aesthetically objectionable blooms of algae and due to the presence of nuisance algal species. The eutrophic conditions at Easter Lake, along with information from the IDNR Fisheries Bureau, suggest that the Class B(LW) aquatic life uses should remain assessed as "partially supported" due to excessive nutrient loading to the water column, high levels of algal turbidity, and siltation in the lake.

The Iowa Water Quality Standards (8) do not include numeric criteria for nutrients but they do include narrative standards that are applicable to Easter Lake 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 Easter Lake in 1979, 1990, and 2000-03 (1,2,3,4,5,20). Additional water quality data was collected by the University of Iowa Hygenics Laboratory (UHL) from July through October of 2003. Data from the 1979, 1992, 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 seven 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.

Interpreting Easter Lake 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 14:1. Data on inorganic suspended solids from the ISU sampling indicate moderate levels of non-algal turbidity. The median level of inorganic suspended solids in the 131 lakes sampled for the ISU lake survey from 2000 to 2002 was 4.8 mg/L. The median level of inorganic suspended solids at Easter Lake during the same time period was 5.2 mg/l, the 56th highest of the 131 lakes.

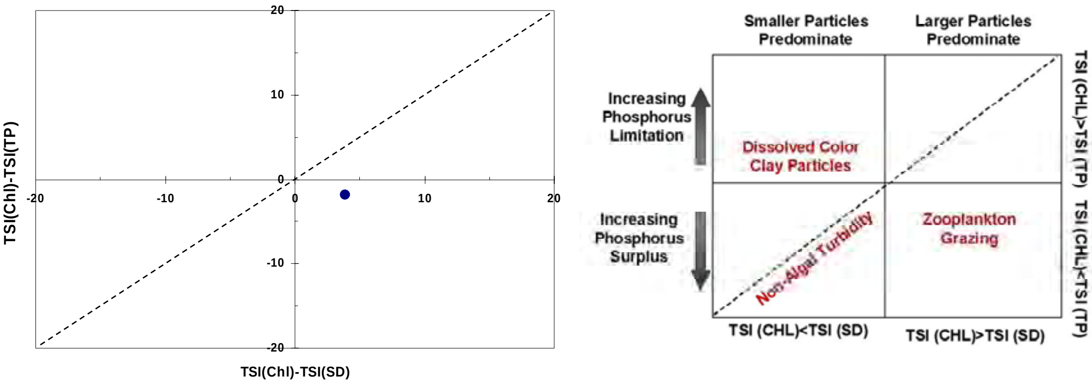
Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for 2000 - 2003 in-lake sampling indicate slight limitation of algal growth potentially attributable to factors other than phosphorus (see Figure 2 and Appendix C).

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

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

Sample Date	Source	TSI (SD)	TSI (CHL)	TSI (TP)
6/26/2000	ISU	67	62	62
7/24/2000	ISU	65	52	77
8/21/2000	ISU	73	55	71
5/29/2001	ISU	59	61	70
6/25/2001	ISU	62	67	72
7/30/2001	ISU	62	58	62
6/3/2002	ISU	59	60	57
7/8/2002	ISU	73	72	70
8/5/2002	ISU	73	73	69
6/2/2003	ISU	57	55	58
7/7/2003	ISU	60	--	62
7/11/2003	UHL	67	65	67
7/22/2003	UHL	63	63	61
8/4/2003	ISU	67	66	71
8/7/2003	UHL	77	76	71
8/22/2003	UHL	77	82	72
9/12/2003	UHL	73	77	77
9/26/2003	UHL	77	77	76
10/10/2003	UHL	63	61	71

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



Data from ISU phytoplankton sampling in 2000 and 2001 indicate that bluegreen algae (Cyanophyta) can 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 (3.8 mg/l) was the 37th lowest of 131 lakes sampled with bluegreens consisting of approximately 58% of the phytoplankton community. The 2001 average summer wet mass of bluegreen algae declined to 2.5 mg/L with bluegreens comprising approximately 29% of the phytoplankton community. Sampling for cyanobacterial toxins was not conducted at Easter Lake for the 2000 - 2003 sampling period. 2000 and 2001 phytoplankton sampling results are given in Table B-7 of Appendix B.

Potential Pollution Sources

The potential nutrient sources for Easter Lake are point sources (regulated storm water), nonpoint sources including atmospheric deposition and internal recycling of phosphorus from bottom sediments.

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 source load.

3.1.2 TMDL Target

The Phase 1 targets for this TMDL are mean TSI values of less than 65 for total phosphorus, chlorophyll and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 68 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

Table 5. Easter Lake 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	67	42 ug/L	<65	<33 ug/L	21% reduction
Secchi Depth	63	0.8 meters	<65	>0.7 meters	N/A
Total Phosphorus	69	90 ug/L	<65	<68 ug/L	24% reduction

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 65, 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 loading 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.

Table 6. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = ANN TP = 90 ug/L, SPO TP = 59 ug/L	Comments
Loading Function	8,430	Reckhow (10); 90% retention basin trap efficiency
EPA Export	5,350	EPA/5-80-011
WILMS Export	2,620	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	4,180	GSM model
Canfield-Bachmann 1981 Natural Lake	2,410	GSM model
Canfield-Bachmann 1981 Artificial Lake	3,560	GSM model
Reckhow 1977 Anoxic Lake	1,540	GSM model
Reckhow 1979 Natural Lake	3,240	GSM model.
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	2,050	GSM model. P out of range
Nurnberg 1984 Oxic Lake	2,930 (internal load = 0)	Annual model. P out of range
Walker 1977 General Lake	1,240	SPO model
Vollenweider 1982 Combined OECD	3,150	Annual model
Vollenweider 1982 Shallow Lake	3,610	Annual model
Walker Reservoir	3,930	GSM model
Walker Reservoir (BATHTUB)	4,250	GSM model. Segmented.

Of the lake response models evaluated, the BATHTUB program using the Walker Reservoir Model gave the result closest to the Loading Function and EPA Export watershed estimates. The BATHTUB program uses empirical eutrophication models but also accounts for advective and diffusive transport in a segmented network.

For the BATHTUB program, the lake was divided into five segments (Yeader arm, middle arm, upper south arm, lower south arm and dam area), each with corresponding sub watersheds. The total influent load was adjusted to match the predicted in-lake concentration with observed sampling data at the maximum depth location while maintaining influent loads from each sub watershed proportional to those determined using the Loading Function watershed estimate. 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. 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 Easter Lake can receive and meet its designated uses. Based on the selected lake response model and a target TSI (TP) value of less than 65, the Phase 1 total phosphorus loading capacity for the lake is 2,540 pounds per year.

3.1.3 Pollution Source Assessment

There are three quantified phosphorus sources for Easter Lake in this TMDL. The first is the phosphorus load from regulated storm water discharges. The second source is nonpoint loading from the watershed areas outside of the corporate limits of the City of Des Moines. The third source is atmospheric deposition. Potential load contributions from groundwater influx and internal recycling of nutrients have not been separated from the total point and nonpoint source loads.

Existing Load

The annual total phosphorus load to Easter Lake is estimated to be 4,250 pounds per year based on the selected lake response model. This estimate includes 4,020 pounds per year from areas included in the City of Des Moines' NPDES permit, 110 pounds per year from the Des Moines International Airport, 60 pounds per year from areas outside the City's corporate boundaries, and 60 pounds per year from atmospheric deposition.

