Limnological Analysis of Lake Altoona, Wisconsin

by

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PREFACE

This study was conducted in response to a request from the Altoona Lake Association, Eau Claire County and the State of Wisconsin Department of Natural Resources (WI-DNR) to the U.S. Army Engineer District (USAED), St. Paul, for planning assistance under Section 22 of the Water Resources Development Act (Public Law 93-251). Funding was provided by Eau Claire County, WI-DNR, and USAED, St. Paul. The study coordinator for Eau Claire County was Ms. Jean Schomish. The study coordinator for WI-DNR was Mr. Patrick Sorge. The Section 22 coordinator for the USAED, St. Paul, was Mr. Terry Engel.

This study was conducted and the report written by Mr. William F. James, Dr. John W. Barko, and Mr. Harry L. Eakin of the Eau Galle Aquatic Ecology Laboratory (EGAEL) of the Environmental Processes and Effects Division (EPED) of the Environmental Laboratory (EL), WES. We gratefully acknowledge Mr. Robert Barfknecht and Mr. Robert Elliot of the Altoona Lake Association for sampling Bridge and Fall Creeks and the Altoona Dam discharge; and Mss. Laura Blegen, Allysa Boock, Susan Fox, Emily Gillis, and Stephanie Sweeney, and Messrs. Dale Dressel, Allan Lamphere, Mathew Pommier, and Eric Secrist of the EGAEL for water and sediment sampling, chemical analyses, and execution of studies on phosphorus release from sediments.

ABSTRACT

We examined external constituent loadings from the Eau Claire River, discharges from Altoona Dam, internal phosphorus (P) fluxes from profundal sediments, and water quality conditions in Lake Altoona, Wisconsin in 2000. Water samples for external loadings and discharge determinations were collected from the Eau Claire River, and Bridge and Fall Creeks, and the discharge of Lake Altoona Dam. Two stations were established in the main basin of the reservoir for limnological profiling during the ice-free period. Station 10 was located near the dam and station 20 was located near the headwaters.

There were a number of storm/snowmelt inflow periods to the reservoir during the ice-free period. During periods of snowmelt and storm inflow, the residence time of the reservoir often declined to< 2 days. During periods of nominal inflow the residence time was still very low (< 15 days). As a result of low residence time and a high flushing rate, the lake only retained ~30% of the annual total suspended sediment load. Annual retention of nitrogen and P loads was not detectable during 2000. Our results did not include an analysis of sandy bed load inputs which have caused reductions in lake volume in the past.

Internal loading of P via release from oxic profundal sediment, measured in laboratory incubation systems, were 0.7 mg m^{-2} d^{-1} (station 10) and 1.0 mg m^{-2} d^{-1}

(Station 20), while P release from anoxic sediment was very high (10.7 to 26.6 mg m^{-2} d^{-1}). However, the lake exhibited only brief periods of anoxia, due to the high flushing rate, suggesting that P release from sediment was minor and controlled via oxic conditions.

Lake Altoona exhibited only brief temporary stratification and minor dissolved oxygen depletion during the summer. Chlorophyll concentrations were relatively low during the summer despite very high concentration of total P in the water column. This unusual pattern was the result of very high flushing rates that essentially caused cellular washout of algae from the lake. Often, the residence time (< 2 days) was less than theoretical doubling time of algae (2-15 days), suggesting that they could not increase in population. As residence time increased during lower flow periods in the summer, chlorophyll concentrations increased and total P concentrations were still high in the water column. These results indicated the residence time, as well as total P, played an important role in the regulation of algal biomass in the reservoir. The Carlson and Wisconsin Trophic State Indices for Secchi disk transparency, viable chlorophyll *a* and total P ranged between 58 and 71, indicative of eutrophic conditions during the summer.

We evaluated two P management scenarios for Lake Altoona. The first scenario constituted management of external P loading during a nominal summer flow period which included control of algal biomass via frequent periods of high flushing and cellular discharge. The second scenario included management of external P loading during a lower flow period with greater residence times and thus, enhanced algal population increase. Although the model indicated that the lake was very responsive to increases and decreases in P loading, it appeared to be more sensitive to changes in P loading under lower flow conditions. We suggest the P management include the watershed upstream of Lake Eau Claire, as well as watersheds below Eau Claire Dam.

