a protocol for establishing sediment TMDLs

DEVELOPED FOR
THE GEORGIA CONSERVANCY AND
THE UGA INSTITUTE OF ECOLOGY

BY THE SEDIMENT TMDL TECHNICAL ADVISORY GROUP

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executive summary

Section 303(d) of the 1972 Clean Water Act requires that each state identify waterbodies that do not, or are unlikely to, meet their identified ambient water quality standards even with the implementation of the minimum prescribed point source pollution controls. For each listed waterbody, the state must prepare a plan to achieve a total maximum daily load (TMDL). According to the Act, a TMDL is the sum of constituents from natural and anthropogenic point and nonpoint sources and is to be set at “a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality” (33U.S.C Section 1313).

In January 2000 the first sediment TMDL documents developed in Georgia were released by the United States Environmental Protection Agency (EPA), Region 4. These TMDLs were for streams in the Savannah River basin. After reviewing the proposed TMDLs, staff at The Georgia Conservancy (TGC) and researchers at the University of Georgia Institute of Ecology (IOE) concluded that the legal and technical challenges associated with TMDL development were preventing good science from guiding their establishment. As a result, TGC and IOE sponsored a forum to discuss the best way to establish sediment TMDLs. Participants at the forum recommended the formation of a TMDL technical advisory group (TAG) composed of scientists from universities, federal and state agencies and non-governmental organizations with interests in sediment-related water quality problems. The goals of the TAG were to identify general characteristics of scientifically-based sediment TMDLs and to recommend a protocol for establishing sediment TMDLs in Georgia. The TAG has met its goals by developing a white paper. This white paper is broken down into sections: section I briefly explains the TMDL legal requirements and history of the TAG; section II defines the relationship between water and its sediment load; section III outlines objectives of TMDLs and the TAG’s recommendations; section IV identifies research needed to improve our understanding of sediment and its impact on aquatic ecosystems. The white paper also includes references, a glossary of terms, and sample calculations.

Section II of the white paper addresses a number of difficult scientific issues associated with sediment TMDLs. The streams requiring that sediment TMDLs be established were listed because surveys by wildlife biologists indicated that fish biologic integrity was low, and the apparent cause was excessive sediment. However, the exact level of sediment that causes impairment in a particular stream cannot be determined from scientific literature. One of the difficulties is that there are several forms of sediment in streams, including suspended sediment. Another difficulty is that the capacity of a stream to carry suspended sediment varies with the amount of stream flow (Q), so the suspended sediment concentration (SSC) is highly variable. Suspended sediment reduces water clarity, which can be measured in nephelometric turbidity units (NTUs) using light-scattering instruments. Although SSC and NTU are highly correlated, the relationship between the two can vary from site to site. Still another difficulty is that many streams in the Piedmont of Georgia received large historic inputs of sediment during the 19th and early 20th centuries. In these streams, often it is difficult to determine if the impairment is due to historic or current sediment inputs.

The recommendations, summarized below in bold and discussed in detail in section III of the white paper, are the result of a consensus-building process and represent the majority of the TAG members. Most of these recommendations concern the first five-year cycle of the TMDL process (Phase I) when all listed streams are scheduled for TMDL development. Due to court orders, Phase I TMDLs will have to be developed under time constraints and with limited resources and data. In the second five-year cycle (Phase II), these TMDLs will be revised. The Phase II TMDLs should benefit from the experience and additional resources and data gathered during the Phase I process.

We recommend, as a preliminary step, that the problem causing biologic impairment be carefully identified. Sediment can carry a variety of organic and inorganic pollutants that may affect biota, and this should be considered. A carefully crafted inventory of the potential sediment sources and the pathways by which sediments enter the waterbody should be developed. A priority system should be used to direct immediate attention to waterbodies that are clearly impaired by sediment and have a high potential for recovery. If a waterbody is listed based on a very limited number of samples or surveys, such waters should be placed on a preliminary list. These waterbodies should be targeted for additional monitoring and analysis. If the requisite data analysis has not been compiled within five years after placement on the preliminary list or if the detailed assessment indicates that the waterbodies are, in fact, impaired, then the waterbodies should be placed on the final list of impaired waters.

To develop a TMDL for a stream that is clearly impaired, the sediment load that the stream can assimilate must be specified. Load is usually given in units of tons of sediment per year or day and is a product of the SSC and Q (with appropriate unit conversions and the use of a rating curve bias factor). We recommend the use of a reference stream wherever possible to determine the acceptable sediment load for impaired stream. Reference streams are streams that are representative of the characteristics of the region and subject to minimal human disturbance. In the case where an appropriate reference stream is not available, we propose using a long-term mean suspended sediment concentration (SSC_0) of 20-30 mg/L and the mean discharge (Q_0) for the impaired stream (this can be estimated if it is not available). Our SSC_0 is based primarily on research being conducted in the Piedmont region of the Etowah River basin that showed that the index of biologic integrity declined when baseflow turbidity exceeded 10 NTU or when baseflow SSC exceeded 10 mg/L. Three other studies on streams in the Blue Ridge region found a similar threshold turbidity level. Baseflow SSC or turbidity may be a good indicator of overall water quality, especially in streams with historic sediment. Clay-size particles settle out slowly so that a stream with a high storm flow sediment load is likely to remain turbid for some time after a storm. In streams where historic sediment is the only source, baseflow SSC and turbidity are likely to be low because the clay-size particles have been carried downstream in the intervening decades. In effect, baseflow SSC is a surrogate for the overall sediment load. Our recommended SSC_0 is higher than 10 mg/L because the long-term mean concentration can be expected to be slightly higher than the baseflow SSC and because of the uncertainty in extrapolating from measures of turbidity (the more likely parameter to be monitored in impaired streams) to SSC. Because of the lack of research regarding SSC_0 in other ecoregions across the state of Georgia, this recommendation should only apply to streams in the Piedmont and Blue Ridge ecoregions.

The TMDL should be expressed as an annual sediment load and a daily sediment load. The daily load will depend on Q. If an average Q is used for daily load, then this would represent an upper limit for baseflow or chronic conditions. If a sediment rating curve slope is available, a Q and SSC for stormflow conditions can be used to calculate a daily-load upper limit that would represent acute conditions (see Appendix A of the white paper).

The TMDL for an impaired stream must be allocated between point source loads and nonpoint source loads and must include a margin of safety and may consider an allowance for future growth. Land-disturbing activities above five acres should be required to obtain a specific, rather than a general, National Pollutant Discharge Elimination System (NPDES) permit. The permit should specify the load allocated to the site. The sum of all permitted loads in a listed watershed should not exceed the total point source load allocation.

Follow-up monitoring is a key component of the TMDL process and should be emphasized in the Phase I TMDLs because of the uncertainty surrounding their development. This information will be critical in developing more accurate TMDLs during Phase II. Implementing TMDLs is critical to the success of the TMDL program. TMDL implementation should be the subject of a separate white paper developed with more stakeholder input. TMDL development and implementation need to be closely linked. Our discussions made it apparent that there are a number of research questions that need to be answered; we have listed those in section V of the white paper.

We thank all those who helped us in our deliberations and TGC and IOE for their assistance and support. It is our sincere hope that this document will advance the effort to improve water quality in Georgia.

members of the sediment TMDL technical advisory group (TAG)

Members of the TAG contributed individual time and experience to the consensus-building process used to produce the “protocol for establishing sediment TMDLs” outlined in this white paper. Members participated in good faith, contributing diligence to the process, professional judgment, and personal expertise. They did not participate to represent the organizations or agencies for whom they work, but participated to improve the process currently used to establish sediment TMDLs and Georgia’s water quality.

The Georgia Conservancy and the Institute of Ecology appreciate the efforts of the U.S. Environmental Protection Agency and Georgia Environmental Protection Division employees who provided procedural and technical information for the TAG's consideration. Listed below are members of the TAG who contributed to the creation of the white paper:

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a protocol for establishing sediment TMDLs white paper

TMDL TECHNICAL ADVISORY GROUP • FEBRUARY 25, 2002

I) INTRODUCTION

No one knows the best way to measure or manage excess sediment in rivers and streams. Throughout the nation, especially in the Southeast, identifying solutions to aquatic and economic problems caused by excess sediment is a contentious issue. Of the nation's waterbodies that do not meet federal standards, nearly 17% are listed for sediment problems. Neither scientist nor policy maker can ignore the complex and difficult issues associated with sediment.

Fortunately, the Total Maximum Daily Load (TMDL) program described in the Clean Water Act provides the United States with a tool to deal with such issues. A TMDL document is a watershed-based plan for protecting water quality and the integrity of streams while accounting for future growth and development activities. Those who contributed to this paper believe in the comprehensive, watershed-based approach outlined in the TMDL program. The contributors believe a TMDL should paint an accurate picture of the existing stream and watershed conditions; identify sources and quantities of excess sediment; establish short- and long-term monitoring plans; and develop an implementation plan that provides individuals and local decision makers with the tools necessary to improve water quality conditions.

The recommendations outlined here are specifically designed to remain open for discussion and to adapt to the dynamic nature of science and policy. This white paper provides a starting point for measuring and managing sediment on a watershed scale, while recognizing the need for more comprehensive water quality data and analysis. Most of the individuals that participated in this process plan to remain active in discussions and research designed to improve the quality of our nation's waters.

Section 303(d) of the 1972 Clean Water Act (CWA) requires that each state identify waterbodies that are unlikely to meet the identified ambient water quality standards for their designated use category, even after point source pollution has been regulated by technology-based controls (Schoenbaum and Rosenberg, 1991, see Appendix B). For each listed waterbody, the state must establish a TMDL to reduce the constituent of concern to an acceptable level. According to the Act, a TMDL is the sum of constituents from natural and anthropogenic point and nonpoint sources and is to be set at "a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality" (33U.S.C. Section 1313).

CHALLENGES OF MEETING TMDL REQUIREMENTS

Federal requirements for TMDLs have presented many challenges. Over the past thirty years, regulators have focused primarily on technological improvements to help reduce point sources of water pollution. Because limiting point sources led to significant reductions in overall pollution levels, and the identification and limitation of nonpoint sources is difficult, the state's legal obligation to look at all contributing sources has been deficient. Despite reductions in point source loadings, water quality problems have persisted and in 1996, several non-governmental organizations (NGOs) filed suit against the United States Environmental Protection Agency (EPA), Region 4, for not forcing the state to carry out provisions of the CWA, namely establishing TMDLs.

The lawsuits have succeeded in requiring EPA, and subsequently the Georgia Environmental Protection Division (EPD), to establish TMDLs. However, the complex nature of and widespread problems associated with point and nonpoint source pollution and the governments agencies' limited resources, in conjunction with the short time frames associated with the various consent decrees calling for TMDL development, have led to scientific concerns about the adequacy of TMDLs.

BACKGROUND OF THE TMDL FORUM AND THE TAG

After reviewing proposed TMDLs for sediment in the Chattooga River basin in Northeast Georgia within the Savannah River basin, staff at The Georgia Conservancy (TGC) and researchers at the University of Georgia Institute of Ecology (IOE) recognized that the legal and technical challenges associated with TMDL development were preventing good science from guiding their establishment. As a result, TGC and IOE sponsored a forum in Athens to discuss the best way to establish sediment TMDLs. Fifty people from various agencies, universities and non-governmental organizations attended the forum, with concurrence from the TGC and IOE, and recommended the formation of a TMDL technical advisory group (TAG). This TAG was composed of scientists from universities, federal and state agencies, and NGOs and represented regionally diverse interests and concerns with sediment-related water quality problems. The goals of the TAG were: (1) identify general characteristics of scientifically-based sediment TMDLs, and (2) recommend to the TGC and IOE a protocol for establishing sediment TMDLs in Georgia.

This white paper is the result of nearly a year and a half of discussion for the sake of improving the region's progress toward less impaired, healthier waterbodies. The recommendations described here, are those of the members of the TAG, but may not represent the government agencies or universities with whom the members are affiliated. The TAG members' scientific expertise has focused primarily on regions of the Southeast that fall north of the fall line. Hence this protocol for establishing sediment TMDLs only addresses the Piedmont, Blue Ridge, and Ridge and Valley physiographic regions of the state.

THE TAG PROCESS

The TAG began meeting in August 2000. At that time the group decided to meet monthly for an undetermined period of time. Meetings, usually held in Athens on the University of Georgia campus, were arranged to be both listening sessions and open discussions. Every meeting was facilitated and began with a review of the previous meeting as well as a discussion of possible consensus items. Presentations were given by individuals who volunteered their time and resources to report on a particular subject of interest, such as current research, the TMDL process in other states, and tools to aid TMDL establishment. Discussions were held throughout the presentations and recorded. The meetings ended with identification of action items to occur before the next month's meeting and the setting of future agenda items.

