Total Maximum Daily Load
For Organic Enrichment
Crystal Lake
Hancock County, Iowa

August 8, 2002

Iowa Department of Natural Resources
Water Resources Section

Appendix A, Crystal Lake
Estimating Phosphorous Loading Using Reckhow's Eutromod Loading Equations for Lakes

Equations utilizing regression analysis have been developed by Kenneth Reckhow for the EUTROMOD Watershed and Lake Model. These equations have been incorporated into the Crystal Lake Restoration Diagnostic/Feasibilty Study to compare total phosphorous concentration values computed using the model equations and those obtained by direct measurement. Information required to use the model equations includes average total phosphorous influent concentration, 0.2 mg/l; mean depth, 1.5 m; and the hydraulic residence time, 0.40 yr.

Calculation of the predicted total phosphorous load is as follows:

$$k = 10.77\tau^{0.39} z^{0.01} P_{in}^{\ 0.82} = 10.77(0.40^{0.39})(1.5^{0.01})(0.2^{0.82}) = 2.021$$

$$\log_{10}(P) = \log_{10}\left[\frac{P_{in}}{1+k\tau}\right] = \log_{10}\left[\frac{0.2}{1+(2.021)(0.40)}\right]$$

$$P = 0.11 mg/l$$

These two equations are from the *EUTROMOD Watershed and Lake Modeling Software* documentation and are described below.

EUTROMOD – KA, MO, OK, AK, IA, NE Lake Models

K. H. Reckhow
Duke University, June 10, 1991

MODEL PARAMETER ESTIMATION

The models have been fitted using robust regression (linear, nonlinear, and logistic). The robust weighting scheme usually results in a model that best (in a least squared error sense) represents the pattern in the bulk of the data. Standard errors have been adjusted to account for the robustness criterion.

MODELS

Total Phosphorous (mg/l)

$$\log_{10}(P) = \log_{10}\left[\frac{P_{in}}{1+k\tau}\right]$$

Where $k = 10.77\tau^{0.39} z^{0.01} P_{in}^{\;0.82}$ standard error = 0.219

Total Nitrogen (mg/l)

$$\log_{10}(N) = \log_{10}\left[\frac{N_{in}}{1 + k\tau}\right]$$

Where $k = 10.77\tau^{0.39} z^{0.01} P_{in}^{\;0.82}$ standard error = 0.108

Chlorophyll a (μg/l)

$$\log_{10}(Chla) = 1.99 + 0.51\log_{10}(\hat{P}) + 0.23\log_{10}(\tau) - 0.35\log_{10}(z)$$

standard error = 0.226

Secchi Disk Depth (m)

$$\log_{10}(SD) = -1.32 - 0.66\log_{10}(\hat{P}) + 0.47\log_{10}(z)$$

standard error = 0.171

Trophic State Index

The TSI is based on that proposed by R, Carlson (1977) using predicted P, Chla, and SD. Allowable Phosphorous loading to meet in-lake goal:

$$\log_{10}(P_{in}) = \log_{10}\left[P\left(1 + 1{,}49\tau^{0.35} z^{-0.97} p^{-0.78}\right)\right]$$

standard error = 0.317

SYMBOLS

P_{in}, N_{in} = average influent concentrations (mg/l)
τ = hydraulic detention time (year)
$\hat{P}$ = predicted in-lake phosphorous concentration (mg/l)
$\hat{N}$ = predicted in-lake nitrogen concentration (mg/l)
Z = lake mean depth (m)
Log_{10} = base 10 logarithm

CONSTRAINTS ON ABOVE MODELS

The following constraints reflect the data set used to fit the models. In some instances (e.g., nutrient retention less than zero) additional constraints were imposed to create homogeneity in the data set or to eliminate suspected errors. Constraints involving phosphorous refer only to models that include phosphorous; constraints involving nitrogen refer only to models involving nitrogen.

Phosphorous Retention (R_P) > zero
0.003 mg/l < P < 0.424 mg/l
0.010 mg/l < P_{in} < 1.334 mg/l
Nitrogen Retention (R_N) > zero
0.090 mg/l < N < 7.185 mg/l
0.268 < N_{in} < 10 mg/l
0.0008 mg/l < Chla < 0.953 mg/l
0.008 year < τ < 285 year
1.2 m < z < 3.6 m

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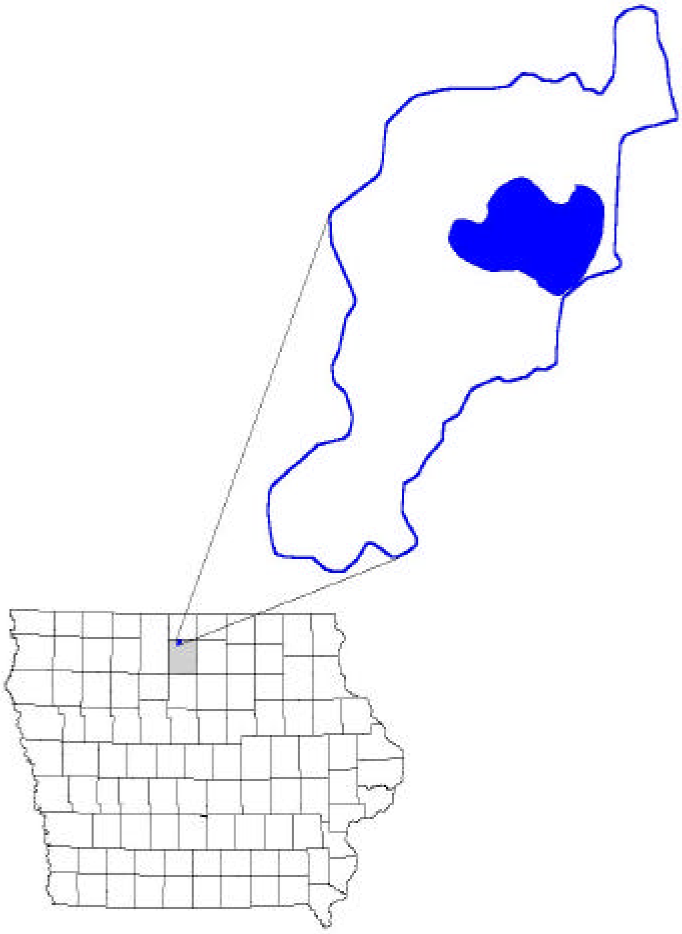
TMDL for Organic Enrichment
Crystal Lake
Hancock County, Iowa

