CHARACTERIZATION OF TEMPORAL AND SPATIAL VARIABILITY OF TURBIDITY IN THE UPPER CHATTAHOOCHEE RIVER

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Abstract. Our objective is to develop the information necessary for establishing a regulatory basis for sediment control. We present sediment data at four USGS monitoring stations in the Upper Chattahoochee River Watershed. The data show that TSS is a strong function of discharge. A unique relationship between TSS and discharge is found for all stations when the discharge is normalized by its long-term mean. With this regional relationship, we can establish a baseline for comparing watersheds as a function of discharge.

INTRODUCTION

Suspended sediment loads in the Chattahoochee River above Atlanta are 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 organics and heavy metals, interfere with municipal water filtration, serve to fill valuable riparian wetlands, floodplains and reservoir capacity, and diminish the flood carrying capacities of channels. For these and many other reasons, an understanding of sediment transport in the Lake Lanier watershed is required.

Study Area

Lake Sidney Lanier is a major water supply reservoir for the Atlanta Metropolitan area. The reservoir also serves to impound water to maintain flows for navigation downstream, for hydropower generation, flood control and for recreation. Buford Dam, which impounds Lake Lanier, is located about 50 miles northeast of Atlanta. The Chestatee and Chattahoochee Rivers are the two main tributaries of Lake Lanier. The drainage area of Lake Lanier is approximately 1,040 square miles in the southern Piedmont physiographic province.

The northern part of this basin is in the Dahlonega Plateau region, which is characterized by mountains and thin, deep valleys. The drainage pattern in this region is generally rectangular and almost entirely controlled by underlying geologic structures.

The lower part of Lanier's drainage area is in the Atlanta Plateau. The land and channel slopes in this area are not as steep as those in the Dahlonega plateau. Both areas have a similar climate, with moderate temperatures and an average annual precipitation greater than 60 inches. Winter and early spring months are the wettest (Faye et al., 1980).

METHODS

Data used for this paper were obtained from U.S. Geological Survey (USGS) sources. Suspended sediment concentrations and discharges were given for four streams: the Chattahoochee River at Cornelia, the West Fork of the Little River, the Chestatee River near Dahlonega, and the Chattahoochee River at Norcross. Sample dates ranged from 1975 to 1994 for the Chattahoochee at Cornelia, and from 1993 to 1995 for the West Fork of the Little (West Fork). For the Chestatee, several discharge values for 1976 and all for 1975 were listed as estimated and were not included in these analyses. Chattahoochee at Norcross data were from 1993 to 1995. This information is summarized in Table 1. Mean discharge for the West Fork Little River is from Carter (1983).

RESULTS AND DISCUSSION

TSS Concentrations

There is considerable overlap in the distribution of Chattahoochee at Cornelia (Cornelia) and Chestatee TSS concentrations. Chattahoochee at Norcross (Norcross) TSS concentrations are generally lower while discharges are generally higher. This station is below Buford dam, so discharges are controlled and sediment loads have been reduced.

The West Fork of the Little River has lower discharges, but the distribution of TSS values is similar to the Chestatee and Cornelia sites. The highest TSS concentrations occur in the West Fork. Ordinary least squares regression fits are summarized in Tables 2 and 3.

TABLE 1: Upper Chattahoochee Watershed Sediment Stations

USGS ID	Location	Record	Area (mi^2)	Mean Discharge (cfs)	Mean TSS Concentration (mg/L)
02331600	Chattahoochee River at Cornelia	1975-94	315	867	14.5
02332830	West Fork Little River near Clermont	1993-95	18.3	36.6	48.6
02333500	Chestatee River near Dahlonega	1957-94	153	370	15.4
02335000	Chattahoochee River at Norcross	1993-95	1,170	2,321	21.3

Table 2. TSS Concentration vs. Stream Discharge

$C = a\,Q^b$ or $\log_{10}(C) = a' + b\log_{10}(Q)$

Station	$a' = \log_{10}(a)$	b
02331600	-2.224 ± 0.273	1.152 ± 0.092
02332830	-1.055 ± 0.277	1.747 ± 0.162
02333500	-3.393 ± 0.201	1.766 ± 0.070
02335000	-3.104 ± 0.823	1.300 ± 0.258

