VALIDATION OF AQUATOX VERSION 1.66 WITH DATA FROM CORALVILLE RESERVOIR, IOWA

Introduction

Coralville Reservoir is a shallow, eutrophic, run-of-the-river reservoir formed when the U.S. Army Corps of Engineers impounded the Iowa River in 1958 for flood control. The dam is located about three miles from Iowa City, and the reservoir was closely monitored by the University of Iowa under contract to the Corps of Engineers. Four years of data (10/1/74-9/30/78) from the Coralville Water Quality Study (McDonald and McDonald, 1976; McDonald, 1977, 1978, 1979) were used for validation.

The extent and depth of the lake are quite variable, depending on the storage capacity. At spillway level (712 ft elevation), the lake extends 35.1 mi (56 km) upstream, and it covers 24,800 acres (10,000 ha); at conservation pool level (680 ft) it extends 21.7 mi (34.7 km), and it covers 4,900 acres (1,990 ha). At its lowest level (670 ft), in late winter because of flood control requirements, the reservoir covers 1,820 acres (735 ha). Going from spillway to conservation to minimum pool levels, the volume varies from 469,400 acre·ft (57,900 ha·m) to 40,300 acre·ft (4,970 ha·m) to 10,600 acre·ft (1,310 ha·m), and the mean depth varies from 19 ft (5.8 m) to 8 ft (2.5 m) to 5.8 ft (1.8 m).

In 1973, just prior to the period simulated (10/1/74 to 10/1/78), 90% of the drainage basin of 4,770 mi^2 (12,350 km^2) was in agriculture; most of the remaining 10% was urban, suburban, and road right-of-way. Of the total land, 77% was in crops, including 30% in corn, and 13% was pastureland (McDonald and McDonald 1976). Agricultural runoff in the basin carries large amounts of fertilizers, pesticides, animal wastes, and silt—all of which have adverse impacts on the Coralville Reservoir ecosystem. Such impacts can be examined with the AQUATOX model. In this validation, the emphasis is on eutrophication as a consequence of nutrient and organic matter loadings.

Input Data

Input data included the above site characteristics and time series of loadings taken from the Water Quality Study reports, time series of pool elevations downloaded from the Army Corps of Engineers World Wide Web (Web or www) Internet site, Iowa River flow data downloaded from the U.S. Geological Survey Web site, and meteorological data downloaded from the Web (Table 1).

Table 1. Data Sources

Variable	Source	Format
Pool elevations	www.water.mvr.usace.army.mil/doc/desc/crvi4.html	daily
Volumes	computed from pool elevations using a regression with 3 observed volumes	daily
Inflow and discharge	www.waterdata.usgs.gov/nwis-w/IA/	daily values upstream at Marengo and at dam
Phosphorus	Coralville Water Quality Studies	approximately twice monthly
Nitrate	Coralville Water Quality Studies	approximately twice monthly
Ammonia	Coralville Water Quality Studies	approximately twice monthly
Biochemical oxygen demand	Coralville Water Quality Studies; converted to detrital values in the model	approximately twice monthly
Temperature	Coralville Water Quality Studies	weekly
Wind	www.solstice.crest.org/cgi-bin/solrad/radiate-form.cgi	average value
Solar radiation	www.solstice.crest.org/cgi-bin/solrad/radiate-form.cgi	average value and range
Initial conditions	Coralville Water Quality Studies	observed values at beginning of simulation

The AQUATOX model was used to simulate the impacts of agricultural runoff on Coralville Reservoir, so loadings of nutrients and organic matter (represented by biological oxygen demand, BOD) were calculated from time series of water discharge (**Figure 1**) and nutrient and BOD concentrations (**Figures 2-5**) for the Iowa River at Marengo, just upstream from the reservoir. As seen from the discharge (**Figure 1**), the second and third years of the simulation period were drought years; the fourth year was characterized by highly variable inflow (**Figure 1**; McDonald, 1979) and prolonged high temperatures (**Figure 6**).

Figure 1. Iowa River discharge at Marengo, Iowa.