Departure from Load Capacity

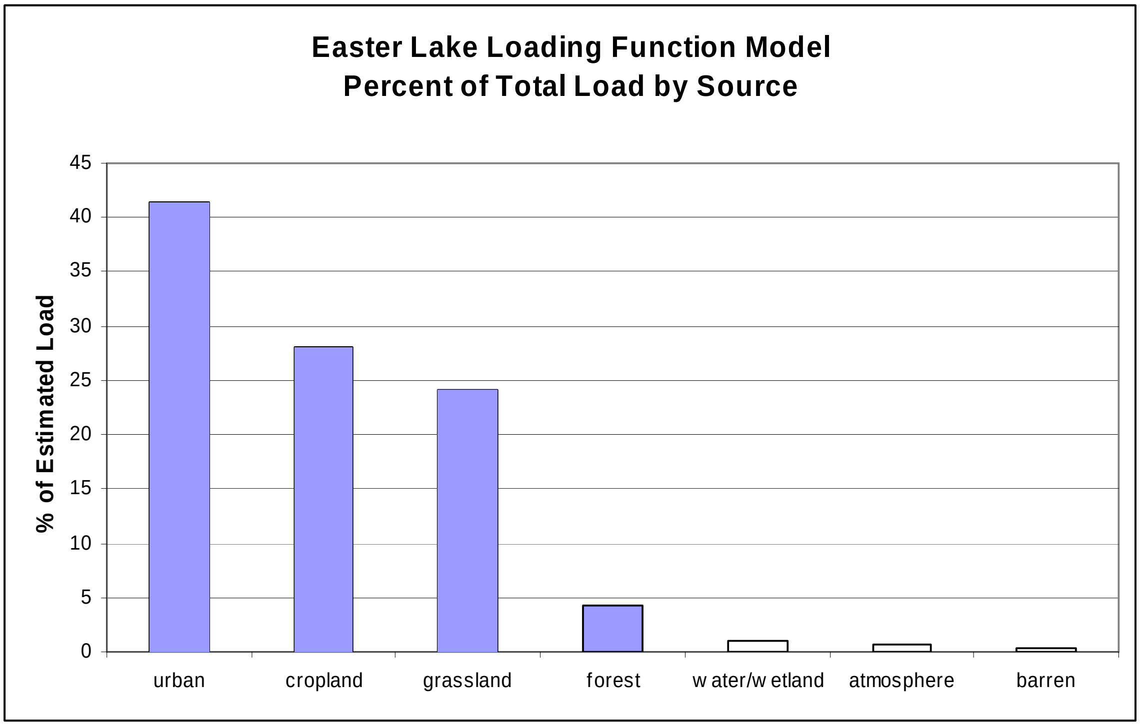
The Phase 1 targeted load capacity for Easter Lake is 2,540 pounds per year or 0.4 pounds per year per acre of watershed area. The estimated existing load is 4,250 pounds per year or 0.7 pounds per year per acre of watershed area if all loads were attributed to the watershed without any internal recycling of phosphorus.

Identification of Pollutant Sources

Two regulated storm water discharges are located within the watershed. The City of Des Moines discharges from a Municipal Separate Storm Sewer System (MS4) under Iowa NPDES Permit #77-27-0-07. The Des Moines International Airport also discharges storm water within the watershed under Iowa NPDES Permit #77-27-0-08.

From the Loading Function Model, the largest source of phosphorus delivered to the lake is from urban landuse as shown in Figure 3. The Loading Function Model also indicates significant loads from cropland, grassland, and forest landuses. It should be noted that while the Loading Function Model provides estimates of the primary potential pollutant sources, the target load was calculated from measured in-lake total phosphorus concentrations using the selected lake response model as described in *Section 3.1.2, Modeling Approach*.

Figure 3. Loading Function Model Source Contributions



Other sources of phosphorus capable of being delivered to the water body exist. 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

The phosphorus load to Easter Lake originates from regulated storm water, nonpoint sources and internal recycling. To meet the TMDL endpoint, the total source contribution to Easter Lake needs to be reduced by 1,710 pounds per year.

3.1.4 Pollutant Allocation

Wasteload Allocation

The Wasteload Allocation (WLA) for this TMDL is 2,200 pounds per year of total phosphorus distributed as follows:

- 2,090 pounds per year allocated to the City of Des Moines.
- 110 pounds per year allocated to the Des Moines International Airport.

The Des Moines International Airport WLA has been set at the estimated existing load because it is minor relative to the total existing load and because there are fewer available options to reduce phosphorus incidental to runoff events from this type of landuse. For the City of Des Moines, the margin of safety, the airport WLA and the atmospheric load were considered fixed and subtracted from the allowable load predicted by the lake response modeling. The resulting value was divided between the areas within and outside of the City's corporate limits in proportion to the estimated existing loads. The areas within the corporate limits are covered under the MS4 NPDES permit and make up the WLA. The areas outside of the corporate limits are included in the Load Allocation described below.

Load Allocation

The Load Allocation (LA) for this TMDL is 90 pounds per year of total phosphorus distributed as follows:

- 30 pounds per year allocated to the portions of the Easter Lake watershed outside of the City of Des Moines corporate limits.
- 60 pounds per year allocated to atmospheric deposition.

Margin of Safety

An explicit numerical MOS of 250 pounds per year (10% of the calculated allowable phosphorus load) has been included to ensure that the wasteload and load allocations will result in attainment of water quality targets.

3.1.5 Nutrient TMDL Summary

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

TMDL = Load Capacity (2,540 lbs/year) = WLA (2,200 lbs/year) + LA (90 lbs/year) + MOS (250 lbs/year)

3.2 TMDL for Siltation

3.2.1 Problem Identification

In 1998, Easter Lake was placed on the impaired water list for siltation. This impairment remained on the 2002 list. Excessive sediment deposition impairs normal aquatic life in many ways:

- Reductions of volume and depth are critical in the shallow bay areas of lakes, where fish utilize the habitat for spawning and rearing of young. These bays are especially vulnerable to siltation, where sediment settles out as stream velocities decrease.
- Shallow lakes are more susceptible to summer algal blooms and winter fish kills due to the loss of volume of water under the winter ice that can provide dissolved oxygen.
- Shallow water favors rough fish such as bullheads and carp. As rough fish populations increase, they tend to overgraze available macrophytes and increase internal sediment and nutrient recycling by stirring bottom sediments

To understand the nature and extent of the siltation problem in Easter Lake, it is important to know how much silt has accumulated and how much of the volume has been lost. IDNR and US Geological Survey have cooperated to develop a method to map the current and original lake bottoms and sediment volume using sonar equipment.

These estimates show that the lake has lost significant volume, depth and some surface area. The Easter Lake siltation problem is predictable because the watershed to lake area ratio of 36:1 is greater than IDNR's current guideline of 20:1 and the estimated sediment delivery ratio (SDR) is high at 27%. This high sediment delivery ratio is the result of the presence of steep slopes and erosive soils.

Bathymetry for Easter Lake was performed and a sediment volume estimate was made by the USGS. The USGS mapping and sediment estimating procedure are outlined in Appendix G. The result of this work was an estimate that 24% of the original lake volume has filled with sediment since 1967 when the lake was constructed. The total siltation estimate tells how much sediment accumulated over 36 years but not when the sediment was deposited.

Data Sources

A bathymetric survey and sediment core analysis was conducted by the USGS under contract with the DNR in the summer of 2003. The bathymetric data provides the current and historical lake bottom and 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 63,870,000 ft^3 (1,466 ac-ft) and the sediment volume is 20,200,000 ft^3 (464 ac-ft). This represents a 24% loss in volume over the last 36 years. The core analysis was used to estimate the average consolidated specific weight of accumulated sediment using methods described in Appendix G of the U.S. Army Corps of Engineers

Engineering and Design Manual for Sedimentation Investigations of Rivers and Reservoirs (24).

A RUSLE erosion model using data from the IDNR geographical information system library was used to evaluate soil loss from the watershed. These estimates of erosion and watershed sediment delivery were used to evaluate current conditions. A description of this model can be found in Appendix F.

Interpreting Easter Lake Water Quality Data

The bathymetric mapping completed in 2003 by USGS provides the most accurate data on the loss of volume at Easter Lake. 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 sonar-derived original bottom was calculated and this volume of 464 acre-feet is the estimate for the siltation volume.

The design life of Easter Lake does not appear to have been explicitly determined when it was constructed. The target for Easter Lake is the average annual siltation rate that equals the rate at which it would take to fill one third of the original volume over a design life of 100 years. 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 its reservoir projects. It is usually considered an economic parameter and not a physical limitation. The original lake volume in 1967 has been estimated at 1,930 acre-feet (see Table 7) and one third of this is 643 acre-feet. If a one-third loss of the original volume is the assumed loss of volume causing an impairment of recreational and aquatic life uses then the total volume loss of 643 acre-feet spread over 100 years yields an average annual volume loss of 6.4 acre-feet per year.