The TAG's overall goal was to help improve the status of the region's impaired streams by identifying ways to produce scientifically defensible TMDLs. In light of this, the TAG believed an effective TMDL should paint an accurate picture of the existing stream and watershed conditions; identify sources and quantities of excess sediment and how much each is contributing; establish short- and long-term monitoring plans; and develop an implementation plan that provides individuals and local decision makers with the tools necessary to improve water quality conditions.

II) BACKGROUND - THE RELATIONSHIP BETWEEN WATER AND ITS SEDIMENT LOAD

At any given time, the capacity of a stream to move sediment varies with the amount of flow and available sediment. As velocity and water depth increase, the stream can move more sediment and also scour more sediment from the channel bottom and banks. Smaller particles, such as clay and silt particles, usually are suspended in the water column, and hence are referred to as suspended load. Larger particles, such as sand and gravel particles, tend to slide, roll or bounce along the channel bed, and thus are referred to as bedload. As explained later in this section, there are different ecological and water quality ramifications of suspended load and bedload. In actuality, there is no sharp distinction between suspended load and bedload in the water column. Rather, the concentration of sediment decreases from the bottom of the channel to the top. In practice, suspended load and bedload operationally are defined by what is collected in suspended load and and bedload sampling equipment.

The term sediment load describes the mass of sediment moving down a stream over a given period of time, so it has units such as tons per day (T/day) or tons per year (T/yr). The short-term sediment load, such as the daily load, is simply the daily suspended sediment concentration (SSC) multiplied by the daily discharge (Q), with the appropriate unit conversion factor:

$$Load\left(\frac{T}{day}\right) - Q(cfs)\cdot SSC\left(\frac{mg}{L}\right)\cdot 0.0027$$

EQUATION 1

The long-term average sediment load is the long-term mean suspended sediment concentration (SSC_0), in milligrams per liter (mg/L), multiplied by the long-term mean flow rate in the stream (Q_0), in cubic feet per second (cfs), and the rating curve bias factor (ß), with the appropriate unit conversion factors. The long-term mean sediment load in units of tons per year may be calculated as follows:

$$Load\left(\frac{T}{yr}\right) = \beta\cdot Q_0(cfs)\cdot SSC_0\left(\frac{mg}{L}\right)\cdot 0.0027\cdot 365$$

EQUATION 2

An accurate determination of sediment load at any given time requires sampling the sediment concentration in a way that accounts for spatial variation from the top to the bottom, as well as across the water column, as well as a measurement of the flow in the stream. As a result of the complexities of sediment movement and monitoring, there are a number of technical difficulties associated with establishing scientifically defensible suspended or bedload sediment TMDLs for impaired waterbodies in Georgia.

Box 1 : The rating curve bias factor. The rating curve bias factor is unit-less and usually has a value between 2 and 3 (Cohn et al., 1989). The bias factor (ß) accounts for the fact that the mean annual load is not the same as the product of the mean discharge and the mean suspended sediment concentration (SSC) (see the section II on sediment rating curves). If long-term records of Q and a rating curve are available (for example from a USGS gaging station), then the value for beta can be calculated as shown in Appendix A. Otherwise, a value between 2 and 3 should be assumed.

QUANTIFYING SUSPENDED SEDIMENT IN THE WATER COLUMN - SSC, TSS, NTU, KTU, AND FTU

Several different terms are used to quantify suspended sediment in the water column. The traditional method used by the United States Geological Survey (USGS) and demonstrated in Equation 1 is suspended sediment concentration (SSC), expressed in mg/L. This is based on measuring the total suspended solids collected in a stream sample, determined by evaporation or filtration. It specifically excludes dissolved solids in the reported value.

Concentration of suspended sediment also is expressed as total suspended solids (TSS) in units of mg/L, especially when the measurements are made by wastewater treatment facilities. This method for determining suspended sediment concentration is similar to that used for SSC, but is performed on an aliquot, not the full water sample, and there usually is not a correction for dissolved solids. Gray et al. (2000) found that there was little difference between SSC and TSS when the suspended material was not high in sand. When the sample was high in sand, the TSS method tended to underestimate SSC because it is difficult to obtain a representative sand aliquot.

The Nephelometric Turbidity Unit (NTU) has become the standard method for determining turbidity. The NTU measurement uses the scattering of light from the sample at an angle from the incident light source. The NTU measurement commonly is calibrated against a stock solution of 40 mg of dispersed kaolin clay in one liter of water, so that 40 NTU = 40 mg/L. The accuracy of the kaolin standard may be compromised, however, by the color and size of the kaolin clay minerals selected, along with subsequent flocculation of the clay particles. A formazin standard is an alternative calibration solution to kaolin. Formazin has a longer shelf-life than kaolin and provides more reproducible results when properly prepared. Formazin standards are stable at dilute concentrations as low as 1 NTU for up to one year and provide an accuracy of ± 5%. The units obtained using the two calibration solutions are the Kaolin Turbidity Unit (KTU) and the Formazin Turbidity Unit (FTU) to distinguish between the two calibration methods.

Turbidity measurements, because of the reliance on scattering, are best suited to measuring particles ranging from 0.1 the Formazin Turbidity Unit (FTU) to distinguish between the two calibration methods.

Turbidity measurements, because of the reliance on scattering, are best suited to measuring particles ranging from 0.1 to 10 micrometers, which corresponds to clay and fine silts, and thus provide poor estimates of larger particles. Turbidity measurements are thus most appropriate in riverine systems flowing through terrain with highly-weathered soils but are probably inappropriate for mountainous systems where sands and gravels are the predominant transported sediments. However, if stream samples (as opposed to kaolin or formazin standards) are used for calibration, turbidity measurements can be used in these situations.

Some research has shown that nearly a one-to-one (1:1) relationship exists between suspended sediment, measured as TSS, and turbidity, measured in NTU, for Piedmont streams (Barnes et al., 1996). In contrast, the DIRT II Committee (see Box 2), which studied erosion from construction sites, found various ratios of SSC to NTU ranging from 1.3 to 1.7 (Warner and Collins-Camargo, 2001). Laboratory calibrations at the University of Georgia School of Forest Resources also do not show a 1:1 relationship between KTU and FTU; instead a relationship of SSC = 1 KTU ≈ 1.65 FTU is obtained. Thus, care must be taken in specifying the methods and calibration materials used when a turbidity measurement is taken. The SSC/NTU relationship clearly needs better definition (see section on research needs). While turbidity is a good measure of the clay-sized fraction (by design), it poorly estimates the sand-sized fraction. At construction sites, where sand can be a major component of soil erosion, the relationship will be poorer than in larger streams where winnowing of the size fractions (as described by Stokes' Law) will have occurred, yielding a better relationship between SSC and NTU.

Box 2: DIRT II Committee. A committee created in the 1993 Georgia General Assembly to determine cost effective methods of preventing sedimentation problems from occurring during construction activities. The Committee's final report, released July, 2001, describes construction techniques and public and private activities that can prevent the degradation of water quality due to construction. It is available at http://www.state.ga.us/dnr/environ/techguide_files/wpb/dirt2/tpcr_published.pdf

Another problem with the SSC/NTU relationship occurs during the summer growing season, when algae and other organic matter in streams may increase the turbidity above the mineral component. Thus, as indicated in the section on research needs, the relationship between SSC and NTU ought to be evaluated for each physiographic province, stream order, and time of year. Despite these uncertainties, turbidities can and should be used to examine the effect of current (modern) sediment inputs, while elevated bedload and the sand-sized fraction, with concomitant low turbidity, are suitable for evaluating historic inputs.

Despite the fact that NTUs were devised to closely approximate mg/L of SSC, the low flow values of NTU typically underestimate SSC, as noted in Table 3. This is largely because of the operational differences between the two techniques. Suspended sediment concentrations are based on the total dry mass of sediment that is retained on a filter after all water has passed through the filter. In contrast, NTU is based on the passage of light through the suspended sediment in a glass vial. It takes about 30 seconds or more to conduct an NTU measurement. During the first 30 seconds after introducing the sample into the glass vial sand and coarse silt particles, along with coarse organic particles, settle to the bottom of the vial and are not measured by the beam of light. Consequently NTU underestimates the "total mass" of sediment by biasing the measurement to fine silts, clays, and fine organic matter. In short, the NTU measurements provide conservative estimates of the total suspended sediment in the water sample.

Suspended sediment can display marked short- and long-term spatial and temporal variability. This raises significant questions regarding sampling for the determination of SSC. Further, the determination of concentrations below 10 mg/L can be imprecise; hence TMDLs for concentrations this low, and their concomitant loads, will require enlarged margins of safety as well as more frequent sampling. Because suspended sediment typically is not distributed homogeneously in fluvial cross-sections, sampling should not be limited to a single "grab" at a single location in the cross-section, but should entail compositing sub-samples from the entire cross-section (Edwards and Glysson, 1988).

There is ample evidence that short-term (hourly, daily) temporal variability in suspended sediment and associated trace element concentrations can be excessive. Further, during wet weather events, the sediment concentration peak may not coincide with the discharge peak. Longer-term (weekly, monthly, seasonal, and annual) temporal variability also impacts sampling frequency. Typically, the annual transport of suspended sediment does not occur at a constant rate throughout the year, but in response to runoff events. The response to stormflows can be extreme, especially in small streams, where as much as 90% of the sediment transport can occur during 10% of the time. In Georgia, the majority of this trans-port occurs during the wet season (October through April). As such, the sampling frequency required for accurate measurements of SSC during major discharge/transport events should be greater than that required during base-flow periods.

In view of the general lack of information on site-specific relationships between suspended sediment and turbidity, we will refer to suspended sediment as SSC, without making a distinction based on how suspended sediment was measured (as SSC or TSS). Where appropriate, we will refer to turbidity measurements (as NTU, KTU, or FTU).

BEDLOAD

The portion of sediment that moves as bedload varies widely between rivers. Therefore, bedload must be measured independently and cannot be calculated simply as some fraction of the suspended load. In a gravel-bedded river, bedload only moves at very high flow, usually less than 1% of the time. In sand bedded rivers, sand dunes can move slowly along the bottom of the channel even during baseflow. Bedload is commonly measured in one of two ways. A bedload sampler, that features a square mouth with a porous bag attached to the back, can be dropped to the bottom of a channel where water and sediment will flow through the mouth and the sediment will be trapped in the bag. By measuring the mass of sediment collected over a specified time interval, bedload can be calculated. Obviously, this requires conducting these measurements at a variety of flows capable of moving sediment and creating a relationship between bedload and flow. There is no automated way to collect bedload samples, so this must be done manually. Another method of measuring bedload is to create sediment traps in the bottom of the channel and measure accumulation of sediment in the traps. This also is a labor-intensive and imprecise process. Because of these difficulties in measuring bedload, few bedload measurements have been made on Georgia streams compared to measurements of SSC.

It is nearly impossible to measure either SSC or bedload continuously, so sediment loads over any given time period usually are determined by multiplying the flow time series by the expected concentration for a specific flow, determined from a sediment rating curve (see this section on predicting suspended sediment concentration).

REGULATORY LIMITS ON SEDIMENT

The Federal government has not established regulatory limits for suspended sediment concentrations or loads. However, the Georgia Erosion and Sedimentation Act (ESCA) of 1975 (O.C.G.A. Section 12-7-1) attempts to establish and implement a statewide program to protect waters of the state from excess erosion and sedimentation that can occur during land disturbing activities. The ESCA requires permits for land disturbing activities and requires that buffers be maintained between the permitted activity and the waters of the state. This act was amended in 2000, in concert with the new regulations for controlling stormwater runoff from construction practices (Georgia R.&Reg. Chapter 391-3-6-.16). The amended ESCA requires that runoff from construction sites larger than 5 acres not cause an increase in turbidity of more than 25 NTU in receiving streams supporting warm water fisheries or more than 10 NTU for trout streams (O.C.G.A. Section 12-7-6.(a)(2)). The amendment was based, in part, on the advice of a scientific panel that also recommended an average (associated with long-term mean discharge (Q_0)) instream turbidity standard of 25 NTU for trout and fishing streams, with an allowance for precipitation in excess of a 10-year event (Rasmussen, 1995). Regulatory limits established in other southeastern states are shown in Table 1.

TABLE 1. REGULATORY LIMITS FOR EROSION CONTROL INTHE SOUTHEAST

STATE	LIMIT
Alabama	Background + 50 NTU
Florida	Background + 29 NTU
North Carolina	Trout streams 10 NTU Non-trout streams 50 NTU Non-trout lakes 25 NTU
South Carolina	Background + 10%

BIOLOGICAL EFFECTS OF SUSPENDED SEDIMENT CONCENTRATION AND BEDLOAD

Sediment TMDLs are intended to deal with the physical impacts of sediment on biota. However, sediment also is a significant carrier of a variety of organic and inorganic constituents that may affect biota. This implies that even if a substantial reduction in suspended sediment concentrations (loads) is achieved, it may not lead to the desired biotic effect if the root cause of the problem is chemical rather than physical.

