FOODWEB MODELING FOR PCBS IN THE TWELVEMILE CREEK ARM OF LAKE HARTWELL, GA/SC

Brenda Rashleigh[1/], M. Craig Barber[1/], and David M. Walters[2/]

AUTHORS: [1/] Ecologist, U.S. Environmental Protection Agency, 960 College Station Road, Athens, Georgia, 30605, [2/] Aquatic Ecologist, U.S. Environmental Protection Agency, 26 West MLK Drive, Cincinnati, OH, 45268

REFERENCE: Proceedings of the 2005 Georgia Water Resources Conference, held April 25-27, 2005, at The University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Abstract. The U.S. EPA is conducting a series of studies on the Sangamo-Weston Superfund Site near Clemson, SC, to examine the pollution of the Twelvemile Creek arm of Lake Hartwell by PCBs that were released from the site until the early 1990s. Monitoring data have shown that while PCB concentration in sediments declined since 1995, PCB concentrations in fish have not. The EPA aquatic ecosystem model AQUATOX has been applied to examine this system. This model provides an understanding of food web dynamics, characterization of bioaccumulation, and identification of most sensitive ecosystem components. The model may eventually be used in prediction of future PCB concentrations in fish under different scenarios for management.

INTRODUCTION AND BACKGROUND

The U.S. EPA is conducting a series of studies on the Sangamo-Weston/Twelvemile Creek/Lake Hartwell Superfund Site. These studies examine the pollution of Twelvemile Creek and Lake Hartwell by PCBs that were released from the Sangamo-Weston property until the early 1990s. Monitoring of PCBs in sediments and aquatic fauna has been conducted since 1995 to gauge the effectiveness of Monitored Natural Recovery (MNR) in lowering PCB concentrations in sediments and aquatic fauna (Environmental Resources Management ERM, 2001). Sampling has focused primarily on Lake Hartwell and the Twelvemile Creek Arm (TCA) of the reservoir.

Even though PCB concentrations in lake fauna are monitored, estimates of recovery time are based solely on hydrologic and sediment dynamics. Modeling efforts are underway to predict the hydrodynamics and sediment regimes, but food web models can contribute valuable information on biotic processing of contaminated material, persistence of PCBs in the aquatic environment, and potential lag times in natural recovery.

Recovery goals include lowering fish tissue PCBs to comply with the tolerance level of 2.0 ppm. Some tissue data show that levels are declining in some species over time and with distance from the TCA (ERM, 2001). However, data for species such as largemouth bass and bluegill sunfish show that PCB levels remain high, unlike the observed trend of lower PCB levels in lake sediments (Brenner et al., 2004). A better understanding of the sources and pathways for PCBs into fishes at higher trophic levels, and the residence times of PCBs in the Lake Hartwell food web, is needed. Such an understanding will enable managers to better predict recovery times and identify sources of ongoing PCB contamination.

Here we applied the AQUATOX model, a simulation model for aquatic systems that predicts the fate of various pollutants and their effects on the ecosystem (U.S. EPA, 2000a), to the TCA. AQUATOX is supported by EPA and was favorably reviewed in a recent evaluation of integrated eutrophication, fate, and effects models by Koelmans et al. (2001): integrated models such as these allow the user to include feedback mechanisms, identify dominating processes, and develop hypotheses on ecosystem functioning. First, the model was set up and calibrated for the site; next, a sensitivity analysis was conducted to identify parameters with the most influence on fish biomass and PCB concentrations, and then the model was run to examine predictions of PCB concentrations.

MODEL SETUP

Because the TCA region of the reservoir is of primary interest, the AQUATOX model was set up for just this arm. The study reach was selected to coincide with hydrodynamic modeling that is being conducted by the EPA for a 20.4 km stretch of the TCA using the U.S. Geological Survey (USGS) gage #02186000 (Twelvemile Creek near Liberty, SC) as the upstream boundary. The boundary between the TCA and lower Lake Hartwell is assumed to be “downstream.” Site information and several physical and chemical inputs are needed to run the AQUATOX model (Table 1).

Table 1. Values used to parameterize AQUATOX for TCA.

