

MEASURING AND MODELING SUSPENDED SEDIMENT YIELDS IN URBANIZING GEORGIA PIEDMONT WATERSHEDS

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Abstract. This paper presents a comparison of U.S. Geological Survey stream monitoring station measurements of total suspended solids (TSS) yield and stream bank erosion monitoring data with a suspended solids model developed by Brown and Caldwell and used by the Gwinnett County, Georgia Department of Water Resources (DWR) to inform its watershed improvement efforts. A comparison between modeled and average measured TSS yield results at each gauging station indicates that a reasonable match exists over the majority of compared watersheds. When removing two stations with less than five years of data (coinciding with a drought of record) and two outlier stations, the average absolute percent difference between modeled and measured results is 20.1%, which is within the sampling error associated with TSS measurements. In general, the model tends to over predict TSS yield. It assumes a streambank TSS loading rate of 12 lbs/ft²/yr per unit area of exposed bank as quantified in the field. Six years of measured streambank erosion rates has documented an average annual production of 7.1 lbs/ft²/yr. The average measured TSS yields at two stations were substantially less than the modeled values. It is thought that other factors are influencing TSS export such as the age of build out conditions. A discussion is presented addressing the potential reasons for the divergence between modeled and measured results as well as the potential for model calibration.

INTRODUCTION

Gwinnett County, Georgia, located in the urbanizing Piedmont northeast of Atlanta, has experienced channel incision and streambank erosion issues, which may be attributed to rapid urbanization of the area (e.g., Booth et al. 1990) exacerbated by deposition of hillslope material in the floodplain from historic land uses (e.g., Trimble 1974). The Gwinnett County Department of Water Resources is in the 10th year of carrying out its Watershed Protection Plan (WPP) in accordance with Georgia Environmental Protection Division (EPD) permitting requirements for new or expanded wastewater National Pollutant Discharge Elimination System discharge permits (Gwinnett 2000a). One aspect of WPP implementation is the creation and implementation of Watershed Improvement Plans (WIPs) for each watershed within the County. The water quality parameter of interest as identified in the

WPP is the yield of total suspended solids (TSS, lbs/acre/year), a measurement of the amount of sediment that is exported within the water column through a stream from a given drainage area. This parameter captures the affects of many water quality issues such as hydrologic modification due to land use change leading to channel erosion and instability and resulting impacts to aquatic biology (Gwinnett 2000a). The County identified a target goal for TSS yield of 1,600 lb/ac/yr, which relates to a benthic macro-invertebrate index of biotic integrity score within a range of "good" based on EPD guidelines (Gwinnett 2000a).

Instituting a program to reduce TSS yields requires an understanding of the locations within watersheds and along streams where excessive sediment is introduced due to channel and bank instability. The County has pursued this question from several fronts. It has partnered with the USGS to develop a network of stream flow and water quality monitoring stations in watersheds throughout Gwinnett County to measure stream flow and water quality constituents, including TSS (Figure 2). This effort has resulted in estimates of instream TSS yields at 14 stations with periods of record ranging from four to twelve years. Extensive water quality modeling has also been conducted for the watersheds within Gwinnett County. This ranges from BASINS/HSPF models for the initial WPP for the entire County to watershed specific spatially distributed TSS yield models. Finally, the County administers a bank erosion monitoring program that measures bank erosion rates in urbanized and urbanizing areas.

To identify subwatersheds and stream reaches exporting TSS in excess of 1,600 lbs/ac/yr of, a TSS yield model was developed for the County. While the TSS yield computation methodology has evolved over time, generally speaking field data of stream bank conditions are used to generate stream bank TSS production rates in conjunction with land cover TSS wash off rates in a spatially distributed model called WIP Tools (Brown & Caldwell 2008). An assumed rate of stream bank TSS production has been used in WIP Tools (12 lbs/ft²) since no actual data had been available for this parameter.

The aforementioned streambank erosion monitoring program developed by Brown and Caldwell for the County has documented bank erosion rates from 50 sites in the

northeastern watersheds of the County since 2005 in order to better constrain the bank erosion rate assumption.

Over a decade of monitoring the surface waters of Gwinnett County has been conducted and within this time frame TSS yield models have been generated for nearly all watersheds within the County. However, to date no comprehensive comparison between the measurement and modeling efforts has been made. It is hoped that as more field data of TSS yield and stream bank erosion becomes available, the assumptions and perhaps methods used in the modeling efforts that drive the WIP process can be improved. The purpose of this paper is to provide a discussion of available data and the state of current modeling efforts, and to present a comparison between the measured and modeled TSS yields in order to assess how well the modeled conditions reflect the measured conditions.