Nationally, there is a great deal of information on the general effects of SSC and bedload on stream biota and habitat (Alexander and Hansen, 1986; Barrett et al., 1992; Burkhead et al., 1997; Waters, 1995). By blocking sunlight penetration, chronically high SSC can reduce photosynthesis, thus reducing the primary productivity of a river. A reduction in primary productivity affects all levels of the food chain and reduces the productivity of the fishery. Chronically high SSC also can abrade gills or block gill function in fish. Similarly, high SSC levels may reduce the feeding efficiency of filter feeders, such as freshwater mussels. In very turbid waters, sight feeders, such as most fish, cannot find their food (Barrett et al., 1992). Fish productivity therefore is reduced in chronically turbid waters simply due to reduced feeding efficiency. All of these effects can be withstood over short periods of time.

Box 3: The Index of Biotic Integrity (IBI). The Georgia Wildlife Resources Division (WRD) uses IBI to assess the biotic integrity of aquatic communities. Streams with low IBI scores and healthy chemical constituents are often determined to be impaired because of problems associated with excess sediment and will require a TMDL be established.

IBI was first developed by Karr (1981) and later adapted to fit the Piedmont ecoregion of Georgia (Georgia DNR, 2000).The assessment focuses on functional and compositional attributes of the fish communities in a waterbody, using measures of species richness and composition, trophic composition and dynamics and fish abundance and condition. Generally, the higher the IBI score the healthier the biotic integrity of the waterbody. For more information on IBI see the most recent draft of the Georgia DNR/WRD *Standard Operating Procedures for Conducting Biomonitoring on Fish Communities in the Piedmont Ecoregion of Georgia (2000).*

Therefore, if SSC levels are high only during storms, the biological community will not be significantly impacted. SSC levels become a concern when they are elevated during normal baseflow conditions.

However, high storm SSC becomes a concern if the fine sediments are not fully flushed from the river system during storms. If substantial amounts of fine sediment settle on the channel bottom after a storm, serious ecological effects may occur. Many macroinvertebrates depend on the hard surfaces of coarse substrate for feeding, and many live within the interstitial spaces of coarse substrate. If fine sediments cover these coarse sediments and block the interstitial spaces, the macroinvertebrate community shifts in composition (Waters, 1995). Aquatic salamanders and lithophilic-spawning fish similarly are affected. Many Southeastern fishes are particularly sensitive to this type of habitat degradation (Burkhead et al., 1997).

High bedload transport rates eliminate pool habitat in streams, cover riffle areas, and reduce the overall habitat complexity in the stream. Fish tend to congregate in pool areas because the lower water velocities reduce their metabolic requirements and because the deeper water provides cover against predators outside the stream. The productivity of many fish species is correlated closely to the amount of pool habitat in a stream. Riffles tend to be very productive areas for the macroinvertebrates upon which fish feed. If riffles are covered in too much sediment or disturbed too frequently, macroinvertebrate productivity declines with direct effects on fish.

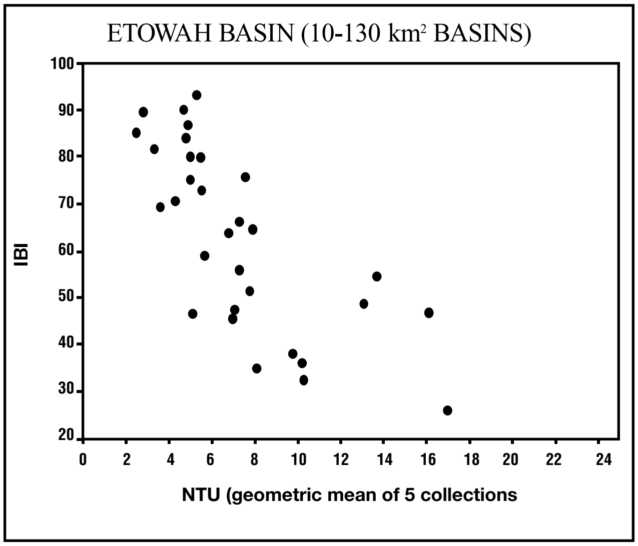

FIGURE 1. PLOT OF THE RELATIONSHIP BETWEEN TURBIDITY (NTU) AND AN INDEX OF BIOTIC INTEGRITY (IBI) FOR FISHES AT 31 WADEABLE STREAM SEGMENTS WHOSE BASIN SIZES RANGE FROM 10-130 KM². THE NTU VALUES ARE THE GEOMETRIC AVERAGES OF FIVE SAMPLES COLLECTED AS GRAB SAMPLES FROM THE CENTER OF STREAMS DURING BASEFLOW AT WIDELY SPACED TIME INTERVALS (ABOUT EVERY 60 DAYS) OVER THE PERIOD OF ONE YEAR. A SIMILAR FIGURE CAN BE FOUND AS FIGURE 2A OF WALTERS ET AL., 2001, WHICH DOES NOT USE THE GEOMETRIC MEAN.

There is a substantial lack of data regarding the effect of suspended and bedload sediment concentrations on the rich diversity of biota in Georgia streams (Barnes et al., 1996). Georgia has 283 freshwater fish species, more than many countries, and 9 of these species are currently listed as federally threatened or endangered. Available evidence suggests that many of these species are sensitive to excess sediments (Sutherland et al., 1998; Sutherland et al., 1999; Meyer et al., 1999; Walters, 2001). Research in tributaries of the Etowah and Little Tennessee Rivers, where baseflow turbidities never exceeded 15 NTU, had higher quality fish assemblages with more rainbow trout, sculpins and darters than did tributaries with higher baseflow turbidities (Meyer et al., 1999). Indices of biological integrity (IBI) based on fishes in 31 tributaries of the Etowah River were also related to baseflow NTU values (see Figure 1); biotic integrity was highest below 10 NTU and uniformly low above that value (Walters et al., 2001). A similar relationship in this study was found between IBI and SSC (see Figure 2) in that biotic integrity was uniformly low for SSC above 10 mg/L (Walters et al., unpublished data).

Sediment has detrimental effects beyond stream biota. Sedimentation can require channel and harbor dredging and result in loss of reservoir storage and cause increased flooding. Sediment also degrades recreational uses of water such as swimming and reduces boating safety due to low visibility and inability to detect underwater hazards (Pimentel et al., 1995). High levels of sediment reduce the efficiency and increase the cost of drinking water purification. Sediment interferes with the disinfection of pathogens at municipal drinking water treatment plants. Coagulants commonly are employed to floculate and settle sediments prior to filtration. Elevated sediment concentrations (above 400 NTU at the Athens-Clarke County Drinking Water Treatment Facility, for example) cannot adequately be removed by coagulation and filtration prior to chlorination. As a result, drinking water facilities must temporarily suspend treatment and must rely on previously stored water in order to meet municipal demands.

BED PARTICLE SIZE

The amount and quality of riffle habitat decreases with increasing sediment load. Riffles, where flow becomes shallower and velocities locally are increased, feature coarser particle size distributions than the rest of the channel. In the Piedmont today, gravel usually is present only in riffles and shoals. Gravel-spawning fish and riffle-feeding fish are highly dependent on the amount and quality of riffle habitat. The amount and quality of riffle habitat is determined through habitat surveys.

Particle size distributions are determined by pebble counts. A pebble count is a random sampling of the surface particle distribution on the bed of a channel. Pebble counts can be done on individual geomorphic elements of

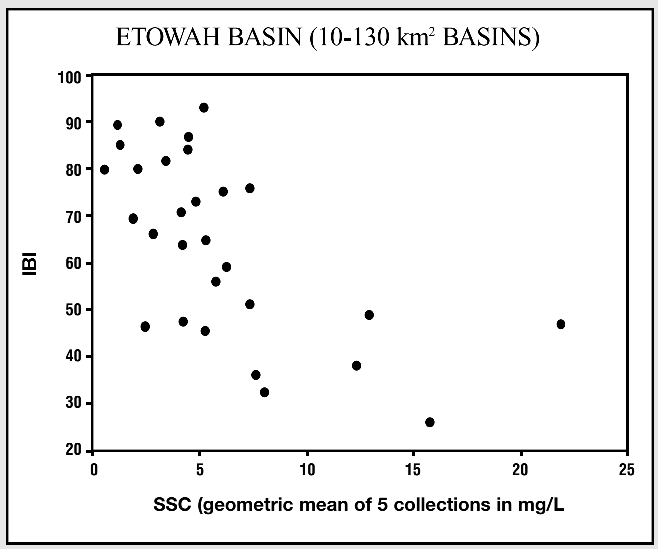

Figure 2.Plot of the relationship between SSC and an IBI for fishes at 31 wadeable stream segments whose basin sizes range from 10-130 km². The SSC values are the geometric averages of three samples collected as grab samples from the center of streams during baseflow at widely spaced time intervals (about every 60 days) over the period of one year. This figure is similar to one presented by Walters et al.(2001), but uses geometric mean values of suspended sediment concentrations (SSC) instead of NTU values.

the stream bed, such as riffles, or on the entire stream bed. On riffles, the observer walks back and forth across the riffle picking up particles, without looking, at pre-set intervals and measuring the b-axis of each particle until at least 100 particles are counted. The resulting particle size distribution is used to compute the percentage of fines (particles less than 2 millimeter diameter) and the median particle diameter (D50). Habitat quality is diminished as the percentage of fines increases. However, the particle size distribution in a riffle is highly dependent on the slope of the stream reach, so the slope of each stream must be measured. Different channels can be compared based on the amount of riffle habitat and the relationship between percent fines and riffle slope. Channels with low sediment loads should have lower percent fines for any given riffle slope, and they should have a higher percentage of riffle habitat for any given reach slope.

Particle size distributions also can be analyzed at the reach scale by the use of zig-zag pebble counts. In a zig-zag pebble count, the observer zig-zags across the channel in either an upstream or downstream direction, again picking up particles, without looking, at pre-set intervals and measuring the b-axis of each particle. The zig-zag count should encompass a representative distribution of habitats found in a reach, and it should include at least 300 particles. Again, the particle size distribution is used to calculate percent fines and D50, and these statistics will depend on reach slope, so an accurate measurement of slope across the reach is needed. This reach-scale estimate of the particle size distribution can be used as a diagnostic tool for assessing sediment loads in the same way that the pebble counts are used.

HISTORIC SEDIMENT ISSUES IN GEORGIA

Sediment issues in Georgia are complicated by the large volumes of sediment that were deposited in streams in the first two centuries following colonization by European and African immigrants. Many of these sediments still fill our Piedmont valleys. While there is little quantitative data on prehistoric stream conditions, naturalists of the late-18th and early-19th centuries describe Piedmont streams as flowing clear with gravel bottoms (Bartram, 1791). Stratigraphic studies clearly show that prehistoric streams transported and deposited sediment, but the sediment concentrations and transport rates probably were much lower than those of the last 200 years (Leigh, 1997 and Leigh, pers. comm.). Accelerated erosion during this last 200 years caused large changes in channel and flood plain geomorphology. Both Trimble (1974) and Ferguson (1997) describe mill dams that were buried by over twelve feet of channel aggradation in the late 1800's. Sedimentary strata deposited in association with historical human activities (e.g. row-crop farming, silviculture, and urbanization) commonly are referred to as historic sediments. Sedimentary strata deposited prior to that time (>200 years) commonly are referred to as prehistoric sediments. Both prehistoric and historic strata are stored sediments in the valley bottoms of all streams, but the historic sediments may exacerbate the sediment flux in some cases. That is, the historic strata may provide an excess supply from cut banks in certain settings where the historic strata is now a terrace. Furthermore, much historic sand still is stored and being remobilized in stream beds. A useful summary of the geomorphic setting and evolution of Piedmont streams is provided by Jacobson and Coleman (1986).

We can identify many causes of accelerated erosion from historic sources. One contribution arose from cotton farming between 1810 and 1930. Trimble (1974) estimated that four to twelve inches of topsoil were lost from the Piedmont landscape in the late 1800s and early 1900s due to poor agricultural practices. Other historic sediments were contributed by placer mining of gold in the North Georgia mountains (Leigh, 1994, 1997). The hydraulic mining of unstable hill slopes mobilized massive quantities of sediments that were redeposited downstream in floodplains and channels. Still other sediments were mobilized as a result of beaver eradication. Beaver pelt harvesting and subsequent export was a major source of state revenues to Georgia before and after the colonial period. The extermination of beaver from the landscape was a major contributor to accelerated erosion (Naiman, et al., 1994, 1999) due to the destruction of beaver dams that led to channel down-cutting and a loss of riverbank stability.

As a result of these historic sediments, Piedmont stream channels often are dominated by sand-sized stored sediments. In these streams sand moves readily as bedload during low flow conditions via dune migration, as well as suspended load during high flows. Impaired benthic habitat results from accelerated bed and bank sediment mobility. However, streams with high baseflow turbidity are likely being caused by current, as opposed to historic, sediment sources, except in cases where stream cutbanks are providing unusually large amounts of sediment during floods.

