SHORT-TERM AND LONG-TERM SEDIMENT AND PHOSPHORUS INPUTS TO LAKE LANIER

Xiaoqing Zeng[1] and Todd C. Rasmussen[2]

AUTHORS: [1]Graduate Student and [2]Associate Professor, UGA School of Forest Resources, Athens, GA 30602.

REFERENCE: Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at The University of Georgia, Kathryn J. Hatcher, Editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Abstract. The rating curve method is used to quantify daily sediment and phosphorus loads to Lake Lanier. The sediment rating curve was constructed using discharge and suspended sediment records for the Chattahoochee River and tributaries. Bedload sediment transport is not included in the sediment rating curve. The daily variability of sediment concentration is reconstructed using the discharge-sediment rating curve. Total phosphorus concentrations are strongly correlated with sediment concentrations. This approach is superior to other sediment and nutrient yield models (e.g., the Universal Soil Loss Equation) because the seasonal and annual estimates provided by these approaches are not compatible with the need to model lake water quality dynamics on a daily basis.

INTRODUCTION

Suspended sediment loading in the Chattahoochee River above Atlanta, Georgia, is a concern to water resources managers from a multitude of perspectives. Suspended sediments diminish aesthetic values in the rivers that flow into Lake Lanier, a major water supply reservoir for the City of Atlanta. The sediments also interfere with recreational opportunities in Lake Lanier, along with fisheries productivity by adversely impacting biological integrity. The sediments also serve as a mechanism for transport of nutrients and heavy metals, interfere with municipal water filtration, serve to fill valuable riparian wetlands, floodplains and reservoir capacity, and diminish channel flood-carrying capacities.

Phosphorus loading into Lake Lanier is another concern. The increased availability of nutrients in the lake, particularly phosphorus compounds (phosphorus is a limiting nutrient in many Georgia lakes), will create conditions ripe for the explosive transient growth of microorganisms which occupy a position at the base of the lake's ecological system. This explosive growth will temporarily unbalance the system during periods within the annual cycle, and also cause gradual change - from year to year - in terms of species abundance and diversity.

The large growth of phytoplankton can be unsightly, and can be linked with taste and odor problems, fish kills and a loss of regional income from tourism around the lake. The phytoplankton and bacterial growth can also markedly increase the costs of treating the lake's water to meet drinking water supply requirements.

Watershed models are readily available to evaluate sediment production and nutrient loading. These models may be broken into two groups, urban (DR3M, STORM and SWMM) and non-urban (ANSWERS, EPIC, SWRRB, WEPP, SWAT, HSPF, and AGNPS). Several of these watershed models have been applied in both settings, but are categorized based on their initial development. Table 1 is a brief summary of these models.

Table 1. Summary of watershed models

Model	Name	Source
DR3M†	Distributed Routing, Rainfall, Runoff Model	USGS Alley and Smith, 1982a
STORM †	Storage, Treatment, Overflow Runoff Model	ACE HEC, 1977
SWMM †	Storm Water Management Model	Metcalf and Eddy CEAM, 1994
ANSWERS †	Areal Nonpoint Source Watershed Environment Response Simulation	U.S. EPA Beasley and Huggins, 1982
EPIC † ‡	Erosion/Productivity Impact Calculator	USDA-ARS-SCS Sharpley and Williams, 1990
SWRRB ‡	Simulator for Water Resources in Rural Basins	USDA-ARS Arnold and Williams 1994
WEPP ‡	Water Erosion Prediction Project	USDA Flanagan et al. 1995
SWAT ‡	Soil and Water Assessment Tool	USDA Arnold et al. 1995
HSPF ‡	Hydrologic Simulation Program-FORTRAN	USGS Bicknell et al., 1993
AGNPS †	Agricultural Non-Point Source	USDA-ARS Young et al. 1994

† USLE – Universal Soil Loss Equation
‡ RUSLE – Revised Universal Soil Loss Equation

LAKE LANIER AND TRIBUTARY WATER QUALITY MONITORING IN 1996/97

Lake Lanier is a 38,500 acres impoundment created by Buford Dam in north Georgia. It is the most important impoundment in the Atlanta metropolitan area. The reservoir is used for water supply, hydropower generation, flood control and recreation. Buford Dam, which impounds Lake Lanier, is located about 50 miles northeast of Atlanta. Average inflow to the lake is 2074 cubic feet per second. Of this flow, about 70% is contributed by the Chattahoochee River and the Chestatee River. The Lake Lanier watershed covers 1040 mi^2, which includes land in Forsyth, Habersham, Hall, Lumpkin, White, Dawson, Gwinnett and Union Counties.