INTRODUCTION

The overall objectives of these investigations were to examine water quality conditions and constituent fluxes in tributary inflows, the main basin, and tail waters of Lake Altoona, Wisconsin. In particular, the relative importance of various internal and external nutrient (primarily phosphorus) loadings were evaluated in relation to water quality conditions and phytoplankton biomass (chlorophyll) in the lake. Predicted impacts of P loading reduction on viable chlorophyll *a* concentrations in the lake were examined using the model *Bathtub* (Walker 1996).

METHODS

EXTERNAL LOADINGS AND DISCHARGES

Stage elevations were monitored on the Eau Claire River at County Road K between November, 1999, and November 2000, using continuous stage height recorders (ISCO Model 4120). Stage elevations were converted to volumetric flow using a rating curve generated by the U.S. Geological Survey. Stage elevations were also monitored at Bridge Creek near highway 27 and Fall Creek at the Fall Creek Dam in Fall Creek, WI, between April and November, 2000, using continuous stage height recorders (ISCO model 4120). These two creeks flow into the Eau Claire River above County Road K. Stage elevations were converted to flow using rating curves generated by the U.S. Geological Survey (for Bridge Creek) and a dam rating curve generated for Fall Creek Dam. Lake Altoona pool elevation fluctuations were obtained from the Eau Claire County Parks and Forest Department (Altoona, Wisconsin). Water volume was estimated via an hypsographic curve generated by the Wisconsin Department of Natural Resources. Discharges from Lake Eau Claire were determined via hydrological mass balance.

Water samples from tributary inflows and the Altoona Dam discharge were collected during storms and routinely at biweekly intervals. They were analyzed for the variables listed in Table 1. For total suspended sediment (TSS) and particulate organic matter

(POM) analyses, suspended material retained on a precombusted glass fiber filter (Gelman (A/E) was dried to a constant weight at 105 ^{o}C, and then combusted at 500 ^{o}C for 1 hour (APHA 1992; Methods 2540 D. and E.). Samples for total nitrogen (TN) and phosphorus (TP) were predigested with potassium persulfate according to Ameel et al. (1993) before analysis. TN and TP were measured colorimetrically on a Lachat QuikChem automated system (Lachat Methods 10-107-04-1-A and 10-115-01-1-A; Zellweger Analytics, Lachat Div., Milwaukee, WI). Subsamples (integrated over the upper 3-m water column) for phytoplankton enumeration were collected approximately monthly and preserved with acid Lugal's solution (Vollenweider 1969). Taxonomic identification and enumeration followed the procedures of Lund et al. (1958). Cell volume for individual species was computed from average cell dimension (Munawar and Munawar 1976). Phytoplankton biomass is reported as mg fresh weight m^{-3}, assuming a cellular specific gravity of 1.0.

Annual and daily external loadings and discharges were estimated using the computer model *Flux* (Walker 1996). Loadings were estimated via either weighting concentrations with respect to flow (Method 2) or via a regression algorithm (Method 6).

INTERNAL LOADINGS

Six replicate intact sediment cores were collected from the profundal sediments of stations 10 and 20 (Fig. 1), for determination of rates of soluble reactive P (SRP) release from the sediment. Sediment cores were collected using a Wildco KB sediment core sampler (Wildco Wildlife Supply Co.) equipped with an acrylic core liner (6.5-cm ID and 50-cm length). Additional lake water was collected from the epilimnion for incubation with the collected sediment.