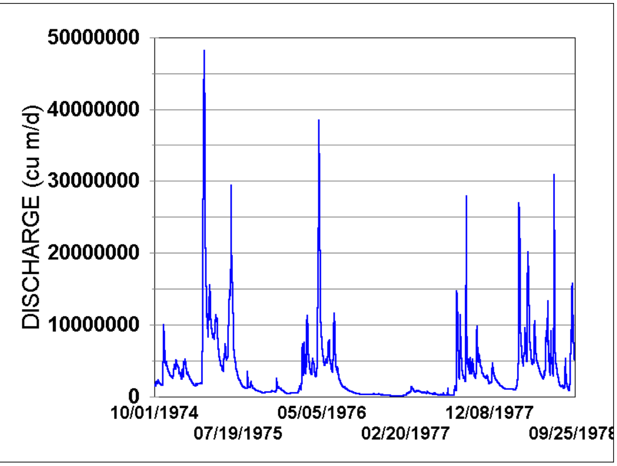


Figure 2. Concentrations of orthophosphate in the Iowa River at Marengo, Iowa.

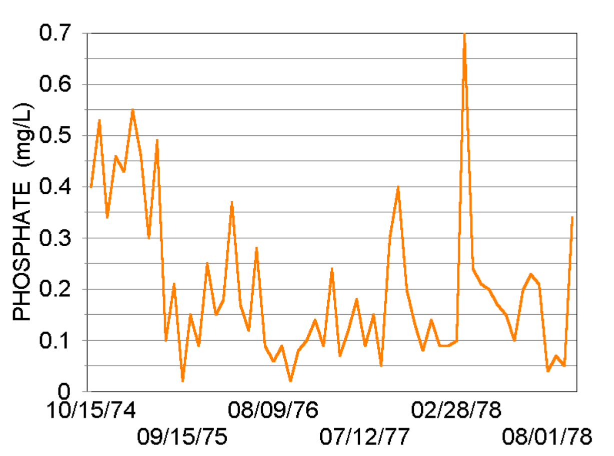


Figure 3. Concentrations of nitrate in Iowa River at Marengo, Iowa.

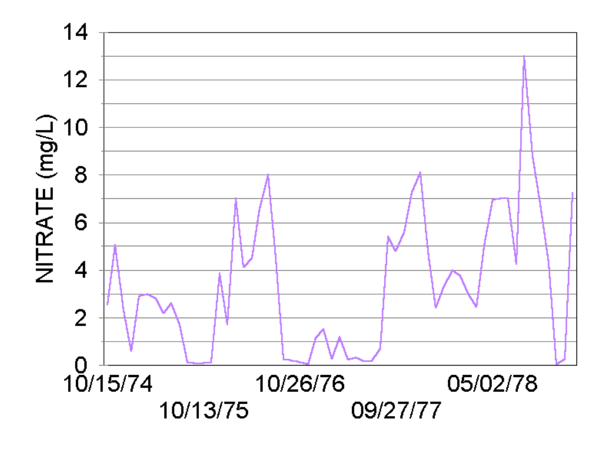


Figure 4. Concentrations of ammonia in Iowa River at Marengo, Iowa.

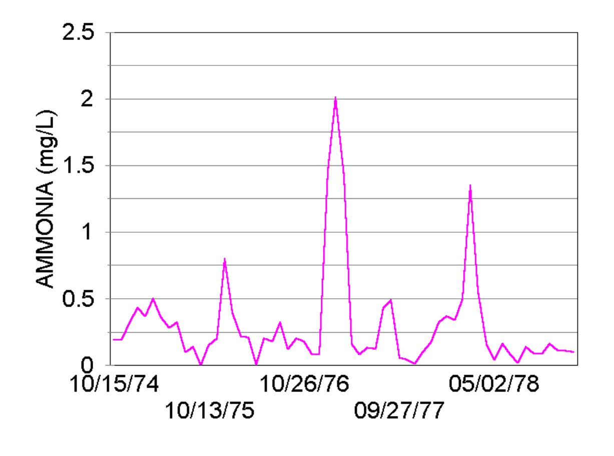


Figure 5. Biochemical oxygen demand, Iowa River at Marengo, Iowa.