Waterbody Name:	Crystal Lake
IDNR Waterbody ID:	IA 02-IOW-04095-L
Hydrologic Unit Code:	070802070101
Location:	Section 16 T97N R25W
Latitude:	43° 14’ N
Longitude:	93° 48’ W
Use Designation Class:	A (primary contact recreation) B(LW) (aquatic life)
Watershed:	2,088 acres
Lake Area:	269 acres
Major River Basin:	Iowa River Basin
Receiving Water Body:	West Fork Iowa River
Pollutant:	Organic Enrichment
Pollutant Sources:	Agricultural NPS
Impaired Use	Aquatic Life
1998 303d Priority:	Medium



1. Introduction

The Federal Clean Water Act (CWA) requires the Iowa Department of Natural Resources (DNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's CWA Section 303(d) list as impaired by a pollutant. Iowa's 1998 303(d) list, the current approved list, identifies Crystal Lake as impaired by organic enrichment. This organic enrichment is caused by excess nutrient loading to the lake as well as resuspension of nutrients within the lake. The purpose of this TMDL for Crystal Lake is to calculate the maximum amount of nutrients (organic enrichment) that the lake can receive and still meet water quality standards, and then develop an allocation of that amount of nutrients to the sources in the watershed.

Specifically this TMDL for Crystal Lake will:

- Identify the adverse impact that organic enrichment is having on the designated use of the lake and how the excess nutrient load (internal and external) is impairing the water quality standards,
- Identify a target by which the waterbody can be assured to achieve and maintain its designated uses,
- Calculate an acceptable nutrient load, including a margin of safety, and allocate the load to the sources, and
- Present a brief implementation plan to offer guidance to Department staff, DNR partners, and watershed stakeholders in an effort to achieve the goals of the TMDL and maintain the lake's intended uses.

Iowa DNR believes that sufficient evidence and information is available to protect Crystal Lake from further degradation by excess nutrients and organic enrichment. The Department acknowledges, however, that additional information will likely be necessary. Therefore, in order to accomplish the goals of this TMDL, a phased approach will be used. This will allow feedback from future assessments to be incorporated into the plan.

Phase I of this TMDL for Crystal Lake will be to reduce the nutrient load (internal and external) that is impairing the aquatic life uses. Phase II will evaluate the effect that the nutrient load target has on the intended results. In Phase II, monitoring of Crystal Lake will continue and the allocation of nutrients will be reassessed. The phased approach allows DNR to utilize a feedback loop to determine if the initial nutrient load target has been effective in reaching the ultimate goal of this TMDL – to have the waterbody meet water quality standards and fully support the aquatic life designated use.

2. Description of Waterbody and Watershed

2.1 General Information

Crystal Lake is one of Iowa's 34 natural, glacial lakes and is located on the north edge of Crystal Lake, Iowa. Crystal Lake has a surface area of 269 acres, a mean depth of 5 feet, a maximum depth of 8 feet, and a storage volume of 1,068 acre-feet.

A 130 acre park at Crystal Lake is owned by the IDNR and managed by the Hancock County Conservation Board. In addition, land along the south shoreline is owned by the City of Crystal Lake and managed as a park. Crystal Lake has designated uses of Class A (primary contact recreation) and Class B(LW) (aquatic life). The lake and park area provide facilities for fishing, camping, boating and picnicking. Park use is approximately 14,000 visits per year.

The Crystal Lake watershed has an area of approximately 2,088 acres and has a watershed to lake ratio of 8:1. The landuses and associated areas for the watershed are shown in the table below.

Landuse in the Crystal Lake watershed (2000)

Landuse	Area in Acres	Percent of Total Area
Cropland	1,455	70
Grass	306	14
Residential	64	3
Timber	80	4
Pasture and Hay	35	2
Other (Roads Farmsteads, etc.)	149	7
Total	2,088	100

In 2000, cropland comprised 70 percent of the watershed. Pasture and hay account for 2 percent of the watershed. Grass (including CRP), account for 306 acres of the watershed (14%). The remaining area includes residential areas, farmsteads, and roads.

2.2 Current Watershed Conditions

The watershed characteristics were identified in 2000 by the local NRCS office as part of the Crystal Lake diagnostic/feasibility study (Downing et al., 2001). Residue levels for both corn and soybeans were estimated at approximately 30%. Grass waterways are present in many fields, but in some cases are not adequately sized to the drainage area, therefore water goes around the waterway eroding channels outside of the waterway. Most terraces in the watershed were constructed in the early 1980's, but still appear to be functioning properly.