Sediment systems, constructed according to the methods of James et al. (1995), were incubated in an environmental chamber at 20 ^{o}C for 1-2 weeks. One set of 3 replicate sediment incubation systems was subjected to an oxic environment while the other set (3 replicates) was subjected to an anoxic environment for each station. The oxidation-reduction environment in each system was controlled by gently bubbling either air (oxic) or nitrogen (anoxic) through an air stone placed just above the sediment surface. Bubbling action insured complete mixing of the water column but did not disrupt or resuspend the sediment. Water samples were collected daily from the overlying water of each sediment system, filtered through a 0.45 μm membrane filter, and analyzed colorimetrically for SRP using the ascorbic acid method (APHA 1992). Rates of P release from the sediment (mg m^{-2} d^{-1}) were calculated as linear changes in SRP mass in the overlying water (corrected for dilution effects due to daily replacement of lake water) divided by time and the area of the incubation system.

LIMNOLOGICAL MONITORING

Station 10 and 20 were established near the dam and headwaters, respectively, of Lake Altoona for limnological monitoring purposes (Fig. 1). During the ice-free period, water samples were collected biweekly at 1-m intervals from the surface (i.e., 0.1 m) to within 0.5 m from the bottom for the water quality variables listed in Table 1. For soluble constituents (i.e., SRP), samples collected from anoxic water in the lake were filtered immediately without exposure to oxygen. Water samples for analysis of soluble constituents were filtered through a 0.45 μm filter (Gelman Metricel) prior to analysis. SRP (Lachat Method 10-115-01-1-A) and ammonium-nitrogen (NH_4-N; Lachat Method 10-107-04-01-A) were analyzed colorimetrically using automated procedures (Zellweger Analytics, Lachat Div., Milwaukee, WI). Samples for chlorophyll were extracted in dimethyl-sulfoxide (DMSO)-acetone (50:50) at < 0 ^{o}C for a minimum of 12 hours. Viable chlorophyll *a* was determined fluorometrically (Turner model TD-700) according to Welschmeyer (1994). In conjunction with the water sampling schedule, measurements of water temperature, dissolved oxygen, pH, and conductivity were collected using a Hydrolab Surveyor III that was precalibrated against Winkler titrations (APHA 1992) and buffer solutions. The Carlson Trophic State Index (Carlson 1977) was estimated using the computer program *Bathtub* (Walker 1996) using Secchi transparency values, TP, and viable chlorophyll *a* concentrations determined over the upper 4 m of the reservoir. In addition, the Wisconsin Trophic State Index was estimated using equations described in Lillie et al. (1993).

The computer model *Bathtub* (Walker 1996) was used as a management tool to forecast the trophic response of Lake Altoona to reductions and increases in external P loading. We used (upper 4 m) measurements of chlorophyll and total phosphorus weighted over different seasonal periods (see results) to explore the trophic response of

Lake Altoona to variations in P loading. The computer program *Profile* (Walker 1996) was used to estimate weighted summer concentrations for input into *Bathtub*.

RESULTS

HYDROLOGICAL CONDITIONS

A period of Spring snowmelt and many storm-related peaks in water income from the Eau Claire River occurred during the ice-free period (Fig. 2). Flows were elevated in late February to early March (peak = 141 cms) as a result of snowmelt (Fig. 2). Storm-related inflows occurred in late April, mid-May, early and mid-June, early July and early September while extended periods of low flow occurred in March through early April, mid-July through early September, and late September through early November (Fig. 2). The greatest storm-related peaks in flow occurred on 3 June (168 cms), 22 June (227 cms), 11 July (132 cms), and 14 September (107 cms). During periods of peak inflow, the residence time of the reservoir often declined to < 1 day. During periods of nominal inflow the residence time varied between ~5 and < 30 days (Fig. 2). Overall, the seasonal (i.e., May-September) residence was only 5 days. Thus, ~20% of the lake was flushed every day.

SEDIMENT AND NUTRIENT SOURCES AND SINKS

External Loadings . Due to the very low residence time and, thus, high flushing rate of the reservoir, the annual retention of sediment and nutrients in Lake Altoona was generally low. The lake retained only 30% of the annual TSS load and 10% of the POM load from the Eau Claire River (Table 2). Annual retention of N and P derived from the Eau Claire River was slightly negative, suggesting that the reservoir exported some N and P to downstream locations (Table 2). Overall, mean annual concentrations of N and P of the inflow were high and indicative of eutrophic conditions. In particular, the mean annual concentration of P was very high at 0.102 mg/L.

