EVALUATION OF TOTAL PHOSPHORUS IN THE ALTAMAHA-OCMULGEE-OCONEE RIVER BASIN

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Abstract. Total phosphorus (TP) data collected by the U.S. Geological Survey (USGS) between 1992 and 2003 for 23 mainstem river and headwater tributary stations in the Altamaha-Ocmulgee-Oconee (AOO) river basin were evaluated. The highest mean TP concentrations occurred at stations in the vicinities of Athens and Macon, the largest cities in the basin. Mean concentrations exhibited more variability at stations in the upper reaches of these two watersheds. Mainstem concentrations in the lower reaches were similar to each other and to concentrations in the Altamaha River. TP concentration and yield decreased in the Oconee River from upstream to downstream of Lakes Oconee and Sinclair. TP loads associated with effluent from wastewater treatment plants were 24 to 31 percent of the TP load calculated for the furthest downstream stations on the mainstem rivers. TP concentrations of the mainstem rivers approximated the midpoint of baseflow and stormflow concentrations reported for forested tributaries in the Apalachicola-Chattahoochee-Flint (ACF) river basin. TP loads in the mainstem AOO rivers were comparable to scaled up loads using the midpoint TP concentration of the forested ACF tributaries as a basis.

INTRODUCTION

Eutrophication of surface waters in the southeastern U.S. is most commonly limited by phosphorus. Support of beneficial uses of surface waters requires effective management of point and nonpoint sources of phosphorus. Predominant point sources of phosphorus are permitted discharges of treated effluent by wastewater treatment plants (WWTPs) to surface waters. Nonpoint sources of phosphorus are largely associated with anthropogenic management practices associated with urban, agricultural, and silvicultural land uses.

The amount of phosphorus at a location in a river or lake reflects the net effect of all natural and anthropogenic inputs and biogeochemical processes occurring at and upstream of that location. Reservoirs of the Georgia Piedmont are particularly influential on phosphorus transport as phosphorus bound to sediments from tributary inflows is attenuated by particle settling and uptake by phytoplankton and macrophyte vegetation (Frick et al., 1996; Parker 2004).

Objectives

The objectives of this paper are to (1) evaluate general trends of phosphorus concentrations and loads, (2) assess the importance of reservoirs and wastewater effluent discharge on in-stream phosphorus, and (3) compare phosphorus concentrations to those reported by Frick et al. 1998 for tributaries in the Apalachicola-Chattahoochee-Flint (ACF) river basin with one predominant land use. This investigation uses total phosphorus (TP) and flow data collected and reported by the U.S. Geological Survey (USGS) for the Altamaha-Ocmulgee-Oconee (AOO) river basin.

Study Area

The Altamaha River is formed by the confluence of the Ocmulgee and Oconee Rivers and discharges to the Atlantic Ocean. The principle physiographic provinces of the AOO basin are the Piedmont and Coastal Plain. Characteristics of the watersheds are described in detail by the Georgia Department of Environmental Protection (Georgia EPD) (1998, 2004a, and 2004b). Forest cover is the predominant land use type in each watershed, comprising approximately 44 to 60 percent of total land cover. Urban areas comprise 1.3 to 3.3 percent of the watersheds. The main urban areas include Atlanta's eastern suburbs and Macon in the Ocmulgee watershed plus Athens in the Oconee watershed. Pasture and cultivated earth comprise 19 to 23 percent. As many as 550 poultry operations plus beef and dairy operations are located in the upper Oconee watershed (Fisher et al., 2000). Clear cut forestry and young pine comprise 9 to 18 percent. Two major reservoirs, Lake Oconee and Lake Sinclair are located on the Oconee River. On the Ocmulgee River, Lake Jackson is located at the confluence of the South, Yellow, and Alcovy Rivers. The Ocmulgee River originates at the mouth of Lake Jackson.

METHODS

Total phosphorus (TP) data were obtained for 23 water quality monitoring stations within the AOO basin (USGS, 2005) (Table 1). Stations were limited to those located on the 3 mainstem rivers plus their respective, larger headwater tributaries. The stations were further limited to those with data covering more than 2 years (24 months) and for which basin area was immediately available. The data used in the evaluation was collected by the USGS between 1992 and 2003. Data collected before 1992 were not included in the evaluation to eliminate the use of data collected before or within one year after a statewide restriction on phosphate detergents was made effective in Georgia in January 1991. For concentrations reported as below detection (<0.02 mg/L), a concentration of 0.01 mg/L was used.