There also are large quantities of sediments in floodplain deposits. Recently, Martin (2001) documented that the volume of sediment in valley storage in a typical rural Piedmont stream was 3,400 times greater than the annual sediment export from the watershed. Martin found an average of 1.6 meters of sediment covering the prehistoric floodplain surface. The historic/prehistoric interface usually is sharp in flood-plain deposits due to the rapid nature of the initiation of the accelerated erosion.

PREDICTING SUSPENDED SOLID CONCENTRATION

The Universal Soil Loss Equation (USLE) has been used for years to estimate mean annual soil erosion from uplands, in tons per acre per year (T/A-yr) for example. However, there may be little or no correlation between USLE-predicted soil erosion loading to streams and instream SSC. This may be the result of various instream sources of suspended sediment. As a result, the application of the USLE for predicting instream suspended sediment concentrations should be used with caution, if at all. The USLE, however, may be useful in allocating loads within a watershed once the load capacity has been determined.

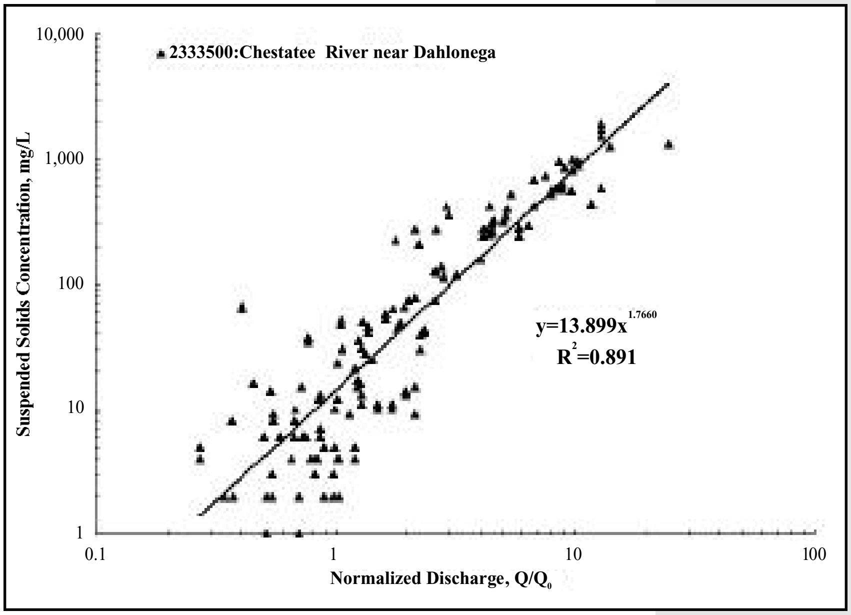

Figure 3. Sediment ratingcurveforthe Chestatee River near Dalonega (USGS gaging station 2333500).

The most common method of modeling instream SSC is through the use of a sediment rating curve or transport curve. This is a log-log plot of SSC (or TSS) as a function of discharge (Q) (see Figure 3). Discharge may be normalized by dividing by the long-term mean discharge (Q_0) so that the x-axis variable is Q/Q_0. The long-term mean suspended sediment concentration (SSC_0) is the value of SSC corresponding to the mean discharge (Q_0) or the normalized mean annual discharge of Q/Q_0 equal to one. The equation that describes a rating curve can be written (where A_1 and A_2 are fitted constants):

$$\log_{10}(SSC) = A_1 + A_2 \cdot \log_{10}\left(\frac{Q}{Q_0}\right)$$

Equation 3

The same equation is often written (where b is equal A_2):

$$SSC = SSC_0 \left(\frac{Q}{Q_0}\right)^b$$

Equation 4

The efficacy of this approach is dependent on the number of data points available to develop the rating curve and how well the points represent the range of discharge and suspended sediment concentration at a site. This approach tends to over-predict suspended sediment concentrations at low discharges, whereas it tends to under-predict suspended sediment concentrations at high discharges. Even with a large number of data points, this approach can produce substantial errors in the prediction of individual (e.g., daily mean) suspended sediment concentrations and their associated loads. Errors tend to be larger for shorter periods of time. This accrues because the shorter the time period, the less chance there is for the over- and under-predictions to cancel out.

Rating curves for ten USGS gaging stations are summarized in Table 2. The number of data points in the calibration data set ranged from 81 to 376. A log-log plot resulted in a linear relationship for six of the ten locations. For one location, the log-log plot was quadratic (Chattahoochee River at Whitesburg) and for three locations the log-log plot was cubic (Snake Creek, Ocmulgee River, and Oconee River at Dublin). A comparison was made between the total sediment load for the calibration data set based on measured sediment concentrations and the data set based on using the rating curve. The true load for each day of the calibration data set was calculated by multiplying the measured discharge by the measured sediment concentration, and the total load was calculated as the sum of the daily loads. The rating curve estimate of the total load was calculated in the same manner, except the rating curve was used to estimate the sediment concentration on each date, rather than the actual measured value.

The error in estimating the total load of the calibration data set ranged from two to 19% and was 10% or less in all but two cases (Table 2). This indicates that the rating curve approach is reasonably accurate for estimating long-term loads, such as annual loads. However, the error in estimating the load on any given day in the calibration data set was often very large.

TABLE 2. SEDIMENT RATING CURVES FOR 10 USGS GAGING STATION LOCATIONS.

USGS Gaging Station	Period	Rating Curve Coefficients[1]				Annual Load Error(%)	SSC_0 (mg/L)
		A_1	A_2	A_3	A_4		
Chestatee River at Dahlonega	12/57-8/98	1.231	1.732	0.0	0.0	15	17
Broad River near Bell	1/58-10/79	1.911	0.770	0.0	0.0	5	82
Falling Creek near Juliette	5/69-8/93	1.316	0.443	0.0	0.0	6	21
Middle Oconee River near Athens	8/63-11/77	1.792	0.605	0.0	0.0	2	62
Chattahoochee River at Cornelia	10/75-1/98	1.803	2.29	0.0	0.0	6	64
Chattahoochee River at Whitesburg	10/67-9/00	1.927	1.558	-0.665	0.0	8	85
Snake Creek near Whitesburg	9/75-9/00	1.411	1.461	0.443	-0.43	7	26
Ocmulgee River at Macon	12/57-7/68	1.825	0.467	-0.417	0.399	19	67
Oconee River at Dublin	3/61-12/71	1.800	-0.008	-0.576	0.644	5	63
Etowah River at Canton	11/57-5/77	1.958	1.396	0.0	0.0	10	91

[1] $Log_{10}(SSC) = A_1 + A_2\ Log_{10}(Q/Q_0) + A_3\ Log_{10}(Q/Q_0)^2 + A_4\ Log_{10}(Q/Q_0)^3$

III) OBJECTIVES AND TAG RECOMMENDATIONS

GOALS OF TMDLs

The goal of every TMDL is to achieve water quality standards for a particular waterbody. As stated in section II on regulatory limits, the federal government has not established regulatory limits or national standards for sediment, therefore making the goal of sediment TMDLs somewhat ambiguous. To date, the primary state-initiated resource evaluation that leads to listing a stream as impaired due to sediment is fish community assessments. It is difficult to determine if the sediment is from an active source, a historic source, channel alteration, or a combination of all the above. Further, it is difficult to segregate the biological impacts that may result from physical effects from those impacts that may result from the chemical constituents associated with sediment. Regardless, the goal of a sediment TMDL is to require solutions that result in improved fish community integrity.

SETTING PRIORITIES

It should be noted that the process outlined in section 303(d) of the CWA primarily involves water quality limited segments (see Appendix B), not just impaired or already polluted waters that are identified under provision of section 305(b) of the CWA (see Title 40 of the Code of Federal Regulation (40 CFR), section 130.2(j) and section 130.7(b)(5)). There is a fundamental difference in the two that is important. Section 305(b) requires a biennial status report on all waters, identifying which are meeting uses and criteria (clean) and which are not (polluted or impaired), which are threatened, and for which the status is not known. It was never intended that the impaired waters from the 305(b) report should be exactly equal to, or simply adopted as, the 303(d) list as is discussed in the law and regulations that apply, as well as EPA guidance. Section 303(d) primarily requires a listing of water quality limited segments, where in order to get or keep waters clean, advanced treatment and/or nonpoint source control [best management practices (BMPs)] are needed. That is, there are treatment needs beyond the minimum of secondary treatment for sewer plants and minimum levels of treatment for industries by category (technology-based effluent requirements identified in section 301 of the CWA).

The regulations state that dilution calculations (modeling) should be used to help identify waters for listing and there does not have to be data showing existing pollution. For example, a sewage plant might not be discharging at full capacity yet, or it may want to expand. With the added flow, it may be determined that there should be an increase from secondary to more advanced (tertiary) treatment. Also, it may be estimated that a stream is threatened due to sediments from increasing stresses, such as construction activities related to sprawling communities, and the available capacity of the water to assimilate the load is being exhausted. Hence, a TMDL may be required if the stream segment is neither impaired nor polluted. It should be noted that the CWA and section 303(d) is designed to prevent pollution as well as correct it, and the difference between water quality-limited (threatened) waters and polluted waters should be kept in mind.

A committee appointed by the National Academy of Sciences to assess the TMDL approach concluded that, in some cases, waters were being listed as impaired or water quality-limited (threatened) based on a very limited number of samples or surveys (Reckhow et al., 2001). The committee recommended that states place such waters on a preliminary list. Those waterbodies on the preliminary list would be targeted for additional monitoring, analysis, and subsequent assessment. If the detailed assessment indicated that the waters were impaired, or water quality-limited, then they would be placed on the final 303(d) list. However, streams should not remain on the preliminary list indefinitely. If a detailed assessment has not been performed within the five-year TMDL cycle, then the streams should automatically be added to the final list. Since EPA guidelines encourage prioritization in listing waterbodies for TMDLs, it would appear that the state has the legal authority to develop a preliminary and final list. The TAG endorses this recommendation.

Also, we recommend that a priority system be developed to direct immediate attention to some listed streams. Such a system should take into account streams in the worst situations, streams with a high potential for recovery (i.e. streams suffering from excess sediment loading from current sources versus streams with problems associated with historic sediment), and threatened waters (those with a high chance of degradation given existing circumstances). Factors that influence a waterbody's recovery potential include social, economic, and political situations. More research is needed to determine the appropriate components of such a system.

Based on the foregoing, it is our objective to propose a protocol for establishing sediment TMDLs for Georgia streams when time and data are very limited (Phase I TMDLs) and when time and data are less limited (Phase II TMDLs).

PHASE I TMDLs

For many of the Georgia streams scheduled for sediment TMDLs during the first five-year cycle (Phase I), there are limited data on stream sediment concentrations and discharge. These TMDLs must be developed with less than adequate data due to existing court orders.

Problem identification

When attempting to identify the constituent causing impairment and the sources of impairment, the agency establishing the TMDL should construct an action plan to identify the types and intensities of surveys/inventories that will be considered or that will be conducted. To the greatest extent possible, problem identification should be based on currently available information, including water quality monitoring data, watershed analyses, information from the public and any existing watershed studies. Ideally, these data will provide insight into the nature of impairment, potential sediment sources, and the pathways by which sediments enter the waterbodies.

Aerial and landscape photographs are very useful tools in evaluating sediment sources, sediment deposition, and changes in geomorphic features over time. Historical photographs of this nature should be acquired to facilitate time-series comparisons. These tools greatly enhance the utilization of geographic information system (GIS) datasets and should be employed regularly.

Problem identification and source assessment also should consider intra-annual variations in erosion and sedimentation. Many land management/modification activities occur during dry weather and for short periods of time, which sets the stage for excessive erosion and sediment delivery when precipitation occurs. As such, an ability to understand and apply geological and hydrological principals as they relate to erosion and sedimentation within a particular watershed must be included.

It also is critical to have a thorough understanding of the relative contribution from various sediment sources. While initial source identification can be based on existing information (such as a watershed plan or land use survey), it is highly recommended that thorough onsite watershed surveys be conducted. Even casual observations at the watershed level can significantly expand the understanding of dynamic cause and effect relationships within any watershed.

Natural and historic sources often may be the greatest sources of sediment. These should be identified and quantified to the extent practical. With respect to anthropogenic sources of sediment, a solid grasp of land management activities within the potential sediment-producing land uses (development, forestry, agriculture, etc.) should be acquired. This may require extensive communications at the local level with various federal, state, county, and non-governmental organizations. Truly understanding land management activities within each land use category of a particular watershed provides the basis for better estimation of erosion and sedimentation and facilitates the identification of potential corrective measures.