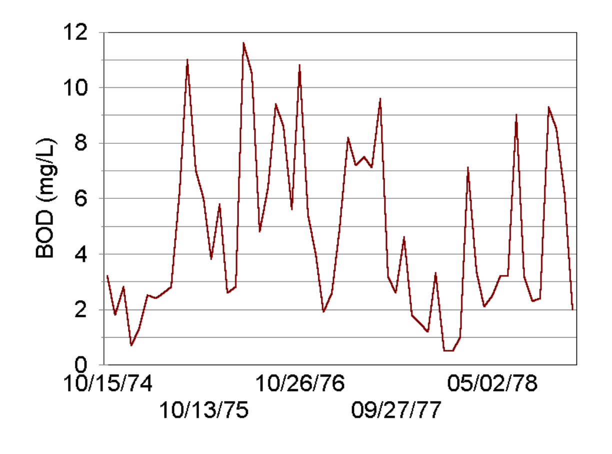
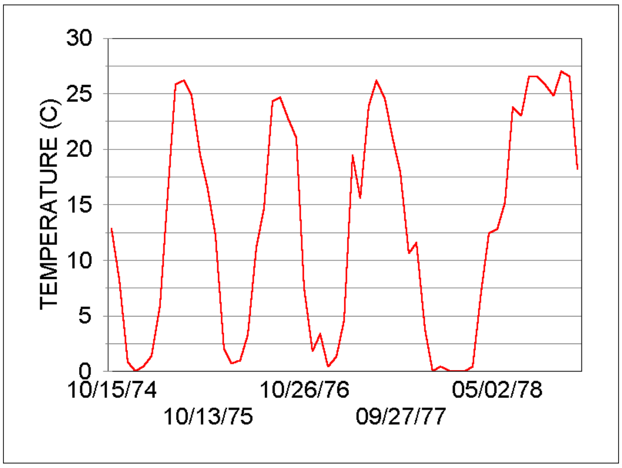


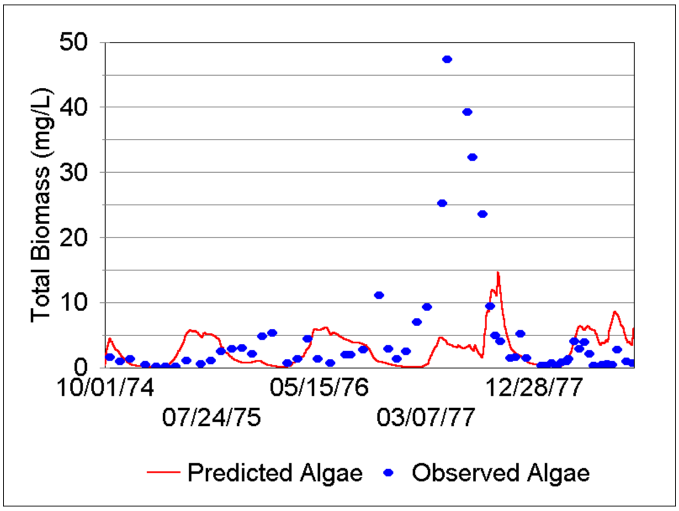
Figure 6. Temperature in Coralville Reservoir, Iowa.



Preliminary Results and Modification

Two levels of simulations were used. First, simulations were run for the period of October 1, 1974 to October 1, 1978, using a constant volume for the reservoir, and adjusting the discharge according to the varying inflow. The model predicted time-varying concentrations of nutrients, detritus, algae, invertebrates, and fish as mg/L (dry weight for the organisms). The observed algae were reported as cells/ml in the Water Quality reports. These values were converted to mg dry wt/L by assuming that an average algal cell = 2E-10 g dry wt; therefore, cells/ml * 2E-4 = mg dry wt/L. The model predicted the average biomass of algae for most of the period, but missed the timing of the algal blooms; furthermore, this implementation almost completely missed a large bloom that occurred during low-flow conditions in the summer of 1977.

