LAKE WATER QUALITY MODEL STUDY

FOR

BIG GREEN LAKE, GREEN LAKE CO., WISCONSIN

Completed By:

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Conclusions

Based on the results of the analysis the following conclusions can be made:

1. The surface total phosphorus concentration in Big Green Lake does not significantly different at various points across the lake.

2. Based on the spring total phosphorus concentration Big Green Lake is eutrophic.

3. Big Green Lake's chlorophyll_a response to total phosphorus is less than what regional regression equations would predict.

4. The lake's low chlorophyll_a response may be the result of food web effects (Daphnia grazing on chlorophyll_a).

5. Based on monitored flow, sediment and total phosphorus loading, 1997 was close to an average year for the lake, while 1998 was below average.

6. Silver Creek contributes the greatest annual total phosphorus loading to Big Green Lake at approximately 44% of the total and 50% of the tributary loading.

7. The Southwest Inlet is the second greatest source of total phosphorus loading at 13% of the total and 15% of the tributary input.

8. The watershed unit area total phosphorus export values for the Silver Creek watershed fall into the lower portion of the range monitored for agricultural land in Wisconsin.

9. Monitoring data indicate that no significant bypassing of Silver Creek's inflow loading is occurring.

Recommendations

Based on the above conclusions it is recommended that:

1. An in-lake total phosphorus goal be established for Big Green Lake in the near future.

2. Watershed modeling be conducted to identify total phosphorus loading source areas and BMP strategies for load reduction.

3. The BMP implementation strategy be supported by watershed modeling and be sufficient to meet the in-lake water quality goal.

4. In-lake and tributary monitoring be continued to document Big Green Lake’s water quality response to land management activities.

Big Green Lake is located in Big Green Lake County of east central Wisconsin. The lake has a surface area of 7,346 acres, mean and maximum depths of 104 and 236 feet, respectively. The lake has two principal inflows, Silver Creek from the east and the Southwest Inlet. The total tributary drainage area to the lake is approximately 91.2 square miles in size of which 53.5 mi^2 and 16.3 mi^2 from Silver Creek and the Southwest Inlet area, respectively. The primary land use in the Silver Creek subwatershed is agricultural while the remaining areas are a mixture of agriculture, residential, wetland and forest. Big Green Lake is a significant resource from both a local and statewide perspective. Local interest in the management of the lake began in the early 1990's with planning grant assistance from the Department of Natural Resources (DNR). After a number of lake planning grants the Lake District received a lake protection grant from the DNR in 1998 to complete a diagnostic feasibility study. One component of the diagnostic study process is the development of a water and nutrient budget for the lake as well as a water quality model. The model will be used in the goal setting process to evaluate the impact of watershed pollutant load reduction on water quality improvement. The modeling effort is supported by in-lake monitoring data collected by self help volunteers and DNR staff along with tributary monitoring data collected by the US Geological Survey. This report will focus on the methods, results and discussion pertaining to the modeling. Any other aspects of the monitoring or diagnostic work will be discussed only briefly and limited in context to modeling.

Analysis Methods

The analysis consisted of two parts monitoring and modeling. Monitoring was conducted both in-lake and on the majority of the tributaries flowing into the lake. The monitoring data was then used in the calibration of a model and the development of a lake loading response curve. The lake loading response curve can then be used in the watershed load reduction, lake response evaluation process.

Initially the lake was divided into three segments and monitoring was conducted at three in-lake stations corresponding to those segments as shown in Figure 1. Lake data was collected during the growing season (April-October) with an emphasis on those parameters most useful for model calibration. Monitoring parameters included surface total phosphorus (TP), chlorophyll_a and Secchi depth transparency. For the purposes of this study, all modeling was eutrophication focused. Temperature, dissolved oxygen and limited phosphorus profile data were also collected at each site as well as phyto and zooplankton data. The response curve for Big Green Lake was developed using the Wisconsin Lake Model Spreadsheet (WILMS) model version 2.00 (Panuska et al. 1996). Copies of the Big Green Lake WILMS runs for 1997 and 1998 are included in Appendix A. Within WILMS the Canfield-Bachmann, 1981 natural lake model (model No. 2) was selected for use. All known loading and flow information was input into the model. The model was then manually fit to observed conditions using an assumed load from unmonitored sources. The unmonitored sources were assumed to include internal loading, shore and bank erosion, loading from geese and any loading error. The lake's response curve was developed by plotting stepwise reductions in external loading against model predicted in-lake total phosphorus values. The loading information used for modeling was placed in pie charts. In developing the loading pie charts, the unmonitored load was combined with the estimated bypassing and placed in a category labeled "net other".