Parameter	Value	Source
Surface area	30381 m^2	From USEPA HEC model
Max., mean depth	13.7, 4.3 m	From USEPA HEC model
Light mean, range	300 ± 175 Ly/d	U.S. National Climatic Data Center (1992) for Greenville, SC. (Photoperiod determined by latitude of USGS gage)
Mean evaporation	37.6 in./yr.	U.S. ACE (1996) for the Savannah River Basin, based on 20 years of data.
Wind	2.9 m/s	Mean of monthly values for 1961-1990 for the Augusta, GA airport from U.S. ACE, 1996
Temp avg., range	19 ±10C	Bechtel Env., Inc. Remedial Investigation Report, 1993. Represented as a sine curve.

Mean monthly flow values available at the USGS gage for the simulation period was used as input. The model determines outflow to maintain a constant volume. Mean values for nitrate (0.2 mg/L), ammonia (0.05 mg/L), phosphate (0.1 mg/L), pH (7), and oxygen (9.9 mg/L) were taken from the EPA STORET database (http://www.epa.gov/STORET/dbtop.html) for the USGS gage location.

AQUATOX models detritus in the form of organic carbon; the model provides default parameters for detritus which are appropriate for most systems (U.S. EPA, 2000a). The initial estimate of 600g/m^2 of sedimented detritus was partitioned as 60% refractory and 40% labile (Park, pers. comm., 2005). ; We assumed that TOC made up 3.5% of TSS (Brenner et al., 2004), and adjusted TSS in calibration.

The AQUATOX model requires the set-up of a foodweb that includes the biological components in the system to be modeled and the feeding interactions between them (Figure 1). We simulated the major components of the TCA food web and accepted the default parameterizations and trophic interactions in AQUATOX for these biota. Fish biomass was initialized with carrying capacity estimates for southeastern reservoirs (gizzard shad=2.86 g/m^2, bluegill=2.11 g/m^2, largemouth bass=1.12 g/m^2) (Leidy and Jenkins, 1977).

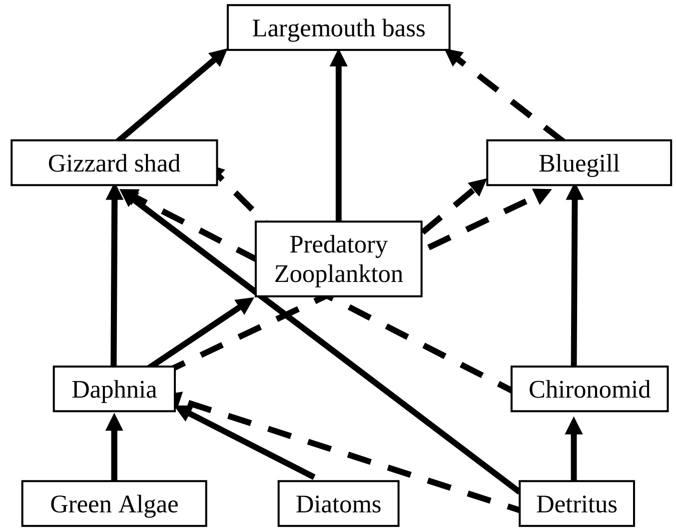

Figure 1. Diagram of foodweb simulated in AQUATOX. Solid lines indicate strong interactions, dashed lines indicate weak interactions.

CALIBRATION AND SENSITIVITY ANALYSIS

The model was initially run for the period of time 1/1/95 – 12/31/2000 without PCBs. Inflow nitrate, ammonia, and phosphate concentrations were adjusted in calibration to 0.6, 0.05 and 0.16 mg/L, respectively, so that mean concentrations in the lake were in agreement with those reported in STORET. Inflow values for total suspended solids (TSS) and detritus were adjusted to 4 mg/L and 0.14 mg/L, respectively to calibrate the model such that mean biomass for each fish species stabilized in the range of its initial value.

The sensitivity of fish biomass to 10% changes in different model factors are shown in Table 2. The high sensitivity of fish biomass to temperature was due to the temperature increase in the warmest months compared to the species' optimum and maximum temperatures. In AQUATOX, growth decreases sharply above species' optimum temperature, and mortality becomes exponential above their maximum temperatures (30C for shad). The model can be adjusted to allow the system to stratify, however, the results showed no sensitivity to this option.