In Georgia most of the streams requiring sediment TMDLs have been listed as impaired because they scored low on the biotic indices for fish, IBI (see Box 3) or benthic invertebrates, with the impairment attributed to excessive sediment, although often no direct measurements of stream sediment were made. Biotic indices provide valuable measures of impairment because the biota integrate and reflect conditions over longer time periods than do grab samples for physical or chemical parameters (Karr and Chu, 1999). Low values of biotic indices indicate that there is some form of impairment and serve as a signal that further analyses are necessary to clarify the cause of the impairment. In addition, in the Etowah River basin, it has been observed that low gradient wadeable streams tend to have low values of biotic integrity, whereas high gradient wadeable streams tend to have higher values, suggesting that gradient may inherently impose limits to biotic quality (Leigh et al., 2001; Walters et al., 2001). As stated in the research section of this paper, more information is needed about the dynamics of this relationship in other parts of the state. For more information see section II on the biological impacts of sediment.

Water quality indicators

The water quality criteria for sediment in Georgia is the narrative standard "to maintain biological integrity of the waters of the State" (Georgia R. & Regs. 391-3-6-.03(2)(a)). Once a stream is listed for TMDL development, the narrative standard must be converted to a numeric value to calculate a TMDL. In Phase I, we focus our recommendations on suspended sediment load as a water quality indicator and essentially ignore the bedload component. This is due to the lack of data available on bedload and the difficulty in predicting bedload without the use of dynamic models. We do recommend bedload be addressed for Phase II TMDLs (see section III on Phase II TMDLs). We recommend two approaches to determine the TMDL suspended sediment load, depending on whether a reference stream is available or not available.

Reference stream available

The reference streams should be selected from only those streams that received the highest IBI category score. Currently, the Georgia WRD is identifying reference streams in each major ecoregion of the state. Those streams identified as reference by WRD, are those that rank in the highest IBI category and highest in a Georgia Specific Index of Well-Being (Iwb.) It should also be noted however, that reference streams may not apply across an entire ecoregion. Other considerations that are not currently taken into account include watershed area and stream gradient.

If an appropriate reference (or unimpaired) stream exists, and there are sufficient data from it (25 to 30 data points covering at least 85% of a typical annual hydrograph) to develop an adequate sediment rating curve, then the reference stream can be used in setting the TMDL suspended sediment load. In this case the desired load for the impaired stream is the reference stream rating curve. This is referred to as a functional numeric target in the EPA Protocol for developing sediment TMDLs (U.S. EPA, 1999), where the desired SSC is a function of discharge. The desired load can be expressed as a mean annual load in T/yr by taking the reference stream SSC at mean discharge (SSC_0) and multiplying by Q_0 and the rating curve bias factor, with the appropriate unit conversions (Equation 2). The load also can be expressed as a yield in tons per acre per year (T/A-yr) by dividing the annual load by the watershed area in acres. However for monitoring purposes, the load should be expressed in units of concentration.

An advantage of the reference stream approach is that storm flows and daily flows may be predicted in addition to annual means. As noted above, rating curves should be used with caution in developing reference concentrations for short (less than annual) time periods, however. A substantial amount of data and effort are needed to develop a rating curve.

In the April 30, 2001, draft of the sediment TMDL for the Chattooga River watershed, EPA developed TMDLs for daily mean, maximum, and low flow conditions, as well as an annual load (U.S. EPA, 2001b). We have used these data to suggest a method for calculating a daily target load for mean and maximum flow conditions (see Appendix A). A sediment rating curve was not available for the reference stream, but one was available at a USGS gaging station within the Chattooga watershed. We assumed that the slope of the sediment rating curve from the gaging station would apply to the reference stream, as well as the impaired streams. In this case the calculated mean flow (Q_0) daily load represents chronic conditions (baseflow) and the maximum flow daily load represents acute conditions (stormflow). We defined maximum flow discharge as ten times the mean discharge in this calculation, but other values might be used to represent storm flow discharge.

If insufficient data are available to develop a rating curve, but some measurements of Q and baseflow SSC are available on an appropriate reference stream and long term Q for an appropriate nearby stream are available, Q_0 can be estimated. Q_0 can be estimated for a reference stream with a short-term record of Q in the following manner:

- calculate mean Q for each month for the reference stream with the short-term record
- calculate mean monthly Q for an appropriate nearby stream with a long-term record
- calculate the regression line between monthly Q on the reference stream with the short-term record as a function monthly Q on the stream with the long-term record
- calculate Q_0 for the reference stream with the short-term record by multiplying the Q_0 for the stream with the long-term record by the slope of the regression line.

Multiply the estimated Q_0 by the mean baseflow reference stream SSC (an estimate of SSC_0) and a bias factor to obtain an estimate of the target mean annual load for the impaired stream (see Equation 2).

If some measurements of baseflow SSC are available but there are no data on Q, calculate the watershed area upstream of the outlet, find the mean water yield (discharge per unit area) from Carter (1983), and calculate Q_0 as the mean water yield times the watershed area. Multiply the estimated Q_0 by the mean baseflow SSC and a bias factor to estimate the mean annual load for the impaired stream (see Equation 2 and Box 1).

If neither a rating curve, nor baseflow SSC are available from a reference stream, a sediment budget may be used to estimate the mean annual load of the reference stream. A sediment budget can be developed for the reference stream using one of the simple loading models, such as the EPA Region 4 Sediment Tool or the Generalized Watershed Loading Function Model. These models employ the USLE and an assumed delivery ratio to estimate sediment input to the stream from various sources within the watershed. Stream processes are generally not simulated, unless they are incorporated into the delivery ratio. The models estimate the long-term mean annual load in T/A-yr. The reference stream load then becomes the desired mean annual sediment load for the impaired stream.

Reference stream not available

In the case where an appropriate reference stream is not available, we propose using a long-term mean suspended sediment concentration (SSC_0) of 20-30 mg/L. This proposed SSC_0 applies only to the Piedmont, Blue Ridge, and the Ridge and Valley regions of the state and is subject to change as more information is made available. Our proposed SSC_0 of 20-30 mg/L is based primarily on the data collected from Walters et al. (2001) for the Etowah Research Project (see Box 3) and supported by data collected in other studies (Sutherland et al., 1998; Sutherland et al., 1999; Meyer et al., 1999). These data show that the IBI declined when baseflow turbidity exceeded 10 NTU (Figure 1) or when baseflow SSC exceeded 10 mg/L (Figure 2, Walters et al., unpublished data). The SSC_0 for a stream can be expected to be slightly higher than the mean baseflow SSC (mean baseflow Q was about 70% of Q_0 in an analysis we performed on the streams in Table 2). For example, when we used the rating curve equations in Table 2 to calculate SSC_0 for a reference stream with a baseflow (Q/Q_0 = 0.70) SSC of 10 mg/L, we obtained SSC_0 values between 10 and 23 with a mean value of 15 mg/L. This is one reason for proposing an SSC_0 higher than 10 mg/L.

Another reason is that, once a TMDL is established for an impaired stream, it is likely that suspended sediment measurements will be monitored to see if the TMDL is being met. These measurements are likely to be made in terms of turbidity (NTU) and the relationship between NTU and SSC is often not one-to-one, as discussed in section II on quantifying suspended sediment in the water column. Even if the measurements are made in terms of SSC, getting a representative depth-integrated sample is difficult. To account for possible error in these measurements, we have chosen a SSC_0 about twice the concentration indicated by the data of Walters et al. (2001), Sutherland et al. (1998 and 1999), and Meyer et al. (1999). Choosing this value was the most contentious issue faced by the TAG due to uncertainty in how widely we should assume the results of Walters et al. (2001) to apply and uncertainty in the relationship between NTU and SSC. A range of 20 to 30 mg/L is given as the upper limit for SSC_0, because we could not find consensus on a single value.

Box 4. Data from the Etowah River basin project (Leigh et al., 2001 and Walters, et al., 2001) are referred to several times in this document because it is one of the few studies in the nation that correlates physical and chemical stream habitat conditions to biota (fishes and macroinvertebrates). Funding for the Etowah project was awarded as a Science to Achieve Results (STAR) grant by the U.S. EPA following a competitive peer review process.The Etowah River basin was chosen for study because it is representative of Piedmont drainage systems that are experiencing rapid urbanization. Land cover in tributary catchments ranges from predominantly urban in the southern part of the basin to predominantly forest in the northern part.This provides a wide array of human

Box 4 continued

impacts and stressors to correlate against the biotic assemblages. Furthermore, streams in the Etowah basin contain a wide range of physical conditions such as stream gradients ranging from 0.1 to 1.0 percent and bed sediment sizes ranging from sand to cobble. The research focuses on 31 small catchments that range in size from 10 to 130 km^2. Additional information about this research can be read in several papers of the 2001 Proceedings of the Georgia Water Resources Conference (Hatcher, 2001) that are posted on a web site (http://etowahepa.ecology.uga.edu/) along with other additional information. The methods used for measuring turbidity and SSC are described in Paul et al. (2001).

If suspended sediment or turbidity measurements are made in a stream for comparison with the recommended SSC_0, it is important that they be made in a manner consistent with the studies from the Etowah River basin project (see Box 4).

The main advantage of using this SSC_0 is the ease of use and the consistent application across streams. One disadvantage of this approach is that it was developed from data collected under baseflow conditions, rather than stormflow conditions when much of the sediment input may occur. However, the TAG believes that baseflow SSC or turbidity may be a good indicator of overall water quality, especially in streams with historic sediment. Clay-size particles settle out slowly so that a stream with a high storm flow sediment load is likely to remain turbid for some time after a storm. In streams where historic sediment is the only source, baseflow SSC and turbidity are likely to be low because the clay-size particles have been carried downstream in the intervening decades (not true of the larger size particles, but these become suspended only during stormflow). In effect, baseflow SSC or NTU is a surrogate for the overall sediment load.

Another disadvantage of using this SSC_0 is that it does not apply to all streams across the state. We do not have the data necessary to develop a recommendation for SSC_0 for streams outside of the Piedmont and Blue Ridge regions. It should be noted, however, that most of the streams currently requiring sediment TMDLs are in the Piedmont and Blue Ridge region.

One can ask, how our recommended SSC_0 compares to SSC_0 measured in Georgia streams. One way to address this issue is to look at the streams for which we have sediment rating curves (Table 2). The Chestatee River at Dahlonega, Falling Creek near Juliette, and Snake Creek near Whitesburg have SSC_0 values near or below our recommended SSC_0, but the other streams have SSC_0 well above 20-30 mg/L. It is important to note that we have no IBI scores for these streams, therefore it would be inappropriate to assume those exceeding 20-30 mg/L are in violation of a water quality standard.

Another way to address this question is to look at studies where SSC has been measured repeatedly under predominately baseflow conditions. As we mentioned above, we expect the upper limit of baseflow SSC to approximate SSC_0. One such study is the U.S. Geological Survey National Water Quality Assessment (NAWQA) program for tributaries of the Chattahoochee River during the period 1993 to 1995 (USGS, 2001). This study monitored streams that drained watersheds with different predominant "indicator" land uses (such as agriculture, urban, etc.). Table 3 shows summary statistics for SSC and NTU measured when stream discharge was at or below Q_0, so some of the values represent conditions that would be at the upper limit of baseflow. Turbidity measurements consistently underestimated SSC but the measurements were highly correlated. All of the stream categories had SSC averages that were below our recommended SSC_0 of 20-30 mg/L.

Table 3. Summary statistics for flow conditions less than or equal to the annual mean discharge for tributaries to the Chattahoochee River fromthe 1993-1995 USGS NAWQA study (USGS, 2001).

USGS Indicator site	Drainage Area (mi^2)	Number of Samples for Turbidity(TSS)	Number of Samples (NTU)	Mean SSC (mg/L)	Mean Turbidity (NTU)
Urban: Peachtree Creek in Atlanta	86.8	26	28	10.4	5.0
Residential: Sope Creek in Marietta	29.2	32	44	12.3	4.4
Agricultural (Clastic): Lime Creek near Cobb	61.8	22	26	13.8	9.5
Agricultural (Karst): Aycocks Creek near Boykin	105.0	12	13	21.9	3.3
Poultry: West Fork Little River near Clermont	18.3	18	18	13.1	6.9
Silviculture: Snake Creek near Whitesburg	35.5	21	22	17.1	8.4
All Data	--	131	151	13.1	6.4

Another study that measured turbidity under predominately baseflow conditions is the United States Department of Agriculture (USDA) Oconee River Basin Agricultural Conservation project (USDA, 2001). In this study, turbidity was measure in situ with a probe (Fisher et al., 2001). As Table 4 shows, mean baseflow turbidity ranged from 7 to 79 NTU, with an overall average of 21 NTU. If we assume that there was a one-to-one relationship between SSC and NTU in these streams, then four of the streams exceed our recommended SSC_0. If we assume that turbidity underestimates SSC at low concentrations (as in Table 3 and described in section II on quantifying suspended sediment in the water column), then the number of streams exceeding our recommended SSC_0 would be greater. As with Table 3, it is important to note that we have no IBI scores for these streams, therefore it would be inappropriate to assume those exceeding 20-30 mg/L are in violation of a water quality standard.