Table 3. TSS Load vs. Stream Discharge

$L = a\,Q^b$ or $\log_{10}(L) = a' + b\log_{10}(Q)$

Station	$a' = \log_{10}(a)$	b
02331600	-4.835 ± 0.273	2.152 ± 0.092
02332830	-3.666 ± 0.277	2.747 ± 0.162
02333500	-6.005 ± 0.201	2.766 ± 0.070
02335000	-5.715 ± 0.823	2.300 ± 0.258

The relationship between TSS concentration and stream discharge could be linear for the Cornelia site and the Norcross site (all analysis is based on a 95% confidence interval). There is no statistically significant difference between the slopes of the Cornelia and Norcross sites, and the slopes of the West Fork and the Chestatee sites. Also, the Norcross site could have the same slope as the Chestatee site. Overall (taking into consideration a and b values), the Norcross site is not statistically different from the Chestatee River at Dahlonega site or the Chattahoochee at Cornelia site.

TSS Loads

TSS loads were found to be related to stream discharge by a power-function, as expected (Meade et al., 1990). The highest TSS loads overall were calculated for the Chattahoochee near Cornelia in 1990. Because sample dates are not the same for each river, it may be that other rivers would have had higher loads if they had been sampled at the same time (assuming these rivers are subject to the same precipitation regimes). The highest West Fork TSS loads were within one order of magnitude of the highest TSS loads delivered by the three other rivers. Several of the West Fork's loads, however, were among the lowest of all four rivers. Ordinary Least Squares Regression fits are also summarized in Table 2. Once again, the slopes of the Cornelia and Norcross sites, and the West Fork and Chestatee sites, are not statistically different. Overall (considering both a and b terms), the Norcross site is not statistically different from the Cornelia site or the C hestatee River at Dahlonega site. The estimated value of the slope for the combined data yielded b = 2.60, or $L = a\,Q^{2.6}$.

Changes Over Time

TSS concentrations vs. discharge data from different time periods were compared for the Chattahoochee River Cornelia and for the Chestatee River near Dahlonega, since these were the only two rivers that had data spanning two decades. The 1989-95 Cornelia line is slightly steeper than the 1969-1984 line. OLS regression fits are summarized in Table 4.

The TSS concentration vs. discharge line is steeper for the later time period (1989-1995). However, based on a 95% confidence interval the equation for the earlier time period (1969 to 1984) could be the same as the equation for the later time period. Data for the Chestatee River near Dahlonega was initially divided into three time periods: 1957 to 1971; 1972 to 1976; and 1989 to 1994. The latest time period (1989 to 1994) has a steeper slope than the previous two time periods. However, the equation for the first time period could be the same as last or middle time periods. Also, the equation for the middle period is not statistically different from the first. Based on this analysis, no trend in TSS concentration in response to discharges is apparent. The first two periods were then combined into a 1957 to 1994 period.

Table 4. Comparison of Early vs. Recent Data.

Station 02331600: Chattahoochee River near Cornelia

Period	a' = $\log_{10}(a)$	b
1969 to 1984	-1.769 ± 0.506	1.019 ± 0.176
1989 to 1995	-2.596 ± 0.332	1.258 ± 0.110

Station 02333500: Chestatee River near Dahlonega

Period	a' = $\log_{10}(a)$	b
1957 to 1971	-2.720 ± 0.678	1.545 ± 0.262
1972 to 1976	-1.962 ± 0.416	1.368 ± 0.130
1989 to 1994	-3.420 ± 0.266	1.745 ± 0.095

Station 02333500: Chestatee River near Dahlonega

Period	a' = $\log_{10}(a)$	b
1957 to 1976	-2.879 ± 0.264	1.641 ± 0.089
1989 to 1994	-3.420 ± 0.266	1.745 ± 0.095

The Chestatee TSS concentration vs. discharge line for 1989-1995 does have a steeper slope than the 1957-1976 line. The slopes for these lines (b values) are not statistically significantly different. The a values, however, are statistically different. The line for the later period is shifted to the right; for any given discharge, the TSS concentration is less.