DATA AND METHODS

USGS Water Quality Monitoring Network. The USGS water quality monitoring network in Gwinnett County was initially installed in the late 1990s with 1998 being the first full water year (WY - September 1, 1997 to October 31, 1998) of data collected for six stations. The network has been expanded over the intervening years to a total of 14 stations, which record stage (and discharge by calculation), precipitation, turbidity, and other water quality parameters at 15 minute intervals (Landers et al. 2007). TSS is measured from baseflow grab samples and flow-weighted flood composite samples. Using the data from the TSS sampling events, the continuous discharge and turbidity data, season, and flow status (base or flood) a regression model of TSS load has been created for each station allowing for annual yield estimates, the results of which are provided in Table 1 (Landers et al. 2007; Landers 2010). The calculated error of prediction of these estimates, which is the difference between measured TSS and regression predicted TSS summed over all samples at each station ranges from +75% to -25% (Landers 2010).

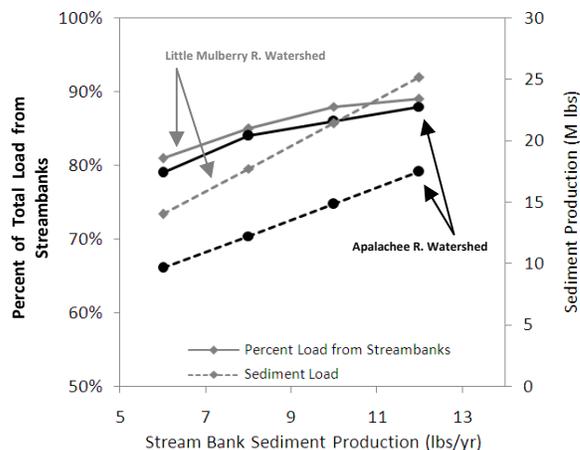


Figure 1. WIP Tools TSS production sensitivity to bank TSS production factor

Additionally, it has been demonstrated that TSS measurement methodology tends to underestimate the total mass of solids in a water sample (as measured by the Suspended Solids Concentration methodology, SSC) (Gray et al. 2002). The SSC analysis methodology involves measuring the total weight of solids within the entire volume of a collected water sample, whereas TSS analysis methodology only measures the total weight of solids in a sub-sample of the collected water sample. Landers (2010) analyzed 380 storm samples from 2001 to 2009 for TSS, SSC, and percent sand composition and found that suspended solids concentration to be 1.6 times greater using the SSC methodology over the TSS methodology for samples where sand comprised greater than 25% of the total mass of suspended solids. The sub-sampling procedure used in the TSS methodology results is therefore biased towards sampling lighter particles, which have a smaller settling velocity. However, general transformations to the data are not appropriate without station specific analysis of percent sand content in suspended sediment. Additionally, water quality regulations target TSS concentrations and not SSC.

WIP Tools Model. WIP Tools is a spatially distributed TSS yield model that uses geospatial data in ESRI's Arc-Map software platform to calculate water quality parameter loading rates (mass/time) and yields (mass/time/area) (Brown & Caldwell 2008). Data used by WIP Tools includes land use coverage (impervious areas), water bodies, a digital elevation map, BMP effectiveness and stream bank erosion data collected from the field (percent exposed surface and bank dimension). Each land cover category is assigned a TSS production or wash-off rate. The bank erosion component of the TSS yield calculation is generated with an algorithm that assume a base TSS production rate of 12 lbs/ft²/yr for exposed bank surfaces, adjusted by Erodibility (Percent Exposed Bank)*(Bank

Area)—estimated in the field— and Erosivity, a ratio of urban and rural 2 yr discharges, as defined below:

$$\mathbf{Bank\ Erosion} \left(\frac{lb}{yr} \right) = \left(\frac{12\ lb}{ft^2\ yr^1} \right) * (\% \text{ Bank Exposed}) * (\text{Bank Area}, ft^2) * \left(\frac{Q_{2yr\ Urban}}{Q_{2yr\ Rural}} \right)^{1.5}$$

Where $Q_{2yr\ Urban}$ is the 2 yr frequency urban flood peak discharge calculated by a USGS regional power law function relating drainage area and percent impervious surface to peak discharge, and $Q_{2yr\ Rural}$ is the 2 yr frequency rural flood peak discharge calculated by a different USGS power law function for the same region. Model output comes in the form of TSS yield rasters (grids) and stream vectors, which have been compiled in Figure 2, below.