As part of the diagnostic/feasibility study, water quality monitoring was completed on Crystal Lake and the tributaries that drain into it. This monitoring indicated that the load of sediment to the lake during the monitoring period (April 1998-June 1999) was 33 tons/year, total phosphorous is 0.3 tons/year, and total nitrogen is 20 tons/year (Downing et al., 2001). Bathymetric mapping of the lake suggests that the current rate of sediment delivery to Crystal lake is 1,500 tons/year, but the rate of sediment delivery to the lake over the last fifty years has been closer to 8,500 tons/year (Downing et al., 2001).

3. Applicable Water Quality Standards

The *Iowa Water Quality Standards* (Iowa, 2000) list the designated uses for Crystal Lake as Primary Contact Recreation (Class A) and Lakes and Wetlands (Class B(LW)). Crystal Lake also has general uses of secondary contact recreation, domestic uses, and wildlife watering.

The State of Iowa does not have numeric water quality criteria for organic enrichment (or nutrients) that apply to Crystal Lake. Crystal Lake was included on the list of Iowa impaired waters based on the best professional judgment of DNR field staff regarding the water quality. Crystal Lake has been assessed as "partially supported" since 1992. The DNR Fisheries Bureau indicated that organic enrichment was impairing the Class B(LW) designated use. The Class B(LW) designated use states that the physical and chemical characteristics are suitable to maintain a balanced community normally associated with lake-like conditions (IAC 567-61.3(1)b(7)). Organic enrichment is altering the physical and chemical characteristics of the lake so that a balanced community normally associated with lake-like conditions is not maintained. The high levels of nutrients and resultant algae cause periodic low levels of dissolved oxygen, particularly near the bottom of the lake. Organic enrichment is impairing the beneficial uses of aquatic habitat, spawning and reproduction, and sport fishing. In addition, the high levels of phytoplankton are aesthetically unappealing to swimmers.

4. Water Quality Conditions

4.1 Water Quality Studies

Water quality surveys have been conducted on Crystal Lake by Iowa State University in 1979, 1990, 2001,and 2000-01 (Bachmann et al., 1980, Bachmann et al., 1994, Downing et al., 2001, Downing and Ramstack, 2001, Downing and Ramstack, 2002).

Samples were collected three times each summer for the lake studies conducted in 1979 and 1990 (Bachmann et al., 1980, Bachmann et al., 1994). This data is shown in Tables 2 and 3 in Appendix 1.

A diagnostic/feasibility study was completed for Crystal Lake in 2001 (Downing et al., 2001). Water quality monitoring was completed on the lake and tributaries from April 1998 – June 1999. A summary of the measurements made on Crystal Lake are presented in Table 5 in Appendix 1.

Crystal Lake was sampled again in 2000-01 as part of the Iowa Lakes Survey (Downing and Ramstack, 2002). This survey will sample the lake three times each summer for five years. The data collected in 2000-01 is shown in Table 5 and 6 (Appendix 1).

4.2 Angling (provided by, Fisheries Biologist)

Fishery analysis. Written by Jim Wahl, Fisheries Biologist, Iowa DNR.

Crystal Lake was chemically renovated during the fall of 1986. At the same time a winter aeration system was installed. Prior to that time, winterkills were frequent (1 out of every 3 years) and the fish population was dominated by species tolerant of low oxygen, primarily bullhead and carp. Since the aeration system was installed, no winterkills have occurred, thus providing a more consistent and higher quality sport fishery.

Crystal Lake is currently managed for largemouth bass, bluegill, crappie, channel catfish, and northern pike. In addition to these species, black bullhead, yellow perch, carp, walleye, and grass carp are also present. Channel catfish and northern pike are stocked annually. Seven-inch catfish are stocked at a density of 10 per acre and three-inch pike at 5 per acre. During 1992 and 1993 a total of 300 adult and 2,000 eight inch fingerling grass carp were stocked in an attempt to control excessive submergent vegetation.

Largemouth bass density in Crystal Lake is good. Thirteen to 15-inch fish currently dominate the fishery. Success of natural spawns varies, however some recruitment occurs each year. Bass growth rates are good and legal size (15 inches) fish represented about 20% of the catch in recent fishery surveys.

Bluegill and white crappie make up the bulk of the Crystal Lake panfish population. Bluegill outnumber crappie, however a successful spawn in 1995 has produced a large year class of crappie that are now 8 to 9 inches long. A variety of sizes of bluegill are present, with the majority running 5 to 6 inches. Small numbers of bullhead exist, however the average size is excellent, with many weighing over a pound. Yellow perch were introduced by local anglers and to date are small in size and density.

Northern pike numbers have been maintained from maintenance annual stockings and limited natural reproduction. Northern pike density is good in the 22 to 25 inch range. Fish of a larger size are common up to 30 inches, and an occasional 10 pound plus pike is creeled. Channel catfish are also dependent upon maintenance stockings. Most catfish are one to 2 pounds, with a few in the 5 to 10 pound range.

Common carp were eradicated from the lake in 1986 during the rotenone application, however a small number of brood stock contaminated the lake during the high water of 1993. A successful spawn during 1995 resulted in a large year class of fish that are currently two pounds. A commercial fisherman has been contracted to remove carp. Water quality has deteriorated substantially since the establishment of this large carp year class.

A few isolated cases of summerkill have occurred in Crystal Lake. Past kills impacted primarily members of the sunfish family and had no long-term impact to the overall sport fishery.