Seasonally, mean concentrations of P were very high for Bridge and Fall Creeks, relative to the Eau Claire River (Table 3). However, because average seasonal flows were much lower for these tributaries compared to the Eau Claire River, they accounted for only 9.8 and 6.1 % of the TP load, respectively, to the Eau Claire River (Table 3).

Internal Loadings. Rates of P release from the sediments, measured in the laboratory, were substantial under anoxic conditions, ranging between a mean of 10.7 and 26.6 mg m^{-2} d^{-1} for stations 10 an 20 (Table 4). In contrast, rates of P release under oxic conditions were much lower, ranging between 0.7 and 1.0 mg m^{-2} d^{-1} (Table 4). Rates were highest for profundal sediments collected near the dam region (Station 10) and lower for sediments collected near the headwaters (station 20; Table 4).

LIMNOLOGICAL CONDITIONS

During the ice-free period of 2000, the reservoir exhibited very intermittent stratification in early May, July, and early August (Fig. 3). Isothermal (i.e., mixed) conditions occurred at the two stations in May through June, coincident with the occurrence of storm-related inflows, and during vernal and autumnal overturn in April and September through October, respectively (Fig. 3).

Due to storm-related flushing and lack of strong stratification, dissolved oxygen depletion was minor in the bottom waters of the lake and anoxic conditions (i.e., dissolved oxygen < 2 mg/L) were observed only for brief periods in late July and early August at station 10, in conjunction with temporary stratification (Fig. 4). During these periods, anoxia was confined to the bottom 1 meter or less (Fig. 4). For most or the ice-free period, dissolved oxygen concentrations were > 5 mg/L throughout most of the water column.

Seasonal patterns in lakewide average concentrations of P and chlorophyll in Lake Altoona appeared to be regulated, in large part, by flow and, thus, residence time (Fig. 5). For instance, during periods of high flow in May through July, lakewide average concentrations of total P were elevated in the lake (Fig. 5) in conjunction with high concentrations of total P in the inflow (Tables 2 and 3). Although total P was very high in the lake during this period, lakewide average concentrations of chlorophyll were very low due to the low residence time, suggesting washout of algae as a result of storm inflow (Fig. 5). During a period of much lower inflow between July and August, chlorophyll concentrations increased dramatically, in conjunction with much higher residence times. This pattern suggested that algae were able to increase in population at a rate greater than the flushing rate of the lake during periods of nominal inflow. P concentrations declined during this period of chlorophyll increase suggesting some sedimentation of P associated with TSS originating from the watershed. However, P concentrations were still very high in the water column, suggesting that algal growth was not limiting with respect to P. Chlorophyll concentrations declined markedly in September in conjunction with a storm inflow (Fig. 5) and decreases in the residence time to < 2 days. This storm most likely resulted in washout of the algal bloom that developed in August.

The algal assemblage at station 10 in Lake Altoona was generally dominated by Diatom species *Cyclotella* sp. and *Melosira granulata* in April through June (Fig. 6 and Appendix A). During the algal bloom in August, the blue green bacteria *Aphanizomenom flos aquae* comprised > 90% of the species assemblage (Fig. 6). Green algae and other species comprised a small fraction of the total species assemblage (Fig. 6).

Overall, Lake Altoona exhibited high concentrations of total P and low Secchi disk transparency during the summer growing period (May through September; Table 5). Chlorophyll concentrations were moderate during this period due to high flushing and washout (Table 5). During lower flow periods such as August through September, chlorophyll concentrations were much higher in conjunction with higher residence times and nutrient-rich water (Table 5). The Carlson and Wisconsin Trophic State Indices for Secchi disk transparency, viable chlorophyll *a* and total P ranged between 58 and 71 under both scenarios, indicative of eutrophic conditions during the summer.