Figure 7. Algal biomass in Coralville Reservoir with constant volume.



In a second level of analysis, the large seasonal and annual changes in volume were incorporated into the simulation. Direct, time-varying observations of volume were not available, but volume estimates were available for three pool elevations (see Introduction). The changing pool elevations (**Figure 8**) and a linear regression of volume on pool elevation (**Figure 9**) were used to estimate changing volume (**Figure 10**).

Figure 8. Observed Coralville pool elevations; values are elevation above mean sea level.

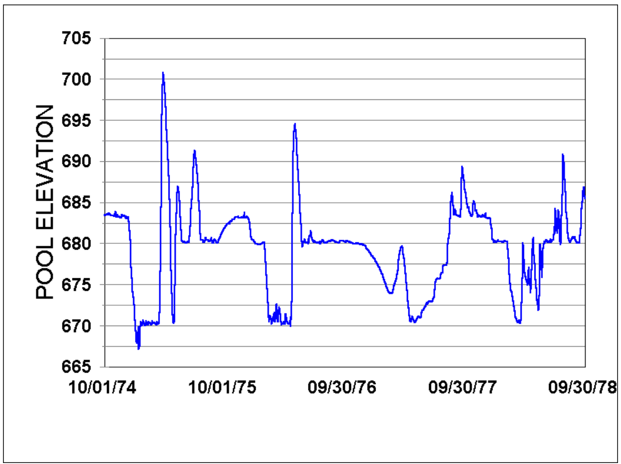


Figure 9. Regression of volume on Coralville pool elevation.

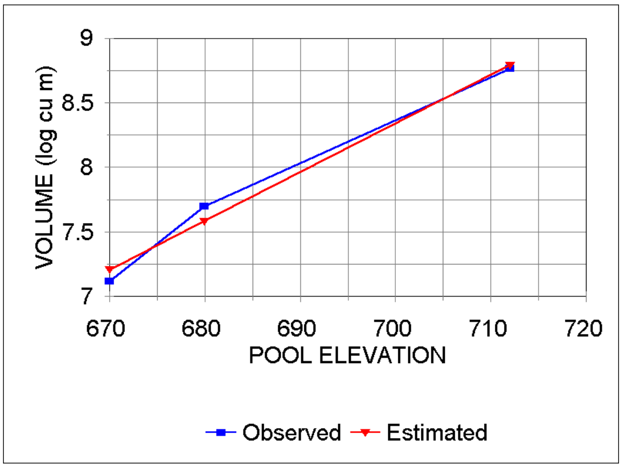
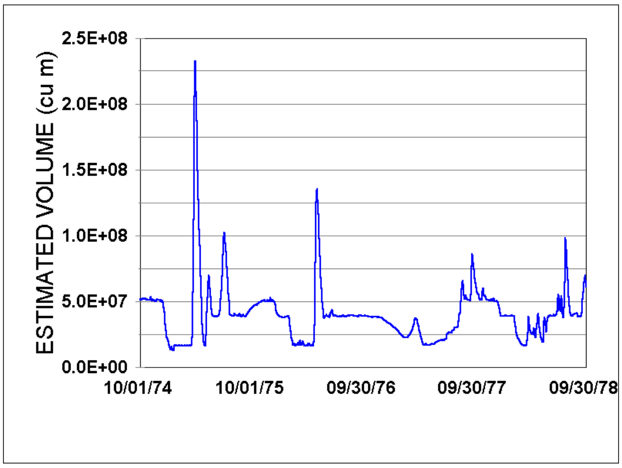


Figure 10. Coralville volumes estimated from pool elevations.



Results

The time-varying volume and associated depth estimates provided more accurate representations of nutrient levels and light penetration, resulting in more realistic simulations of algal biomass, as seen from the arithmetic (**Figure 11**) and log plots (**Figure 12**). The model was off by a factor of only two in predicting the large algal bloom in 1977. A more rigorous test is the Kolmogorov-Smirnov statistic, which compares the cumulative distributions of the predicted and observed data (**Figure**

13). As seen in Table 2, the distributions are not significantly different. The behavior of the model is deemed acceptable, considering that the model was not calibrated or "fit" to the observed data, and the simulation period spanned high-flow, low-flow, and normal hydrologic periods. The large bloom may have been predicted even better had the simulation been set up to represent the temporary stratification that occurred at that time. (AQUATOX can represent stratified conditions; but Coralville Reservoir was modeled as a completely mixed system because it stratifies so seldom.)