No creel surveys have been conducted within the past 20 years, so sportfish harvest data is unavailable. Fishing pressure has been fairly heavy since the fishery became established following renovation. Pressure was reduced during the early 1990’s due to the presence of Eurasian watermilfoil. Milfoil became so thick that by 1992 and 1993 it was extremely difficult to boat after the middle of June. A whole lake treatment with SONAR eradicated the milfoil in 1994 and the plant has not returned to the lake.

5. Desired Target

The listing of Crystal Lake as impaired by organic enrichment is based on narrative criteria. Crystal Lake was included on the list of Iowa impaired waters based on the best professional judgment of DNR field staff regarding the water quality. Crystal Lake has been assessed as “partially supported” since 1992. The DNR Fisheries Bureau indicates that organic enrichment is impairing the Class B(LW) designated use. There are no numeric criteria for organic enrichment (nutrients) applicable to Crystal Lake or its sources in Chapter 61 of the *Iowa Water Quality Standards* (Iowa, 2000). The targets for Crystal Lake include an organic enrichment (nutrient) load as well as a measurement of the aquatic life. This is a phased TMDL and each phase will incorporate a separate target. Phase I will include a target for organic enrichment (nutrient) delivery to the lake. The Phase II target is a measurement of the aquatic life in Crystal Lake. Monitoring the water quality and the fishery of the lake will be included in both Phase I and Phase II.

5.1 Organic Enrichment

The Phase I organic enrichment target will address the amount of nutrients delivered to the lake from the watershed. A direct measure of the nutrient load is difficult to make given seasonal variability and actual measurement tools. Reckhow’s EUTROMOD model was used to determine the reduction of nutrient inputs necessary to achieve the desired targets. Based on the monitored tributary loading (1998-99), the model predicted an in-lake phosphorus concentration of 110 ìg/L (Appendix 2). This is about half of the actual observed values in Crystal Lake. EUTROMOD takes into account tributary loading, but does not consider internal nutrient loading or recycling of phosphorus, which can help to explain the discrepancy between the monitored and calculated values. Crystal Lake is very shallow, with a mean depth of 5 feet, and is subject to mixing by wind and rough fish. This constant mixing of the water column in Crystal Lake allows resuspension of nutrients from the lake bottom to considerably influence the water quality of the lake. The difference between the monitored and calculated in-lake phosphorous values can be explained in part by this large internal component. Based on these differences and the lake's susceptibility to internal nutrient loading, it is assumed that approximately half of the nutrient load originates from within the lake, while the other half is delivered to the lake from the watershed.

The Crystal Lake Diagnostic/Feasibility study indicated that a total phosphorous concentration of 70 µg/L is achievable and would significantly improve the water quality of Crystal Lake (Downing et al., 2001). If phosphorous levels were maintained at this level, green and blue-green algae blooms would be reduced, and water quality would improve. This improved water quality can be realized by increased water clarity, reduced blue-green blooms, and lower oxygen demands by decomposing organic matter (algae). Reduced algae blooms and the increased water clarity will also be more aesthetically appealing to swimmers. To achieve this concentration, a 60% reduction of current internal and external loads is needed.

The diagnostic/feasibility indicates the ratio of total nitrogen to total phosphorous in the lake changes seasonally from 30:1 in spring to <10:1 in summer. These ratios indicate that Crystal Lake is phosphorous limited during the majority of the growing season, and nitrogen limited during mid-summer. The internal loading of phosphorous and nitrogen is difficult to measure, but it is expected that a combination of efforts can significantly reduce this contribution. This includes rough fish removal, installation of windbreaks, and finally dredging of the lake.

The current external load of phosphorous to Crystal Lake is 0.3 tons/year, and total nitrogen is 20 tons/year, as measured from March 1998 to June 1999 as part of the diagnostic/feasibility study (Downing et al., 2001). If it is assumed that half of the load to the lake is from external sources, then half of the reduction would be needed from the external sources. A total reduction of 60% is needed to achieve the desired target of 70 µg/L, a 30% reduction of the external load and a 30% reduction of the internal load. This would result in a total phosphorus target of 0.21 tons/year and a total nitrogen load of 14 tons/year delivered to the lake from external sources. The 30% reduction from internal sources will be achieved by dredging the lake, removing rough fish, installing windbreaks, and maintaining shoreline rip-rap. The current dredge plan for Crystal Lake will deepen 173 acres (64%) of the lake. The dredging will reduce internal loading by removing nutrient laden sediments from the lake, and also by deepening the lake and reducing the amount of internal recycling that occurs by wind, wave and rough fish. The installation of windbreaks on the northwest and southeast shores will reduce winds across the lake, reducing internal mixing. These measures are expected to more than account for the 30% reduction needed from internal sources.

5.2 Aquatic Life

The Phase II aquatic life target for this TMDL will be achieved when the fishery of Crystal Lake is determined to be fully supporting the Class B aquatic life uses. This determination will be accomplished through an assessment conducted by the DNR Fisheries Bureau. This assessment will be in accordance with the Statewide Biological Sampling Plan protocol (Larscheid, 2001). This protocol is currently being used to develop benchmarks for the fishery of Iowa's lakes. The results from the Crystal Lake assessment will be compared with the benchmarks being developed. These assessments will include age, growth, size structure, body condition, relative abundance, and species.

Crystal Lake will not be considered restored until the Phase II target is achieved. If the aquatic life target is achieved prior to the nutrient delivery target, then the level of land practices may be maintained at a level at or above those in place at the time of the assessment. If however, after a reasonable time following the completion of the nutrient delivery practices the aquatic life has not been restored, then further study and practices may be necessary.