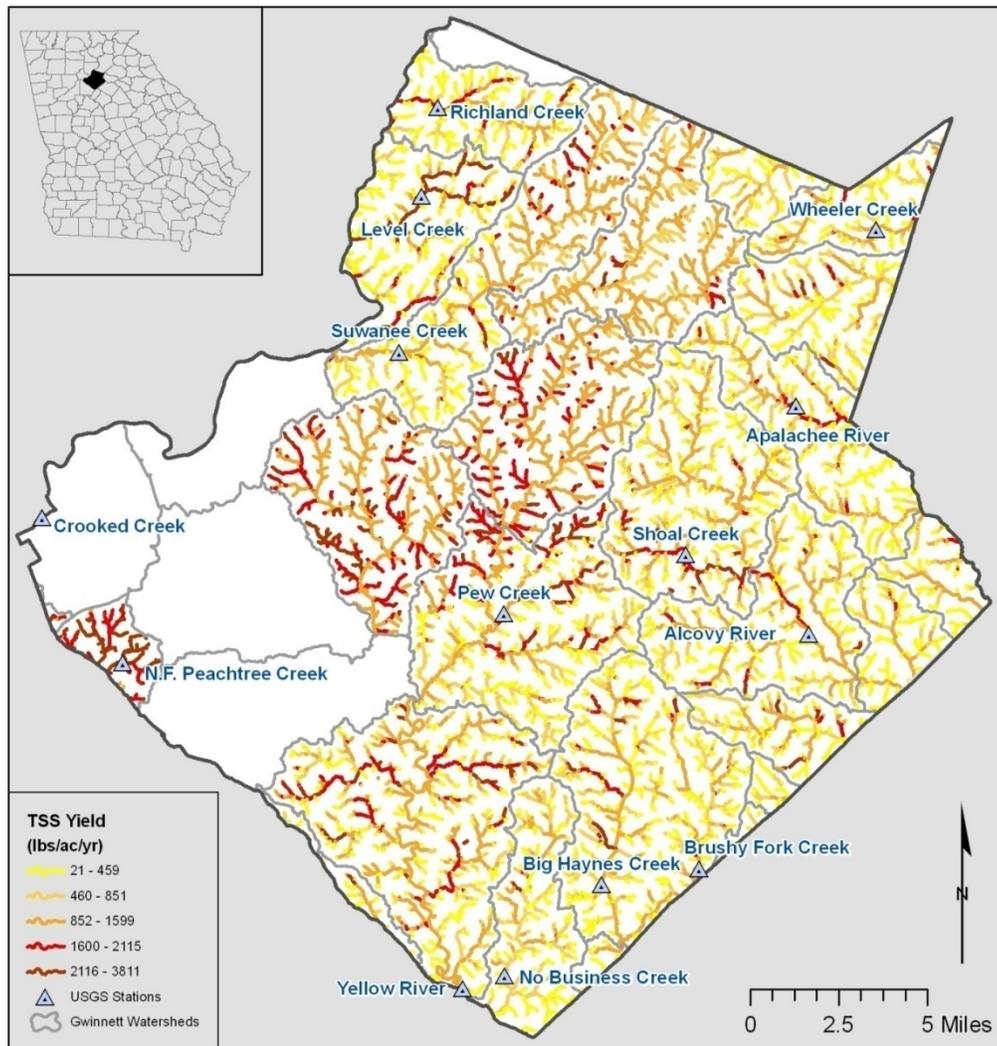


Figure 2. Overview map of gauged Gwinnett County watersheds with modeled TSS yield vectors.

NOTE: Some eastern watersheds have not been modeled using the WIP Tools methodology. However, with the exception of Crooked Creek, all USGS stations are located in watersheds that have been modeled using this methodology. The modeled TSS yield at the Crooked Creek station was generated from a BASINS-HSPF model (Gwinnett 2000b).

Total suspended sediment yield calculations produced by this methodology reflect mean annual conditions. WIP Tools does not consider spatial or temporal variability in precipitation to simulate inter-annual changes in TSS yield. Rather, it is utilized as a planning level tool to identify reaches and subwatersheds that may be exceeding the TSS yield threshold of 1,600 lbs/ac/yr identified by the County.