Table 7. Sedimentation estimates based on bathymetric mapping completed in 2003 by USGS.

Original Lake Volume (1967)	Existing Lake Volume	Cumulative Sedimentation	Average Sedimentation Rate
1,930 ac-ft	1,466 ac-ft	464 ac-ft	12.9 ac-ft / yr

The volume loss, or inversely, the sediment gain, between 1967 and 2003 was 464 acre-feet (24% loss of volume). Although the specific sediment delivery rates and when the siltation occurred are unclear, the average annual sedimentation rate between 1967 and 2003 was 12.9 acre-feet per year.

Potential Pollution Sources

Potential sources of sediment in the Easter Lake watershed include both point and nonpoint sources. Point sources consist of regulated storm water discharges within the City of Des Moines while nonpoint sources include sediment from those areas outside of the City's corporate limits as well as sources outside the City's NPDES control area. Point and nonpoint sediment delivery to the lake originate from sheet and rill erosion, shoreline erosion, channel erosion, and erosion associated with construction and development activities.

Natural Background Conditions

Natural background contributions of sediment were not separated from the total point and nonpoint source loads.

3.2.2 TMDL Target

The useful life of Easter Lake is 100 years, at which time recreational and aquatic life uses will become impaired. To ensure that Easter Lake meets its useful life, a sediment delivery target has been established. This target is based on the volume of sediment that can be delivered to the lake annually and not cause an impairment of the lake's designated uses. This results in a volume loss of 6.4 acre-feet per year. Using an average consolidated specific weight of 70.4 pounds per cubic foot for accumulated sediment over a 100-year time period, this is equivalent to 9,900 tons per year of sediment deposited in the lake.

The trap efficiency for Easter Lake was calculated to be 93% using Brune's Curve (24). Using this trap efficiency and the allowable deposition rate of 9,900 tons per year, the targeted sediment delivery to the lake over a 100-year design life is 10,600 tons per year.

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for siltation. Siltation is a loss of lake volume, area, and depth that can be measured. For Easter Lake, the volume loss from 1967 to 2003 is known to be 464 acre-feet. To meet the designated uses for Easter Lake, the average sedimentation rate should not exceed 6.4 acre-feet per year over the 100-year life of the lake.

Selection of Environmental Conditions

The critical condition for which this sediment TMDL applies is the remaining design life of the lake, or 64 years. An annual loading period was used to define Easter Lake's sediment loading capacity. However, the sediment load for any given year may exceed the annual average target load provided that the overall average for the duration of the remaining lake design life does not exceed the target value. Sediment loads are actually the result of periodic intensive and/or high volume precipitation events. Non-point source controls are typically designed for long-term average annual conditions.

Waterbody Pollutant Loading Capacity

The load capacity for this siltation TMDL is the amount of sediment delivered to Easter Lake annually that does not exceed the allowable volume loss rate based on the design life of the lake. The silt storage volume is one third of the original lake volume or 643 acre-feet. The total storage volume spread over the 100-year design life of Easter Lake results in an allowable average annual sedimentation rate of 6.4 acre-feet per year. However, over the first 36 years, the lake lost 464 acre-feet, resulting in an average annual volume loss of 12.9 acre-feet per year. The average consolidated specific weight of the sediment over a 36-year time period is estimated to be 65.7 pounds per cubic foot (note that consolidated specific weight increases as the age of the sediment increases).

Using this specific weight and a trap efficiency of 93% the annual average mass of sediment delivered to the lake over the 36-year time period is 19,800 tons per year.

Since Easter Lake received sediment above the targeted annual rate for the first 36 years, the sediment delivery must be lowered for the remaining 64 years. The sediment loading capacity is:

$$\frac{10{,}600\ \text{tons/year} \times 100\ \text{years}\ -\ 19{,}800\ \text{tons/year} \times 36\ \text{years}}{64\ \text{years}} = 5{,}400\ \text{tons/year}$$

3.2.3 Pollution Source Assessment

Easter Lake sediment sources fall into several categories. The first is sheet and rill erosion estimated using watershed erosion models. The second category is channel and shoreline erosion. A third category is erosion caused by urban development activities. This source is temporary and difficult to quantify, but under existing NPDES storm water permitting, is expected to be held to a minimum and is assumed to be negligible for the purposes of calculating the current loading conditions.

From 1967-2003, the average annual sediment delivery was 19,800 tons per year. Table 8 shows estimated current sediment delivery rates by sub-watershed from sheet and rill erosion based on a sediment delivery ratio of 27% and a trap efficiency of 90% for the retention basins already constructed. The current sediment delivery to Easter Lake from sheet and rill erosion is estimated at 3,100 tons per year.

Table 8. Sediment Delivery Estimates, IDNR RUSLE Modeling, SDR = 27%

Tributary / Sub-Watershed	Potential Sheet & Rill Erosion (tons/year)	Unit Basis (tons/acre/year)	Sheet & Rill Delivery (tons/year)	Unit Basis (tons/acre/year)
Yeader Creek	2,000	0.6	500	0.1
Middle Arm[1]	1,700	6.0	200	0.7
South Arm[2]	12,000	8.5	1,100	0.8
Direct Drainage	5,000	4.7	1,300	1.2
Total	20,700	3.2	3,100	0.5

Current channel and shoreline erosion are more difficult to quantify but channel erosion is believed to be significant based on observed streambank conditions and sediment deposition in the upper sections of the lake. Shoreline erosion does not appear to be significant based upon limited fetch, stable water levels, and comparisons of historical aerial photos of the shoreline. For the purposes of this TMDL, channel erosion has been estimated by the direct volume method (14) with recession rates of 0.2 feet per year for Yeader Creek and 0.1 feet per year for the middle arm and south arm channels. These recession rates were applied for the entire channel length for Yeader Creek and the channel lengths below the existing retention structures for the other two main channels. A delivery ratio of 100% was assumed for channel erosion and a soil density of 85 pounds per cubic foot was used to convert eroded volume to mass. The estimated channel erosion is shown in Table 9.

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[1] Refererred to as Side Channel 6 in the Southeast Annex Area Storm Water Study (26)

[2] Refererred to as Main Channel in the Southeast Annex Area Storm Water Study (26)

Table 9. Estimated Channel Erosion

Tributary / Sub-Watershed	Channel Length (feet)	Channel Erosion (tons/year)
Yeader Creek	20,000	3,400
Middle Arm	2,600	100
South Arm	6,400	400
Totals	29,000	3,900

Existing Load

For the purposes of this TMDL, both the historical and current sediment loads are estimated. The historical and TMDL target sediment loads are based on recent bathymetric mapping, which provides the most accurate estimate of sediment delivery to the lake. However, the current sediment load estimate should be considered as approximate with a potentially wide margin of error for two primary reasons.

First, the eastern portion of the Easter Lake watershed is currently in a state of transition from agricultural to urban land uses. Any estimate of sediment loading from sheet and rill erosion depends heavily upon the land use types in the watershed. The GIS-derived land uses applied in the RUSLE modeling are “snapshots” of the watershed at a specific point in time and may not reflect the most recent land use changes. The potential effect of land use changes is illustrated by previous sediment modeling performed for the Southeast Annex Area Storm Water Study (26). In review of the sediment modeling, the report notes that “The land usage change is from a predominant agricultural area to an urban type area composed of residences and commercial park zones” and that “it becomes apparent the biggest factor in the reduction of the sediment loading comes not from the proposed improvements but rather from the change in land usage”.

Secondly, the estimated existing channel erosion is based on assumed average streambank recession rates over entire stream lengths and not upon measured field values. A detailed field survey of the tributaries to determine eroding areas and long-term monitoring of streambank erosion to determine actual recession rates would provide a more accurate estimate of channel erosion. Unfortunately, this information is not currently available.