6. Loading Capacity

The State of Iowa does not have numeric water quality criteria for organic enrichment or nutrients that apply to Crystal Lake. Crystal Lake was included on the list of Iowa impaired waters based on the best professional judgment of DNR field staff regarding the water quality. Excess nutrients are impairing the Class B(LW) designated use by altering the physical and chemical characteristics of the lake so that a balanced community normally associated with lake-like conditions is not maintained (IAC 567-61.3(1)b(7)).

According to the diagnostic/feasibility study, reductions in phosphorous loading can be calculated that would bring the lake close to a reasonable level of 70 µg/L of phosphorus (Downing et al., 2001). Such an improvement would require a reduction in phosphorous loading of about 60% from internal and external sources, and result in a loading capacity of 0.21 tons of phosphorous per year from the watershed. Crystal Lake is nitrogen limited during part of the year, therefore reductions in nitrogen are also needed, and a 60% reduction in nitrogen loading from internal and external sources would result in 14 tons/year of nitrogen delivered to the lake from the watershed.

7. Pollutant Sources

Water quality in Crystal Lake is influenced only by nonpoint sources. There are no point source discharges in the watershed.

The watershed of Crystal Lake is comprised of 70% cropland. The majority of this land is in good management practices. Residue levels for both corn and soybeans are estimated at approximately 30%. Grass waterways are present in many fields, but in some cases are not adequately sized to the drainage area, therefore water goes around the waterway eroding channels outside of the waterway. Most terraces in the watershed were constructed in the early 1980's, but still appear to be functioning properly.

Streambank erosion is an observed problem in the Crystal Lake watershed. An Illinois study (Roseboom and White, 1990) showed that 40-60% of the sediment yield from the watershed was the result of channel and streambank erosion. While streambank erosion is a noted problem, there is little to no active gully erosion in the watershed. The principle source of sediment and nutrients to the lake is from streambank erosion, and to a lesser degree, sheet and rill erosion. Internal resuspension of sediment and nutrients is a significant contributor to the water quality of Crystal Lake. Shoreline erosion has also historically been a significant contributor of sediment and nutrients to the lake, but efforts by the local Save the Lake group have rip-rapped the majority of the shorline, thereby minimizing this source. Reducing the wind and wave action on Crystal Lake will reduce both shoreline erosion and internal loading.

8. Pollutant Allocation

8.1 Point Sources

There are no point source discharges in the Crystal Lake watershed. Therefore, the Wasteload Allocation for organic enrichment (nutrients) established under this TMDL is zero.

8.2 Non-Point Sources

Crystal Lake receives significant nutrient inputs from the agricultural watershed as well as the regeneration of sedimentary nutrients throughout the summer. Total nitrogen concentrations peak during agricultural planting and fertilizing in the spring. Total phosphorous concentrations are also dominated by inputs from the watershed as well as regeneration of phosphorous from decomposing sediments. Phosphorous concentrations in Crystal Lake increase throughout the summer, indicating much of the summer phosphorous derives from sediment decomposition, wind mixing, and continuous mixing and disruption of sediment by carp and bullheads (Downing et al., 2001). In order to achieve a total phosphorous concentration of 70 µg/L, a 60% reduction in nutrient loading is needed from a combination of internal and external sources. The current external loads are 0.3 tons/year of phosphorous and 20 tons/year of nitrogen. Therefore, a 30% reduction from the external sources results in a Load Allocation for organic enrichment (nutrients) of 0.21 tons/year of phosphorous, and 14 tons/year of nitrogen. In addition, a 30% reduction of the current internal loading will be achieved by in-lake improvements, including dredging 64% of the lake area deeper, rough fish removal, and shoreline stabilization.

8.3 Margin of Safety

The margin of safety for this TMDL is implicit. The dual targets for this TMDL assures that the aquatic life uses will be restored regardless of the accuracy of the organic enrichment target. Failure to achieve water quality standards will result in review of the TMDL, allocations, and/or sediment management approaches and probable revision. In addition, calculations were made using conservative estimates.

9. Seasonal Variation

This TMDL accounts for seasonal variation by recognizing that (1) loading varies substantially by season and between years, and (2) impacts are felt over multi-year timeframes. Nutrient loading and transport are predictable only over long timeframes. Moreover, in contrast to pollutants that cause short-term beneficial use impacts and are thus sensitive to seasonal variation and critical conditions, the organic enrichment impacts in this watershed occur over much longer time scales. For these reasons, the longer timeframe (tons per year) used in this TMDL is appropriate.

10. Monitoring

Monitoring will be completed at Crystal Lake as part of the Iowa Lakes Survey conducted by Iowa State University under contract with the IDNR. In-lake water monitoring will be completed three times per year for each of the field seasons 2000 – 2004. In addition, the DNR Fisheries Bureau will conduct an assessment of the fishery of Crystal Lake in accordance with the Statewide Biological Sampling Plan protocol (Larscheid, 2001). At the completion of this assessment, the data will be evaluated to determine the listing status of Crystal Lake.

11. Implementation

11.1 General Information

The Iowa Department of Natural Resources recognizes that an implementation plan is not a required component of a Total Maximum Daily Load. However, the IDNR offers the following implementation strategy to DNR staff, partners, and watershed stakeholders as a guide to improving water quality at Crystal Lake.

This TMDL is being designed as a Phased TMDL. In Phase I, the amount of nutrients delivered to the lake will be reduced so that the TMDL is met. In-lake restoration and an assessment of the fishery will be completed during Phase II.