The WIP Tools model or methodology has been used to generate baseline TSS yield maps for each subwatershed within Gwinnett County where USGS water quality monitoring stations exist with the exception of the Crooked Creek watershed (USGS Station ID 02335350), for which TSS yield was calculated by the original Gwinnett WPP BASINS/HSPF model, which assumed TSS

loading or wash off rates from upland sources only, and no explicit instream sources (see Gwinnett 2000b for model description). Streambank TSS production accounts for the majority of modeled TSS production within WIP Tools. For example, 88% of total TSS production resulted from stream banks in the Little Mulberry River watershed WIP Tools model (Figure 1).

A sensitivity analysis was conducted to determine the impact of the streambank TSS production rate assumption on total yield. The assumed streambank TSS production rate of 12 lbs/ft²/yr was changed to 10, 8 and 6 lbs/ft²/yr for two Gwinnett County WIP Tools watershed models and the production rates and yields were calculated. At the Wheeler Creek Station (Little Mulberry River watershed, USGS Station ID 02217274), the modeled TSS yield re-

duced from an initial 1,374 lbs/ac/yr to 760 lbs/ac/yr (-55.3%) when the assumed streambank production rate was changed from 12 to 6 lbs/ft²/yr (Figure 1). A comparable result was produced in the Apalachee River watershed model. This indicates that the modeled TSS yield follows an approximately linear relationship with the assumed bank production rate.

Stream Bank Erosion Monitoring. To provide information regarding the amounts of stream sediment production in Gwinnett County, the County initiated a stream erosion monitoring program in 2005. The monitoring program consists of 50 sites located in the northeast portion of the County representing a range of land uses including residential, commercial, agricultural, and forested. Bank pins are placed on both banks at each site and depth of erosion is measured at each pin each year. Additionally, monumented cross sections are surveyed each year for inter-annual comparison, pebble counts are conducted and Bank Erosion Hazard Index scores evaluated. The first data collection effort at monitoring sites occurred in spring 2005 and follow up field measurements were collected in the spring of 2006, 2007, 2008, 2009, and 2010.

The TSS production rate value assumes that all bank material is converted into suspended load. If applied to an estimate of TSS yield, this assumption may overestimate that yield because some of the bank material is likely transported as bed and dissolved load. Sediment weight is based on bulk density measurements of samples of bank sediment from each bank at each site.

This monitoring effort has resulted in an average production rate of 7.1 lbs/ft²/yr. This production rate is 70% less than the assumed bank sediment production rate of 12 lbs/ft²/yr used in WIP Tools. It should be noted that estimation of bank erosion is highly variable due to localized measurement techniques and spatially variable erosive forces along a streambank. Also, several of the years for which the stream bank monitoring was conducted were during a drought which may skew the results to be lower than during years with typical rainfall. Additionally, bank erosion monitoring sites are concentrated in the northwest portion of the County and may not reflect bank conditions throughout the streams in the remainder of the County.

RESULTS

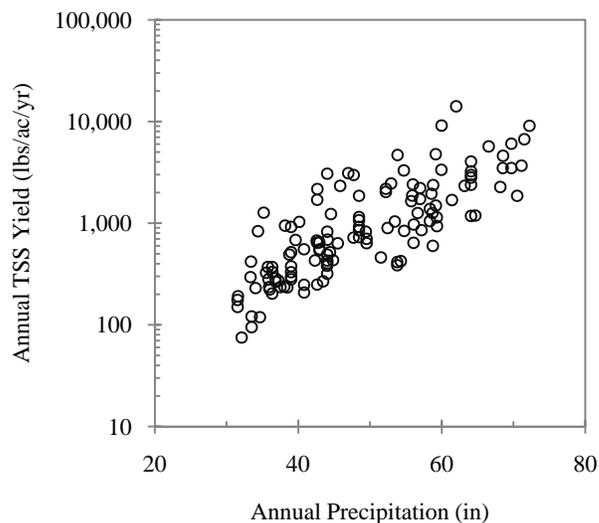
Both hydrologic and geospatial models have been created to estimate TSS yield at the basin and stream reach scale. These modeled yields are used to identify which watersheds and streams within Gwinnett County are not meeting the 1,600 lb/ac/yr TSS yield target. Watersheds and stream reaches not in compliance with this goal are targeted for retrofit and restoration in Watershed Improvement Plans. Water quality data collected by the

USGS for Gwinnett County compliments this effort by providing a long term, inter-annual assessment of the state of the County's watersheds. The monitoring program can also inform the planning tools used to develop WIPs within the County to provide more accurate assessments of baseline conditions and better predictions of management strategies on future water quality.