In-stream TP loads (kg/day) were calculated for each station as the product of mean TP concentration and the station's mean annual flow. Mean annual flow was determined through application of a power equation ($Q = 2.0923*A^{0.9219}$; $R^2=0.9988$) relating mean annual flow (Q in cfs) to basin area (A in mi^2) for 11 USGS gaging stations (Table 2) in the AOO basin with 20 or more years of recorded flow data (Hickey et al., 2004). Note that the stations listed in Table 2 do not all correspond to stations in Table 1.

Table 1. Monitoring Stations with Total Phosphorus Concentration Data Used in Evaluation

Station I.D.	Station Name	Number of Observations
02204810	South R. nr. Snapping Shoals	81
02208005	Yellow R. nr. Stewart	134
02209620	Alcovy R. nr. Stewart	135
02210500	Ocmulgee R. nr. Jackson	39
02212950	Ocmulgee R. abv. Macon	112
02213700	Ocmulgee R. nr. W. Robins	132
02214265	Ocmulgee R. nr. Bonaire	37
02215260	Ocmulgee R. at Abbeville	24
02215500	Ocmulgee R. at Lumber City	139
02217515	Mid. Oconee R. at Athens	25
02217646	N. Oconee R. nr. Nicholson	26
02217740	N. Oconee R. at Athens	51
02217950	N. Oconee R. at Whitehall	25
02218000	Oconee R. nr. Watkinsville	136
02218300	Oconee R. nr. Penfield	24
02223000	Oconee R. at Milledgeville	50
02223250	Oconee R. nr. Toomsboro	33
02223600	Oconee R. nr. Dublin	132
02224310	Oconee R. nr. Soperton	24
02224500	Oconee R. nr. Mt. Vernon	37
02225000	Altamaha R. nr. Baxley	38
02226010	Altamaha R. nr. Gardi	128
02226160	Altamaha R. nr. Everett City	62

Table 2. USGS Gaging Stations with Mean Annual Flow Data Used in Evaluation

Station I.D.	Station Name	Basin Area (mi^2)	Mean Annual Flow (cfs)
02219000	Appalachee R. nr. Bostwick	176	239
02217500	Mid. Oconee R. nr. Athens	398	525
02218300	Oconee R. nr. Penfield	940	1265
02223000	Oconee R. at Milledgeville	2950	3125
02223500	Oconee R. at Dublin	4400	4482
02225000	Altamaha R. nr Baxley	11600	11650
02226000	Altamaha R. at Doctortown	13600	13730
02208450	Alcovy R. abv. Covington	185	248
02210500	Ocmulgee R. nr. Jackson	1420	1779
02213000	Ocmulgee R. at Macon	2240	2669
02215500	Ocmulgee R. at Lumber City	5180	5482

Wastewater effluent data were obtained for 36 (>1 MGD) WWTPs permitted to discharge to AOO basin surface waters. Data were obtained from the U.S. Environmental Protection Agency's (EPA) Permit Compliance System database (EPA, 2005). The period of data is 1998 to 2004. Mean daily TP loads were calculated for each WWTP using mean monthly effluent discharge and TP concentration data. For 16 WWTPs that did not report TP concentration to EPA, a TP concentration of 1.00 mg/L was used. This concentration represents the mean monthly effluent TP concentration calculated from the 20 WWTPs for which effluent TP concentration was reported.

TP concentration data reported by Frick et al. (1998) were obtained for ACF basin tributaries draining watersheds with one predominant land use. These data were collected between 1993 and 1995. The midpoint between median base flow and storm flow TP concentrations was interpreted from a box-whisker graph in Frick et al. (1998) for tributaries with poultry (0.395 mg/L), urban (0.265 mg/L), forest (0.08 mg/L) land uses. This data was used for two purposes. First, it was compared with TP concentrations in the AOO basin. Second, the data was converted to TP loads by multiplying the land use-based concentrations times mean annual flow as a function of basin area. The scaled up loads were compared with TP loads calculated for USGS monitoring stations in Table 1.