BATHTUB MODELING

Since it appeared that residence time, as well as P, played an important role in the regulation of algal blooms in Lake Altoona, we explored two scenarios to examine algal response to P loading reductions and increases (Table 6). Scenario 1 was an examination of algal response to variations in P loading for the period May through September, when average flow was greater and the residence time was only 4.4 d. For scenario 2, we used the time period August through September, when average flow was lower and the residence time was nearly double at 7.7 d. External P loadings, calculated for these two periods using the program FLUX (Table 6), were used as input for the model *Bathtub*.

The uncalibrated chlorophyll model for scenario 1 suggested that chlorophyll concentrations should be extremely high in Lake Altoona under normal residence times for reservoirs (i.e., > 15 days), based on current total P concentrations (Table 7). The chlorophyll model had to be calibrated using a coefficient << 1.0 to account for the apparent loss of algae from the system as a result of high flushing and washout (Table 8). For scenario 2, the uncalibrated chlorophyll model predicted a mean concentration that was much closer to the observed value (Table 7). However, flushing was still high (although not as high as for scenario 1) necessitating calibration of the chlorophyll coefficient (Table 8).

For both scenarios, external phosphorus loading via the Eau Claire River was incrementally increased and decreased to examine the effects of changes in phosphorus loading on chlorophyll concentrations in the reservoir (Fig.7). Both total phosphorus and chlorophyll varied linearly as a function of changes in phosphorus loading, while Secchi transparency responded positively primarily as a function of phosphorus loading reduction. Under scenario 1, responses to P loading reduction or increase were more dampened due to apparent regulatory effects of flushing on algal concentrations (Fig. 8). Under scenario 2, chlorophyll concentrations were more sensitive to changes in watershed P loading (Fig. 8). With 50% P loading reduction, chlorophyll concentrations were reduced by ~ 55% under scenario 1, while they were reduced by ~60% for scenario 2. Conversely, a 50% increase in P loading resulted in a 55% increase in chlorophyll concentration under scenario 1 versus a 63% increase for scenario 2. In addition, baseline concentrations of chlorophyll (i.e., under current P loading conditions) were higher under lower flow (and higher residence time) versus higher flow (and lower residence time) conditions.

The BATHTUB algal bloom frequency represents the probable length of the growing period that algae will exhibit a given chlorophyll concentration as a result of the external P loading rate (Fig. 9). For instance, under scenario 1 nominal external P loading conditions, Lake Altoona exhibited an estimated bloom frequency of > 10 mg m^{-3} for ~

82% of the summer, > 20 mg m^{-3} for 42% of the summer, and > 30 mg m^{-3} for ~20% of the summer. Under scenario 2 external P loading conditions, the lake exhibited greater frequencies of bloom occurrence at higher chlorophyll concentrations due to greater residence times (Fig. 9).

Simulated increases in external P loading resulted in increases in both the concentration and frequency of occurrence of algal blooms during the summer for both scenarios (Fig. 9). Conversely, simulated decreases in external P loading resulted in decreases in both concentration and the frequency of occurrence of algal blooms for both scenarios (Fig. 9). However, as with chlorophyll (see above), the magnitude of change in the frequency of occurrence and severity (i.e., concentration of chlorophyll) of algal blooms was greatest for the Lake in response to changes in external P loading under lower flow conditions (Fig. 9). Responses to changes in external P loading were lower in magnitude at the higher flow condition due to apparent impacts of algal washout on chlorophyll concentrations in the reservoir.

CONCLUSIONS

Summer water quality conditions in Lake Altoona were strongly impacted by a very low water residence time and high flushing rate, due to storm-related inflows. As a result of high inflow, the residence time of the lake often declined to < 2 days. During lower flow periods, the residence time was usually < 14 days. These patterns appeared to result in substantial flushing of algal biomass from the system despite high concentrations of TP entering the system which could potentially stimulate algal productivity. As residence time declines below ~ 7 days doubling times of algae cannot compensate for cellular losses as a result of rapid flushing of the water column (James et al. 1992). In particular, the uncalibrated chlorophyll model used in *Bathtub* suggested that chlorophyll concentrations should have been much higher in Lake Altoona (Table 7) than observed had residence time been much greater (i.e., >> 14 days).