Field observations conducted by ISU Limnology Laboratory for the Crystal Lake Diagnostic/Feasibility Study (Downing et al., 2001) indicate that grass waterway maintenance, streambank stabilization, and lake shoreline stabilization are major needs in the watershed. In addition, windbreaks installed at the northwest and southeast ends of the lake will help to reduce wind and wave action, and the resulting resuspension of sediment and nutrients within the lake.

A principle objective of the feasibility study (Downing et al., 2001) was to provide the greatest protection to the lake at the least cost. AGNPS was applied to identify areas in the watershed that are currently supplying the highest rates of sediment and nutrient delivery. The AGNPS model was used to simulate sediment and nutrient transport following rain events in the Crystal Lake watershed and to analyze the affect of changes in the watershed on sediment and nutrient delivery to the lake.

11.2 Land Conversion

Through the use of model simulations, it was found that installing 100 ft wide riparian buffer strips and vegetative filter strips along stream channels would impact 23 acres and could reduce sediment transport to the lake by 11% and phosphorus transport to the lake by 7%. This would be a significant reduction, while impacting only a small amount of land.

There are two areas in the northwest part of the Crystal Lake watershed that are presently or may be in the future placed under permanent easements in the Wetland Reserve Program. This would convert approximately 317 acres to wetlands, wetland-associated vegetation, and native upland vegetation. When this landuse change is combined with the installation of the filter strips, sediment transport is reduced by 20% and phosphorous transport reduced by 17%.

11.3 Sediment Basins

Small impoundments are well known to immobilize significant amounts of sediments and nutrients in agricultural watersheds. AGNPS was used to predict the impact of the installation of small nutrient retention ponds in critical areas throughout the watershed. Four ideal impoundment sites and three potential wetland sites were located and added to the landscape in areas recommended and found suitable by NRCS. By placing a pond in the landscape in the path of moving water, sediment and sediment-related nutrients are efficiently removed from channel flow. The results from modeling this change combined with the two alternatives listed earlier produced a 62% reduction in predicted sediment loading to the lake and a 55% reduction in predicted phosphorus loading.

Phase II of this TMDL includes in-lake restoration to Crystal Lake. This could include construction of fish habitat, jetty construction for access, and dredging of accumulated sediments from the lake bottom. Resources should not be spent on in-lake restoration until proper management practices are in place in the watershed and the load reductions called for in Phase I are met. These management practices should protect the lake from further excessive loading of sediment and nutrients.

11.4 Sediment Removal

Restoring Crystal Lake to its original, post glacial volume would require the removal of 1.62 million cubic yards of sediment. A realistic goal for the lake is to restore the center of the basin to near its original depth, and to dredge progressively shallower in more peripheral areas closer to the lakeshore. Dredging in the main lake would provide important additional volume for the dilution of incoming nutrients and additional depth for improvement of fish habitat.

The proposed dredge plan for Crystal Lake would remove a total of 1.1 million cubic yards of sediment from the lake. This would increase the maximum depth from 8 feet to nearly 14 feet. The proposed dredging and spoil areas are shown in the diagnostic/feasibility study (Downing et al., 2001). The removal of sediments from Crystal Lake will reduce the amount of internal resuspension of sediment and nutrients by allowing the lake to stratify, rather than continually mix.

Phase II of this TMDL will be achieved when the fishery of Crystal Lake is determined to be fully supporting the Class B aquatic life uses. This assessment will be in accordance with the Statewide Biological Sampling Plan protocol (Larscheid, 2001). This protocol is currently being used to develop benchmarks for the fishery of Iowa's lakes. The results from the Crystal Lake assessment will be compared with the benchmarks being developed. These assessments will include age, growth, size structure, body condition, relative abundance, and species.

12. Public Participation

Public meetings were held in Des Moines and Crystal Lake regarding the proposed TMDL for siltation and nutrients for Crystal Lake on January 14 and February 4, 2002. A second public meeting was held in Crystal Lake on June 10, 2002 to present and discuss the draft TMDL. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

13. References

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14. Appendix 1

Table 2. Data collected in 1979 by Iowa State University (Bachmann et al., 1980).

Date Collected	7/19/79		8/22/79		9/26/79	
Depth (meters)	0	3	0	3	0	3
Secchi (meters)	1.6		0.8		1.4	
Suspended Solids (mg/L)	3.4	5.2	6.4	8.8	4.3	5.7
Dissolved Oxygen (mg/L)	3.8	4.0	5.8	6.0	9.2	9.8
Total Phosphorus (mg/L) po4	.59	.63	.46	.48	.49	.51
Chlorophyll a (ug/L) Corrected	2.8	4.9	2.2	1.9	8.6	10.7

Table 3. Data collected in 1990 by Iowa State University (Bachmann, et al, 1994).

Date Collected	6/17/90			7/12/90			8/10/90		
Sample Number	1	2	3	1	2	3	1	2	3
Secchi (m)	2			0.6			0.5		
Suspended Solids (mg/L)	15	13.3	13.5	38.1	44.5	41.1	34.3	27.7	26
Total Nitrogen (mg/L)	3.1	2.3	2.8	3.3	2.8	3.7	2.1	2.2	1.9
Total Phosphorus (mg/L)	0.48	0.63	0.47	0.56	0.50	0.50	0.22	0.23	0.24
Chlorophyll a (ug/L) Corrected	14.5	14.5	22.4	83.1	76.9	72.3	26.6	24.3	26.3

Each sample was a composite water sample from all depths of the lake.

