MODELING PHOSPHORUS LOADING TO LAKE ALLATOONA: IMPLICATIONS FOR WATER QUALITY TRADING

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Abstract. Lake Allatoona, a large reservoir north of Atlanta Georgia that drains an area of about 2870 km^2, is threatened by excessive algal growth and scheduled for a phosphorus (P) TMDL. In this paper, we use the Soil Water Assessment Tool (SWAT) computer model to estimate the total P load to Lake Allatoona during the periods 1992-1996 and 2001-2004. We also use the model to estimate the contribution from different sources in the watershed. The total P load to Lake Allatoona increased by 20% between the two time periods. The contribution from point sources decreased from 30% to 13% of the total load due to permit restrictions on P for poultry processing plants. The largest nonpoint source of P was estimated to be forest land use in 1992-1996 accounting for 31% of the load and urban land use in 2001-2004 accounting for 50% of the load. Poultry/cattle land use accounted for 18% in 1992-1996 and 15% in 2001-2004. The implications for a program to trade P credits are: 1) point sources and poultry/cattle operations account for similar percentages of the current load, 2) urban development accounts for most of the current P load and should be brought into a trading program, 3) poultry processing plants that have not upgraded to better P removal technology might trade their current load to wastewater treatment facilities that accept their wastewater, 4) cattle in streams and row crops are not large sources according to our model, and 5) there is little net loss of P to streams during transport to Lake Allatoona so distance of a source from the lake may not be important in a trading scheme.

INTRODUCTION

Lake Allatoona is a large reservoir northeast of Metropolitan Atlanta threatened by excessive algal growth. Rapid population growth has occurred in the southern part of the watershed and broiler production is an important activity in the more rural northern part of the watershed. A typical broiler operation also raises beef cattle on pasture where broiler litter is applied. A comprehensive study of water quality in Lake Allatoona (the Lake Allatoona Phase I Clean Lakes Diagnostic Feasibility Study, referred to hereafter as the Clean Lakes Study) classified the lake as being in transition between mesotrophic and eutrophic, with P being the primary limiting nutrient for algal growth (Rose, 1999). As a result, the Georgia Environmental Protection Division (GAEPD) imposed a P load restriction of not more than 1.3 lb/acre-ft of lake volume per year (GAEPD, 2004). In 2006, the entire lake was placed on the state's 303(d) list due to excessive chlorophyll-*a* and a lake-wide TMDL for P is scheduled to be developed by 2008 (GAEPD, 2006).

Emissions trading has become a widely accepted tool of cost-effective environmental protection over the past two decades. The best known examples are the Acid Rain Trading Program created by Title IV of the 1990 Clean Air Act Amendments and the architecture for international burden sharing under the Kyoto Protocol. Emissions trading programs designed to meet water quality standards bring additional complexities compared to these better-knows programs that regulate atmospheric emissions. US EPA's recently-finalized policy on water quality trading (US EPA, 2003) sets forth the Agency's current framework for trading to meet water quality objectives. A primary objective of water quality trading is to meet or exceed environmental objectives at lower cost than alternative regulatory structures. Those entities that face high costs of nutrient emission reductions can transfer their obligation to those that have lower costs, and do so in a way that makes both parties better off from the exchange.

The Soil and Water Assessment Tool (SWAT) model has been widely used for modeling P loading at the watershed scale (see for example Srinivasan et al., 2005). In this paper, we use SWAT to develop an estimate of the P load during the same period that the Clean Lakes Study was conducted (1992-1996) and in a more recent period (2001-2004). We also use SWAT to estimate the sources (point, forest, urban, and agricultural) of the load. Last, we discuss the implications of our model estimatees for a P trading program in the Lake Allatoona Basin.

MATERIALS AND METHODS

We subdivided the Lake Allatoona watershed into six sub-watersheds and a SWAT model was set up for each sub-watershed (Figure 1). Two sets of land cover data for this watershed were obtained from the Multi-Resolution Land Characteristics Consortium: NLCD 1992 (National Land Cover Data 1992) and NLCD 2001.