The average annual sediment delivery to Easter Lake from 1967-2003 was 19,800 tons per year. The current sediment delivery rate from sheet and rill erosion based on RUSLE modeling with the constructed retention basins is 3,100 tons per year. Sediment delivery from channel erosion is estimated at 3,900 tons per year. Therefore the estimated current total sediment delivery rate to Easter Lake is 7,000 tons per year. This estimate includes 3,030 tons per year from areas included in the City of Des Moines’ NPDES permit and 3,970 tons per year from areas outside of the City’s NPDES control area.

Departure from Load Capacity

The estimated current sediment delivery rate to Easter Lake is 7,000 tons per year. The targeted load capacity is 5,400 tons per year. A sediment delivery reduction of 1,600 tons per year is required to achieve the TMDL endpoint.

Identification of Pollutant Sources

There are two quantified sediment sources for Easter Lake in this TMDL. The first is the sediment load from regulated storm water discharges. The second source is nonpoint loading from the sources outside of the City's NPDES control area.

Linkage of Sources to Target

The existing average annual sediment load of 7,000 tons per year to Easter Lake originates from both point and nonpoint sources. This sediment load needs to be reduced by 1,600 tons per year to reach the target of 5,400 tons per year. The target for this siltation TMDL is an average annual rate of sediment delivery that will not cause water quality impairments.

3.2.4 Pollutant Allocation

Wasteload Allocation

The Wasteload Allocation (WLA) for this siltation TMDL is 2,100 tons per year of sediment allocated to the City of Des Moines. The Des Moines International Airport is not considered a significant source of sediment to Easter Lake.

For the City of Des Moines, the margin of safety was subtracted from the allowable load calculated from bathymetric mapping. The resulting value was divided between the areas within and outside of the City's NPDES control area in proportion to the estimated existing loads. The areas within the NPDES control area are covered under the MS4 NPDES permit and make up the WLA. The areas outside of the control area are included in the Load Allocation described below.

Load Allocation

The Load Allocation (LA) for this siltation TMDL is 2,760 tons per year of sediment.

Margin of Safety

The explicit margin of safety (MOS) for this TMDL is a 10% reduction of the loading capacity of 5,400 tons per year. The MOS is 540 tons per year.

3.2.5 Siltation TMDL Summary

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

TMDL = Load Capacity (5,400 tons/year) = WLA (2,100 tons/year) + LA (2,760 tons/year) + MOS (540 tons per 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 Easter Lake water quality.

4.1 Nutrients

If the entire phosphorus load were attributed to watershed sources, the estimated loading from watershed sources would need to be reduced from 0.7 pounds/acre/year to 0.4 pounds/acre/year to meet the TMDL. 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.

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

- Reduce watershed and recycle loading from 4,300 pounds per year to 3,700 pounds per year by 2010.
- Reduce watershed and recycle loading from 3,700 pounds per year to 3,100 pounds per year by 2015.
- Reduce watershed and recycle loading from 3,100 pounds per year to 2,500 pounds per year by 2020.

Best management practices to reduce external nutrient delivery, particularly phosphorus, should be emphasized in the Easter Lake watershed. For agricultural land uses, these practices include the following:

- Nutrient management on production agriculture ground to achieve the optimum soil test category. This soil test category is the most profitable for producers to sustain in the long term.
- Incorporate or subsurface apply phosphorus (manure and commercial fertilizer) while controlling soil erosion. Incorporation will physically separate the phosphorus from surface runoff.
- Continue encouraging the adoption of reduced tillage systems, specifically no till and strip tillage.
- Initiate a fall-seeded cover crop incentive program. Target low residue producing crops (e.g. soybeans) or low residue crops after harvest (e.g. corn silage fields). This practice increases residue cover on the soil surface and improves water infiltration.

With much of the watershed already devoted to urban land uses and future anticipated development, Best Management Practices (BMPs) for controlling nutrient delivery associated with urban runoff are of particular importance in the Easter Lake watershed. These practices include:

- Addition of landscape diversity to reduce runoff volume and/or velocity through the strategic location of filter strips, rain gardens and grass waterways, etc.
- Installation of 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.
- Use of low or no-phosphorus fertilizers on residential and commercial lawns.
- Use of appropriate erosion controls on construction sites to reduce delivery of sediment and phosphorus to the lake.

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

As noted previously in *Section 2.2, The Watershed*, the City of Des Moines has already constructed a number of BMPs through implementation of the Southeast Annex Area Comprehensive Storm Water Study and Master Plan (26). In addition, the City of Des Moines' NPDES MS4 permit requires development of a Storm Water Pollution Prevention & Management Program (SWMP). The SWMP includes requirements for implementation of BMPs including controls to reduce pollutants in discharges from municipal application of fertilizers and operation of a public environmental information and education program to inform the public about the proper use of fertilizers.

The ongoing implementation of the Storm Water Study and Master Plan and BMPs required under the City's and the Des Moines International Airport's NPDES permits are expected to be sufficient to implement the WLAs for total phosphorus. Therefore, numeric effluent limitations for total phosphorus will not be included in the NPDES permits. The effect of implemented BMPs will be assessed as part of Phase II of this TMDL and, if necessary, the NPDES permits modified.

4.2 Siltation

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

Channel erosion: Channel erosion has been identified as a significant sediment source. Channel contributions should be identified and stream bank restoration work done. Areas of severe channel erosion should be identified and targeted for restoration activities. Suggested controls are:

- Installation of structures to reduce peak flows during runoff events.
- Installation of stream bank protection measures such as vegetation and graded rock.
- Stabilization of 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. Suggested controls are:

- Agricultural management practices that will increase crop residue such as no-till farming,
- Construction of terraces and grassed waterways.
- Installation of buffer strips along stream corridors.
- Construction of grade stabilization structures.
- Implementation and enforcement of erosion control measures at development sites.

In addition to remediation of the water quality impairment in Easter Lake, the sediment target identified in this TMDL is necessary to protect the public investment in the lake and surrounding park. If future evaluations of the lake condition indicate that the sediment delivery goal is inadequate to prevent the siltation impairment, the TMDL will be revised and new sediment allocations will be made.

Like the WLA for total phosphorus, implementation of the Storm Water Study and Master Plan and BMPs required under the City's NPDES permit are expected to be sufficient to implement the WLA for sediment. Numeric effluent limitations for sediment will not be included in the City's permit. The effect of implemented BMPs will be assessed as part of Phase II of this TMDL and, if necessary, the SWMP modified as allowed for under the NPDES permit.

5. Monitoring

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

As noted in comments provided by the Polk County Conservation Board, the bathymetry-derived water and sediment volumes do not account for sediment volumes in the upper-reach lake areas that have completely silted in. The IDNR believes that the volume lost in these shallow areas is within the sediment TMDL margin of safety. However, further investigations to determine the original volume lost in these areas is warranted to more accurately define the sediment target and historical sediment delivery to the lake. In addition, current measurements of channel and shoreline erosion need to be obtained. The IDNR will work with local stakeholders to collect this data to verify and improve the implementation of this TMDL.