The 1996-97 monitoring program was conducted by the Upper Chattahoochee Basin Group primarily to collect data required for development and application of watershed loading and lake water quality response models for Lake Lanier. The general data requirements were defined through the identification of particular water quality concerns. Monitoring began in March 1996 and ended in March 1997.

Tributary monitoring was conducted at the mouths of ten significant tributaries to Lake Lanier. These stations were divided into two subsets: (i) major stations at the Chattahoochee River and the Chestatee River, and (ii) minor stations at the other tributaries. Routine tributary monitoring was conducted monthly at all minor stations and biweekly at the Chattahoochee River and the Chestatee River stations. Monitoring parameters include dissolved oxygen, pH, specific conductivity, secchi depth, total suspended solids, total dissolved solids, total organic carbon, dissolved organic carbon, alkalinity, total phosphorus, total Kejldahl nitrogen, ammonia, nitrite plus nitrate, total iron and total manganese.

SHORT-TERM EVALUATION OF SEDIMENT AND PHOSPHORUS INPUTS

Most watershed models as reviewed before use either the Universal Soil Loss Equation (USLE) or Revised Universal Soil Loss Equation (RUSLE) to estimate sediment production. Both approaches uses factors such as erosivity index (R), soil erodibility factor (K), field slope (S) and length (L), crop management factor (C), and conservation practice factor (P), which are difficult to quantify accurately. Moreover, USLE or RUSLE were developed for the estimation of annual sediment production, and have limited ability to predict on a daily-basis.

Geographical Information Systems (GIS) are increasingly being used to determine the important watershed factors (such as topography, soil type and land use, etc). GIS applications improve the convenience of modeling, but the accuracy may still be limited due to complicated processes associated with sedimentation. In addition, GIS focuses on soil erosion to the whole water network in the watershed, therefore it is difficult to provide information for the final receiving water body.

An alternative approach for quantifying sediment loading into Lake Lanier uses the Rating Curve Method, which uses the correlation between stream discharge and suspended sediment concentration. Previous research by Holmbeck-Pelham and Rasmussen (1997) has established the following functional equation based on USGS daily data in the past 20 years:

$$SSC(t) = SSC_o \left[\frac{Q(t)}{Q_o}\right]^b \tag{1}$$

Where $SSC(t)$ and $Q(t)$ are the average suspended sediment concentrations and discharges on tth day, Q_o is the long-term annual mean discharge, b is equal to 1.6 ± 0.05 for the four USGS stations in the Upper Chattahoochee River watershed and the Chestatee River watershed, and SSC_0 is the suspended sediment concentration at mean discharge for each site. SSC_o was estimated using USGS sediment and stream discharge data for the Lake Lanier watershed, which is 16.5 mg/L, yielding:

$$SSC(t) = 16.5 \left[\frac{Q(t)}{Q_o}\right]^{1.6} \tag{2}$$

The daily sediment load (assuming uniform flow during the day) is:

$$W(t) = \left[\sum_j Q_j(t)\right] SSC(t) = Q_T(t)\ SSC(t) \tag{3}$$

Where $Q_j(t)$ is the discharge of jth tributary on tth day and $Q_T(t)$ is the total inflow of the watershed on tth day.

Equation (3) estimates daily sediment loading by multiplying the continuous daily sediment concentration and continuous daily inflow. It is important to know the average daily concentration and average daily inflow, especially for high-inflow event days. From Figure 1, the measured maximum concentrations of SSC in the Chattahoochee River and the Chastatee River is approximately 120 mg/L. Therefore we set this value as the upper limit when using equation (3). Otherwise the loads will be overestimated for high-inflow event.

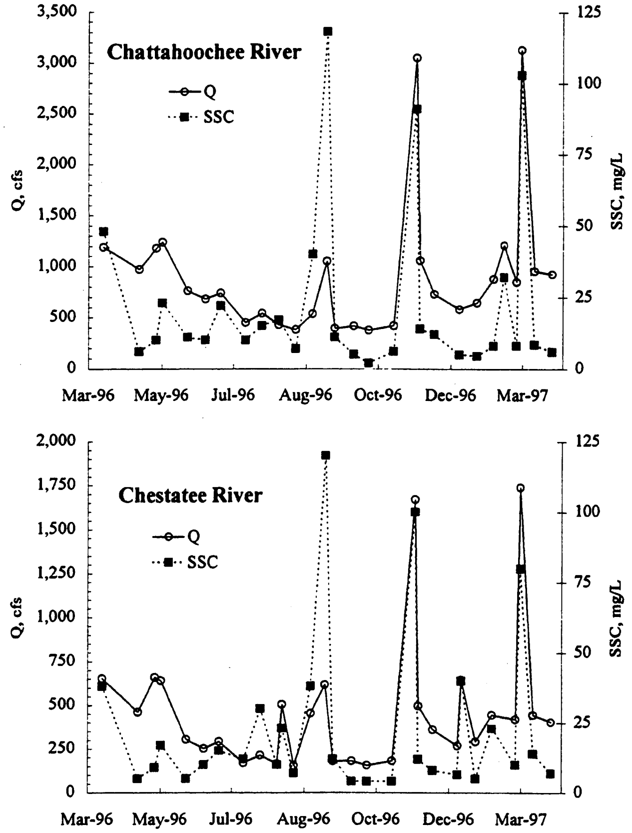

Figure 1. Discharge (Q) and Suspended Solids Concentration (SSC) for the Chattahoochee River (above) and Chestatee River (below).