The pasture area used by the poultry/beef-cattle operations was estimated using 1999 aerial photos assuming that pasture within a 0.75-km radius of poultry houses received poultry litter. The soil test P (STP) concentration in soils of the watershed were estimated using county averages contained in a database of samples submitted to the University of Georgia Environmental Services Lab by landowners in the watershed. All pasture used by the poultry/beef-cattle operations were assumed to receive 6.73 Mg ha^{-1} broiler litter each year with a P content of 1.6%.

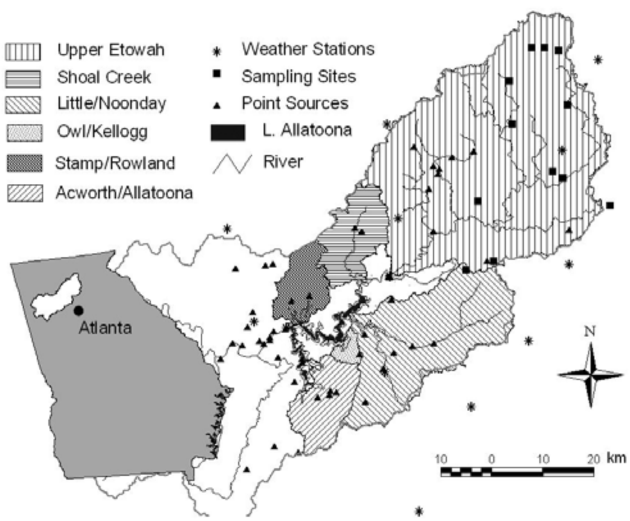

Figure 1. Lake Allatoona watershed and the six sub-watersheds.

The sediments and P loadings resulted from cattle in streams were incorporated into our SWAT models as “point sources” in sub-basins. Based on measurements by Matthew (2001), we estimated the total sediment load from cattle in streams for each sub-basin was 1.54 kg ha^{-1} day^{-1}. Byers et al. (2005) using GPS units attached to beef cows estimated that, on average, cattle spend about 7.0% of the time in streams. We used this estimate along with literature estimates of manure production and P content for beef cattle to estimate the daily load to streams of inorganic P (0.00038 kg ha^{-1} day^{-1}) and organic P (0.00063 kg ha^{-1} day^{-1}).

Overall, about thirty point source dischargers were identified within the Lake Allatoona watershed. But only 21 of them had monthly discharge monitoring reports (DMRs) that were available through the USEPA Envirofact database (http://www.epa.gov/enviro/index.html, last accessed August 21, 2006) or through the GAEPD Cartersville Regional Office. DMR data was not available for the two poultry processing plants in the watersheds during the 1992-1996 period since P limits were not imposed in their NPDES permits. We assumed that TP concentrations in the effluents from poultry processing and rendering plants changed significantly before and after the plants were required to start monitoring the TP concentrations in their effluents in 2001. The range of the TP concentration in the effluent from a typical poultry processing plant (including slaughter, further processing and rendering processes) was 15-48 mg L^{-1} before it was required to monitor TP concentrations (U.S.EPA, 2004). Therefore, an average TP concentration of 18 mg L^{-1} in the untreated effluents from poultry processing plants was assumed when data were not available. By comparison, the average monitored TP concentration in the effluent from a poultry processing plant located in the Upper Etowah sub-watershed was 4.14 mg L^{-1} over the recording time period (2003-2004) when the effluents received treatment.

Stream ecologists use the concept of “uptake length” to measure the net assimilation rate of nutrients in streams. The uptake length is defined as the average distance that a dissolved nutrient molecule travels before being taken up (Newbold et al., 1981). In a manner similar to the experiments conducted by stream ecologists, in our SWAT models we added a small point source in a headwater sub-basin, then adjusted the in-stream parameter values to get an uptake length of P similar to the values measured in the streams in this region.