Combined Data Sets

Combining data from all sites to estimate a common slope coefficient and unique intercepts for each site yields a value of b = 1.60 ± 0.05, or $C = a\,Q^{1.6}$. Using this approach, we find substantially lower standard errors of the slope and intercept coefficients. The progression of stations, from best to worst is: Chattahoochee River at Norcross (below Buford Dam), Chattahoochee River at Cornelia, Chestatee River near Dahlonega, and the West Fork Little River. Interestingly, this ranking is a function of drainage area, indicating that smaller drainages tend to have increased sediment concentrations, thus requiring compensation for area.

If we standardize the watersheds by their mean discharge (presented in Table 1), we find that sediment concentrations are clearly related to this new, standardized discharge variable (Figure 1). The OLS regression fit to this data is:

$$C = 16.5\,(Q/Q_{mean})^{1.6} \tag{1}$$

The regression fit is also shown if Figure 1, along with a two-standard error estimate of the confidence interval, estimated using (Abraham and Ledolter, 1983, eqn 2.36):

$$y_p \pm t_{\alpha/2}(n-p-1)\, s\, [1 + x^T (X^TX)^{-1} x]^{1/2} \tag{2}$$

Figures 1 and 2 are instructive in several ways. First, it is clear in the first figure that the few observations that exceed the 95-percent confidence region occur over a wide range of discharges. A policy that only focuses on elevated turbidities would not identify exceedences at lower discharges.

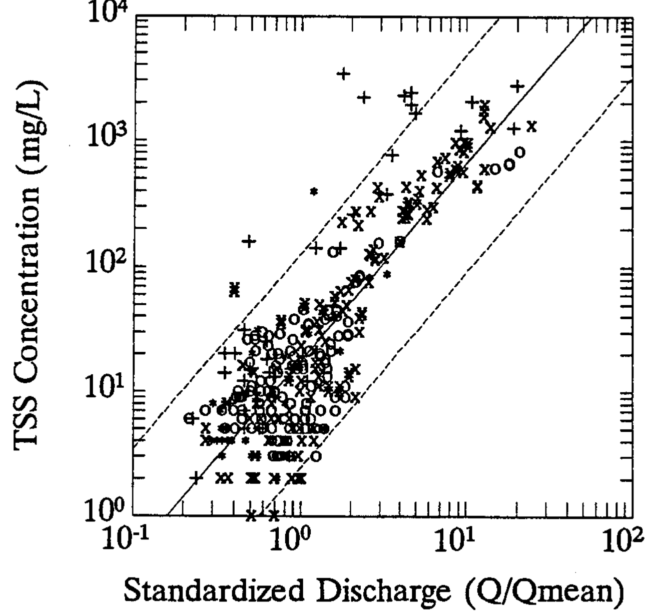

Figure 1. TSS concentration vs. standardized discharge

USGS Stations:

o = Chattahoochee River at Cornelia
+ = West Fork Little River near Clermont
* = Chattahoochee River at Norcross
x = Chestatee River near Dahlonega