Table 4. Summary of measurements made on Crystal Lake during the diagnostic study (Table 7, Downing et al., 2001)

Parameter	**Mean**	**Standard Error**	***n***
Secchi Depth m	0.4	0.05	15
Chlorophyll *a* (ug/L)	50	25	10
NH_3+NH_4^+ -N (mg/L)	1.4	0.1	56
NO_3+NO_2-N (mg/L)	1.2	0.2	68
Total Nitrogen (mg/L as N)	3.4	0.2	72
Total Phosphorus (ug/l as P)	250	16	72
pH	8.42	0.06	71
Alkalinity (mg/L)	121	7	56
Total Suspended Solids (mg/L)	56	7	66
Dissolved Oxygen (mg/L)	10	0.4	67

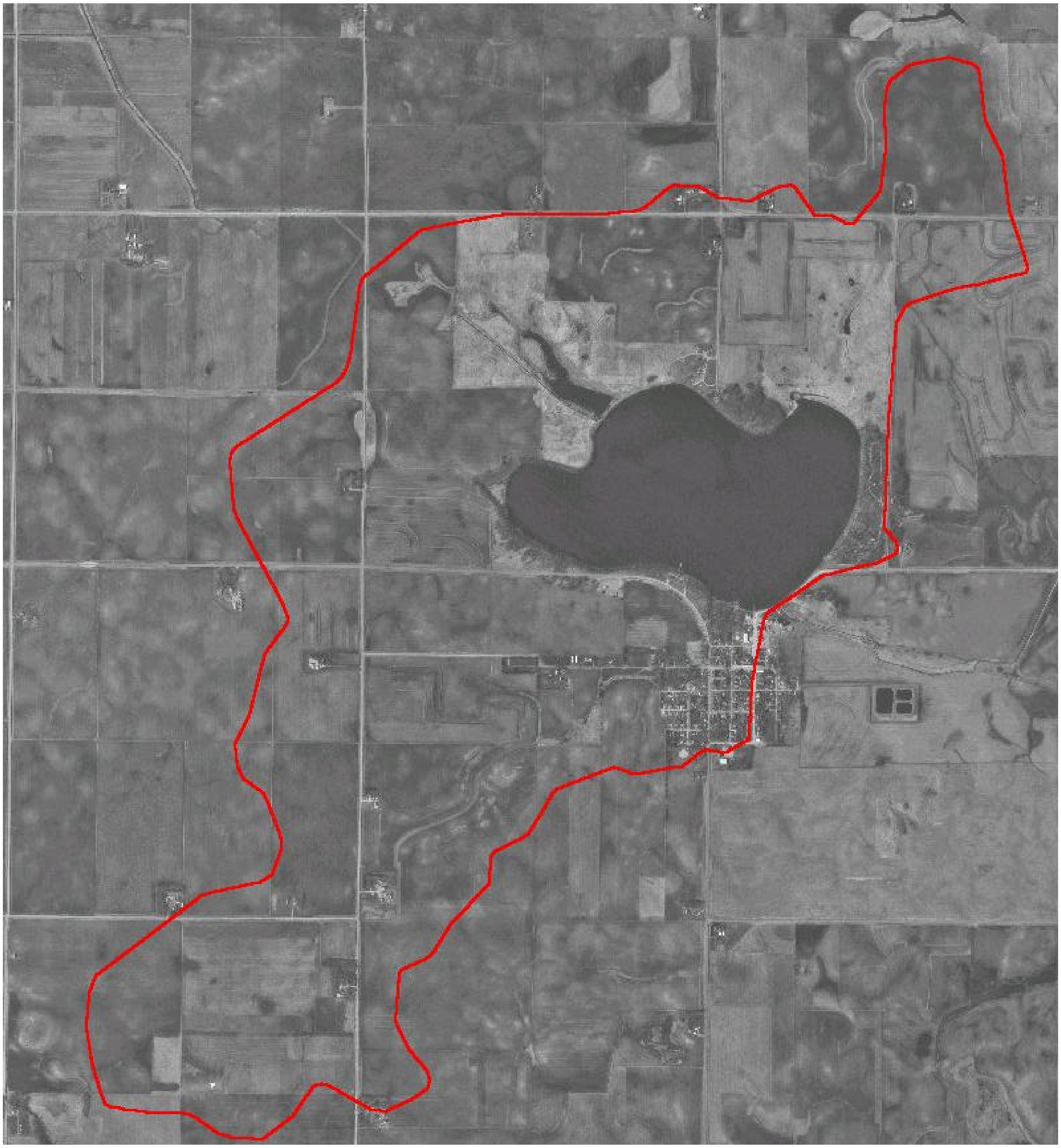
Table 5. Data collected in 2000 by Iowa State University (Downing and Ramstack, 2001)

Parameter	**7/5/2000**	**7/31/2000**	**9/6/2000**
Secchi Depth m	0.3	0.1	0.1
Chlorophyll (ug/L)	50	116	76
NH_3+NH_4^+ -N (ug/L)	1785	1787	1854
NH_3 –N (un-ionized) (ug/L)	1	222	21
NO_3+NO_2-N (mg/L)	0.65	0.16	0.09
Total Nitrogen (mg/L as N)	2.62	2.60	2.43
Total Phosphorus (ug/l as P)	313	383	371
Silica (mg/L as SiO_2)	49	47	62
pH	6.1	8.4	7.5
Alkalinity (mg/L)	177	124	137
Total Suspended Solids (mg/L)	68.1	34.4	11.2
Inorganic Suspended Solids (mg/L)	41.1	20.6	7.8
Volatile Suspended Solids (mg/L)	27.0	13.9	3.5