A two-stage strategy was employed to calibrate the SWAT models. In the first stage, a classical approach suggested by the SWAT User’s Manual – stream flow is calibrated first and the calibrations of sediment and P concentrations follow (Neitsch et al., 2002) –was adopted. In this stage, except for the Etowah River daily streamflow, the calibrations of water flow, SS and TP concentrations in all tributaries were carried out manually due to the relatively sparse datasets (biweekly sampling). The daily streamflow in the Etowah River at Canton, GA was calibrated automatically by the method proposed in Lin and Radcliffe (2006). In the second stage, the refining of the calibrations of water flow, SS and TP concentrations in streams was carried out simultaneously using PEST, the model-independent auto-calibration software developed by Doherty (2004).

RESULTS

P Loading to Lake Allatoona

The primary land uses in the Lake Allatoona watershed are forest, pasture, and urban (Figure 2). The region has recently undergone rapid urbanization and the area of urban land cover increased 227% from 1992 to 2001. Pasture and grassland grew about 50% while forest and row crop agriculture lost about 20 % and 91%, respectively.

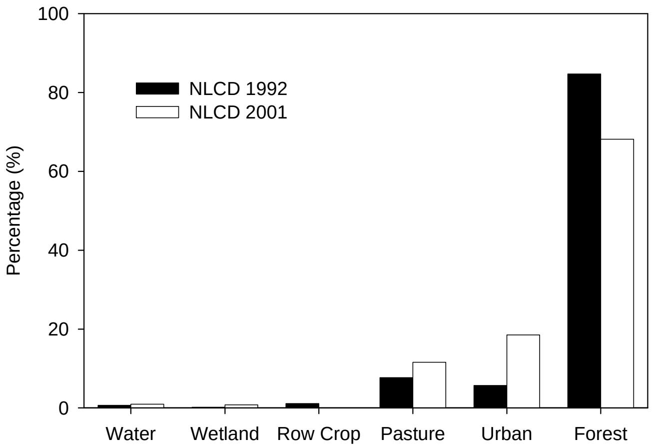

Figure 2. Lake Allatoona watershed land use distributions for 1992 and 2001.

Soil test P concentrations were highest in pasture land use based on samples taken during the period 1992-1996 and 2001-2004 (Figure 3). This is probably due to repeated application of poultry manure which has a high proportion of P relative to nitrogen (N) in terms of the agronomic requirements of pasture. When poultry manure is applied at a rate sufficient to satisfy the N needs of pastures, an excess of P accumulates in the topsoil. The lowest level of STP occurred in forest landuse. Between the two time periods, STP in urban land use dropped slightly. There were no STP data for forest in 1992-1996, hence we could not determine changes. The average soil test P levels in both pasture and row crop land uses increased one third from the time period of 1992-1996 to the time period of 2001-2004.

According to the SWAT models, the average annual total P load to Lake Allatoona was 131,611 kg/yr during the period 1992-1996 (Table 1). This load represented 68% of the limit on annual P load imposed by GAEPD (2004). Point sources accounted for 30% of the total load. Forest land use litter was the largest nonpoint source, contributing 31% of the P load. Forest contributed a high percentage of the total load because of the high land use in the watershed (Figure 2). Pasture that received litter contributed 15% of the load. This land use had a high load due to the high STP levels (Figure 3). Urban land use contributed 17% of the load during this period. Row crops were a minor source due to the low percentage of land use (Figure 2). Cattle in streams contributed only 1%.

During the period 2001-2004, the average annual total P load to Lake Allatoona increased by 21% to 172,216 kg/yr. This load represented 86% of the limit on annual P load imposed by GAEPD (2004). The point source contribution decreased to 13% of the total load during this period due to routing of the discharge from one of the poultry processing plants to a waste water treatment facility. Urban land use was the largest contributor with 50% of the load. Next was forest land use with 20%. Urban contributions grew between the time periods due to increased land use (Figure 2). Cattle in streams and row crops were still minor contributors.