In the goal setting process it is also necessary to know what the corresponding lake water quality will be at various levels of in-lake phosphorus. The regression relationships between in-lake TP and chlorophyll_a were developed specifically for Big Green Lake. A lake specific regression was developed because the regional regression equation from Lillie et al. (1993) for TP and chlorophyll_a did not adequately describe conditions in Big Green Lake. However, the regional regression for chlorophyll_a and Secchi depth transparency was found to be adequate. Additional discussion on the use of these equations to predict water clarity is included in the Results section of this report.

Tributary load monitoring was conducted by the US Geological Survey. Continuous gage sites with automatic samplers were established for Silver Creek at its inlet to the lake and for White Creek. Grab samples were collected after storm events from a number of the smaller tributaries and used in the load estimation calculations. Two years (1997-1998) of flow monitoring was conducted (corresponding to the lake monitoring). An analysis of historic flow, sediment and TP loading was also conducted using data from 1988-98 in order to provide a basis for comparison to long-term means. An analysis of the outflow and in-lake TP concentration data also included an estimate of the input TP load being by-passed. All monitoring years are water years defined as October through September.

Results

At the time of the initial study design, three in-lake water quality stations were established with the goal of identifying water quality responses in each segment. Review of the 1997 and 98 data indicated no significant differences between the three segments as shown in Figure 2. This implies that wind mixing eliminates any spatial water quality differences across the lake making it appropriate to model the lake as a single basin. For this reason the three individual lake station values were volume weighted and reported as single whole-lake values. Table 1 summarizes the monitored in-lake water quality data for 1997 and 1998. Additional detailed information can be found in Appendix B.

Table 1
Water Column Water Quality Data Summary

Year	Spring TP (ug/l)	Summer TP (ug/l)*	Chlorophyll_a (ug/l)	Secchi Depth (m)
1997	27	18	5	3.9
1998	22	9	3	4.5
1997 TSI	----	51	47	40
1998 TSI	----	45	43	38

* Summer equals April through October

Table 2 summarizes the results of a comparison of 10 years of monitored flows and loading with the 1997 and 1998 results.

Table 2
Comparison of 1997 - 98 Data with the 11 Yr. Medians
(Annual value / 11 year median)

Year	Flow (cfs)	Sediment (tons / day)	TP (pounds / day)
1997	32.7 / 30.6	2.2 / 2.2	26 / 26
1998	28.7 / 30.6	2.7 / 2.2	21 / 26

The lake response curve for Big Green Lake is included as Figure 3. The trophic response regression equations for total phosphorus /chlorophyll_a and chlorophyll_a/Secchi depth are as follows and as illustrated in Figures 4 and 5. Additional evaluation of the TP/chlorophyll_a predictive relationship indicated that Big Green Lake's chlorophyll_a response to TP was about 1/2 of what a regional regression equation would predict and the regional regression was therefore adjusted accordingly.

$$\textbf{Chl a} = e^{-2.63 + 1.49 \ln(TP)}$$

The above equation is modified from Lillie et al. (1993), where Chl a = chlorophyll_a in ug/l and TP = total phosphorus in ug/l.

$$\textbf{SD} = e^{2.00 - 0.58 \ln(\text{Chl a})}$$

The above equation is from Lillie et al. (1993) for central region drainage lakes, where: SD = Secchi depth (m) and Chl a = chlorophyll_a in ug/l.

The unit area loading by tributary for 1997 and 1998 is shown in Figures 6 and Figure 7, respectively. The unit area export and water yield for 1997 and the table in Appendix C summarizes the 1998 values. The total loading by tributary is shown in Figures 8 and 9 for 1997 and 98, respectively. As mentioned earlier, the "net other" category represents the sum of the unmonitored loading sources and the estimated bypassing. The estimated TP load by-passing for 1997 and 1998 were 6 and 8%, respectively when all load sources are considered.

The WILMS model outputs for 1997 and 1998 are included in Appendix A. A summary of the WILMS output is included in table 5 below.