The following is a comparison of the USGS measured TSS yield data with modeled baseline TSS yields. Though many factors influence the TSS yield of a basin, TSS yield correlates positively with precipitation as shown in Figure 3, below. Simply put, greater rainfall results in greater runoff and hence erosion and sediment transport. In order to contextualize the USGS TSS yield results with the modeled results, which assume "average" conditions, an effort was made to identify years with near average precipitation for which TSS yield measurements exist within each monitored watershed. Precipitation depths from USGS rain gages (daily) within and surrounding Gwinnett County were summed over each water year for which at least 350 days of recorded precipitation observations existed. Monthly precipitation data from a NOAA Coop station located in Norcross, Georgia was also used. The USGS datasets begin in WY 2002. Prior to 2002 spatially distributed precipitation data was not readily available and a single precipitation depth value from the NOAA Coop station was applied to all stations with TSS records from 1998 to 2001.

Rainfall maps were created for each water year from 2002 to 2009 through interpolation in order to generate precipitation depth coverage over each monitored watershed. Rainfall depth was averaged over the area of each monitored watershed for each year. Several near average precipitation years were selected based on a comparison with a County-wide precipitation average; and one to three

Figure 3. Annual TSS Yield vs. Precipitation Depth



measured annual TSS yield years were then identified and averaged for comparison with the modeled yields.

and the modeled TSS yield was 68%. This average percent difference was nearly equal when average annual precipi-

Table 1. Comparison of Modeled and Measured Results

USGS Station ID	Station Name	Drainage Area (mi ²)	Year Installed	USGS TSS Measurements (lbs/ac/yr)			Modeled Baseline (lbs/ac/yr)	% Dif. from P.O.R. Avg	% Dif. from Mean Precip Year
				P.O.R. Avg	Average by Mean Precip Year	Error of Prediction			
02205522	PEW CREEK	7	2006	554	791	-7%	1,555	181%	97%
02207120	YELLOW RIVER	162	1998	1,771	906	-8%	1,479	-16%	63%
02207185	NO BUSINESS CREEK	10.1	2002	611	457	1%	775	27%	70%
02207385	BIG HAYNES CREEK	17.3	1998	992	583	23%	1,452	46%	149%
02207400	BRUSHY FORK CREEK	8.2	1998	978	652	16%	1,056	8%	62%
02208130	SHOAL CREEK	3.9	2006	578	1,260	4%	1,868	223%	48%
02208150	ALCOVY RIVER	30.8	1998	1,832	1,050	38%	1,699	-7%	62%
02217274	WHEELER CREEK	1.3	2002	1,334	1,346	-26%	1,417	6%	5%
02218565	APALACHEE RIVER	5.7	2002	1,272	1,248	-19%	1,698	34%	36%
02334480	RICHLAND CREEK	9.3	2002	2,930	3,143	75%	1,663	-43%	-47%
02334578	LEVEL CREEK	5	2002	1,008	1,020	-4%	3,019	200%	196%
02334885	SUWANEE CREEK	47	1998	1,215	846	9%	1,281	5%	51%
02335350	CROOKED CREEK	8.9	1998	2,654	2,370	-2%	2,438	-8%	3%
02336030	N.F. PEACHTREE CREEK	1.4	2002	1,157	1,781	-5%	2,874	148%	61%
OVERALL AVERAGES				1,349	1,247	16.9%	1,734	68.1%	67.9%

NOTE: TSS yield data is presented in units of lbs/ac/yr. Period of Record Average (P.O.R.) refers to TSS yield values averaged at a station across all years monitored at that station. Average by Mean Precipitation Year refers to the average of TSS yield values at a station from the one to three years closest to the county-wide average rainfall depth. Overall percent difference averages based on absolute values of individual percent differences.

While annual precipitation depths do vary spatially across Gwinnett County, using USGS TSS yield values from average precipitation years did not reduce average percent difference between measured and modeled TSS yield in comparison with average percent difference between period of record TSS yield averages (Table 1).

Modeled TSS yields were generally obtained from TSS yield rasters (grids) generated with the WIP Tools methodology described above. TSS yield values were extracted from the raster at the location of each monitoring station. The explicit bank loading rate assumption of 12 lbs/ft²/yr was included in all WIP Tools models and covers all stations except the one located in the Crooked Creek watershed. The modeled TSS yield for the Crooked Creek watershed (USGS Station ID 02335350) was generated from a BASINS/HSPF model as described in the Chattahoochee Basin Impacts Assessment report (Gwinnett County 2000b).