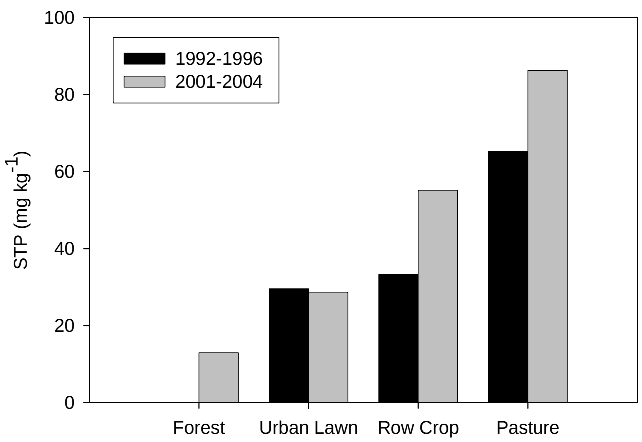

Figure 3. Soil test P concentrations in the Lake Allatoona watershed during the periods 1992-1996 and 2001-2004.

Table 1. Sources of P load in 1992-1996 and 2001-2004.

Source	**1992-1996**		**2001-2004**	
	kg/yr	**%**	**kg/yr**	**%**
Point	40,258	29.5	22,948	13.3
Pasture with Litter	19,974	14.6	22,317	13.0
Pasture without Litter	5,052	3.7	3,713	2.2
Row crops	4,901	3.6	784	0.5
Forest	41,993	30.7	33,958	19.7
Urban	22,515	16.5	85,566	49.7
Cattle in Streams	1,918	1.4	2,930	1.7
Total	136,611	100.0	172,216	100.0

Our estimates of P uptake length under a short period of baseflow conditions ranged from 52 to 149 km. This is comparable to the uptake lengths measured by Gibson (2004) in the main stem of Chattahoochee River near Atlanta (11 to 85 kilometers). We also performed our "measurements" of uptake length over the entire calibration period which included storm flow conditions and found that uptake lengths were much longer, 71-227 km. This indicated that on a long-term basis, the stream reaches are not a large sink for P and most of the P that enters streams in the Lake Allatoona watershed reaches the lake within a few years.

Implications for Water Quality Trading

Obropta and Rusciano (2006) propose a method for assessing the suitability of a watershed for a P trading program. One of the criteria is related to the relative size of the nonpoint and point source P loads. If the nonpoint source load is small compared to the point source load, then it is a "thin market" and there are not enough sellers of P credits. If the point source load is too small then reducing point source loads through trading is not likely to have a significant impact. Obropta and Rusciano (2006) assume that a trading ratio between 2:1 and 4:1 is likely to account for uncertainty in the nonpoint source and arrive at a preferred range for the ratio of nonpoint:point loads between 4:1 and 10:1. Using the percentages in Table 1, we obtained estimated ratios of 2.4:1 in 1992-1996 and 6.5:1 in 2001-2004 for the Lake Allatoona watershed. These ratios are close to the range specified by Obropta and Rusciano (2006), indicating that there is a significant point source load and there are sufficient nonpoint sellers to accommodate a large trading ratio to account for uncertainty.

The nonpoint source contributors (and therefore potential sellers) are poultry/cattle operations and urban land uses. The contribution from row crops is minimal so buying credits to implement conservation tillage practices would have minimal impact. Similarly, the contribution from cattle in streams is very small and this surprised us since we thought limiting cattle access to streams would be an important credit that could be sold. It may be that the way we implemented the effect of cattle in streams in SWAT did not account for the full impact. This could be true if cattle are more likely to defecate when they are near streams (there's anecdotal evidence of this) or if cattle reduce the ability of stream biota to store P.

Our results that show long nutrient uptake lengths when we include periods of storm flow indicate that most of the P that enters a stream arrives at Lake Allatoona within a few years. This implies that the distance from the lake of a nonpoint seller of P credits is not an important factor.

Point source reductions have been achieved when GA EPD allowed a poultry processing plant to "trade" it's waste load allocation to a WWTF which had much lower discharge P concentrations. The WWTF gained additional waste load allocation for future expansion. This may be a model for point-to-point trades in this and other watersheds.

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