Table 5

Summary of WILMS Model Output

Year	Runoff Volume (AF)	Precipitation – Evaporation (In)	Water Retention Time (Yr.)	Flushing Rate (1/Yr.)	Areal TP Loading (Lb./Ac./Yr.)
1997	43,029	0.8	17.5	0.06	2.91
1998	42,785	-0.5	18.0	0.06	2.18

Discussion

Review of table 1 indicates that Big Green Lake falls into the mesotrophic range based on chlorophyll_a and Secchi depth transparency and the eutrophic range based on TP. Lakes in this range are considered to have elevated productivity relative to natural levels. One goal in managing a eutrophic lake with a predominantly agricultural watershed such as Big Green Lake should be load reduction where feasible and a strong emphasis on protection. Though the chlorophyll_a concentration is not excessively high, lakes in the eutrophic range are subject to growing season algal blooms the frequency of which is related to TP loading and water column concentration. When applying the regional regression equations for TP and chlorophyll_a it soon became apparent that Big Green Lake's algal response (as measured by chlorophyll_a) was lower than the regional regressions would predict. For example the 1997 mean TP of 27 ug/l, when input into a state wide regression equation yields a predicted chlorophyll_a of 11ug/l or approximately twice of the observed. This trend is consistent in the TSI values as well. Conditions such as these have the advantage in that the lake exhibits good (actually better than expected) water clarity. One disadvantage from a modeling perspective is that the ability to predict chlorophyll_a and water clarity is difficult. The greatest implication from a management perspective is to implement measures, which will maintain this condition in a stable state. One possible reason for depressed chlorophyll_a concentrations in Big Green Lake is the abundance of microscopic zooplankton (animals) called Daphnia. These small zooplankton can very effectively graze on algal cells resulting in a reduction in algal biomass. A strategy therefore becomes one of managing the fishery to providing conditions that favor Daphnia abundance.

As summarized in table 2, 1997 is close to an average year for flow and TP loading and was used for modeling and comparison. In reviewing the TP loading pie charts, Silver Creek contributes the greatest annual tributary loading to the lake ranging between 50 and 55% followed by the Southwest Inlet area ranging between 15 and 17%. The unit area TP loads for all tributaries range from 0.28 to 0.68 Lb./Ac./Yr. The state wide range in TP export values for agricultural land are from 0.17 to 2.6 Lb./Ac./Yr. while forested areas range from 0.04 to 0.15 Lb./Ac./Yr. (Panuska and Lillie, 1995). In the case of Silver Creek , unit area export values range from 0.22 Lb./Ac./Yr. in 1997 to 0.28 Lb./Ac./Yr. in 1998. Clearly these values fall on the lower end of the range for agricultural TP export, the principal land use in the Silver Creek watershed. These results should NOT be interpreted to mean that additional improvements can't or shouldn't be made. A better interpretation is that unless otherwise proven, the loading source area is very diffuse and the entire watershed should be considered in formulating BMP strategies. Of the individual tributary areas, White Creek has the highest unit area export at 0.68 and 0.35 Lb./Ac./Yr. in 1997 and 1998, respectively making it an area of interest for watershed management activities. These values compare to 0.64 Lb./Ac./Yr. monitored prior to watershed BMP implementation conducted in the late 1980's. Based on these data it would appear that the historically high unit area loading from White Creek has not been reduced. The results of the watershed modeling will be of significant importance in determining watershed load reductions and the targeting of BMPs.

As previously discussed, the lake monitoring program was designed to allow an estimate to be made of the fraction of Silver Creeks load that is bypassed directly to the outlet. The goal of this effort was to determine to what extent inflows from Silver Creek are currently short-circuiting directly to the outlet. The calculated values of 6 and 8% indicate that the bypassing of Silver Creek’s inflows does not occur to a great extent at Big Green Lake. As previously discussed, the bypassing estimate was determined using the difference between in-lake and outflow concentrations. It is therefore not possible to accurately determine how much of the calculated bypassing is Silver Creek inflow and how much is from near-shore land areas adjacent to the outlet. However, in the case of Big Green Lake, it is most likely that the load being bypassed is from the area immediately adjacent to the outlet approach channel. Based on this data it would therefore appear that significant bypassing of Silver Creek's inflow is not occurring.

Any management plan for Big Green Lake should include a strong lake protection element. As watershed development occurs, measures must be in place to reduce a future increase in loading and prevent further degradation. Big Green Lake is a high quality resource and pollution prevention will pay dividends in the long term.

References

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APPENDIX A

APPENDIX B

APPENDIX C