Figure 11. Algal biomass (arithmetic) in Coralville Reservoir with changing volume.

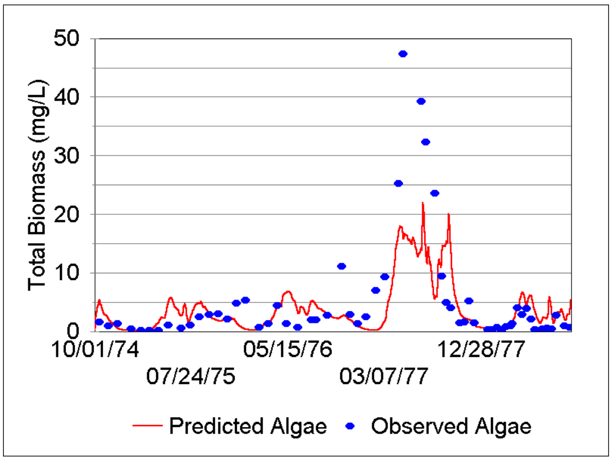


Figure 12. Algal biomass (logarithmic) in Coralville Reservoir with changing volume.

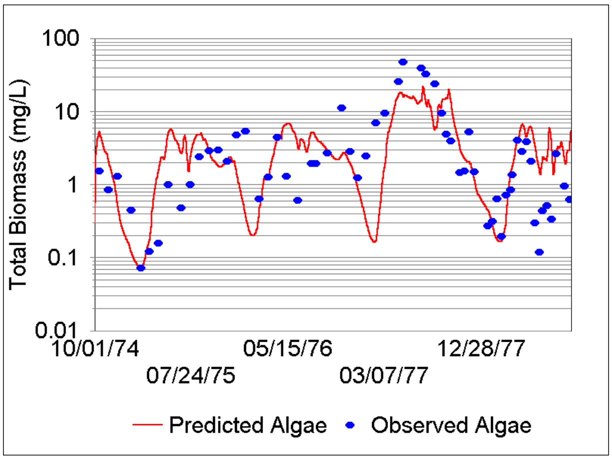


Figure 13. Cumulative distribution of Algal biomass in Coralville Reservoir.

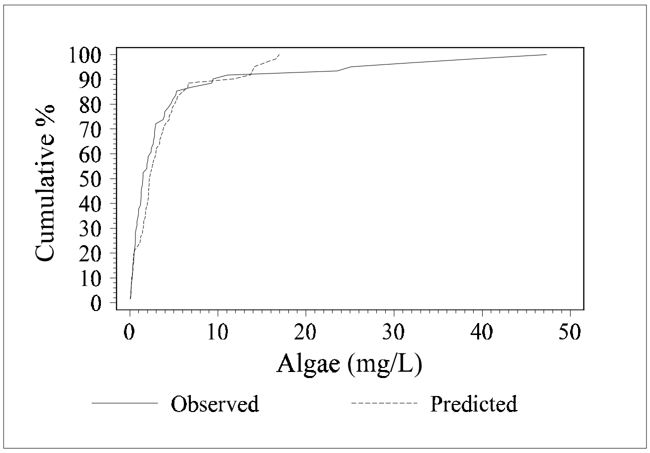


Table 2. Summary Statistics for Algae in Coralville Reservoir

Time Period	Group	Algae (mg/L)					
		No. of Obs.	Mean	Median	Std. Dev.	Std. Err.	p-value from KS Test
1974-1978	Observed	61	4.82	1.51	9.31	1.19	0.081[a]
	Predicted	61	3.81	2.27	4.32	0.55	

[a.] Not significantly different at α=0.05. Statistics courtesy of Jie Tao and William Warren-Hicks, The Cadmus Group.