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

6. Public Participation

A public meeting was held in Des Moines on January 27, 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)**
$\overline{Q}_{A} = 1.17 \times 10^{-3} DA^{0.998} \overline{P}_{A}^{\,1.54} S^{-0.261} (1+F)^{0.249} C^{0.230}$	98.7	0.177268 (n=26)
$\overline{Q}_{JAN} = 0.213 DA^{0.997} \overline{A}_{JAN}^{\,0.949}$	89.0	0.729610 (n=26;same for all $\overline{Q}_{MONTH}$)
$\overline{Q}_{FEB} = 2.98 DA^{0.955} \overline{A}_{FEB}^{\,0.648} G^{-0.594} (1+F)^{0.324}$	97.0	0.07089
$\overline{Q}_{MAR} = 6.19 DA^{1.10} B^{-0.386} G^{-0.296}$	97.8	0.07276
$\overline{Q}_{APR} = 1.24 DA^{1.09} \overline{A}_{APR}^{\,1.64} S^{-0.311} B^{-0.443}$	97.1	0.257064
$\overline{Q}_{MAY} = 10^{(-3.03+0.114H)} DA^{0.846} \overline{P}_{A}^{\,2.05}$ Hydrologic Regions 2, 3 & 4 Only	92.1	0.958859
$\overline{Q}_{MAY} = 1.86 \times 10^{-3} DA^{0.903} \overline{P}_{A}^{\,1.98}$	90.5	1.07231
$\overline{Q}_{JUN} = 10^{(-1.47+0.0729H)} DA^{0.891} C^{0.404} \overline{P}_{JUN}^{\,1.84} (1+F)^{0.326} G^{-0.387}$ Hydrologic Regions 2, 3 & 4 Only	97.0	0.193715
$\overline{Q}_{JUN} = 8.13 \times 10^{-3} DA^{0.828} C^{0.478} \overline{P}_{JUN}^{\,2.70}$	95.9	0.256941
$\overline{Q}_{JUL} = 1.78 \times 10^{-3} DA^{0.923} \overline{A}_{JUL}^{\,4.19}$	91.7	0.542940
$\overline{Q}_{AUG} = 4.17 \times 10^{7} DA^{0.981} (1+B')^{-1.64} (1+U)^{0.692} \overline{P}_{A}^{\,-7.2} \overline{A}_{AUG}^{\,4.59}$	90.4	1.11413
$\overline{Q}_{SEP} = 1.63 DA^{1.39} B^{-1.08}$	86.9	1.53072
$\overline{Q}_{OCT} = 5.98 DA^{1.14} B^{-0.755} S^{-0.688} (1+B')^{-0.481}$	95.7	0.375296
$\overline{Q}_{NOV} = 5.79 DA^{1.17} B^{-0.701} G^{-0.463} (1+U)^{0.267} (1+B')^{-0.397}$	95.1	0.492686
$\overline{Q}_{DEC} = 0.785 DA^{1.18} B^{-0.654} (1+U)^{0.331} (1+B')^{-0.490}$	92.4	0.590576
$Q_{YEAR} = 3.164 \times 10^{-4} DA^{0.942} P_{YEAR}^{\,2.39} A_{YEAR}^{\,1.02} S^{-0.206} \overline{P}_{A}^{\,1.27} C^{0.121} (1+U)^{0.0966}$	83.9	32.6357 (n=716)

General Application

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

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

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

Application to Easter Lake - Calculations

Table A-5. Easter Lake Hydrology Calculations

Lake	Easter Lake	
Type	Impoundment	
Inlet(s)	Yeader Creek, unnamed creeks(2)	
Outlet(s)	Yeader Creek	
Volume	1466	(acre-ft)
Lake Area	178	(acres)
Mean Depth	8.24	(ft)
Drainage Area	6375	(acres)
Mean Annual Precip	31.3	(inches)
Average Basin Slope	--	(%)
%Water	--	
%Forest	--	
%Grass/Hay	--	
%Corn	--	
%Beans	--	
%Urban/Artificial	--	
%Barren/Sparse	--	
Hydrologic Region	--	
Mean Annual Class A Pan Evap	50.00	(inches)
Mean Annual Lake Evap	37.00	(inches)
Est. Annual Average Inflow	5411.60	(acre-ft)
Direct Lake Precip	464.43	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	0.2495	(yr)
Est. Annual Average Det. Time (outflow)	0.2752	(yr)

9. Appendix B - Sampling Data

Table B-1. Data collected in 1979 by Iowa State University (Bachmann, 1980)

Parameter	**7/19/1979**	**8/21/1979**	**9/27/1979**
Secchi Depth (m)	1.2	0.7	1.0
Chlorophyll (ug/L)	15.5	52.2	26.4
NO_3+NO_2-N (mg/L)	--	--	0.07
Total Phosphorus (ug/l as P)	49.4	62.8	56.7
Alkalinity (mg/L)	118	126	124

Data above is averaged over the upper 6 feet.

Table B-2. Data collected in 1990 by Iowa State University (Bachmann, 1994)

Parameter	**6/01/1990**	**7/06/1990**	**8/04/1990**
Secchi Depth (m)	0.6	0.8	0.7
Chlorophyll (ug/L)	53.4	24.7	55.2
Total Nitrogen (mg/L as N)	1.8	1.8	1.2
Total Phosphorus (ug/l as P)	164.9	71.1	72.6
Total Suspended Solids (mg/L)	68.3	22.1	27.7
Inorganic Suspended Solids (mg/L)	62.5	6.2	16.8

Data above is for surface depth.

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

Parameter	**6/26/2000**	**7/24/2000**	**8/21/2000**
Secchi Depth (m)	0.6	0.7	0.4
Chlorophyll (ug/L)	24	9	12
NH_3+NH_4^+ -N (ug/L)	812	259	948
NH_3 –N (un-ionized) (ug/L)	3	34	10
NO_3+NO_2-N (mg/L)	0.09	8.95	0.04
Total Nitrogen (mg/L as N)	0.99	1.14	1.26
Total Phosphorus (ug/l as P)	57	153	100
Silica (mg/L as SiO_2)	21	21	30
pH	6.8	8.4	7.3
Alkalinity (mg/L)	111	116	109
Total Suspended Solids (mg/L)	21.2	5.0	7.7
Inorganic Suspended Solids (mg/L)	14.5	1.4	5.2
Volatile Suspended Solids (mg/L)	6.8	3.6	2.5

Table B-4. Data collected in 2001 by Iowa State University (Downing and Ramstack, 2002)

Parameter	**5/29/2001**	**6/25/2001**	**7/30/2001**
Secchi Depth (m)	1.1	0.9	0.9
Chlorophyll (ug/L)	23	39	16
NH_3+NH_4^+ -N (ug/L)	295	989	3991
NH_3 –N (un-ionized) (ug/L)	8	225	397
NO_3+NO_2-N (mg/L)	0.92	0.06	0.35
Total Nitrogen (mg/L as N)	1.46	1.78	0.74
Total Phosphorus (ug/l as P)	95	113	54
Silica (mg/L as SiO_2)	7	6	9
pH	7.9	8.6	8.2
Alkalinity (mg/L)	148	105	118
Total Suspended Solids (mg/L)	14.1	16.4	10.0
Inorganic Suspended Solids (mg/L)	8.0	7.9	4.3
Volatile Suspended Solids (mg/L)	6.1	8.5	5.7

Table B-5. Data collected in 2002 by Iowa State University (Downing et al., 2003)

Parameter	**6/03/2002**	**7/08/2002**	**8/05/2002**
Secchi Depth (m)	1.1	0.4	0.4
Chlorophyll (ug/L)	21	69	79
NH_3+NH_4^+ -N (ug/L)	195	89	212
NH_3 –N (un-ionized) (ug/L)	23	15	42
NO_3+NO_2-N (mg/L)	0.11	0.14	0.15
Total Nitrogen (mg/L as N)	0.80	1.06	1.01
Total Phosphorus (ug/l as P)	40	98	91
Silica (mg/L as SiO_2)	2	4	3
pH	8.3	8.4	8.6
Alkalinity (mg/L)	122	100	80
Total Suspended Solids (mg/L)	8.7	23.6	16.0
Inorganic Suspended Solids (mg/L)	4.7	8.0	4.0
Volatile Suspended Solids (mg/L)	4.0	15.6	12.0

Table B-6. Data collected in 2003 by Iowa State University (Downing et al., 2004)

Parameter	**6/02/2003**	**7/07/2003**	**8/04/2003**
Secchi Depth (m)	1.2	1.0	0.6
Chlorophyll (ug/L)	11.5	--	34.2
NH_3+NH_4^+ -N (ug/L)	360	225	216
NH_3 –N (un-ionized) (ug/L)	19	24	34
NO_3+NO_2-N (mg/L)	0.73	0.23	0.16
Total Nitrogen (mg/L as N)	1.64	0.90	1.22
Total Phosphorus (ug/l as P)	43	57	77
Silica (mg/L as SiO_2)	1.9	3.2	2.6
pH	8.1	8.2	8.4
Alkalinity (mg/L)	90	84	70
Total Suspended Solids (mg/L)	9	12	17
Inorganic Suspended Solids (mg/L)	8	5	7
Volatile Suspended Solids (mg/L)	1	7	11

Table B-7. 2000 and 2001 Phytoplankton Data (Downing and Ramstack, 2001, 2002)

	2000	**2001**
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	0.562	0.508
Chlorophyta	0.079	5.239
Cryptophyta	2.113	0.248
Cyanobacteria	3.813	2.543
Dinophyta Wet	0	0.087
Euglenophyta	0.041	0
Total	6.609	8.625

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:

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

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

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

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

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

SD = lake Secchi depth, meters

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

Table C-1. Changes in temperate lake attributes according to trophic state (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.