As for Lake Altoona, James et al. (1998) found that high flushing in Lake Holcombe, Wisconsin, coincided with low chlorophyll concentrations during the summer and a low chlorophyll:tTP ratio. They suggested that flushing played an important role in the regulation of algal biomass in this reservoir. Similarly, Van Nieuwenhuyse and Jones (1996) found low chlorophyll:total phosphorus coefficients for riverine systems and suggested this pattern is due to greater flushing of chlorophyll in these systems. Walker (1996) indicated that at high nutrient turnover times and low residence times chlorophyll production may not be in equilibrium with nutrient levels in the water column and response to phosphorus loading reduction could be dampened. This scenario appears to be the case for Lake Altoona as well.

In contrast, periods of lower summer inflow and greater residence times in Lake Altoona appeared to be accompanied by greater chlorophyll concentrations in the water column. These results suggested that algal populations were able to increase more rapidly than the flushing rate of the reservoir during nominal inflow periods. High TP concentrations in the water column during these periods sustain algal productivity and promote higher chlorophyll concentration. Thus, water quality conditions are expected to deteriorate (i.e., greater occurrence of algal blooms) as inflows decline and water residence time increases, due to drought periods, etc.

The Eau Claire River overwhelmingly dominated constituent inputs, particularly P, to Lake Altoona. In contrast, Bridge and Fall Creeks, tributaries flowing into the Eau Claire River upstream of Lake Altoona, contributed only ~ 15% of the TP load during the summer. In earlier work, James et al. (1999) found that internal P loading from profundal sediments of Lake Eau Claire, located upstream of Lake Altoona, represented a substantial P load to the reservoir. Discharge of this P source from Lake Eau Claire, and transport to downstream Lake Altoona, may represent an important P flux to Lake Altoona and needs to be considered in P control plans for improving Lake Altoona.

Internal P loading from profundal sediments in Lake Altoona represents a potentially important P source to the lake, particularly if sediments are subjected to bottom water anoxia. Rates of P release from profundal sediments were very high under anoxic conditions and indicative of eutrophic sediments (Nürnberg et al. 1986) that could contribute substantial P to the water column. Mean rates of P release under anoxic conditions observed for the profundal sediments of Lake Altoona were also very similar to rates observed for profundal sediments collected in Lake Eau Claire (i.e., 9.9-15.1 mg m^{-2} d^{-1}; James et al. 1999). During periods of high inflow, however, low residence time and high flushing appeared to disrupt thermal stratification and the development of dissolved oxygen depletion and bottom water anoxia in the lake. Thus, high flushing and adequate dissolved oxygen in the bottom waters most likely inhibited anoxic P release from sediments during the summer. However, during conditions of lower flow and greater residences times, dissolved oxygen depletion and anoxia could develop in the bottom waters as a result of the establishment of strong thermal stratification, resulting in enhanced P flux from the sediment into the water column.

Net retention of TSS appeared to be minor compared to other reservoirs in the area, due to the high flushing rate which acted to reduce fine particle settling. In contrast, net retention of TSS was more substantial in upstream Lake Eau Claire, as this lake retained > 50% of the external TSS load on an annual basis. Our estimate did not, however, include bed load inputs of coarse material to the reservoir. Transport of sand, etc, and sedimentation in the headwaters has been substantial, resulting in the need to dredge in recent years (R. Barfknecht; personal communication). Net retention of external nutrient loads such as nitrogen and phosphorus was also minor in Lake Altoona during the study period. These patterns were due, in large part, to the high flushing rate of the reservoir which prevented sedimentation.