As seen in **Figure 14**, an area graph that displays additive rates for each day, the predicted diatom biomass in 1975 is a function of highly variable loading from upstream (Load2) and photosynthesis (Photosyn2), with equally variable loss rates due to respiration (Respir2), nonpredatory mortality (Mort2), washout due to flow-through (Washout2), and minor sedimentation (Sediment2). Loss due to grazing or predation (Predation2) is small, as reported by McDonald (1979). Diatoms are reported to be dominant in the lake (McDonald 1977), as they are in the simulation (**Figure 15**).

Figure 14. Predicted rates for diatoms (2nd algal group) in Coralville Reservoir in 1975.

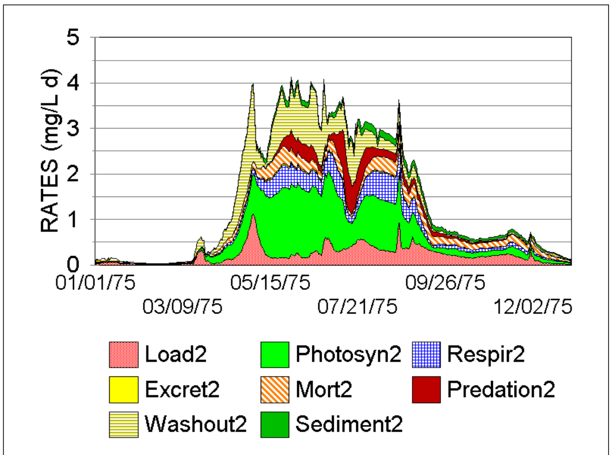
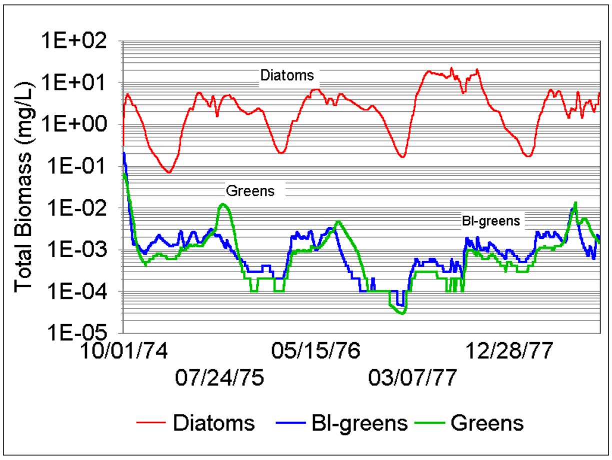


Figure 15. Predicted relative importance of phytoplankton.



Another measure of the validity of AQUATOX in simulating the Coralville ecosystem is seen when the predicted biomass of buffalofish is plotted against the observed mean. This fish is very abundant in the reservoir. The simulation was started with a low initial condition of 10 g/m^3, but the predicted mean of 53 g/m^3 was rapidly attained (**Figure 16**). The mean observed biomass of 47 g/m^3 is based on records from 1966-1970 (Mitzner 1972), before the lake supported a large commercial fishery (fishing pressure, which would lower the biomass, is not considered directly in the model). Time-varying biomass was not reported for the reservoir.

Figure 16. Predicted biomass of Coralville buffalofish, compared with mean observed value.