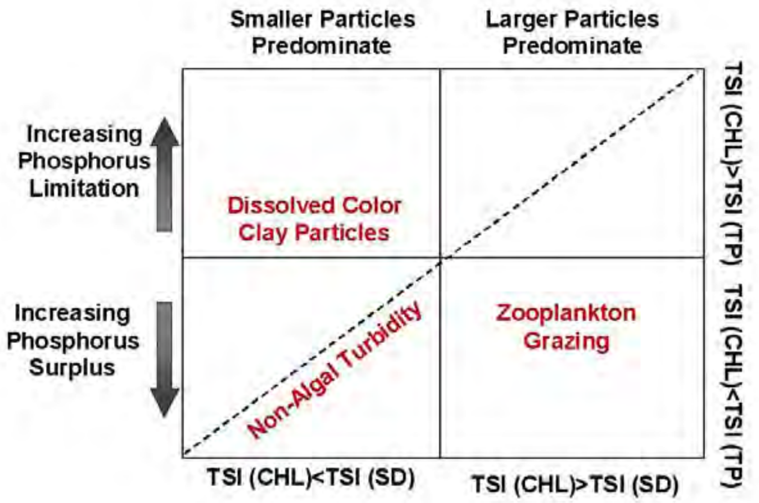
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for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



Easter Lake TSI Values

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/19/1979	57	57	60
8/21/1979	65	69	64
9/27/1979	60	63	62

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/1/1990	67	70	78
7/6/1990	63	62	66
8/4/1990	65	70	66

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

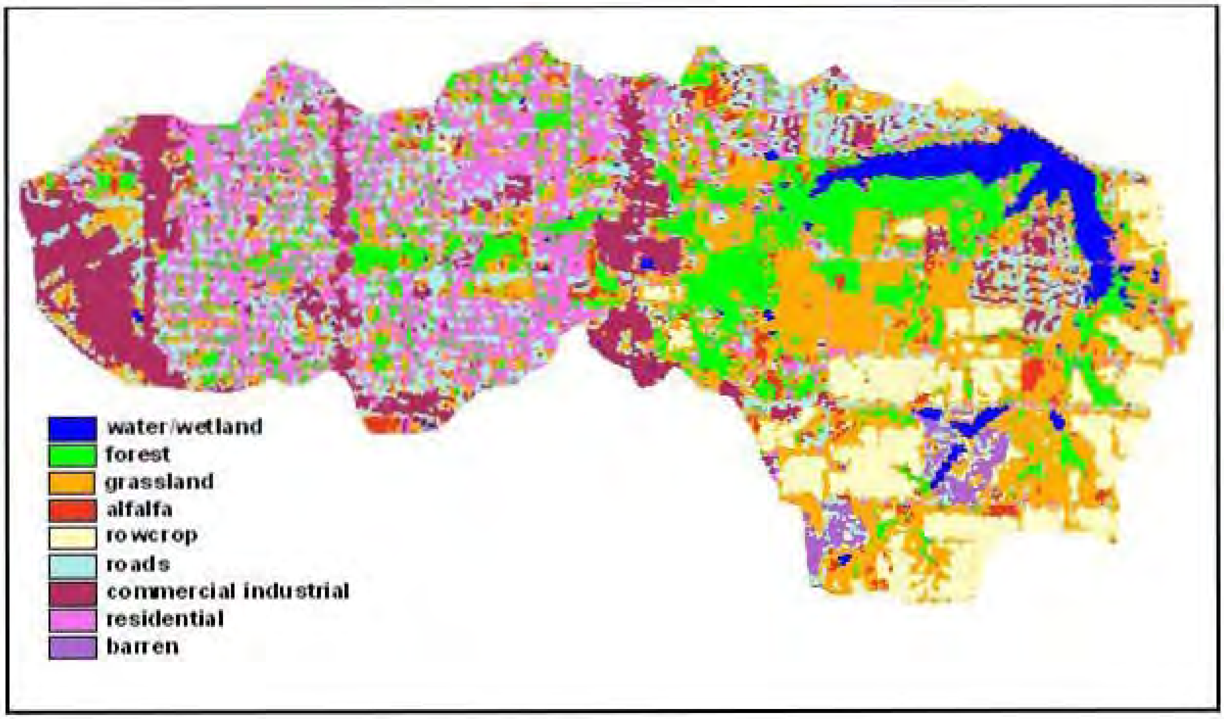
Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
6/26/2000	67	62	62
7/24/2000	65	52	77
8/21/2000	73	55	71
5/29/2001	59	61	70
6/25/2001	62	67	72
7/30/2001	62	58	62
6/3/2002	59	60	57
7/8/2002	73	72	70
8/5/2002	73	73	69
6/2/2003	57	55	58
7/7/2003	60	--	62
8/4/2003	67	65	67

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

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/11/2003	63	63	61
7/22/2003	67	66	71
8/7/2003	77	76	71
8/22/2003	77	82	72
9/12/2003	73	77	77
9/26/2003	77	77	76
10/10/2003	63	61	71

11. Appendix D - Land Use Map

Figure D-1. Easter Lake Watershed 2002 Landuse



12. Appendix E - Bathtub Program Input/Output

Easter Lake
File: **C:\Bathtubexe2\easter.btb**
Description:

Five Segments

suggested default values for model options & model coefficients

nitrogen budgets not modeled

phosphorus budgets based upon total P only
availability factors ignored

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.795	0.0
Evaporation (m)	0.94	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	39.8	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	
Seq	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Yeader Arm	2	1	0.304	2	1.6	2	0.12	0	0	0.08	9.65	0	0	0	0	0	0
2	Dam Area	0	1	0.162	4.57	0.6	4.3	0.12	0	0	0.2	1.69	0	0	0	0	0	0
3	Middle Arm	2	1	0.073	2	0.5	2	0.12	0	0	0.08	0.2	0	0	0	0	0	0
4	Lower South Arm	2	1	0.146	2.01	0.7	2	0.12	0	0	0.08	9.17	0	0	0	0	0	0
5	Upper South Arm	4	1	0.036	0.61	0.3	0.6	0.12	0	0	0.08	0.2	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)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	99	0.2	0	0	88	0.3	0.5	0.2	0	0	0	0	0	0	0	0
2	0	0	90	0.1	0	0	42	0.3	0.8	0.1	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	96	0.2	0	0	82	0.3	0.5	0.2	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	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)	
Seq	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

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	Yeader Creek	1	1	17.18	4.21	0.1	0	0	199	0.2	0	0	0	0	0	0
2	Mid Arm Creek	3	1	1.4	0.38	0.1	0	0	457	0.2	0	0	0	0	0	0
3	Upper South Arm Creek	5	1	6.5	1.68	0.1	0	0	420	0.2	0	0	0	0	0	0
4	Dam	2	1	0.6	0.17	0.1	0	0	177	0.2	0	0	0	0	0	0
5	Lower South	4	1	0.84	0.23	0.1	0	0	657	0.2	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)	0.100	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

Easter Lake
File: C:\Bathtubexe2\easter.btb

Segment & Tributary Network

--------Segment: 1 Yeader Arm
Outflow Segment: 2 Dam Area
Tributary: 1 Yeader Creek Type: Monitored Inflow

--------Segment: 2 Dam Area
Outflow Segment: 0 Out of Reservoir
Tributary: 4 Dam Type: Monitored Inflow

--------Segment: 3 Middle Arm
Outflow Segment: 2 Dam Area
Tributary: 2 Mid Arm Creek Type: Monitored Inflow