External phosphorus loading reduction via BMPs (Best Management Practices), development of vegetated shoreline buffer strips, and restoration of wetlands within the Eau Claire River watershed will be important avenues for controlling chlorophyll and the frequency of algal blooms in Lake Altoona during the summer. In particular, attention to P control in the watershed upstream of Lake Eau Claire will have a beneficial impact on

P in Lake Altoona. Although we cannot compare directly the impact of P discharge from Lake Eau Claire(James et al. 1999) on P inflows to Lake Altoona because studies on these two lakes were conducted during different water years, an analysis of P loading from the two sources during different years can provide some insight into the potential importance of Lake Eau Claire on P in Lake Altoona (Table 9). Average flow from the Eau Claire River into Lake Altoona in 2000 was 1.84 times greater than the average discharge from Lake Eau Claire in 1998. If we assume that P loading is approximately proportional to water load, the data suggest that P discharge from Lake Eau Claire could account for most of the P load into Lake Altoona, as the proportional adjustment of P discharge from Lake Eau Claire Dam in 1998 overestimated P loading to Lake Altoona in 2000 (i.e., 38312 kg P y^{-1} x 1.84 = 70494 kg P y^{-1} ; versus 55912 kg P y^{-1} load to Lake Altoona in 2000; Table). Based on *Bathtub* results, it appears that chlorophyll and algal bloom frequency will respond dramatically to reductions in P inputs, particularly during periods of lower flow and higher residence time.

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TABLES

Table 1. Variable list for tributary loadings

FLOW, cms
POOL ELEVATION, m
TOTAL SUSPENDED SEDIMENT, mg/L
POM, mg/L
TOTAL NITROGEN, mg/L
TOTAL PHOSPHORUS, mg/L

Variable list for limnological monitoring of Lake Altoona.

WATER TEMPERATURE, ^{o}C
DISSOLVED OXYGEN, mg/L
pH
CONDUCTIVITY, μS/cm^2
SECCHI TRANSPARENCY, cm
TOTAL SUSPENDED SEDIMENT, mg/L
PARTICULATE ORGANIC MATTER, mg/L
TOTAL NITROGEN, mg/L
AMMONIUM-NITROGEN, mg/L
TOTAL PHOSPHORUS, mg/L
SOLUBLE REACTIVE PHOSPHORUS, mg/L
VIABLE CHLOROPHYLL *a*, μg/L

Table 2. Summary statistics for annual external loads to and discharges from Lake Altoona. CV represents the coefficient of variation.

Tributary	Seston			Particulate Organic Matter			Total N			Total P		
	LOAD kg y^{-1}	CONC. mg L^{-1}	CV	LOAD kg y^{-1}	CONC. mg L^{-1}	CV	LOAD kg y^{-1}	CONC. mg L^{-1}	CV	LOAD kg y^{-1}	CONC. mg L^{-1}	CV
Eau Claire River	2.7×10^6	4.9	0.197	8.9×10^5	1.6	0.139	651707	1.194	0.033	55912	0.102	0.073
Altoona Dam	1.9×10^6	3.5	0.147	8.0×10^5	1.5	0.378	667400	1.223	0.057	65249	0.119	0.112

Table 3. A comparison of seasonal (i.e., May-September) total phosphorus (TP) loads from the Eau Claire River and from Bridge and Fall Creeks, which drain into the Eau Claire River north of County Road K. CV represent the coefficient of variation and percent TP load represents the percent contribution of the various tributaries to the total TP load measured for the Eau Claire River.

Tributary	Flow, Cms	TP Load, kg	TP Conc. mg/L (CV)	Percent TP Load
Eau Claire River	26.5	35938	0.102 (0.07)	100
Bridge Creek	1.2	3524	0.256 (0.15)	9.8
Fall Creek	0.5	2183	0.338 (0.10)	6.1

Table 4. Mean (± 1 standard deviation) rates of phosphorus release from the profundal sediments (mg m^{-2} d^{-1}) of various stations measured under oxic and anoxic conditions.

Station	Oxic Rate	Anoxic Rate
10	0.7 (0.1)	10.7 (2.2)
20	1.0 (0.4)	26.6 (3.3)

Table 5. Estimates of Carlson and Wisconsin Trophic State Index (TSI) values for Lake Altoona under flow conditions during the summer of 2000 (May-September) and under lower flow conditions during August through September, 2000. Concentrations of chlorophyll, total phosphorus (TP), and Secchi disk transparency (SD) represent means (± coefficient of variation, CV) over the upper 4-m water column of the reservoir.