Table 4. Mean baseflow turbidity for streams in the Oconee River Basin Agricultural Conservation Efficacy study (USDA, 2001).

Site	DrainageArea (mi^2)	BaseflowTurbidity (NTU)
North Oconee River SR323-Gillsville Highway	45	16
North Oconee River Chandler Cemetery Road	81	28
Pond Creek CR2456-Lipscomb Lake Road	17	17
Allen Creek Wayne Poultry Road	24	16
Walnut Creek Pocket Road	35	19
Middle Oconee River Old Pendergrass Road	122	23
Middle Oconee River SR319 Double Bridges Road	150	32
Mulberry River SR319 Double Bridges Road	156	79
Mulberry River New Liberty Church Road	41	20
Hard Labor Creek Browning Shoals Road	30	14
Big Sandy Creek Sandy Creek Road	16	36
Hard Labor Creek Double Bridges Road	62	9
Big Sandy Creek Sandy Creek Road	64	24
Hard Labor Creek Lower Apalachee Road	153	21
North Little Sugar Creek Plainview Road	9	23
Sugar Creek Bethany Creek Road	6	16
Sugar Creek Seven Islands Road	30	15
Sugar Creek Mount Zion Road	38	14
Greenbriar Creek Astondale Road	2	23
Rose Creek Astondale Road	3	13
Greenbriar Creek Marshal Store Road	8	7
Rose Creek Elder Mill Road	6	12
Greenbriar Creek Johnny Carson Road	15	8
Rose Creek Antioch Church Road	16	12
Greenbriar Creek Double Bridges Road	18	19

We emphasize that the recommended SSC_0 is a mean value and therefore to compare stream SSC or turbidity to the recommended value, multiple measurements must be made. We suggest a minimum of ten measurements of SSC or turbidity at various times of the year and all under baseflow conditions. A geometric mean, rather than an arithmetic mean, should be calculated. If turbidity is measured rather than SSC, then a site-specific relationship between turbidity and SSC should be used to convert NTU to SSC.

Other recommended conditions

We have recommended a condition for suspended sediment concentration. Alternatively, a recommended condition could be developed that addresses bed characteristics, such as bed particle size if that has been measured in the impaired stream and reference stream. The recommended value could be the bed particle size of the reference stream. In this case the load capacity (discussed in next section on calculating the load capacity) could be estimated by applying the desired percent reduction in fine particles to the current mean annual load in the impaired stream, calculated using a simple sediment budget. This is similar to the approach used in the Garcia River sediment TMDL (U.S. EPA, 1998). Regardless, we advocate measurement of the stream bed particle size characteristics to obtain a better understanding of current stream habitat and how it relates to future improvements and imposed limits on biotic quality.

Calculating the load capacity

The sediment TMDL for a stream is equal to the load capacity (LC), an estimate of the amount of sediment the stream can assimilate and still meet water quality standards. In many cases, the LC will be in terms of a mean annual sediment load expressed as T/yr or T/A-yr. If the reference stream approach (described in section III on reference stream available) is used to calculate the current load of the reference stream (in T/yr or T/ day, for example), then the LC is equal to the reference stream load.

If no reference stream is available and the SSC_0 of 20-30 mg/L is employed, then the LC is the chosen value for SSC_0 (between 20 and 30 mg/L) times Q_0 and the rating curve bias factor (Appendix A), with the appropriate unit conversions:

$$LC\left(\frac{T}{yr}\right) - \beta \cdot Q_0(cfs) \cdot SSC_0 \left(\frac{mg}{L}\right) \cdot 0.0027 \cdot 365$$

Equation 5

In either case, the LC of a stream must translate to daily loads. This feature of a TMDL is especially important in watersheds where point sources are contributing to the degradation of the water quality. Entities holding National Pollution Discharge Elimination System (NPDES) discharge permits must be able to make appropriate reductions in the quantity or quality of their permitted discharge, as determined on a daily basis

In Appendix A, we show how to convert mean annual sediment loads (in T/yr) to a mean daily sediment load (in T/day) and to a mean daily SSC (in mg/L). Example calculations are given based on a sediment TMDL conducted for the Chattooga River watershed in Northeast Georgia (U.S. EPA, 2001). The mean daily load would apply to baseflow conditions. A storm flow daily load can be calculated if a sediment rating curve exponent is available. For example, in the Chattooga River watershed, a sediment rating curve was developed for the USGS gage station #02177000, located in the watershed. If we assume that the exponent (b) or slope of the sediment rating curve was the same in all of the Chattooga River tributaries, then we could calculate a high flow daily load corresponding to flow at ten times the mean flow ($Q/Q_0 = 10$).

Allocating the load capacity

The LC that will maintain water quality standards must be allocated between point source loads (known as wasteload allocations (WLA)) and nonpoint source loads (known as load allocations (LA)). Since the LC calculation is an estimate using current conditions, it also must include a margin of safety (MOS) to account for the uncertainty in the estimate and to provide an allowance for future growth (FG):

$$TMDL = LC = WLA + LA + MOS + FG$$

Equation 6

In a watershed that drains to a stream impaired by sediment, land-disturbing activities as defined in the Georgia ESCA of 1975 (O.C.G.A. Section 12-7-1) should be required to obtain a specific, rather than a general, NPDES permit. The permit should specify the load allocated to the construction site (annual loads and daily loads.) The sum of all point source permits in a listed watershed should not exceed the WLA. As part of the specific permit, land-disturbing sites should be required to develop a sediment control plan that includes a combination of best management practices (BMPs) that will result in sediment loss less than or equal to the permitted load. The sediment control plan should also apply to any subcontractors. This approach may result in more comprehensive sediment control measures at a site than would be required by the current state regulations (DNR, 2000). No new NPDES permits for land disturbing activities should be issued for a watershed requiring a sediment TMDL, unless it can be shown that the additional load will not cause the sum of all permitted point source loads to exceed the WLA.

Calculating percent reductions and the current load

WLA and LA, should be listed as percent reductions as well as loads. The percent reduction in WLA and LA should be specified by comparing the estimated current load with the TMDL. Ideally, the current load of the impaired stream should be calculated by making measurements of SSC under baseflow conditions, calculating a mean concentration, and using this as an estimate for the current SSC_0. Q_0 can be estimated using any of the methods described above and the current load should be calculated using Equation 2. A value between two and three can be chosen for the rating curve bias factor, or it can be calculated using long-term discharge data from a USGS gaging station for a stream with similar flow characteristics (see the method in Appendix A).

If no measurements of SSC are available or can be obtained, then the current load can be estimated by developing a sediment budget using current land uses and the USLE with a delivery ratio. It is important to realize that there is considerable error using this approach and the estimated current load for the impaired stream may be less than the LC (implying a zero percent reduction).

This does not necessarily indicate that the stream is not impaired or that historic sediment is the source. It may simply be due to the fact that the LC and current load were estimated using different methods. In this case, it should be stated that an accurate estimation of the current load was not available. The USLE approach is best for ranking impaired streams and inventorying sources, not for calculating current loads.

Margin of safety

The margin of safety (MOS) should be explicit (typically 5-20% of the LC) and not implicit (based on the use of conservative assumptions). Ideally, it should represent the error between predicted loads (from a model, for example) and the observed loads. The MOS should be greater in instances where there is greater uncertainty in the estimated sediment budget, or where the suitability of the reference stream is in question. If the load reductions are assigned primarily to the point sources, then the MOS can be relatively small since loads are more readily monitored for point sources than for nonpoint sources. Conversely, if the load reductions are assigned primarily to nonpoint sources, then the MOS should be relatively large. Also, the MOS should reflect the amount of data available at the time the TMDL is being established. For example, a greater MOS is expected for Phase I TMDLs than Phase II TMDLs.

Future growth

If no allowance for future growth is included in the TMDL, then it may be shown (with a sediment budget or watershed model, for example) that an additional load will cause the sum of all permitted point sources to exceed the WLA. In this case, no new permits for point sources should be allowed in the watershed unless existing NPDES permit loads are reduced. This can be accomplished, for example, through the installation of more advanced treatment systems.

MANAGING STORED SEDIMENT

As discussed in section II on historic sediment issues in Georgia, a potential source of sediment for many Piedmont streams is stored sediment that may include mostly historic sediments, but also some prehistoric sediment. If it is concluded that stored historic sediment is the primary source of impairment, then the maximum practical limitations on current inputs (WLA and LA) should be imposed. Simply concluding that streams will repair themselves over time with no reductions in current loads is not recommended. If nothing is done, then centuries or millennia may be needed to fully remove stored historic sediments by natural forces. Alternatively, but with more potential for ecological damage, historic sediments can be removed by dredging the channel and floodplains to reestablish the original channel and floodplain conditions.

Another set of options would be to stabilize the historic sediments, trapping them in place, by creating conditions favorable for sediment sequestration. Controls, such as preventing cattle within riparian and floodplain areas and prohibiting large woody debris removal in these areas could lead to effective sediment sequestration.

Yet a final set of options would be to limit energy inputs to the riverine system. Because energy from stormwater is the leading cause of historic sediment remobilization, efforts should be taken to prohibit, or substantially curtail, impervious surfaces and stormwater runoff within the watershed. A stormwater energy TMDL could be specified to limit the energy inputs to stream systems so that conditions favorable for historic sediment remobilization are avoided.

IMPLEMENTATION PLAN

Implementation plans are a critical part of the TMDL program and should be the subject of a separate white paper developed with more stakeholder input. Most of the TAGs discussions focused on TMDL establishment, however we recognize that establishment and implementation need to be closely linked.

Once the problems causing impairment are identified by the regulatory agency responsible for establishing TMDLs (i.e. EPA or EPD), corrective measures should be developed to address known sources of the impairment (see section III on problem identification). Environmental, economic and social considerations should form the basis of potential corrective measures. Under current rules and regulations, many of the corrective measures to address water quality impairments require a voluntary management approach. Corrective measures that do not adequately address all three considerations in a voluntary framework will not be successful. Thus, economic, social, and environmental analyses will be integral components of any solution that facilitates water quality improvement.

Implementation plans for sediment TMDLs should be developed with stakeholder input. Therefore, as a result of time constraints, implementation plans for the Phase I TMDLs probably will have to be developed separately from the initial TMDL document. Nevertheless, the various measures that are to be implemented to achieve the required sediment load reductions should be indicated for both WLA and LA. Sources of funding to achieve load reductions should be identified as part of the reasonable assurance requirement that TMDLs will be implemented and meet water quality standards.

Since Phase I TMDL implementation plans will be developed at the local level, it is essential that the TMDL and the establishment process be understood by the local stakeholders. Each TMDL should be released with a detailed description of the data and processes used to develop it. Efforts should be made to insure that the TMDL can be understood by individuals not familiar with water quality and modeling efforts. Where practical, all assumptions and data inputs should be listed so that stakeholders developing the implementation plan can validate and relate to the TMDL without having to go to numerous external sources.

MONITORING PLAN

Follow-up monitoring is a key component of the TMDL process and should be particularly emphasized in the Phase I TMDLs because of the uncertainty surrounding their establishment. This information will be critical in developing more accurate TMDLs during Phase II. At a minimum the monitoring program will have to address the issues of how SSC varies with discharge (day, week, etc.). The monitoring plan must incorporate the use of consistent and accurate sampling and analytical procedures. Monitoring requirements should be based on the individual TMDL.

During the first year after a sediment TMDL has been established, the identified reach should undergo a thorough water quality assessment. At a minimum the assessment should be performed twice, once under low flow conditions (when point sources are likely to exert the most impact) and once under high flow conditions (when nonpoint sources are likely to exert the most impact). These water quality assessments should include measurements of appropriate physical and chemical water quality parameters that could have caused the initially detected biotic impairment. Obviously, biotic assessments should be performed including fish and macroinvertebrate surveys. Because the impact of excess sediments is in part a function of local stream slope (Walters et al. 2001), stream slope should be measured as a component of biotic sampling at all sites. After the water quality assessment, the need for a sediment TMDL should be re-evaluated in case the original biotic impairment was identified in error or erroneously attributed to excess suspended sediment.

If excess sediment is not eliminated as the root cause of the biotic impairment, then additional monitoring must be initiated. It is recommended that instream turbidity, SSC, and stream discharge be measured in the impaired stream segments during both dry weather and wet weather events to determine the site-specific relationship between these parameters. In addition, selected streams located adjacent to specific land uses should be monitored to determine the impact various land use practices have on instream SSC and turbidity. It is also recommended that pebble count data be collected. The median particle size (D_{50}) can then be compared to a D_{50} derived from regional reference values. Median particle sizes smaller than regional reference values may indicate unacceptable rates of sediment accumulation and, hence, sediment-related impairment. Once application of BMPs to nonpoint sources has begun, annual or semi-annual biotic assessments also should be performed.