--------Segment: 4 Lower South Arm
Outflow Segment: 2 Dam Area
Tributary: 5 Lower South Type: Monitored Inflow

--------Segment: 5 Upper South Arm
Outflow Segment: 4 Lower South Arm
Tributary: 3 Upper South Arm Creek Type: Monitored Inflow

Easter Lake
File: C:\Bathtubexe2\easter.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	Yeader Arm	2	4.2	0.1459	13.7	11.0	22.1	8.8	3.2
2	Dam Area	0	6.6	0.1128	40.5	5.3	10.8	1.6	0.0
3	Middle Arm	2	0.4	0.3952	5.1	1.3	1.5	0.3	0.7
4	Lower South Arm	2	1.9	0.1558	12.9	4.5	10.9	1.6	5.6
5	Upper South Arm	4	1.7	0.0131	46.5	22.9	49.9	3.4	11.3

Morphometry

		Area	Zmean	Zmix	Length	Volume	Width	L/W
Seg	**Name**	**km^2**	**m**	**m**	**km**	**hm^3**	**km**	**-**
1	Yeader Arm	0.3	2.0	2.0	1.6	0.6	0.2	8.4
2	Dam Area	0.2	4.6	4.3	0.6	0.7	0.3	2.2
3	Middle Arm	0.1	2.0	2.0	0.5	0.1	0.1	3.4
4	Lower South Arm	0.1	2.0	2.0	0.7	0.3	0.2	3.4
5	Upper South Arm	0.0	0.6	0.6	0.3	0.0	0.1	2.5
Totals		0.7	2.5			1.8		

Easter Lake
File: C:\Bathtubexe2\easter.btb

Overall Water & Nutrient Balances

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

Trb	**Type**	**Seq**	**Name**	**Area** km^2	**Flow** hm^3/yr	**Variance** $(hm3/yr)^2$	**CV** -	**Runoff** m/yr
1	1	1	Yeader Creek	17.2	4.2	1.77E-01	0.10	0.25
2	1	3	Mid Arm Creek	1.4	0.4	1.44E-03	0.10	0.27
3	1	5	Upper South Arm Creek	6.5	1.7	2.82E-02	0.10	0.26
4	1	2	Dam	0.6	0.2	2.89E-04	0.10	0.28
5	1	4	Lower South	0.8	0.2	5.29E-04	0.10	0.27
PRECIPITATION				0.7	0.6	5.26E-04	0.04	0.80
TRIBUTARY INFLOW				26.5	6.7	2.08E-01	0.07	0.25
***TOTAL INFLOW				27.2	7.2	2.08E-01	0.06	0.27
ADVECTIVE OUTFLOW				27.2	6.6	2.50E-01	0.08	0.24
***TOTAL OUTFLOW				27.2	6.6	2.50E-01	0.08	0.24
***EVAPORATION					0.7	4.13E-02	0.30	

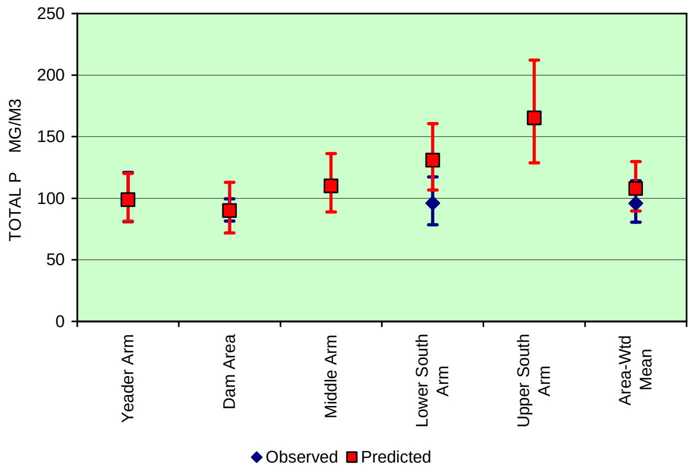
Overall Mass Balance Based Upon **Predicted** **Outflow & Reservoir Concentrations**
Component: **TOTAL P**

Trb	**Type**	**Seq**	**Name**	**Load** kg/yr	**%Total**	**Load Variance** $(kg/yr)^2$	**%Total**	**CV**	**Conc** mg/m^3	**Export** $kg/km^2/yr$
1	1	1	Yeader Creek	837.8	43.5%	3.51E+04	55.8%	0.22	199.0	48.8
2	1	3	Mid Arm Creek	173.7	9.0%	1.51E+03	2.4%	0.22	457.0	124.0
3	1	5	Upper South Arm Creek	705.6	36.6%	2.49E+04	39.6%	0.22	420.0	108.6
4	1	2	Dam	30.1	1.6%	4.53E+01	0.1%	0.22	177.0	50.1
5	1	4	Lower South	151.1	7.8%	1.14E+03	1.8%	0.22	657.0	179.9
PRECIPITATION				28.7	1.5%	2.06E+02	0.3%	0.50	50.1	39.8
TRIBUTARY INFLOW				1898.2	98.5%	6.27E+04	99.7%	0.13	284.6	71.6
***TOTAL INFLOW				1926.9	100.0%	6.29E+04	100.0%	0.13	266.0	70.7
ADVECTIVE OUTFLOW				591.0	30.7%	1.98E+04		0.24	90.0	21.7
***TOTAL OUTFLOW				591.0	30.7%	1.98E+04		0.24	90.0	21.7
***RETENTION				1336.0	69.3%	5.69E+04		0.18		

Overflow Rate (m/yr)	9.1	Nutrient Resid. Time (yrs)	0.1012
Hydraulic Resid. Time (yrs)	0.2756	Turnover Ratio	9.9
Reservoir Conc (mg/m3)	108	Retention Coef.	0.693

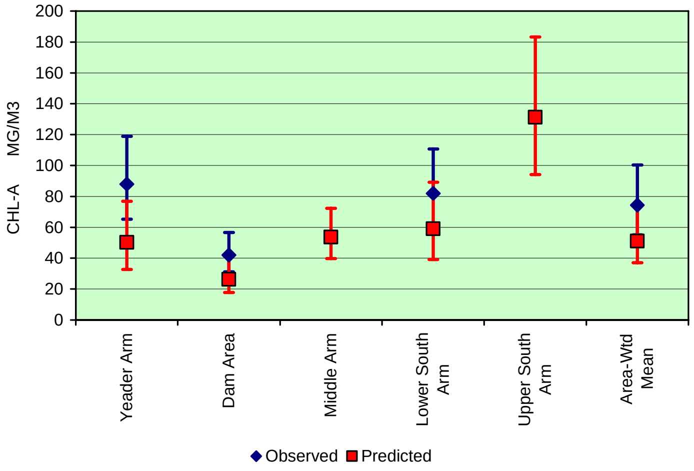
Easter Lake
File: **C:\Bathtubexe2\easter.btb**
Variable: **TOTAL P MG/M3**

	Predicted		**Observed**	
Segment	**Mean**	**CV**	**Mean**	**CV**
Yeader Arm	98.8	0.20	99.0	0.20
Dam Area	90.0	0.23	90.0	0.10
Middle Arm	110.0	0.21		
Lower South Arm	131.0	0.20	96.0	0.20
Upper South Arm	165.3	0.25		
Area-Wtd Mean	107.8	0.19	95.9	0.18



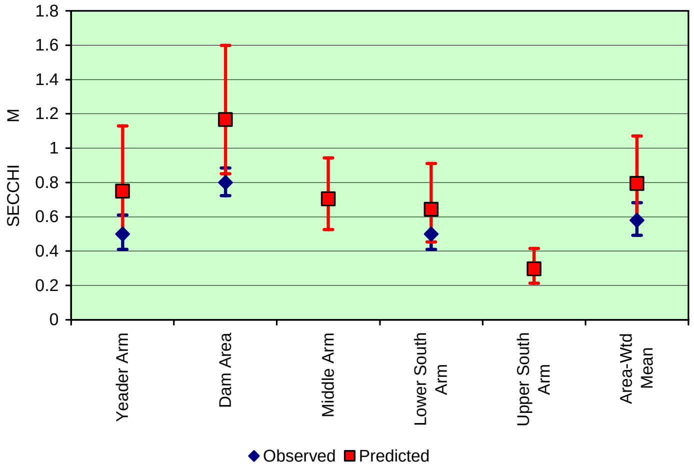
Easter Lake
File: **C:\Bathtubexe2\easter.btb**
Variable: **CHL-A MG/M3**