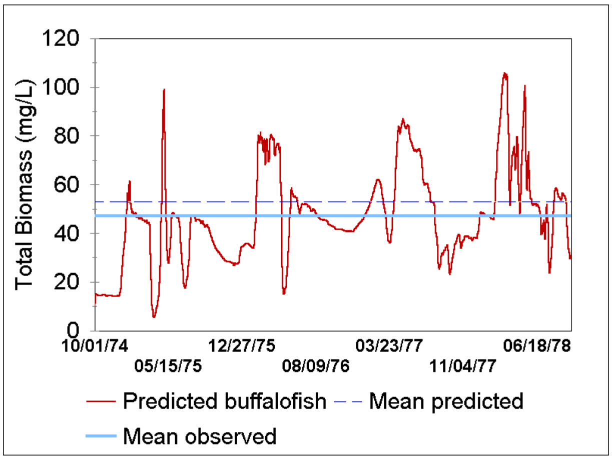
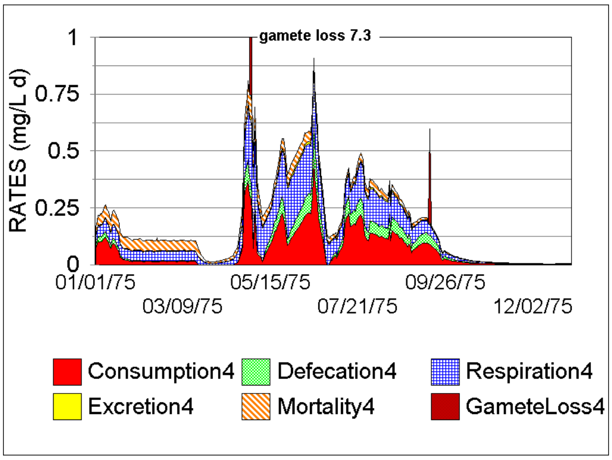


Figure 17. Predicted rates for buffalofish (the 4th animal in the simulation) in Coralville Reservoir for 1975.



The predicted buffalofish biomass is a function of consumption (the only plus term), defecation, respiration, minimal excretion, and, at times, spawning, and mortality. The predicted *in situ* rates for 1975 (**Figure 17**) indicate that the rate of consumption (Consumption4) was quite variable and that loss due to defecation (Defecation4) was equally variable. At times, such as in early May, the predicted diet was largely zoobenthos and defecation loss was very low; at other times detritus was an important component of the diet, and defecation of this low-quality food source was high. Predicted respiration rate (Respiration4) was low during the winter months, and mortality rate (Mortality4) was high in late winter and early spring. Due to the way spawning is represented in the model (as a function of temperature and growth), the predicted rate of gamete loss (GameteLoss4) had a sharp peak in May and a smaller peak in September. Detailed observations of fish dynamics are sparse, but Mitzner (1972) reports that the success of buffalofish age classes is highly variable in the reservoir and that mortality due to anoxia occurs in some years when spring runoff causes high BOD.

Biomass data for other organisms in Coralville Reservoir are scarce, so that only qualitative comparisons can be made with model predictions (**Figure 18** and **Figure 19**). Zooplankton biomass is small in both the simulations and in the actual Coralville ecosystem; a maximum of 2.3 mg/L was observed in the lake (McDonald 1979) and that same value was predicted by the model. Zoobenthos biomass fluctuates in the simulation depending on sediment conditions and predation; a maximum of 2.6 mg/L is predicted. No quantitative estimates of either biomass or numbers were available from the field, but McDonald (1979) states that zoobenthos are sparse.

Bluegills are unimportant in both the lake and in the simulation (predicted mean of 0.5 mg/L for 1977-78). However, adult bass (but not young-of-year) are predicted to be important (predicted mean of 9.9 mg/L for 1977-78). Interestingly, bass are absent in Coralville sport fish harvest data (Leidy and Jenkins, 1977) and in gill net catches (Mitzner 1972). Perhaps their absence is due to the periodic low dissolved oxygen levels—the known sensitivity of bass to low oxygen levels is not well simulated by the model. Alternatively, agricultural pesticides, such as dieldrin, are known to be present, and may be causing toxicity. In order to test this possibility, dieldrin would have to be included as a state variable in the simulation.

Figure 18. Predicted Coralville invertebrates.