While the SSC occasionally exceeds 120 mg/L on small streams during the sampled period, these events have a small effect on the final estimation result of the whole watershed because their discharges are much less than the Chattahoochee River and the Chastatee River.

Applying equation (3) to the whole year, the total sediment loading (W_T) in the watershed can be expressed as:

$$W_T = \sum_{t=1}^{365} W(t) = \sum_{t=1}^{365} Q_T(t)\ SSC(t) = k\ Q_o\ SSC_o \qquad (4)$$

Where $Q_o = 2704$ cfs is the mean annual inflow to Lake Lanier in 1996, $SSC_o = 25.22$ mg/L is the mean suspended sediment concentration at the mean flow in 1996, and $k = 2.0$ is a factor that accounts for the rating curve bias between annual- and daily-based methods. Figure 2 is the estimated result of daily sediment concentration.

Phosphorus concentration is strongly correlated with suspended sediment concentration. The relationship derived from the tributary monitoring data in 1996/97 is shown in Figure 3. Daily phosphorus loading can be estimated based on this relationship (Figure 4).

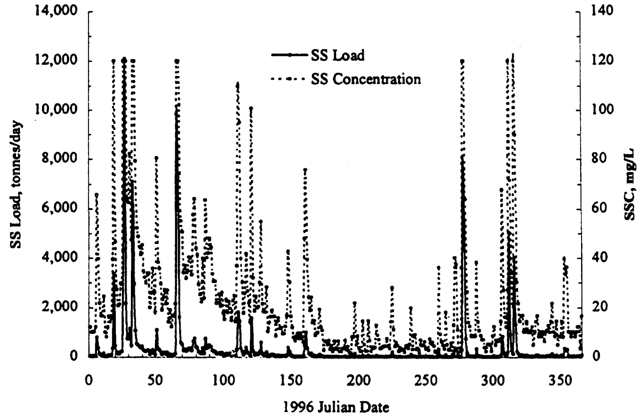

Figure 2. 1996 Lake Lanier inflow Suspended Solids Concentration (mg/L) and Load (tonnes/day).

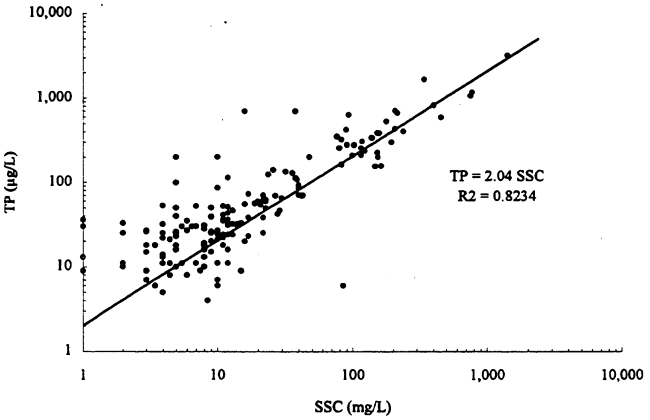

Figure 3. Total Phosphorus Concentration vs. Suspended Solids Concentration for Lake Lanier, 1996.

LONG-TERM EVALUATION OF SEDIMENT AND PHOSPHORUS INPUT

Equation (1) was obtained from statistical analysis of 20-years of USGS daily data. The equation is useful for the short-term analysis of sedimentation, as well as for long-term evaluations if there exist sufficient long-term daily data. When there are only annual data, Equation (4) provides a simple way to estimate the long-term sediment production. Figure 5 is the estimation results using Equation (3) and Equation (4) based on historical inflow into Lake Lanier between 1979-1999. The results coincide well. In addition, Figure 5 also indicates that the trend of the long-term estimation result is similar to the observed.