Segment	**Predicted**		**Observed**	
	Mean	**CV**	**Mean**	**CV**
Yeader Arm	50.2	0.43	88.0	0.30
Dam Area	26.3	0.39	42.0	0.30
Middle Arm	53.6	0.30		
Lower South Arm	59.0	0.41	82.0	0.30
Upper South Arm	131.3	0.33		
Area-Wtd Mean	51.0	0.32	74.4	0.30



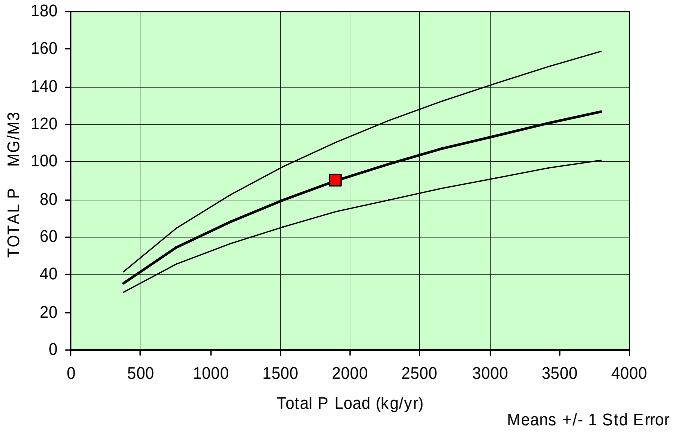
Easter Lake
File: **C:\Bathtubexe2\easter.btb**
Variable: **SECCHI M**

Segment	**Predicted**		**Observed**	
	Mean	**CV**	**Mean**	**CV**
Yeader Arm	0.7	0.41	0.5	0.20
Dam Area	1.2	0.32	0.8	0.10
Middle Arm	0.7	0.29		
Lower South Arm	0.6	0.35	0.5	0.20
Upper South Arm	0.3	0.34		
Area-Wtd Mean	0.8	0.30	0.6	0.16



Easter Lake
File: **C:\Bathtubexe2\easter.btb**
Load / Response
Tributary: **All**
Segment: **02 Dam Area**
Variable: **TOTAL P MG/M3**

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m^3	TOTAL P Mean	MG/M3 CV	Low	High
Base:	6.7	1898.2	284.6	90.0	0.23	73.4	110.4
0.20	6.7	379.7	56.9	35.7	0.17	30.6	41.6
0.40	6.7	759.3	113.8	54.3	0.19	45.6	64.7
0.60	6.7	1138.9	170.8	68.4	0.21	56.7	82.6
0.80	6.7	1518.6	227.7	80.0	0.22	65.7	97.5
1.00	6.7	1898.2	284.6	90.0	0.23	73.4	110.4
1.20	6.7	2277.9	341.5	98.8	0.23	80.1	121.9
1.40	6.7	2657.6	398.4	106.7	0.24	86.1	132.3
1.60	6.7	3037.2	455.4	114.0	0.24	91.6	141.8
1.80	6.7	3416.9	512.3	120.6	0.25	96.6	150.6
2.00	6.7	3796.5	569.2	126.8	0.25	101.2	158.9



13. Appendix F - Erosion Model and Model inputs

The Revised Universal Soil Loss Equation (RUSLE) (25) is an erosion model designed to predict the longtime annual average soil loss (A) carried by runoff from specific field slopes in specified cropping and management systems. The equation used by RUSLE is:

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

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

Data from IDNR soil, landuse and other GIS coverages have been used as input to the RUSLE equation. The IDNR RUSLE erosion model uses a grid of 30 by 30 meter cells to estimate 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. Easter Lake RUSLE modeling results, potential sheet & rill erosion

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.

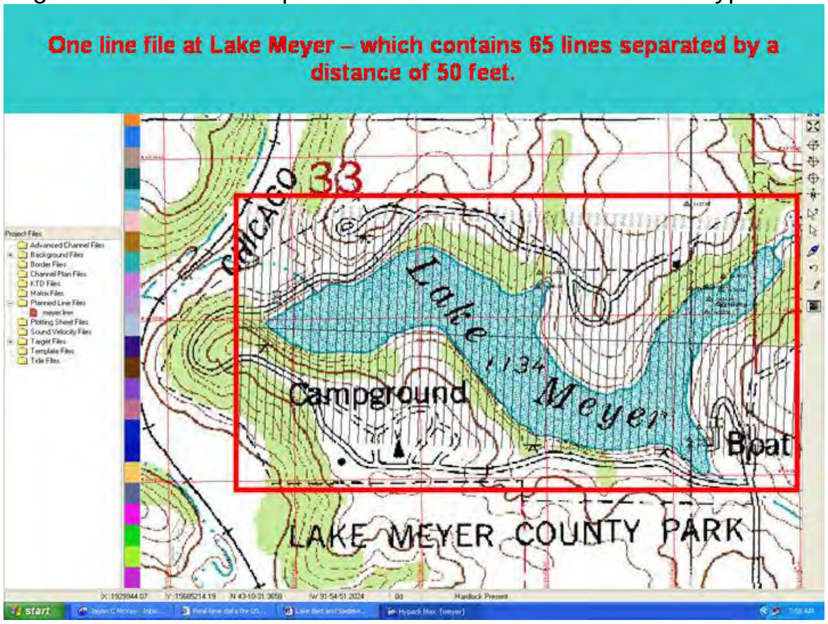
Computer Setup
Preparation includes computer setup and identifying the location of established benchmarks. Computer preparation work involves loading background maps (digital raster USGS topographic maps) in the file format. Background map files are used to help establish the lines that will be used 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 G-1 - Screen capture of data collection lines within Hypack® Max


One line file at Lake Meyer – which contains 65 lines separated by a distance of 50 feet.

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

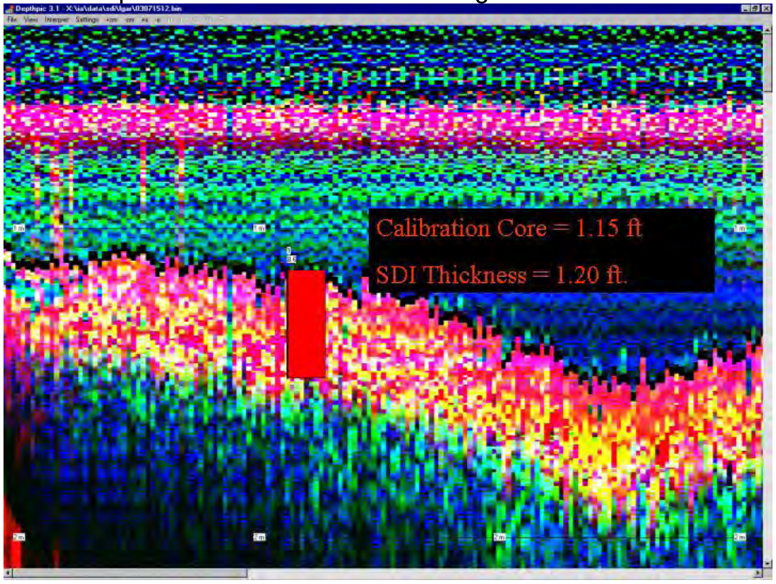
Sediment mapping has the same water depth limitations as the bathymetry. Collection of sediment cores is needed in lake areas where seismic data collection is not possible. Sediment cores are used to interpret sediment thickness during post-processing. Upon collection of the core samples, a visual determination 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 G-2. Example of a calibration core and digital view of a cross-section.



Calibration Core = 1.15 ft

SDI Thickness = 1.20 ft.

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.