					Carlson TSI			WI TSI	
Period	Secchi, m	Chla, μg/L	TP, μg/L	TSI_{SD}	TSI_{chla}	TSI_{TP}	$WTSI_{SD}$	$WTSI_{chla}$	$WTSI_{TP}$
May-Sep	0.9 (0.1)	20.9 (0.26)	108 (0.11)	62	61	71	62	58	64
Aug-Sep	0.9 (0.1)	30.0 (0.37)	86 (0.23)	62	64	68	62	61	63

Table 6. Summary statistics for external P loads from the Eau Claire River for the period May-September (2000 summer conditions) and the period August-September (low flow conditions) used in *Bathtub* modeling. CV represents the coefficient of variation. hm^3 represents 1000 m^3.

Period	Flow $hm^3 y^{-1}$	P LOAD, kg	CONC. $mg\ L^{-1}$	CV
May-Sep	837	35938	0.102	0.073
Aug-Sep	484	5706	0.070	0. 256

Table 7. A comparison of observed versus estimated values for the uncalibrated BATHTUB model. Scenario 1 represents summer growing conditions while scenario 2 represents low flow conditions.

Scenario	Variable	Observed	Estimated
1 (May-Sep)	Total P, mg/L	0.106	0.125
	Chlorophyll, mg/m^3	21.5	93.1
2 (Sep-Aug)	Total P, mg/L	0.086	0.082
	Chlorophyll, mg/m^3	30.0	51.0

Table 8. Calibration coefficients and models used in BATHTUB for scenario 1 (May through September) and scenario 2 (lower flow period of August through September).

Model	Calibration Coefficients	
	Scenario 1 Summer Flow	Scenario 2 Low Flow
Phosphorus Model: 2nd Order Decay	2.24	0.79
Chlorophyll Model; P, Jones and Bachmann	0.29	0.56
Dispersion Model: Fisher Numeric	1.00	1.00

Table 9. A comparison of average flow and annual P load from the Eau Claire River at Lake Eau Claire Dam (1998) and from the Eau Claire River at County Road K (2000).

Location	Flow, cms	P load, kg y^{-1}
Eau Claire River at Lake Eau Claire Dam (1998)	9.61	38312
Eau Claire River at County Road K (2000)	17.75	55912

FIGURE CAPTIONS

Fig. 1. Map of Lake Altoona showing water and sediment sampling stations.

Fig. 2. Seasonal variations in flow from the Eau Claire River at County Road K and theoretical retention time of Lake Altoona in 2000.

Fig. 3. Contour plot of seasonal and depth-related variations in water temperature at station 10 and 20 in Lake Altoona in 2000.

Fig. 4. Contour plot of seasonal and depth-related variations in dissolved oxygen concentration at station 10 and 20 in Lake Altoona in 2000. Blackened area represents regions and periods of anoxia (i.e., dissolved oxygen < 2.0 mg/L).

Fig. 5. Seasonal variations in flow from the Eau Claire River at County Road K, and chlorophyll and total phosphorus (P) concentrations in Lake Altoona. Chlorophyll and total P concentrations represent a weighted average for the upper 4 m of the lake.

Fig. 6. Seasonal variations in phytoplankton biomass distribution among different algal groups during the summer in Lake Altoona.

Fig. 7. Variations in the external P load for the period May-September (summer flow season) and August-September (lower flow season) used for *Bathtub* modeling. External phosphorus loading was increased or reduced relative to nominal external total phosphorus loading conditions that occurred during the two summer periods investigated.

Fig. 8. Estimated changes in total phosphorus (P), chlorophyll, and Secchi transparency in Lake Altoona as a function of external phosphorus loading increases or decreases for the period May-September (summer flow season) and August-September (lower flow season).

Fig. 9. Estimated changes in the frequency of algal bloom occurrence of different concentrations of chlorophyll versus different external phosphorus loading conditions. External phosphorus loading was increased or reduced relative to nominal loading conditions that occurred during the period May-September (summer flow season) and August-September (lower flow season).