RESULTS AND DISCUSSION

Figure 1 is a graph of mean TP concentrations reported by the USGS for the monitoring stations listed in Table 1. The y-axis is TP concentration and x-axis is basin area. Stations within each of the three individual AOO watersheds are shown. Mainstem stations are connected by solid (Ocmulgee), dashed (Oconee), and solid, bold

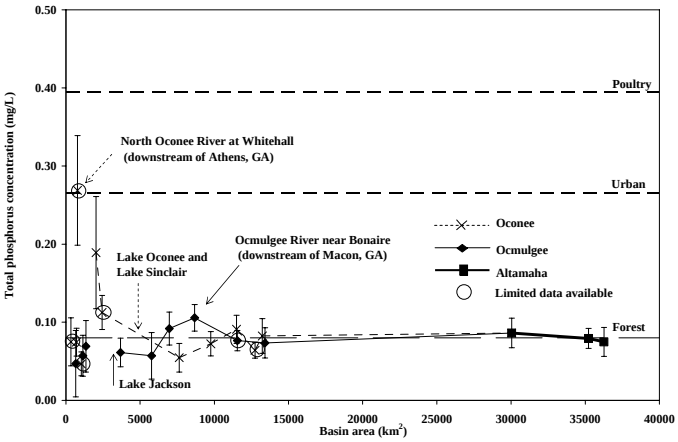

Figure 1. Total phosphorus concentrations in AOO basin, 1992-2003.

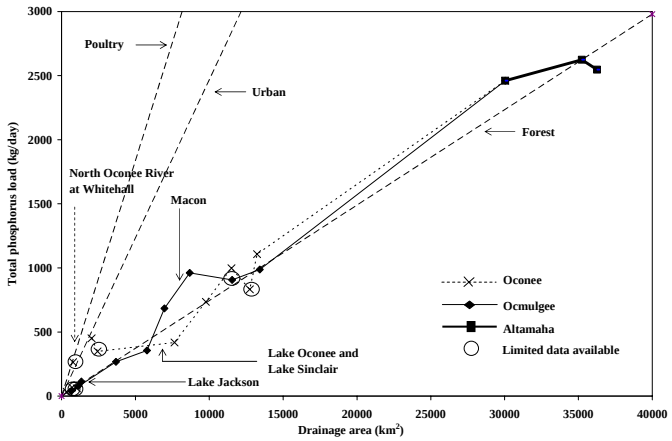

Figure 2. Total phosphorus loads in AOO basin, 1992-2003.

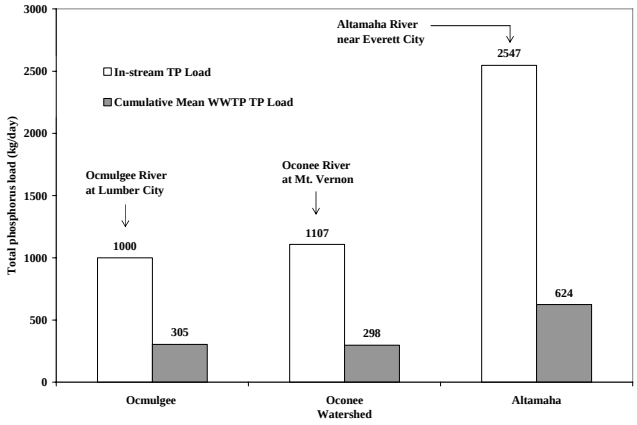

Figure 3. Comparison of in-stream and WWTP total phosphorus loads in the AOO basin.

(Altamaha) lines. Error bars correspond to the standard deviation of TP concentration data for each station. The circles indicate stations with only two years of data. The highest mean TP concentration occurred on the North Oconee River at Whitehall. This station is the first USGS station downstream of Athens and a 10.72 MGD (Georgia EPD, 1998) WWTP that discharges to the North Oconee River. The highest mean TP concentration of all Ocmulgee River watershed stations occurred in the Ocmulgee River near Bonaire, which is downstream of Macon. Two WWTPs in Macon discharge to the Ocmulgee River with a combined, permitted discharge of 44 MGD (EPD, 2004).

The data displayed in Figure 1 suggests that the mean TP concentrations are more variable on a station-to-station basis in the upper portions of the AOO basin. Mean TP concentrations in the Altamaha River appear to be less variable than concentrations at stations in the Ocmulgee and Oconee watersheds. The concentrations in the lower reaches of the Ocmulgee and Oconee rivers are similar to each other as well as to the concentrations observed in the Altamaha River.