A 10% increase in nutrients increased the biomass of bluegill and bass by 10-20%, and a 10% increase in TSS resulted in a decline in fish biomass by 18-38%. Increased nutrients stimulate growth of algae that serve as food for invertebrates and fishes, while TSS increases shading and reduces the light available at depth for algae. An increase in flow led to lower biomass for most species,

Table 2. Sensitivity of fish biomass to model factors.

Model factor increased by 10%	Mean percent difference in fish biomass		
	Shad	Bluegill	Bass
Temperature	-93.2	-40.3	-58.2
TSS	-34.0	-38.3	-18.6
Flow	-18.3	-20.6	-1.7
Nutrients	0.9	10.9	18.1
Initial biomass of biota	2.3	-1.6	-0.5
Detritus	-1.6	-1.0	0.8
Light	1.2	-0.5	0.9
Carbon dioxide	<0.1	<0.1	<0.1
Wind	<0.1	<0.1	<0.1
Oxygen	<0.1	<0.1	<0.1
pH	<0.1	<0.1	<0.1

due to washout of algae, detritus, and invertebrates. Sensitivity to the other parameters was generally low.

MODEL ANALYSIS WITH PCBS

The toxicant was represented with the default parameterization for PCB 1254. Initial toxicant levels in fishes were specified based on existing data from a representative site within the study reach from the initial study year (gizzard shad=2.35 ppm, bluegill=3.15 ppm, largemouth bass=3.33 ppm). PCB concentrations in fish showed low sensitivity (<10%) to a 10% increase in initial PCB concentrations in all biota. Initial levels in algae and benthic invertebrates were set to zero and allowed to equilibrate. Initial levels of PCBs in detritus were based on the range of concentrations measured in sediment (1.4 ppm, Brenner et al., 2004). The concentration of PCB in inflow water was set initially to the value measured upstream of the gage in 2000 (50 ng/L, Battelle, 2003).

We examined the response of fish PCB concentrations under different scenarios for toxicant loading: 1) no loadings, 2) constant PCB loading in water alone, 3) constant PCB loading in detritus alone, and 4) constant loading in both water and detritus. Results of these analyses are shown in Figure 2.

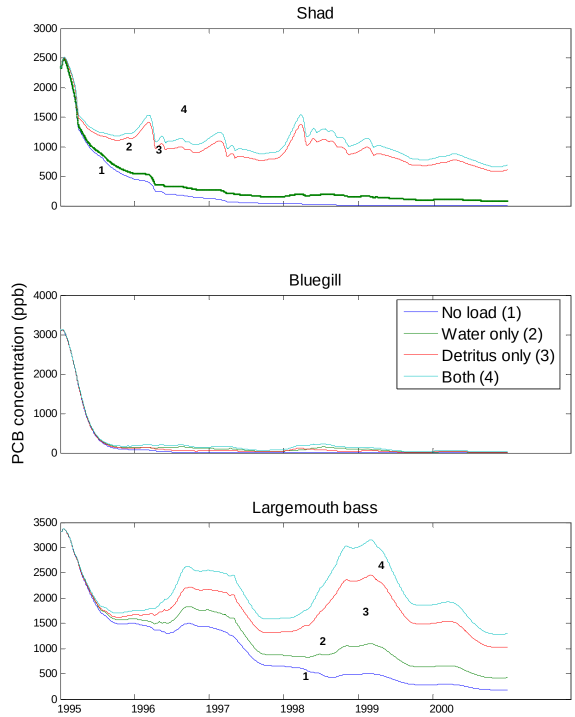

Figure 2. Predicted PCB concentrations in fish under alternative scenarios for PCB loading in Lake Hartwell TCA.

Overall, all the PCB levels in fish show a general downward trend with time. PCB levels in bluegill are generally low and are not affected by any of the scenarios. This is likely due to the high default elimination rate constant in the model (0.005/d), compared to the other two species (0.001 and 0.0007/d). This may not be realistic and may need more study. Largemouth bass concentrations stayed highest through time, which is expected due to the process of biomagnification.

When all PCB inputs were set to zero, PCB concentrations in gizzard shad and bluegill declined to nearly zero in 1997, while PCB concentrations in largemouth bass declined in a linear fashion to a value of 0.91 ppm at the end of the simulation.

Not surprisingly, the scenario with loading in both water and detritus results in the highest predicted PCB concentrations in fish. The predicted concentration of PCB in the lake for this scenario is 6-25 ng/L, which is in the range of the measured concentration of PCB in water at the study site in 2000 (7-70ng/L, Battelle, 2003). Surprisingly, the predicted PCB concentrations for sedimented detritus (the component of the sediment with which contamination would be associated) was very low, i.e., <1 ng/L.