The modeled TSS yields were generally greater than the average measured yields (Table 1, Figure 4); however there was some variability in these differences among the stations. The average of the absolute values of the individual percent differences between the values of measured TSS yield average over the period of record at each station

was used to choose the year(s) of measured TSS yield data to make the comparison.

DISCUSSION

The above comparison of modeled and measured TSS yields and the results from the streambank erosion monitoring program indicate that the models may be overestimating the TSS yield within each watershed. While the average absolute percent difference between modeled and measured results over all monitoring stations is 68%, by removing the two sites where only four years of TSS measurements exist (two years coinciding with a drought of record) and two other outlier stations (greater

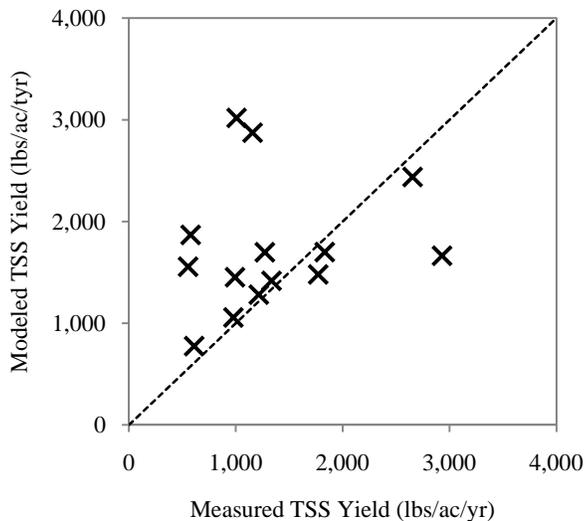


Figure 4. Modeled vs. Measured TSS Yields

than $\pm 100\%$ difference between measured and modeled results), then the average absolute percent difference reduces to 20%, which is within the sampling error associated with USGS TSS measurement methods. Calibrating the WIP Tools model to USGS data could be accomplished by altering bank erosion base rates by watershed to create a better match. However, it should be noted that TSS yield measurements in each watershed demonstrate a high level of inter-annual variability and average yield values are likely to change as more data is incorporated.

Regarding the case of the two outlier stations (Level Creek and N.F. Peachtree Creek), the modeled TSS yields were 200% and 149% greater than the measured yields, respectively. This may indicate that streambank erosion, a dominant source of sediment in the WIP Tools model, may not play such a large role in these watersheds. For example, the N.F. Peachtree Creek watershed contains much older urban development than other areas in Gwinnett County. As such, historic floodplain deposits and/or channel incision and bank mass wasting, two sources/drivers of instream sediment production in urbanizing watersheds (Trimble 1974; Booth 1990), may have already been exhausted. Additionally, as discussed previously, the TSS measurement methodology may tend to underestimate suspended sediment concentrations for streams and storm events where sand constitutes greater than 25% of the suspended sediment concentration.

In an effort to target streams impacted by sedimentation, Gwinnett County has established a metric that attempts to relate a desired ecological outcome, as measured by a macro-invertebrate index of biotic integrity, with an average annual TSS yield value. As revealed by the bank erosion and USGS data, sediment erosion and transport processes are highly variable year to year and strongly correlated to annual rainfall depth. Long term monitoring

provides the County with better estimates of mean conditions within its watersheds to compare with its TSS yield target. However, a static and uniform metric of TSS yield does not account for the spatial variability in yield among the watersheds of the County (Table 1.) nor does it account for the inter-annual variability resulting from changes in precipitation depth and flood magnitude and frequency. An adaptive and risk-based approach to identifying which areas are more vulnerable to the impacts of higher TSS yields, using available monitoring data as guidance and WIP Tools output for greater spatial resolution, may aid in focuses resources towards water and habitat quality goals.

When considering all available field data, the modeling approach to Gwinnett County's Watershed Improvement Program may be conservative in that it results in higher TSS yields than are measured from year to year. As with any environmental system, uncertainty and variability exist not only for measurements of water quality parameters but with the impacts of water quality on aquatic ecology. That is to say, even if the current modeling framework identifies more stream reaches and watersheds that exceed the 1,600 lbs/ac/yr TSS yield water quality criterion than exceed it in reality, the cumulative effects of land use change, altered hydrology, and impacts on other water quality constituents may create poorer ecological conditions within the streams of Gwinnett County than modeled TSS yield values indicate. Hence, a conservative approach to watershed improvement planning may be reasonable.

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