On the Oconee River, TP concentrations decreased from upstream to downstream as the river passes through Lake Oconee and Lake Sinclair. This decrease continues a decrease from the station further upstream on the Oconee River. On the Ocmulgee River, the TP concentration downstream of Lake Jackson is comparable to the range of TP concentrations in the 3 influent tributaries to Lake Jackson. Decreases in TP concentrations in the Chattahoochee River were reported by Frick et al. (1996) for three of the four reservoirs on that river.

The TP concentrations corresponding to ACF basin tributaries with poultry, urban, and forest land uses are shown as horizontal, dashed lines in Figure 1. With the exception of two stations in Oconee River watershed, TP concentrations at AOO basin stations approximate the TP concentration representing the midpoint between median baseflow and stormflow TP concentrations of forested tributaries in the ACF basin. The TP concentrations at the other two stations in the Oconee watershed are closer to the urban midpoint concentration.

The TP concentrations shown in Figure 1 are shown as TP loads in Figure 2. Scaled up TP loads based on TP concentrations of ACF tributaries with one predominant land use are also shown in Figure 2. In general, TP loads increased with basin area, which suggests that TP load is dependent on mean annual flow. TP loads at AOO stations in the upper part of the Oconee River watershed approximate scaled up loads of tributaries predominated by poultry and urban land uses in the ACF basin. TP loads in the Altamaha River approximate scaled up loads of forested tributaries in the ACF basin.

In Figure 2, TP loads increased slightly in the Oconee River from upstream to downstream of Lake Oconee and Lake Sinclair. The conversion of these loads to yields suggests that the reservoirs attenuated TP loads from the Oconee River. TP yield decreased from approximately 52 to 20 kg/km/yr. Frick et al. (1996) reported decreases in both TP loads and yields associated with the four reservoirs on the Chattahoochee River.

In Figure 3, mean TP loads at the furthest downstream mainstem stations on the three rivers of the AOO basin are compared with mean cumulative WWTP TP loads discharged to each river. The TP loads at the AOO basin stations shown in Figure 3 may reflect average TP yields at the mouths of each river. The cumulative WWTP loads are 24 to 31 percent of the TP loads calculated for the mainstem river stations. This suggests that the remainder of TP loads in the AOO basin rivers were attributable to non-point sources. Point and nonpoint sources of phosphorus may not pose the same risk of eutrophication to a river or stream. For the Chattahoochee River in Georgia, Wangsness et al. (1994) reported that only about one third of nonpoint source phosphorus entering surface water is bioavailable. In contrast, nearly all phosphorus from point sources is bioavailable.

SUMMARY

The results of this evaluation are useful as a general characterization of TP concentrations and loads in the surface waters of the AOO basin. Further work will include a more robust statistical evaluation of AOO TP concentrations and loads. In addition, for comparisons with AOO TP data, data reported for other forested streams in the southeastern U.S. plus applicable EPA ecoregional nutrient criteria will be compiled. Further work, in particular, is necessary to determine the appropriateness of the reference concentrations and scaling up used for comparisons with AOO data.

For the years 1992 to 2003, TP concentrations and loads of the mainstem rivers in the AOO basin approximated the midpoint of baseflow and stormflow TP concentrations reported by Frick et al. (1998) for forested streams in the ACF basin. TP in the headwater tributaries to the Ocmulgee and Oconee Rivers were representative of the midpoint concentrations associated with tributaries predominated by urban and poultry land uses.

Results of the evaluation suggest that TP concentration and yield of the Oconee River were attenuated by Lake Oconee and Lake Sinclair. This would occur through settling of particulate forms of phosphorus or uptake by phytoplankton and macrophytes. The Oconee River is not the only influent tributary to these lakes which further suggests that these lakes are phosphorus sinks.

TP loads associated with WWTP effluent may have comprised 24 to 31 percent of the TP load in the AOO basin rivers. In terms of the risk of eutrophication, these point source loads from WWTPs are presumed to be much more bioavailable than the non-point source loads entering AOO basin waters. When evaluated near the mouth of the Altamaha, loads are slightly different from what might be expected from a fully forested watershed.

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