Under the scenarios for the loading in water and detritus alone, predicted PCB concentrations in fish were intermediate. Under the scenario of constant PCB loading in water, PCB concentrations in fish from 1996-2000 stayed approximately constant at the following levels: gizzard shad=1.4 ppm, bluegill=0.2 ppm, largemouth bass= 2.4 ppm. The PCB concentration in bass at the end of the simulation was lower when detrital PCB loading was removed (0.96 ppm), as compared to the removal of water loading (1.8 ppm). As comparison, mean PCB concentrations measured in 2000 in gizzard shad, bluegill, and largemouth bass for the study site are: 4.7, 3.7, and 7.1 ppm. Some factors that could account for why predicted levels are still lower than observed include inaccurate growth rates of the fishes and inaccurate characterization of the amount and contamination of the input detritus.

CONCLUSIONS AND RECOMMENDATIONS

Ecological models can provide an understanding of food web dynamics and bioaccumulation in food webs. For Lake Hartwell, a calibrated simulation with the AQUATOX model suggests that fish biomass is controlled by lower trophic levels, and that detailed data are needed in particular for nutrients and TSS inputs. Also, fish biomass data through time are needed to calibrate model predictions. As more data are collected for calibration, the model predictions can be better refined and uncertainty reduced.

Once uncertainty is reduced in model inputs, the model may be used in the prediction of future PCB concentrations in fish under different scenarios for management of contaminated sediment. Our preliminary analyses suggest that some PCB loading into the system is occurring, in order to maintain the PCB levels in fish. This implies that continued loading will maintain measurable levels of PCBs in fish, particularly largemouth bass.

PCB concentrations in fish respond more strongly to inputs of contaminated detritus than contaminated water. The concentrations in input detritus are largely unknown, and these results suggest that quantifying this key component of the system is important for understanding the current dynamics.

An interesting finding is that the model was able to reproduce the observation that fish concentrations remained high while sediment concentrations declined to near zero. We attribute this result to the process by which contaminated detritus that enters the systems is consumed by benthic invertebrates and fish rather than being incorporated in the sediment.

ACKNOWLEDGMENTS

We are grateful for the assistance of Dick Park, Marjorie Wellman, Jon Clough, Earl Hayter, Bob Ambrose, Jim Lazorchak, Marc Mills, and two anonymous reviewers.

DISCLAIMER

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

LITERATURE CITED

Battelle, 2003. Natural Recovery of Persistent Organics in Contaminated Sediments at the Sangamo-Weston/ Twelvemile Creek/Lake Hartwell Superfund Site—Phase II. Submitted to EPA, Cincinnati, OH.

Brenner, R.C., V.S. Magar, J.A. Ickes, E.A. Foote, J.E. Abbott, L.S. Bingler, and E.A. Crecelius, 2004. Long-term recovery of PCB-contaminated surface sediments at the Sangamo-Weston/Twelvemile Creek/Lake Hartwell Superfund Site. *Environmental Science and Technology* 38:2328-2337.

Environmental Resources Management, 2001. Lake Hartwell 2001 Fish and Sediment Study: Operational Unit 2 ROD Monitoring Program. Report prepared for Schlumberger Limited.

Koelmans, A.A., A. van der Heide, L.M. Knijff, and R.H. Aalderink, 2001. Integrated modelling of eutrophication and organic contaminant fate and effects in aquatic ecosystems: a review. *Water Resources* 35:3517-3536.

Leidy, G.R. and R.M. Jenkins, 1977. The development of fishery compartments and population rate coefficients for use in reservoir ecosystem modeling. Report Y-77-1, USDI Fish and Wildlife Service, Fayetteville, Arkansas.

U.S. Army Corps of Engineers, 1996. Savannah River Basin Water Control Manual. U.S. Army Engineer District, Savannah , GA.

U.S. EPA, 2000a. AQUATOX for Windows, Volume 1: User's Manual. EPA-823-R-00-006, Office of Water, Washington, DC.

U.S. EPA, 2000b. AQUATOX for Windows, Volume 2: Technical documentation. EPA-823-R-00-007, Office of Water, Washington, DC.