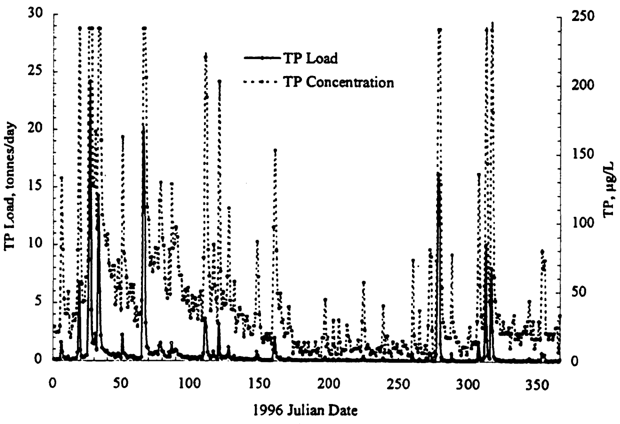

Figure 4. 1996 Lake Lanier Total Phosphorus (TP) Concentrations and Loads.

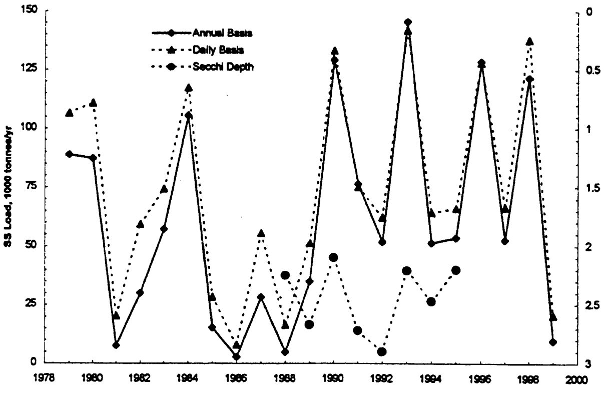

Figure 5. Comparison between Suspended Solids Loads and observed Secchi Depths, Lake Lanier, 1979-1999.

CONCLUSIONS

Knowledge of the temporal variability of sediment and phosphorus loads into Lake Lanier from the principal tributaries (i.e., the Chattahoochee River and the Chestatee River) is crucial to evaluation of the future response of the lake to changes in these inputs. The rating curve method is shown to accurately simulate patterns of loading. It is also shown that a rating-curve bias correction factor ($k \approx 2$) should be applied when using annual mean inflow and mean concentrations of suspended sediment and phosphorus to estimate annual loads. Annual loads are underestimated when the rating-curve bias correction factor is not used.

LITERATURE CITED

Alley, W. M., and Smith, P.E. (1982a). "Distributed routing rainfall-runoff model—Version II; Computer program documentation user's manual," Open-File Report 82-344, U.S. Geological Survey.

Arnold, J. G., and Williams, J. R. (1994). "SWRRB; A watershed scale model for soil and water resource management," Grassland Soil and Water Research Laboratory, U.S. Department of Agriculture-Agriculture Research Service, Temple, TX.

Beasley, D.B. and F.F Huggins. (1977). ANSWERS (Areal Non-point Source Watershed Environmental Response Simulation) User's Manual (EPA-905/9-82-001). U.S. Environmental Protection Agency, Region IV, Chicago, IL.

Bicknell, B. R., Imhoff, J. C., Kittle, J. L., Jr., Donigian, A. S., Jr., and Johanson, R. C. (1993). "Hydrological Simulation Program—Fortran user's manual for Release 10," EPA/600/R-93/174, U.S. Environmental Protection Agency, Athens, GA.

Center for Exposure Assessment Modeling. (1994). "SWMM, storm water management model version 4.30," U.S. Environmental Protection Agency, Office of Research and Development, Athens, GA.

Flanagan, D. C., Ascough, J. C., II, Nicks, A. D., Nearing, M. A., and Laflen, J. M. (1995). "Overview of the WEPP erosion prediction model," *USDA-Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation*, D. C. Flanagan and M. A. Nearing, eds., NSERL Report No. 10, U.S. Department of Agriculture-Agriculture Research Service, National Soil Erosion Research Laboratory, West Lafayette, IN.

Hydrologic Engineering Center. (1977). "STORM storage, treatment, overflow runoff model user's manual," CPD-7, U.S. Army Corps of Engineers, Davis, CA.

Sharpley, A. N., and Williams, J. R., eds. (1990). "EPIC-Erosion/ productivity impact calculator; 1. Model documentation," Technical Bulletin No. 1768, U.S. Department of Agriculture.

Skelly A. Holmbeck-Pelham, Todd C. Rasmussen. (1997). Proceedings of the 1997 Georgia Water Resources Conference. March 20-22, 1997, Athens, GA. pp 144-147.

Young, R. A., Onstad, C. A., Bosch, D. D., and Anderson, W. P. (1994). "Agricultural Non-Point Source Pollution Model, Version 4.03, AGNPS user's guide," North Central Soil Conservation Research Laboratory, U.S. Department of Agriculture-Agriculture Research Service, Morris, MN.