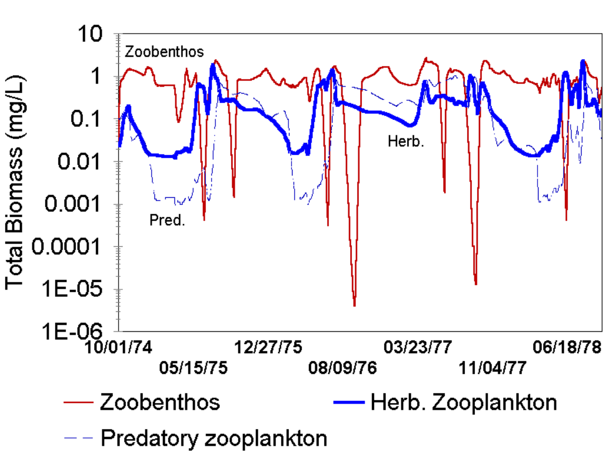
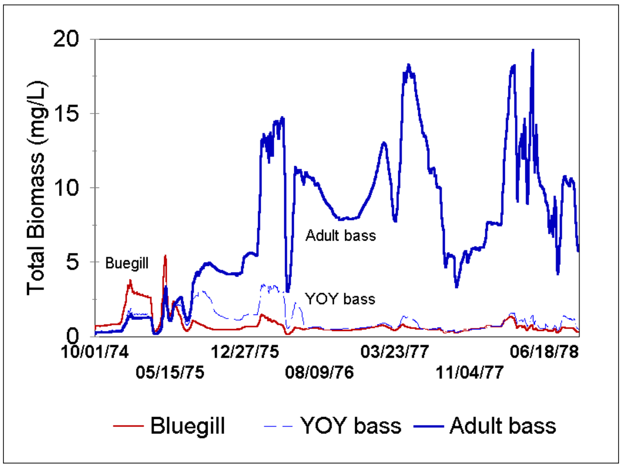
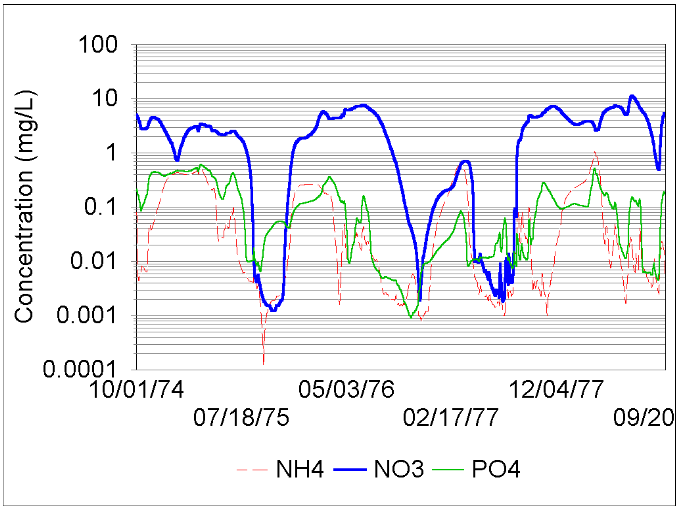


Figure 19. Other predicted Coralville fish.



The simulated and reported ranges in nutrient levels are comparable. The simulated nutrient levels vary widely during the period as a function of the varying hydrologic regime and assimilation by algae (**Figure 20**). Time varying nutrient data were not available, however, the observed maxima correlated well with the predicted maxima. In 1977-78 the maximum observed nitrate concentration was 13 mg/L, compared to 11.2 in the simulation; the maximum observed ammonia value was 1.4, compared to 1.04 in the simulation; and the maximum observed phosphate value was 0.85, compared to 0.6 in the simulation.

Figure 20. Predicted nutrient concentrations.



Conclusions

When applied to Coralville Reservoir, a eutrophic run-of-the-river reservoir, AQUATOX yielded results for algal biomass that were similar to those observed—predicting blooms under varying hydrologic conditions. The model also predicted the biomass of the dominant fish, buffalofish, within 13% of the mean observed value. Furthermore, with the exception of bass, AQUATOX satisfactorily represented the qualitative importance of diverse groups of algae, invertebrates, and fish. The model is shown to be suitable for simulating reservoir eutrophication, given standard water quality data.

References

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Mitzner, L. 1972. *Population Studies of Bigmouth Buffalo in Coralville Reservoir with Special Reference to Commercial Harvest.* Iowa Fisheries Research Technical Series No. 72-3, Iowa Conservation Commission, 36 pp.