In the case of sediment, during the first five-year TMDL cycle, it may be very difficult to detect a significant reduction in annual sediment load through direct stream monitoring. As rating curves show, stream SSC can vary with Q, but other data have indicated that these concentrations are supply-limited. Hence, to compare values of SSC over time, they must be corrected to the same value of Q. Essentially, enough data must be collected to determine if the intercept of the rating curve developed from measurements taken after load reduction measures have been implemented is different from the intercept of the rating curve before implementation. In most cases, detecting such a change probably will take more than five years of careful measurement. As noted in the previous section, annual or semi-annual biotic surveys should be included in the monitoring plan. As with the rating curve intercept, these, too, are unlikely to show a significant improvement within the first five-year cycle due to the inherent variability in these characteristics.

One of the most important sources of information regarding implementation of the TMDL will consist of evidence that BMPs are being implemented as required in the implementation plan. Therefore, the implementation of BMPs should be monitored and recorded as part of the monitoring plan. This would include spot inspections, such as a visit to harvested forest sites to ensure that the sediment control plan is being followed and a visit to farms to ensure that agricultural BMPs are in place and functioning.

The TMDL should include a five-year plan for monitoring, identifying the responsible parties and securing sources of funding. The plan should include milestones to determine if control actions are being implemented and standards attained.

PHASE II TMDLs

Given the nature of scientific research, this white paper serves as a living document. As more data and information become available, the recommendations here may change. Also, in light of our limited experience in establishing sediment loads and limits, the TAGs recommendations for TMDLs established during the second five-year cycle (Phase II), and subsequent cycles, will be less detailed than those recommendations for Phase I. If the appropriate monitoring is conducted during the time between Phase I and Phase II TMDLs (see section III on monitoring plans), time and data will be less limited and the following procedures should be used.

Further research on the relationship between biotic indices and SSC, hopefully, will be developed in time for many Phase II TMDLs. These data may be more region or site specific. Similarly, more information may be available on the extent of contributions from stored sediment . Stakeholder involvement in identification of the problem, and in development and implementation of the TMDL is critical.

New recommendations in addition to a SSC_0, may be developed in the near future, based on a better understanding of the relationship between biotic indices, SSC and bedload. There is a particular need to develop a standard for chronic (baseflow) and acute (storm driven) sediment loads. A discharge limit for the TMDL should be agreed upon and load reduction measures should be designed to protect water quality standards up to this discharge limit, but not beyond. As an example of a design discharge, the maximum monthly mean flow from long-term records was used as the critical daily flow in the Cimmaron River TMDL (New Mexico Environment Department, 1999)

For Phase II TMDLs, the LC should be estimated using an analysis of the impaired stream and a reference stream using a sediment transport model that includes processes not accounted for in the simple loading models used to estimate a sediment budget and accounts for bedload as well as suspended load. Such models may include Agricultural Nonpoint Source Model (AGNPS), National Sedimentation Laboratory, 2001), Hydrologic Simulation Program Fortran (HSPF), and Soil and Water Assessment Tool (SWAT) (U.S. EPA, 2001a). The chosen model should be calibrated using site-specific monitoring data and it should be run on both the reference stream and the impaired stream. The model may be used to interpolate between the observed monitoring-derived data points to estimate, for example, SSC at daily or hourly time steps. Thus, models from an appropriate reference stream potentially could be used to determine reference chronic and acute sediment loads (in terms of SSC and bedload) for purposes of developing the LC for the impaired stream. In this case, the TMDL should be specified at a daily time step for both acute and chronic conditions.

The LC must be allocated to point and nonpoint sources, a margin of safety, and an allowance for future growth, as discussed above. Depending on model availability and accuracy, as well as adequate site-specific calibration data, the loads may be for temporal resolutions ranging from daily to annual loads. The percent reduction in current loads should be specified by comparing the estimated current load (computed from the model predictions) with the LC.

The MOS should be explicit, expressed as a load (not a percent reduction), and should be based directly on the uncertainty in the model. For example, if the average error between the model predictions and the observed measurements of annual load is five T/A-yr (the annual root mean squared error), then the MOS should be five T/A-yr. If replicate measurements of stream loads are available, then the error in the monitoring data can be calculated, as well, and this should be added to the MOS.

Since ample time is available in this case to include stakeholder input, the Phase II TMDL document should include a detailed implementation plan. Monitoring plans, as always, are the key to determining the success of a TMDL. Long-term monitoring should be required in order to develop rating curves for the treated streams and new surveys of biotic indexes should be conducted.

IV) RESEARCH NEEDS

The TAGs discussions and development of this white paper have made apparent a number of research questions that need to be answered to support the establishment of scientifically-based sediment TMDLs. Most of these issues are raised throughout the paper and include, but are not limited to:

- More research to understand the relationship between biotic indices and SSC
- Monitoring and assessment of physical parameters (sediment loads, watershed surveys, etc…) in reference streams identified by WRD and EPA in each hydrological and ecological region in Georgia
- Identification and monitoring by WRD of physical, chemical, and biological conditions in an appropriate set of reference streams in each geographical and ecological region in Georgia (These are needed to identify appropriate reference conditions for water quality and to calibrate more complex sediment transport models.)
- Standards for acute (storm driven) sediment loads
- Reference conditions based on bed characteristics
- Techniques for obtaining timely land-use data that correlate temporally with water quality monitoring data to better detect and quantify temporal issues
- Estimation techniques to measure various components of sediment budgets (bedloads, streambank recession, construction sites, dirt roads, etc.)
- Development of methods to derive the margin of safety (MOS) from model uncertainty
- More research to understand the relationships between:
  - Baseflow and stormflow turbidity and SSC,
  - Bedloads, percent embeddedness, particle size, and pebble counts,
  - NTU and SSC in each geographical and eco-region in Georgia.

For more information contact Alice Miller Keyes at The Georgia Conservancy: 404-876-2900 or visit our website at www.georgiaconservancy.org

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glossary of terms

Taken in part from the Protocol for Developing Sediment TMDLs (U.S. EPA, 1999)

Allocations. That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources

- A wasteload allocation (WLA) is a portion of the loading capacity allocated to an existing or future point source, and
- A load allocation (LA) is that portion allocated to an existing or future nonpoint source or to natural background source. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading

Assimilative capacity. The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life

BASINS. Better Assessment Information System, EPA software for developing TMDLs

Bedload. Portion of sediment load transported downstream by sliding, rolling, bouncing along the channel bottom. Generally consists of particles >1 mm

Benthic. Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody

Benthic organisms. Organisms living in, or on, bottom substrates in aquatic ecosystems

Best management practices (BMPs). Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures

Biological criteria. Also known as biocriteria, biological criteria are narrative expressions or numeric values of the biological characteristics of aquatic communities based on appropriate reference conditions. Biological criteria serve as an index of aquatic community health

Channel. A natural stream that conveys water; a ditch or channel excavated for the flow of water

Channel improvement. The improvement of the flow characteristics of a channel by clearing, excavation, realignment, lining, or other means in order to increase its capacity. Sometimes used to connote channel stabilization

Clean sediment. Sediment that is not contaminated by chemical substances. Pollution caused by clean sediment refers to the quantity of sediment, as opposed to the presence of pollutant-contaminated sediment

Colluvium. Soil and rock debris on a hillslope that has been transported from its original location

Concentration. Amount of substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm)

CWA. Clean Water Act

Dilution. The addition of some quantity of less concentrated liquid (water) that results in a decrease in the original concentration.

Direct runoff. Water that flows over the ground surface directly into streams, rivers, and lakes.

DIRT II Committee. A committee created in the 1993 General Assembly to determine cost effective methodology to prevent sedimentation problems from occurring during construction activities. The Committee's final report, released July, 2001, describes construction techniques and public and private activities that can prevent the degradation of water quality due to construction. It is available at http://www.state.ga.us/dnr/environ/techguide_files/wpb/dirt2/tpcr_published.pdf

Discharge. Flow of surface water in a stream or canal or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent fro a facility or to chemical emissions into the air through designated venting mechanisms.

Discharge permits (NPDES). A permit issued by the US EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge into a receiving water; it also includes a compliance schedule for achieving those limits. It is called the NPDES because the permit process was established under the National Pollutant Discharge Elimination System, under the provisions of the Federal Clean Water Act.

Drainage basin. A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.

Dynamic model. A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.

Ecoregion. A physical region that is defined by its ecology, which includes meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Effluent. Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic systems, pipe, etc.

Embeddedness. The degree to which fine sediments fill the spaces (interstices) between rocks on the substrate.

Endpoint. An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).

EPA. United States Environmental Protection Agency

EPD. Georgia Environmental Protection Division

ESCA. Georgia Erosion and Sedimentation Control Act of 1974

Geomorphology. The study of the evolution and configuration of landforms.

GWLF. Generalized Watershed Loading Functions model.

HSPF. Hydrologic Simulation Program Fortran, part of the BASINS software

Index of biotic integrity (IBI). The IBI uses measurements of the distribution and abundance or absence of several fish species types in each waterbody for comparison. A portion of a waterbody is compared to a similar, unimpacted waterbody in the same ecoregion.

IOE. University of Georgia Institute of Ecology

Loading, load, loading rate. The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.

Load allocation (LA). The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished. (40 CFR 130.2(g))

Loading capacity (LC). The greatest amount of loading that a water can receive without violating water quality standards.

Low-flow (7Q10). Low-flow (7Q10) is the 7-day average low flow occurring once every 10 years; this probability-based statistic is used in determining stream design flow conditions and for evaluating the water quality impacts of effluent discharge limits.

Margin of safety (MOS). A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, qualitatively, a TMDL = LC = WLA + LA + MOS).

Monitoring. Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.

Narrative criteria. Nonquantitative guidelines that describe the desired water quality goal.

National Pollution Discharge Elimination System (NPDES). The national program for issuing, modifying, revoking, and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 402, 318, and 405 of the Clean Water Act.

Natural waters. Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.

Nonpoint source. Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pebble counts. A random sampling of the surface particle distribution on the bed of a channel; can be done on individual geomorphic elements of a stream or on the entire stream

Permit. An authorization, license, or equivalent control document issued by EPA or an approved Federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

Phased approach. Under the phased approach to TMDL development, Las and WLAs are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reductions strategies while collecting additional data.

Point source. Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollutant. Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munition, chemical wastes, biological material, radioactive material, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discarded into water. (CWA Section 502(6)).

Pollution. Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical biological, chemical, and radiological integrity of water.

Q. Stream discharge, usually in cfs

Q_0. Long-term mean stream discharge, usually in cfs.

Rating Curve Bias Factor. Used to account for the positive correlation between discharge and sediment concentration when estimating the arithmetic average sediment load. Ignoring the correlation can result in a substantial underestimate in arithmetic average load because larger flows are accompanied by higher sediment concentrations. In this case, the arithmetic average sediment load is not the product of the arithmetic average sediment concentration with the arithmetic average discharge. Instead, the product must be further multiplied by the rating bias factor to obtain the arithmetic average sediment load. The rating bias factor is not required when geometric averages are employed (Cohn, 1995).

Receiving waters. Creeks, streams, rivers, lakes, estuaries, ground-water formation, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.

Reference sites. Waterbodies that are representative of the characteristics of the region and subject to minimal human disturbance.

Riparian areas. Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.

Riparian vegetation. Hydrophytic vegetation growing in the immediate vicinity of a lake or a river closely enough so that its annual evaportranspiration constitutes a factor in the lake or river regime.

Riparian zone. The boarder or banks of a stream. Although the term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to the floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.

Runoff. That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Sediment. Particulate organic and inorganic matter that accumulates in a loose, unconsolidated form on the bottom of natural waters.

- Historic sediment. Sedimentary strata deposited in association with historical human impacts on the landscape during the last 200 years or so (i.e. row-crop farming, silvaculture, and urbanization).
- Prehistoric sediment. Sedimentary strata deposited over 200 years ago

Sediment delivery. Contribution of transported sediment to a particular location or part of a landscape.

Sediment rating curve. This is a log-log plot of SSC (or TSS) as a function of discharge (Q). Discharge may be normalized by dividing by the long-term mean discharge (Q_0) so that the x-axis variable is Q/Q_0.

Sediment yield. Amount of sediment passing a particular point (e.g., discharge point of the basin) in a watershed per unit of time.

Sedimentation. Process of deposition of waterborne or windborne sediment or other material ; also refers to the infilling of bottom substrate in a waterbody by sediment (siltation).

Slope. The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in decimal fraction (0.04); degrees (2 degrees 18 minutes), or percent (4 percent).

STAR. Science to Achieve Results

Surface runoff. Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.

Suspended sediment concentration (SSC). Used to quantify suspended sediment in the water column; method based on measuring the total suspended solids collected in a stream sample, determined by evaporation or filtration; expressed in mg/L.