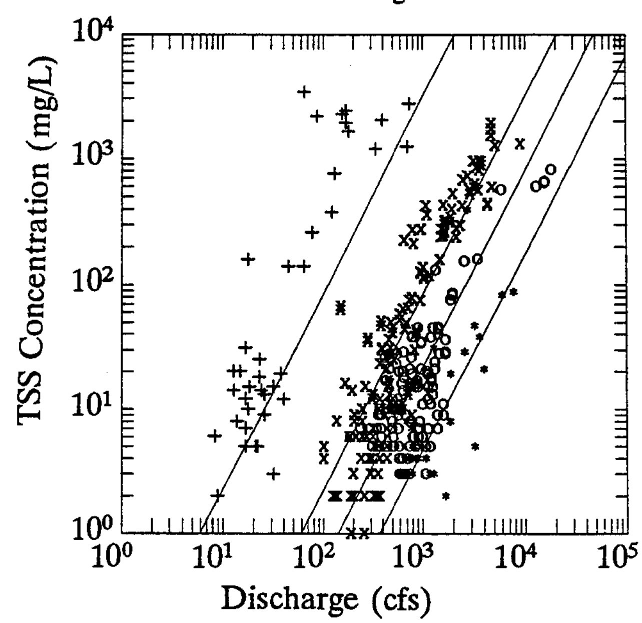

Figure 2. TSS concentration vs. discharge

Also, many of the higher turbidities are clearly a natural aspect of the region. Second, it can also be noted in the first figure that all stations, except for the Cornelia site, exceed the confidence region at some time. Thus an envelope curve that allows occasional exceedences will be necessary. From the second figure, it is clear that incorporation of the mean discharge as part of the predictive equation correctly identifies the trend in TSS as a function of discharge. This is to say that streams depart from a mean turbidity as a function of their departure from the mean discharge. Account must thus be taken not just of the observed discharge, but the discharge relative to the mean. It is also clear that the West Fork of the Little River exceeds the 95% confidence region much more of the time than any other station, indicating problems with this watershed.

Equation (1) can also be used to indicate mean sediment concentrations because $Q = Q_{mean}$ implies that $Q/Q_{mean} = 1$, which leads to $C_{mean} = 16.5$. Extension of this analysis to conditions such that $C = 25$ leads to the conclusion that $Q/Q_{mean} = 1.30$, or when Q is 30 percent greater than the average discharge. Values of C_{mean} are given in Table 1 using log-log estimates of $C = C_{mean} (Q/Q_{mean})^{1.6}$ for the four stations.

POLICY IMPLICATIONS

Promulgation of a turbidity standard that is protective of the aquatic environment requires the ability to discriminate between natural and anthropogenic disturbances. Identification of anthropogenic disturbances is complicated by the large variation in turbidity due to changes in discharge. The goal of this paper has been to identify whether a unique, background relationship between turbidity and discharge could be established, and if so, could this relationship be used to identify harmful levels of turbidity in streams.

Based on TSS concentrations at four USGS monitoring stations in the Upper Chattahoochee watershed, we propose a monitoring program that relates discharge (or stage as a surrogate) to turbidity. This relationship can be used to identify whether a particular stream segment is consistent with other stream segment, or whether it significantly deviates from other stream segments.

At least one low-flow measurement and one storm event should be collected quarterly for a minimum of one year. Low flow measurements should be collected using grab samples. High flow events should be sampled at multiple stages using USGS-style automatic rising-stage samplers. All samples should be collected at one-half of the stream depth. Due to the extensive number of streams that require sampling, monitoring should proceed on a watershed-by-watershed basis, beginning with the aquatic systems that are more vulnerable to turbidity. Sampling should initially focus on larger streams, with subsequent sampling proceeding upstream with greater priority placed on the sampling of influent tributaries showing higher turbidities.

Sufficient data should be collected to establish a log-log plot of turbidity vs. discharge (or a semi-log plot with stage). An envelope line should be constructed that encompasses 95 percent of the observations. The slope of the envelope line should be based on long-term regional data. While this slope equals 1.60 for the Upper Chattahoochee River Watershed, it is bound to vary as a function of physiographic factors. There is no reason to assume that this slope would be consistent state-wide.

Streams in Georgia with average turbidities greater than 25 NTU could then be designated as nonattainment streams, which would be monitored more frequently (both spatially and temporally) to identify the origin of the elevated turbidities. Routine monthly and event sampling should be required. Inspection of land-disturbing activities for compliance with required site plans should also be required.

Streams in Georgia with average turbidities greater than 100 NTU could be designated as severely degraded streams. Active management plans for stream restoration must be proposed within one year of designation that specifies the means for reducing average turbidities to below 25 NTU. As part of the active management plan, effluent discharge standards should be set. Stricter protection of stream buffers, prevention of instream and nearstream disturbances, limitations on impervious area and the number of acres permitted for land disturbance on an annual basis, paving of unsurfaced roads, or other measures should be considered.

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