Table 6. Data collected in 2001 by Iowa State University (Downing and Ramstack, 2002)

Parameter	**6/4/2001**	**7/10/2001**	**8/6/2001**
Secchi Depth m	0.3	0.4	0.2
Chlorophyll (ug/L)	45	227	224
NH_3+NH_4^+ -N (ug/L)	1260	866	2466
NH_3 –N (un-ionized) (ug/L)	18	105	144
NO_3+NO_2-N (mg/L)	2.52	0.10	0.24
Total Nitrogen (mg/L as N)	4.28	1.69	3.37
Total Phosphorus (ug/l as P)	171	246	485
Silica (mg/L as SiO_2)	12	14	36
pH	7.7	8.4	7.9
Alkalinity (mg/L)	140	109	141
Total Suspended Solids (mg/L)	55.8	20.4	43.9
Inorganic Suspended Solids (mg/L)	36.9	6.3	15.2
Volatile Suspended Solids (mg/L)	18.8	14.1	28.7

Crystal Lake and Watershed



Appendix A, Crystal Lake
Estimating Phosphorous Loading Using Reckhow's Eutromod Loading Equations for Lakes

Equations utilizing regression analysis have been developed by Kenneth Reckhow for the EUTROMOD Watershed and Lake Model. These equations have been incorporated into the Crystal Lake Restoration Diagnostic/Feasibilty Study to compare total phosphorous concentration values computed using the model equations and those obtained by direct measurement. Information required to use the model equations includes average total phosphorous influent concentration, 0.2 mg/l; mean depth, 1.5 m; and the hydraulic residence time, 0.40 yr.

Calculation of the predicted total phosphorous load is as follows:

$$k = 10.77\tau^{0.39} z^{0.01} P_{in}{}^{0.82} = 10.77(0.40^{0.39})(1.5^{0.01})(0.2^{0.82}) = 2.021$$

$$\log_{10}(P) = \log_{10}\left[\frac{P_{in}}{1+k\tau}\right] = \log_{10}\left[\frac{0.2}{1+(2.021)(0.40)}\right]$$

$$P = 0.11 mg/l$$

These two equations are from the *EUTROMOD Watershed and Lake Modeling Software* documentation and are described below.

EUTROMOD – KA, MO, OK, AK, IA, NE Lake Models

K. H. Reckhow
Duke University, June 10, 1991

MODEL PARAMETER ESTIMATION

The models have been fitted using robust regression (linear, nonlinear, and logistic). The robust weighting scheme usually results in a model that best (in a least squared error sense) represents the pattern in the bulk of the data. Standard errors have been adjusted to account for the robustness criterion.

MODELS

Total Phosphorous (mg/l)

$$\log_{10}(P) = \log_{10}\left[\frac{P_{in}}{1+k\tau}\right]$$

Where $k = 10.77\tau^{0.39} z^{0.01} P_{in}^{\ 0.82}$ standard error = 0.219

Total Nitrogen (mg/l)

$$\log_{10}(N) = \log_{10}\left[\frac{N_{in}}{1 + k\tau}\right]$$

Where $k = 10.77\tau^{0.39} z^{0.01} P_{in}^{\ 0.82}$ standard error = 0.108

Chlorophyll a (μg/l)

$$\log_{10}(Chla) = 1.99 + 0.51\log_{10}(\hat{P}) + 0.23\log_{10}(\tau) - 0.35\log_{10}(z)$$

standard error = 0.226

Secchi Disk Depth (m)

$$\log_{10}(SD) = -1.32 - 0.66\log_{10}(\hat{P}) + 0.47\log_{10}(z)$$

standard error = 0.171

Trophic State Index

The TSI is based on that proposed by R, Carlson (1977) using predicted P, Chla, and SD. Allowable Phosphorous loading to meet in-lake goal:

$$\log_{10}(P_{in}) = \log_{10}\left[P\left(1 + 1{,}49\tau^{0.35} z^{-0.97} p^{-0.78}\right)\right]$$

standard error = 0.317

SYMBOLS

P_{in}, N_{in} = average influent concentrations (mg/l)
τ = hydraulic detention time (year)
$\hat{P}$ = predicted in-lake phosphorous concentration (mg/l)
$\hat{N}$ = predicted in-lake nitrogen concentration (mg/l)
Z = lake mean depth (m)
Log_{10} = base 10 logarithm

CONSTRAINTS ON ABOVE MODELS

The following constraints reflect the data set used to fit the models. In some instances (e.g., nutrient retention less than zero) additional constraints were imposed to create homogeneity in the data set or to eliminate suspected errors. Constraints involving phosphorous refer only to models that include phosphorous; constraints involving nitrogen refer only to models involving nitrogen.

Phosphorous Retention (R_P) > zero
$0.003 \text{ mg/l} < P < 0.424 \text{ mg/l}$
$0.010 \text{ mg/l} < P_{in} < 1.334 \text{ mg/l}$
Nitrogen Retention (R_N) > zero
$0.090 \text{ mg/l} < N < 7.185 \text{ mg/l}$
$0.268 < N_{in} < 10 \text{ mg/l}$
$0.0008 \text{ mg/l} < Chla < 0.953 \text{ mg/l}$
$0.008 \text{ year} < \tau < 285 \text{ year}$
$1.2 \text{ m} < z < 3.6 \text{ m}$