- The long-term mean suspended sediment concentration (SSC_0) is the value of SSC corresponding to the long-term mean discharge (Q_0) or the normalized mean discharge of $Q/Q_0 = 1$.
- As recommended by the TAG SSC_0 = 20-30 mg/L, is to be used in calculating the LC of a stream when a reference stream is not available.

Suspended solids (sediment) or load. Organic and inorganic particles (sediment) suspended in and carried by a fluid (water). The suspension is governed by the upward components of turbulence, currents, or colloidal suspension. Suspended sediment usually consists of particles <0.1 mm, although size may vary according to current hydrological conditions. Particles between 0.1 mm and 1 mm may move in suspension or be deposited (bedload).

SWAT. Soil and Water Assessment Model, part of the BASINS software.

TAG. Technical Advisory Group

TGC. The Georgia Conservancy

TMDL. Total maximum daily load

TSS. Total suspended solids, usually in mg/L

Total suspended solids (TSS). Used to quantify suspended sediment in the water column; method based on measuring the total suspended solids collected in a stream sample. Method similar to that for SSC, but performed on an aliquot, not the full water sample; expressed in mg/L

Turbidity. A measure of opacity of a substance; the degree to which light is scattered or absorbed by a fluid.

USLE. Universal Soil Loss Equation predicts mean annual sediment loss from upland sources, usually in T/A-yr.

Wasteload allocation (WLA). The portion of a receiving water=s loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Water quality. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.

Water quality standard. Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an anti-degradation statement.

Watershed-scale approach. A consideration of the entire watershed, including the land mass that drains into the aquatic ecosystem.

Watershed. A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

SAMPLE CALCULATION OF ANNUAL LOADS AND DAILY LOADS

In this appendix, we use the data from the Chattooga River watershed sediment TMDL (U.S. EPA, 2001b) to suggest a method for calculating current daily sediment loads and concentrations, given an estimate of the mean annual load and a sediment rating curve. All the numeric references throughout the appendix refer to data taken directly from this TMDL or calculated from data found in the TMDL document (U.S. EPA, 2001b). Table 5 of this white paper was created using the data from the Chattooga sediment TMDL.

If a reference stream is available, then the current annual and daily loads of the reference stream become the annual and daily load capacity (LC) and can be used to calculate an annual and daily TMDL. In the Chattooga River watershed, Cutting Bone Creek was used as a reference stream. The mean annual sediment load was given in the Chattooga River sediment TMDL. It was calculated using the USLE and a delivery ratio, considering the different land use, soils, and elevation in each watershed. The sediment rating curve was also given in the TMDL, and it was developed from the Chattooga River USGSA gage #02177000:

$$SSC\left(\frac{mg}{L}\right) = 13 \cdot \left(\frac{Q}{Q_0}\right)^{1.37}$$

where Q_0 is the arithmetic average of a large number (n) of measured daily discharge:

$$Q_0 = \frac{1}{n}\sum_{i=1}^{i=n} Q_i$$

The streams are listed in column 1 of Table 5. The watershed areas are listed in column 2. We calculated an estimated mean flow in column 3 of Table 1. This value was calculated using the estimated water yield (mean discharge per unit watershed area) in cfs/mi^2 for the Chattooga River area of Georgia taken from Carter (1983). The estimated water yield for this area is approximately 2.5 cfs/mi^2. The estimated mean flow is the product of the watershed area (column 2) and the water yield:

$$Mean\ flow\ (cfs) = Area\ (mi^2) \cdot 2.5\left(\frac{cfs}{mi^2}\right)$$

Mean flow might be obtained in other ways without using the estimated water yield. If the discharge record is available for a stream, the mean flow is the long-term average flow in cfs. It may be possible to use the discharge record from nearby stream, calculate the water yield for that stream and use it in the above equation.

The mean annual sediment load in T/yr (where 1 T = 2000 pounds (lb)) is given in column 4. The mean annual load can be converted to a daily load at mean flow and high flow. We will define high flow as ten times the daily mean flow (Q/Q_0 = 10.0). The mean annual load can be converted to a daily mean load as follows:

$$Daily\ mean\ load\left(\frac{T}{day}\right) = \frac{Mean\ annual\ load\ \left(\frac{T}{yr}\right)}{365\left(\frac{day}{yr}\right)\cdot ß}$$

The rating curve bias factor (ß) accounts for the fact that the mean annual load is not the same as the product of the mean discharge and the mean SSC, due to the nonlinear nature of the rating sediment rating curve (Cohn et al., 1989). It can be estimated from the daily discharge data:

$$ß = 1 + \frac{b^2+b}{2}\sum_{i=1}^{n}\left(\frac{Q_i}{Q_0} - 1\right)^2 + \frac{b^3-b}{6}\sum_{i=1}^{n}\left(\frac{Q_i}{Q_0} - 1\right)^3$$

where b is the exponent of the rating curve (1.37 in this case). For the daily discharge data from the Chattooga River USGS gage #02177000 (for the period 01/01/1970 to 01/01/2000), the value of the rating curve bias factor was calculated as ß= 2.39.

We used the above equation to calculate the daily mean load values in column 5 of Table 5. For example, for Scott Creek:

$$1.24\ \left(\frac{T}{day}\right) = \frac{1078\left(\frac{T}{yr}\right)}{365\left(\frac{day}{yr}\right)\cdot 2.39}$$

The daily load can be converted to a daily mean SSC in mg/L by dividing by the mean flow in cfs and multiplying by a unit conversion factor:

$$Daily\ mean\ SSC\left(\frac{mg}{L}\right) = \frac{Daily\ mean\ load\left(\frac{T}{day}\right)}{Daily\ mean\ flow\ (cfs)}\cdot 371\left(\frac{mg\cdot cfs\cdot day}{L\cdot T}\right)$$

That is, the daily mean SSC (column 6) is column 5 divided by column 3 and multiplied by the conversion factor. Using Scott Creek again as an example:

$$30\left(\frac{mg}{L}\right) = \frac{1.24\left(\frac{T}{day}\right)}{15.23\ (cfs)}\cdot 371\left(\frac{mg\cdot cfs\cdot day}{L\cdot T}\right)$$

The daily mean SSC can be converted to a daily high flow (Q/Q_0 = 10) SSC, using the following equation:

$$Daily\ high\ flow\ SSC\left(\frac{mg}{L}\right) = Daily\ mean\ SSC\left(\frac{mg}{L}\right)\cdot 10^b$$

where *b* is the exponent of the rating curve. In this case, the rating curve exponent is 1.37, so using the Scott Creek example, we calculate the values in column 8 (note we are skipping column 7 for the moment) by multiplying the values in column 6 by $10^{1.37}$:

$$705\left(\frac{mg}{L}\right) = 30\left(\frac{mg}{L}\right)\cdot 371^{1.37}$$

The daily high flow SSC can be converted to a daily high flow load using the following equation:

$$\textit{Daily high flow load}\left(\frac{T}{day}\right) = \frac{\textit{Daily high flow SSC}\left(\frac{mg}{L}\right)\cdot \textit{Mean flow}\ (cfs)}{371\left(\frac{mg\cdot cfs\cdot day}{L\cdot T}\right)}$$

That is, column 7 is calculated by multiplying column 8 by column 3 and dividing by 371. Using Scott Creek again we have:

$$29\left(\frac{T}{day}\right) = \frac{705\left(\frac{mg}{L}\right)\cdot 15.23\ (cfs)}{371\left(\frac{mg\cdot cfs\cdot day}{L\cdot T}\right)}$$

Other ways could be used to determine the high flow discharge (instead of assuming a value of ten times the mean discharge). If a daily record of discharge is available for a stream, it can be converted to daily SSC using the sediment rating curve. Then the critical conditions for maximum flow could be chosen by using the record for an average year and selecting the maximum SSC observed in that year. This was the approach used in by U.S. EPA (2001b), but it is not clear how the sediment rating curves were adjusted for different streams.

Table 5. Currentannualand daily loads (mean and high flow conditions) for streams inthe Chattooga River watershed

Stream[1]	Area[1] (mi²)	Mean Flow[1] (cfs)	Sediment Load[1] (T/yr)	Current Load or SSC			
				Mean Flow (Q/Q_0=1)		High Flow (Q/Q_0=10)	
				Load[2] (T/day)	SSC_0[2] (mg/L)	Load[2] (T/day)	SSC[2] (mg/L)
Scott Creek	6.09	15.23	1078	1.24	30	290	705
Stekoa Creek above Clayton	1.71	4.26	786	0.90	78	211	1837
Saddle Gap Creek	2.75	6.88	1078	1.24	67	290	1562
Chechero Creek	4.21	10.53	737	0.84	30	198	698
Pool/She Creek	4.75	11.88	504	0.58	18	135	423
Cutting Bone Creek[3]	**2.10**	**5.25**	**149**	**0.17**	**12**	**40**	**283**
Stekoa Creek at Boggs Mtn. Rd.	21.30	53.25	7455	8.55	60	2003	1395
Upper Warwoman Creek	9.00	22.50	2251	2.58	43	605	997
Roach Mill Creek	0.73	1.83	118	0.14	27	32	644
Law Ground Creek	0.93	2.33	251	0.29	46	67	1076

[1]Information and data taken directly from the Chatooga River watershed sediment TMDL (US EPA, 2001b)
[2]Calculation made using data from the Chatooga River watershed sediment TMDL (US EPA, 2001b)
[3]Reference stream used in US EPA (2001b)

CLEAN WATER ACT SECTION 303(d)

(d) Identification of areas with insufficient controls; maximum daily load; certain effluent limitations revision

(1)(A) Each State shall identify those waters within its boundaries for which the effluent limitations required by section 1311(b)(1)(A) and section 1311(b)(1)(B) of this title are not stringent enough to implement any water quality standard applicable to such waters. The State shall establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters.

(B) Each State shall identify those waters or parts thereof within its boundaries for which controls on thermal discharges under section 1311 of this title are not stringent enough to assure protection and propagation of a balanced indigenous population of shellfish, fish, and wildlife.

(C) Each State shall establish for the waters identified in paragraph (1)(A) of this subsection, and in accordance with the priority ranking, the total maximum daily load, for those pollutants which the Administrator identifies under section 1314(a)(2) of this title as suitable for such calculation. Such load shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality.

(D) Each State shall estimate for the waters identified in paragraph (1)(B) of this subsection the total maximum daily thermal load required to assure protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife. Such estimates shall take into account the normal water temperatures, flow rates, seasonal variations, existing sources of heat input, and the dissipative capacity of the identified waters or parts thereof. Such estimates shall include a calculation of the maximum heat input that can be made into each such part and shall include a margin of safety which takes into account any lack of knowledge concerning the development of thermal water quality criteria for such protection and propagation in the identified waters or parts thereof.

(2) Each State shall submit to the Administrator from time to time, with the first such submission not later than one hundred and eighty days after the date of publication of the first identification of pollutants under section 1314(a)(2)(D) of this title, for his approval the waters identified and the loads established under paragraphs (1)(A), (1)(B), (1)(C), and (1)(D) of this subsection. The Administrator shall either approve or disapprove such identification and load not later than thirty days after the date of submission. If the Administrator approves such identification and load, such State shall incorporate them into its current plan under subsection (e) of this section. If the Administrator disapproves such identification and load, he shall not later than thirty days after the date of such disapproval identify such waters in such State and establish such loads for such waters as he determines necessary to implement the water quality standards applicable to such waters and upon such identification and establishment the State shall incorporate them into its current plan under subsection (e) of this section.

(3) For the specific purpose of developing information, each State shall identify all waters within its boundaries which it has not identified under paragraph (1)(A) and (1)(B) of this subsection and estimate for such waters the total maximum daily load with seasonal variations and margins of safety, for those pollutants which the Administrator identifies under section 1314(a)(2) of this title as suitable for such calculation and for thermal discharges, at a level that would assure protection and propagation of a balanced indigenous population of fish, shellfish, and wildlife.

(4) Limitations on revision of certain effluent limitations. -

(A) Standard not attained. - For waters identified under paragraph (1)(A) where the applicable water quality standard has not yet been attained, any effluent limitation based on a total maximum daily load or other waste load allocation established under this section may be revised only if (i) the cumulative effect of all such revised effluent limitations based on such total maximum daily load or waste load allocation will assure the attainment of such water quality standard, or (ii) the designated use which is not being attained is removed in accordance with regulations established under this section.

(B) Standard attained. - For waters identified under paragraph (1)(A) where the quality of such waters equals or exceeds levels necessary to protect the designated use for such waters or otherwise required by applicable water quality standards, any effluent limitation based on a total maximum daily load or other waste load allocation established under this section, or any water quality standard established under this section, or any other permitting standard may be revised only if such revision is subject to and consistent with the antidegradation policy established under this section.